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The Effect of Peripheral Displays on Navigation in Desktop Virtual Environments

Abdul Rahman Hasan, Ali

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The Effect of Peripheral Displays on Navigation in Desktop Virtual Environments

submitted by
Ali Abdul Rahman Hasan
for the degree of Master of Philosophy
of the
University of Bath
Department of Computer Science
September 2010

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Virtual reality systems aim to provide an egocentric representation of a virtual world to generate a user experience that is reminiscent of moving through and interacting with objects in the real world. However, technological limitations and conventions keep this goal from being fully achieved. One of the biggest limitations is the reduced field of view of most virtual reality systems. The human field of view extends to about 200 degrees horizontally and 135 degrees vertically. Both head-mounted displays and desktop computers typically provide a fraction of this range: approximately 30-60 degrees in the horizontal plane and 30-40 in the vertical¹. The horizontal field of view is marginally wider than the vertical, reflecting the fact that objects are typically arrayed horizontally about the viewer, and that human binocular vision is more sensitive to horizontal than vertical extension. However, even the latest desktop displays do not extend in the far periphery. Several studies show that reducing this field of view impedes performance on several tasks, including navigation, locomotion, and object manipulation. However, all of these studies have focused on the near- and mid-periphery: fields of view extending out to approximately 70 degrees either side of the viewer's line of sight. We are aware of no studies taking into account the effect of visual information in the far periphery (70 - 100 degrees) on performance in a virtual environment.

¹ This example is for a 17" 4:3 aspect monitor at a 50cm viewing distance

Many researchers seem to ignore this visual area, and most display designers do not take it into consideration. In this thesis, we developed a display configuration that is specifically focused on supporting the far periphery to compare against typical desktop computers and evaluate what effects and benefits they might have. We did this by adding peripheral displays, in the form of additional computer monitors, to the side of the user, thus providing visual information in the further 30 degrees or so of the periphery. Our studies investigate different aspects of navigation, such as cognitive mapping, object location memory, search, and exploration. We identify which tasks benefit from the addition of peripheral displays, and look at individual differences, particularly between genders.

1.2 THESIS STATEMENT

"Women benefit from the provision of visual information in the far periphery in terms of improved route knowledge in virtual environments. Providing an additional peripheral display with such information, 73 degrees away from the line of sight and beyond, is sufficient for significant improvements to be found in route-based cognitive mapping and route memory. There is no evidence for its benefit in other types of task".

1.3 MAIN CONTRIBUTIONS

Our main findings can be described as follows:

- Effect of peripheral displays on gender: We show how adding peripheral displays improves performance of tasks requiring route knowledge in female participants. We demonstrate that the difference in gender performance on tasks requiring route knowledge in desktop virtual reality is due in part to the visual display limitations.

- Classification of tasks improved by displays: We identify which tasks are improved by adding peripheral displays, and which are not, and propose reasons for them. Route-based tasks, such as route-based cognitive mapping and route memory, improve with the addition of these displays. The other tasks we investigated did not show an improvement when using peripheral displays. It is suggested that the particular value added by peripheral displays in desktop virtual reality is restricted to tasks based on route knowledge.
- Proposal of reason for benefits: We propose a hypothesis for why the peripheral displays benefit route-based tasks. Based on our results, we conclude that these displays provide a better sense of "grounding" in the virtual world.

1.4 STRUCTURE OF THESIS

In this thesis, we begin by looking at a brief history of virtual reality displays (Chapter 2), noting the advantages and disadvantages of each. We focus on non-immersive virtual reality and the traditionally limited field of view. This limitation forms the exploratory question of our thesis. We follow this chapter by a look at the human eye and peripheral vision in particular (Chapter 3). We then review studies on different display sizes and fields of view and their effect on task performance in virtual reality (Chapter 4)

In Chapter 5 we look at individual differences in spatial ability, focusing mainly on gender differences. These differences are so fundamental that it becomes a major consideration in our studies.

In Chapter 6 we outline our research, specifying our stated goals, experimental design, and methods for analysis. Chapters 7 through 9 outline each of our experiments, from design to implementation to result analysis. We conclude in chapter 10 where we use all of our results to determine our sum conclusions. We also give guidelines on display design based on our results, and ideas for future work in this field. The appendices provide additional documents and data related to our study.

1.5 DEFINITION OF TERMS

Terms in this thesis are defined as they appear. However, we define in this section some of the most commonly used terms.

Desktop Virtual Reality: Virtual reality presented on a desktop or laptop computer.

Display Field of View: That part of a user's field of view occupied by a computer display, expressed in degrees of visual angle.

Euclidean Navigation: A navigational strategy based on an understanding of the Euclidean properties of an environment, such as distance estimation and cardinal directions. Contrast with Landmark-based navigation.

Field of View (FOV): The angular range of visual area which the user can see, expressed in degrees and centered on a point mid-way between the eyes. For a person with normal vision, FOV extends to about 200 degrees of visual angle.

Foveal vision: Human perception concerned with sense data provided by a specialized area of the human retina that delivers high levels of acuity and colour information at the expense of movement and low-light sensitivity. In this thesis, a virtual reality user's foveal vision is treated as the central 5 degrees of FOV.

Geometric Field of View: The field of view of a virtual environment.

Head-Mounted Display (HMD): A wearable device which presents a virtual environment to the user while occluding the real world.

Landmark-Based Navigation: A navigational strategy based on an understanding of the relative positions of landmarks in the environment. Contrast with Euclidean navigation.

Line of sight: An imaginary line representing the direction of the user's gaze. Objects in the line of sight are what the user is looking at.

Near-Periphery, Mid-Periphery, and Far-Periphery: Areas of the field of view dealing with peripheral vision. There are no agreed upon demarcations for each area. In this thesis, near-periphery is treated as a range of visual angle extending out between 5 and 30 degrees from a person's line of sight, and mid-periphery treated the further range of visual angle extending between 30 and 70 degrees. For our study, far-periphery is defined as beginning from 70 degrees away from the line of sight out to the limits of the user's field of view.

Peripheral Display: A peripheral display is any visual display not in the line of sight (i.e. not in front of the user). In our experiments, peripheral displays lie parallel to the line of sight, to the exact left and right of the user, and cover a visual angle of 73 to 107 degrees.

Peripheral Vision: Vision that deals with all information outside the fovea. It is divided into near-, mid-, and far-peripheral vision.

Vection: A sensation of self-motion caused by the perception of motion in surrounding objects.

Visual angle: the angle in degrees subtended by specified points and a person's eyes, within their field of view.

CHAPTER 2

OVERVIEW OF VIRTUAL REALITY DISPLAYS

2.1 INTRODUCTION

“Virtual Reality” is a term for many different technologies which provide user interaction with a non-real environment. These technologies include both software aspects, such as graphics and simulation, as well as the hardware aspects of the interfaces between user and world. The form of these interfaces influences the experience of the environment. For example, virtual reality systems that provide haptic and audio feedback are perceived differently from those which only provide visuals; and there is a clear distinction between immersive and non-immersive virtual reality, based directly on the perceptual experience that can be generated by the output capabilities of the hardware used.

In this chapter we discuss the different types of virtual reality hardware. We begin with a brief history of VR technologies, followed by a more detailed look at some of the more prevalent examples, focusing on their advantages and disadvantages. Finally, we look at desktop virtual reality, and focus on its limitations in providing a fully immersive virtual reality experience. The most important of these is the limited field of view.

2.2 HISTORY OF VIRTUAL REALITY TECHNOLOGIES

While the origin of the concept of virtual reality is arguable, having connections with both science and science fiction, the earliest technologies in the field were developed in the 1960s (McLellan, 2004). In 1962, Morton Hellig presented a prototype of Sensorama. This was a multimodal one-person video machine, providing haptic and olfactory feedback (e.g. wind and scents) along with the typical audio and video to simulate an experience, such as riding a bicycle out in the open (Rheingold, 1991). Another major contribution of the time came from Ivan Sutherland, who developed what is considered the first wearable virtual reality system in the form of a head-mounted display (HMD). The basic concept was to provide image changes which corresponded with user movement, thus simulating a three-dimensional experience (Sutherland, 1968). Concomitant with these events was the continued development of flight simulators. In the 1950s, recorded video was used for this task. Different recordings would be played depending on the user control input. In the 1960s, computer generated displays were developed by General Electric for the U.S. space program (Rolfe and Staples, 1988).

Limitations in graphics technology and the high cost of these devices, amongst other problems, meant these technologies would either become obsolete or were only applicable to large research facilities. While improvements in graphics and hardware technologies developed incrementally, few new VR technologies were presented. The main one in the 1970s was the Aspen Movie Map (Mohl, 1982). In 1978, a team at MIT created the first navigable simulated environment of a real city. The city of Aspen, Colorado was photographed extensively and then a basic simulated version of the city was created based on the photographs. Users could travel through the city by making movement decisions, which would result in image changes that corresponded to egocentrically appropriate representations of position and orientation within the city. All of this data was recorded on Laserdisc, and was played back on a large screen. Additional monitors contained extra travel information and allocentric representations of the world model, such as maps of the city (Naimark, 2006).

In the 1980s and 90s, attempts were made to create fully immersive systems. These are systems which envelop the user's senses to further the illusion of the environment's reality and immediacy.

Improvements in designs for head-mounted displays (Fisher et al. 1986) and wired gloves (Zimmerman et al., 1987) at the NASA Ames Research Centre led to so-called “Gloves 'n' Goggles” VR. In these systems, the wired glove detects motion which allows for interaction with the virtual environment displayed on the goggles. Today, HMDs are still manufactured, usually independent of virtual gloves.

The most notable of these was the Cave Automatic Virtual Environment (CAVE) (Cruz-Neira et al., 1992). Projectors are used to create a surround environment by displaying images on the walls, floor, and ceiling of a specially constructed room. These images are enhanced with the use of stereoscopic glasses, for the creation of the illusion of three dimensionality.

The popularisation of personal computers, along with the improvements in graphics and other technologies, resulted in desktop virtual reality. In these systems, virtual environments are presented on a personal computer screen, with or without additional interfaces. Detailing the history of desktop VR is difficult because of the disagreements over what is considered virtual reality. For example, depending on the definition, VR may or may not include first person computer games, avatar-based worlds, and even text-based systems. For all of these technologies, however, the designers have typically assumed that the display hardware would be a single CRT, and later LCD, monitor placed at a fixed viewing distance immediately in front of the user. One enhancement to desktop monitors is Fish Tank VR, developed by Ware et al. (1993). Fish Tank VR adds a device for tracking user head position, and goggles for presenting images in stereo. The process provides a greater sense of depth perception and has higher resolution than HMDs

(Mulder and van Liere, 2000). However, it still maintains some of the limitations of desktop VR, specifically in the narrow field of view and lack of freedom of motion.

Focusing on the current state of the art, it is recognised that the advances in technology have made graphics equally applicable to all of the systems mentioned. In the following section we look at the advantages and disadvantages of each system.

2.3 IMMERSIVE VR NON-IMMERSIVE VR

Virtual reality is divided into immersive and non-immersive technologies. As mentioned above, Immersive VR envelops the user's senses and demands his attention, thus creating a stronger feeling for the user of being in the virtual world. Non-immersive VR, on the other hand, allows the same interactions with the environment, such as navigation and object manipulation, without making any special demands on the user's focus.

The term “Immersion” itself has many conflicting definitions, some defining it as a psychological trait and others as a technological metric. This is the distinction between it being a measurement of the user or of the system; (a similar problem exists for defining presence, see Chapter 6). In this paper we use the definition of immersion provided by Slater et al. (1995). This definition states that immersion is a quantifiable description of how well a technology affords users to immerse their physical selves in a computer generated environment. It is composed of five characteristics which can be used to measure the technology's immersiveness. They are:

1. Extensiveness: the number of types of sensory feedbacks it provides.
2. Level of surrounding: the angular range of the world from which input can be obtained.
3. Inclusiveness: the extent to which external stimuli are occluded.
4. Vividness: the quality of the input.

5. Level of matching: specifically, the level of matching between body movements and updates in the feedback displays.

By this definition, immersive technologies provide multimodal interfaces and feedbacks, freedom of movement and completely immersive displays. These displays can either surround the user completely, as with the CAVE, or they can provide part of a scene and occlude all external output, as with HMDs. For the purposes of our comparison we look at the main current examples of virtual reality. These are the head-mounted display, the CAVE, and the desktop computer. We have ignored the other technologies mentioned either because they have fallen into disuse, or were never widespread to begin with.

2.3.1 IMMERSIVE VR: CAVES AND HMDS

The most commonly used examples of immersive VR systems are the HMD and CAVE. Both satisfy the five points mentioned by Slater et al. (1995), but utilise different strategies to achieve them.

The head-mounted display is a wearable device which provides an updated view of the virtual world. By making physical motions, such as walking or head turning, the view is updated on the screen. HMDs provide limited fields of view, typically between 30 and 60 degrees horizontally, although wider angle HMDs also exist. The proximity of the glasses and the use of dual monitors allows for high resolution images to be presented to each eye. In addition to being costly, the main disadvantage of HMDs are problems with comfort levels. Due to their bulk, they are a physical burden (Youngblut et al., 1996). There is also a long history of problems of motion sickness with these displays (Howarth and Costello, 1997; Stanney et al., 1998). Additionally, the view on the HMD needs to update with every user movement, whether directional or positional. This leads to HMDs having a lower frame rate than CAVEs, which impacts the quality of the graphics (Verbrees et al., 1999; Göttig et al., 2005).

In the CAVE, the user is actually placed within the virtual environment, in the sense that each wall, the floor, and ceiling of the CAVE have projections of the world on them. With the aid of specialised shutter glasses, the illusion of three dimensionality is created. These glasses allow users to see the real world as well as the virtual world, but only that which is also confined within the cave. This allows users to interact with real objects (such as a chair) or even other people. Because of the need for a specialised room, CAVEs have inhibitive costs and physical demands which preclude them from ever becoming widespread outside research facilities and specialised exhibits. See Table 2.1 for comparison between CAVEs and HMDs.

Attempts have been made to create personal immersive technologies in the form of large, surround virtual environments. These systems were intended to be cheaper technologies for home and office use. However, lack of applications and the still relatively high cost has kept these technologies from becoming widespread. Examples of these products include the FakeSpace Systems ConCave (no longer being developed) and the Elumens Visual Station (company filed for bankruptcy; Baysden, 2006).

2.3.2 NON-IMMERSIVE VR: DESKTOP VIRTUAL REALITY

While other types of VR displays can be referred to as non-immersive, desktop computers are the most common. Other examples of non-immersive VR exist, such as the Chameleon which uses palmtop computers for a display (Fitzmaurice and Buxton, 1995) and the Virtual Workbench, which resembles a table (Obeysekare et al., 1996). Research on 3D VR in mobile phones is, at the time of this writing, in its early stages but has been shown to be possible (Henrysson et al. 2005; Curticapean et al. 2008). It remains to be seen whether it will find many applications, although it is highly likely.

In most of the characteristics required for immersion, as defined by Slater et al. (1995), desktop computers are limited. They typically provide only audio and video feedback, do not exclude the real world, and do not typically provide the motion tracking required for high levels of matching.

Despite these disadvantages, desktop VR has many advantages over immersive VR. Desktop computers are a lot more prevalent, are cheaper, comfortable to use, and familiar. They allow for both single and multiple user use, and have a wide array of applications. Additionally, networking facilities allow for collaborative VR. The ability to enhance desktop computers, as was done with Fish Tank VR, is also possible with the use of peripheral devices.

The greatest limitation of desktop computers is the small visual area. Desktop computers do not typically provide a large enough view to surround or immerse the user. Larger screens, in the forms of projections and other displays, and multiple monitor solutions have been shown to have a positive effect on both user immersion and presence levels, as well as on their ability to perform a number of tasks. The effect of size and field of view is discussed in more detail in chapter 4.

2.4 CONCLUSIONS

From a design point of view, the major distinctions between VR technologies are the types of feedback, the freedom of movement, and the display shape and size. In our research we are interested in the effect of visual feedback only. Freedom of movement is a useful advantage, but it is our belief that users adapt to simulations of motion using other inputs. In our estimation, the single most important hardware factor affecting user experience is the surrounding nature of the virtual displays; in other words, the width of their field of view. CAVEs are already fully surrounding, and studies on HMDs have shown a great deal of correlation between performance and field-of-view. Different types of configurations of desktop monitors have been used to evaluate performance and experience on both virtual and non-virtual tasks. These include comparing smaller screens with large projections, single monitors with tiled monitors, straight and curved monitors, and narrow and wide field-of-view displays. The following chapter looks at this research in more detail.

Despite all this, we recognise that most of the research has focused on information size and data in the near periphery. No research has been done, as far as we know, on the potential advantages of presenting data in the far periphery in virtual worlds. We chose to test desktop computers as our medium due to their relative low cost, ease of use, adaptability to multiple modifications, and for having the most potential applications.

In the next two chapters we look at the human visual system, focusing on peripheral vision, and reviewing the studies on its uses, including the effect of increasing the field of view in virtual reality displays.

Immersion Metric	Head-Mounted Displays	CAVEs
Extensiveness	Mainly video. Audio and haptic feedback devices are sometimes included.	Video and audio. Audio is provided by 3D speakers. Haptic devices also possible.
Level of Surrounding	HMDs vary in field of view, mostly between 30-60 degrees, although wider ones are developed.	Environment literally surrounds the user. Audio is also surround.
Inclusiveness	Physical mechanism of HMD occludes the real world. Depending on the field of view, some peripheral vision is “blacked out”.	Real world outside the CAVE is blocked by walls. Real world inside the CAVE can be used as part of the environment (augmented reality).
Vividness	More changes in the visual world leads to a lower frame rate, and thus lower quality graphics.	Fewer changes in the world are needed, since the world does not need to update when user rotate. This leads to a higher frame rate and, in turn, higher quality graphics.
Level of Matching	The visual world changes with changes in the users' movements, either positional or directional. The user has, theoretically, more freedom of movement.	Only changes in perspective are needed. User is limited in movement to the physical dimensions of the CAVE

Table 2.1 Comparison of HMDs and CAVEs for Immersion

CHAPTER 3

PERIPHERAL VISION IN HUMANS

3.1 INTRODUCTION

In this thesis we are studying the effect of adding visual displays to a regular desktop computer on the performance of virtual reality tasks. Since these displays lie outside the central region of a user's field of view, the information they provide is processed mainly by the component of the human visual system that deals with sensory information from the periphery of the retina. For the purpose of completeness and self-containment, we provide this chapter to discuss peripheral vision. We begin by looking at the general theory of evolution of the eye. Then we discuss the different types of photoreceptor cells in the eye and their functions. We compare foveal and peripheral vision, noting their roles, strengths, and weaknesses. Before concluding, we review some studies of the effect of peripheral vision on different physiological and psychological tasks in humans.

3.2 EVOLUTION OF THE EYE

The human visual system is one of the most complex in the biological world, and there has been some debate and difficulty in determining the evolution of the eye. However, there is much evidence supporting the idea that the eyes of most species came from a common ancestor organ (Gehring and Ikeo, 1999; Arendt 2003). The separate evolution of eyes of animals to match their environment results in differences in structure and

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function. For example, colour vision is believed to have evolved for the purpose of food recognition (Regan et al., 2001). Obtaining food is also a major factor in the evolution of visual acuity – the ability to resolve fine detail – and field of vision – how much of the world around the animal can be seen at any instant. Carnivorous animals tend to have stronger binocular vision. This occurs when the eyes of the animal are close together in the front of the head. Very similar stimuli are obtained by each eye and they are combined to form a well-defined image with highly accurate depth perception. This is an advantage in finding and hunting prey. The proximity and structure of the eyes leads to a narrower field of vision. However, this is not a problem since predators do usually need to react quickly to stimuli (Sperling, 1970).

On the other hand, animals which tend to be prey do require a wide field of view, since predators may attack from any direction. In these animals, eyes are usually on opposite sides of the head, creating two very distinct images representing the left and right view of the world. These images are combined to form a wide panorama of the world. Changes in this world, such as sudden motion, can be detected by the animal as an important survival mechanism. The visual acuity and depth perception of these animals is lessened because of this, but is not a problem since these creatures are herbivores and insectivores and do not require them to gather their food (Howard and Rogers, 1995).

Humans have evolved requiring both types of vision, since they are both predator and prey. Humans have weaker binocular vision than most carnivores, and a narrower field of vision than most herbivores. The average human field of vision is about 200 degrees horizontally and 135 degrees vertically (Werner, 1991). In addition to the positioning of the eye, the strength of different aspects of vision are dependent upon the position, number, and type of photoreceptor cells in the retina.

3.3 PHOTORECEPTOR CELLS: RODS AND CONES

The retina of the eye contains photoreceptor cells, whose function is to transform photons into neural signals. All eyes contain two types of cells, referred to as rods and cones. Additionally, mammalian eyes contain a third type of photoreceptor called photosensitive ganglions. Ganglions are responsible for non-visual functions, such as regulating melatonin levels (Brainard et al., 2001) and determining pupil size (Gamlin et al., 2007), although it has been shown that they have some effect on recognising light (Zaidi et al., 2007).

Rods and cones, however, are the cells responsible for creating the phenomenon of sight. Rods are much more numerous than cones. In the human eye there are an average of 92 million rods and 4.6 million cones (Curcio et al., 1990). Rods are better at detecting motion than cones are, but have worse visual acuity. Rods are much more sensitive to light and are distributed on the periphery of the retina, being absent in the fovea. For these two reasons, rods are responsible for night vision and peripheral vision, respectively. All rods respond to light uniformly, making them insensitive to colour.

Cone cells, on the other hand, are categorised into three different types, which react differently to different light wavelengths. These are called S, M, and L cones, which are used to detect short, medium and long wavelengths, respectively. These wavelengths correspond to different ranges of the colour spectrum. For this reason, cone cells are responsible for colour vision. Problems in cone cells, such as dystrophy, are the cause of different forms of colourblindness (Deeb and Kohl, 2003). Cone cells are prevalent in the fovea, and decrease in density the further they are in the periphery of the retina. Therefore they are stronger in foveal vision and weaker in peripheral vision. Additionally, these cells are less responsive to light, meaning they work best in bright light.

	RODS	CONES
Number	92 million	4.6 million
Distribution	None in the fovea. Increased distribution in the near periphery. Decreased distribution in the far periphery.	High distribution in the fovea. Decreases rapidly in the periphery.
Sensitivity to Light	Highly and uniformly sensitive to light.	Less sensitive to light than rods. Three types of sensitivity levels
Roles	Peripheral Vision Night Vision Motion Detection	Foveal Vision Colour Vision

Table 3.1 Comparison of Rod and Cone Cells in the Human Eye

3.4 AREAS OF VISION: THE FOVEA, NEAR-, MID-, AND FAR-PERIPHERY

Foveal vision is the vision obtained by the fovea centralis, which is positioned near the centre of the retina. The fovea contains a large number of cone cells and no rod cells. This vision represents the centre of gaze or focus. Objects in this area are highly defined, both in form and colour. Everything outside the foveal view is considered to be in the periphery, and is viewed by peripheral vision. Because rod distribution is not uniform, but changes with angular distance from the fovea, the peripheral vision is often divided into parts called the near-periphery, mid-periphery, and far-periphery. However, these are not exact definitions and there is no concordance of where each one begins and ends. For the purposes of this thesis, the far-periphery is defined as 70 degrees away from the centre of gaze and further. An exact estimation of the relative extent of near- and mid- periphery are not important to our study. However, for the purpose of comparison with the fovea

and the far-periphery, the near-periphery of a desktop VR user's FOV is treated as extending between approximately 5 and 30 degrees of visual angle from a person's line of sight, and mid-periphery treated as a range of visual angle extending 30 and 70 degrees.

In peripheral vision, images form on the retina outside the fovea centralis, and seem more blurry the further they are from the centre of gaze. As we mentioned in the previous section, the number of cone cells decrease as we extend in the periphery, until they become non-existent. Rods are also less frequent in the far periphery than the mid periphery, although they are much more abundant than cones (Curcio et al., 1990).

3.5 EFFECT OF PERIPHERAL VISION

The main evolutionary purpose for peripheral vision is to alert the watcher to changes in areas outside the centre of gaze, such as the emergence of threats. On its most basic level, it also adds to the field of view. However, peripheral vision has been found to have many other advantages. Because rod cells are responsible for all three, peripheral vision is related to night and motion detection. Furthermore, peripheral vision is responsible for or conducive to a number of physical and psychological functions. Many studies have proven a relationship between peripheral vision and, amongst other things, locomotion, postural balance, and hand-eye coordination.

1. Night Vision (Scotopic Vision)

Rods are much more sensitive to light than cone cells are at the lower end of the wavelength spectrum (up to 700 nm). For this reason, the rod cells perform better in low light situations than cones do, and are thus responsible for night vision (Beynon, 1985). The distribution of rods in the retina increases from very little in the fovea to a peak in the near periphery, before gradually reducing. Therefore, night vision should be strongest in the near-periphery, gradually decreasing further in the periphery. A study by Jackson and Owsley (2000) using a visual field analyser, confirms this. This study found visual

sensitivity in low light was stronger in the near periphery (8-12 degrees from the line of gaze) than they were in either the fovea or further in the periphery. The same study found visual sensitivity in bright light to be strongest in the fovea. van de Grind et al. (2000) found that visual acuity decreases a lot more severely when changing from high to low luminance in the fovea than it does in the periphery.

2. Motion and Target Detection

Like night vision, motion detection is also due to rod cells, and is thus connected with peripheral vision. Theoretically, motion detection should be strongest in the near periphery. However, many studies of the relationship between motion detection and target eccentricity focus on response times; and in these tests, at least, the fovea is found to be superior. Wall et al. (1997) found response times to be lowest in the fovea, and to increase further away. However, this work was done in a computer-based test, where a series of flickering dots were used to represent the motion rather than using real or virtual objects in a scene. In contrast, Tynan and Sekuler (1982) found response times to decrease with eccentricity for slow-moving objects, although they did not find any difference for rapidly-moving objects. Nunes and Recarte (2004) found similar results in a driving exercise.

Tests on static target detection, in which an entire scene is displayed and a specific object is to be found, have also shown advantages presentation in the peripheral FOV. Carrasco et al. (1995) used a display array of red and blue lines. Participants needed to assess whether a specific target (a red line, either tilted or vertical) was present in the array. When present, the target was placed between 0.7 and 3.5 degrees from the original centre of gaze. Even with such a small range, an effect of eccentricity on errors and response times increased. Scialfa and Joffe (1998) modified this test for eccentricities of 3.8, 8.3, and 13.9 degrees. Tipples et al. (2002) replicated these tests using images of plants and animals as stimuli, and using eccentricity degrees of 4.5 and 12.3 degrees. The results in both tests confirmed the inverse effect of eccentricity on target detection, i.e. response

times for knowing that something is present reduces as targets are presented further out into the periphery. Knowing just what that thing might be is a different matter. Thorpe et al. (2001) asked participants to determine whether briefly screened (28 ms) naturalistic scenes contained an animal over a large range of angles (0 to 70 degrees). Accuracy was highest at 0 degrees, and decreased with increments in eccentricity.

Both Scialfa and Joffe (1998) and Viviani and Swensson (1982) noted a correlation between eccentricity and the number of saccadic eye movements. Saccades are rapid movements of the eye for the purpose of creating a mental image of the surrounding environment. When targets appear in the peripheral view, a saccade automatically attempts to bring the target onto an area of the retina with better resolution. This reflexive saccade may explain why response times to targets are always faster in the fovea than the periphery.

3. Optical Flow and Vection

Optical flow refers to the apparent flow of motion of objects. Vection is the phenomenon of perceived self-motion from the optical flow of objects surrounding the viewer. This effect is of particular importance in non-immersive virtual reality, where the user is stationary but is under the impression that he is moving because of the change of position of objects on the screen. Objects becoming larger, for example, give the viewer the impression of walking towards them. Many studies have shown that peripheral vision is primarily responsible for both optical flow (1985) and vection (Brandt et al., 1973; Berthoz et al., 1975; Webb and Griffin, 2002; Webb and Griffin, 2003). It is theorised that vection is a necessary component for many motor skills, such as postural balance, walking, and reaching and grasping.

A. Postural balance

Many studies have shown that the ability to maintain postural balance is associated with peripheral vision. Amblard and Carblanc (1980) contrasted balance in participants in three conditions: full view, foveal view alone, and peripheral view alone. The findings showed that balance was significantly reduced in the foveal view only condition. In other words, when peripheral vision was impaired, so was balance. Berensci et al. (2005) confirmed this finding under different circumstances. Stoffregen et al. (1987) found that children (aged 5 years and under) performed better in a standing test when peripheral optic cues were available.

B. Locomotion and route-following

There is evidence that peripheral vision has a special role to play in helping people to understand where they are in relation to where they are going as they follow a route. Stoffregen et al. (1987) found that the same effect of optical flow cue applied to young children for both standing and walking tests. That is, providing flow cues in the periphery improved stability during walking trails, while cues in the fovea had little effect. Black et al. (1997) compared people with reduced peripheral vision (due to retinitis pigmentosa) with a control group with normal vision on following an indoor route, going through three rooms, marked on the floor and measuring 1.2 metres wide. Comparisons were made on percentage preferred walking speed (ratio of trial walking speed with speed on a straight 20 metre course) and number of errors made, in the form of collisions with obstructions, loss of balance, or exiting the defined route. Those with peripheral vision loss had significantly lower percentage preferred walking speed and significantly higher errors made. This means they were slower and more likely to collide, lose their balance, or stray from the route than their normal vision counterparts. A study on patients suffering from glaucoma (which also leads to peripheral vision loss) by Turano et al. (1999) found that they were 10% slower than normal vision patients in following a path.

For vehicular locomotion, surveys have found that those suffering from peripheral vision loss have significantly more traffic accidents than those with normal vision (Fishman et al., 1981; Johnson and Keltner, 1983; Owsley and McGwin, 1999).

C. Pointing and Aiming

A hypothesis set by Paillard and Amdblard (1985) is that in tasks involving movement towards a target, two separate visual channels exist which give feedback regarding the task. These were called the static and kinetic channels. The static channel obtains non-moving and slow-moving information through the fovea, and is used to determine positional information. The kinetic channel is used for fast-moving information gathered through the periphery (the optical flow cues); this is used for motion tasks.

