EXPERIMENTAL EVALUATION OF INTERACTION DESIGN IN VIRTUAL REALITY

Eleanor Marshall, BEng (Hons)

Thesis submitted to the University of Nottingham
For the degree of Doctor of Philosophy

February 2005

Abstract

Desktop Virtual Reality (VR) is a simple and affordable way to implement VR technology into an organisation. With PC technology developing at a phenomenal pace fast processor speeds enable the relatively easy development of visually impressive Virtual Environments (VEs) that can be used with familiar desktop PCs for novice and expert end users alike. A need had consequently evolved to ensure that VE development is structured so that VEs can be visually impressive, usable and effective for their purpose. Interaction between the user and the VE is a distinguishing feature of VR but the importance of interaction on the effectiveness of the VE has been little explored, in particular how to measure that effectiveness with a view to providing guidance to VE developers in this case for training applications using the familiar and affordable desktop medium. The use of VR as a training tool has been widely investigated and implemented in both research and industry.

Through experimentation this thesis reviews the design of effective interaction, primarily with the design of selection hotspots (cued objects within the VE designed to prompt the user to select that object) and the importance of implementing task guided interaction into the users experience with the VR system.

Five experiments were performed to examine the appropriate design of selection hotspots and the importance on the inclusion of a task to the effectiveness of desktop VR training. The initial experiment examined the importance of the user's ability to select within the VE, control their own navigation and the influence of visual realism on the VEs effectiveness as a training tool. The second experiment explored the importance of the user performing a task on the VE's effectiveness and the effectiveness of various selection hotspot cue designs. The third experiment examined influencing factors on the recall of non-task related aspects of the VE. Experiment four examined the effectiveness of selection hotspot cues when they are no longer congruous to the surrounding VE context and the final experiment investigated if participants perceived and recognised the cued objects or were merely responding to the cue and the influence of the inclusion of cues and their design. Effectiveness was measured using the recall of aspects of the VE by the user and measures of usability, presence and enjoyment.

Main findings were that the use of the same incongruous interaction hot spot cues throughout the VE to prompt the selection of specific points within the VE were most effective and using task directed interaction improved task related recall but significantly reduced selection within the VE. Selection significantly increased recall when in a non-task directed VE. With the application of these findings it is possible that designers can produce more effective VEs for their purpose, in this context as a training VE on a desktop VE system.

Acknowledgements

Firstly I would like to thank my supervisor Dr Sarah Sharples who in the eventful years over which my research has taken place has provided constant support, encouragement and patience. I am truly grateful.

I would also like to thank everyone from the Human Factors Research Team without exception for always being ready and willing to help be it with technical difficulties or a cuppa and a supportive word. In particular I would like to thank Richard Eastgate for his technical wizardry and in particular his help with Superscape, Gareth Griffiths, Steven Kerr, Ash Patel, Mirabelle D'Cruz, Gemma Cox, Alex Stedmon and Sue Cobb for her additional guidance.

Thanks also to my friends that have understood and helped along the way, you know who you are, you have made the whole process so much easier to survive, thank you.

And finally to my family for their unwavering support throughout my studies and never doubting that I would make it in the end, Thank you.

Table of Contents

List of Tables

List of Figures

Abbreviations

2D	Two Dimensional, a 'flat' drawing, scene or object that exhibits no sense of depth
3D	Three Dimensional, a drawing, scene or object with the appearance of sense of depth
AbsVE	Abstract Virtual Environment, a virtual environment designed and built to in no way replicate the real world in appearance and behaviour
BOOM	Binocular Omni-Orientation Monitor, virtual reality display system
CAVE	Cave Automatic Virtual Environment, fully immersive virtual reality system
CRT	Cathode Ray Tube, virtual environment display screen technology
DOF	Degrees Of Freedom
FOV	Field of View, area of virtual environment the participant is able to see at any one time
FSNC	Participants in this experimental group have Free Selection and Navigational Control within the virtual environment and are not required to perform a task
FSNC(Abs)	Participants in this experimental group have Free Selection and Navigational Control within the virtual environment and are required to perform a task, using the abstract virtual environment (AbsVE)
GUI	Graphical User Interface, something you can see or interact with, such as a button you could click on.
H&S	Health and Safety
HMD	Head Mounted Display, head mounted virtual reality display system
LCD	Liquid Crystal Display, virtual environment display screen technology
N/S	Not Seen, an object was not seen by the participant
NASA	National Aeronautics and Space Administration
NC	The participants in this experimental group have Navigational Control but are unable to select within the VE and are required to perform a task
PC	Personal Computer
RW	Real World, the actual physical environment
RWVE	Real World Virtual Environment, a virtual environment designed and built to replicate a real world environment in appearance and behaviour
S/S	Seen/Selected, an object was selected by a participant within the virtual environment and there was no noticeable reaction
S/S/R	Seen/Selected/Reacted, an object was selected by a participant within the virtual environment and it reacted visually or audibly as a result of that selection
SD	Standard deviation
SNC	Participants in this experimental group have Selection and Navigational Control within the virtual environment and are required to perform a task (cued and non-cued selection hotspot objects, specified according to experiment)
SNC(Abs)	Participants in this experimental group have Selection and Navigational Control within the virtual environment and are required to perform a task using the abstract virtual environment (AbsVE)
SSC	Short symptoms checklist (Nichols et al., 2000), a measurement scale of sickness symptoms induced by virtual reality use
TFT	Thin Film Transistor, a type of LCD flat-panel display screen
VE	Virtual Environment, the simulation experienced by the user
VIRART	Virtual Reality Applications Research Team, University of Nottingham
VR	Virtual Reality, the technology or system on which the virtual environment is displayed
VRT	Virtual Reality Toolkit, virtual environment development software
WIMP	Windows Icons Mouse Pointer, computer operating system

Glossary

All (Cue Design)	The entire reactive aspect of the object is cued.
Cued Object	An object within the VE is indicated in some way to prompt the user to select it.
Effectiveness	The extent to which a specific goal or task is achieved. Measures include recall, presence, involvement, usability, time taken and sickness symptoms.
Feedback	The participant is aware of a change in the VE (visual or audible) as a consequence of an action that they have taken.
Immersion	A feeling of psychological involvement in a VE. Also describes the period of VR use and the extent to which the VR system is capable of delivering an inclusive, surrounding illusion of reality to the participant's senses.
Interaction	Any action made by the user that results in a change in the VE, selection and navigation.
Interaction Device	Computer hardware used to translate the users desired actions to the VR system, such as a mouse or joystick
Interactivity	The potential for a VE to react to the participant's movements and behaviour.
Navigation	The process of the user affecting their field of view within the VE, in effect moving around the VE.
Objects	In a VE context objects are visual representations of an entity (could be made up of many shapes).
Part (Cue Design)	Only a part of the reactive aspect of the object is cued.
Presence	The users sense of actually 'being there' within the VE (Sheridan, 1992).
Reaction	Object responds visually or audibly to selection by the participant.
Realism	How closely the VE visually and audibly resembles the real world environment on which it is based.
Recall	What a participant remembers when questioned on the VE that they just viewed/used.
Selection	The user clicking on a specific object within the VE using the interaction device with the aim of causing a reaction.
Selection Hotspots	Points in a VE that are cued in some way to prompt selection.
Surround (Cue Design)	The reactive aspect of the object is surrounded by the cue.
Task Performance	How successfully a specific task/desired aim or goal of the VE use is achieved.
Usability	The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use' ISO (1995).

Chapter 1 - Introduction

1.1 Background

Advances in computer technology have resulted in the development of virtual environments (VEs) for an ever increasing range of applications from training surgeons, pilots and astronauts; rehabilitation of brain trauma victims; industrial design and development applications; teaching and research aids; architecture and entertainment to name but a few. As technology has improved, the limitations of these systems with respect to VE factors such as visual quality and rendering speeds and the size and flexibility of the virtual reality (VR) system used to display them are decreasing. Restrictions in VE development and the uptake of such systems now usually occur due to factors such as programming time and thereby cost, consequently it is usually still not possible to make all aspects of the VE as interactive as may be preferred or wished. As a result of this it is often left to the programmer to decide where programming time should be focused, such as choosing which objects are made interactive or which are included purely to increase the realism of the environment, with very few coherent design guidelines for the development of effective usable VR systems.

The work this thesis presents aims to provide guidance for programmers when they are developing VEs on how to include interaction by identifying key elements in VE design and their influence on the effectiveness of the VE application.

1.2 Definition of Problem

VEs by their very nature do not have the depth and cues that are available in the real world; it is therefore important to establish what is required in the development of an effective VE and therefore should be included. As noted in Eastgate (2001) in a VE points of interaction are likely to be representations of 3D objects. VR systems are unable to provide the huge variety of interaction methods that the real world is able to, such as pressing buttons, pulling and pushing doors and levers and so forth. This is as a result of the limitations in the interaction devices that are available and subsequently interaction needs to be designed to replace these real world methods that is both intuitive and effective, enabling the user to perform the tasks they wish without being hindered by having to work out how to use the interaction device first. This problem is confounded by users not being able to identify objects that it is possible to select and distinguish them from objects included for aesthetic and realism reasons. This consequently results in user frustration and confusion when selection fails to result in feedback that may be expected.

An area requiring consideration in the development of a VE is the method by which the user is encouraged to examine the VE that they are in, whether this is through task directed exploration or navigational cues for example. If users are able to identify objects that can be selected it is still possible, due to the freedom of VE interaction and how a VE is viewed and navigated, that depending on the user's position these objects can be obscured from view or too distant to see clearly. If this is the case the user may need to be encouraged to navigate to a position so this is no longer the case.

These points have led to Herndon, Van Dam and Gleicher, (1994) noting that 'Most have realised that 3D graphics applications are significantly more difficult to design than their 2D counterparts'.

Guidelines that currently exist for human computer interaction are mainly based on 2D interfaces such as the WIMP (Windows Icons Mouse Pointers) GUIs (graphical User Interfaces) and do not take into account the additional degrees of freedom available to users of a VE or that navigation in a VE can be unstructured, unpredictable and non-linear. In a VE users will usually be required to navigate to the point of selection before being able to select it. This requires further considerations for design, such as how to get the user to that point without having a negative influence on the effectiveness of the VE application. This lack of guidance coupled with the speed in the advancement in technologies not equalled by research into the area has resulted in the development of many VEs that are designed inappropriately for their application.

What is required is the establishment of measures of effectiveness and the identification of influencing factors on prompts to selection within a VE and prompts to exploration of a VE to be identified in order to provide guidelines for VE developers to create more effective VEs. This PhD addresses these requirements.

1.3 Overview of Research

This research was performed with the aim of identifying methods of measuring interaction with a VE and its influence on a VE's effectiveness for a chosen application. The VE was used in a training context on a desktop VR system. This was investigated with respect to how tasks and selection should be designed within it. From the outset an experimental approach was chosen, the goal being to produce findings that were directly applicable to real applications of VR currently being used in commercial and industrial situations. This theory of real world relevance was also applied in the choice of VR system for experimental exploration and the application chosen to be examined within the research.

A PC desktop VR system is both a cost effective and familiar interface. This familiarity was thought to lead to reduced uncertainty in first time users of such a system who may consequently not be inclined to use it. For example, even if users are not very computer literate using interaction devices that they are familiar with such as a computer mouse and a joystick often used in computer gaming may be less daunting than high-tech VR equipment that is available and would also reduce the time required to learn how to use the system before training can begin. A VE was designed and developed using Superscape Virtual Reality Toolkit (VRT) VE development software, to use on a desktop VR system that enabled a suitable and measurable training task to take place that could be adapted so the importance of various factors on the effectiveness of the system could be assessed. Whilst this technology is no longer state of the art core interaction methods such as interaction devices based on the mouse (2D or 3D) or joystick for separate selection and navigation through a projected image of a VE is transferable to, and the basis of, most advanced VR systems. The level of VE detail were similar to other state of the art sophisticated VR technology experienced through the VIEW project at the Fraunhofer Institute, Stuttgart including a six walled CAVE system (Hoffmann and Stefani, 2002).

Training was chosen as a suitable application as VR systems are currently being used in a vast array of training applications for high level immersive surgery training (Immersion, 2004) to low level immersive classroom teaching aids (Crosier, 2000). It is also possible to directly compare the effectiveness of such a training application by measuring recall after using such a system. Adult participants were selected as representative potential end users of a desktop training application with at least a basic level of computer literacy.

Measures were developed that would establish a robust assessment of the effectiveness of a VR system with respect to the user's subjective experience of the system and how well it performed its function, in that the user learned from their experience of it and were able to relate that learning to the real world. The user's experience and opinion of the system were measured using presence and usability measures and task performance in the VE was assessed through the user's recall of detail about the VE that they experienced.

1.4 Aims and Objectives

1.4.1 Aims

The overall aim of this research was to measure the influence of interaction on the effectiveness of a VE. This was achieved using a training application on a desktop VR system. Examined was what prompts user object selection, the influence of guiding user VE exploration and the level of control the user has within a VE. This will help to define how interaction should be designed by VE programmers most effectively. Effectiveness of a desktop training VE was determined by measuring the usability of the VR system and the task performance of participants under varying conditions for each factor.

1.4.2 Objectives

The objectives of this research were to;

- Review existing methods of measuring the effectiveness of a VE and establish a method of measuring the influence of interaction on the effectiveness of a VR system for a chosen application.
- Construct a suitable VE upon which the influence of stated factors on effectiveness can be measured for a given application.

- Use an experimental approach to establish:
  - o The most effective prompts to encourage selection of specific objects within a VE.
  - o Whether selection and task guided exploration within a VE have any influence on the measures of effectiveness recorded.
- Use the outcomes of these experiments as a basis for formulating a series of recommendations for VE design.

1.5 Thesis Structure

The structure of this thesis is shown in Figure 1-1

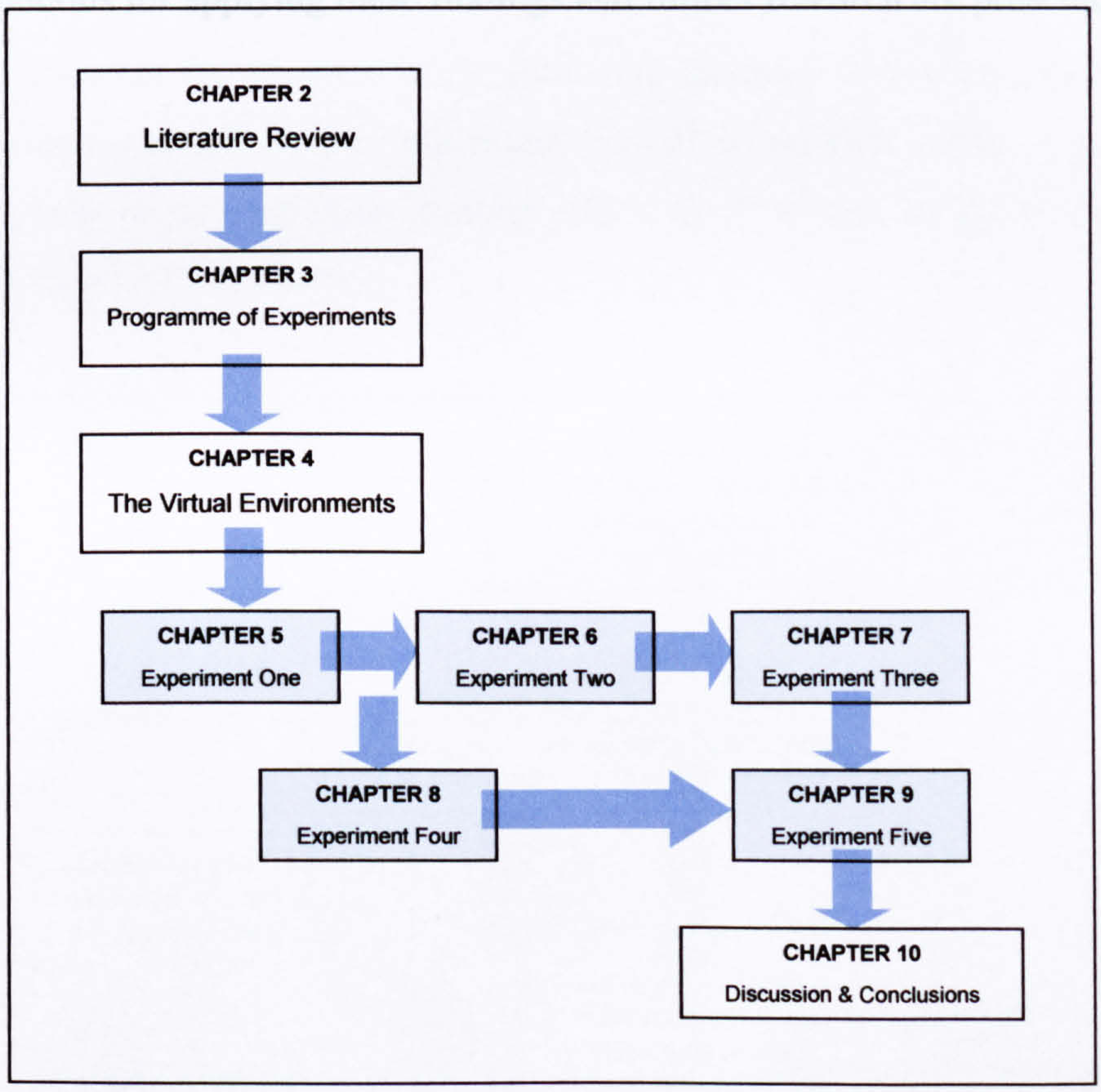


Figure 1-1: Thesis structure

Following the introduction, chapter two examines the literature concerning VR and associated issues such as usability, presence and task performance, all of which may contribute to how effective the VE and VR system is for its chosen application in that the desired outcome from using the VE is achieved. Also examined are current applications of VR in use and technologies that are available.

Chapter three describes the experimental process used and chapter four presents the design and development of the VEs used for experimentation throughout the experimental program.