This distinction was put to test in two pointing experiments by Bard et al. (1990). In these experiments, participants would be seated with a moving lever and shown a series of targets. In one experiment, they would be measured for directional accuracy by pointing the lever towards the target. The metric used was angular distance between actual and estimated direction. In the second experiment, the targets would appear in front of the user, at eye level, but at different distances. The participant would have to move the lever until its tip was directly under the light. Accuracy was measured as the axial distance between the position of the lever and the target.

In these tests, three conditions were tested: no view of hand and lever, central view only (up to 10 degrees), and peripheral view only (10 to 40 degrees). The results showed that central vision was responsible for accuracy in the distance estimation task; while both foveal and peripheral vision were responsible for accuracy in the direction estimation task. These results were later confirmed using similar (Abahnini et al., 1997) and different apparatuses (Abahnini and Proteau, 1999).

D. Reaching and Grasping

As with pointing and aiming, reaching for an object and grasping involve different visual channels. Paillard (1982) stated that peripheral vision is responsible for navigating the trajectory of the hand towards the target, while central vision is needed for the final part of reaching and grasping.

Sivak and MacKenzie (1990) demonstrated that peripheral vision was necessary to determine the location of the object, while foveal vision was needed to determine the object's shape and size. Thusly, peripheral vision was important for reaching, while foveal vision was needed for both reaching and grasping.

E. Cybersickness

Vection is believed to be connected with a sense of motion sickness in virtual reality systems (also called simulator sickness, VR sickness, and cybersickness). Some tests have shown a connection between field of view and motion sickness (Hettinger et al., 1990; Lin et al., 2002) in virtual environments. It has been argued that this feeling of motion sickness can be avoided with improvements in technology, such as increased frame rates (LaViola, 2000).

3. Spatial ability

Research on spatial ability has found peripheral vision to be essential to a number of tasks, including distance estimation, cognitive mapping, spatial memory, search, and navigation.

Severe restrictions of field of view have been shown to lead to underestimation in immediate distance judging (Dolezal, 1982; Sivak and Mackenzie, 1990; Watt et al., 1997). Creem-Regehr et al. (2005) and Wu et al. (2004) found that this is true only when

head movements are restricted. When allowed, head movement can compensate for the lack of field of view in this task.

Alfano and Michel (1990) used specially-designed goggles to limit the field of view to 9, 14, 22, and 60 degrees, and found a direct correlation between field of view and the ability to walk in a room, as well as form a cognitive map. Restricted fields of view also led to higher reports of discomfort and disorientation. Toet et al. (2007b) ran a similar test with restricted fields of view of 30, 45, 60, and 75 degrees, as well as an unrestricted field of view. The environment was a narrow room with three wall obstacles. The participant would have to slalom the walls in a forward direction, and then retrace their route backwards. They were allowed to rotate their heads as much as they liked. Participants were measured for speed, as well as accuracy, which was defined as the area between the path taken during the run and the “ideal” path taken during the unrestricted run. For both metrics, greater fields of view showed significantly better results. The unrestricted field of view, unsurprisingly, provided the fastest results. Toet et al. (2007a), using goggles with horizontal fields of view of 30, 75, and 120, as well as an unrestricted field of view, tested users on an obstacle course within a closed area. Vertical field of view for all cases was constant (48 degrees). The area consisted of a single corridor with four turns, and obstacles in the form of objects to step over, duck under, or slalom around, similar to that in Toet et al. (2007b). Performance in the unrestricted view was significantly faster than all others, and performance in the most restricted view (30 degrees) was significantly slower than all others. This was found to be true for the course in general, as well as for each obstacle in particular. No significant difference was found between 75 and 120 degrees.

Several tests have been conducted on virtual environments. We discuss these in more detail in the following chapter.

3.6 CONCLUSION

Peripheral vision is an important component of the human visual system. It is strongly related with motion detection and night vision. Limiting the field of view has shown reduction in many visuomotor and dynamic spatial tasks, but little to do with static inspection and object recognition. In particular, there is evidence that restrictions in peripheral FOV can have severe consequences for a person's ability to generate an understanding of the space in which they are located and to follow a route through it. This confirms the importance of presenting a wide field of view in virtual reality displays, since these types of tasks are essential for proper navigation and immersion.

In chapter 4 we look at further studies on this topic focusing on virtual reality and computerised tests. We look at the effect of different display sizes, as well as displays with wider fields of view.

CHAPTER 4

THE EFFECT OF DISPLAY SIZE AND FIELD OF VIEW ON PERFORMANCE IN VIRTUAL REALITY

4.1 INTRODUCTION

Restricting the field of view has been shown to have negative consequences on several tasks essential to navigation, particularly those associated with dynamically following a route. In many virtual displays, both immersive (e.g. the HMD) and non-immersive (e.g. desktop computers) the field of view is much narrower than the average human's. This is due to technological limitations. HMDs typically increase in price with the field of view (Arthur, 2000). Nonetheless, it is implicit that this reduced field of view inhibits user performance in these environments.

In this chapter we look at the research regarding how changing the visual display can affect user performance. We focus mainly on the issue of display size (large vs. small) and field of view (wide vs. narrow).

4.2 TERMINOLOGY

In virtual reality, field of view may refer to the angular range provided either by the virtual environment or by the physical display on which the environment is displayed.

The geometric field of view (GFOV) refers to the three-dimensional range provided by the user's egocentric viewing frustum of objects rendered in a virtual environment. It is defined as the angular range the observer has of the virtual world, including depth. Representations of objects lying outside this range (beyond the limits of x, y and z rendering for a given frustum at a given moment) are not visible to him.

The physical field of view, also called the display field of view (DFOV), is the two-dimensional angular range the observer has of the display. It is calculated as the angular distance between the left and right (or top and bottom) ends of the display. While a 1:1 GFOV:DFOV ratio is both common and desirable in both horizontal and vertical dimensions, it is not universal, and so the distinctions are important.

In this thesis we use the term "field of view" (FOV) to refer to the geometric field of view. We refer to "display field of view" by that term to distinguish it.

In this review we also distinguish between studies comparing large displays with small displays (both FOV and DFOV constant), and studies comparing wide and narrow FOVs.

4.3 EFFECT OF DISPLAY SIZE

Performance on large displays is often cited as being superior to performance on smaller displays, in both spatial and non-spatial tasks. Some of the most basic reasons for this include:

- The larger the display, the more room is available for multiple objects to be shown at the same time.
- The larger the display, the higher the resolution, making objects clearer.

Non-spatial tasks which have been shown to benefit from larger screens include spreadsheet searching (Simmons and Manahan, 1999), web browsing (DiPierro et al., 1999), and text learning (de Bruijn et al., 1992).

Research comparing large display (0.68 x 0.54 metres and larger) with typical desktop monitors have found higher performance rates by users on the former on spatial tasks. In these tests, the larger displays are presented at a greater distance so as to preserve the same visual angles. Larger display sizes have the advantage of higher visibility, since more pixels are used for each item; and the disadvantage of requiring more physical navigation, since the user has to search a greater physical area (Ball, 2006).

4.3.1 SPATIAL TESTS IN 2D ENVIRONMENTS

A series of tests based at the Virginia Polytechnic Institute and State University (Ball et al., 2005; Ball, 2006; Sabri et al., 2007) compared small, medium, and large displays by tiling single monitors into grids. A small display consisted of a single 17 inch monitor (approximately, 0.34 x 0.27 metres); a medium display consisted of 4 monitors tiled into a 2x2 grid (0.68 x 0.54 metres); and a large display consisted of 9 monitors tiled into a 3x3 grid (1.02 x 0.81 metres). The specified tasks were search and navigation tasks in a 2D environment.

The first experiment (Ball, 2006) consisted of two static search tasks. In the first task, participants were asked to identify targets consisting of red dots that were hidden among a cluster of grey dots. In the second, targets consisting of shapes composed of red dots were hidden in a cluster of grey dots. It was shown that for small targets (4 pixels per dot), search times decreased as the display size increased. Participants were also found to make fewer repetitions (reporting finding the same target twice) as the size increased, with no such mistakes being made on the 3x3 display.

In the second experiment (Ball, 2006), a raster map of a large city (Providence, Rhode Island) was used. Only part of the map could be shown at one time, and users would have to pan to find different parts of the map, introducing a dynamic element to the display. Tasks involved searching for a landmark, tracing a route from source to destination, comparing two distances to determine which was closer, and advanced geographic questions (e.g. “Find the deepest water in Providence River”). All participants in this task were male. A significant effect of display size on time was found for the search and route-tracing tasks. Performance on the 3x3 display was twice as fast as that on the single monitor. No significant time difference was found for the other geographic tasks set. It was theorised that these tasks were too difficult for the sample participants to yield any significant difference (a floor effect).

A similar experiment was run by Ball et al. (2005), in which monitors were tiled to form 3 rows, and varied in column width from 1 to 8 monitors. They were used to display a housing map of a large city, namely Houston, Texas. Tasks included searching for a specific house, navigation to a certain house, and answering questions regarding house patterns (e.g. “Where is the largest cluster of houses?”). Results showed that performance time decreased as the number of columns increased. Shupp et al. (2006) also found large displays provide better results in map tasks, including search and route retracing.

Sabri et al. (2007) found that these results extend to game situations in which navigating a 2D area was a key factor. Participants who used the medium and large displays required significantly less time to navigate, won more often, and had higher scores than those who used a single screen.

Tyndiuk et al. (2004) compared performance of spatial tasks on a desktop monitor (0.30 x 0.23 metres, 0.5 metres away) with a large display (3.30 x 2.80 metres, 5.50 metres away). In the first test, the environment used was simple and sparse, containing 30 chairs. One chair would flicker, indicating it as the target which the participants would have to find and reach, prompting another chair to flicker. Two runs of this test were designed: a

naïve travel task and a prime travel task. In the naïve travel task, the next target chair was close enough to be visible; while in the prime travel task, the next target chair would be out of view and would need to be searched for. The large display was found to improve performance (number of chairs found in a four-minute time limit) for the naïve task, but no difference was found on the prime task.

Tan et al. (2003; 2004; 2006) compared user performance on a 17.5 inch desktop monitor (approximately 0.36 x 0.27 metres, 0.63 metres away from the user) with a large projection display (approximately 1.9 x 1.4 metres, 3.5 metres away from the user) on a series of tasks, both spatial and non-spatial. Differences were found in spatial tasks only. A reading comprehension task showed no significant difference between displays. However, the same participants were shown to perform better on the large display for a Guilford-Zimmerman Spatial Orientation (GZSO) test. In this test, users are shown a before and after picture representing the view from onboard a boat. The user is asked to identify which direction the boat has moved in between the pictures. Results of post-test questionnaires showed that these participants significantly preferred the large display for the spatial task, but had no preference for the reading task (Tan et al., 2003).

Tests on three other static spatial tasks found no effect for display size (Tan et al., 2004). These tests were the Card Test, Cube Test, and Shepard-Meltzer Test. In each test, a number of questions were asked showing a target and a stimuli, and asking if the two objects were the same or different after some manipulation. In the card test, the manipulation was a rotation of a 2D object, including mirror manipulations. In the Cube Test, it was the rotation of cube with six different sides. The Shepard-Meltzer test utilised representations of three-dimensional objects (similar to the Mental Rotation Test, see Section 5.4.1).

4.3.2 SPATIAL TESTS IN 3D ENVIRONMENTS

Patrick et al. (2000) compared users on a head-mounted display, a 21 inch desktop computer (approximately 0.30 x 0.44 metres, 0.69 metres away from the user), and large display (3.35 x 2.30 metres, 2.66 metres away from the user), all matched to the same resolution and field of view. The task was a cognitive mapping one. Participants were given a virtual amusement park to navigate, according to instructions presented by the experimenter. When they had navigated all the rides, they were given a map of the virtual park with several landmarks highlighted, but undefined. They were asked to identify which ride matched each highlighted object. In other words, they were asked to statically relate the knowledge of the space they had built up through their egocentric visual experience in the virtual world to an allocentric representation of the virtual world. Results on the three displays showed the only significant difference between the monitor and large display.

As mentioned, Tan et al. (2006) compared user performance of a 17.5 inch desktop monitor (approximately 0.36 x 0.27 metres, 0.63 metres away from the user) with a large projection display (approximately 1.9 x 1.4 metres, 3.5 metres away from the user). In a wayfinding test, participants were moved in a virtual environment along two straight lines. Upon reaching the end point they were asked to return to their point of origin. Users were measured for distance errors between the point of origin and the point they actually returned to. Participants on the large display gave significantly smaller distance errors.

Further tests by these researchers also showed the large displays to be superior on object-finding tasks. In the first of these experiments, participants had to find objects by dynamically exploring a simple virtual environment, which consisted of the target objects, walls for navigating around, and a boundary fence. Users were measured for distance and time taken to find objects. A similar experiment was run on a commercial computer game, containing more complex worlds with more distinct landmarks. In both experiments, the effect of the display size was found to be significant, with the larger display showing quicker times and shorter distances.

Bakdash et al. (2007) tested a pointing task using a 25 inch (approximately 0.51 x 0.38 metres) and 72 inch (approximately 1.44 x 1.10 metres) for comparison. Pointing errors were found to be smaller on the large display.

Source	Test	Metric	Result (S = Smaller Display, L = Larger)
Ball (2006)	Target Search	Time	S > L
		Repetition of same results	S > L
	Route-Tracing	Time	S > L
	Distance Comparison	Distance	S > L
	Map-Searching	Correctness	S = L
Sabri et al. (2007)	Competitive Navigation-based Game	Navigation Time	S > L
		Wins	S > L
Tyndiuk et al. (2004)	Search (objects immediately visible)	Task Score	S < L
	Search (objects not immediately visible)	Task Score	S = L

Table 4.1 Review of Studies Comparing 2D Spatial Task Performance on Small and Large Displays

Source	Test	Metric	Result (S = Smaller Display, L = Larger)
Bakdash et al. (2007)	Pointing Task	Pointing Error	S > L
Patrick et al. (2000)	Cognitive Mapping	Placement Error	S > L
Tan et al. (2006)	Pointing Task	Pointing Error	S > L
	Object Finding (Simple World)	Time	S > L
		Distance	S > L
	Object Finding (Complex World)	Time	S > L
		Distance	S > L

Table 4.2 Review of Studies Comparing 3D Spatial Task Performance on Small and Large Displays

4.4 EFFECT OF HORIZONTAL FIELD OF VIEW

Comparisons of display size alter the dimensions and distance of the display area, while maintaining the geometric field of view of the virtual environment. The same information is being viewed, but at a larger scale, and in greater detail. As discussed in chapter 3, restricting the field of view has adverse effects on visuomotor and spatial task performance. Virtual environments tend to restrict users' horizontal field of view greatly from the average in real life. Humans have a horizontal field of view of around 200 degrees. HMDs have typical horizontal fields of view between 30 and 60 degrees. The widest HMDs we are aware of have a horizontal field of view of 145 degrees. Desktop computers limit the field of view even further.

The problems in restricting field of view reported in real world situations apply to virtual environments, as well, and may even be magnified. Willemsen et al. (2004), for example, found that participants in a distance judging experiment performed significantly worse on a HMD than they did on a "mock HMD", which was a restrictive viewing device meant to provide the same field of view and mechanical properties of the real HMD in a real world situation. de Vries and Padmos (1997) similarly showed a difference between performance in real and mock HMDs when performing a dynamic task: manoeuvring a vehicle. Paillé et al. (2005) found errors in distance estimation to be greater in virtual environments than in real ones.

Wells and Venturino (1990) investigated the impact of HMDs with fields of view ranging from 20 degrees to 120 on finding objects within a virtual world. Participants found more targets, and were faster in finding the targets, with larger fields of view. They also made

fewer, but quicker, head movements with the large fields of view, implying that both more efficient and confident of their dynamic egocentric viewpoint on the virtual world. Another search task was run by Piantanida et al. (1992), using fields of view of 28, 41, and 53 degrees. Again, the wider field of view provided the best response times. de Vries and Padmos (1997) also found performance to increase and head movement to decrease with wider fields of view, in their virtual vehicle manoeuvring task. McCreary and Williges (1998) showed that field of view had a significant effect on route and configuration knowledge after navigating through a virtual house using a HMD. There was no significant effect on landmark knowledge.

In his doctoral thesis, Arthur (2000) compared HMDs with fields of view of 48, 112, and 176 degrees on a number of tasks. These tasks included a search task, locomotion task, distance estimation, and spatial memory. In the search task, participants were allowed only to turn left and right, without moving forwards, backwards, or to the side. Their task was to find a series of target objects, one at a time, which were outside the field of view at the beginning of their search. The locomotion test required navigating a simple maze without colliding with the walls. In both of these tests, the metric was time. The same maze was used for the distance estimation and spatial memory test. In these tests, more stimuli were added in the maze, in the form of coloured circles. After navigating the maze, participants were asked to go to the position of a specific circle from the maze without the aid of the rest of the maze. This was the distance accuracy task. The main metric in this task was distance accuracy, or the ratio between estimated distance and actual distance. In the spatial memory task, the participant would have to recall the position of five other coloured circles in the maze. The metric used here was the error in position between actual position and estimated position. Significant differences were found for both of the dynamic activities Arthur had asked his participants to perform: the searching and locomotion tasks. In these two tests, the wider fields of view yielded a significant difference over the narrower ones with an impressive effect size. On the other hand, no significant difference was found in the static tasks: distance estimation and

spatial memory. It should be noted that only five participants (3 female) were used for all of these experiments.

Evaluations of field of view on desktop computers have also shown an effect on performance (Czerwinski et al., 2002; Tal et al., 2003a). These studies are of particular interest to us in that they take into account gender differences (discussed in detail in Chapter 5). Czerwinski et al. (2002) compared two fields-of-view (32.5 and 75 degrees) and two physical display widths (18 inch and 36 inch) on 32 participants (15 male, 17 female). In this study, participants had to collect a series of target cubes and then navigate to a corresponding drop-pad area to place them. After the task was complete, a pointing task was performed in which the target cubes and the drop-pad areas disappeared, and users had to “point” to where they thought they were from certain positions in the virtual world. This test showed that both the wider field of view and screen width resulted in faster times in the object-placement task, and lower errors in the pointing task, for both men and women. Additionally, women were found to disproportionately benefit from the wider field of view compared to men in terms of these two measures. Another interesting result showed how the change from narrow to wide field of view affected men differently than women in distance travelled. Female participants travelled greater distances in the wider field-of-view, while male participants travelled shorter distances. Further study confirmed the benefit of the wider field of view on performance for females. Lessels and Ruddle (2004) found that a wide FOV combined with photorealism led to improved performance and behaviour more similar to real-world navigation. Riecke et al. (2002) conducted simple navigation tasks on a 180 degree half cylinder display. They found that this display improved performance of these tasks, and that this may partly be attributed to the wider field of view, although other attributes of the display may have also contributed.

Tan et al. (2003a) hypothesised that wider fields of view aid in providing a better sense of optical flow, which, in turn, is necessary for better spatial understanding. Optical flow is the relative motion of objects surrounding an observer as he moves through a world.

Optical flow is especially important for dynamic activities in virtual worlds supported by egocentric spatial representations. In the Tan et al. (2003a) experiment, the surface of the display was curved around participants, providing a 120 degree display field of view. The task set in this study was based on the experiments run by Cutmore et al. (2000), in which users had to navigate a maze by selecting through a series of doors. It was found that females' navigation performance benefited significantly from the addition of optical flow cues, while male participants did not. This result implies one possible gender-specific benefit of visual information in the far periphery in dynamic virtual reality tasks. For subjective metrics, Lin et al. (2002) found that wider fields of view increased both the sense of presence and enjoyment, but also increased feeling of simulator motion sickness.

Source	Test	Metric	Result
Arthur (2000)	Search	Time	N > W
	Navigating a Maze	Time	N > W
	Object Location Memory (Positional)	Positional Error	N = W
	Object Location Memory (Coordinate)	Coordinate Error	N = W
Czerwinski et al. (2002)	Pointing Task	Pointing Error	N > W
McCreary and Williges (1998)	Cognitive Mapping	Route Knowledge Score	N < W
		Configuration Knowledge Score	N < W
		Landmark Knowledge Score	N = W
Piantanida et al. (1992)	Object Search	Time	N > W
Tan et al. (2003a)	Navigating a Maze through Route Memory	Time	N > W
de Vries and Padmos (1997)	Vehicle Manoeuvring	Overall Performance	N < W

		Head Motion Time	N > W
Wells and Venturino	Object Search	Number of Targets Found	N < W
		Number of Head Movements	N > W
		Head Motion Time	N > W

Table 4.3 Review of Studies Comparing 3D Spatial Task Performance on Narrow and Wide FOV Displays

4.5 DISCUSSION

The results from these studies show a trend in performance benefits from both large displays and increased fields of view. Analysing these studies, we find that the tasks which were tested can be categorised into the following groups:

- Cognitive Mapping: The formation of a mental map (usually 2-dimensional) of the 3-dimensional virtual world. The formation of this map contributes to other navigation tasks, such as remembering a route or recalling the location of an object. Pointing tasks, for example, are heavily indicative of cognitive mapping.
- Object Location Memory: Remembering the position of a given object. This can be relative to other landmarks (positional) or based on Euclidean information (coordinate). We distinguish object location memory from cognitive mapping when a mental map is not required. For example, Arthur (2000) conducted two experiments in which participants walked through a virtual environment twice: once with the landmarks present, and once with the landmarks removed. To place the landmarks in their original place they remembered their relative or exact locations compared to the rest of the 3D virtual world. In contrast, Czerwinski et al. (2002) had participants traverse a virtual world and then afterwards asked them to draw the relative location of landmarks on a two-dimensional map.
- Locomotion: The ability to manoeuvre through an environment. Heavily dependent on type of manoeuvring apparatus (e.g. HMD, joystick, keyboard, treadmill, mouse).
- Search: The ability to find an object in a world. This objects could be hidden or otherwise. Search can be naïve or based on previous information, require

locomotion, and may or may not make use of cognitive mapping. In the studies mentioned above, search was mostly independent of cognitive mapping.

In all of the studies we have reviewed, the larger displays proved superior to the small ones, and the wider displays proved superior to the narrower ones, in all three-dimensional spatial tasks except for object location memory (Arthur, 2000) and landmark knowledge (McCreary and Williges, 1998). For those two tasks, no effect for display size or field of view was found.

Overall, there is strong evidence for the effect of display size and width seems to have an effect on route knowledge (McCreary and Williges, Tan et al, 2003a) and little for its effect on landmark knowledge. While an improvement in landmark positional knowledge on a larger screen was reported by Patrick et al. (2000) the procedure for this test was a route-based series of instructions (e.g. “Go to landmark A. Turn to your right to see landmark B”.) This means that the improved cognitive mapping may be attributable to route knowledge rather than landmark knowledge.

The most interesting of these studies for us is the maze search test conducted by Tan et al. (2003a). This is for two reasons. Firstly, because it is the closest study to testing the effect of the far periphery. Secondly, because it takes exposes a possible differential benefit of wide FOV as a function of gender: women may derive a particular advantage from the provision of this type of information in dynamic virtual world tasks.

In the study, users navigated a maze by choosing one of three doors, each one of which led them to a new room with a further three doors. Correct memory of the route (i.e. a cognitive map) was integral to proper navigation. Users did not perform any other interaction besides choosing which door to go through. For examples, users could not freely move about in or look around the room; the transitions were animated after they made their decision. This makes the improvement in the wider screen interesting, since there is no additional information provided that might help performance.

This means that the additional visual area helped user performance of the task, despite not contributing any additional objective information about the content or composition of the virtual world. Tan et al. (2003a) argue that it is due to the presence of optical flow cues, which help build a cognitive map. It is also possible that the much larger field of view helps the user create stronger positional relationships. The wider field of view allows the user to imagine the right and left walls continuing behind him. The user is better “grounded” in the room. What we mean by this is that the user has better cues to form relational information between objects in the environment and his own body. (This should not be confused with presence, which is the feeling of being in the virtual environment as opposed to the real world. See Chapter 6).

The second important aspect of this study is the review of gender performance. Females were found to benefit from the wider field of view more than males did. The reasons for this may be attributed to physiological differences in vision, or to strategic differences in navigation. Regardless of the reason, this and other studies (Czerwinski et al. 2002; Czerwinski et al., 2006), suggest that there may be an inherent bias in computer displays that works against females’ ability to perform certain sorts of virtual world activities. Providing a wider horizontal field of view could help alleviate this bias.

4.6 CONCLUSION

Studies have shown a relationship between display size and performance, as well as field of view and performance, on several tasks. These tasks can be divided into cognitive mapping (including pointing tasks), search, and locomotion. No effect was found for static object location memory. The effect on cognitive mapping has been found even when no additional useful information is included. The effect may be due to a number of factors. One argument is it being due to the effect of experiencing optical flow cues in egocentrically represented space whilst performing dynamic tasks. We theorise that it

may be due to an increased sense of “grounding”. Either way, the effect is due to visual information in the periphery.

The studies reviewed in this chapter also indicate a different effect on males and females. We look in the next chapter at the differences between men and women in spatial ability, both in real world and virtual tests.

CHAPTER 5

GENDER DIFFERENCES IN SPATIAL ABILITY

5.1 INTRODUCTION

In our study we aim to assess how a change in a virtual environment affects user performance. To do this, it is necessary to understand what factors affect user performance. This is important for the following two reasons. Firstly, to balance participants over conditions. Secondly, to test possibly different outcomes on different groups.

Of all the personal factors which have been studied in relation to spatial ability (age, culture, ethnicity, sexual orientation), the most commonly studied and well understood is the effect of gender. It has been shown that there are differences in spatial abilities between males and females, in both real world and virtual world studies. However, the differences vary from task to task, being significant in some and insignificant in others, and large in some and trivial in others.

In this chapter we will discuss gender differences in spatial ability. We will look at the theoretical explanations for these differences, then cite research which has studied this difference in short-range and long-range spatial tasks. We note research done in real-world experiments, paper-based experiments, and virtual experiments. We find that, while the gender difference is not always found in these tests, it is common enough, especially

in virtual tests, to require us to consider it as a factor in our own research. We also look at other factors which have been proposed as the underlying drivers of differences between men and women in their ability to perform spatial tasks.

5.2 THEORETICAL ORIGIN FOR GENDER DIFFERENCES IN SPATIAL ABILITY

Sexual differences in a species are the result of sexual selection. Sexual selection is the evolutionary process in which members of one sex of a species compete amongst themselves to attract members of the opposite sex (Darwin, 1871). Sexual dimorphism in a species is related to its mating habits. Species which practice monogamous mating habits show limited sexual dimorphism (Kleiman, 1977), while species which practice polygamous mating habits show greater sexual dimorphism (Trivers, 1972). This is because polygamous species feature one sex (usually male) competing for the attraction of mates. The more successful genetic traits are preserved and passed on separately in the two genders. Another factor is the assignation of specific gender roles, for example in parenting or food-gathering, which require distinct traits. These differences can be both physical and psychological.

An example of a psychological trait which may have been passed down separately is spatial ability. In polygynous species, males usually have a larger ranging area than females, implying that spatial ability for long-range navigation is a more important characteristic for males than females (Gaulin et al., 1986). In early humans, dating to the Plio-Pleistocene era (1.5 – 2.5 million years ago), males were designated as hunters and females as plant-gatherers. The two activities required different ranges (long and short, respectively) and sets of skills. Long-distance spatial skills, such as wayfinding, became important amongst males. Short-distance spatial skills, such as object-locating, are more important amongst females (Silverman and Eals, 1992). It also led to distinctions in spatial strategies (Euclidean vs Landmark-based – Galea and Kimura, 1993).

These differences are likely to be less pronounced today than they are supposed to have been among early humans. However, these differences are still found and are, in many areas, prominent. Some researchers argue that the differences are environmental and experiential, not evolutionary (Munroe and Munroe, 1971; Nerlove et al., 1971; Nash (1975); Serbin and Connor, 1979). These studies show a relationship between environment and spatial ability, without proving a causal effect. For example, Munroe and Munroe (1971) demonstrated that boys in a Kenyan village had a greater home range than girls, and scored higher on a spatial task; and Serbin and Connor (1979) showed that males who partook in masculine-defined game-playing outperformed those who partook in feminine-defined game playing on spatial tasks.

While it is accepted that experience and learning does affect spatial ability, studies have also shown a hormonal effect on performance (Christansen and Knussmann, 1987; Hampson and Kimura, 1988; Hampson, 1990; Gouchie and Kimura, 1991; Janowsky et al., 1994; Moffat and Hampson, 1996; Duff and Hampson, 2000; Aleman et al., 2003; Hooven et al., 2004; Driscoll et al., 2004) as well as neurological differences between men and women when performing a navigation task (Grön et al., 2000). Studies have also shown that differences between genders are robust when controlling for environmental experience and educational status.

5.3 TYPES OF SPATIAL ABILITY

Different categorisations of spatial ability exist. McGee (1979) divides spatial ability into two categories: visualisation and orientation. Visualisation is defined as the ability to imagine an object after some change is applied, such as rotation, folding, or inversion; while orientation is described as a combination of abilities regarding perceiving objects changing in space (e.g. recognising spatial patterns in objects from different angles).

Linn and Petersen (1985) divided spatial ability into three categories: mental rotation, spatial visualisation, and spatial perception. These divisions are made based on perceived cognitive and psychometric distinctions between the tasks. This is why mental rotation was considered separately from other forms of spatial visualisation. Spatial perception was defined as the ability to determine spatial relationships between objects.

None of these models take into account navigation. While the ability to perform a navigational task is partly dependent on these abilities, it is also an ability in itself.

We therefore make the distinction between short-range and long-range spatial ability skills. For short-range skills, we use the Linn and Petersen (1985) model as a basis. This is because their distinctions are based on a comprehensive meta-analysis of studies; their model has been adopted by many researchers hence; and the distinctions have proven useful in showing varying levels and extents of gender differences. In addition to the three spatial ability skills mentioned here, we add a fourth which we refer to as “spatial memory”. This is based on research done by Silverman and Eals (1992) and refers to the memory of the location of objects.

For long-range spatial skills, we look at different aspects of navigation which have been studied, such as cognitive mapping and wayfinding.

5.4 GENDER DIFFERENCES IN SHORT-RANGE SPATIAL ABILITIES

Using the Linn and Petersen (1985) model, we look at differences in spatial ability between the genders based on the following categories: mental rotation, spatial visualisation, and spatial perception. We also add object location memory, since much research has been done on gender differences in this ability. The tests devised for the spatial ability categories described here are predominantly sit-down pencil-and-paper or solid-object tests (such as a puzzle).

5.4.1 MENTAL ROTATION

Mental rotation refers to the ability to visualise an object rotated in space. Mental rotation tests are amongst the most frequently used spatial tests, since mental rotation covers an important area of spatial ability and is relatively easy to measure. Johnson and Brouhard (2005) argue that measuring mental rotation is a vital element of modelling human intelligence, along with verbal and perceptual abilities. Furthermore, rotation tests have been the “most robust and most consistent example of a sex difference in human cognition” (Brosnan et al., 2009). Rotation tests have consistently been shown to favour male participants for 3D objects.

The most commonly-used rotation test is the Mental Rotation Test (MRT) developed by Vandenberg and Kuse (1978). It is a paper-and-pencil test consisting of 24 questions. In each question, a target object is presented, which is a three-dimensional object made up of 10 adjacent cubes. Each cube is attached to other cubes by exactly two of its faces, except for the end cubes which are attached to only one other cube. Each question also presents four other objects, which are created in the same way. Two of these objects match the target object after rotation, and two do not. The participant is asked to select the two correct answers for each target. Participants are compared on number of correct answers.

Results of the MRT consistently show a higher performance amongst males. This gender difference has been found cross-culturally. Studies which have demonstrated this have been conducted in the United States (Geary and DeSoto, 2001), Canada (Silverman et al., 1996), China (Geary and DeSoto, 2001), Japan (Mann et al., 1990; Silverman et al., 1996; Flaherty, 2004), Norway, (Amponsah and Krekling, 1997; Nordvik and Amponsah, 1998), Ireland (Flaherty, 2004), France (Guillot et al., 2007), Ecuador (Flaherty, 2004), and Ghana (Amponsah and Krekling, 1997).

Furthermore, Nordvik and Amponsah (1998) argue that the difference is demonstrably not due to experience or environment. In their experiments, 161 technology students and 293 social science students from the Norwegian University of Science And Technology, all Norwegian and from similar backgrounds, environmentally and educationally, participated in the test. Not only did the male students in each study group significantly outperform their female participants, but the male social science students had significantly better results than the female technology students.

Another mental rotation test is the Purdue Spatial Visualization Test: Rotations (PSVT:R) developed by Guay (1977). The paper-and-pencil test consists of 30 questions, with a 20 minute time limit. Each question demonstrates the rotation of a three-dimensional object. A target is shown of a different object which the participant is asked to visualise rotated in the same way. Five options are given, with only one being the correct answer.

Questions vary in difficulty as to the number of rotations. Items are rotated 90 degrees around one axis, 180 degrees around one axis, 90 degrees around one axis followed by 90 degrees around another axis, or 90 degrees around one axis followed by 180 degrees around another axis.

Similar to the MRT, results of PSVT:R has shown a significant advantage amongst male users (Medina et al., 1998; Sorby, 2006; Brus and Boyle, 2009). These tests were performed on students in Michigan Technological University and University of Iowa in the United States, and Escola de Engenharia Maua in Brazil. Another similar test was devised for students in Michigan Tech with similar results (Medina et al., 1998).

Computerised mental rotation tests have also been used to demonstrate the gender difference. Roberts and Bell (2003) found better male performance on a computerised version of the MRT, while Voyer et al. (2006) developed and validated their own computerised rotation test, with the same results. A study at the University of Washington found that not only did the gender difference transfer to a computerised test, but that it

was also magnified. In these tests the same images were presented statically, but on a computer screen rather than paper. The effect was shown not to be due to computer experience (Hunt and Allahyar, 2001).

5.4.2 SPATIAL VISUALISATION

Spatial visualisation is the ability to imagine manipulations of a three-dimensional object. Different tests have been developed for different types of manipulations, such as cutting, folding, and joining objects together. As with mental rotation, tests have shown a clear gender difference in favour of male participants. Common tests include the Surface Development Test (folding), the Mental Cutting Test (cutting), and the Block Design Test (joining).

In the Surface Development Test a two-dimensional shape is shown with numbered side. Besides it is the three-dimensional solid it is folded into. The test-taker is asked to match the sides on the two-dimensional shape with their equivalent on the three-dimensional shape. Several studies on this (Nordvik and Amponsah, 1998; Gregory and Berenbaum, 1998; Saccuzzo et al., 1996) all show a significantly higher male performance level.

The Mental Cutting Test (MCT) was developed by the College Entrance Examination Board (CEEB) of the United States (now the College Board) in 1939 (CEEB, 1939). It is a timed, paper-and-pencil test, consisting of 25 questions. In each question, an image of a three-dimension geometric solid intersecting with a plane is shown. Five options are given of the cross-section, only one of which is correct. The test-taker is asked to determine the correct answer.

The results of MCT tests have shown a gender difference with overall better results amongst males (Gorska et al., 2001; Gorska, 2005; Tsutsumi et al., 2005; Nemeth et al., 2006; Nemeth et al., 2007; Nemeth, 2007). These results were found to be international, but the test has not been administered as widely as the MRT. Also, perhaps because of its

use as part of a college entrance exam, the comparisons for MCT was mostly made amongst engineering students.

The Block Design Test was adapted by Wechsler (1981) from earlier tests. In the test, several blocks are provided, each with sides that are all white; all red; or half-white, half-red, separated diagonally. Participants are shown an overall pattern and asked to make it using the blocks provided. The test is predominantly used on children and on adults with cognitive problems, such as frontotemporal dementia, which reduces performance (Rascovsky et al., 2002) and autism, which enhances it (Shah and Frith, 1993).

One study of the block design task for healthy, adults was conducted by Herlitz et al. (1997). They gave the test to 1000 Swedish participants (530 female), aged 35-80 and found a significant difference in performance between the genders, favouring males.

5.4.3 SPATIAL PERCEPTION

Spatial perception is the ability to recognise relationships between objects in space. Many of these tests were designed to evaluate cognitive abilities in children. As such, many of the tests are done on children and adolescents. However, tests performed on adults have also yielded significant gender differences. Linn and Petersen (1985) mention as examples of spatial perception tests the Rod-and-Frame Test (RFT) and the Water Level Test (WLT).

Linn and Petersen (1985) report that age influences gender gap in spatial perception. They cite Block and Block (1982) for their research on the RFT. In this test, developed by Witkin and Asch (1948), the test participant is shown a tilted frame with a tilted rod inside, and is asked to rotate the rod until it is vertical with the ground. Block and Block (1982) tested the RFT on children at different ages. The tests found girls outperforming boys at age 4, but boys outperforming girls at age 5. The difference increases by age and, at 11, was found to be significant. These differences remain through adolescence and

adulthood. Maccoby and Jacklin (1974) reviewed 21 RFT tests and found significant differences favouring male participants in 16 of them.

The Water Level Test was developed initially by Jean Piaget (Piaget and Inhelder, 1956) to test children's spatial cognition, but has often been used to show differences in adults. Participants are asked to draw a line on a tilted water bottle showing where they think the water level is. Significant differences have been found in favour of males (Linn and Petersen, 1985; Nordvik and Amponsah, 1998; Voyer et al., 2004). It has been argued that this difference may be due to less understanding of the physical principles governing fluids in containers (Vasta et al., 1993). The effect of rule explanation and training has been shown to be variable (Liben and Golbeck, 1984; Barsky and Lachman, 1986) and it is still debatable how much of the difference is due to cognitive gender differences.

5.4.4 SPATIAL MEMORY

Spatial memory refers to the ability to remember the position of objects, either in relation to other objects, or in a correct coordinate position. A test which measures the former is the Object Location Memory Test (OLMT). The OLMT is the only visuospatial test for which females have demonstrably higher performance rates than males (de Goede and Postma, 2008). This was first posited by Silverman and Eals (1992) who developed it. In this paper-and-pencil test, 27 drawn objects are presented in a cluster within a frame. Participants are told to look at the picture for one minute and to memorise the location of the objects. They were then given a second drawing of the same 27 objects within the frame. However, seven pairs of objects were randomly swapped. The task was to identify these pairs.

Silverman and Eals (1992) found females outperform males in this task, and this has been verified by others (James and Kimura, 1997; Duff and Hampson, 2001; Levy et al., 2005; Voyer et al., 2007). These results were shown on both paper-and-pencil and computerised versions of the test (Barnfield, 1999). James and Kimura (1997) also found a female

superiority when pairs of objects were swapped, as in the original OLMT. However, when objects were shifted to new, previously unoccupied locations, no sex differences were found.

A different test was devised by Duff and Hampson (2001), similar to the card game Concentration. In this test, a 4-by-5 array of ten pairs of images are shown to the user. The images are then hidden behind flaps. Participants were allowed to open the flaps, two at a time, to search for matching images. The task was to find all ten pairs of matching items with as few steps as possible.

Duff and Hampson (2001) found females to perform significantly better, both in number of errors and overall time. Lejbak et al. (2008) extended this test to include three different sets of stimuli and tested them on both paper-and-pencil and computerised versions. In all six cases, the female advantage was found to be significant and large. An earlier test by McBurney, et al (1996) showed female superiority in a similar task, using Milton Bradley's Memory™ board game. The test used more stimuli (33 pairs, compared to 10) and did not show the participants their position prior to the search.

Jordan et al. (2000) conducted a test in which participants were presented with a 4-by-4 grid containing 11 stimuli for 15 seconds. The participants would then be asked to recall the objects and their locations. The test was run with two different forms of stimuli: words and images. There was no significant difference in recalling the objects, but there was a significantly higher recall among female participants for object location.

Results from Postma et al. (1998) showed different results. In their test, 40 participants (20 female) were shown an array of 10 objects, displayed on a computer screen for 30 seconds. The array then disappeared and the objects were shown in a row. The user was charged with matching the objects with their position in the array. Three trials of the test were run. In the first, the positions were marked so that the participant had to match each object to its correct position. In the second, the objects were all given equal value, so that

the participant had to mark the position, regardless of object. In the third, all objects were distinct and their positions were unmarked. No difference was found between genders for recalling object location when positions were marked. However, when positions were not marked, a significant difference favouring male participants was found in positional reconstruction. This test was replicated by Postma et al. (2004) with similar outcome.

These results, along with the James and Kimura (1997) finding, seems to indicate that the object location task favours female participants only when the object space is a finite and discrete space (such as the Concentration game, the OLMT, and the Duff and Hampson (2001) test).

Iachini et al. (2005) designed a real-world version of an object location memory task, similar to the OLMT. Participants were asked to memorise the spatial layout of a cylindrical room with seven objects. Participants were then exposed to the room after the seven objects had been relocated and with the addition of seven new objects, and given the task of returning the objects to their original locations. No significant difference was found for object recognition or spatial relation (i.e. identifying which objects were originally in the room and where they were in comparison to each other). A coordinate measure was used for object location. For this metric, male performance was found to be significantly more accurate. As this was an object relocation to an unmarked origin task, the results are in keeping with James and Kimura (1997), Postma et al. (1998), and Postma et al. (2004).

Explanation for the female superiority in some aspects of object location memory vary. Silverman and Eals (1992) presented an evolutionary theory, based on the foraging practices of females in the Plio-Pleistocene epoch. Alexander et al. (2002) posits that the difference in performance is due to differences in cerebral activity. Saucier et al. (2007) theorise that it is due to differences in the spatial-motor systems which respond to spatial problems differently depending on their location. Spatial tasks are divided into those performed in peripersonal space and those performed in extrapersonal space. Peripersonal

space is the space immediately surrounding a person, which is within reach. Extrapersonal space is the space beyond peripersonal space. It was theorised (Saucier et al., 2007) that females outperform males in the former, while males outperform females in the latter. This was confirmed by comparing the results of an OLMT in peripersonal and extrapersonal space.

5.5 GENDER DIFFERENCES IN LONG-RANGE SPATIAL ABILITIES

Navigational ability is an umbrella term for several skills required to travel between points in a world. These skills include choosing routes, establishing position and orientation, updating position and orientation while moving, and recognising location points (Loomis et al., 1996). It has been long established that men and women tend to use different navigational strategies and have different performance rates in navigational tests. Most notably, women have been shown to depend more frequently on landmarks while travelling, while men are more likely to use Euclidean methods.

Navigational tests can be divided by type of ability measured. Different abilities which can demonstrate the differences between males and females include those used to measure cognitive mapping, distance assessing, wayfinding, and object-locating. Because these skills are not necessarily employed in the same way in different environments, tests can also be divided by the type of world. Navigating a two-dimensional world (paper or computerised 2D) requires different skills to navigating a three-dimensional world (real world or virtual). Also, worlds differ in their openness and density. Some skills required to navigate a desert differ from those required to navigate a jungle; and traversing a car park is different from traversing a shopping mall, a street, or a hedge maze.

In this section we focus on the different skills measured in these tests, primarily in 3D worlds. These tests are both real world and virtual, indoor and outdoors, and encompass many differing situations. We begin by looking into research on navigational strategies.

5.5.1 NAVIGATIONAL STRATEGIES (LANDMARK VS. EUCLIDEAN)

People's navigation of an environment depends on their understanding of it. Knowledge of an environment is divided into many different aspects. The main division is between route knowledge and landmark knowledge. Landmark knowledge is the knowledge of the position, size, and shape of distinctive objects or scenes. Route knowledge is the knowledge of the paths (or routes) connecting these landmarks. An additional form of knowledge associated with mental mapping is survey knowledge. Montello (1998) defines survey knowledge as "configurational knowledge of the locations and extents of features in some part of the environment that is not limited to particular travel paths".

Many theories have been proposed as to how this knowledge is obtained and mentally mapped through experience of an environment. Earlier theories proposed that knowledge was obtained in stages. Siegel and White (1975) proposed that landmark knowledge was obtained first after initial explorations of an environment. Route knowledge would then be developed after further familiarity with the environment through paired association between landmarks. Different routes would then build upon each other to create a more detailed network of the environment. Another model was proposed by Thorndyke and Hayes-Roth (1982) in which navigation of an environment presents users with route knowledge, whereas navigation of a map presented users with more landmark knowledge. The conclusion of this is that route knowledge is obtained first through exploring an environment, and landmark knowledge is built upon it later. This model is somewhat supported by O'Keefe and Nadel (1978) who argued that the human mind is equipped with an *a priori* facility for imposing Euclidean knowledge on experience.

Newer interpretations have moved away from the idea of different types of spatial knowledge being built upon each other, but rather that they coincide. Montello (1998) argues that there is no point at which a "pure" landmark or route knowledge exists. In

their theory, the initial mental map of a world contains both kinds of information in a basic state. With more familiarity with the environment, all types of knowledge (survey, route, landmark) increase. This increase is dependent on individual differences.

Tests to determine navigational strategy tend to fall into two categories: self-report questionnaires and direction-giving tasks. Self-report questionnaires ask the participants directly what strategies they use. Direction giving tasks require users to give directions to a certain location. Their responses are analysed for landmark-based or Euclidean content. For example, the number of cardinal terms (Left, Up, Behind) can be counted to compare for Euclidean navigation. A third type of test can design a task which requires or encourages a specific strategy, or compares conditions where landmarks are present with those in which they are absent, thus assessing user dependence on them.

Self-report questionnaires

Lawton (1994) developed a Way-Finding Strategy Scale to compare navigational strategies. The test consists of 14 points. Each point refers to a strategy used when driving to an unknown target in a moderately familiar city, which the user rates on a scale from 1 to 5 referring to how well they describe the user's strategy in such a scenario. Questions were weighted for their level of route (landmark-based) and orientation (Euclidean) strategy, so that each strategy was given a score based on the scale response and strategy weight. Examples of points with high route strategy values include "I kept track of the direction (north, south, east or west) in which I was going" and "I referred to a published road map". Examples of points with high orientation strategy values include "Before starting, I asked for directions telling me how many streets to pass before making each turn". Results found females had a significantly higher route strategy score, while males had a significantly higher orientation strategy. O'Laughlin and Brubaker (1997) replicated this experiment and found similar results (difference on the orientation strategy approached significance ($p < 0.07$)).

Lawton (1996) developed a similar test for indoor wayfinding. A tour of an indoor environment (a single floor of a university building) was followed by an Indoor Wayfinding Scale questionnaire. The scale was similar in design to the Way-Finding Strategy Scale, but with points more appropriate to the indoor task (e.g. “Whenever I made a turn, I knew which direction I was facing”.) Participants were also given the Way-Finding Strategy Scale. In both scales, females were confirmed to have a higher route strategy score, and males a higher orientation strategy.

Direction Giving Tasks

Direction giving on a map was evaluated by Ward et al. (1986), Miller and Santoni (1986) and Dabbs et al. (1998). In each of these experiments, males were found to use more Euclidean, cardinal, and distance terms, while females used more landmark terms.

Saucier et al. (2002) inverted these tests by giving participants directions which were either landmark-based or Euclidean, and evaluated how well users could navigate part of a university campus by following them. The metrics used were the number of errors made and the overall time taken. When using Euclidean directions, female participants made more errors and took longer times to complete the tasks than their male counterparts. They also made more errors and took longer than females and males using the Landmark directions. No other significant differences were found between the four groups. The results of these studies can be summed up as:

- Men perform better than women when following Euclidean directions.
- There is no gender difference when following Landmark-based directions.
- Women perform better when following Landmark-based directions than they do Euclidean directions.
- There is no difference in performance for men between following Landmark-based and Euclidean directions.

The implications of these results is that they extend to other tasks as well.

Other Tests

Sandstrom et al. (1998) found males performed better in a virtual Morris water test (see Section 5.5.5) when no landmarks are present. However, when landmarks were provided, the gender difference disappeared.

Jansen-Osmann and Weidenbauer (2004) evaluated performance by children and adults on a virtual maze. Participants were made to familiarise themselves with the maze, through learning trials, in which landmarks were present in the form of virtual toy animals. After completing four learning trials without error, participants were given a test trial in which they had to navigate the maze without the landmarks. No gender difference was found in the learning trials, but females were shown to make more errors in the test trial.

Galea and Kimura (1993) simulated a route on a 2D map. Following this, subjects were asked to recall landmarks that were on the specified route, and landmarks that were not. Female participants were found to remember significantly more items in both cases. Females also remembered more of the street names. Another experiment by Galea and Kimura (1993) was designed to test Euclidean ability. Three 2D maps were displayed, one at a time. The maps had overlapping areas. Afterwards, subjects were asked to specify the positional relationship between two objects from separate maps. Males were shown to answer these questions more accurately than females.

The results of all these tests show a general difference in strategies, with males using Euclidean navigation and females using landmark-based strategies. This gives males an advantage in navigation tasks in which landmarks are not present, are scarce, or are heterogeneous.

5.5.2 COGNITIVE MAPPING

Cognitive mapping refers to the ability to transform stimuli in a three-dimensional spatial environment into mental information which can be used to navigate the world (Kitchin, 1994). As such, cognitive mapping is connected with spatial visualisation and mental rotation skills, and should therefore show a gender difference favouring males. Tests to measure cognitive mapping ability involve participants traversing a world, which they are then required to map, usually by working with an allocentric representation such as drawing an outline of the room, retracing a route, or relocating objects to their positions.

It has been hypothesised that greater home ranges amongst males accounts for differences in cognitive mapping abilities for familiar environments (Evans, 1980; Matthews, 1986). However, tests on non-familiar environments have also shown a significant difference favouring males.

Gender differences in cognitive mapping have been found in children. Herman and Siegel (1978) found such differences in children as young as 7-8 in a reconstruction task. The participants were presented with a large-scale model of a town which they walked through, and were then asked to reconstruct. Differences for this task were also found for children aged 10-11, but not for kindergarten children. On the other hand, Siegel and Schadler (1977) did find differences between boys and girls in kindergarten in a similar test. In this experiment, the environment was one more familiar to the children, specifically their kindergarten classroom. The participants were shown a model of their classroom (approximately 30.5 x 50.8 x 12.7 cm) with the classroom doors highlighted. Three trials of this test were conducted. In two of the trials, the children were given no more orientational cues beside the doors. In the third, four extra landmarks (e.g. teacher's desk and piano) were placed into the model. Children were asked to name other landmarks (furniture) in their classroom and then given a model of said landmark, which they were asked to place in the model. After the child stopped naming landmarks, the

participant would give the child one selected randomly to place. A total of 40 landmarks were associated with the room (including the four already placed in the cued condition). In all three trials, there was no difference found in recalling which objects were in the room. However, boys were found to perform better in placing the landmarks, both in distance from the correct to-scale position, and by positional relationships between the landmarks.

Montello et al. (1993) compared the cognitive mapping skills of adults. A tour of part of the University of California, Santa Barbara campus was given, following which participants were asked to sketch a map. Male users were shown to have made significantly fewer errors in evaluating the route distance and the overall direction. No significant difference was found for number of wrong turns (including extra turns, neglected turns, and turns in the wrong direction) nor in evaluating the overall distance from start to end points.

Holding (1982) evaluated the ability of undergraduates at the University of Louisville to reconstruct and recognise the map of a familiar environment; namely, the main campus of their university. 22 students (11 female) took part in a grid placement and a map placement task. In the grid placement task, a 255-square grid was provided representing the university campus. Three campus buildings were placed onto three squares in accordance with their relative position on campus. The participants were asked to place four other buildings onto the map in an accurate position. In the map placement task, a map of the campus was provided with the names of the buildings removed. The participants were asked to locate a list of buildings they would be familiar with. In both tests, the gender difference was significant, with males outperforming females.

McGuinness and Sparks (1983) provided participants with part of a map in the form of a number of landmarks, and asked them to fill in the missing roads, paths, and buildings. Males were found to make significantly fewer errors in the spatial positioning of the

landmarks. However, females were found to make significantly fewer errors in the distance between landmarks.

O'Laughlin and Brubaker (1997) conducted an experiment of cognitive mapping using video. A three-minute videotaped tour of a nine-room, one-level house was shown to the subjects. There were two trials. One group were shown a furnished house, and the other unfurnished. This was to compare navigation with and without landmarks. No significant difference between gender performance was reported for this task. O'Laughlin and Brubaker (1997) cite limitations in the study which may have led to reduced cognitive mapping performance overall and may account for the lack of gender difference. These include:

- The use of video restricted the subject's freedom to explore the world, either visually or physically.
- The overall layout was too dense and complex.

We add to this list the fact that participants were allowed to record written notes during the tour, reducing the “cognitive load”, thus leading to a less accurate evaluation of cognitive mapping.

Pearson and Ferguson (1989) also found no significant difference between males and females in sketching maps based on an uncontrolled tour of a city. In this case, the tour was shown via a series of slides, which also restricted subjects' ability to navigate freely.

5.5.3 ROUTE RETRACING

In route retracing, participants are taken through or shown a given route, and are then asked to retrace it. An early experiment was conducted by Lord (1941) on 173 boys and 144 girls in grades 5 through 8 (ages 10 through 14). In this experiment, the participants were taken on automobile rides through a town. Boys were found to reconstruct the

journey more accurately. Matthews (1986) used a similar test on a more familiar environment. 166 children aged 6-11, living in Coventry, were asked to map their journey from home to school. Boys were found to be significantly more accurate and detailed in their mapping.

Galea and Kimura (1993) performed a route retracing test on a 2D map. In their test, participants were shown a route taken on the map, and were then asked to retrace it. Male participants were found to take significantly less time to finish the task and made significantly fewer errors.

Ward et al. (1986) tested college students on information gained from maps and asked them to give directions to certain points. Subjects were compared for errors and omissions. When the map was present during direction-giving, no difference was found between genders. However, when the map was absent, males made significant fewer errors and omissions.

5.5.4 DIRECTIONAL ACCURACY

Directional accuracy is the ability to determine the position of one object in relation to a given position, or in relation to another object. The accuracy is measured by difference of reported angle from correct. These tasks often take the form of pointing tests. Participants are told to imagine they are standing at a certain point i.e. to adopt an egocentric frame for the task. They are then told to indicate the direction from that point to a number of landmarks. Bryant (1982) conducted a test on students from the University of Berkeley, who were told to imagine they were standing on a particular, familiar location in the university campus. They were then given the name of 9 other locations and asked to mark the direction in which a particular landmark was found. The metric for accuracy used was the angular distance between recorded and actual direction. Males were found to be significantly more accurate.

Kirasic et al. (1984) conducted a similar experiment, distinguishing between “easy-to-locate” and “difficult-to-locate” landmarks. No gender difference was found for easy-to-locate landmarks, while males were more accurate in pointing towards difficult-to-locate landmarks.

Pointing tests on unfamiliar environments have yielded varying results. Lawton et al. (1996) reported significant difference in favour of male college students in a pointing task after being given a tour in an unfamiliar building. However, Sadalla and Montello (1989) and Montello and Pick (1993) found no significant difference in their tests of an unfamiliar indoor (building) and outdoor (campus) environment, respectively. Dogu and Erkip (2000) also found no difference in a pointing task inside a shopping centre, but had not taken familiarity with the specific mall into consideration, which they listed might have contributed to this. A virtual version of a pointing test in a shopping centre by Tlauka et al. (2005) also found no significant difference.

New et al. (2007) conducted a pointing test in which participants were led around a market and made to partake in specific fruit and vegetables at each stall. The study found that females were significantly more accurate than males in pointing to non-visible stalls. They theorised that this was due to the evolutionary mechanism involved for food foraging being stronger in women, due to role assignation in early man, in accordance with Silverman and Eals's (1992) theories.

A virtual version of the pointing test was conducted by Lawton and Morrin (1999). Participants were placed in single-path virtual mazes of varying complexity (two-turn, four-turn, and six-turn mazes). Upon reaching the end of the maze, they were asked to point to the direction of the starting point using a specially-designed compass. Males were found to be significantly more accurate, regardless of maze complexity, with an average difference of 20 degrees of pointing accuracy.

Waller et al. (2001) conducted pointing tests on two types of virtual mazes (wireframe and surface-rendered) as well as a real maze. In all cases, men were significantly more accurate in pointing than women. The difference, however, was larger in the virtual environments than in the real environments.

5.5.5 SEARCH AND WAYFINDING

Search refers to the ability to locate a target object. Wayfinding refers to the ability to locate a target position. The ability to perform these tasks requires other cognitive skills, such as cognitive mapping and route retracing. Tests have been performed in real-life and computer-based environments.

Real World Wayfinding

Schmitz (1997) tested children aged 10-17 on a real-world maze and found boys to complete the maze significantly faster. This was found over several runs of the maze. In an outdoor setting, Malinowski and Gillespie (2001) tested US military college students in an orienteering task, using a map and a compass. The male students found significantly more of the points. They were also faster in the task, although this may be attributed to physical differences. Soh and Smith-Jackson (2004) performed a real-world map-based test on civilians in which the trail to be taken was shown on the map. They found no difference between genders in any of their metrics, which included overall time, decision-making time (at bifurcations), accuracy of decisions, and overall time deviated from the set trail. However, the test also failed to show a difference in any of these metrics between experienced and non-experienced participants, a fact explained by the researchers as being due to the skills required for the task being more basic than general wayfinding. The small number of female participants in this test may also partly account for this (only 8 vs 28 male participants).

Touch-Screen Computer Wayfinding

Devlin and Bernstein (1994) used a computer-based navigation test utilising touch-screen technology. In the test, users were shown a route in the form of a series of photographs. Seven versions of this experiment were run. In one, the photographs were shown without any other information. In the six others, some additional information was added, such as directional text or a map of the route.

After being shown the route, participants were asked to replicate the path taken by choosing the directions to take from each point. Females were shown to make more errors in this test than males did.

Virtual Wayfinding

The ease of constructing virtual environments and the interest in exploring the nature of navigation has led to many different studies on virtual wayfinding. These tests have utilised a number of different environments. Mazes are a common environment. These are easier to construct virtually than in the real world, and provide easy wayfinding metrics for comparison purposes, such as time taken and number of false turns. Virtual environments also allow for the Virtual Morris Water Maze to be tested on humans; a test, which in real life, is not accurate for humans.

1. Virtual Mazes

Moffat et al. (1998) found gender differences in a virtual maze environment. By conducting five learning trials per participant, it was possible to evaluate the ability to spatially learn a novel environment. Overall, males were found to spend less time and make fewer errors (deviations from the route) than females.

Cutmore et al. (2000) constructed a maze composed of 49 square rooms composed in a 7x7 grid. Each room had from one to four doors, one maximum per wall, which could be

used to pass to the next room. Controls were simplified to “GO THROUGH LEFT DOOR”, “GO THROUGH FRONT DOOR”, “GO THROUGH RIGHT DOOR”, and “ROTATE 180 DEGREES”. Three versions of this experiment were run. In one, no extra information was provided besides the maze walls and doors. In another, a compass heading indicating the cardinal direction was provided. In the third, a landmark, in the form of an everyday item, was added to each room. The task was to find the exit in the maze as quick as possible. Six trials were run for each participant. In all cases, male participants made fewer moves to find the exit. After the trials, participants were given a paper map of the maze and asked to show the shortest path to the exit. Once again, males performed significantly better in the task.

Ahmad et al. (2005) used a mobile augmented reality system to test navigation in a simple maze (only three bifurcations). Differences in time were larger (over two minutes) and approached significance ($p < 0.10$).

2. Virtual Morris Water Mazes

Some researchers have used virtual versions of the Morris Water Navigation Test. In the original test, developed by Morris (1984) for testing the spatial memory of rats, a pool of water with a hidden escape platform is combined with visual cues surrounding the pool. The rat escapes when it reaches the platform. Initial trials require chance for platform location, while subsequent trials test the rat's spatial memory. In humans, the real-life version of this test is trivial in a to-scale pool. A floor effect would occur and no gender differences would be found. However, virtual Morris water tests have shown significant gender differences. Newhouse et al. (2007) designed a version of the test for children aged 8-10. The test consisted of 16 regular trials, as defined above, and a probe trial in which the platform was removed. When participants had reached the correct position where the platform was, they were alerted through visual and tactile stimuli. Boys found the target more often than girls, and were significantly faster in escape time and took shorter distances to do so. Boys were also shown substantially to improve time over

trials, while improvement was less evident for girls. This indicates a difference in spatial memory. Furthermore, in the probe trial, boys were found to spend more distance looking for the platform in the quadrant where it was normally located than girls. Trials in which the platform was visible showed no significant difference in time or distance, indicating that the differences in the other trial were not due to hardware or virtual environment familiarity.