Chapters five to nine report on the experiments performed providing hypotheses, detailed procedures followed and findings leading to subsequent experimentation (for a detailed diagram of the experimental program see 'Figure 3-1: Experimental programme flow diagram', p.85). Chapter ten discusses the findings made from all research and experimentation performed, conclusions drawn from the findings discussed and recommendations for applying these findings and further research are presented.

Chapter 2 - Literature Review

It is noted by Wilson et al. (1996) that the distinguishing features of a VE over other 3D modelling systems is its 'concentration on real-time graphics, interaction and presence, rather than on pure quality of graphics'. The first and most fundamental clarification to be made within this research is the meaning of the main terms used that refer to this area of study, that is 'virtual reality' and 'virtual environments'. These terms are often used interchangeably to refer to both real time computer generated simulations of real or imaginary worlds and the technologies on which they are displayed. Within this thesis the term virtual environment (VE) refers to the simulation experienced by the user and virtual reality (VR) to the technology or system on which it is displayed (Wilson et al., 1996).

Figure 2-1 illustrates the structure of the following literature review and show how this research became centred on the implementation of interaction within a training VR system and how to develop it to greatest effect. Each section of the review will be examined in light of this structure.

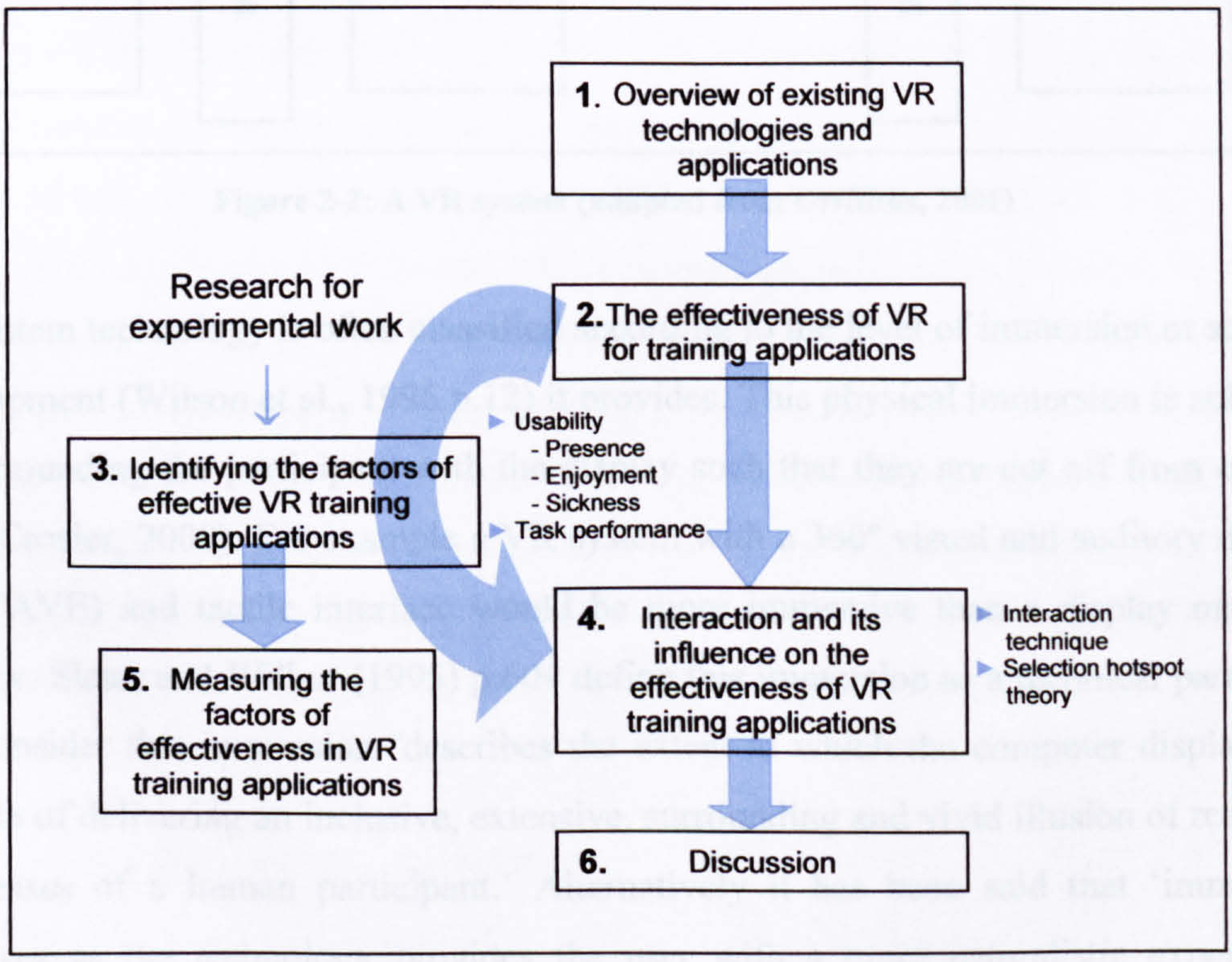


Figure 2-1: Literature review structure

2.1 Overview of VR Technologies and Applications

2.1.1 VR Display Technology

Within the field of VR an assortment of technologies have evolved to suit a variety of applications ranging from basic technology such as a desktop PC to the high technology CAVE set up where the VE is projected onto up to six walls, totally surrounding the user. A VR system usually comprises of a computer that runs the system, one or more methods of user input and the resulting feedback from that input (usually in the form of a visual display) and the software to run the VEs in real time. Figure 2-2 demonstrates the common elements of a VR system.

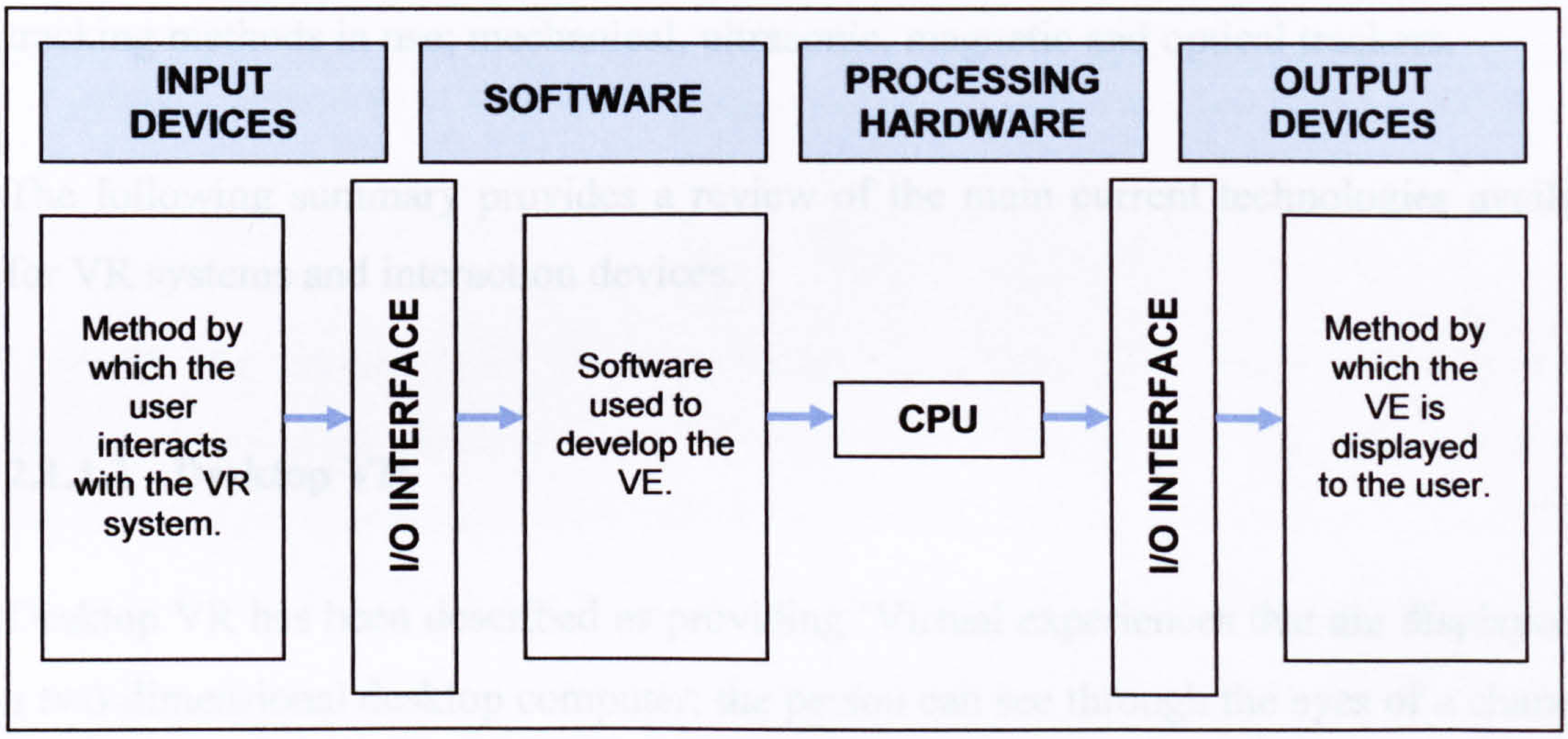


Figure 2-2: A VR system (adapted from Griffiths, 2001)

VR system technology is often classified according to the level of immersion or scale of envelopment (Wilson et al., 1996 p.12) it provides. This physical immersion is achieved by surrounding the participant with the display such that they are cut off from outside cues (Crosier, 2000). For example a VR system with a 360º visual and auditory display (i.e. CAVE) and tactile interface would be more immersive than a display on a PC monitor. Slater and Wilbur (1995) p.604 define this immersion as a technical parameter and consider that immersion 'describes the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant.' Alternatively it has been said that 'immersion increases as the technology provides the user with a more naturalistic experience' (Neale, 2001). It is consequently possible for an individual to experience immersion or 'being absorbed' in what they are doing through a system that is not enveloping or immersive, such as a desktop VR system. For example a person playing a computer game on a PC can become so immersed that they are unaware of what is going on around them and do not hear questions for example. This experience of immersion is often defined as presence and will be discussed later with respect to its importance to the effectiveness of the VR system.

Tracked VR systems refer to when the position of the user (i.e. their head in a HMD system or their hand when using a data glove) in free space is monitored by the system and updated in real time so that the view that the user sees through the display is in accordance with their physical position. There are four main position and orientation tracking methods in use; mechanical, ultrasonic, magnetic and optical trackers.

The following summary provides a review of the main current technologies available for VR systems and interaction devices.

2.1.1.1 Desktop VR

Desktop VR has been described as providing 'Virtual experiences that are displayed on a two-dimensional desktop computer; the person can see through the eyes of a character on the screen, but the experience is not three-dimensional' (Stanney, 2002). Such systems are usually run on PCs that, with a suitable graphics cards installed, now have the processing speeds to render the display in real time with almost photo realistic display quality. Displays typically use a CRT (cathode-ray tube) or TFT (Thin Film Transistor) monitor (with a fast refresh rate) and interaction (navigation and selection) occurs through 3D input devices such as the space mouse, multi-axis joysticks. Alternatively VEs can be designed to enable the use of standard 2D input devices such as the roll ball PC mouse, often by using on screen navigation icons.

2.1.1.2 Head Mounted Display (HMD)

Often regarded as the typical VR system it includes a headset that provides a visual (and usually auditory) display and an interaction device for navigation and selection. The device as its name suggests is fitted to the user's head and two LCD (liquid crystal display) screens provide an image of the VE for each eye. Interaction devices tend to be more complex to allow for the free movement nature of the system. Examples include wands or data gloves. Both the input device and the HMD are tracked in real time to allow the system to update the display seen by the user according to their direction of view and the interaction the user performs.

Figure 2-3: Examples of available HMD Systems: AddVisor – Sabtech (left), V8 – Virtual Research (middle) and HMD 800 – 5dt (right) – pictures courtesy of Inition at 'www.inition.co.uk' (2004)

2.1.1.3 Projection system

Typically the image of the VE is projected via a three CRT video projector onto a display screen which is then viewed through shutter glasses creating a 3D effect with the (lead) users' position tracked with a head tracking system. It is usually possible for more than one user to view the VE at one time but interaction (navigation) is usually performed by just one. Essentially the processor is that of the desktop system except the display provides a greater field of view, often using more complex free space input devices such as wand or data glove and the user's position in free space is tracked, thereby updating the user's virtual field of view in real time according to their physical position. A projection system display can have a variety of configurations, where more projections tend to create a more immersive (and usually more expensive) system, such as the following:

- **Workbench:** A single horizontal display is used, as with a real workbench, in front of the user, usually using hand tracking devices such as the data glove. This provides a physically realistic set-up for the training of workbench based tasks for example.

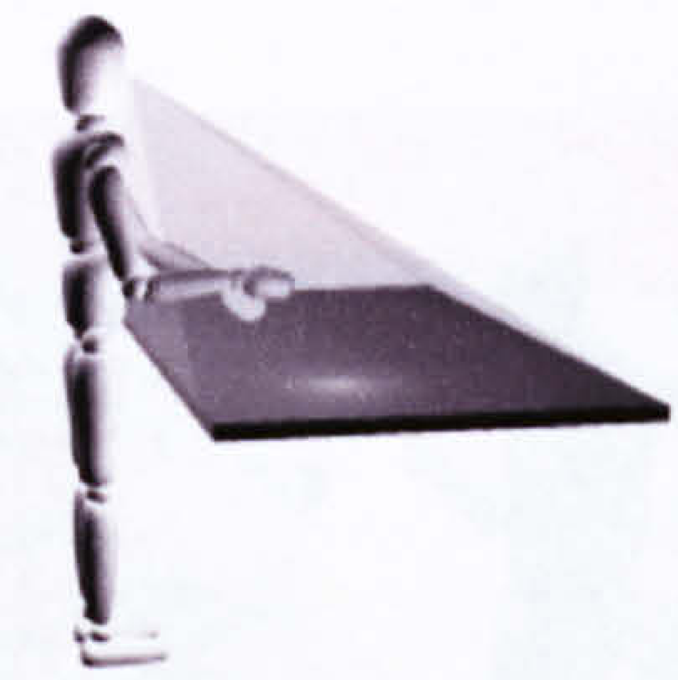


Figure 2-4: Workbench projection system (VIEW D1.1)

- **Power wall:** A single vertical display in front of the user and is usually interacted with using free space interaction devices such as the data glove or wand with the user's position being tracked.

Figure 2-5: Power wall projection system (VIEW D1.1)

- **L-shaped system:** Two display screens are used in an 'L' shaped configuration with the user standing on the horizontal display with a vertical display in front of them, free space interaction devices are usually used with tracking devices such as 3D mice, data gloves and wands.

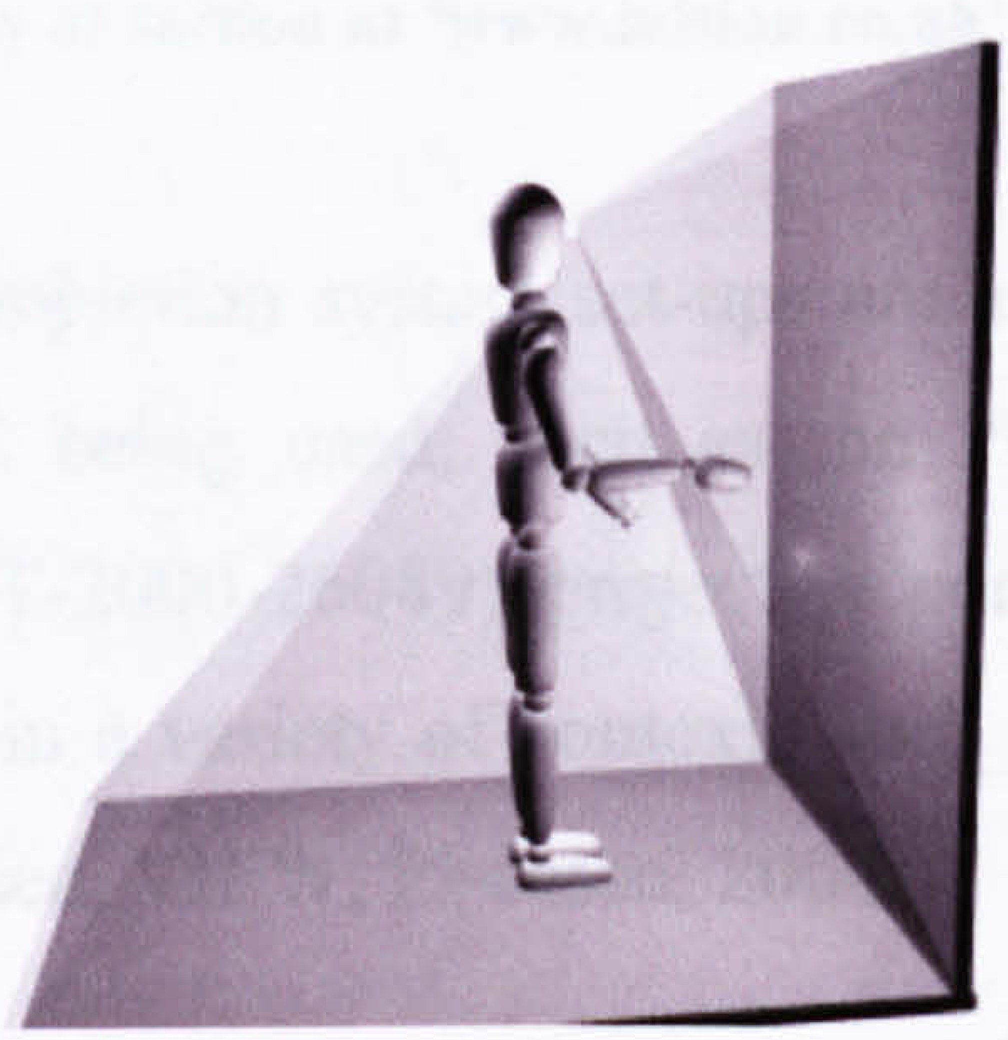


Figure 2-6: L-shaped projection system (VIEW D1.1)

- **CAVE:** Developed by Fakespace Systems the VE is projected onto 2-6 walls of a room that the user(s) stands within, creating a fully immersive system free space interaction devices are usually used with tracking devices such as 3D mice, data gloves and wands. Figure 2-7 demonstrates a 6-sided cave with one user interacting.

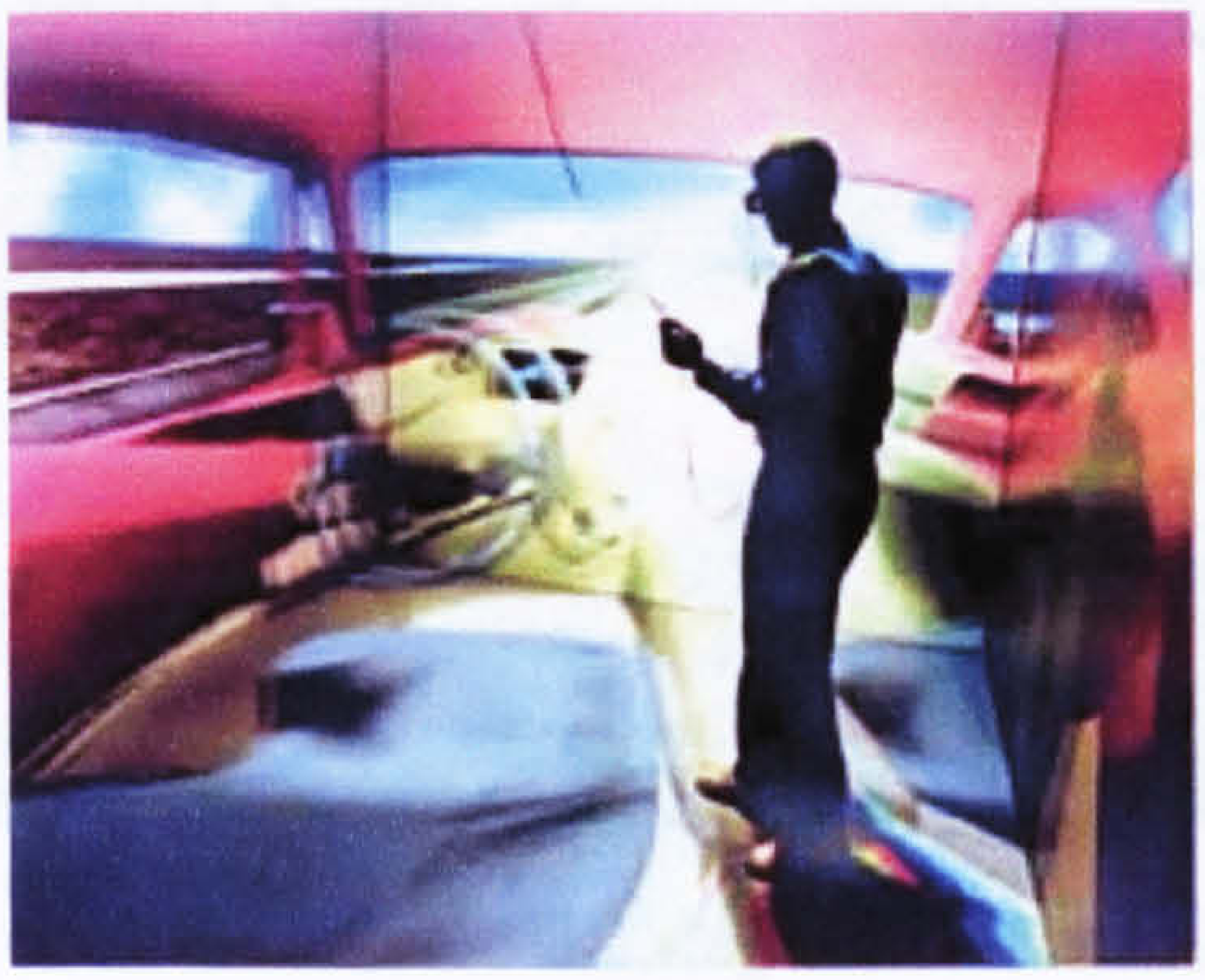


Figure 2-7: Example of a CAVE VR projection (VIEW D1.1 p 101)

- **Curved Screen:** A curved version of the power wall to further surround the user than with the power wall thereby creating a larger field of view (FOV), see Figure 2-8, they are often used on a large scale for demonstration purposes as a virtual theatre.

Figure 2-8: Example of a curved VR projection screen, GVR-120E from Panoram – picture courtesy of Inition at 'www.inition.co.uk' (2004)

Adaptations of these basic projection system set-ups are available developed to satisfy the requirements of the VE being used, such as the PI-casso system (Figure 2-9) developed in the VIEW (IST-2000-26089) project, a portable affordable power wall system for flexibility of use in a variety of contexts such as working in a VE and at a desktop PC simultaneously (see, VIEW, PI-casso, 2004).

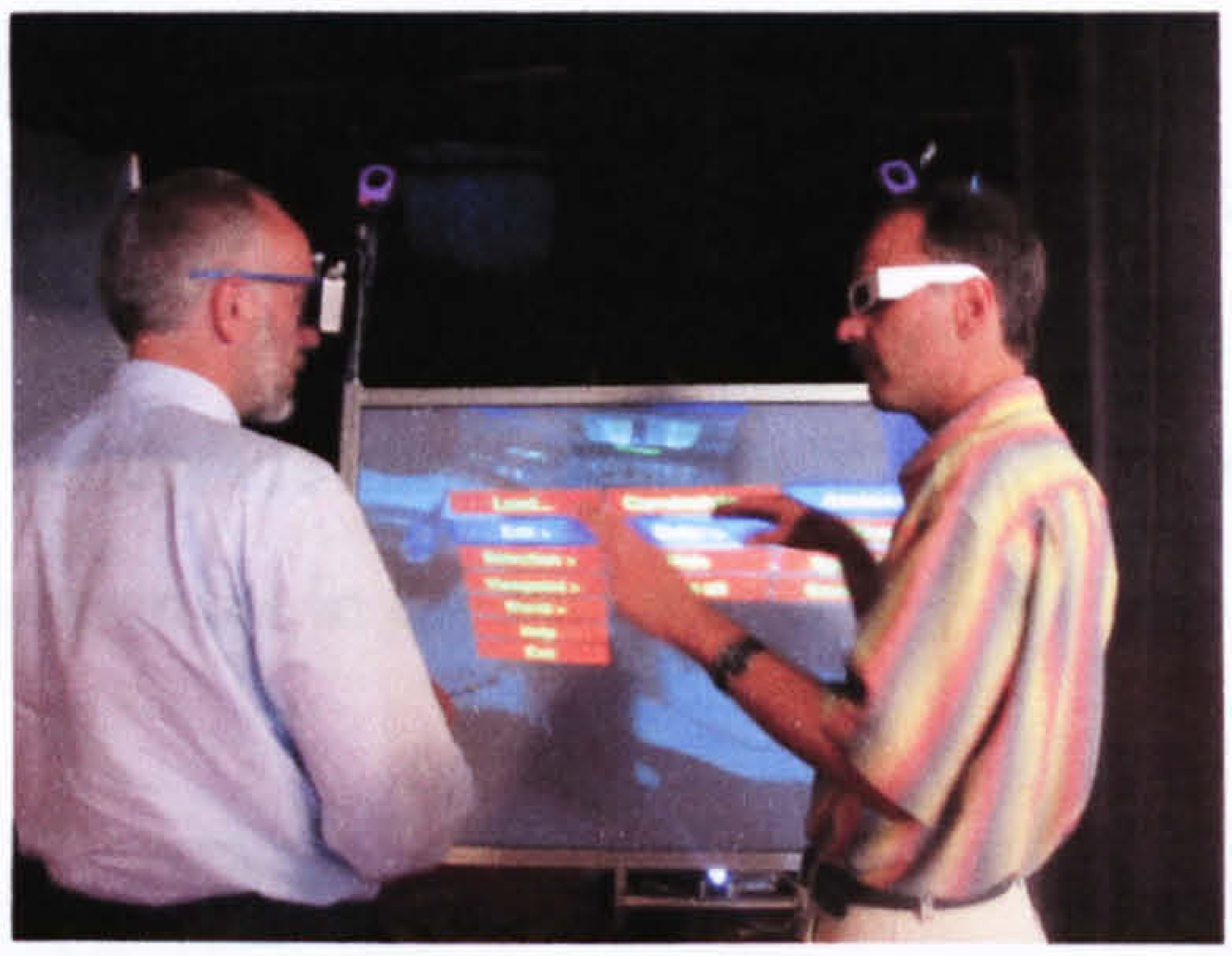


Figure 2-9: PI-casso in use showing two users collaborating

2.1.1.4 BOOM (Binocular Omni-Orientation Monitor)

Developed by 'Fakespace Systems' the visual display showing the VE is a 'box' that the user looks into suspended on a multi-link arm that can be guided by the user anywhere within the range of the arm. The user's position is tracked and the VE viewed accordingly through the effectively 'weightless' viewing system that allows the user greater and more realistic body movement than more static projection systems. It is possible to have both a system where the user stands and views the VE or where the user is seated and uses the system with and input device, for example in a car or aeroplane cockpit simulation, Figure 2-10.

Figure 2-10: The BOOM 3C (left) and BOOM HF (right) VR from Fakespace Systems – picture courtesy of Inition at 'www.inition.co.uk' (2004)

2.1.1.5 Augmented reality

Augmented VR systems are a combination of both real and virtual displays; in effect the virtual display overlaps what the user can actually see. This type of VR is often used in training applications to give additional information to the user for the task they are performing in the real world. Examples include maintenance tasks thereby replacing complex manuals (see Figure 2-11) or of submerged pipe work systems for road works or building maintenance. Glasses with transparent lenses display the virtual information and the head is tracked to update the virtual field of view and information provided according to the user's movement in the real world.

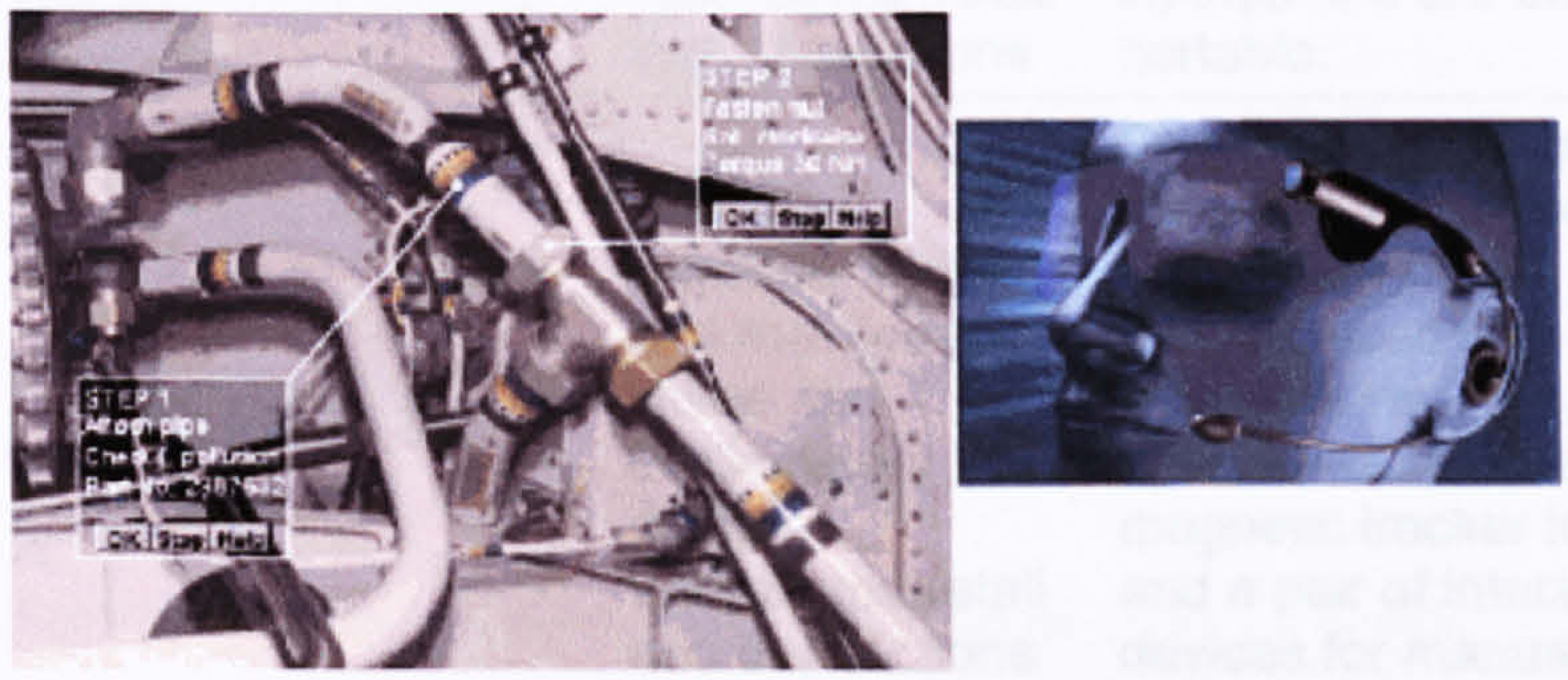


Figure 2-11: Example of augmented information overlay to a real world maintenance task – picture IAW (2004), www.iaw.rwth-aachen.de

2.1.1.6 VR technology costs

Table 2-1 provides an example of the cost of more immersive display systems such as projection screens and CAVE. Cost is a huge influencing factor in the choice of a system for a particular application and can be crucial in the initial decision to implement VR technology at all.

Table 2-1: Example of VR system costs and applications (adapted from VIEW D1.1, 2001)

Systems (examples)	**Cost in Euros** (indicative values)	**Typical applications** (indicative)	**Characteristics** (examples)
PC desktop system	Approximately 1 – 3,000	• Education • Training • Home use • Participatory design • Web-based retail and transactions	Typical PC is used, the standard monitor displaying the view of the VE with two dimensional interaction devices. Can also run on laptops and are therefore portable.
Single-wall projection system	Up to 250,000	• Education • Industrial training and maintenance • Home use • Participatory design • Web-based retail and transactions	One screen is used. The wall consists of 2 projectors. The wall is driven by 2 synchronised high-end PC-workstations. Also, a wireless optical head tracker, a magnetic tracker for the hand and a pair of interaction devices for manual interaction are included.
Two-wall projection system	250,000-1,000,000	Mainly 2D semi-immersive systems for: • Health and safety effects evaluation • Desktop design • 2D driving simulation	Two screens are used. Each wall consists of 2 projectors. Each wall is driven by 2 synchronised high-end PC-workstations. Also, wireless optical head tracking, magnetic tracking for the hand and a pair of interaction devices for manual interaction are included.
Six-wall CAVE system	Over 1,000,000 (approximately 1.8 - 3 million Euros, depending on the application)	Immersive stereoscopic applications (3D) for: • Architectural visualisation • Cooperative product design • High-end medical applications	Six screens are used. Each wall consists of 2 projectors, 12 in total. Each wall is driven by 2 synchronised high-end PC-workstations, 12 in total. Also, wireless optical head tracking, magnetic tracking for the hand and a pair of interaction devices for manual interaction are included.

2.1.2 VR Input Device Technology

As VR systems technologies develop, methods of interacting with these systems are continually evolving to use with them. The following provides a summary of the most common methods of interaction within VR systems, not including tracking systems discussed with VR display systems such as the HMD for navigation, examined earlier. There are two main categories of interaction device: free space and stable platform. Free space devices are those that can be used freely in a 3D area and are tracked by the VR system so that their position in relation to the VE and the VR system is monitored and updated. Stable platform devices require a surface to operate from, such as the horizontal surface that is required for the operation of a PC mouse.

- **Mouse:** A normal PC mouse can be used for selection and navigation within VEs, usually with on screen directional icons for example. They tend to be used with desktop display systems or work bench systems as they require a stable platform to work. More flexibility in 3D space providing six degrees of movement is achieved using 3D mice such as the 'SpaceBall' (designed for use within 3D Worlds) or 'SpaceMouse®' (mainly used in CAD applications for navigation 3D models), versions of which are made by '3Dconnexion' (3Dconnexion, 2004) though these devices also require a stable working platform and can not be used in three dimensional or 'free space'. Combinations of a basic mouse design and wand design interaction devices have been developed for use on both stable platforms and free space such as the '6D Mouse ™' (Ascension Technology, 2004) where trackers are included to monitor the position of the device which can be used as a traditional mouse or in free space.
- **Wand:** The wand is a development of the mouse with 6 degrees of freedom, specifically for use in free space. It can be used as a navigational device and for selection. It is designed to fit in the users' hand, usually with buttons for specific point and selection of objects and often thumb operated joysticks for menu or environment navigation. An example of such a device is the 'Wanda®', made by 'Ascension Technology Corporation' (Ascension Technology, 2004). A development of this is to include a position tracker for navigation such at the '3D Navigator ™' also made by 'Ascension Technology Corporation' (Ascension Technology, 2004) which combines a magnetic head tracking device and the Wanda® hand held pointer. Wands are mostly used when interaction is required in free space such as larger displays like the L-shaped or curved displays and more immersive CAVE interaction.
- **Joystick:** Joysticks provide six degrees of freedom primarily for navigation but can be programmed for selection. They require a stable platform for operation, so are not used in free space unless incorporated into a wand device (these are usually small and thumb operated unlike the traditional hand operated stable platform devices). Often they are used in pilot simulation and recent developments to basic gaming joysticks provide force-feedback to increase the realism for the user.

Examples of such products are those made by 'Logitech' (Logitech, 2004) the 'Logitech® Force ™ 3D' and the 'Logitech® Extreme ™ 3D Pro'. Joysticks are most often used with less immersive displays and a suitable stable platform such as desktop VR.