Astur et al. (1998) performed three versions of this test, in which the only difference was the specificity of the language explaining the environment. In all three cases, a large and significant difference was found in favour of male participants both in the trials (time to find platform) and the probe (distance spent in platform quadrant). Again, tests with a visible platform showed no difference between the genders. These findings were replicated by Mueller et al. (2008). Driscoll et al. (2004) not only found similar results, but also found a correlation between testosterone levels and performance.

Sandstrom et al. (1998) found a gender difference favouring males when no reliable landmarks could help determine the location of the hidden platform. This was done by running the experiment in a virtual environment, once without landmarks and once with landmarks changing from trial to trial. In a third run of the experiment, in which the landmarks were stable throughout the tests, no gender difference was found.

3. Non-maze

Tlauka et al. (2005) found gender differences in a non-maze environment. A virtual model of a shopping centre was used to test navigational abilities. Participants were first required to follow a route provided on a map. Then, they were required to find the route back without the use of the maps. Male participants were found to be significantly faster and made significantly fewer mistakes while following the map; and were found to be faster in following the route back.

5.5.6 MAP READING

In these tests, participants are given a 2D map of the world and are required to interpret it for use in a 3D world, real or virtual.

Gilmartin and Patton (1985) evaluated the ability of children (aged 9-10) and undergraduate students on basic map skills, such as route planning and visual search. While they found the boys performed better than the girls on the task, there was no difference between the undergraduates. Golledge et al. (1995) also could not find any difference on similar tasks. Montello et al. (1999) found no difference in a map-learning and remembering task. As mentioned before, Ward et al. (1986) found no difference between genders in number of errors and omissions in a direction-giving task when a map was present. However, when the map was studied and then taken away, female participants made significantly more errors and omissions.

5.5.7 SELF-PERCEPTION OF SPATIAL ABILITY

Studies in visuo-spatial ability have found gender differences in self-assessment of spatial ability skills. This has been evaluated by questionnaires asking users to rate their own abilities, as well as by questionnaires seeking factors which might hinder performance, such as disorientation, anxiety, or getting lost.

Furnham (2000) gives an overview of self-assessment of spatial ability. In general, there is a tendency amongst males to rate themselves significantly higher than females in spatial abilities, as well as in other mathematical abilities.

LaGrone (1969) reported that women had higher levels of disorientation when navigating, while Kozlowski and Bryant (1977) found women had a greater fear of getting lost, and Bryant (1982), reported significant gender differences in self-reported sense of direction, as did Cornell et al. (2003) and Hölscher et al. (2006).

Lawton (1994) developed the Spatial Anxiety Scale (SAS) and found higher responses amongst females. Schmitz (1997) developed a separate anxiety scale for a maze navigation test for children aged 10-17. The scale incorporates points on general anxiety, test-related anxiety, and darkness anxiety. The results showed higher anxiety levels amongst the girls. Relationship between self-reports of spatial ability and anxiety, and spatial performance has been shown (Bryant 1982, Lawton 1994, Lawton 1996, Schmitz 1997).

5.6 OTHER FACTORS

In addition to gender, many personal factors have been studied for their possible effect on, or prediction of, spatial ability. These include: age, ethnicity, sexual orientation, handedness, and hormone levels. We look at each of these factors briefly.

5.6.1 AGE

Different spatial abilities manifest themselves at different ages. Some become apparent in prepubescence (Herman and Siegel, 1978), and others in adolescence (Macoby and Jacklin, 1974). Differences in performance amongst adults have mainly been shown between age groups. The choice of age ranges differs by study. Moffat et al. (2001) divided groups into young (under 45), middle (45-65), and old (over 65), for a virtual maze test, and found the same degradation effect as regards time. Moffat and Resnick (2002) used the same age groups, and found the same effect in a Virtual Morris Water Test. Driscoll et al. (2004) also found an age effect in a Virtual Morris Water Test, dividing groups into young (20-39), Middle (40-59), and Old (>60), it was shown that performance decreased significantly by age group.

The degradation of spatial ability skills is associated with the degradation of cognitive abilities, in general. This degradation is generally more significant after age 50 (Salthouse 68

et al., 1989; Verhaeghen and Salthouse, 1997). Willis and Schaie (1998) conducted MRT tests on elderly participants (over 60) over a 14-year period, in seven year intervals, and found a decline in performance with age. In adults under 50, age has less of an effect on performance differences.

5.6.2 ETHNICITY AND CULTURE

Due to its controversial nature, not much research is done comparing ethnic groups for mental abilities. Rosselli and Ardila (2003) argue that many non-verbal neuropsychological tests, including the spatial ability tests mentioned here, are not valid cross-culturally. For example, maps may be meaningless to certain cultures, and 2D drawings are not always interpreted as representations of 3D objects.

Furthermore, in multicultural societies, factors due to ethnicity and culture may in fact be due to class and educational levels (Perez-Arce and Puente, 1996). Education has been shown to be a strong indicator of performance (Rosselli and Ardila, 2003).

Marjoribanks (1972) tested 11-year old boys from five different Canadian ethnicities on verbal, number, reasoning, and spatial tasks. No significant differences could be found for spatial ability that could not be accounted for by environmental differences.

There is no reason to believe spatial differences exist in different ethnicities, although the differing environmental cultures may lead to some differences.

5.6.3 SEXUAL ORIENTATION

Some studies have shown differences in spatial ability based on sexual orientation. Amongst men, some researchers have found a difference favouring heterosexual men in the MRT (Sanders and Ross-Field, 1986; Gladue et al., 1990; Neave et al., 1999; Peters et al., 2007), and WLT (Sanders and Ross-Field, 1986; Gladue et al., 1990; Sanders and

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Wright, 2005), and favouring homosexual men on the OLMT (Rahman et al., 2002; Hassan and Rahman, 2007). Gladue and Bailey found no difference on the MRT or WLT (Gladue and Bailey, 1995).

Amongst women, results have been more varied. Some have found a difference favouring homosexual women on the MRT (van Anders and Hampson, 2004; Peters et al., 2007), while other studies have found no difference (Gladue et al., 1990, Neave et al., 1999). Heterosexual women were shown to have higher scores in a WLT test (Gladue et al., 1990), while homosexual women were shown to have higher scores in a spatial visualisation (paper-folding) and spatial perception (Guilford-Zimmerman Spatial Orientation) test.

There is some support for theories that exposure to high levels of prenatal hormones has an effect on both sexual orientation and spatial ability, (van Anders and Hampson, 2004). However, these results are far from conclusive (Hines et al., 2003; Hines, 2006).

In all cases where a difference was found based on sexual orientation amongst males, no significant difference was found between homosexual men and heterosexual women.

5.6.4 HANDEDNESS

Studies on handedness are usually divided by gender, since the results are different for men and women. However, these results have been conflicting. For males, Yen (1975) showed right-handers were superior in spatial ability, while Sanders et al. (1982) found left-handers to be better. Others have found no significant difference (Annett, 1992; Peters et al., 1995). Amongst these mentioned, only Sanders et al. (1982) found a difference amongst females, favouring right-handers.

5.6.5 LEVEL OF HORMONES

Correlation between levels of testosterone and spatial ability have been well established for both men and women (Christiansen and Knusmann, 1987; Gouchie and Kimura, 1991; Silverman et al., 1999; Cherrier et al., 2001; Aleman et al., 2003). Moffat and Hampson (1996) determined that the relationship between testosterone and spatial ability is curvilinear, where those with intermediary levels outperformed those with both high and low levels.

Oestrogen levels have also been shown to have an effect on spatial ability. This is usually done by comparing women during different stages of their menstrual cycle. Performance on tests which favour males, such as the MRT, are found to worsen during high-estrogen phases. Conversely, performance on tests that favour females, such as the OLMT, improve during these phases.

In contrast, Estrogen levels have been shown to have an inverse relationship with spatial ability skills usually associated with male performance (such as MRT) (Hampson, 1990; Hampson and Kimura, 1988) and a direct relationship with skills associated with female performance (such as object location memory) (Duff and Hampson, 2000).

5.6.6 EXPERIENCE

A study by Waller (2000) at the University of Washington tested 151 participants (79 female) on a number of spatial ability and navigation tests. In this experiment, the navigation tasks specified were a pointing task, distance estimation task, and map reconstruction task. A virtual maze was utilised. The maze contained eight landmarks. Participants were shown what these landmarks would look like beforehand and told to explore the maze. They were given five minutes to do so. They were then placed in three locations in the virtual maze and asked to point to the position of specific landmarks, and also to specify their distance. The angular and distance error were used as metrics. They were then given pieces of the maze and asked to reconstruct it

The results showed that previous experience with the interface had a strong influence on the ability to obtain spatial information from a virtual environment. The study found that the effect of gender was task-dependent. The difference was much more pronounced in the pointing and distance estimation tasks, than they were in the map reconstruction task. Furthermore, the effect of gender on performance of the map reconstruction task was attributable to the effect of gender on the previous experience of the user. In other words, when differences in previous experience and previous experience were taken into account, gender did not have a significant effect on performance.

However, in the pointing and distance estimation tasks, it was shown that gender did have an effect on performance and that this effect persisted even when taking into account prior user experience. This means that a difference between male and female users was detected that could not be explained by other factors.

A major difference between these tasks is that pointing and distance estimation are Euclidean tasks (concepts of distance and angles being quantitative), whereas the map reconstruction was, in this experiment, landmark-based (relative position of objects). This distinction is important, taking into account, as discussed in this chapter, that males have been shown to be stronger than females in Euclidean tasks.

In contrast to these findings, Newhouse et al (2007) showed that gender differences between boys and girls performing a virtual Morris water maze test was robust with training, with boys outperforming girls. Additionally, boys seemed to benefit from the experience, as opposed to the girls in the experiment (see Section 5.5.5).

5.7 CONCLUSIONS

Studies have confirmed the theorised difference in men and women in regards to spatial ability. In short-range spatial tests, males are shown to have superior spatial visualisation,

spatial perception, and mental rotation skills, while females perform better on the Object Location Memory Test and similar positional spatial memory tests. Most of the tests on these abilities are two-dimensional paper-and-pencil tests. The exceptions to this are the spatial memory tests, which can and have been tested in real world and virtual situations.

Tests on navigation and long-range spatial abilities evaluate user performance on numerous metrics, as we have discussed. In our review, we found evidence of superior male performance, particularly in desktop virtual environments with a limited field of view, in the following tasks:

- Cognitive Mapping
- Route Retracing
- Directional Accuracy
- Search and Wayfinding

In addition to the difference in performance, men and women have also been shown to employ different strategies for navigation.

The existence of these differences demonstrates the need for distinguishing between male and female participants in any experiments conducted on spatial abilities. In Chapter 4, we reviewed several studies on different configuration types and their effect on user performance. Some of these studies (Czerwinski et al. 2002; Tal et al., 2003a; Czerwinski et al., 2006) showed a different effect on male and female participants.

In section 4.5 we categorised the metrics which were tested into cognitive mapping, search, locomotion, and object location memory. The first three were shown to improve with larger and wider displays. Only one study was found for object location memory and, although it found no significant effect for field of view, it only utilised five participants.

With the exception of locomotion, which is not applicable to desktop VR, these tasks are suitable for our study. Also, all three have been shown to have gender differences.

In the following chapter we discuss our experimental setup, including how we chose to test for each of these abilities.

NOTE:

See Appendix C and D for a summary of literature on gender differences in navigation as described in this chapter.

CHAPTER 6

EXPERIMENTAL SETUP

6.1 INTRODUCTION

Beginning with the investigative question, “why isn't peripheral vision used more often in desktop computers for virtual reality and game systems?” we set out to design a series of experiments that would look into the effect peripheral displays had on participants performing different tasks in a virtual environment.

We began by designing a configuration to act as our experimental condition, to compare against our control condition of a single standard computer. In this experimental condition configuration, peripheral displays would be added to provide visual information in the far periphery.

After deciding on the configuration, we created a set of tasks and metrics to evaluate and compare user performances. We designed and conducted six experiments, focusing on testing spatial ability in virtual reality. In Chapter 4 we reviewed several studies and found that spatial tasks which were affected by display size and field of view included cognitive mapping, object location memory, and search. These three tasks were assessed in our experiment.

With each experiment we discovered new ideas that allowed us to reshape our research area. Our initial experiments were designed with less emphasis on gender. We did take care to obtain enough participants of each gender, in the case that the gender gap would prove to be substantial. The results of our very first experiment (see Chapter 7) not only confirmed the existence of a gender gap, but more importantly showed that the peripheral displays had a different influence on the genders. Peripheral displays were found to benefit female participants more greatly and were found to reduce the gender gap. In some cases, male participants seemed to perform less well with these displays.

The subsequent experiment designs specifically took into account the question of differing gender performance. Changes were also made to the type of data our programs recorded, as well as to the interview questions. These are discussed more fully in the chapters detailing each experiment.

In this section we will look at how and why we chose each aspect of our experiments. We will look at the control and experimental conditions, how the programs were implemented, and the metrics and types of analyses used, including both the performance and subjective metrics.

Every stage of this was performed by the researcher. This included the design of the experiments; the design, implementation, and testing of all the programs; the obtaining and testing of all test subjects; and the collection and analysis of all the data.

6.2 THE HARDWARE

As fits our research question, our hardware consisted of desktop computers. The starting question for our investigation was about the effect that added information in the peripheral vision would have on a user of a virtual environment. Peripheral vision can be described as anything outside the immediate centre of gaze. On average, peripheral vision extends from about 2 degrees to 100 degrees to the left and right of the field-of-view.

In a typical personal computer setup only a small amount of this peripheral vision is taken up by the virtual world.

A typical computer monitor (38 to 54 cms, diagonally) viewed at a distance of 50 cms, gives no more than 45 degrees of display field of view. Sitting closer increases the field of view, but leads to less image clarity. Solutions, such as wider screens and large projections increase the field of view and have some effect on user performance (see Chapter 4). However, they only extend the field of view into the near- and mid-periphery. Very few system (or even experiment) designs have taken into account the far periphery. Immersive VR technologies are more likely to fill the far periphery, although this is not always the case, such as with most HMDs which only provide 60 degrees of viewing angle.

We therefore decided to focus on evaluating the effect of providing information in the far periphery in the form of the side views of the virtual world. The basic argument for the importance of the far periphery is that it contributes to vision in the real world. On the simplest level, people use this area to detect objects to their sides. A person with normal vision in real life can identify a wall to his immediate left and avoid colliding with it, but someone suffering from tunnel vision tends to bump into objects more often. The limited field-of-view of virtual environments replicate this to a degree. A user strafing to the left can collide with an object and fail to move but have no idea why until he rotates. Similarly, a user playing a game might be attacked from the side (for example, shot at) without knowing which direction the shots are coming from, without rotating. A review of the effect of limiting field of view, both in real life and virtual situations is provided in Chapter 4.

In addition to these situations, however, we are interested in seeing whether adding information in the far periphery has a positive effect on performing general navigation tasks. The ability to perform any of these tasks is dependent on other navigational factors.

For example, the ability to traverse a world efficiently depends partly on the user's ability to identify objects and their comparative positioning. Having information in the periphery facilitates these comparisons being made. It follows that adding information in the periphery may improve the ability to traverse the world efficiently.

This last conclusion, however, and all similar conclusions regarding different navigation tasks needs to be proven. We, therefore, set out to create a configuration which fills the far periphery with virtual information (the experimental condition) for the purpose of evaluating user performance of navigational tasks and comparing them against users in a standard configuration (the control condition).

6.2.1 THE EXPERIMENTAL CONDITION CONFIGURATION: ADDING PERIPHERAL DISPLAYS

To increase the field of view, we utilised additional computer screens, which we refer to as peripheral displays. The number and position of these displays were what needed to be decided upon. In all the layouts we considered we started with a standard display to the front of the user, representing the essential information in the line of sight of the user. The need for this is obvious.

Since studies have already tested the effect of increasing the field of view into the near- and mid-periphery, we opted to go beyond. Therefore, the monitors would have to be placed in positions covering angles of 60 degrees to the left and right of the user and beyond. The first option, that of using several monitors side by side (Figure 6.1), was ignored on this basis. Regardless of how far apart or wide these displays would be, they would never include the furthest of the far periphery. Whichever configuration was chosen would have to accommodate for side views (90 degrees and beyond), simulating a curved, or bent, display.

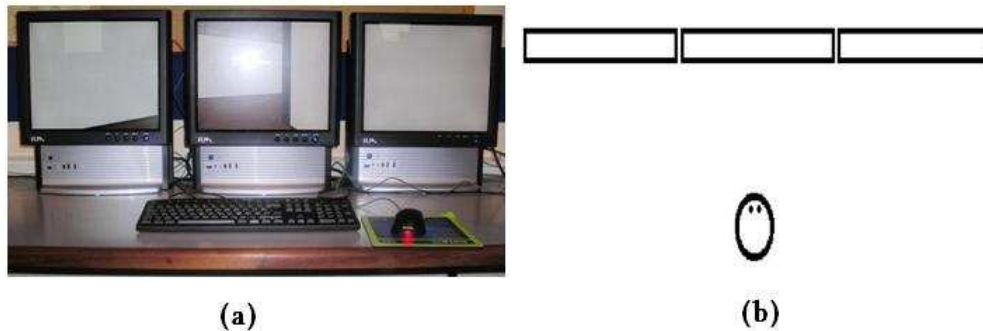


Figure 6.1 Side-by-Side Configuration. (a) Normal view. (b) Diagram of Bird's Eye View. Ellipse represents viewer's position.

A second option was based on a configuration we had already experimented with in a prior study. In that experiment, three monitors were placed side by side, but with the peripheral displays rotated 30 degrees towards the user (Figure 6.2). Placing them side by side resulted in a panoramic view, and this layout is popular amongst gamers (surround gaming). In an ideal situation the display would be curved, but this would prove too costly from a hardware point of view and too difficult to program from a software point of view to be feasible either for common usage or for our experiments. We could fill in the far periphery by moving the monitors further away. The main problem with this layout was in the rotation angle. If the displays were moved around but maintained the same rotation angle, the distance from one edge of the display to the viewer would be different to the distance from the other edge (Figure 6.3). This would create a visual problem. The only solution would be to rotate the displays further.

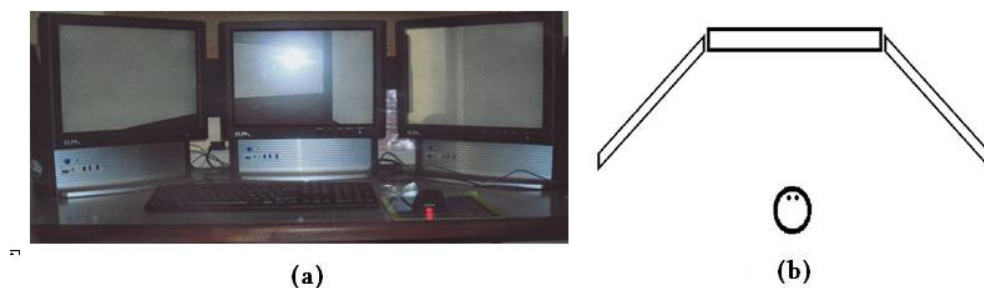


Figure 6.2 Wraparound Configuration. Each side monitor is rotated towards the user. (a) Normal View. (b) Diagram of Bird's Eye View.



Figure 6.3 Spaced Wraparound Configuration. Each side monitor is rotated towards the user and moved further in the periphery. (a) Normal View. (b) Diagram of Bird's Eye View.

Considering our examples above of the importance of being able to see objects on the left and right we decided to alter the layout to one in which the displays were to the exact left and right of the user, forming what we called a box configuration (Figure 6.4). In this case, the peripheral displays would be placed to the left and right of the user, perpendicular to the standard display in front of the user. These displays would thus be to the exact left and exact right of the user. The advantage of this layout was that it provided information in the far periphery while still maintaining a familiar layout to users. The box layout could be likened to a square room with a front, left and right wall; or to a car, with a windscreen, right and left windows to look out of.

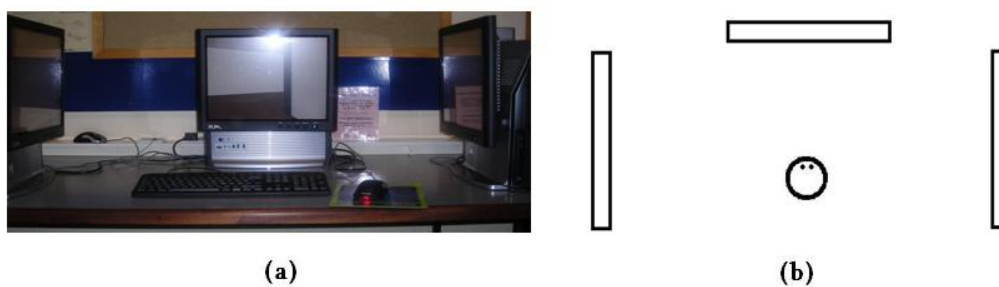


Figure 6.4 Box Configuration. Side monitors are rotated 90 degrees towards the user. (a) Normal View. (b) Diagram of Bird's Eye View.

This layout leaves a gap between the standard display and the peripheral displays. This gap has several disadvantages. It not only creates a hole in the field-of-view that must be filled in by the user's imagination, but it also fills that hole up with real-world information that could act as a distraction. In terms of mental effort, users would have to track visible object trajectories from a peripheral screen whilst, in effect, occluded by the missing monitors. Seen as a problem of occlusion, we argue that this configuration is a more extreme version of, for example, a pilot's eye view of the world which is partially obscured by the structural pillars either side of their frontal cockpit window. We considered filling these gaps up by adding another set of displays (Figure 6.5) effectively combining the layouts of Figures 6.2 and 6.4. However, this was decided against for the following reason: adding displays to fill in the gaps meant that the virtual information was now available across the entire field-of-view from 0-100 degrees and beyond. As such, if any benefit could be found from this layout it could not be determined which area provided the advantage. It could be argued that any benefit was the result of the displays placed in the gaps, replicating the results of experiments done on wide screens. It would, therefore, be difficult to determine whether the displays in the far periphery had any effect, either individually or in conjunction with the other displays. As a result, we aimed to begin our experiments with the box layout as described while keeping in consideration the effect of the gaps on the cognitive demands of the task. If the layout was found to be too unnatural by the user, or the results were found to be uninteresting, we would attempt to reconfigure our layout based on user responses. However, the layout we described provided interesting enough results that we maintained it throughout our experiments.

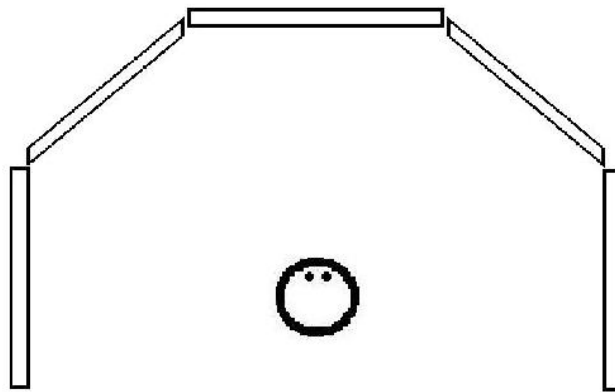


Figure 6.5 Bird's Eye Diagram of Complete Surround Display. Side Monitors cover the entire visual field of view and are rotated towards the user.

The distance of the displays was the next step to determine. This was an important step. Placed too far and the displays would be too small to notice. Placed too close, and they would be too blurry. It was decided that a unified set of distances would be used for all participants, rather than having them change the layout to what they perceived was their own convenience. This was both for the sake of having a unified scientific assessment, since changing the distances might provide different experiences and results, and also because users might not be able to assess what a good distance would be for themselves. Additionally, any changes they made might end up eliminating what we were testing. Thus we aimed to find a unified set of distances and obtain participants with normal or corrected-to-normal vision who would be able to work within them.

To assess the proper distance that the screens should be placed at, a test program was designed in which a user could navigate a limited virtual area. The researcher tested different distances to estimate what would be viable, based on personal experience. After deciding on these distances, a set of volunteers were asked to do the same to see if the distances were appropriate. Finally, it was decided upon the following. The front screen would be placed at a distance of 55 cms away from the user. Each of the side screens would be placed at a distance of 61 cms from the sagittal plane of the user. The marginally longer distance of the side displays was due to the human eye not being on the

sagittal axis. Also, if a user rotated his neck 90 degrees to view the eye would be move closer to the peripheral display. Each of our experiments began with a pilot study which assessed several aspects of our study, including the appropriateness of these distances. These distances were then maintained throughout our research.

Our choice of distances, along with our use of 17 inch (43 cm) monitors with 4:3 aspect ratio, resulted in this configuration providing a main field of view of about 34 degrees (17 degrees left to 17 degrees right) on the front display, and peripheral fields of view ranging from 73 to 107 degrees. These were determined to be sufficiently close to our original estimate of 70 degrees and beyond.

As such, the experimental condition configuration layout was specified. A final argument was considered, which was to have several different configurations and test them against each other. For example, in addition to the box layout we described, we could also test out the layout considered in Figure 6.5 as well as other potential layouts. However, after considering the time required, resources provided, and number of participants that could realistically be obtained, it was decided that having more than one experimental condition would prove unrealistic for the scope of this project. We therefore stayed with the box layout and left all the other comparisons to be made in future work, should evidence suggest there is specific value in supporting the far periphery with a central field of view, compared with only a central field of view, even given the possible cognitive load added by users having to mentally fill in the near-periphery gaps in their field of view.

6.2.2 THE CONTROL CONDITION CONFIGURATION

We assess the effect of the peripheral displays on user performance and reaction in our experimental condition by comparing with the performance and reaction in the control condition. We therefore need to select a suitable configuration therein. Our initial response is to go with a single, standard computer screen placed to the front of the user.

The distance between the user and screen is similar to the distance between the user and the front screen in the experimental condition (55 cms). The viewing angle is 34 degrees. The selection of this layout raises some questions as to its appropriateness. There is more virtual information presented in the experimental condition by virtue of there being three times as many displays. Does this factor not give an immediate advantage to the experimental condition? As a result, should we not create a control condition with as much virtual information?

However, we posit that this is an appropriate control condition for the following reasons. Firstly, the single screen configuration is the standard desktop configuration used by most users. Secondly, it is the lack of the information on the periphery that we consider a potential problem and therefore wish to assess. Thirdly, providing as much information as the experimental condition in a different formation raises its own issues. If the information is placed in a different position then it will be either a different set of information, such as an allocentric ‘radar view’ representation of the space around a user, or it will be in the wrong place (the position in the virtual world would not match with where their position would be in the real world). As such, the two sets of virtual information would be unequal.

For these reasons, we select the control condition as a single screen. We do this with the understanding that the results we obtain will therefore tell us what effect the *addition* of the peripheral displays has on the user, given our primary design goal of exploring an egocentric navigation model.

6.2.3 TURNING HEADS

In the experimental condition as defined above, the screens on the left and right represent the far peripheral areas of the user's vision. It is designed so that the front screen represents the typical line of sight. However, it is possible for the user to turn his head or body to the right or left at any moment, so that the peripheral views will be in the line of

gaze. This movement, therefore, changes the immediate function of the layout. We therefore considered whether this will affect the usefulness of our results and, if so, whether we should place restrictions on user head and body movement so that the line of sight is always towards the front screen.

In a previous experiment concerning user response rates to targets on screen we did impose this restriction. However, we now believe this was a mistake in that experiment, and that it would be a mistake to impose it in these experiments as well. There are many arguments for this. The ability to turn one's head is not only a natural way of observing objects in the periphery, it is a common way to react to stimuli; whereas imposing restrictions on turning the head would be the unnatural response. In immersive VR systems, such as CAVEs and HMDs, users have freedom of mobility, including that of the head. Also, users of a single screen computer have the freedom to turn their heads to help focus on different parts of the screen. The final and most important argument for not imposing restrictions on head movement is that we are not concerned with determining differences in ocular behaviour or how the eye reacts to different stimuli. The concern of our research is the effect the peripheral displays have on performance. It can be argued that this effect is due to the physiological structure of the eye, but it can also be argued to be effected by other factors, such as navigational strategies, both conscious and subconscious. While we may posit reasons why we get the results we do, our main concern is not to determine why, but to discover whether differences exist between our groups. By giving the users the freedom to turn their heads and look directly at the left and right screens we allow for a natural and realistic approach to the tasks we set out. For all these reasons we avoid putting any restrictions on head movement.

6.3 THE TASKS

As reviewed in Chapters 4 and 5 there are many aspects to spatial ability which can be measured. We divided these tests into those measuring short-range spatial abilities and

long-range spatial abilities. Short-range abilities include spatial visualisation, perception, and memory and can be performed from a stationary position. Long range abilities include navigational tasks, such as wayfinding, search, or orientation. They require some traversal by the user to get a larger understanding of the world. Long-range abilities depend on some short-range abilities. For example, wayfinding depends on accurate cognitive mapping of a world, which in turn depends on spatial perception and memory.

Virtual environments depend on navigation. In our research we aimed to evaluate different aspects of navigational abilities. Our selection of these tasks was based on them holding certain characteristics. They needed to be quantifiable, clear and straightforward, and have some application in actual virtual environments, and some analogue in the real world. They would also have to maintain the freedoms of virtual reality. For example, some tasks were considered which would require the user to be “moved” through the environment by the program outside their control. These were disregarded based on the fact that the ability to move freely is one of the key aspects of virtual reality. Also, considering the major effect of gender on performance, and the unique effect of the peripheral displays for each gender, we also aimed to find tasks with a gender gap. If the effect of the displays led to the elimination of the gender gap, it could lead to further conclusions on their importance.

Our first pair of experiments focused on cognitive mapping and object location memory. After traversing a world, users would have to select a map of the world from a number of options, and to relocate objects to their proper corresponding location on the map. These experiments fit all of the criteria we set above. It was here that we first encountered the gender differences (on cognitive mapping) which made us redirect our focus as a result. For each subsequent experiment, tasks were selected with the added caveat that they be known or expected to show a gender bias under normal computing circumstances (those replicated in the control condition).

Many tasks were considered as follow-ups, but were ignored because they did not fit one of the above characteristics. Sometimes this was discovered in the design stage. Other times, this was discovered only after implementing a prototype. The second set of experiments, it was finally decided, would be coordinate object location memory tasks. Users had to return objects to their point of origin in a sparse, open world, with the use of few landmarks. The choice was made because it was found to fit all our characteristics. Additionally, it was a task for which the lack of peripheral vision would be a great disadvantage. Users who used landmarks to geometrically assess the position of the objects would have to rotate fully to assess their positions, and would be limited in the number of landmarks they could see at one time. It was argued that adding more information would help ground the user in the world and provide a better situation to perform the task. (The fact that this did not happen is interesting, and we discuss this in Chapter 8). The other reason this task was selected was that it was seen to provide a gender difference. While object location memory tasks favour females for relational metrics, males have been shown to perform better in coordinate metrics (Iachinia et al., 2005). This means that females are better at remembering where objects were placed in relation to other objects, while males are better at remembering their coordinate location. This is the distinction between landmark-based and Euclidean navigation. The task we designed favours the latter, as only a few landmarks were used in the world, just enough to get a grounding of the world. The navigation in this environment remains largely Euclidean.

Our third set of experiments focused on search and object finding. Users were asked to search a virtual maze with the use of a map. This task was found to fit all our characteristics. It is the addition of the map which is the key aspect of this task, as it added a new type of cognitive mapping. In the first experiment, the users would have to map the 3D virtual world onto a 2D world (the drawn outline). In the second experiment, the users performed all their assessment and wayfinding within the 3D virtual world itself. In the maze experiment, users would have to map a 2D world (the map) into a 3D

virtual world. Additionally, this task was anticipated to have a clear gender bias, due to its non-landmarked, maze-based aspect.

Each of these tasks is described in more detail in their respective chapters (Chapters 6 – 8).

6.4 THE PROGRAMS

For each experiment, a pair of programs needed to be designed. The programs would facilitate the viewing, navigation, and interaction with the virtual world. The difference between the two programs would be that one would be designed to run on a single monitor (control condition) and the other would run on three monitors (experimental condition). We describe in this section how we rendered the world, how movement through the world was facilitated, and how collision detection was performed. We also look at how we connected the three computers in the experimental condition.

All programs were run on computers operating on Microsoft Windows XP, and later Windows Vista. They were programmed using Microsoft Visual C++ and using the Open Graphics Library (OpenGL). We forego going into the details of our programs, focusing only on the key aspects. We begin by describing how multiple computers were connected in our experimental conditions. We then give a brief description of how the virtual worlds were represented and drawn, and how collision detection was employed.

6.4.1 CONNECTING SEVERAL COMPUTERS

In our experimental condition we needed to show a virtual world displayed on three computer monitors. Two precepts governed how these monitors would be connected. Firstly, they would all have to respond to the same user input. If a user moved or turned, then the view of all three monitors would have to update to accommodate the user's new position and direction. Secondly, the three displays would need to update concurrently.

Any lag between the updating of the worlds in the three displays could lead to problems in viewing and understanding the world.

To split a virtual environment across three or more monitors we could have used special computer graphics chips (such as Matrox Parhelia or Radeon R3000) or other hardware (such as the Matrox TripleHead2Go) which were introduced into the market during the period of our research. However, a cheaper and simpler method was discovered which would suit our experiments just as well. By using the Winsock (Windows Socket API) library in Microsoft Visual C++, we were able to connect computers in a Local Area Network in the Bath University Computer Science Department. Users were allowed to interact through the keyboard with one computer only, namely the computer representing the front screen. This computer acted as the server or listening socket. The peripheral displays were the monitors connected to other computers, which acted as clients, or sending sockets. Each of these computers, whether server or client, was given an executable program, which draws the appropriate view of the virtual world for that computer. For the virtual world to run on multiple screens, the server program would be executed first, then each of the client programs would be executed. When the listening socket on the server accepts the connections of all the clients, each of the individual programs continues with its codes, thus providing each screen with the necessary view.

Subsequently, any movement from the user should change the view on all displays. Therefore, whenever a change in position or direction occurred, a message was sent from the server to the clients. This message contained the position of the user as x- and z-coordinates (the y-coordinate represents the height of the user and remains constant) and their direction as an angle on the x-z plane. This information would be read in by the client program and these values would replace the previous values held by the x-coordinate, z-coordinate, and angle value of the client. As the new frame of the virtual world was drawn, the view would be updated based on these values. All other actions, such as collision detection, were performed independently on each computer, so as to reduce message load.

For this setup to work we needed to ensure that these messages were sent fast enough not to cause any noticeable discrepancy or lag between the views. To avoid this, the message send rate for a keypress would have to be much less than the frame time. Frame time is the inverse of the frame rate. In OpenGL, the highest frame rate that can be reached is 60 frames per second. Therefore, the frame time equals $1/60 = 0.017$ seconds. Fortunately, the message send time was much lower than this ($<.000001$ seconds). For further confirmation, each experiment was preceded with test runs and a pilot study, in which the researcher and other subjects run the experiment and ensured that no noticeable lag or discrepancy was present.

6.4.2 REPRESENTING AND DRAWING THE WORLDS

OpenGL allows the rendering of virtual objects via geometrical functions. These functions take parameters representing point coordinates and other geometric data, such as lengths and radii. Drawing several objects in sequence creates a virtual world for a single frame. Repeating this process, creates several frames of the virtual world. By changing the values of these parameters, changes can be made to the virtual world across frames, thus giving the illusion of movement or other phenomenon, such as growth or colour change.

Several geometric shapes are provided in OpenGL, such as spheres and cylinders. However, we programd our own code to create Objects representing Rectangles and Boxes. The Rectangle object consists of a centre-point (x, y and z coordinate) and a height and width value, from which the rectangle could be drawn. The Box object consists of a centre-point (x, y and z-coordinates) and the length, breadth, and height of the sides. Our own objects were used instead of the provided shapes so as to have more control over the world. For example, the boxes in our code could have multiple textures.

Boxes were chosen as a base shape from which all of our virtual worlds could be created. This choice was made due to the ease of programming for the shape (e.g. drawing, collision detection), as well as the multitude of objects which could be created using it (buildings, the ground, walls). For example, in the Art Gallery experiment (Chapter 7) each of the walls is a separate Box object, as are the floor, ceiling, and each painting.

6.4.3 CONTROLS

Users were allowed to traverse the world along the x-z plane. Movement was provided via the keyboard. Initial controls were given to move forward and backwards, and to rotate left and right. A combination of these moves would allow the user to traverse any area of the virtual environment. Based on participant suggestions from our first pair of experiments, a strafing motion was also added, using the S and D keys.

6.4.4 COLLISION DETECTION

In each of the programs in our experiments a number of objects were placed. Depending on the task, objects could be picked up by the user by walking through them, or they acted as barriers which the user would bounce off if they tried to walk through them. In either case, some form of collision detection needed to be employed.

The virtual world is rendered depending on the position of the user and the direction he is facing. These, in turn, are determined by the values of the x- and z-coordinates and the angle of rotation. To employ collision detection, an invisible (i.e. non-rendered) bounding box was included in the program, centred on the user. The box shape was chosen for the bounding area because of the simplicity of its implementation and the speed of its execution. This is especially true since the design all the programs used box-shaped objects to represent all objects. Using a simple algorithm, it could easily be detected when the user collided with an object, thus setting off the appropriate response sequence.

6.5 PERFORMANCE METRICS

To compare the two configurations we have set we look into two general areas: performance and experience.

Performance data can be recorded for the primary task in an experiment, as well as secondary tasks which are not explicitly set, but can be seen to be beneficial to the main task. For example, users may be set the task of finding their way out of a maze using a map as fast as possible. The ability to get out of the maze and the time taken to do so would be the primary performance metrics. However, a secondary metric could be the number of wrong turns taken. A user wanting to reduce their time would try to minimise the number of wrong turns they take. Having a secondary metric like this can be helpful in understanding and comparing our groups. In our example, two users may have similar times in performing the task. However, one may have far more wrong turns. It is possible that this user made up for this by being more adept on the input controls than the other. Certain metrics are accepted as being desirable, such as speed of task and efficiency. While these metrics vary in their importance depending on their situation, we can state that they are important in our experiments because users are told they are important or because they are implied to be so. The performance metrics we choose depend on the task that we set and are discussed in further details in the chapters pertaining to these experiments.

Experience refers to how the users “felt” while performing the set tasks. This is a more difficult area, both to define and to measure. Users can have a myriad of responses or feelings while in a virtual environment. The question becomes how do we decide which of these responses are important? And once we determine that, how do we decide which of these important responses are desirable?

6.6 SUBJECTIVE METRICS

In addition to the specific, quantifiable measures, we wanted to measure user attitudes to the system. We did not focus on this area, since we recognised that our experiment was designed in such a way that would not be ideal for actual use (e.g. non-continuous display) but which we did not want to change for a number of reasons (e.g. evaluating one area of the visual field). This would be the focus of much of the user's complaints with the systems, rather than the areas that we wanted to focus on. Nonetheless, we still provided some questions in order to obtain some user feedback.

In our first set of experiments we did this by giving the users a written question in which they were asked what problems they had with the task they faced. They were told they could use this area to refer to any aspect of the experiment and their performance in it.

Because of the negative wording of this topic, we decided to reword this question. In our remaining experiments we asked users what their strategy for performing the task was. In this case, the experimenter asked the question and recorded the responses the user gave. This was done so that the user could be more free with their responses, and so that the experimenter could ask follow up questions.

Finally, because of the importance of strategy and the effect it might have on our results, we maintained a list of information regarding user behaviour towards the task. Starting from the second experiment participants using peripheral displays were observed and asked whether they looked at the left and right screens. In the maze experiments, users were also observed and asked whether they stopped using the map, and whether they turned the map around. This information was to be used to help analyse why certain results were obtained.

6.7 THE PARTICIPANTS

For each experiment we ran, it was considered whether we should use a within-groups or between-groups design. In a within-groups design each participant would run the experiment on one of the two conditions, and then again on the other. In a between-groups design, one set of participants would have run the experiment on the control condition, and the other set on the experimental condition.

A within-groups design's advantage is that it compares the conditions directly by testing them on the same users. This design would have been ideal for our experiments, except that it presents the problem that the experiment in the two conditions would have to be different but equal. If the task set in the experiment was to find an object in a maze, then it should be equally difficult to find the object in the control and experimental condition. However, the two mazes and the location of the object can not be identical, since the participant, having already traversed the maze once to find the object, will have a better understanding of the maze when they perform the task again. Therefore, for each experiment we designed we considered whether or not it was possible to create two alternative experiments which were sufficiently different in design but clearly of equal difficulty. In none of the six experiments could we come to the conclusion that this was possible. For this reason we used a between-groups configuration for each experiment.

For each experiment we needed to obtain a pool of participants who could be divided between the two configurations. Participants were mainly obtained from the University of Bath's student and staff. These ranged in age from 17-46. We did not focus on the effect age had on performance. In Section 5.6.1 we estimated 50 as the age after which spatial ability decreases noticeably. This was based on a review of several studies. All of our subjects were under this age.

All users had normal or fixed-to-normal vision. Also, for each experiment, we obtained a minimum of 24 participants of each gender. We had anticipated that the effect of adding peripheral displays on female and male participants might be different in magnitude. However, the results of our first experiment (Chapter 7) showed that not only the extent, but also the nature of this effect (whether positive or negative) could be different for males and females. Because of this, it was considered a better option to look at each gender group separately. This gave us four groups overall, combining genders and configurations: control-male (SM), control-female (SF), experimental-male (PM), and experimental-female(PF) groups. (The S and P in these acronyms stand for Single and Peripheral, respectively).

To compare the effect of adding the peripheral displays we looked at its effect on each gender separately. We compared the control-male with the experimental-male, and the control-female with the experimental-female.

Additionally, to understand the nature of these effects, we also looked at the difference between male and female users. We did this by comparing the two genders in each configuration separately. In the control configuration, we compared the control-male and control-female.

The control condition was designed to resemble normal computing activities and it is on this configuration that a difference between male and female participants had been found in certain areas. This is what we refer to as the gender gap. Whenever we found a significant difference between male and female users in the control condition we refer to it as the Gender Gap. In the experimental condition, we compared the experimental-male and the experimental-female conditions. We noticed in our results that the difference between male and female participants' results in this condition tended to be less and almost always insignificant.

The purpose of all these comparisons was to answer the following questions:

1. What effect, if any, did the peripheral displays have on all users?
2. What effect, if any, did the peripheral displays have on male users?
3. What effect, if any, did the peripheral displays have on female users?
4. What differences, if any, were found between male and female performers in the control condition?
5. What differences, if any, were found between male and female performers in the experimental condition?

And, as a result of our findings, we added:

6. Did adding the peripheral displays reduce the Gender Gap, where it existed?

Comparisons were made on all quantifiable data. We used a 2x2 Factorial Analysis of Variance (ANOVA) to compare the effect of gender (male, female) and configuration (with, without peripheral displays) on the performance metrics. In certain situations, where only two groups were compared, a student's t-test was used. Holding with convention, values of p under 0.05 were considered statistically significant. Values between 0.05 and 0.1 were considered to be approaching significance.

6.8 CONCLUSIONS

In this chapter we discussed the setup for the experiments used in our research, explaining what they were designed to find, how they were designed to do so, and how we intended to use them to make our conclusions. In the next three chapters we discuss each of these experiments individually and in more detail, focusing on their task design and the results obtained therein. We follow these chapters with a general discussion of

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our conclusions from all our experiments and a final analysis.

CHAPTER 7

EXPERIMENT 1.1 AND 1.2: COGNITIVE MAPPING

7.1 INTRODUCTION

In our first pair of experiments we tested the effect of peripheral displays on users performing cognitive mapping tasks. We had determined cognitive mapping as one of the spatial abilities which improved with larger displays (Patrick et al., 2000) and wider fields of view (McCreary and Williges, 1998). It was theorised that our peripheral displays configuration would also improve it. Distinction had been made between types of cognitive mapping. For example, McCreary and Williges (1998) distinguish between route, configuration, and landmark knowledge as parts of cognitive mapping. In their study they found that route and configuration knowledge increased with wider fields of view, while landmark knowledge did not benefit at all.

Therefore, we opted to study the effect of each aspect of cognitive mapping separately by running two experiments. The two experiments differed in the type of world, which would influence the navigational strategy. Both experiments featured walled-in worlds (i.e. a building). However, the first was a large room with multiple, distinct landmarks, while the second was a series of corridors with no landmarks. The two variants were chosen since they accommodated two different navigational strategies. The former encouraged landmark-based navigation (while still allowing for Euclidean navigation),

while the latter only allowed for Euclidean navigation. It should be noted that Euclidean navigation can be used in all situations.

The size and shape of the rooms were also designed for this purpose. In the first experiment, the room was spacious and open, and most of it could be viewed by the user standing in one spot in the middle and rotating their view. In the second, the building was a series of corridors. Each corridor was rectangular in shape. Where the corridors overlap, paths would open in the corridor allowing users to turn left or right (see Figure 7.4). In this world, the user could only see a small section of the building at any one time. This fact further contributed to the dependence on Euclidean navigation, as differences in corridors could prove subtle.

The chosen task was cognitive mapping. Several studies had shown a positive effect of field of view on performing this task. For both tasks, the task was to sketch a map of the outline of the virtual world. In the first experiment, an additional task involved identifying the position of the distinct landmarks. The tasks, therefore, also tested for landmark-based cognitive mapping and route-based (Euclidean) cognitive mapping. Since it is established that males, on the whole, use Euclidean navigation and females, on the whole, use landmark-based navigation (Saucier et al., 2002; McFadden et al., 2003) we expected this to mean that male participants would do better than their female counterparts in the corridors experiment, while the gap would not be so great in the open room experiment. We therefore designed these tasks to compare and analyse the difference between male and female participants.

In this chapter we look at the specifics of our experiment design (Section 7.2) before discussing each experiment in turn (Experiment 1.1 in Section 7.3; Experiment 1.2 in Section 7.4). We discuss our results in Section 7.5, before determining our next step (Section 7.6).

7.2 EXPERIMENT SETUP

As described in Chapter 6 each of our experiments utilised the same experimental setup for control and experimental conditions, and followed the same method of analysis. The difference in each experiment would be in the tasks set, the metrics used for analysis, and the number of participants.

As a brief reminder, the control condition consisted of a single 17 inch (43 cm) computer monitor at a distance of 55 cm in front of the user, providing a field of view of roughly 34 degrees. The control condition consisted of this same setup with the addition of two peripheral displays perpendicular to the main screen and at a distance of 61 cms to the left and right of the test subject. This provided additional data in the area covering 73 to 107 degrees to both the left and right of the user. The area between 17 and 73 degrees showed no virtual information.

Prior to the experiments, participants were familiarised with the environment and controls by being placed in a virtual environment similar to the art gallery experiment. A simple room was created with plain walls. Users were told to spend as much time as they needed until they felt comfortable with the controls. On average, participants spent 28 seconds familiarising themselves with the controls (SD = 10 seconds).

The tasks in these experiments included a cognitive mapping task and object location memory task. Both tasks are indicative of spatial ability. One study had shown that large displays facilitated better performance on cognitive mapping (Patrick et al., 2000). We theorise that adding peripheral displays would have a similar benefit. We are unaware of any studies on object location memory and display size, but it seemed reasonable to anticipate a positive effect from having a wider view of the world. Males are shown to perform better in cognitive mapping tests (Siegel and Schadler, 1977; Herman and Siegel, 1978; Holding, 1982; Montello et al., 1993). On the other hand, females perform better

in object location memory tasks (Silverman and Eals, 1992; Barnfield, 1999; James and Kimura, 1997; Duff and Hampson, 2001; Levy et al., 2005; Voyer et al., 2007). As such we considered the effect on each gender group separately.

Two experiments were designed and run to compare and contrast user performance. These were dubbed the Art Gallery and Corridors experiments. The same group of participants were asked to run both experiments. Participants were divided into two groups, one for each of our configuration conditions. Analysis was performed by comparing the user metrics between configurations, as well as by comparing the performance of male users and female users.

Interaction with the world was done using the keyboard. Participants were given the ability to move through the world using the arrow keys, as follows:

Up	Move Forward
Down	Move Backwards
Left	Rotate Left
Right	Rotate Right

Table 7.1 Controls for Experiments 1.1 and 1.2

7.2.1 PARTICIPANTS

54 participants (24 female) took part in this experiment. They were divided by configuration into two groups with 15 male and 12 female participants each. Analysis was first done between the two sets of participants as a whole. We call these the Control All Users (SA) and Experimental All Users (PA) groups. We then compared each gender group separately, giving us four groups of gender-configuration: Control Male (SM), Control Female (SF), Experimental Male (PM), and Experimental Female (PF). These

participants were aged between 18-35. Care was taken to balance out users as much as possible by age, and VE expertise. Pre-questionnaires asking this information was given to each user (see Appendix A). However, male and female users could not be balanced on previous experience with VEs, since far more male participants were familiar with these environments. Of our participants, 18 of the males stated that they regularly used such environments (at least a few times a month), compared with 12 who did not. In contrast, only 2 female participants stated they used these environments regularly, compared with 22 who did not. For this reason, we acknowledge that any differences found in this (or all subsequent experiment) may be due to this difference in experience between the genders.

7.2.2 DATA COLLECTION AND ANALYSIS

Performance data was collected from each user and compared using a 2 x 2 Factorial ANOVA, with sex (male, female) and configuration (with, without peripheral displays) as the independent variables. The specific metrics used in our analysis were task-dependent and are discussed in the section(s) below.

7.3 EXPERIMENT 1.1: THE ART GALLERY EXPERIMENT

In our first experiment we studied the effect of peripheral displays on cognitive mapping in a landmark-based virtual environment. The virtual world was made to resemble an art gallery, with distinct paintings as landmarks. The cognitive mapping tasks included sketching the outline of the room and identifying the position of the paintings on the walls.

7.3.1 TASK

In this experiment, participants were assessed for their ability to mentally map a single-room, landmark-based virtual world. Each keypress moved the user 0.1 unit in the appropriate direction. The shape and dimensions of the room are shown in Figure 7.1.

Each participant was placed in and asked to navigate a closed room designed to resemble an art gallery, with no doors or portals leading out. The gallery featured 10 plain walls with a total of 11 framed paintings (two on one wall, one on each of the others). Participants were given a distraction task of studying all the paintings and counting the number of inanimate objects in the room. They were told to do so within a three-minute period but were not forced to adhere to that time limit exactly. (Outliers in the time limit domain would be eliminated later in analysis).

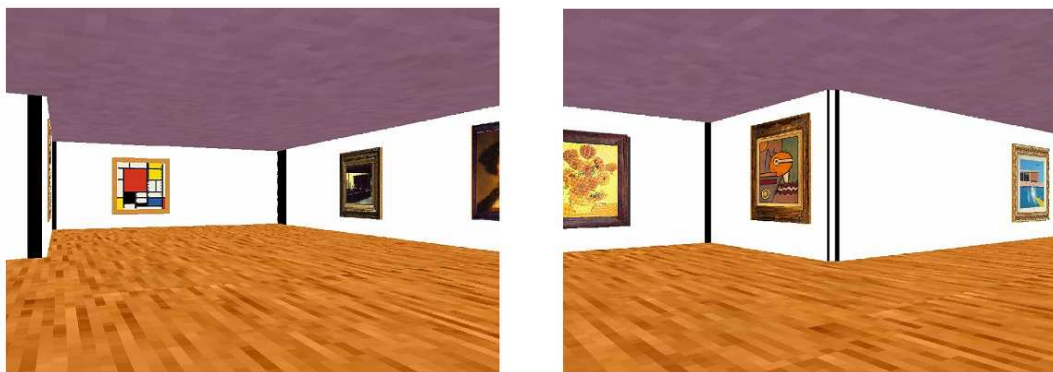


Figure 7.1 Two views of the Art Gallery program

After completing the task, users were asked to solve a series of problems concerning the shape of the room and the position of the paintings. To ensure that they thought about the shape of the room before making a choice, they were first asked to sketch a bird's eye view of the room, using graph paper. Then, they were asked to select from a series of 16 options, which they thought most accurately represented the shape of the room they had been in (see Figure 7.2b)

After they made their choice, they were informed of the correct answer and asked to select from a further series of 9 options, all with the same outline, which one they thought

most accurately represented the scale of the room. Each incorrect choice was given a number of “errors” in the form of passages being longer or shorter than their scale (see Figure 7.2c). Analysis was made comparing the number of errors in the option chosen. Finally, they were given an outline of the room with the positions of the paintings indicated, as well as a graphical representation of the paintings (Figure 7.2a). They were asked to place the paintings in their correct order on the indicated slots. A total of 11 paintings were provided, and 11 slots, and a one-to-one relationship was specified. Participants were given a point for each correct painting assigned.

We considered using a grading system out of 10. This was because we assumed that it would be impossible, logically, for a participant to get 10 correct answers exactly and not the eleventh, since a participant who figured out the other ten correctly, would by a matter of simple elimination place the last remaining painting in the last remaining spot. Despite this, however, one participant did manage to get a score of 10 by repeating a painting answer for two separate slots. Furthermore, in our analysis, replacing the scores of 11 with the scores of 10 did not yield different results in our significance tests, so we are satisfied by using a grading system out of 11.

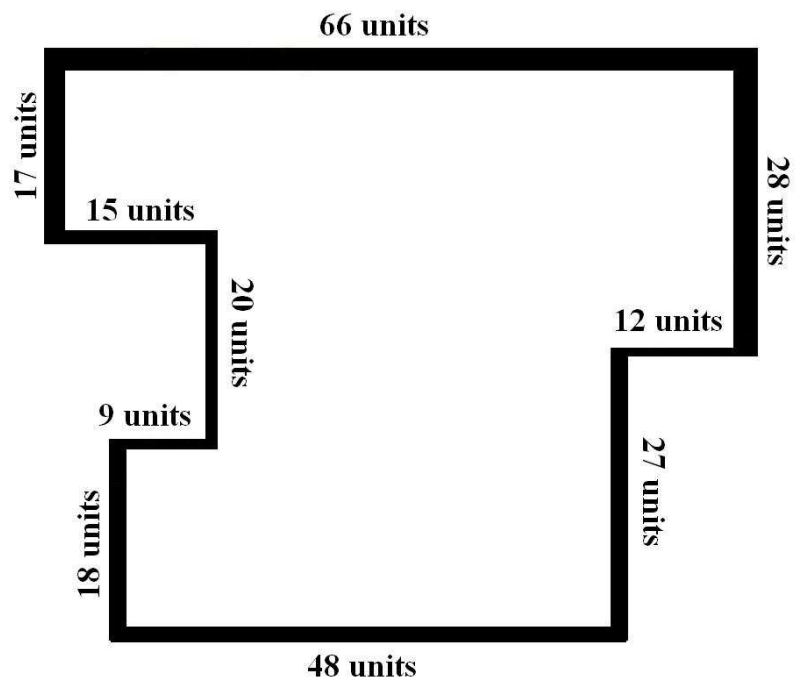


Figure 7.1 outline and scale of Art Gallery environment.

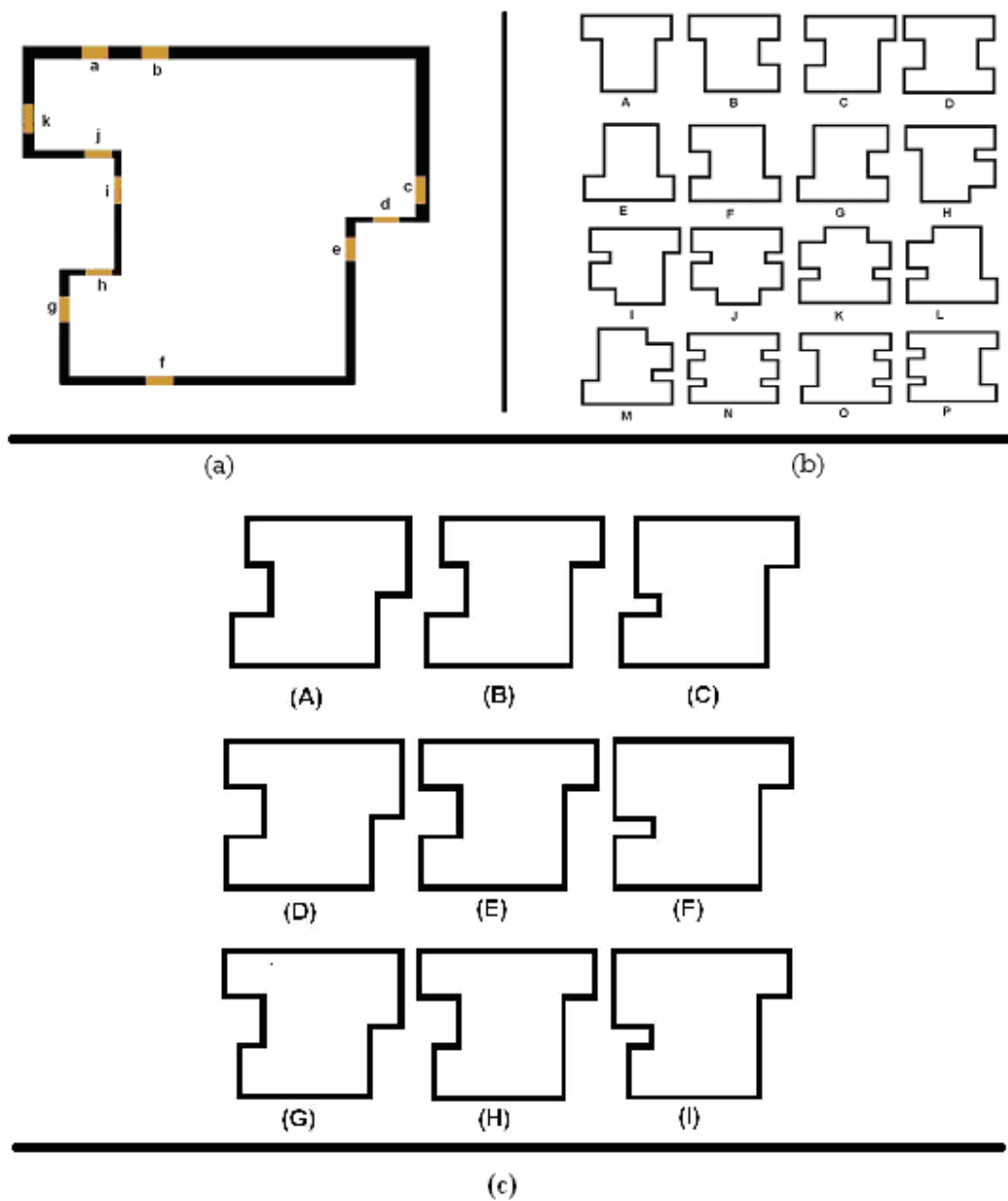


Figure 7.2 (a) The outline of the room with the position of the paintings highlighted. (b) The 16 shape options. The correct answer is option C. (c) The 9 scale options. The correct answer is option G.

7.3.2 RESULTS

Selecting the Correct Outline

One participant, male in the single screen condition (SM), did not record any result for this part. Of the fourteen remaining male participants, exactly half (7) managed to successfully identify the correct outline from the 16 choices. In comparison, only one female participant out of twelve managed to do the same. In the peripheral displays configuration, only three male participants out of the fifteen managed to select the correct outline, compared to two out of twelve female participants.

Selecting the Correct Scale

A total of 11 out of 54 participants managed to choose the correct option. These were 3 males and 3 females in the single screen configuration, and 2 males and 3 females in the peripheral displays configuration.

When comparing the error distance, no main effect for sex was ($F(1, 50) = .218, p = 0.64$). There was no main effect for configuration ($F(1, 50) = .030, p = 0.86$), nor any interaction ($F(1, 50) = .490, p = .57$).

The fact that a minority of the participants managed to complete the first task successfully shows that many of the participants guessed the scale option, explaining the lack of any distinction between performances. This was verified by many of the users who stated to the examiner that they had no reason to prefer one option to the other. It is also further verified by the fact that only three participants out of the 53 who responded to both parts managed to pick both correctly (all male – one in the single screen configuration, two in the peripheral displays configuration). All this leads us to conclude that this part of the experiment does not reveal any useful information regarding performance, due to a floor effect.