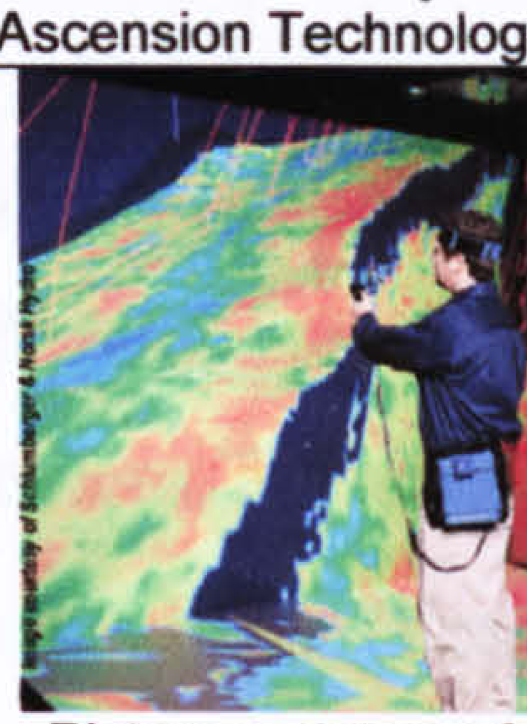
- **Interaction gloves:** Interaction gloves come in a variety of forms and consist of the mapping of the movements made by the human hand in the VE by the user wearing a glove that monitors their hand movements and tracking device to monitor the hand position in free space. A variety of types are available, some of which provide force-feedback to improve the realism of the interface for the user and additional details from the VE application such as suggestions of the texture and weight of the objects manipulated for example the 'Vti CyberGrasp' (Inition, 2004). '5th Dimension Technologies' (5dt, 2004) manufacture a variety of glove interaction devices such as the '5DT Data Glove' that have a range of sensitivity to real hand movements depending on requirements and can be remote from the computer or attached. Developments have also been made into the creation of data gloves that provide temperature feedback, providing a sensation of surface temperature of the object being manipulated within the VE (NICVE, 2004). The PINCH Glove operates in a slightly differently way, instead of monitoring real hand gestures it measures the connection between two digits whilst the user is wearing an interaction glove and various connections between digits result in pre-programmed interactions within the VE to suit the application. This type of glove is manufactured by 'Fakespace Labs' (Inition, 2004). Gloves are often used with workbench display systems and immersive displays such as the CAVE or HMDs.
- **Mechanical arms/haptic devices:** Haptic devices are designed specifically to provide realistic force-feedback from the object being manipulated within the VE. Initially developed for teleoperation, in particular in the nuclear industry where safety implications mean it is safer to operate systems from a remote site. Mechanical arms provide six degrees of freedom with force feedback in the form of devices such as the 'PHANTOM®' made by 'SensAble Technologies' (SensAble, 2004). Main applications are in design and modelling and as they require a stable platform on which to work they are most commonly used in desktop displays as opposed to more immersive free space displays such as the CAVE.
- **Speech:** Speech is a relatively new direction for VR interaction and is only recently becoming feasible as speech recognition technologies improve. Speech reduces the

need for the user to be 'connected' to the system and is potentially very important for interaction with immersive displays that can involve user movement, i.e. CAVE or BOOM displays. Problems do still exist regarding the command words that can be used, systems adapting to changes of tone in the user's voice (for example when frustrated) and training systems to recognise the user's voice prior to use. Speech recognition also requires high powered computers which can be a problem if the same computer is also running the VE (Crosier et al., 2001, p.41). In theory the user speaks commands into a microphone to control navigation and selection and the computer responds appropriately. Often speech interaction is coupled with other interaction devices for example using speech for 'hands free' selection of objects and an interaction device previously described for object manipulation. It is noted in Stedmon (2003) p.1251 that 'anecdotal evidence suggests that speech may not be best suited for specific actions such as navigation and so the best use of speech may be in combination with other input devices for a more integrated approach'.

The following table provides an overview of the input devices examined, Table 2-2 prices provided are an approximate guide according to a review of technologies performed in September 2004.

Table 2-2: Overview of interaction technologies

Example Input Device		Typical VR Display System	Example Price (Euro)
PC mouse	 Picture courtesy of Kelkoo	Desktop	15 (www.kelkoo.co.uk, 2004)
SpaceBall	 Picture courtesy of Inition	Desktop	500 (www.inition.co.uk, 2004)
SpaceMouse®	 Picture courtesy of Inition	Desktop	500 (www.inition.co.uk, 2004)

6D Mouse ™	 Picture courtesy of Ascension Technology	Desktop, Projection	650 (www.ascension-tech.com, 2004)
3D Navigator ™	 Picture courtesy of Ascension Technology	Projection, Augmented Reality	25,000 – 30,000 (www.ascension-tech.com, 2004)
Wanda®	 Picture courtesy of Inition	Projection	2,000 – 2,500 (www.inition.co.uk, 2004)
PC joystick	 Picture courtesy of Kelkoo	Desktop, BOOM	30 – 35 (www.kelkoo.co.uk, 2004)
Logitech® Force ™ 3D	 Picture courtesy of Logitech	Desktop, BOOM	60 – 65 (www.logitech.com, 2004)
Vti CyberGrasp	 Pictures courtesy of Inition	Projection, HMD, Augmented Reality	35,000 – 40,000 (www.inition.co.uk, 2004)
5DT Data Glove (low-high spec)	 Pictures courtesy of Inition	Projection, HMD, Augmented Reality	450 – 4,000 (www.inition.co.uk, 2004)
PINCH Glove	 Pictures courtesy of Inition	Projection, HMD, Augmented Reality	2,000 (www.inition.co.uk, 2004)
PHANTOM® (low-high spec)	 Pictures courtesy of Inition	Desktop	15,000 – 70,000 (www.inition.co.uk, 2004)

Many of these technologies are now available in a wireless form (in particular wireless mice and joysticks) using remote technology to enable the user to interact with the VR system without cumbersome wire attachments restricting their movement in free space.

Although this review is not exhaustive of all the available interaction displays and devices for VR systems it provides an overview of the technology currently in use. New systems and interaction devices are continually being developed to suit specific VR applications. For example the PDA (Personal Digital Assistant) has been used as an interaction device (Bayon and Griffiths, 2003) and has been shown to be effective for navigation, object selection and manipulation with the additional benefits of being wireless, cheap and easily obtainable. If used with a system developed via xhtml (Extensible HyperText Markup Language)/html (HyperText Markup Language) it is possible to access the VE thorough the use of Internet Explorer enabling more than one user to interact with the VE at the same time.

2.1.3 Applications

VR has been used in a variety of applications for many years and the following review provides a selection of such applications in a variety of domains to describe how the use of VR has influenced the area in which they have been implemented.

- **Rehabilitation:** VR systems have been used in many rehabilitation applications effectively, as reviewed in Rose et al. (2000), these range from the rehabilitation of brain trauma patients and amnesia patients to those with learning difficulties and autism. The main advantage of VR over other potential rehabilitation methods is that is can be tailored to suit the needs and abilities of a particular user to enable interaction that may be otherwise impossible or potentially harmful to the patients in the real world. Rose, et al., (2001) state with respect to VR rehabilitation for people with brain damage 'It [VR] allows training to be conducted in situations that have a significant degree of ecological validity while going some way towards containing costs, in terms of staff time, and sometimes also in terms of risks to both patient and staff of training in real-world situations.' Examples of research are varies with respect to what they aim to rehabilitate the suitability of VR for the application (Davies, 2000), the type of VR systems that are used and aspect of VR systems examined for rehabilitation applications. These include the use of immersive VR systems in brain injury physical rehabilitation (Crosbie et al., 2004), the development of interaction devices and methods (Wallergård, 2003), the use of robots for physical rehabilitation therapy, in this case using a driving simulator (Johnson et al., 2003) and as a preparatory aspect of speech rehabilitation (Sik Lányi et al., 2004) where focus is on the development of software.

- **Industry**: The manufacturing industry adopted VR for its usefulness and cost effectiveness for modelling and designing. Development time of new products can be reduced from 2-3 months for the building of a prototype to one day (Crosier et al., 2001, p.100) as VE mock-ups can be made 'virtually' then viewed, examined and adapted in VR systems. For example in the design of engine parts at Rolls Royce VR is used for design and development with respect to part functionality and in consideration for the future maintenance of the final complete product for part access and replacement (Harrison and Jaques, 1996). This makes the whole development process cheaper and enables the spotting of potential problems with the design before a single component is manufactured. VR systems also provide the opportunity to display designs and ideas to a wide audience effectively, avoiding possible misunderstandings between customers and manufacturers and impressing future customers with the VR display technology, again this is possible before any aspect of the product has been manufactured. As well as aiding the functionality aspect of the design and manufacturing process, VR has also been used in the application of ergonomic principles. The principle of prototyping can be used for testing the ergonomics of a product or workplace and varying scenarios explored to examine their suitability. 'Caterpillar ®' manufacturers of construction and mining equipment, engines and gas turbines use virtual simulations to conduct ergonomic studies to improve products before they are manufactured (VREfresh, 2004). BMW use VR for crash simulation to design safer vehicles without the need to create prototypes (SGI, 2004) and British Nuclear Fuels Ltd (BNFL) use VR for the planning of work space layout in control rooms at nuclear plants where the positioning of controls is of paramount importance for safe workplace practice. Manufacturing cell modelling has also been an effective VR application, used for exploring different scenarios, the organisation of manufacturing cells and testing of different manufacturing processes to achieve the most time and cost effective solution before it is created (Korves and Loftus, 1999).

- **Education:** Teaching with the aid of VR has been shown to provoke interest and motivation as a teaching method due to the user's involvement (immersion in the VR and interacting with it) and it is possible for users to be in different geographical locations whilst learning together. It is also possible to convey conceptual information visually that may not be easily described through other media (Cobb and Stanton, in press). Affordable and familiar VR systems can be used such as the desktop PC with one or many students and can teach things otherwise difficult to teach for health and safety reason as shown in Crosier (2000) that teaches the properties of radioactive materials to secondary school children or the teaching of concepts otherwise difficult to visualise such as the solar system, cell structure and molecules in a compound. Research of virtual learning environments such as these is reviewed in Cobb and Stanton (in press). Tan (2000) and Brown, Cobb and Eastgate (1995) summarise the advantage of using VR systems in teaching with respect to acknowledged teaching theory for both students with and without learning difficulties as follows:

  Self-directed activity: VEs encourage self directed learning as the user decides what will be done next and how.

  Motivational: VR systems capture the attention of the student and encourage active involvement in their education, encouraging the student to act and react unlike many traditional educational methods.

  Role of play: This is important in development in education and VR enables students to create their own environments and act out roles in scenarios otherwise not possible.

  Natural semantics: The properties of virtual objects can be discovered through interaction, no-one needs to explain it to the student, thereby bypassing traditional methods of symbolic schooling (natural semantics being what a child learns before symbolic schooling). This is of particular benefit to students with learning difficulties who have difficulty with symbolic schooling.

  Safe space: VR systems enable users to explore knowledge and skills and scenarios and their consequences that may otherwise not be possible in the real world due to the danger or expense they present.

- **Research:** With the aid of VE simulations it is possible to model and examine molecular structures in a way that has never before been viable. Sharma et al., (2003) explain that they have 'interactively explored simulated materials in an immersive environment to better understand and track atomic features responsible for macroscopic phenomena'. An example is provided of scientists walking through simulated fractured ceramic fibre composite material to investigate atomistic processes that make the material tough. Mazuryk and Gervautz, (1996) refer to the use of VR for scientific visualisation, as with Sharma et al., (2003) this involves the use of VR to visualise in 3D things that would otherwise not be possible. NASA Ames Research Centre uses an immersive virtual wind tunnel for such an application, visualising virtual airflow around virtual aeroplanes or space shuttles that can be viewed and manipulated without the expense and time required for a physical mock up, see Figure 2-12.

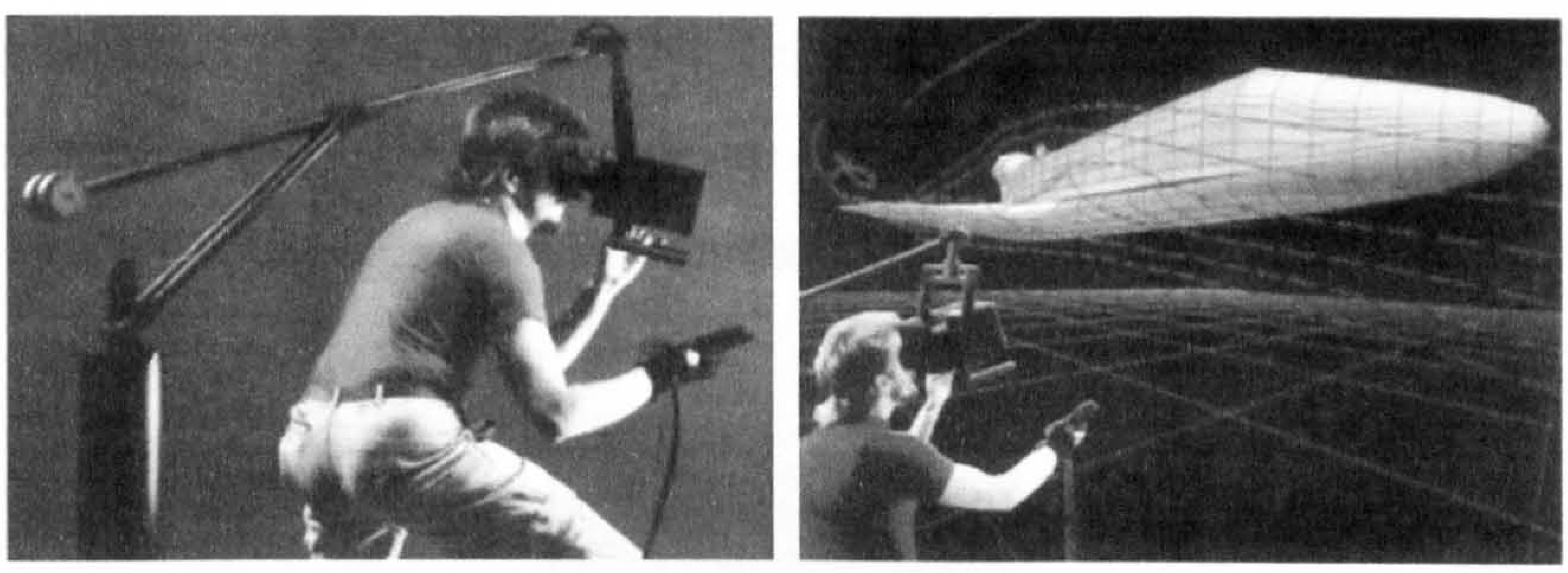


Figure 2-12: Exploration of airflow using Virtual Wind Tunnel – NASA Ames: outside view (left), inside view (right) Bryson (1993)

- **Medical**: VR may one day be used during surgical procedures as an aid to the surgeon performing the operation. Augmented technology can be used to transpose virtual information 'over' the real world that would otherwise not be available, such as patient background details, test results and scans for example. The technologies that enable augmented reality are becoming smaller and less obtrusive to the user ('Augmented reality', section 2.1.1.5) and the information it is possible to display on them is more advanced. VR has been used for the visualisation of precise tumour location from scan information and enables the planning of radiation trajectories to avoid healthy cells (Satava, 1995). Alternative to the surgical application of VR in medicine there are also psychological and therapeutic treatments possible for the treatment of phobias for example, the possibilities of which are only recently being explored. The fact that the VR system is not the real world in this case is a benefit as patients are aware that they are not experiencing a situation that they fear in real life yet are still able to face their fear realistically. In Botella et al., (2000) patients suffering claustrophobic fear showed an improvement in measures of anxiety after VR treatment, which were maintained over a period of three months. Hoffman et al., (2003) successfully treated participants with a fear of spiders, finding that the greater the tactile feedback experienced by the participant during VR exposure therapy the greater the effectiveness of the treatment. A common social phobia such as public speaking has also been shown to be effectively treated with VR therapy (Harris et al., 2002); fear of heights (Hodges et al., 1995) and fear of flying (Hodges, et al., 1996) have also been treated with VR. This suggests that this field of application for VR is both expanding and effective.

- **Entertainment**: The use of VR in entertainment, in particular computer gaming, has resulted in the development of the visual appearance of VEs and specialised graphics cards such as an 'NVIDIA® GeForce™ 6800' graphics card and a Pentium III processor now enable almost photo realistic real time rendering of images on normal PCs as well as games consoles (see Figure 2-13).

Figure 2-13: Example of photo realistic imaging with a NVIDIA® GeForce™ 6800 graphics card (NVIDIA, 2004)

The entertainment industry has also been responsible for the advancement in many associated technologies, for example force feedback interaction devices such as joysticks and car driving wheels (Logitech WingMan Formula Force GP – wheel and pedals set for PC use and the Logitech WingMan Force 3D). Developments have also been made in the form of projection screen display systems for example IMAX ® cinema, used to display films on large curved screens designed to fill the spectators' peripheral vision and immerse users in the projected image displayed to large groups. Alternatively in the leisure industry VR is being used to add realism to the use of rowing, cycling and jogging machines to make the simulated experience more enticing by providing incentives such as simulated competitors or competition between machines.

- **Training**: Training has always been a popular VR application suited to the flexible adaptable nature of VR systems and VE development. With a variety of technologies now available the use of VR has changed from the larger industrial companies using large expensive immersive systems for design or sales and full size simulators for aeroplane flight training to smaller desktop systems used for procedural training. Rose et al (2001) summarise VR training applications as diverse as pilots, console operators, medical staff, naval officers, soldiers, space mission ground control staff, parachutists and fire fighters.