Position of Paintings

There was no main effect for configuration ($F(1, 50) = 2.31, p = 0.14$). Nor was there a main effect for sex ($F(1, 50) = 3.47, p = 0.07$). There was no interaction between the two ($F(1, 50) = 0.00, p = 0.95$).

	Men	Women	Display mean	(SD)
Single	1.40 (1.18)	1.75 (1.48)	1.56	(1.31)
Peripheral plus central	1.53 (1.06)	1.50 (1.24)	1.52	(1.12)
Gender mean (SD)	1.47 (1.11)	1.625 (1.35)		

Table 7.2 Mean errors (standard deviations in parentheses) made by men and women in selecting the correct map, in single or peripheral-plus-single display conditions.

	Men	Women	Display mean	(SD)
Single	6.87 (3.46)	5.00 (4.07)	6.04	(4.56)
Peripheral plus central	5.33 (3.96)	3.58 (2.31)	3.79	(3.39)
Gender mean (SD)	6.1 (3.74)	4.29 (3.32)		

Table 7.3 Mean number of paintings (standard deviations in parentheses) correctly positioned by men and women in single or peripheral-plus-single display conditions.

Post-hoc power tests were administered for each effect. This revealed adequate sample sizes for both sex ($\eta^2=0.49$, power = 0.931) and configuration ($\eta^2=0.408$, power = 0.818).

7.4. THE CORRIDORS EXPERIMENT (Cognitive Mapping in a narrow world without landmarks)

To contrast with the landmark-based Art Gallery experiment, our second program featured a heterogeneous corridor world. The views from the world were similar in that the only objects were the walls, ceiling, and floor, none of which changed colour or texture in the program (Figure 7.3). Cognitive mapping for this task, therefore, would be route-based as opposed to landmark-based.

7.4.1 TASK

The same 54 participants (24 female) from the previous experiment, took part in a second experiment directly afterwards. In this experiment, they were asked to navigate a virtual world which they were told represented an abandoned building. The building was formed by a series of narrow corridors, with no doors or portals for escape. The corridors were rectangular in shape and had the same width and varying lengths. Each corridor lay either on the vertical or horizontal plane when seen from above – in other words, any two corridors were either parallel or perpendicular. When two corridors intersected this provided a turn or bifurcation. See Figure 7.4 for shape and dimensions. Each keypress moved the user 0.1 unit in the appropriate direction.

The participants were assigned the task of understanding the shape of the room they were in without the use of pen or paper so that they could recreate it later. As in the previous experiment, they were told to do so within a three-minute period but were not forced to

adhere to that time limit. (Outliers in the time limit domain would be eliminated later in analysis).

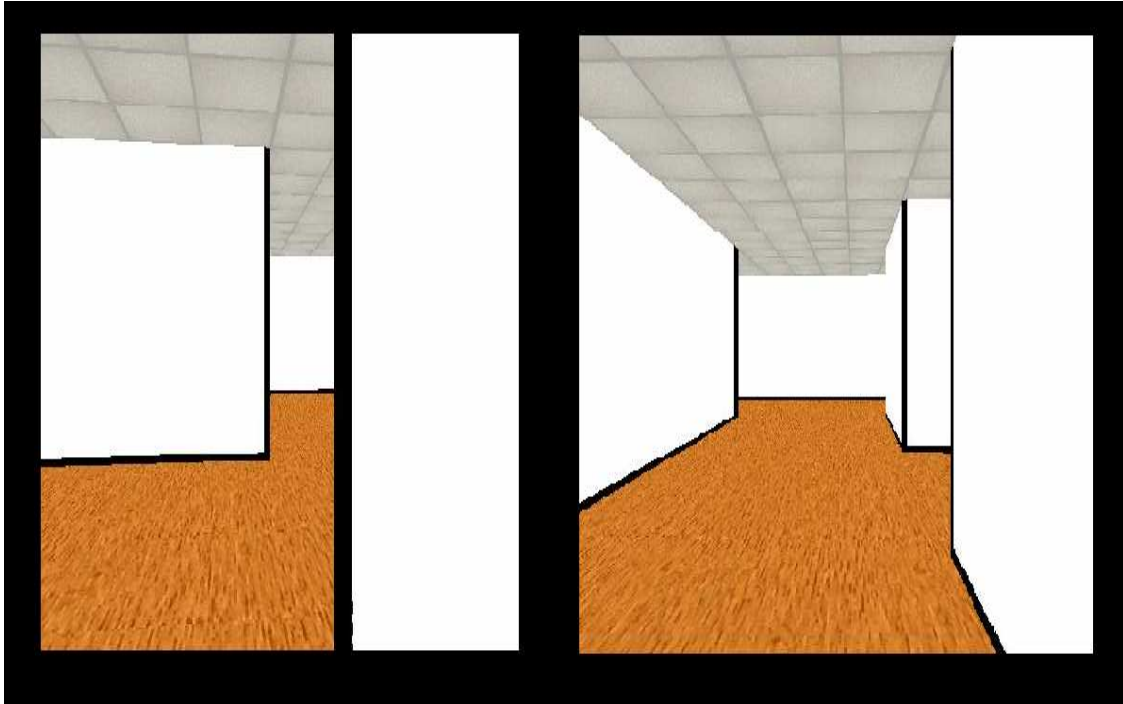


Figure 7.3 Two Views of the Corridors Experiment

After completing the navigation of the world, users were asked to sketch the room and choose the shape of the room from a series of 16 possible options, only one of which was correct. Each of the 15 incorrect options was based on the correct outline with one to four common errors added to it. These errors came in the form of adding, removing, or moving sections of the maze. Some options contained only one of the changes, while others combined a combination. Not all possible combinations of the four errors were chosen; a random selection was made using a random-number generator, ensuring only that differing degrees of incorrectness remained in the options.

Analysis on accuracy would be done by measuring binary correctness (either choosing the correct answer or failing to do so) as well as “distance” from the correct answer (number of introduced errors in the chosen answer).

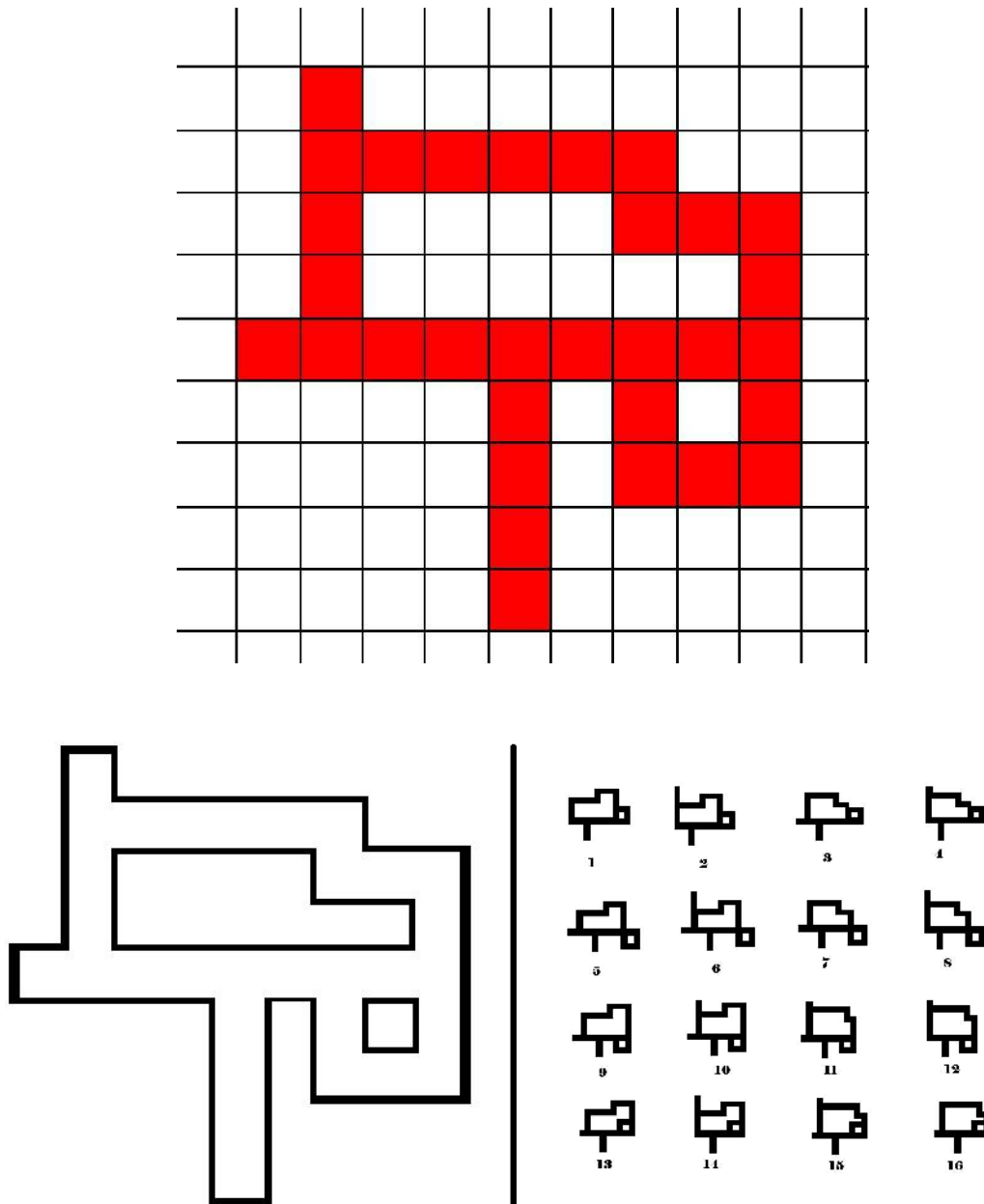


Figure 7.4 (a) The outline of the corridors – the black lines represent the walls. (b) The 16 options provided to each participant to choose from. The correct answer is number 11.

7.4.2 RESULTS

There was no main effect for configuration ($F(1, 50) = 1.82, p = 0.18$). In both the single screen and peripheral displays configurations, 14 participants out of 27 managed to select the correct answer.

A main effect was found for sex ($F(1, 50) = 9.62, p < 0.01$) with males ($M = 0.50$) having a shorter error distance than females ($M = 1.21$), indicating a gender gap in this task. However, an interaction was found between sex and configuration ($F(1, 50) = 11.51, p < 0.01$) which eliminated this gap in the peripheral displays configuration.

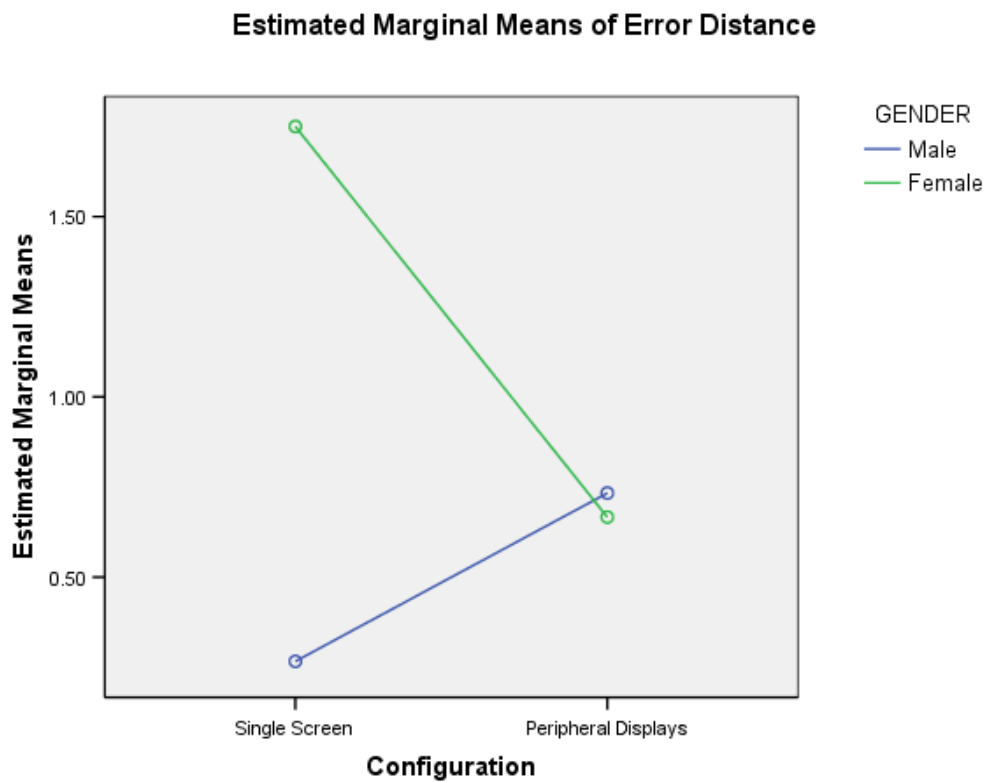


Figure 7.5 Interaction Effect of Sex and Configuration on Error Distance in Corridors Experiment

While male participants made more errors in the peripheral displays configuration than the single screen, female participants made far fewer on average. This reduction in errors led to the elimination of the gender gap.

	Men	Women	Display mean (SD)
Single	0.27 (0.59)	1.75 (1.06)	0.93 (1.11)
Peripheral plus central	0.73 (0.96)	0.67 (0.65)	0.7 (0.82)

Gender mean	0.5	1.21	
(SD)	(0.82)	(1.02)	

Table 7.4: Mean errors (standard deviations in parentheses) made by men and women in selecting the correct map, in single or peripheral-plus-single display conditions.

Subjective Metrics

In the single condition, some users complained about the narrowness of the world and about constantly colliding with the walls. References to the peripheral displays were rare. One participant stated that he used them to help align himself with the corridors to assist in evaluating the length of the corridors. Two female participants mentioned that looking at the peripheral displays caused them to lose their orientation.

7.5 DISCUSSION OF RESULTS

The two experiments in this section were designed intentionally to have similar tasks (cognitive mapping) but to be advantageous to different navigational strategies. The Art Gallery experiment featured a landmark-based cognitive mapping test. The Corridors experiment featured a route-based cognitive mapping test. We establish from these facts and the results we obtained a number of conclusions. Firstly, it confirms McCreary and Williges's (1998) finding that route knowledge but not landmark knowledge improved with more visual information, although in our experiment we utilised a different viewing area. Secondly, it supports the existence of a gender gap in some but not all navigation tasks when using virtual environments. There was no evidence of a gender gap in the Art Gallery test of positioning the paintings. However, a large gender gap in favour of males existed in mapping the world in the Corridors experiment. Thirdly, the improvement from the peripheral displays in the Corridors experiment was only apparent for female users. Male users did not benefit from the addition of the displays. This indicates that desktop displays are not suitable for female navigation in a virtual environment, since the limited

field of view inhibits cognitive mapping abilities. It also shows that the far periphery is a useful visual area that can improve cognitive mapping in females.

7.6 NEXT STEP

Having looked into cognitive mapping, our next set of experiments would look into other areas we expected to benefit from our displays. These were object location memory (Chapter 8) and search (Chapter 9).

When we designed these experiments, we expected a different degree of effect of adding the peripheral displays on male and female users. We did not, however, expect the effect to be as radically different as we found. Our results suggest that it is possible for only one gender to benefit from the peripheral displays. The differences in both navigational strategies and spatial abilities require different display needs.

As a result of this, we opted not to place extra emphasis on gender in our design. We looked at each gender group separately and attempted to balance out the number of participants. Our research questions became more focused as we looked into the following gender-based questions:

1. Does adding peripheral displays improve female performance?
2. Is the effect of peripheral displays different for males and females?
3. Does gender bias disappear as a result of adding peripheral displays?

In the next chapter, we look at our second set of experiments which aimed to address all of these points and further analyse the advantages and disadvantages of peripheral displays.

CHAPTER 8

EXPERIMENT 2.1 AND 2.2 COORDINATE OBJECT LOCATION MEMORY

8.1 INTRODUCTION

Having shown in our previous pair of experiments that cognitive mapping improved with the addition of peripheral displays, we decided to assess another spatial ability. Object location memory was the second of the spatial abilities which has been shown to improve with an increase of field of view (see Chapter 4).

We chose a coordinate object location memory task, rather than a positional one, to avoid the possible benefit of cognitive mapping. In positional object location, participants are measured for their relative positioning of the objects. Remembering which painting hung where in an art gallery would be an example of such a test. Forming a cognitive map can help in performing this task, especially in larger environments. In coordinate object location memory, participants are measured for the distance between their positioning of an object and its actual position. This task therefore is less likely to benefit from a cognitive map.

We conducted two experiments to assess to assess performance on this task. In the first, users had to return to a point of origin from which they began. In the second, they had to

return objects to their original position. The difference is in assessing object location from an egocentric or an exocentric view.

In this chapter we describe our experiment from setup (Section 8.2) to implementation (Sections 8.3 and 8.4) to results and analysis (Section 8.5). In Section 8.6 we review what we have learned and determine our next step.

8.2 EXPERIMENT SETUP

Two experiments were designed and implemented to evaluate user performance. In both experiments an open virtual landscape (no walls or limits) were designed and populated with a series of objects. Two types of objects were included, which we called Monoliths and Landmarks. In our programs, Monoliths were long, narrow, single-coloured, non-textured boxes which the participant could “pick up” by walking through. Landmarks were shorter, wider, textured boxes which could not be picked up. Collisions with the Landmark would lead to the user bouncing back.

The tasks set to the users required them to pick up the monoliths and then to either return the monoliths back to their initial position, or to return to their own original position. Landmarks were placed to assist with navigation for the tasks. The details of each task are described in their subsequent sections below.

As in the previous set of experiments, participants were divided into two groups. In the control condition, participants ran the experiments on the single screen configuration. In the experimental condition, peripheral displays were added. Analysis was performed between groups. In addition to which condition they were placed in, participants were divided in our analysis by gender as well.

Interaction with the world was done using the keyboard similar to our previous experiments. Based on user suggestions, we added a strafing motion so users could “sidestep” to the left and right. The input keys for motion were as follows:

Up	Move Forward
Down	Move Backwards
Left	Rotate Left
Right	Rotate Right
S	Strafe Left
D	Strafe Right

Table 8.1 Controls for Experiments 2.1 and 2.2

Prior to the experiments, participants were familiarised with the environment and controls by being placed in a virtual environment similar to that used in the experiments, with monoliths that could be picked up and landmarks that could not. Users were told to spend as long as they needed until they felt comfortable with the controls. The amount of time taken in these environments was not recorded, but was similar to that in the previous experiments (see Section 7.2).

8.2.1 PARTICIPANTS

52 participants (26 female) were brought in to take part in these experiments. After seeing the clear distinction between male and female participants' performance in the previous experiments, it was decided that gender groups need to be balanced for each configuration. Four groups were thus made when divided by gender and configuration:, each with 13 participants; Single Configuration Male (SM), Single Configuration Female (SF), peripheral display configuration Male (PM), and peripheral display configuration Female (PF). These participants were aged between 18 and 35 years. Care was taken to balance out users as much as possible by age group, self-perceived navigational skill, and

VE experience. Pre-questionnaires asking this information were given to each user (see Appendix A). As in the previous set of experiments, male participants were more experienced than the females, and so experience could not be balanced between the sexes. 18 of the 26 male participants were regular users of virtual environments (a few times a month at least), compared with only 1 one of the 26 female participants.

Six of the participants (four female) took part in the previous set of experiments (see Section 7.2). Four of these were in the single screen configuration (two female), and the other two (both female) were in the multiple screen configuration. In our estimation, enough time had passed between the two experiments (approximately 7 months) that this previous experiment would not have affected the results. However, we acknowledge the possibility that a “learning effect” may have affected the results.

8.2.2 DATA COLLECTION ANALYSIS

Performance data was collected from the participants via the program, which recorded their timing and the positioning of their important moves, specifically the picking up and placing down of the monoliths and their return to the starting point. An attempt was made to also record the exact movements of the participants via the program but this was later discovered to not work as intended. A modified and usable version of this was implemented for our third set of experiments (Chapter 9).

Subjective metrics were also evaluated through written questions. We replaced the essay question “What problems did you face in the [experiment]?” used in our previous experiment with a series of interview questions. This was because the essay question resulted in users replying mostly about aspects of the program unrelated to our aim (such as commenting about the input devices). It also did not allow the interviewer to refocus the user on the points most pertinent to our research. The interview question began with the question “What strategy did you use to perform the task?” Participants using the

peripheral displays were asked if they utilised them and if they thought they benefited from them. Follow-up questions were added on as deemed necessary by the interviewer.

As in all our experiments, we analysed the quantifiable data by comparing the control and experimental condition for three groups: all participants (SA vs. PA), male participants (SM vs. PM), and female participants (SF vs. PF). Also, we compared the male and female participants for each configuration (SM vs. SF and PM vs. PF). The specific metrics used in our analysis were task-dependent and are discussed in the section(s) below.

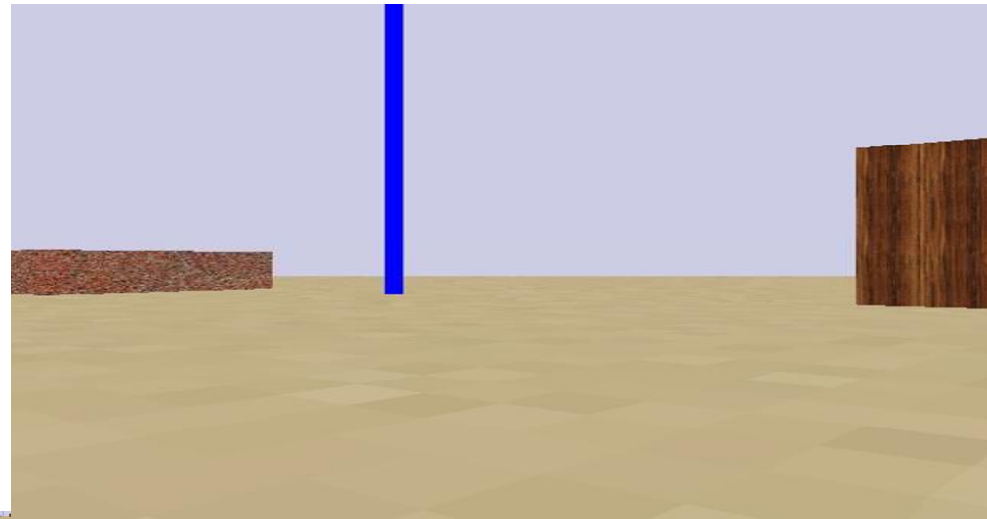


Figure 8.1 View from Monoliths program. The blue structure is a “monolith”. The two textured structures are “landmarks”.

8.3 THE MONOLITHS I EXPERIMENT: RETURNING TO THE STARTING POINT

In the first experiment, participants were given an egocentric object location task. After navigating a world they needed to return to their point of origin. To assess the correct position and distance they would need to use the landmarks surrounding them in relation to their position.

8.3.1 TASK

In this experiment participants were evaluated on their ability to return to their point of origin after performing a collection task. Participants were placed in a sparsely populated virtual world. The world was designed to be open (no walls) and shadowless, and contained 4 monoliths and 3 landmarks. The users were given the task of collecting the four monoliths in a specific order (Red – Blue – Yellow – Black) and then returning to their point of origin and pressing the H key when they were done. They were told that they would be evaluated on how close they were to the point of origin.

The landmarks and monoliths surrounded the user's starting point as in Figure 8.2. The range of this area (including all landmarks and monoliths) was 56 virtual units. Each keypress moved the user 0.1 units in the respective direction.

They were also told that their time would be recorded. Although they were not given a time limit, outliers for time would be removed from analysis. Outliers were determined as anyone falling outside three standard deviations of the mean. Participants were analysed for their proximity to the point of origin as a main metric, and time as a secondary metric.

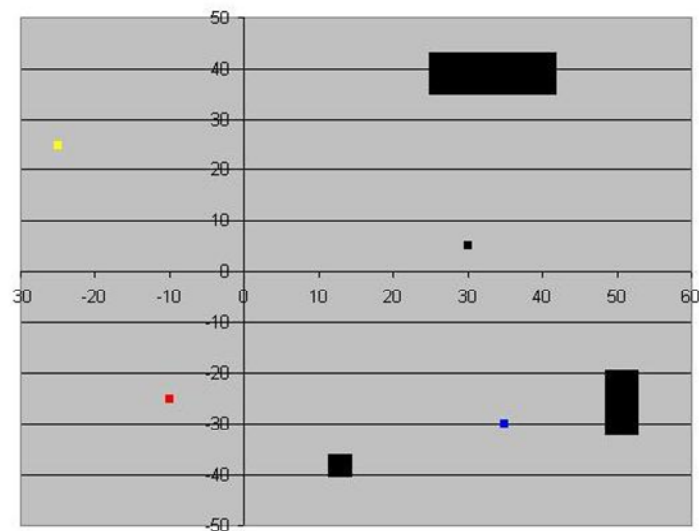
“GETTING LOST”

One eventuality that was not taken into consideration and which did not appear in our test of the program or pilot studies was the possibility of “getting lost”. The world was designed with no barriers or limits, so users could continue walking indefinitely in any direction. All landmarks and monoliths were placed within a certain radius of the starting point. Furthermore, if the participant were to move a certain distance away from the objects, they would disappear from view. This is a standard concept in computer graphics

which helps reduce the need to render far-away objects. However, it also means that participants who went too far in one direction would not be able to find their way back.



(a)



(b)

Figure 8.2 (a) Bird's eye view of Monoliths I program with start point (point of origin) added. (b) Schematic of the world in virtual distance units.

Though rare, participants who managed to get lost would end up giving up rather than completing the task, since they could no longer see the landmarks and knew they were nowhere close to the point of origin. These participants were discarded from analysis, as described below.

8.3.2 RESULTS

Two male participants were removed from our analysis for “getting lost” in the world, leaving us with 13 participants in each of the female groups (SF and PF) and 12 in each of the male groups (SM and PM).

A main effect for configuration was found ($F(1, 46) = 6.35, p < 0.02$). Participants who used the single screen configuration completed the task with a shorter distance from point-of-origin ($M = 24.47, SD 18.4$) than those in the peripheral displays ($M = 37.66, SD 19.03$). In other words, the peripheral displays were shown to have a negative effect on performance. This was true for both male and female users (see Table 8.2). There was no main effect found for sex ($F(1, 46) = 2.92, p = 0.09$). Also, there was no interaction between sex and configuration ($F(1, 46) = 0.02, p = 0.89$).

	Men	Women	Display mean (SD)
Single	19.42 (12.49)	39.14 (22.03)	24.47 (18.4)
Peripheral plus central	31.93 (16.35)	41.60 (21.21)	37.66 (19.03)
Gender mean (SD)	26.41 (15.68)	35.37 (22.12)	

Table 8.2 Mean errors (standard deviations in parentheses) made by men and women in pinpointing the point of origin in the Monoliths I experiment, in single or peripheral-plus-single display conditions.

Post-hoc power tests were administered for sex. This revealed inadequate sample sizes ($\eta^2=0.161$, power = 0.205). A larger sample size would be needed to test gender differences. However, since we obtained a significant difference between the two display configurations favouring the single screen display, we can conclude that the peripheral displays had a negative effect on this task.

8.4 THE MONOLITHS II EXPERIMENT: RETURNING OBJECTS TO THEIR POSITION

In the second experiment, users performed an exocentric object location task. To perform the task, users could compare the position of the placed object to other objects in their view.

8.4.1 TASK

In this experiment, participants were given a similar task to the Monoliths I experiment, in that they had to pick up a number of monoliths. However, instead of being evaluated on their returning to their point of origin, they were evaluated on how well they returned the monoliths to their original position.

Participants were placed in another sparsely-populated virtual world. This world contained 3 monoliths and 2 landmarks. The users were given the task of collecting the three monoliths in any order. After they had collected all three monoliths, they would then have to return each monolith to its original position. They could do this by going to this position and pressing the appropriate keyboard key associated with that monolith [R-Red monolith. Y-Yellow Monolith. B-Black monolith.] Participants were allowed to

change the position of the monolith if they felt they had put it in the wrong place. They could do this by moving to a new position and pressing the key again. They would not have to pick the monolith up again to do this.

Participants were told that they would be evaluated on how closely they managed to place the monoliths to their point of origin. They were also told that their time would be recorded. Although they were not given a time limit, outliers for time would be removed from analysis. After completing the task, participants were analysed for the average proximity of the monoliths to their original positions as the primary metric. Time was used as a secondary metric. The range of this area (including all landmarks and monoliths) was 52 virtual units. Each keypress moved the user 0.1 units in the respective direction.

8.4.2 RESULTS

Due to glitches in the program, four participants' data could not be used for our analysis. For three of the participants, the program did not record their performance data. This was due to an error in file management when the program is terminated, which was undiscovered until the analysis stage. The fourth participant was stricken from analysis, since the program did not respond to his keypresses at one stage of the experiment. This problem did not repeat for any other participant. All of these stricken participants were male. Two occurred in the single screen configuration and two in the peripheral screen configuration. We were left with 13 participants in each of the female groups (SF and PF) and 11 in each of the male groups (SM and PM).

The metric used was the proximity of the placed monoliths to their original position. Each participant had to place three monoliths. The average distance of the three was used for comparison.

No main effect for either sex ($F(1, 44) = 2.48, p = 0.12$) or configuration ($F(1, 44) = 1.78, p = 0.19$), nor an interaction ($F(1, 44) = 0.96, p = 0.33$).

GROUP	AVERAGE	STANDARD DEVIATION
SM	16.37	10.85
SF	26.62	22.41
PM	29.62	25.71
PF	32.9	16.67

Table 8.3 Mean errors and standard deviations made by men and women in pinpointing the point of origin in the Monoliths I experiment, in single or peripheral-plus-single display conditions.

Post-hoc power tests were administered for each effect. This revealed an adequate sample size for sex ($\eta^2=0.425$, power = 0.848) but not for configuration ($\eta^2=0.29$, power = 0.532). Further tests with a larger sample size would be needed to show whether a difference between the two configurations existed.

8.5 ANALYSIS

The first thing that our results show is that the addition of the peripheral displays was *not* conducive to performance of this task in this environment. In fact, performance when using peripheral displays was found to be on average lower than with the main screen alone. In the Monoliths I experiment this difference was found to be significant.