2.2 *The Effectiveness of Using VR for Training Applications*

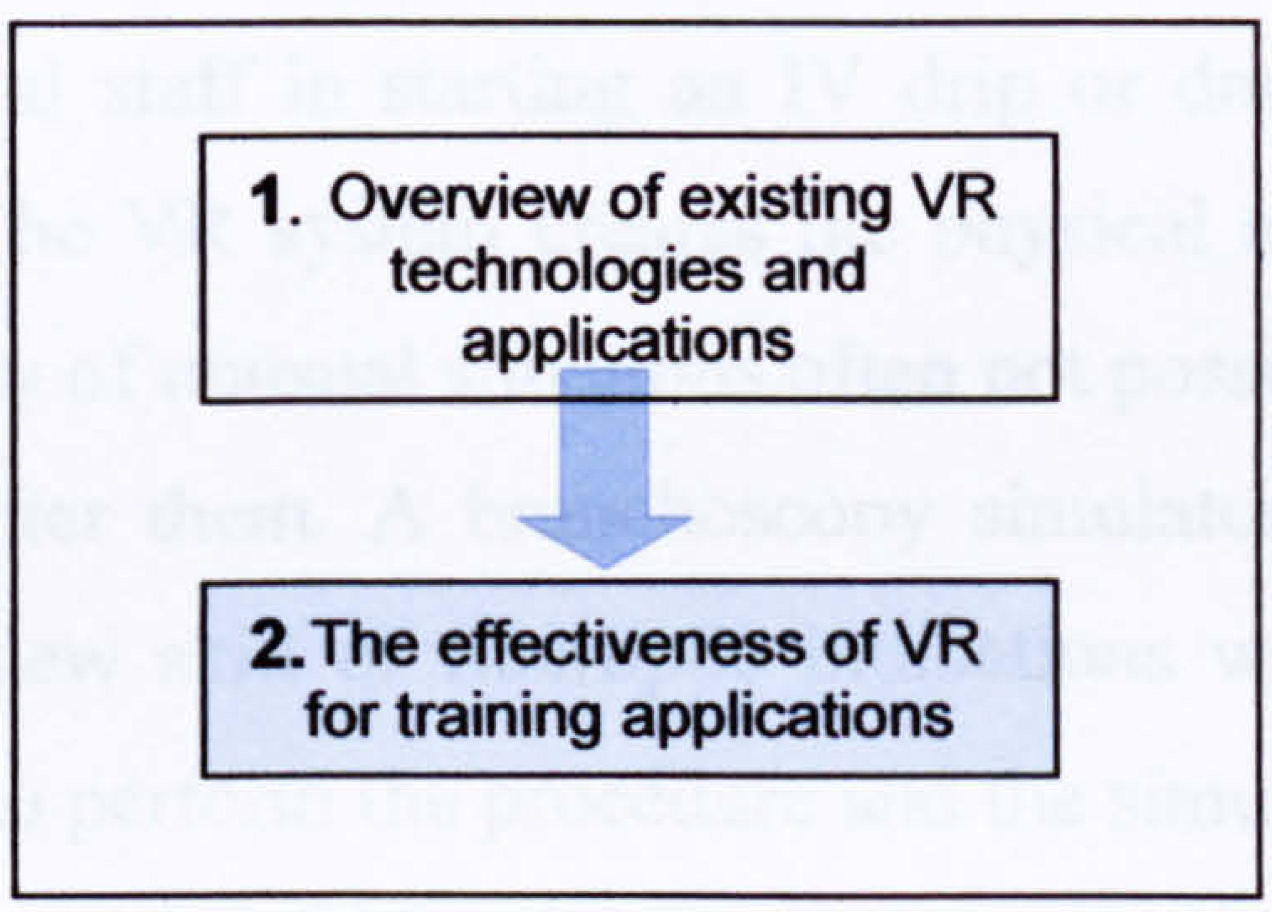


Figure 2-14: Literature review structure – VR training applications

From research into existing VR technologies and applications ('*Overview of VR Technologies and Applications*', section 2.1) using VR for training applications is both an established and effective application and provides a realistic context for both commercial and industrial relevance to any findings made from research carried out. Initial research into the area of training applications was driven by military and aerospace sectors with high end VR as reviewed in D'Cruz (1999). To establish the effectiveness of VR as a training application existing training applications must be examined in a variety of domains to ascertain where they have been implemented effectively and where they have not. The following review covers a selection of the more prevalent training systems in use currently, assesses their appropriateness for training and how they are used as training applications.

2.2.1 Existing VR Training Applications

- **Medical training:** Healthcare is continually changing profession where knowledge needs to be frequently updated and new skills are often required throughout a career. The flexible adaptive nature of VR training makes it an effective method of providing this training. Medical training has been developed in many forms from realistic fully immersive operating training simulators to emergency scenario training and has been found to be effective (Mantovani, 2003). Medical applications include the development of simulators with visual, auditory and tactile feedback that recreate medical procedures, allowing training and practice with no danger to patients, and enable the assessment of skills obtained. Examples of such applications include detailed simulations including 'CathSim® Vascular Access Simulator' for the training of medical staff in starting an IV drip or drawing blood for example (Immersion, 2004). The VR system creates the physical experience of the process and simulates a variety of unusual situations often not possible to practice before the trainee would encounter them. A bronchoscopy simulator (AccuTouch®) used to train residence in a new skill of fiberoptic intubations was found to significantly improve times taken to perform the procedure and the simulation enabled practice of 20-30 cases a day, far more than possible in the operating room normally (Rowe and Cohen, 2000).
- **Flight simulator training:** One of the earliest applications for fully immersive VR simulators was designed for training pilots. With the obvious benefit of providing the pilot with training in ordinary flight procedures without the expensive and time consuming need to fly real planes it is also possible to simulate almost limitless 'what if?' scenarios and train pilots for dealing with emergency situations safely. The VR technology tends to surpass that used in other fully immersive VR systems, such as the CAVE, to create as real a simulation as possible with real cockpits (see Figure 2-15) with high quality displays (see, Figure 2-16) mounted on hydraulics to produce movement in relation to the pilots' movement (see Figure 2-17).

Figure 2-15: Internal view of the CAE Helicopter Flight Deck (pictures courtesy of The Royal Aeronautical Society 2004 www.raes.org.uk)

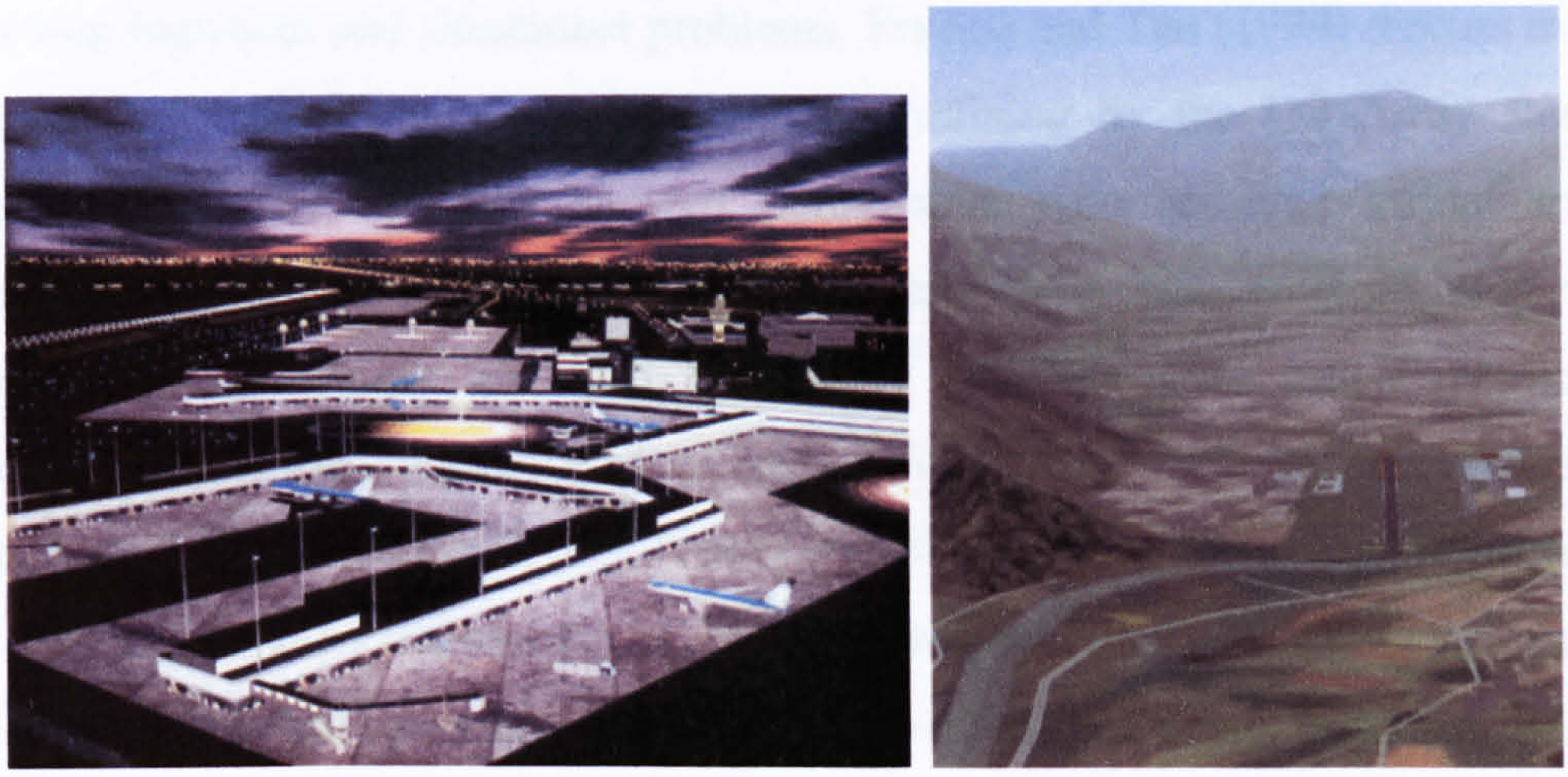


Figure 2-16: CAE MaxVue Night time Airport Scene – left and CAE MaxVue Mapped Scene – right (pictures courtesy of The Royal Aeronautical Society 2004 www.raes.org.uk)

Figure 2-17: CAE Simulator & Motion System (pictures courtesy of The Royal Aeronautical Society 2004 www.raes.org.uk)

Full flight simulators developed by companies such as CAE physically replicate the cockpit of the aircraft being simulated and reproduce the visual environment the aircraft appears to be flying in, including a variety of weather conditions and details such as landing approaches of airports around the world. In the case of military simulators, additional features such as combat scenarios are also simulated for training exercises. The simulators also create sound and motion of the aircraft, including details such as the feel of tyres as the aircraft lands. They can be programmed to create specific conditions a pilot could encounter such as an emergency for example.

- **Military training:** The military has embraced VR as a potential solution to many existing logistical and situational problems. Francis and Tan (1999) discuss military use of VR building and terrain navigation training by the US Army Research Institute (USARI). Results showed participants who received virtual training performed better in real world navigation than those who received only verbal training. The military are also using VR simulations to teach maintenance procedures, for example the RAF is using a Virtalis avionics training simulator at the Tornado Maintenance School (TMS) at RAF Marham. It enabled the teaching of 25 times more tasks than previously possible and was able to teach up to 8 students simultaneously at a cost of only one tenths of previous non-VR set ups (Virtalis, 2004). Stone (2003) reports on the RAF using a VR voice marshalling simulator to improve the 'quality and efficiency of ground based training (typically based on briefings and very simplistic scale models of the operational environment) and to provide a more cost effective mode of remedial training'. The use of the simulator provides a solution to previous problems with flight restrictions and the cost of flying for training, and has resulted in a lower student failure rate. Stone (2003) also reports on the Royal Navy using multi participant semi-immersive VR systems for close range weapons training both for training and post immersion de-briefing. It has been calculated to have saved the Royal Navy 4.9 million Euros from live ammunition training previously used (Stone, 2003 p.1255). Doxford and Judd (2002) review military (UK and US) applications of VR for real time interactive engagements between different weapons systems which are geographically remote. It is noted that the army's move to the use of simulation for training is prompted in the US by economic and operational factors and tightening regulatory controls and in the UK due to space constraints due to population density. The use of VR is described as having the most potential for reducing the environmental impacts of army training and dramatically reducing costs, examples of cost benefits for specific exercises are shown in Table 2-3.

Table 2-3: Cost advantage of VR simulation military training

Type of Training	Cost Live (US$)*	Cost Simulated (US$)*	Percentage
Apache 1.5 hour live firing exercise	259 188	186	0.07
M1 tank driver training (per mile)	75	5.44	7.25
Single tank live firing exercise	21 000	11	0.05
Single M2 Bradley live firing exercise	4760	11	0.23

*source Wiehagen (1997) in Doxford and Judd (2002)

Wiehagen (1997) also defines the benefits of simulation as enhancing the value of live training, expanding training opportunities, reducing fuel, maintenance and ammunition expenditure, reducing safety and environment concerns and enhancing readiness.

- **Space training**: VR has been used in the training of astronauts, for example NASA use a virtual 'glove box' (Figure 2-18) to simulate biological experiments in a weightless environment would otherwise be difficult to recreate.

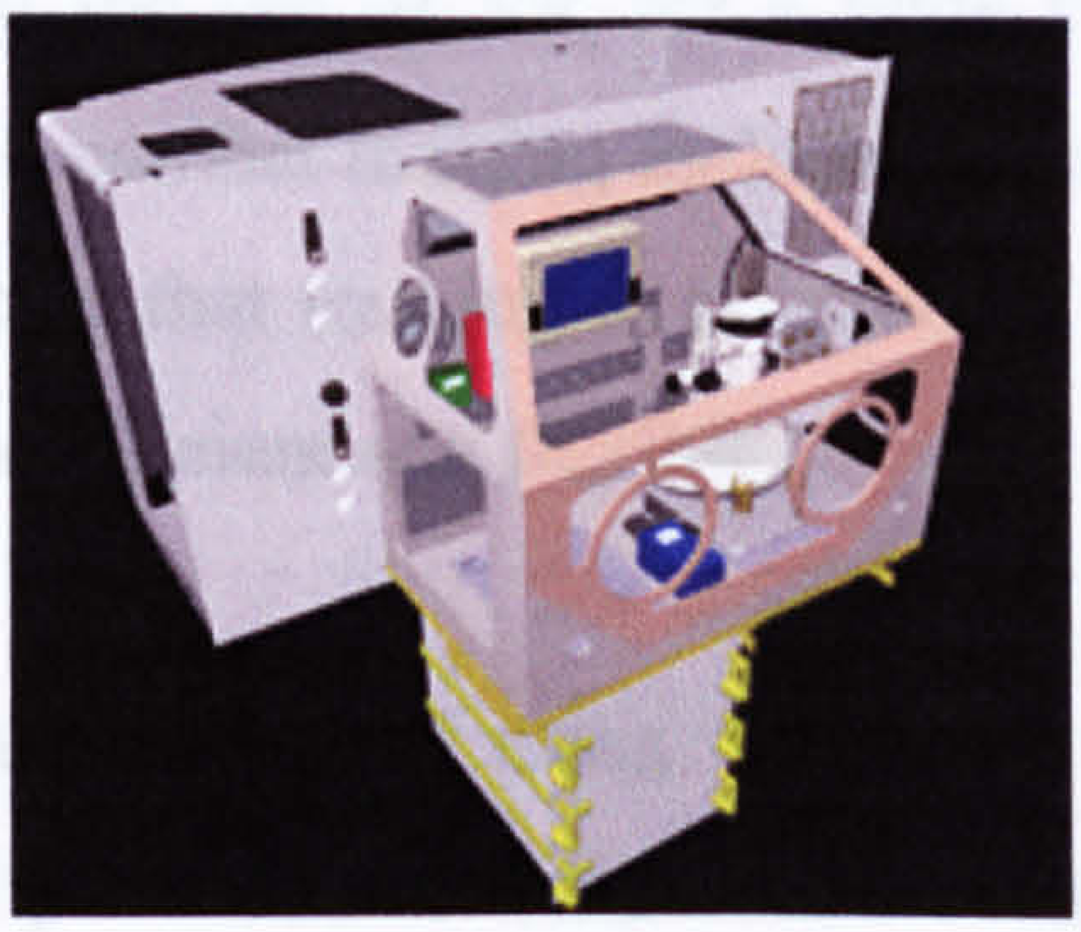


Figure 2-18: Virtual 'glove box' for astronaut training NASA (2004)

'The advantage of a virtual reality tool is that you can simulate microgravity ... For biological research, that means using fluids that float away, securing all objects, and using small forces and fine motor control when performing experiments. We hope to provide cues to astronauts to give them insight to what it would be like to do experiments in space.' Dr. Jeff Smith, deputy director of the BioVIS Technology

Center, NASA (2002). Astronauts have also been trained for maintenance procedures in weightless conditions otherwise very difficult to replicate when not in space, with the added benefit of creating almost limitless scenarios and the ability to repeat training and monitor performance.

2.2.2 The Effectiveness of VR Training Applications

It has been shown in medical training applications the use of VR is effective because procedures can be performed repeatedly which, without such a system may not be possible. There is also no risk to patients whilst the medical professional is learning a new skill which there otherwise may be if that skill were being learnt on real patients (Rowe and Cohen, 2000).

With flight simulator training the main benefit of using a VR system is twofold with respect to costs and training for 'what if?' scenarios. The process of flying a plane is obviously expensive and if it is possible to replicate this effectively for training at a fraction of the cost benefits include better-trained pilots, as financially it is possible for them to practise more. More paramount is the ability to train pilots to deal with situation it would otherwise be impossible to create, such as crash situations.

The military have embraced the use of VR for a wide variety of applications from navigation of unknown areas, combat training including vehicle training and equipment maintenance. Findings indicate that training is effective at less cost financially and to the environment is more time efficient and flexible.

With space training the main benefit of using VR is that the user can be trained in conditions otherwise not possible or very difficult to simulate, in this case weightlessness.

Stanney et al., (1998) state that 'to justify the use of VE technology for a given task, when compared to alternative approaches, the use of a VE should improve task performance when transferred to the real world task because the VE system capitalises on a fundamental and distinctively human sensory, perceptual, information-processing or cognitive capability.' Table 2-4 summarises the main positive and negative aspects of using VR systems for training applications from a variety of disciplines.