To explain the reasons for this we looked at our post-experiment discussions. Many male participants complained about the layout of the world, the lack of landmarks, shadows, or other cues with which to indicate direction, and that the peripheral displays compounded these problems by providing more empty areas. Some of the participants in the peripheral

configuration were not affected adversely by it. Indeed, the best overall performance, and two of the top four, were participant from the PM group. When asked, both stated they only used the peripheral displays when picking up and placing the monoliths, to ground themselves with the landmarks. For many of the other participants, however, the displays seem to have acted as a distraction. Their responses show the use of other strategies, such as counting time, or a dependence on route memory, rather than landmark-based navigation. In this environment, with very few directional cues, these strategies would not always work.

The female participants in the single configuration (SF) found trouble using the landmarks as well. Some said they kept turning and trying to remember their position, while others tried to use the computer screen itself as a yardstick for distance estimation. One participant stated that there weren't enough landmarks for navigation to be feasible. More of the female participants in the peripheral configuration (PF) stated that they used landmarks for navigation. Their ability to see more of the world helped them ground themselves with the landmarks, although they still had problems in estimating distances correctly. Based on the overall negative results obtained using the peripheral displays, as well as the user comments, we conclude that this configuration of peripheral displays was not suitable for the scenario presented in this experiment. It is possible that a more densely-populated environment, or one with more specific geometric turns (e.g. a maze), would have yielded different results. While the same configuration had a positive effect on female participants in the previous experiment, it was found here to be a distraction. The second interesting result is that the negative effect on male participants was greater than it was on females.

There was no evidence of a gender gap in this task. In experiment 1, this lack of evidence may have been due to an insufficient sample size. However, since this task was shown not to benefit from the addition of peripheral displays, we will not pursue this matter further.

8.6 NEXT STEP

These experiments showed that the addition of the peripheral displays could have a negative as well as positive effect on user performance. This effect was larger on male than female participants, indicating that the two genders do react differently to these displays. The fact that it is a negative as well as a positive effect makes it more difficult to come up with a set of guidelines on how to design a system with peripheral displays, as it is unadvisable to improve one group's performance of a given task at the expense of another group's ability to perform a different task. It would be necessary for a greater set of tests to be run comparing different types of configurations – perhaps different fields of view, or comparing continuous and non-continuous configurations, to see whether it is the gaps that have caused the problem.

However, we decided that it was important to investigate further into the configuration that we had designed. We believed that we needed to test it further. We concluded that a closed or densely-populated environment probably benefited from these displays. We also wished to further assess the effect of gender. Finally, we wished to look at a different type of navigation task from what we had done so far. All of these points were taken into consideration and led to the design of our third set of experiments: search tasks in a mapped maze.

CHAPTER 9

EXPERIMENT 3.1 AND 3.2 THE MAZE EXPERIMENTS

9.1 INTRODUCTION

In our previous experiments we had found a significant positive effect for our peripheral displays on route-based cognitive mapping abilities in females. We found no such advantage for males; nor did we find any improvement for either gender in landmark-based cognitive mapping. Coordinate object location memory and distance assessing also failed to show an improvement for either gender. In fact, there was evidence of a reduced performance for male participants. Before concluding our study, we opted to look at the third spatial ability which has been shown to benefit from an increased field of view: search (see Chapter 4).

Search tasks can be implemented in many ways, varying in complexity, type of environment, and type of search mechanism. For example, search tasks can be for targets which are hidden or unhidden. Hidden targets can be obscured by obstacles such as walls or trees and require the user to navigate around them to find the objects. Unhidden targets are in the open and require only the user's focus to be found. We take it for granted that searching for unhidden targets improves with an increase of visual space, for the simple reason that a larger percentage of the world can be viewed at one time, and it is usually faster to turn one's gaze than to rotate in the world. In Chapter 4 we reviewed some

studies that confirm this (Wells and Venturino, 1990; Piantanida et al., 1992). We therefore utilise hidden target search.

The next issue was to decide upon the virtual environment. One of the most common types of search in virtual environments is the maze. Mazes are simple to design since they keep the search area limited without reducing its complexity. This was also useful to our study, since there are documented performance differences between male and female participants in maze-based tasks, both real (Schmitz 19997) and virtual (Moffat et al., 1998; Cutmore et al., 2000; Jansen-Osmann and Wiedenbauer, 2004). Experiment 1.2 also resembled a maze, and confirmed this difference existed on a single screen. It also showed improvement in adding peripheral displays. For these reasons we chose the virtual maze as our search environment.

Another point was to determine whether to employ naive or primed search. In naive search, the user is completely unaware of the location of an object. In primed search, the user has some a priori knowledge of the object's location. There are two general ways of doing this: provide the location in the form of a map or instructions, or allow for multiple iterations of the search, so that the user is familiar with the position of the object. The disadvantage of the latter approach is the increased time demands on participants and the increased mental load. We therefore opted for the former approach, utilising a map of a maze.

The disadvantage of testing naïve search is that there is a greater element of chance in finding the object. The disadvantage of primed search is that a priori knowledge of the object location allows the user to find the target without depending on navigational abilities. For example, running multiple iterations of the test allows the user to memorise the keypresses; while using a map to find the objects allows the user to predetermine the directions to take. In both cases, performing the task becomes a geometric problem to a degree.

We therefore included two types of search in our experiment. The first experiment included a primed search only. Participants would have to find objects as marked out on a map. Since this was not a spatial task it was anticipated that no advantage could be seen from the peripheral displays. In the second test, a map was provided of the virtual world. However, participants were informed that there were errors in the map. The location of the errors were not disclosed to the participant. There was in this task both a naive (location of the error) and primed (partial knowledge of the world) search element to the task.

In this chapter we look at these experiments, from setup (Section 9.2) to design, implementation, results (Sections 9.3 and 9.4) and analysis (Section 9.5). We conclude in Section 9.6.

9.2 EXPERIMENT SETUP

Two experiments were designed and run, utilising the same set of participants for both. As with our previous experiments, participants were divided into two groups: a control group performing the experiments on a single screen, and an experimental group using the peripheral displays. Both experiments involved participants performing navigation tasks on a virtual maze. The mazes were designed using Visual C++ and OpenGL. Each maze contained a number of turns, dead-ends, and forks, but no exit points. Collision detection was employed so that if the participant hit against the wall she would bounce back.

Interaction with the world was done using the keyboard. Participants were given the ability to move forwards and backwards, rotate left and right, and to strafe. The controls are the same as in our last experiment.

Up	Move Forward
Down	Move Backwards
Left	Rotate Left
Right	Rotate Right
S	Strafe Left
D	Strafe Right

Table 9.1 Controls for Experiments 3.1 and 3.2

Prior to the experiments, participants were familiarised with the environment and controls by being placed in a virtual environment similar to that used in the experiments, namely a maze which could be navigated. Users were told to spend as long as they needed until they felt comfortable with the controls and environment. The amount of time taken in these environments was not recorded, but was longer than that in the previous two sets of experiments (see Sections 7.2 and 8.2).

For each experiment, each participant was given a map of the maze highlighting their start position and direction. Participants would start the experiment by being placed inside the maze at the highlighted position and then asked to perform the task. We look at the nature of each experiment's task independently below.

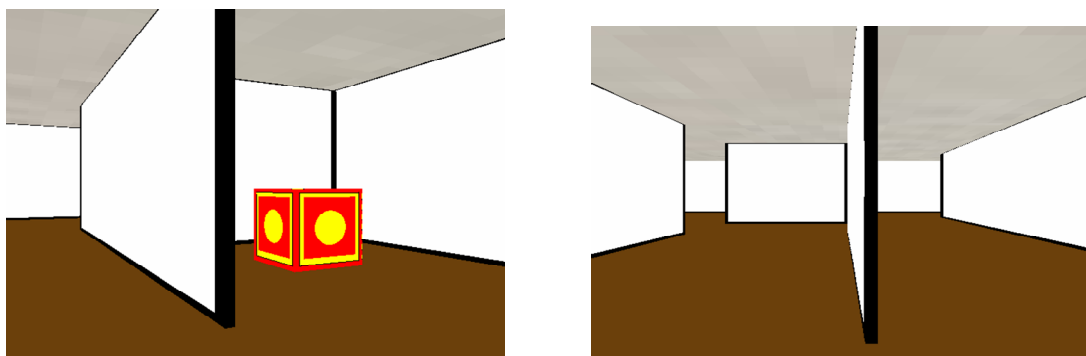


Figure 9.1 Images from the Maze programs.

9.2.1 PARTICIPANTS

A total of 48 participants were obtained (24 female; 24 male) to run the two experiments. Participants were divided by configuration and gender, giving us four groups of 12 users each: Single Configuration Male (SM), Single Configuration Female (SF), Peripheral Display Configuration Male (PM), and Peripheral Display Configuration Female (PF). These participants were students and staff at the University of Bath between the ages of 18-44. Care was taken to balance out users as much as possible by age, self-perceived navigational skill, and previous VE experience. Pre-questionnaires asking this information were given to each user (see Appendix A). Once again, more male participants were familiar with VEs than females. As a result, we could not balance experience between the sexes. 11 of the 24 male participants reported themselves as regular users of VEs (a few times a month, at least), compared to only 2 of the 24 female participants.

Twelve participants (four female) had taken part in a previous experiment. These consisted of four males and two females for each configuration. One participant (male, multiple) had taken part in both prior experiments. As with the Monoliths experiment (see Section 8.2.1), we estimated that enough time had passed (approximately ten months between experiments 2 and 3, and seventeen months between experiments 1 and 3) for there to be any “learning effect”. However, we acknowledge the possibility that this may have affected our results and that, in an ideal experiment, only new participants would have been obtained.

9.2.2 DATA ANALYSIS

Performance data was recorded by the computer and experimenter, measuring quantifiable metrics such as the time taken to perform a task, the amount of distance and area covered, and the number of keys pressed.

In addition to this, each test was programmed such that the user's exact route through the maze would be recorded. This is a new form of analysis in our experiments. A similar attempt had been made in experiments 2.1 and 2.2 (Chapter 8) but had failed to record properly. This information could be used to retrace and display the steps taken by the participants, thus enabling us to both compare and evaluate user efficiency in pathfinding and to present visual aid when comparing navigational strategies.

Analysis for was performed in the form of independent factorial ANOVA tests when all four groups were compared, and a student's t-test when only two groups were compared (see Section 9.4.2). The independent variables were sex and configuration. The specific metrics used in our analysis were task-dependent and are discussed in the section(s) below.

9.3. EXPERIMENT 3.1 – FINDING BOXES IN A MAZE

In the first experiment we assessed performance on a primed search task in a virtual maze. Optimal performance of the task required solving the 2D maze in the map (see Figure 9.2) and following the same paths. Therefore, we theorised that the task could be performed with a minimum of three-dimensional spatial ability. If this hypothesis is true, the addition of the peripheral displays would not improve search performance.

9.3.1 TASK

Experiment 3.1 was designed to measure the ability of finding items in a virtual maze. Participants were placed in the maze and provided with a map shown in figure 1. The maze measured 40 x 40 units. Each keypress moved the user 0.05 units in the respective direction. The map indicated their starting position (marked by the X), the direction they were facing (marked by the arrow), and the position of four red boxes (marked by the numbers 1, 2, 3, and 4). They were then charged with the task of finding and collecting

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the four red boxes in numerical order by navigating the maze to where the boxes were and picking them up by walking through them. Once a box was “collected” it was longer display in the VR.

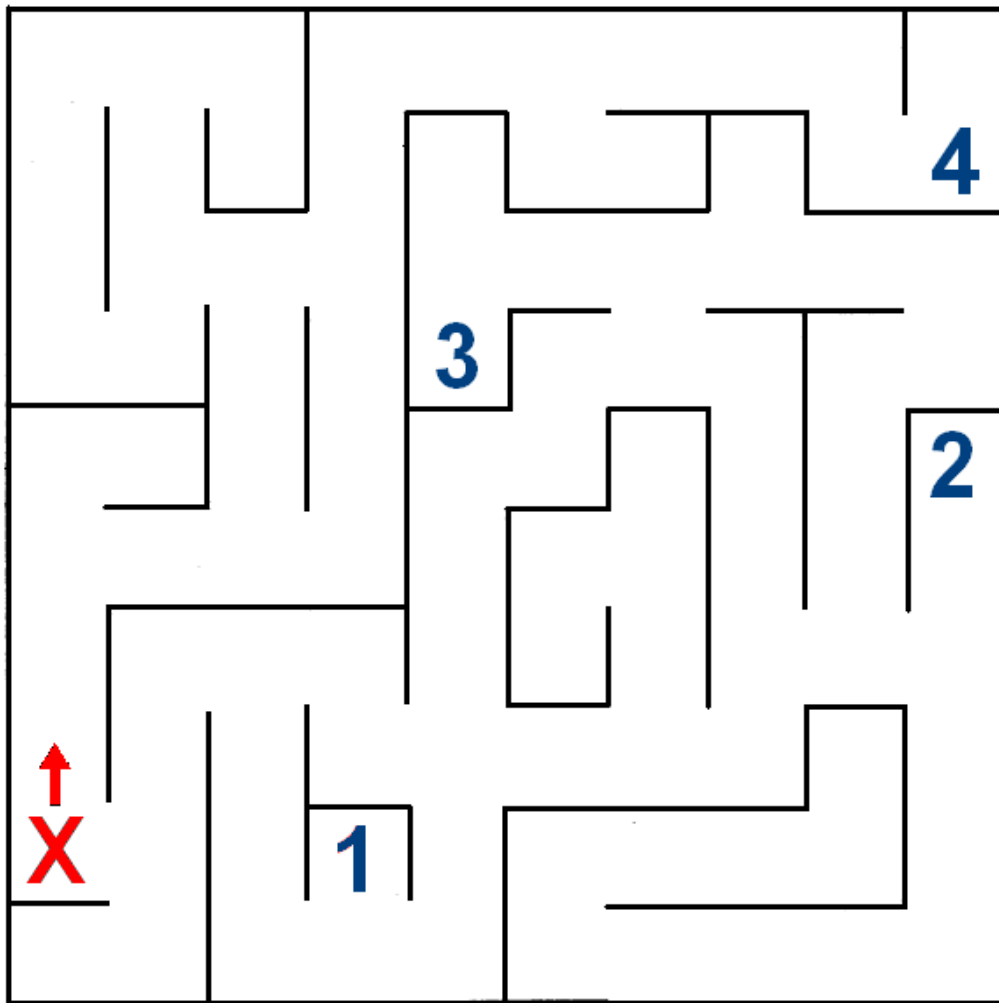


Figure 9.2. Map of Maze used in Experiment 3.1

The participants were told that they would be measured for number of boxes found and time taken to find each box. For Box 1, the timer was started with the first user keypress.

For all remaining Boxes, the timer was started from when the previous box was collected. Both of these metrics were measured and recorded automatically by the program.

Since the distance for finding each box is different, we divided the time it took for collecting a box by the minimum distance in unit squares. For example, the distance to reach box 1 from the starting point was 9 units square, while the distance to reach box 2 from box 1 was 12 unit squares (Figure 9.2). We called this metric time-per-distance. Each participant recorded up to 4 values of this metric. Comparisons were made on the average time-per-distance for each user.

9.3.2 RESULTS

As mentioned, two sets of tests were performed. Inter-gender tests, which compared male and female participants to see if a gender gap existed; and inter-configuration tests, which compared single-screen users with those using the peripheral displays.

Regarding the former, it confirmed our expectation of a performance difference between the sexes. It can be demonstrated that the male participants were able to perform the tasks more ably and with an overall higher sense of enjoyment and confidence.

Number of Boxes Collected

All the male users, in both configurations, managed to complete the task of finding all four red boxes. In comparison 9 out of 12 female participants managed this task in the single configuration, and 11 of the 12 managed it in the peripheral display configuration. There is no demonstrable statistical evidence of a significant difference in this metric between any of our groups, probably due to the low ceiling on completion. A test with a larger maze and a larger number of boxes to find may prove to test this metric more thoroughly, but would also change somewhat the nature of the task at hand.

Time

A main effect for sex was found ($F(1, 44) = 9.02, p < 0.01$) with male users taking on average less time to find the boxes than females. It should be noted that since some female participants did not manage to collect all four boxes, this sex difference in search performance is even larger than what these test results tell us. There was no main effect for configuration ($F(1, 44) = .014, p = .91$), nor any interaction ($F(1, 44) = 0.298, p = 0.59$).

	Men	Women	Display mean	(SD)
Single	3.58 (4.26)	7.05 (4.79)	5.32	(4.78)
Peripheral plus central	2.98 (2.44)	7.98 (6.97)	5.48	(5.71)
Gender mean (SD)	3.28 (7.52)	7.52 (5.87)		

Table 9.2 Average time (standard deviations in parentheses) for finding boxes by men in single or peripheral-plus-single display conditions.

Post-hoc power tests were administered for configuration. This revealed an inadequate sample size ($\eta^2=0.05$, power = 0.055). A larger sample size would be needed for testing differences between configurations.

9.4 EXPERIMENT 3.2

In the second search experiment, users were given some a priori knowledge of the world, in the form of a faulty map, but were not instructed as to the position of the targets. The ability to perform the task required a search element, an ability to identify errors, and an ability to update the map of the world.

In naive search there is no single correct route to take. However, performance can be measured by how efficiently the world was traversed. Users could be measured for how much area they covered or how many times they traversed the same route repeatedly. We therefore used these measures as well as the basic search metrics of number of targets found and time. This task included a maze solving element similar to experiment 1, but also a cognitive mapping element due to the need to update map information upon finding errors. We use the results from our experiment to determine how well each element was affected by the peripheral displays.

9.4.1 TASK

In experiment 3.2, the same participants were once again placed in a maze and provided with a map, indicating their start position and direction. In this experiment, however, they were informed that the map they were given had four errors, meaning four differences from the virtual maze they were placed in. These errors could be one of two types: walls drawn on the map that did not exist in the maze, or open paths on the map that were actually walls. A different map was used. The map had the same dimensions (40 x 40 units). Each keypress moved the user 0.05 units in the respective direction.

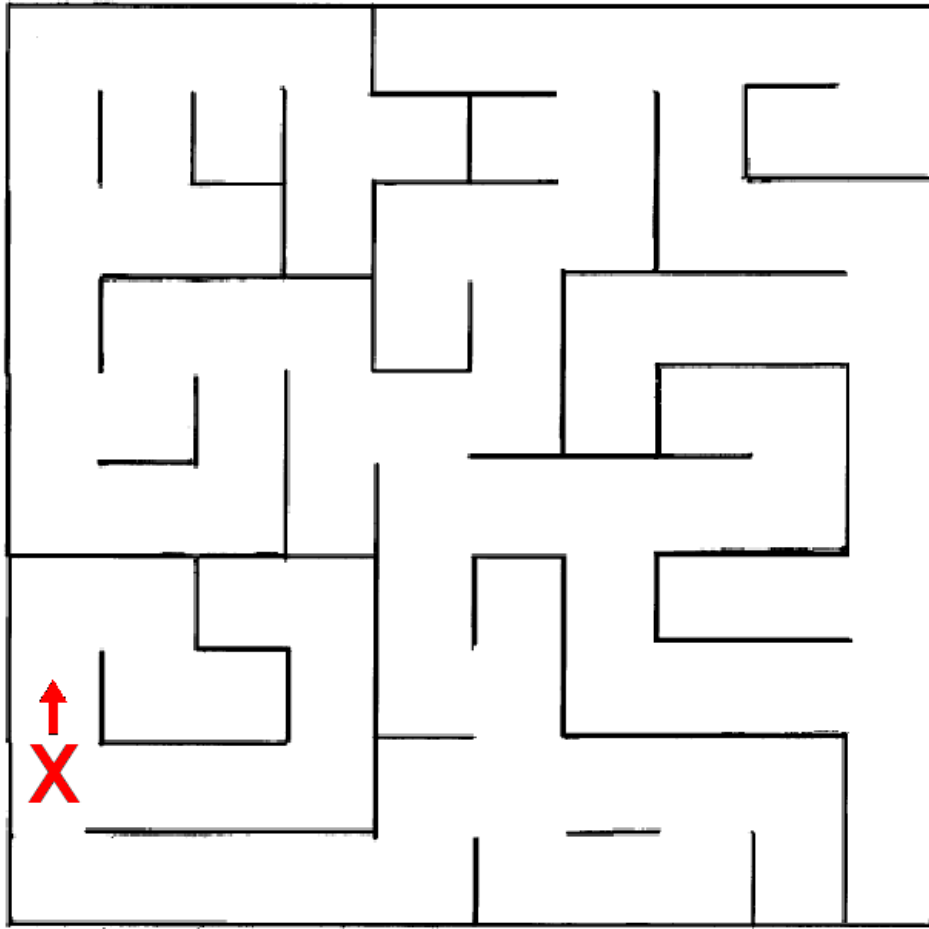


Figure 9.3 Map of maze used in experiment 3.2

The participants were charged with the task of navigating the maze and finding these errors. They were told they would be assessed by ability to complete the task (how many of the errors they correctly found) and would be measured for time.

To perform the task users would have to be able to explore different areas of the maze and identify the existence of errors. Exploring the maze in this naive search task would include being able to traverse the maze and visit new areas. It would also require them to have route knowledge of areas previously visited; otherwise, they would most likely traverse the same areas repeatedly or even enter a loop.

We aimed to measure all of these aspects. To measure the first two elements (exploration, error-finding) we use the number of correctly-identified errors found for each user. Time was recorded, but was not regarded a reliable metric, since it is only a useful metric when comparing users who have found the same number of errors. Using a time to errors found ratio as a metric was also dismissed, since some participants, it was expected would find zero errors correctly. This expectation transpired to be true. Nor could it be determined that all errors were equally findable. The same applies for the distance covered.

To measure the exploration factor by itself we looked at the area covered. We did this by dividing the maze into 100 squares, each square consisting of smallest width and length of wall used in the maze. A square was counted as having been covered if the user traversed any of the area within the square. The number of squares traversed was then used to evaluate the area covered.

To measure the route knowledge we looked at the ratio between the overall distance covered by the user to the area covered in squares. A lower distance-to-area ratio would indicate a more efficient traversal of the maze. If a difference was found in this metric, we confirmed it by printing out the diagrams of the participants and counting the number of squares which were traversed three times. The number three was chosen since it was determined that a participant would have to cover each square *at most* twice, since there were dead ends and loops in the maze. The lower the number of the Triple Crossed Squares metric, the more efficient the traversal of the maze.

A summary of the metrics used are as follows:

- Number of Errors Found
- Area Covered
- Distance to Area Ratio
- Triple Crossed Squares

9.4.2 RESULTS

From the peripheral configuration group, one female participant's data was discarded. Many of the metrics recorded for her performance were noticed to be irregularly high (outliers, lying outside three standard deviations of the mean). When contacted later, it transpired that she had misunderstood the instructions. Thus we were left with 11 female participants in the peripheral display configuration, and 12 participants in each of the other three groups.

Analysis of the results when comparing users between configurations provided some interesting information. The peripheral displays were shown to have no discernible effect on male participants in any of the areas we tested for. Females were not found to benefit from the peripheral displays in number of errors found or area covered. However the distance-to-area ratio and the number of triple crossed squares were all significantly lower in the group using peripheral displays. A summary of the results are described below.

Number of Errors Found

Male participants were able to find more errors than female participants in both configurations. A main effect was found for sex ($F(1, 43) = 14.77, p < 0.01$), indicating a gender gap in this task favouring males. There was no main effect for configuration ($F(1, 43) = 0.16, p = 0.74$) nor interaction ($F(1, 43) = 0.37, p = 0.55$) indicating that the gender gap was not removed by the addition of peripheral displays.

	Men	Women	Display mean	(SD)
Single	3.25 (1.06)	1.75 (1.66)	2.5	(2.46)
Peripheral plus central	3.33 (1.07)	1.36 (1.29)	1.56	(1.53)
Gender mean (SD)	3.29 (1.04)	1.57 (1.47)		

Table 9.3 Number of maze map errors found (standard deviations in parentheses) by men and women in single or peripheral-plus-single display conditions.

Post-hoc power tests were administered for configuration. This revealed an adequate sample size ($\eta^2=0.61$, power = 0.99).

Area Covered

Analysis of this field yielded similar results to the error found attribute. Once again, a main effect was found in favour of male participant ($F(1,43) = 27.42$, $p < 0.01$). There was no main effect for configuration ($F(1,43) = 1.029$, $p = 0.32$) nor interaction ($F(1,43) = 0.524$, $p = 0.47$).

	Men	Women	Display mean	(SD)
Single	64.50 (9.03)	47.67 (16.08)	56.08	(15.38)
Peripheral plus central	63.42 (13.94)	41.18 (10.69)	52.78	(16.68)
Gender mean (SD)	63.96 (11.50)	44.57 (13.87)		

Table 9.4 Maze area covered (standard deviations in parentheses) by men and women in single or peripheral-plus-single display conditions.

Post-hoc power tests were administered for configuration. This revealed an adequate sample size ($\eta^2=0.518$, power = 0.953).

For both the number of errors found and area covered, males outperformed females in both configurations. A gender gap exists for the task which the peripheral displays could not remove.

Distance-to-Area Ratio and Triple Crossed Squares

The number of errors found in this task and the amount of area covered in the maze are indications of exploring new parts of the maze. To measure the understanding of already-visited parts of the maze, we used the distance-to-area metric. This metric compared the ratio of the overall distance the participant travelled to the area of the maze he covered. A higher distance-to-area value indicates that the participant crossed the same area of the maze more often, possibly due to disorientation or loss of way.

Because male and female participants covered significantly different areas of the maze (in both configurations) it was decided that comparing them with this metric would not be useful. An efficient distance-to-area ratio combined with a smaller area coverage or number of errors found may simply indicate earlier concession of the task. Therefore, only the two female groups (PF and SF) were compared, since no significant difference was found for either the number of errors found or area covered between them ($p>0.05$).

A student's t-test was used to compare the two groups of females. A significant difference was found in the distance-to-area metric ($n = 23$ [12 SF; 11PF]; $t=2.5409$; $p=0.02$; t-test: unpaired equal variance). Female participants in the single display had a significantly higher ratio than females in the peripheral display. Since the difference in the covered area between the two groups was non-significant, it was theorised that females in the peripheral display covered a significantly lower distance. Further analysis proved this to

be the case ($n = 23$ [12 SF; 11PF]; $t = 2.1984$; $p = 0.04$; t-test: unpaired equal variance). This result seemed to indicate that females in the peripheral display were more efficient in their maze traversal, needing less distance to cover similar area and find a similar number of errors.

We tested this hypothesis by comparing the number of triple crossed squares for each group. The result of our comparison showed a large and significant difference ($n = 23$ [12 SF; 11 PF]; $t = 2.8849$; $p = 0.009$; t-test: unpaired equal variance). Females in the single screen configuration covered almost three times as much of the maze (15.92 to 5.55 blocks out of 100) three times or more. To ensure that this wasn't due to individual differences in area coverage, we even devised a Triple Cross Squares to Area Covered ratio and found the same significant differences ($n = 23$ [12 SF; 11 PF]; $t = 3.0087$; $p = 0.007$; t-test: unpaired equal variance). We further studied the routes taken by each user visually to ensure that the multiple crossings were uniform in the maze and not due to a particularly difficult error or area.

	MEAN	SD
SF	9.11	2.74
PF	6.76	1.41

Table 9.5 Average and Standard Deviation of Area Covered

	MEAN	SD
SF	15.92	11.25
PF	5.55	4.06

Table 9.6 Average and Standard Deviation of Triple Lines Crossed

	MEAN	SD
SF	0.13	0.09
PF	0.32	0.18

Table 9.7 Average and Standard Deviation of Triple-Lines-to-Area Covered Ratio

9.5 ANALYSIS

In these two experiments, we tested the ability of users to perform search tasks in a virtual maze. The main results can be summarised in the following points:

1. A gender gap exists in the tasks defined in this chapter: Males were able to find more of the search items (either objects or errors) and were able to do so more quickly.
2. Male users could not be shown to have benefited from the peripheral displays: no significant differences were found between configurations for male participants in any quantifiable field.
3. In the first experiment (Maze I) the peripheral displays had no demonstrable effect on female users either: neither the number of items nor the search time were improved or reduced.
4. In the second experiment (Maze II) the peripheral displays did not improve female ability to find errors or navigate the maze. However, there was a significant improvement in route awareness.

These main results raise several questions. Why wasn't female performance improved for all metrics, and why was the gender gap not reduced when adding the peripheral displays? There are two possible answers. Either the gender gap is partly internal and can not be fully removed in all areas of navigation, or there are other external factors increasing the gender gap that are not addressed in this configuration. While there is plenty of evidence that the former is true (see Chapter 5), we cannot dismiss the second possibility out of hand. The configuration design we present in this thesis had some known design flaws from the beginning. Most notable amongst these was the large gap between front and side screens. We discussed in Section 6.2 why we chose this setup for our experiments, but we never proposed that this be a viable condition for actual use. In fact, many participants in our experiments (including this one) commented on the problems of having gaps between screens, leading to confusion and disorientation. As one

participant in the Mazes II experiment put it “I needed to remind myself [which way was which] when switching back [from the side to the front screen]”. As such, it is evident that the existence of these gaps did have a negative effect on some users which may have affected their performance by introducing additional cognitive problems to the task. In future, a continuous setup would be preferable, in which no gaps existed in the virtual world. To counteract the problem of not knowing whether the near-, mid-, or far-periphery were responsible for any noted differences, the environments would need to be designed in such a way that the essential bits of information would exist only in one region.

Other possible reasons as to why the peripheral displays did not improve the performance of females could be the nature of the environment and the nature of the task. We mean by the former the number and nature of visual cues, or landmarks, we have in the virtual world. We have argued the point of differing navigation strategies between men and women, and their dependence on landmarks and Euclidean information, respectively. However, we do not believe it is the lack of landmarks that is the cause in this experiment, since the nature and look of the mazes are similar to that of the corridors in Experiment 1.2 (Chapter 7), and a significant improvement was found there.

That leaves us only with the nature of the task. In the Mazes I experiment, users had to find four red boxes in the maze. They were provided with an accurate map. The most efficient performance of the task would require them to follow pre-set directions based on the map, rather than make decisions based on the environment they were in. For example, if a user came upon a bifurcation in the maze, they should know which path would be the correct one to take. Users might need to update their position if they got lost by comparing the world they are in with the 2D map, but this was a rare occurrence. Either it occurred once, before the users reoriented themselves, or the user gave up on the task. The problem, therefore, becomes one of geometrically following the map's route. User responses confirm this as most of them stated they followed the map in this way. Some stated they tracked the route with their finger. Those who lost their position admitting to

running through the maze without the help of the map, until they found another box, to help reorient themselves.

The existence of a significant gender difference in this task means that the male participants were better than the females in either solving the two-dimensional map maze, or in navigating the three-dimensional world, or both. We do not believe that it is the former. Each participant was given as much time as they needed to study the map before beginning the test, and none expressed either during the test or afterwards during the interview any difficulty with this aspect. All comments regarding the difficulty of the task were aimed at the virtual maze. Therefore, these results indicate that males outperformed females in virtual maze traversal, and that this gender gap cannot be compensated by adding peripheral displays.

In the Mazes II experiment we conducted another maze search task. In this task, there was no *a priori* knowledge of the targets' positions. Unlike the previous experiment, performing the task depended on *exploring* the world, rather than following an optimal set of directions. In addition to being able to navigate an area of the maze (as was done in the Mazes I experiment) users would have to understand the route taken so far.

The results of our test showed that the ability to navigate the maze and locate the errors once again featured a gender gap in favour of males which could not be eliminated by the peripheral displays. However, the route efficiency improved significantly for female users with the peripheral displays. One way of describing this effect is that the peripheral displays did not improve their ability to know where they were going, but improved their knowledge of where they had been.

We have already shown (Chapter 7) that the peripheral displays improve route-based cognitive mapping in females. The results from the experiment in this chapter confirm that route-based knowledge is what improves in females with the addition of visual

information in the far periphery. Results from our other experiments have found no evidence of improvement in any other task or ability.

9.6 CONCLUSION

Having completed our third set of experiments, we had a set of results regarding the effect of peripheral displays on three different types of navigational tasks in virtual reality. In the following chapter, we look at the results of all our experiments to come up with one set of conclusions regarding peripheral displays, looking at both the advantages and disadvantages they provide, determining the areas in which they have an effect, and setting design guidelines for virtual reality systems in order to utilise them. We also look at a set of future work which could be done in this area.

CHAPTER 10

CONCLUSION: ANALYSIS AND FUTURE WORK

10.1 INTRODUCTION

All of our studies have been conducted to test whether information displayed in the far periphery would affect users of a desktop virtual reality system. This visual area has been ignored by desktop designers, either due to historical limitations of the technology, or to the assumption that it has no great value. These technological limitations no longer apply, and all of our experiments have shown that this area does influence user performance in navigating. This effect, however, is not the same for all users, nor is it uniform across tasks.

Six experiments were run in total, evaluating three different aspects of navigation. These were cognitive mapping, coordinate object location memory, and search tasks. These tasks were chosen due to their being quantifiable, clear, and straightforward, and also for having an analogue in the real world. Furthermore, studies had shown that performance on these tasks was affected by display size and field of view. We showed that women can benefit from the addition of displays in their far periphery for tasks requiring route-based knowledge. It was therefore concluded that they would make for the best tasks in judging the effect of displays in the far periphery.

Cognitive mapping is the mental ability to represent a three-dimensional world. Coordinate object location memory is the ability to remember the Euclidean position of objects after they have been removed. Search is the ability to location an object or determine a path to a goal. The ability to perform any one of these tasks requires a composite of abilities. For example, searching an area could utilise elements of cognitive mapping and object location memory. Analysis of our search task distinguished between remembering the paths taken, which would depend on cognitive mapping, and searching new paths, which would not.

In each set of experiments, a different type of environment was used. These differed in the size of the world, nature of the objects, and the density of landmarks. It is important to note that task performance is partly dependent on environment. For example, someone using a landmark-based navigation strategy may perform well in a dense environment, but poorly in a sparse one; while someone using Euclidean navigation may not perform equally well in both. While it was not possible to test every combination of task and environment, we take environment into consideration when analysing their effect on task performance.

In this chapter we discuss the results of all our experiments to draw out a set of implications for designers who are considering the utility of peripheral displays. We look at what effects we have found for the peripheral displays, dividing this effect by gender. We also look at the types of task which are affected and, as mentioned above, the type of environment. This includes proposing an explanation as to why environment type affects user performance. Based on these conclusions we set out a series of guidelines for desktop VR design. Finally, we set out some areas related to our studies which require further research.

10.2 EFFECT OF PERIPHERAL DISPLAYS ON TASK AND GENDER

A robust and clear difference between genders has been demonstrated in navigation. These differences have been found in the strategies employed by users as well as the measures of task performance. In our studies, we were able to show that the two genders have different needs when it comes to navigating a virtual environment. In certain tasks, it was found that adding peripheral displays had a significant effect on task performance on female participants, but no such effect on males. These were, specifically, the route-based cognitive mapping task in Experiment 1.2 and the route efficiency metrics in Experiment 3.2. In experiments 2.1 and 2.2, a coordinate object location task, the peripheral displays were found to have a negative effect on performance for both genders, but a much larger negative effect on males. These peripheral displays were shown to have no effect on any of the other tasks, which were a landmark-based cognitive mapping task (Experiment 1.1) and maze search tasks (Experiments 3.1 and 3.2).

Female participants performed better on the peripheral displays on tasks involving route-based knowledge. Of the two cognitive mapping tasks in Experiment 1, the first was based on remembering the location of objects, and the second on remembering the route taken. It was only in the latter that a benefit was found with peripheral displays. Similarly, in Experiment 3.2, participants did not benefit from the peripheral displays in exploring the maze or finding the errors, but seemed to improve their knowledge of the routes they had already taken.

In a study on increasing the field of view into the mid-periphery, Tan et al. (2003a) found that females' route memory improved with the wider screens. In a maze-like environment, where each room consisted of a similar design of three doors (to the front, left, and right) and no distinguishing landmarks, participants were asked to recall the path taken. Increasing the field of view did not provide any obvious extra information, yet still improved route memory of the maze. Tan et al (2003a) believed that the improvement

was due to a sensation of vection helping in creating route memory. And while this may be true, we believe that a sense of grounding in the environment is also important.

In contrast to this, we were unable to find any evidence of the peripheral displays improving female performance in any of the other tasks we measured: landmark-based cognitive mapping, coordinate object location memory, and maze search. We attempt to explain the reasons why this is.

The landmark-based cognitive mapping test showed no significant gender gap in the control condition. The typical computer screen provided enough of a field of view to create object positional relationships in the cognitive map of the user (see Figure 7.1). While decreasing the field of view would probably have a negative effect on performance, increasing the field of view provides unnecessary additional information, which may distract the user. In fact, the average number of correctly-placed landmarks was lower in the experimental configuration, although this difference was not significant. The lack of any significant difference between genders in this experiment indicates that there is no gender gap in this task, and that females do not require more visual information to perform the task as successfully as males.

For the coordinate object location memory task, a gender gap was demonstrated in the control condition. And while the gender difference did was insignificant in the experimental condition, this was attributed more to a reduction in male performance rather than an improvement in female performance. There was no evidence that the peripheral displays had improved female performance of this task. This raises the question as to why this is, especially since it can be argued that placing the objects in their correct coordinate location could be considered a route memory task. After users picked up all the monoliths, they could replace them either in the same order or in reverse. Either way, memory of the route could help in task performance.

One reason that no improvement was found could be due to the nature of the environment. We had intentionally developed a landmark-sparse world for this task. It was believed that the increase in visual area would improve the ability to gauge object position more accurately, since the user could see more of the world at the same time. By seeing more of the world, the user would have a better knowledge of landmark position, and would thus be able to position other objects more accurately. However, this proved not to be the case. Instead, the increased visual information seems to have reduced user understanding of object location. As mentioned above, male performance on these tasks decreased when using the peripheral displays. Since males are more likely to utilise a route-based navigation strategy, the peripheral displays must have reduced the route knowledge. These displays created a larger view of the world which was mostly (and for most of the time) empty of any additional visual information. The user was therefore faced with a larger view of the world in which to get positionally lost. Compared with Experiments 1.2 and 3.2, in which the user was grounded by boundaries (walls) which helped give a meaning to the route taken, the user in this experiment had no way of grounding himself, and therefore route memory was reduced.

We believe it is the sense of grounding, and notvection, as Tan et al. (2003a) surmised, that affect route knowledge and memory. A sense ofvection was provided in this experiment. The ground in these experiemnts were textured and navigation provided optical cues in both the near periphery (the front screen) and the far periphery (the side displays).

We did not test to see whether coordinate object location memory would improve if there were more grounding cues (such as walls or more landmarks) and have left it for futrue work (Section 10.6).

The final task type was a search task. Increasing the field of view in an unobstructed targets search task provides improved performance since more of the world can be seen at the same time, and so targets can be located more quickly. This was taken for granted and

we aimed to explore the effect on searching for hidden targets. While the same principle applies (the more visual area is available, the more likely a target will be located at any given point), we aimed to test how well participants could explore a virtual area when searching for their targets. Once again, a gender gap was found in this task in both the control and experimental conditions. No significant improvement could be shown for female participants by adding peripheral displays.

The ability to explore a virtual maze was not improved by increasing the field of view to include the far periphery. Providing a sense of grounding did not increase the ability to navigate new areas of the maze. We explain this by saying that grounding provides users with a positional understanding of their current location and its relationship to previous locations, thus helping them create cognitive maps and remember routes. It does not, however, provide information with yet-to-be-visited locations, and has no effect on searching or exploring an area. We can summarise the effect peripheral displays have as follows:

- Effect on different type of tasks: Peripheral displays were beneficial for route-based tasks, such as cognitive mapping. The amount of increased visual information is believed to give the user a better understanding of their surroundings. A positive effect was not found for landmark-based cognitive mapping, coordinate object location memory, or maze search.
- Effect on different type of environment: The peripheral displays required an environment with grounding cues to be beneficial. These cues include any landmarks, walls, or barriers. Lack of landmarks in the environment increases the likelihood of getting positionally lost in the world.
- Effect on gender: Female participants benefited significantly from the peripheral displays, while male users did not gain from their addition. We deduce that women benefit much more from the provision of visual information for cognitive mapping and navigation. In the sparse environment, males were more adversely affected by the peripheral displays.

10.3 BENEFIT OF PERIPHERAL DISPLAYS: VECTION OR GROUNDING?

As mentioned above, we believe that the improved route-based knowledge provided by the peripheral displays is due to an increased sense of grounding. We believe that by providing displays to the left and right, users get a better spatial understanding of the position of the objects. For example, in the environment developed by Tan et al (2003a), the wider field of view gives the impression of extending to the left and right of the user, creating a stronger sense of left and right, and thus gives the user the feeling of being in the centre of the room surrounded by three walls, rather than being faced with a single narrow portal onto a virtual world. This is important when moving through the virtual world. For example, say that a user takes a turn in the virtual environment. On a single screen, the user will see the view of the world change. However, there is nothing connecting this new view to the previous one. When using the peripheral displays, when turning to the left the user connects the new image with the image that was on the left display before the turn. This is not to say that users remember the images on each of the displays and associate them exactly. Rather, there is an understanding of how what they are seeing now is related to a previous view. As such, an improved route knowledge is provided.

We did not design these studies with this theory in mind. We present it based on the results we obtained. As mentioned, alternative explanations also exist. The most prominent is that it is optical cues that improve route knowledge. Neither our study nor that of Tan et al. (2003a) proves one hypothesis or the other, since both could be used as explanations. We argue that it not vection since there were optical flow cues in Experiments 2.1 and 2.2, which showed no improvement in route memory. We also conclude that in Experiments 1.2 and 3.2, the corridors of the maze/building were so narrow that much of the side view was often limited to a plain, non-textured, white wall. In that case, there would be little if any optical flow cues provided from the side displays.

None of this, however, is conclusive. We present our hypothesis of grounding being the cause of benefits in peripheral displays, and propose future work in which its effect is tested, as opposed to that of optical flow cues. We suggest that both performance and subjective metrics be used to measure this.

10.4 GUIDELINES FOR USING PERIPHERAL DISPLAYS

As hardware technology improves, we are able to imagine many advanced computer displays that would not have been possible in the past. The development of specialised graphic chips and flat-screen monitors, and the reduction in computer monitor prices have allowed for multi-monitor systems to become feasible for home and office use. Research on curved (Starkweather, 2003) and bendable screens (Schwesig et al., 2004) should also radically change the way we interface with computers.

As with all hardware and software advances, there needs to be concurrent studies into human-computer interaction and usability. Virtual reality goggles were heavily touted as a breakthrough and were popularised by media and public interest. However, many users suffered from motion sickness after using them and complained about their cumbersome physical nature.

We therefore propose that much research needs to be done on different displays sizes and types. We talk about some of the future work that can be done in this field in the section below. For our part, we present some guidelines which, based on our research and literature review, future designers need to take into account for virtual reality environments.

1. Increase the field of view. There is a clear correlation between field of view and performance on many factors. The simplest advantage is that it increases the

- visual information of the world. Further advantages have been seen in numerous navigation and spatial ability tasks.
2. Utilise the far periphery. Mostly ignored by desktop computer designers, the far periphery has many uses, such as some motion detection. A key aspect here is picking up optical flow cues, which provide vection, thus simulating the idea of motion. Vection is a key aspect of non-immersive virtual reality. In our studies, we found the data in the far periphery improved the route knowledge of participants. Obviously, the far periphery will only provide an advantage if the world is densely populated so that there is something in the periphery most of the time.
 3. Keep the displays continuous. Many participants commented that they did not like having gaps between displays. Not only was it unnatural and distracting, but it also led to some disorientation. Some participants stated that shifting their attention from the central display to a peripheral one and back, led to some confusion as to which direction they were facing. This problem might be reduced if the area in between was filled.
 4. Increase immersion. While our study focused on the visual aspects of computer displays, there can be advantages in improving the multimodality of computer systems, such as 3D audio. Additionally, some freedom of movement could be introduced through the use of novel interface devices, such as an electronic balance board, motion detecting camera, or a wearable motion detector. Stereoscopic glasses may also prove useful for providing depth perception.

10.5 LIMITATIONS OF THE WORK

The design of our experiments is subject to three limitations, which may have affected our results and, subsequently, our conclusions. They are:

- The display was non-continuous.

- Participants' previous experience with virtual environments was not balanced.
- Some participants were retained between experiences.

We look at each of these in detail, explaining why they might lead to problems and reiterating our justification for our decisions to continue our experiments under these circumstances.

1. The display was non-continuous.

In Section 6.2.1, we described our design for our experimental condition. We opted for a configuration with three computers with gaps between them. We mentioned in that section that this would lead to problems by creating a gap in the field of view and filling it up with real-world information that could act as a distraction. We maintain that this setup was not designed as a viable system for real-world usage, but only to experiment on a specific area of the field of view. However, we acknowledge that possibility that the gap may lead to additional cognitive load in order to connect the disparate screens, thus potentially negating benefits the peripheral information would have. Future tests would preferably utilise a continuous screen configuration and adopt a different technique for testing the effect of information in the far periphery.

2. Participants' previous experience with virtual environments was not balanced.

As mentioned for each experiment (see Sections 7.2.1, 8.2.1, and 9.2.1) our test population consisted of students and staff at the University of Bath. They were given pre-questionnaires in order to balance them across four groups, where the independent factors were sex and configuration. Dividing participants across by age across these groups was a simple matter. However, dividing them by experience proved problematic, since there were far more male participants who were experienced with virtual environments than females. We accepted this disparity as indicative of our samples, and that selecting only males who were unfamiliar with virtual environments or only females who were regular

users of such environments would not be. Regardless, there is a strong argument (Waller, 2000) that interface experience rather than gender is an indicator of performance in these tasks. While we still believe that sex differences are large enough to warrant studies, we accept that a larger sample size and more varied participant would be a preferred method of conducting these experiments. 2x2x2 tests [Configuration x Sex x Experience] would provide better and more comprehensive results for these tests.

3. Some participants were retained between experiences.

As mentioned in Section 8.2.1 and 9.2.1, some participants were retained between sets of experiments. These were a minority of participants (six in Experiment 2.1 and 2.2, and twelve in Experiment 3.1 and 3.2). There is some concern that this might lead to a learning effect, by which these participants would benefit from their previous experience and thus perform more adequately in the environments. We decided to ignore this, due to the long gap between experiments (minimum 7 months) and short duration of exposure to the environments (maximum 30 minutes for each experimental set). Any experience from these environments would not be substantial, in our estimation. However, there is the possibility that participants may have adapted strategies after performing an experiment which they would employ in future tests, that they would not have done otherwise. While we do not believe this was the case, based on our interview with the participants, we maintain the possibility. We therefore acknowledge that it would have been ideal to not reuse participants, a requirement that is not, unfortunately, always possible.

In addition to this, each pair of experiments featured the same set of participants. So experiment 1.1 and 1.2 used the same participants, as did experiments 2.1 and 2.2, as did experiments 3.1 and 3.2. This leads to a much higher possibility of a “learning effect”. While we did not directly compare the first and second of any pair of experiments (for example, we do not compare time in experiment 3.1 with time in experiment 3.2) we did compare them indirectly by stating that some had main effects and others did not, thus inferring that certain tasks were affected by the configuration and others did not. It is

possible that the learning effect, in this case, had an effect on our results. This could happen if participants in one group (for example, the single screen females) benefited from this learning effect while another group (for example, the single screen males) did not.

There are reasons we do not believe this to be the case. The first reason is that participants were given an orientation program which they were allowed to use for as long as they liked. Most participants were familiar with the controls and were satisfied within a minute of using the program. The second is that the experiments were different enough for that learning effect to be small. Additionally, even accepting the flaw in having the two experiments together in rapid succession, the only situation in which this effect may have happened is in Experiments 1.1 and 1.2, in which the two environments were the most different (the open-spaced art gallery and the corridors). In this case, we do not believe that the improved performance of females in Experiment 1.2 was due to a learning effect. Regardless, we acknowledge that it would have been ideal not to use the same participants for more than one experiment.

10.6 FUTURE WORK

There is much future work that can be done in this field. We divide this into four areas: work evaluating the benefits of the far periphery; work comparing different display configurations; work exploring individual differences in navigation; and work into explaining why peripheral displays benefit route-based knowledge.

1. Evaluating the benefits of the far periphery.

While we have isolated some tasks which benefit from the far periphery and others which do not, there is still much work to be done. Research can be done into studying other types of task and whether they are or are not affected. Many tasks which could be studied include a large cognitive mapping element. An example of this would be pointing tasks

(after travelling a world, indicate the direction of an object). These could be used to verify the effect on a cognitive mapping task. Other tasks may not include a cognitive mapping task. For example, certain memory tasks (asking about the nature of objects in the environment).

One of the conclusions we reached was that the peripheral displays had a different effect not only on each gender, but also on different tasks, and in different environments. In future work we would take this into account in designing our experiments. More participants would be needed and they would be compared in a 2x2x2 (gender x configuration [with or without peripheral displays] x type of environment [landmark-dense or landmark-sparse]) analysis of variance.

2. Comparing different display configurations

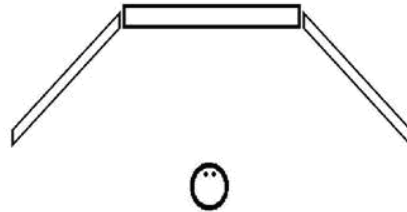
In our experiments we evaluated a box configuration with gaps between main and peripheral display, and found some advantage to the peripheral displays over a single screen configuration. However, there are multiple configurations which can be tested and compared. For example, a continuous display (Figure 10.1e) can be compared with a similar environment not using the peripheral displays (Figure 10.1b). This would show whether the need for the far periphery can be compensated for by the mid-periphery. Different fields of view could be used to find the optimal angles. Furthermore, comparisons could be made between a combination of flat screens, as used, and a curved screen. However, technological improvements in the rendering of virtual environments on curved screens must first be made.

We also propose that it might be advantageous to have display screens outside the field of view. If it is indeed the improved sense of grounding that the peripheral displays provide, then having a computer screen behind the user with virtual environments may also improve route-based cognitive mapping. This, of course, opens up a number of new configurations to try out.

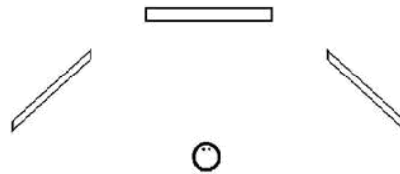
a)



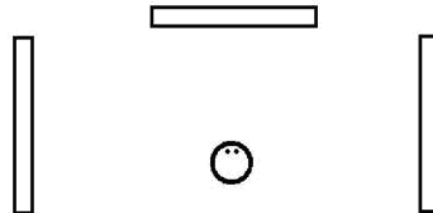
b)



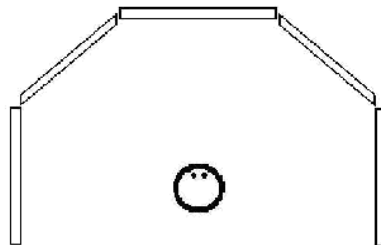
c)



d)



e)



Fi

Figure 10.1 Different Multi-Display Layouts

3. Exploring individual differences

A good demarcation for individual differences in spatial ability is gender. Men generally perform better than women in most spatial tasks, and this gap is found to be wider in virtual environments. Nevertheless, there is naturally a great deal of variance amongst each gender. Several studies have a correlation between the level of sex hormones and spatial ability (Christiansen and Knusmann, 1987; Hampson and Kimura, 1988; Hampson, 1990; Gouchie and Kimura, 1991; Moffat and Hampson, 1996; Silverman et al., 1999; Duff and Hampson, 2000; Cherrier et al., 2001; Aleman et al., 2003). Some have even reported differences based on sexual orientation (Sanders and Ross-Field, 1986; Gladue et al., 1990; Neave et al., 1999; Peters et al., 2007; Sanders and Wright, 2005; Rahman et al., 2002; Hassan and Rahman, 2007; van Anders and Hampson, 2004). Hormonal levels vary from individual to individual in the same gender, and can even vary in the same individual from time to time (example, for a woman different phases of the menstrual cycle). Evaluating the effect of hormones is bound to be difficult. However, thorough and detailed insights in this field could prove invaluable in determining why people navigate differently in virtual environments.

4. Explaining the benefit of peripheral displays

We proposed a hypothesis as to why peripheral displays benefit route knowledge in females. In our hypothesis, the feeling of being grounded in an environment improves with the addition of the peripheral displays and creates a better sense of connection between different parts of the virtual environments while travelling. We gave some arguments as to why we propose this hypothesis, but did not design our studies to investigate this. To test whether this is true an experiment needs to be set up which tests this theory, via both performance and subjective metrics. This experiment should also be designed to investigate whether it is grounding or optical flow cues which benefit route knowledge.

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APPENDIX A

EXPERIMENT PRE-QUESTIONNAIRE

PRE-QUESTIONNAIRE

Name:

Age:

Under 18

18-22

22-25

25-30

30-35

Over 35

Gender:

Male

Female

Do you have any visual problems (not corrected by eyewear)?

Yes

No

If yes, what?

Did you ever play a first-person video game (e.g. Doom, Halo) or use a first-person virtual reality room?

Yes

Yes, but not anymore

No, Never

If Yes, how often did you play?

Very
Rarely

A Few Times
a Year

A Few Times
a Month

A Few Times
a Week

How well do you think your navigation skills are?

Very Poor

Poor

Fair

Good

APPENDIX B

CONSENT FORM

INFORMED CONSENT TO PARTICIPATE IN

Virtual Reality Navigation Exercise

A study in the effects of peripheral displays on male and female subjects is being conducted by Ali Abdul Rahman (A.H.A.Rahman@bath.ac.uk) in the Department of Computer Science at the University of Bath.

You are being asked to take part in this study by attempting two navigation tasks in virtual environments on desktop computers. The whole experiment should take less than 30 minutes.

The study will be recorded for analysis purposes only. Your data will be kept anonymous.

If you choose, at any point during the experiment, to withdraw, you may do so.

If you agree to participate in this experiment as described, and for your data to be used in publications anonymously, please indicate your agreement by writing your name, e-mail address, then sign and date below. Thank you for your participation in this research.

Name:

E-Mail:

Signed:

Date:

APPENDIX C

SUMMARY OF GENDER DIFFERENCES IN SHORT-RANGE SPATIAL ABILITY (CHAPTER 5)

SOURCE	TEST	RESULT
MENTAL ROTATION		
Amponsah and Krekling (1997)	MRT	M > F
Brus and Boyle (2009)	PSVT:R	M > F
Flaherty (2004)	MRT	M > F
Geary and Desoto (2001)	MRT	M > F
Guillot et al. (2007)	MRT	M > F
Hunt and Allahyar (2001)	MRT	M > F
Mann et al. (1990)	MRT	M > F
Medina et al. (1998)	PSVT:R	M > F
Nordvik and Amponsah (1998)	MRT	M > F
Roberts and Bell (2003)	MRT	M > F
Silverman et al. (1996)	MRT	M > F
Sorby (2006)	PSVT:R	M > F
SPATIAL VISUALISATION		
Gorska et al. (2001)	MCT	M > F
Gorska (2005)	MCT	M > F
Gregory and Berenbaum (1998)	SDT	M > F
Herlitz et al. (1997)	BDT	M > F
Nemeth et al. (2006)	MCT	M > F
Nemeth et al. (2007)	MCT	M > F
Nemeth (2007)	MCT	M > F
Nordvik and Amponsah (1998)	SDT	M > F

Sacuzzo et al. (1996)	SDT	M > F
Tsutsumi et al. (2005)	MCT	M > F
SOURCE	TEST	RESULT
SPATIAL PERCEPTION		
Block and Block (1982)	RFT	F > M - Age 4 M > F - Age 5+
Linn and Petersen (1985)	WLT	M > F
Macoby and Jacklin (1974)	RFT	M > F in 16 tests M = F in 5 tests
Nordvik and Amponsah (1998)	WLT	M > F
Voyer et al. (2004)	WLT	M > F
SPATIAL MEMORY - POSITIONAL		
Barnfield (1999)	OLMT	F > M
Duff and Hampson (2001)	Concentration Card Game	F > M
Duff and Hampson (2001)	OLMT	F > M
Iachini et al. (2005)	Real World Object Location Memory Test	M = F
James and Kimura (1997)	OLMT	F > M - Objects Swapped M = F - Objects moved
Jordan et al. (2000)	Grid Memory	F > M
Lejbak et al. (2008)	Concentration Card Game	F > M
Levy et al. (2005)	OLMT	F > M
McBurney et al. (1996)	Memory™ Board Game	
Postma et al. (1998)	Object-to-Position Matching	F = M
Silverman and Eals ()	OLMT	F > M
Voyer et al. (2007)	OLMT	F > M
SPATIAL MEMORY - COORDINATE		
Iachini et al. (2005)	Real World Object Location Memory Test	M > F
Postma et al.	Object to Unmarked Position Replacement	M > F

APPENDIX D

SUMMARY OF GENDER DIFFERENCES IN LONG-RANGE SPATIAL ABILITY (CHAPTER 5)

SOURCE	TEST	METRIC	RESULT
Ahmad et al. (2005)	Augmented Reality Maze	Time	M < F
Astur et al. (1998)	Virtual Morris Water Maze	Distance from Correct Position	M < F
Bryant (1982)	Pointing	Directional Error	M < F
Cutmore et al. (2000)	Virtual Maze	Moves Needed to Find Exit	M < F
Devlin and Bernstein (1994)	Route Retracing	Errors Made	M < F
Dogu and Erkip (2000)	Pointing	Directional Error	M = F
Dirscoll et al. (2004)	Virtual Morris Water Maze	Distance from Correct Position	M < F
Galea and Kimura (1993)	Route Retracing	Time and Errors Made	M < F
Gilmartin and Patton (1985)	Map Reading	Performance (Battery of Tests)	M > F - age 9 M = F - adult
Golledge et al. (1995)	Map Reading		M = F
Herman and Siegel (1978)	Cognitive Mapping	Reconstruction Accuracy	M = F - age 5 M > F - age 7+
Holding (1982)	Cognitive Mapping	Building Placement Accuracy	M > F

Kirasic et al. (1984)	Pointing	Directional Error	M = F - easy-to-find targets M < F - difficult-to-find targets
SOURCE	TEST	METRIC	RESULT
Lawton and Morrin	Pointing	Directional Error	M < F
Lawton et al. (1996)	Pointing	Directional Error	M < F
Lord (1941)	Route Retracing		
McGuinness and Sparks (1983)	Cognitive Mapping	Positional Accuracy	M > F
		Landmark Distance Errors	F < M
Malinowski and Gillespie (2001)	Orienteering	Number of Points Found	M > F
		Time	M < F
Matthews (1986)	Route Retracing	Map accuracy and detail levels	M > F
Moffat et al. (1998)	Virtual Maze Traversal	Time and Errors	M < F
Montello and Pick (1993)	Pointing	Directional Error	M = F
Montello et al. (1993)	Cognitive Mapping	Distance and Direction Errors	M < F
Montello et al. (1999)	Map Learning	Items Remembered	M = F
Mueller et al. (2008)	Virtual Morris Water Maze	Distance from Correct Position	M < F
New et al. (2007)	Pointing	Directional Error	F < M
Newhouse et al. (2007)	Virtual Morris Water Maze	Distance from Correct Position	M < F
O'Laughlin and Brubaker (1997)	Cognitive Mapping	Accuracy	M = F
Pearson and Ferguson (1989)	Cognitive Mapping	Reconstruction Accuracy	M = F

Sadalla and Montello (1989)	Pointing	Directional Error	M = F
Sandstrom et al. (1998)	Virtual Morris Water Maze	Distance from Correct Position	M < F
SOURCE	TEST	METRIC	RESULT
Schmitz (1997)	Real World Maze Traversal	Time	M < F
Siegel and Schadler	Cognitive Mapping	Reconstruction Accuracy	M > F - age 5
Soh and Smith-Jackson (2004)	Map Trail	Overall Time, Decision-Making Time, Deviation Time	M = F
		Wrong Decisions	M = F
Tlauka et al. (2005)	Pointing	Directional Error	M = F
	Route Following	Time	M < F
	Reverse Route Tracing	Time	M < F
Waller et al. (2001)	Pointing	Directional Error	M < F
Wart et al. (1986)	Route Retracing	Errors and Omissions	M = F - with map M < F - without map