Table 2-4: Positive and negative aspects of using VR for training over real world training

Positives	Negatives
• Cost effectiveness • Safe learning environment for users • Flexible nature of VE and VR system • Allows assessment • Can train for scenarios not possible in the real world • Time efficient (more trained at once and in a shorter time)	• Initial financial outlay can be high • Little proven benefits • Lack of realism, such as tactile feedback, smell and sound • Need for expert programmers/instructors

Although these findings are generalised over all applications it is the case that in some applications not all the positives or alternatively all the negatives will be applicable (for example surgical training applications are hugely realistic), it is possible to say that at some point they have been a consideration in the development of the system application and VE design.

Through reviewing literature it became evident that training is an effective application for VR and provides an applicable context for research. For all the applications examined there is a common theme throughout, in that the user is trained through interacting with the VR system.

2.2.3 Methods of Training Using VR

In medical training applications the skills being taught from the VR system are fine motor skills that require the use of highly tactile interfaces and extremely realistic VEs that enable skills to be transferable. Whereas in the case of Crosier (2001) low detail VEs on desktop VR systems were found to be effective in teaching science to school children. It is therefore clear that specific design requirements for a training VE will be specific to the individual application requirements. This is not to say that it is not possible to develop generic guidelines for the building of effective training VEs, there are aspects of VR use that are common to many if not all applications for example the ability of the user to manipulate the VE.

The development of such design guidance provides benefits for both the VE developer and the end users. The VE developer will be able to focus on developing aspects of the VE that will make the final product as effective as possible and reduce the time and therefore cost of developing features of the VE that do not add to its overall value and as consequence the end user will gain the greatest benefit from the use of the VE for the lowest cost.

VE design is generally an iterative process making changes according to the observation of users and how they use the VR system in question. What is required through this research is the structured examination of aspects of the VE that influence the effectiveness of the system, for example interaction. The ability of the user to interact with the VE is the primary feature of VR that distinguishes it from other non hands on training methods such as video training. It is also possible to use interaction within a VE in a manner that would otherwise not be possible in the real world, for example highlighting the important parts of the VE that the user should select for the purpose of the training to enable the learning of a process. It is this interaction that should be looked at in a structured manner to inspect first its influence on the efficiency of the VR training system and secondly how it can be designed to be most effective in a training scenario.

2.3 Factors that Influence the Effectiveness of VR Training Applications

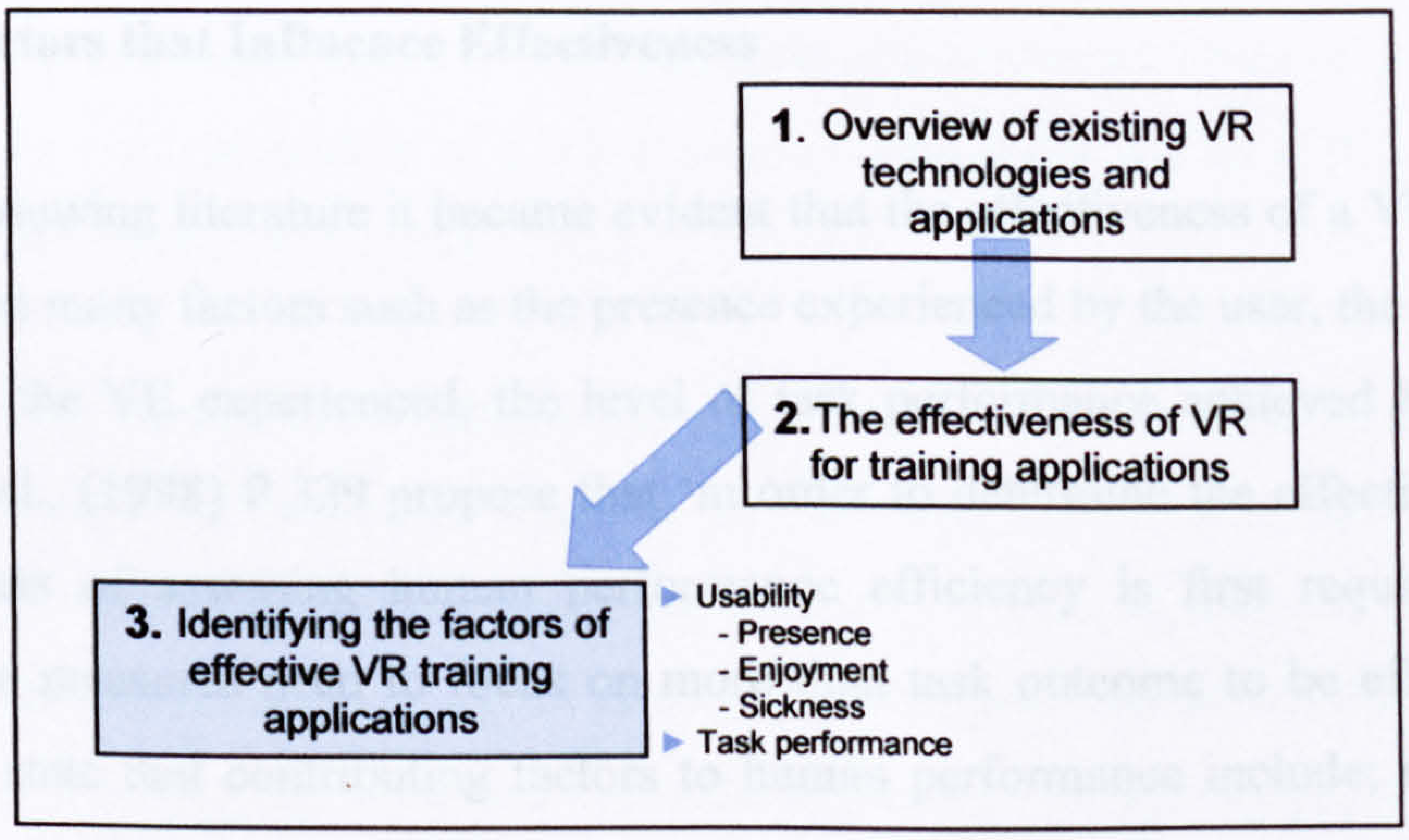


Figure 2-19: Literature review structure – factors of effective VR training applications

The following section formulates a method of assessing the effectiveness of a VR training system (reviewed in '*The Effectiveness of Using VR for Training Applications*', section 2.2) and how effectiveness is influenced by adaptations to design and methods of use.

2.3.1 Defining Effectiveness

Effectiveness is the achievement of the desired optimum outcome from using the environment; the term is defined by the Oxford English Reference Dictionary as '1. Having a definite or desired effect'. In the context of virtual reality this would be the extent to which a specific goal or task is achieved through use of the VR system.

Effectiveness, as with many terms (such as presence or usability) within the area of VR is difficult to define, as for different applications different outcomes would be considered effective and different factors would consequently be influential in that effectiveness. Therefore potential users and potential systems must be considered when determining the effectiveness of a particular VE.

Due to the lack of measures available to directly assess effectiveness in a VR context the definition above will form the basis of the author's concept of VR effectiveness within this research.

2.3.1.1 Factors that Influence Effectiveness

Through reviewing literature it became evident that the effectiveness of a VR system is dependent on many factors such as the presence experienced by the user, the usability of the system, the VE experienced, the level of task performance achieved by the user. Stanney et al., (1998) P.329 propose that 'in order to determine the effectiveness of a VE, a means of assessing human performance efficiency is first required ... VE performance measures need to focus on more than task outcome to be effective' and goes on to state that contributing factors to human performance include; navigational complexity of the VE, the degree of presence provided by the virtual world and the user's performance on benchmark tests. From this the influencing factors of usability, presence (including enjoyment and simulator sickness experienced) and task performance can be derived as influencing the overall effectiveness of a training VR system.

2.3.1.2 The Cost of Virtual Reality

An important influence on the effectiveness of a VR system is not purely how well it works according to its application; also relevant is its cost for its application. This is considered within this research because the choice of system, and to some extent the application, is partially dependent on its cost and the consequent likelihood of it being used in the real world. As reported in D'Cruz (1999) from a survey of 40 companies that have not considered implementing VR systems, reasons given included that they considered the perceived cost too great. Therefore taking into account the cost effectiveness of a system will assist in making findings transferable and applicable to real world applications.

To measure cost effectiveness is not an easy task and must consider many aspects of the environment and desired outcome of using the VE to be a useful measure. Cost effectiveness can be evaluated by measuring costs against outcomes; problems with this arise when defining what an acceptable cost is, and alternatively what a desirable outcome is. It is usually the case that if you pay more then the outcome will be improved though it is likely to level out to a point where increased costs make no notable increase in outcome. The ideal cost effectiveness in this case would be the point before which performance starts to level off. Cost effectiveness is important in trying to establish if the implementation of a VR system is appropriate for an application and in choosing which system is suitable.

Examples of the theory of cost effectiveness applied include Case (1999) concerning the cost effectiveness of particular journals in the field of Physics, Economics and Neuroscience. Cost effectiveness was measured with respect to cost per use, cost per 1,000 characters and cost per impact factor. The data provided an overall context for assessing the quality, relevance, and cost effectiveness of the journals in a given field. This provides a way of looking at the issue of cost effectiveness in a particular area and how different aspects of were considered as applicable to cost effectiveness and measured accordingly.

In Sturm and Wells (1995) the quality and cost-effectiveness of care for severely depressed patients was examined. In this case cost effectiveness was considered with respect to value of care. For example if an employee can function far more effectively on the job for a slightly higher investment in treatment, then the benefits to the employer in terms of increased productivity, or to patients in terms of increased income and quality of life, would justify the expenditure. 'Cost-effective care does not necessarily mean cheap but rather, high-value care. Improving the quality of care for depression may be cost-effective even if it increases direct treatment costs.'

Jones and Simonson (1990) reviewed Iowa state legislature that has mandated distance education will be used by the schools, colleges and universities in the state. 'Educators have always worried about costs of new educational innovations, but they traditionally have looked at effectiveness first and then asked "Can we afford it?" This may well be a similar concern to the possible implication of VR applications. In this paper the cost effectiveness of a variety of options are considered with respect to the desired outcome. Each possible option was considered with respect to cost, adaptability, installation, maintenance, complexity of use and requirements for teaching before a suitable option was selected. Again an example of factors specific to a particular use, used to establish cost effectiveness.

A study into CEA (Cost Effective Analysis) in managed care organisations Jacobson and Kanna (2001) uses a ratio where the denominator is the gain in health (such as adverse reactions avoided) and the numerator is the incremental cost of obtaining the benefits. The denominator may be expressed in years of lives saved or undesirable outcomes avoided. A disadvantage is that the denominator does not include all possible beneficial aspects such as quality of life, satisfaction, different preferences, values, etc. and it is acknowledged that: 'There is no common conceptual understanding of what it [cost effectiveness] means or how it should be used'.

When considering the cost effectiveness of a VR system it should be asked, are the initial and ongoing cost of the use of the VR system (maintenance, re-training etc.) less than that of the benefits (direct and hidden) achieved by its use? If the answer to this question is yes then the environment could be considered cost effective, but establishing the answer to this question is not easy. Considerations must include factors that can not be given a monetary value directly such as 'interest' and 'enjoyment' from increased ability or confidence for example. It is possible in cases such as this each should be considered with respect to a factor that can be assigned a monetary value, such as increased performance or improved efficiency or a rating system of some kind can be used. If this is the case each situation must be considered individually.

2.3.2 Usability

2.3.2.1 Defining usability

The ability to develop bigger and better technologies on which to use increasingly visually impressive VEs has evolved. This has resulted in VEs themselves becoming more and more advanced with ever increasing realism. Without a usability structure for this development it can lead to visually impressive yet difficult to use interfaces (Kalawsky, Bee & Nee, 1999). Barfield et al., (1995) also note that 'while technological advancements in the equipment have been quite impressive, what is currently lacking is a conceptual and analytical framework in which to guide research'. This suggests a fundamental need to generate usable systems but what first must be established is what constitutes 'usability' in a VR context. As was recognised by Wann and Mon-Williams (1996) p.845 'the goal is to build (virtual) environments that minimise the learning required to operate them, but maximise the information yield.' In making the VR system usable the learning required to operate it will be minimal and consequently improve the effectiveness of the system as a training tool.

A simple definition of usability was made by Eason (1984) stating that 'a major indicator of usability is whether a system or facility is being used'. Though this appears over simplified it is true to say that if the user has a choice and chooses to use the system then it is either a user-friendly system or simply preferable any other option available.

The term usability has been formally defined by the International Standards Organisation (ISO) as the 'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use' (ISO 1995). As it can be seen from this definition there is a strong dependence on the specifics of the product and its context of use.

Preece (1994) defines usability as 'ensuring interactive products are easy to learn, effective to use, and enjoyable from the user's perspective.' (p.14). According to Nielson (1993) usability applies to all aspects of a system with which a human might interact. The concept has multiple components and is associated with 5 attributes.

- Learnability - how difficult is it to learn from i.e. a new task?
- Efficiency - how much effort is required to achieve the desired outcome?
- Memorability - is it easy to remember or not?
- Errors - how many errors are being made when in use?
- Satisfaction - is it agreeable to use?

It can be seen that 'learning', 'effectiveness or efficiency' and 'user satisfaction or attitude' are consistent factors between these definitions suggesting their importance to the concept of usability as a whole.

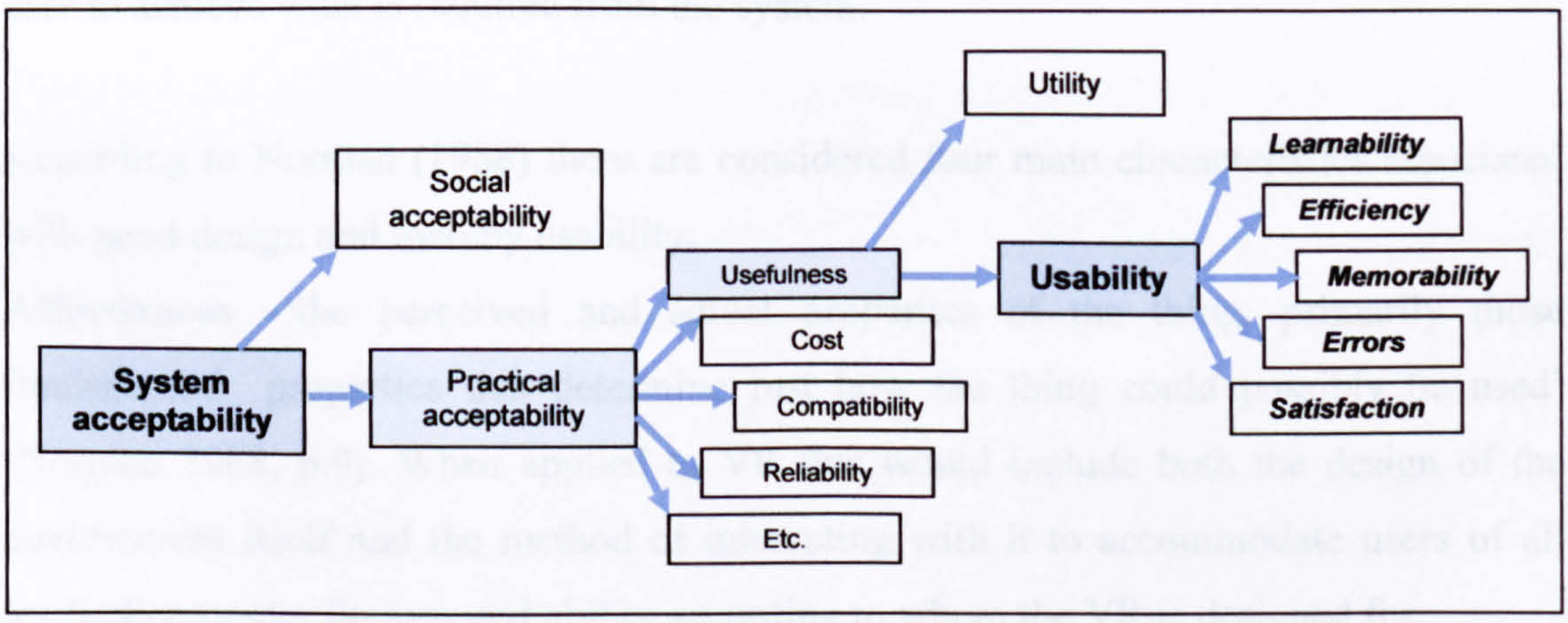


Figure 2-20: A model of the attributes of system acceptability, Nielson (1993)

Figure 2-20 shows the division by Nielson (1993) of the five attributes of usability. The acceptability of the system (a noted aspect of its usability) is split into social acceptability and practical acceptability, and usability is an aspect of its usefulness (if it can be used to achieve a specific goal or task) as a system. Utility in this case defines the helpfulness of the system in terms of aiding the user to fulfil one or more real world tasks. These defining factors of usability are reiterated in Lindgaard (1994) who suggests usability concerns the users, user's tasks, user's tools and the environment in which the users function. The four proposed areas of usability can be seen in Table 2-5.

Table 2-5: Usability dimensions (Lindgaard, 1994)

Area	Description
Effectiveness	Level of user performance (tasks completed) measured in terms of speed and/or accuracy.
Learnability	Ease with which new or occasional users accomplish a certain task, may relate to training provided, to performance on two or more trials separated by a certain amount of time.
Flexibility	Variation in ways a system can achieve a similar goal. A trade off between flexibility and complexity must be achieved to provide the best solution.
Attitude	User acceptability of the system, explicitly seeks user opinion generally measured in interviews or surveys.

There are directly comparable aspects of usability to the definition proposed by Nielson (1993) previously (Figure 2-20). Learnability (also memorability in Nielson, 1993) is prominent in both definitions as is reference to user attitude towards the system (satisfaction in Nielson, 1993). Efficiency and effectiveness (and errors in Nielson, 1993) are interchangeable between the definitions referring to what is required of the user to achieve what is required from the system.

According to Norman (1988) there are considered four main characteristics associated with good design and thereby usability.

Affordances –'the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used' (Norman 1988, p.9). When applied to VR this would include both the design of the environment itself and the method of interacting with it to accommodate users of all level of computer literacy and ability according to whom the VR is designed for.

Constraints – Such as those expected in the real world, for example gravity, things will not float and it is not possible to walk through solid objects. All of which contribute to the realism and possible presence experience by the user if the VE is based on the RW.

Mappings – The relationship between two things which would be in this case the interaction in the VR and the result of that interaction. As far as is possible natural mapping that takes advantage of physical analogies and cultural standards i.e. move a joystick left the viewpoint moves to the left, cupboards tend to open out, doors can usually be opened (Norman 1988, p.23).

Feedback – 'Sending back to the user information about what action has actually been done, what result has been accomplished' (Norman 1988, p. 27). For example in a VE when a door or draw is selected it opens and a suitable sound is heard, or when a computer button is selected a beep such as that heard on a real computer is heard and the monitor changes. Shackel (1986) states that 'the capability in human functional terms to be used easily and effectively by the specified range of users, given specified training and support, to fulfil the specified range of tasks, within the specified range of environmental scenarios' is a possible definition for a usable computer system.

'The evolution of virtual interfaces or VR has led to an important new human/computer interaction medium with the potential to present the "ideal" interface between the user and a synthetic computer-generated environment' Kalawsky, Bee and Nee (1999b) p. 128. For this to be possible factors must first be established that aid the generation of this 'ideal' usable interface. The point is made in this paper that the speed at which technology has developed in the field of VR means that the ability to understand the human factor issues behind its use has been left behind.

There are two main aspects to consider when attempting a definition of the concept of usability, the first being the usability of the VR (mainly the interface between the user and the VE) and the second is the usability of the VE itself. Marsh and Wright (1999) split the definition of usability problems within the VE into two categories; Low and high quality usability. Low quality usability problems are judged to be of low importance and the user would have no problem overcoming them with more time within the VE. High quality usability problems are judged to be of high importance they occur frequently, are not likely to be overcome with more usage over time and could shock or startle the user i.e. collisions with or moving through objects.

It can be concluded that an overall definition for usability with respect to VR systems combines the system being used, how easily it is used and the user achieving the desired outcome from its use.

2.3.2.2 Factors that influence usability

Within VR the concept of usability has been considered with respect to specific, unique aspects concerning a particular application or VR system. Research has also been conducted to examine aspects of usability generic to a variety of systems and applications. In the following discussion these considerations are reviewed to obtain an overview of current opinion of the factors that influence the usability of VEs and VR systems.

The usability of any one system is dependent on a multitude of factors that may even very between individual users. These could include aspects of system design (including the hardware, interface and tasks), the needs, capabilities and preferences of the user, the task to be performed and the context of the systems use (Neale, 2001). This covers the following main areas

- usability of the system
- usability of the system's application

Efficiency, effectiveness, safety, learnability/memorability, errors, flexibility and user attitude/satisfaction were presented in section 2.3.2.1 and found to be defining factors that influence the usability of a system. Examples of usability measured with respect to specific properties and applications of a specific VR system include Chu, Dani and Gadh (1998) who use of VR to provide an interface for CAD concept design to incorporate voice driven commands and hand gestures, and considers usability with respect to the translation of an idea accurately to a computer package. Greenhalgh et al. (1997) consider the use of collaborative VE for virtual meetings, its main consideration with respect to usability is the network traffic created and issues of embodiment, navigation and interaction.

In Kaur (1997) is it indicated that major usability issues in the development of VEs exist in the form of interaction problems such as:

- Maintaining suitable viewing angles
- Loosing whereabouts after bumping into objects (disorientation), and
- Recognising interactive hotspots in the environment.

These can result in user frustration and low usability and as a consequence of this a low acceptance of VR in general. The use of clear labelling (red signs with a white italic ‘*i*’) in a VE was used to indicate that information was available about aspects of that environment and proved very successful with fewer usability incidents and significant improvements in task performance. To help evaluate and improve the usability of a VE once it has been designed a cognitive walkthrough method with a question checklist for each interaction stage was developed, for example at the ‘scan’ stage the question checklist includes ‘When scanning the VE, can users distinguish and recognise many/few/none of the objects?’

Following the ‘development of VEs for usability’ process Kaur (2002) proposed a set of guidelines for basic usability requirements within a VE, split into three sections of usability: design of objects, design of user actions and design of system control. Table 2-6 provides details of each of these areas. The guidelines were presented in the form of an internet based tool providing examples of recommended guidelines and their context of use to aid VE design for environment developers.

Table 2-6: Design of VEs and interaction guidelines (Kaur 2002) adapted.

	Design of Objects
Distinguishable	From all viewpoints with clear boundary's and important parts of the object easily distinguishable. This can be done with exaggerated colouring and shading.
Identifiable	Recognisable and specific parts (especially interaction points) should be easy to identify. Objects should be represented accurately and appropriately to match expectations the user has.
Interactivity & Significance	It should be clear whether or not the objects can be interacted with and the relative importance of objects in the environment to the user task. More consideration should be given where the object is abstract and/or the user has no prior knowledge of it.
Accessible	Objects should be easy to approach and be easy for the user to take up a suitable position close to objects.
	Design of User Actions
Availability	Of an action should be made clear to the user to aid them in finding available actions during exploration.
Purpose	It should be made clear the purpose of the action is and the results of taking that action meeting expectations the user may have.
Performance	The sequence of operations required to carry out actions should be clearly defined and match any user expectations.
Execution	Ease of execution, the action sequence being as simple as possible and the demand of manipulation precision and motor co-ordination should be within usual human ability.
Effect	Feedback on user actions provided and should be easy for the user to distinguish (timely, accurate and integrated across all modalities i.e. sound, vision etc.)
	Design of System Control
Show Beginning and End	When a system takes control of interactions from the user and control is returned to the user it should be made clear.
Show Why	The goal of the system taking control should be made clear, and when that control is likely to be returned.
Show Actions Available	Actions available during system control should be made clear.

These points provide some general common sense guidelines for the design of a usable VE, and consider a variety of possible influencing factors on the measures of usability for a VR system and VE. Lindgaard (1994) provides a summary of typical user defects in computers interaction systems in general; many of which are applicable to a VR context, see Table 2-7.

Table 2-7 Table 2-7: Usability defects and VR (Lindgaard 1994) adapted

Defects	Relation to VR
Navigation	Ease at which the user moves around the VE (interaction device, display fidelity, lag time etc.)
Screen design and layout	How information is displayed on the screen i.e. for selection
Terminology	Less applicable, covers instructions and labelling within the VE (words, sentences, 'jargon', codes, commands etc.)
Feedback	How the system informs the user the result of actions and state of the system (warnings, highlighting, confirmation messages) – visual, audible or tactile?
Consistency	System performing in a predicable, standard manner i.e. method of selection is consistent, system response to selection is consistent etc.
Redundancies	Repetitions, parts of the system that are not used or impede performance.
User Control	Users feeling of being in control, interaction device, field of vision, rate of update etc. Trust/confidence user has in the environment (i.e. results of actions taken)
Match with user tasks	How well does it map and reflect what the users want and the way they want to do it?

When considering the design of VEs Griffiths (2001) describes the foundations of VE usability as the following aspects that should be considered when implementing usability into VEs.

Explorability: enabling the feeling of exploring as freely as possible in the real world to increases the feeling of *realism* experienced by the user.

Experimentation: enabling the possibility of trying out different scenarios and enabling the *selection* and manipulation of objects.

Virtual task awareness: If the VE is based on task based interactions it is important that the task is clear to reduce boredom or frustration.

Likeability: The VE should be designed in such a way that that the user finds it familiar and that it promotes a feeling of ease for the user whilst within it. For example a room devoid of objects will be less likable than a room with familiar furniture and function such as an office with a desk and chair etc.

Support and help: Should be available within the VE so that users do not have to exit the VR system to ask for guidance, thereby influencing the experience of the system for them.

Consistency: with a single VE or between VEs so users know how to use aspects of the VE and become familiar with it.

Expectance: users may expect more from virtual reality interfaces than currently exists due to futuristic systems portrayed in the media and from impressive graphics available in current gaming technology. This may lead to disappointment and reduced usability when they use a VR system of a lesser specification.

Usability within virtual reality ranges from the assessment of the usability of the VR system directly to the user's subjective experience of the system and its usability. Factors that have been shown to be important include spatial orientation, way finding/navigation, image quality and subjective levels of user presence and involvement experienced. These factors have been reviewed within this section. For research that is less concerned with high specification VR technology and the development of new technologies and is performed on low specification, familiar desktop VR systems it is the subjective aspect of usability that is important, how the users themselves rate their experience of the VR and the resulting relationship between subjective usability on the effectiveness of the VR system for training.

2.3.2.3 Defining presence

The term presence is difficult to define as put by Kalawsky, Bee & Nee (1999a) p. 130 'unfortunately, the term presence has defied all attempts to define it in quantifiable terms'

A clear definition of the concept of presence with respect to VEs is that made by Barfield and Weghorst (1993) p. 701 presence is 'generally conceived as a hypothetical subjective state of awareness and involvement in a non-present environment.'

The concept of presence has been applied to VEs from origins going back to original interfaces of literature, graphic arts, theatre or film where the goal has been to involve the observer and achieve a feeling of presence in the simulated medium. Sheridan (1992a) asked, 'what do the new technological advances add, and how do they affect this sense, beyond ways in which our imaginations have been stimulated by authors and artists for centuries?' This is ultimately what researchers in the area of virtual reality have been trying to discover and define in respect to the new medium of VR ever since the question was proposed.

The closest there has been to an agreed definition of presence describes the participant's sense of 'being there' within the VE (Sheridan, 1992b) and this has been used as an initial bench mark for research into the concept of presence by many. This makes it difference from other feelings of being part of a non-real interface for example a viewer flinching whilst watching a particularly shocking scene in a film or crying at an emotional scene. This type of behaviour can mean the viewer feels involved but not that they are experiencing the feeling of 'being there' which is associated with presence (Barfield et al., 1995).

The original identification of presence as an aspect of the effectiveness of a VE was made by Sheridan (1992b) who defined virtual presence as the 'sense of being physically present with visual, verbal or force displays generated by computer'. He later separated this into two different definitions, (Sheridan 1996) the first being telepresence, where human participants feel they are at a location other than that which is actual (real and immediate) and virtual presence where human participants feel they are present at a location that is synthetic, created only by a computer and various visual, auditory, or haptic displays. In either case the user of the system is likely to be coping with the 'suspension of disbelief' or the compulsion to 'believe that one is apparently located in space other than where one physically exists'. Sheridan (1992b) also presents the theory that virtual presence is an experience, whereas a VE is what is experienced.

Witmer and Singer (1998) interpret a similar meaning to the concept of presence and define it as 'the subjective experience of being in one place or environment even when one is physically situated in another' and use this definition as a basis for their study. They reiterate this definition in Singer and Witmer (1999) and argue that involvement and immersion are both required for the participant to experience presence. Involvement is defined as the 'psychological state experienced as a consequence of focusing ones attention on a coherent set of stimuli or meaningful related activities and events'. Immersion defined as a 'psychological state characterised by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences'. Immersion in this case clearly refers to the participants' perception of their feeling of immersion, such that it can occur on a desktop VR system or a fully enveloping display screen such as a CAVE system.

Immersion has also been defined as purely the physical set-up of the VR system technology (Slater et al., 1996).

Heeter (1992) considers the subjective experience of presence, stating 'a sense of presence in a virtual world derives from feeling like you exist within but as a separate entity from a virtual world that also exists'. Three dimensions of the subjective experience of presence are defined; subjective personal presence (a measure of the extent to which the subject feels like they are in the virtual world), social presence (extent of which other beings exist in the world and appear to react to the subject) and environmental presence (the extent to which the environment appears to know the subject is there and to react to them).

Slater and Wilbur (1995) define presence as a 'state of consciousness, the [psychological] sense of being in the VE.' This definition concurs with that of Sheridan (1992b). It is clear that a VE will never be able to fully simulate the infinite cues supplied by the real world to enable a full feeling of presence, as stated by Grove (1996) they are always an 'approximation of reality' what is important to consider within research of VR is how much, if any, of a sense of presence is required to enable effective use of VR. It is possible for example that the lack of feeling that you are actually 'there' in the virtual world is beneficial to the VR application as it may reduce sickness symptoms experienced by the user as conflicts between what the user is seeing and believing and what they are physically experiencing are less than if high levels of presence were experienced. Barfield et al., (1995) p. 474 ask 'is the sense of "presence" simply a concomitant benign phenomenon, or even a distraction? Or is the quality of "presence" the critical psychological indicator of physical stimulus sufficiency?'

Slater, (1999) summarises the work within the area of presence definition suggesting that presence includes three aspects; the sense of 'being there', the extent the VR becomes dominant (participants respond to events in VE rather than the real world) and the extent participants remember the VR experience as having visited a place rather than just seen computer generated images.

From considering these various attempts at clarifying the concept of presence and its importance it has become evident that although no single agreed definition exists for the concept of presence its general meaning as a feeling of participation and inclusion within a VE is clear. It is this general concept that will be considered, with the aim of aiding the effectiveness of that environment for a particular task, within this research.

2.3.2.4 Factors that influence presence

Barfield et al., (1995) note that it is possible to 'invoke a high level of presence in VEs without having to stimulate every sensory system of the human. In fact, many current VE systems successfully invoke presence by stimulating only the visual and auditory modalities'.

Nichols, Haldane and Wilson (2000) note that there are many factors that could have an influence on presence such as 'display fidelity, temporary lags, sensory channels engaged, degree of interactively allowed and characteristics of the individual, task and context of use'. It is suggested that the difficulty of determining the influencing factors in presence is the lack of a set of established measures for presence.

Barfield and Weghorst (1993) propose possible influences to the level of presence experienced by a VR user that include; display fidelity, sensory bandwidth (variety and dynamic range of output displays), interactive fidelity, individual variables and task variables. In defining the achievement of virtual presence state 'when attentional resources are allocated to computer generated sensory information... presence for that stimulus event(s) occurs.' The indication of this is that many personal (affect of memory), task (affect of attentional resources) and context variables influence presence within a VE and as a result should be considered both individually and with respect to their interaction with each other.

Slater and Wilbur (1995) suggest that presence is determined by the type of sensory information required to perform the task at hand, for example would visual or verbal data be of more use? Also considered is the representational system preferred by the subject as an influencing factor on the level of presence they will experience, for example if the subject prefers visual or verbal displays of information, suggesting that individual characteristics will have a strong influence on the measures of presence of the same VR experience for different participants.

Bystrom, Barfield and Hendrix (1999) suggest that the nature of the task itself may indirectly influence the level of presence experienced i.e. a particularly engaging task may require the allocation of more attentional resources and as a result increase the sense of presence experienced by the subject 'If the participant allocates sufficient attentional resources to the VE, and if there is a sufficient degree of sensory fidelity, the participant may "suspend belief" and view the environment as an actual place, thereby developing a sense of presence in the VE.'

Sheridan (1992a) identifies three major aspects that determine the level of presence that is experienced and predicted that additional environmentally important sensory information to a display increases the presence levels:

- The extent of sensory information
- The control of relations between sensors and display
- The ability to modify the physical environment

Singer and Witmer (1998) combine and add to this list, creating four areas or 'factors' that relate to or form the basis of the presence experienced by the user,

- User control (over relations of sensors to the VE, appropriateness of control effect on the VE and naturalness of the control)
- Sensory input/output
- Realism of the simulated world
- Distraction (level of isolation form the local environment or 'immersion' in the VR)

This list and examples of contributory influences on presence can be seen in Table 2-8.

Table 2-8: Factors hypothesised to contribute to presence (Witmer and Singer, 1998)

Control Factors	Sensory Factors	Distraction Factors	Realism Factors
Degree of control	Sensory modality	Isolation	Scene realism
Immediacy of control	Environment richness	Selective attention	Information consistent with objective world
Anticipation of events	Multimodal presentation	Interface awareness	Meaningfulness of experience
Mode of control	Consistency of multimodal information		Separation anxiety/disorientation
Physical environment modifiability	Degree of movement perception		
	Active search		

2.3.2.5 Enjoyment

The importance of user enjoyment on both the presence experienced by that user and their inclination to use the VR system initially or repeatedly as required is a factor that should be considered in the development of any VR system or VE as if it is not used, whatever its purpose, it will not be effective. There are also the benefits of additional job satisfaction from enjoying the training and from effective training.

2.3.2.6 Simulator Sickness

From early applications of VR systems reports of sickness resulting from their use have been reported. This has been a potential barrier to the uptake of VR in many applications and consequently has been the focus of attention to establish why it occurs, how and methods of monitoring, reducing or eliminating such effects. Welch (2002) notes that 'adverse effects of VEs pose a serious obstacle to optimal task performance and training with these devices'

Cobb et al., (1999) suggest that the main reason for sickness symptoms experienced whilst using a VR system is the conflict between what the visual senses are experiencing and what the other physical spatial sensors (the vestibular and nonvestibular proprioceptive systems) are experiencing (Reason and Brand, 1975). The user sees movement through the VR system, the conflict occurs because the user does not physically experience it. It is also suggested that different types of VR systems 'may actually produce different levels and types of sensory conflict'.

Simulator sickness or VRISE – Virtual Reality Induced Symptoms and Effects (Nichols et al., 2000) experienced through VR includes both positive and negative effects and has been summarised in the following table, Table 2-9.

Table 2-9: Virtual Reality Induced Symptoms and Effects (VRISE), Nichols et al., (2000)

Effect	Example
Physical symptoms	Headache, nausea, blurred vision
Physiological changes	To the visual system or general physiological state
Psychological effects	Attitude to VR system, task or subsequent task

The main findings from a range of experiments performed using different VR systems and VEs reported in Nichols et al., (2000) were as follows. The more immersive HMD VR systems were found to cause significantly greater sickness symptoms than desktop or reality theatre display systems. There was found to be no significant difference between VRISE experienced by participants in light or darkened room conditions using the desktop VR system and participants who did not have control over their movement (passive viewers of the VR system) experienced higher levels of symptoms than those who did. This is possibly as a result of the greater contrast experienced between the visual and motion sensory systems passive viewers experienced than the active users with greater control who knew where they were navigating etc. Stanney et al., (1998) provide a review of research into influencing factors on sickness experienced through VR use.

Kennedy et al., (2000) report a positive correlation with simulator sickness experienced and duration of VR use and a negative correlation with repetition of use and sickness. Kennedy et al., (2000) suggest that there are two main schools of thought with respect to the cause of simulator sickness, the first being that it is as a result of technical factors such as field of view, optical distortion, flicker, refresh rate etc. the other suggests that individual user differences (including factors such as user experience, age, gender, postural stability etc.) is the cause, it is possibly a combination of the two.

2.3.3 Task Performance

2.3.3.1 Defining task performance

It is difficult to produce a generalised definition of task performance within virtual reality as it is specific to the environment and the particular outcome desired from its use. It is possible to loosely characterise this measure as how well (as in with the fewest errors) the desired conclusion of using the environment is achieved. Task performance in training applications has two potentially different aspects, firstly how well a task is performed whilst within the VE and secondly (depending on the VR application) how well the knowledge gained from the VR system is transferred to the real world.

2.3.3.2 Factors that influence task performance

First the influence of presence on task performance must be considered Bystrom, Barfield and Hendrix (1999) suggest that presence does not necessarily facilitate or hinder performance, but that having some sense of presence in an environment is necessary for performance to occur.

It has been considered important to study presence because of a potential relationship between presence and task performance. In Barfield et al. (1995) it is said that "not only is it necessary to develop a theory of presence for VEs, it is also necessary to develop a basic research program to investigate the relationship between presence and performance using VEs. ... We need to determine when, and under what conditions, presence can be a benefit or a detriment to performance?" (p.473).

As a result of this it could be considered that the relationship between presence and performance defines why presence is important. The issue of whether or not presence itself enhances performance is important because the greater the degree of presence, the greater the chance that participants will behave in a VE as they would in the real world. For example if a VE is being used to train military, fire-fighters or surgeons presence is crucial so that the professionals being trained behave appropriately in the VE, then transfer knowledge to corresponding behaviour in the real world (Slater and Wilbur, 1995). Welch (1999) proposes 'it is possible that presence facilitates the performance of tasks that are in the process of being learned or have not yet attained a requisite level of performance; or, perhaps, presence leads to the positive transfer of performance to the real world tasks for which the user is being trained' (p.575).

Mania and Chalmers (1999) describe one of the few pieces of research that compares feelings of presence and task performance within real and virtual worlds, with the aim of achieving a better idea of how to design and implement VR systems. This then incorporates the real world into VE applications and is a useful starting point for further research in this area. Romano, Brna and Self (1998) suggested that behaving naturally and feeling present within a VE 'come together' and concluded that if achieving natural behaviour is the key to improving task performance the sense of presence within an environment will also improve performance.

It is important to look wider than the influence of presence on task performance, it is reasonable to say for example that if the VR system is usable the task performance will be improved; therefore usability is another possible influencing factor on the task performance achieved.

2.4 Interaction

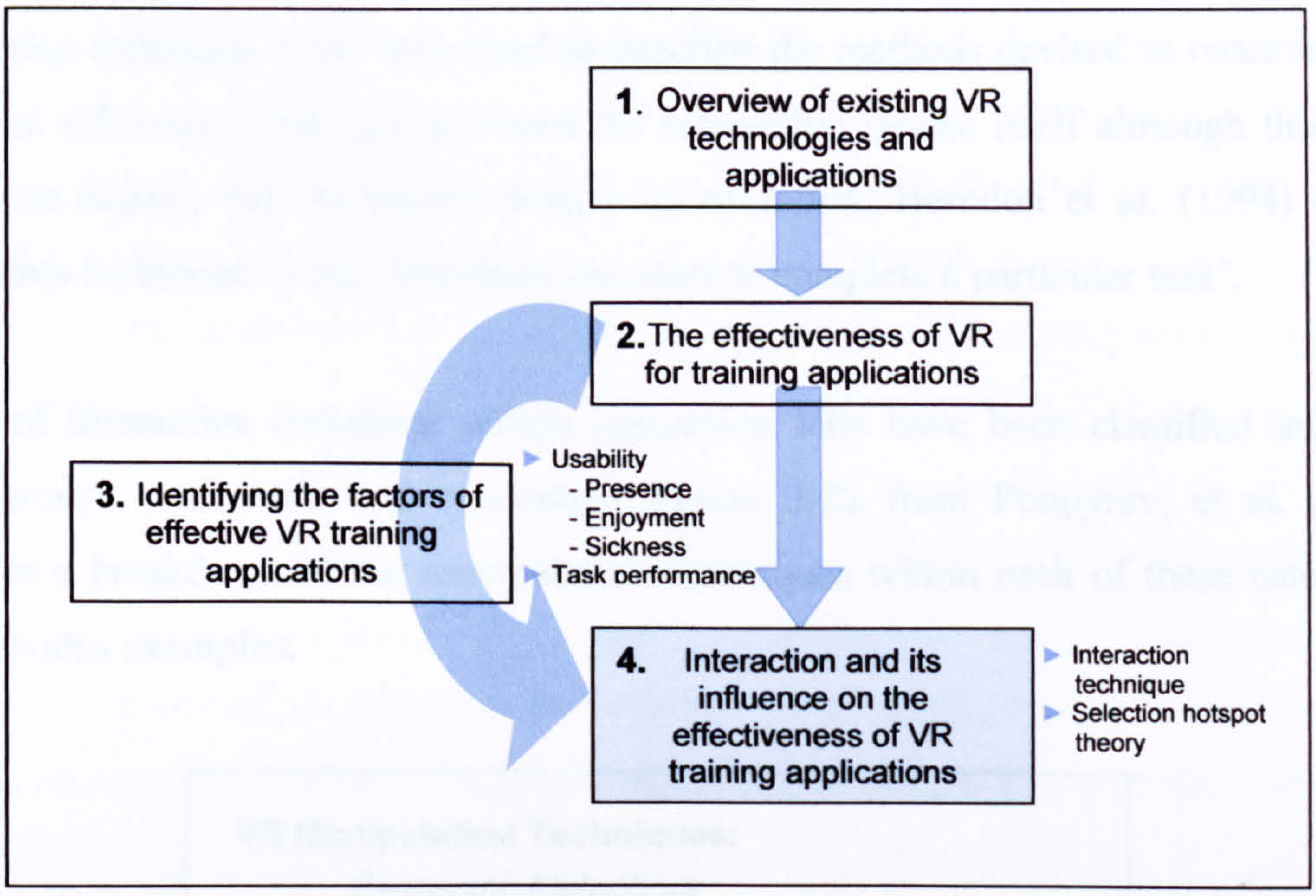


Figure 2-21: Literature review structure – interaction and effectiveness

The following section reviews methods of user interaction with VR systems that currently exist and design factors of VR systems that influence the amount of selection of specific aspects of a VE. The concept of interaction was investigated as a consequence of research into the effectiveness of VR for training applications ('*The Effectiveness of Using VR for Training Applications*', section 2.2) as it became evident that interaction was a common thread in existing VR training applications. However details of how interaction should be designed and implemented to be most effective has received very little research attention. It is noted by Stanney et al., (1998) p.328 that 'maximising the efficiency of the information conveyed in VEs will require developing a set of guiding principles that enable intuitive and efficient interaction so that users can readily access and comprehend data'.

The efficiency of different methods of interaction on VR training applications can then be assessed through the factors established in '*Factors that Influence the Effectiveness of VR Training Applications*', section 2.3.

2.4.1 Interaction Technique

Interaction technique is the term used to describe the methods devised to communicate with and influence a VE, not so much the interaction device itself although this is of course an aspect, but the theory behind its operation. Herndon et al. (1994) define interaction technique as the 'interfaces one uses to complete a particular task'.

Types of interaction technique within immersive VEs have been classified into two main groups, exocentric and egocentric, Figure 2-22 from Poupyrev, et al. (1998) provides a breakdown of the manipulation techniques within each of these categories and provides examples.

VE Manipulation Techniques:

- *Exocentric Metaphors*
  - E.g. World in Miniature (WIM)
- *Egocentric Metaphors*
  - Virtual Hand Metaphors
    - E.g. Classical Virtual Hand
  - Virtual Pointer Metaphors
    - E.g. Ray Casting

Figure 2-22: Classification of VE manipulation techniques depending on their underlying metaphors – adapted Poupyrev, et al. (1998)

Exocentric interaction is where the user selects items from outside the environment, for example an overlay interface on the display screen (such as in a training environment where a selection of tools can be chosen from a list always available at the side of the VR system display to perform the task represented in the VE) or by looking at the VE in miniature from above (in WIM) and in contrast egocentric interaction is performed within the environment. Examples have been given by Poupyrev, et al., (1998); virtual hand metaphors where the user can touch and pick up objects within the environment using a virtual representation of their real hand or pointer metaphors where extensions to the users usual reach (usually in the form of a line or 'pointer' extending from a virtual hand) intersect the object to be manipulated and are used to select items from a distance.

Currently there is no clear definition of the selection of items and the manipulation of those items whilst within a VE, often the terms selection and interaction are used interchangeably referring to both detailed selection and general VE navigation. The theory of interaction includes the whole process of the user being within the environment, including the navigation and control of the system itself and user actions performed within it. Within this general definition of interaction there is a requirement for more detailed definitions of particular aspects of interaction such as selection and manipulation.

Marsh and Wright (2000) do consider interaction as a basis for the whole experience or 'illusion' of using a virtual world. In this case interaction is not broken down into different aspects such as selecting an item and manipulating it to achieve a goal or create a reaction but considers the whole experience of using a VR system as interacting with it.

More detailed classification of the process of interaction has been performed by Bowman and Wingrave (2001) who characterise interaction into four 'universal interaction tasks' that can be seen in Table 2-10.

Table 2-10: Universal interaction tasks (Bowman and Wingrave, 2001)

Interaction Task	Description
Navigation	Moving the viewpoint through an environment both cognitive (way finding) and motor (travel).
Selection	The task of choosing one or more objects from a set.
Manipulation	Referring to the specification of an objects properties i.e. position and orientation.
System control	Changing system state or mode of interaction.

2.4.2 Selection Hotspots

Within the design of a VE for a training application there are likely to be certain points or objects that the user is required to specifically select, for example objects that have further information available that can be obtained by selection; menus for navigation, selection or manipulation within the VE or for navigation alone. Within the research area of VR interaction the author considers the term 'selection', to refer to the user choosing a point in the VE and the term 'selection hotspot' to refer to a point within a

VE that affords or encourages selection in some way. Examples of how this is achieved include the use of cues to attract attention or as part of a task that the user must complete by selecting it, usually resulting in visual (or auditory) feedback such as a change in colour or texture.

Selection hotspots have been used to encourage the selection of specific points with a VE, designed by the VE developer through observation of VE users, in this case virtual learning environments for users with learning disabilities Brown, Kerr and Bayon (1998). No formal evaluation took place concerning the effectiveness of the selection hotspot design nor was the term selection hotspot used but they were designed to prompt selection of specific aspects of the VE. Figure 2-23 demonstrates the use of red highlighted, flashing cues used to prompt the user to select the highlighted object.

Figure 2-23: Red flashing cues in the Virtual City (Brown et al. 1998)

Selection is shown as one of four universal interaction tasks within a VE in 'Table 2-10: Universal interaction tasks (Bowman and Wingrave, 2001)', section 2.4.1. Selection hotspots could prove important, even vital, for the design of an effective and usable VE for a given purpose in particular a training environment where selection hotspots can be used for a variety of purposes, such as to provide specific information about an item, to aid the memory of that information or of the items location.

The main interaction problems within VEs were defined in Kaur et al., (1998a, b and c) as; disorientation, perceptual misjudgements and difficulty finding and understanding available interactions. The development of a model of interaction was based on Norman (1988) theory of interaction with the real world. Three inter-connected models described the major modes of interactive behaviour within a VE. The 'task action model' describing behaviour in planning and carrying out specific actions as part of the users task or goal/ intention, the 'explore navigation model' describing opportunistic and less goal orientated behaviour and the 'system initiative model' describing reactive behaviour to system prompts and events and the system taking interaction control from the user (i.e. a pre-set tour of a VE). The aim of this model was to provide a basis for developing design guidelines for interaction within VEs and they were evaluated through user studies. Kaur et al. (1999b) p.405 note that 'tasks in VEs are often loosely structured with more emphasis on exploration and opportunistic action' demonstrating that the opportunity to interact with the VE is almost infinite; therefore ways of encouraging the user to interact with the important aspects of the environment and establishing where interaction can be used most effectively are essential.

Most work within the area of interaction in VEs is concerned with the method of communicating the users' intentions to the virtual world be it the interaction device or technique behind the use of that device (Milne 1995; Poupyrev et al, 1999; Bowman and Hodges, 1999). To date there has been little research into aspects that entice a user to select objects within the environment and of equal importance the consequences of that selection, for example increased recall of those objects selected and improved enjoyment, effectiveness and usability are all possible consequences of well designed selection hotspots.

2.4.2.1 Object Selection

Poupyrev et al. (1997) claim object manipulation within VEs is 'awkward and inconvenient' and suggest reasons for this are

- Lack of tactile feedback
- Lack of tracker noise
- Poor design of interaction techniques
- The weightlessness of objects, a principal difference from the real world

Although the research performed by Poupyrev et al. (1997) centred on the design process of manipulation interfaces for VE applications this opinion indicates the need to investigate further into the area of selection prompts and getting them right in the context of the VR system being used and goal of its use. Poupyrev et al. (1998) suggest that interaction should maximise user performance and result in efficient and enjoyable virtual interfaces. Although the work was centred mainly on interaction devices (the virtual pointer and virtual hand), it is noted that interaction needs to be developed so that the low level motor activities of object manipulation do not distract from high level tasks. Poupyrev et al., (1998) p.41 note that that 'there is little understanding of how VE manipulation interfaces should be designed to maximise user performance in immersive environments' and that as a consequence of this and the fact that research in the area is sparse 'VE designers have had to rely on their intuition and common sense, rather than on research results (p.41)'.

Kaur et al. (1998a, b and c) state that problems with interaction such as disorientation, perceptual misjudgement and finding and understanding available interactions results in user frustration and low usability and acceptability for the VE. Research has been performed into overcoming disorientation and perceptual misjudgement in Murta (1995); Witmer and Kline (1998); Johnston (2001); Sinai, et al. (1999) but little research to date has been done in finding and understanding available interactions. This reinforces the need to develop a clear understanding of design aspects that reduce these negative VR usability factors. Kaur (1999c - p.1 electronic workshop proceedings) notes that designers [of VEs] lacked a coherent approach to interaction design' and also 'They [designers] appeared to be preoccupied by difficult technical issues and thought little about supporting user interaction'. Considering this Herndon et al. (1994) examine methods of evaluating computer interfaces that provides a useful guidance tool of points to consider in the design of selection hotspots. The list comprises of the following points:

- Layout/visibility
- Legibility/affordances
- Ergonomics
- Colour
- Shape
- Feedback

It is also noted that 'when affordances are taken advantage of, the user knows what to do by looking: no picture, label, or instruction is required.' (Norman, 1988 p.9) Although this concept is reasonable in establishing a method for good design practise actually putting it in to practise is not so easy. This concept should be applied directly into the design of selection hotspots; the difficulty comes in knowing how to provide a user with suitable affordances. It should also be noted that the effective application of affordances it is difficult and rarely achieved within the real world without the additional difficulties of applying usable and effective interaction techniques to a virtual world. With the additional fact that there are more cues in the physical world than there are ever in the virtual world due to its very nature it is difficult for the user to understand how to "perform actions in free space" (Bowman et al, 2001). Interaction cues emphasised in a manner to attract attention to prompt action within the virtual world may make the users ability to identify available actions harder. When commenting on menu system requirements (another aspect of selection hotspots within a VE) Bowman and Wingrave (2001) noted that good feedback, affordances, constraints and visible items and actions are all required. These correspond with Norman's (1988) factors of good design practice – affordances, constraints, mappings and feedback.

Marsh and Wright (2000) note that 'if the VE is uninspiring, dull or boring to use, it will not hold participant attention for any period of time'. This puts a strong case for the inclusion of interaction within a VE to make it interesting. Alternatively the interaction method must also be made interesting to make the participant wish to interact initially and to maintain their attention.

Herndon et al. (1994) introduce the concept of functional fidelity as a characteristic of 3D user interfaces to exploit the 'perceptual and spatial reasoning skills' of the user, therefore having a positive effect on the usability and experience for the user. Functional fidelity is defined as the collective sensory cues (colour, movement, sound etc.) provided within a given 'synthetic environment' and the functional fidelity of an application must be appropriate to the tasks being performed. It also states that representation of 3D objects in a scene should be useful, but not necessarily photo-realistic. Other suggested characteristics for interaction are quick responsiveness to user input, interface affordances for what can be done, an appeal to mental representations and multiple/integrated input and output modalities. Future work suggested includes determining how much realism a synthetic environment must have to be understandable, it is currently thought to be task and user experience dependent with few existing general guidelines.

2.4.3 Interaction Conclusions

As shown in this section it is evident that interaction is a fundamental aspect of VR technology and what distinguishes it from other visual systems such as video or animation. Although research has been performed into methods of designing interaction most effectively and to some extent defining the components of interaction, in general work is sporadic and mainly concerns the use of interaction devices. What is clearly still an area of uncertainty is that concerning prompts to specific selection within a VE as opposed to interaction in general (such as navigation and interaction devices). In addition, the benefits achieved from that selection, be it enhancing the user's VR experience or resulting in a more effective learning experience from a training VR system, have not been thoroughly investigated.

With respect to training VR systems, selection provides the additional advantages of not having real world restrictions and therefore it is possible to make certain important aspects of the environment attention drawing so that they are recalled or attended to by the user. This attention can be used in a variety of ways, for example to promote aspects of the environment, provide additional details for the user of aspects of the VE selected or enabling interaction that it may not be possible to perform in the real world (such as safety critical training of emergency control room scenarios in nuclear power stations).

2.5 Measurement of Effectiveness

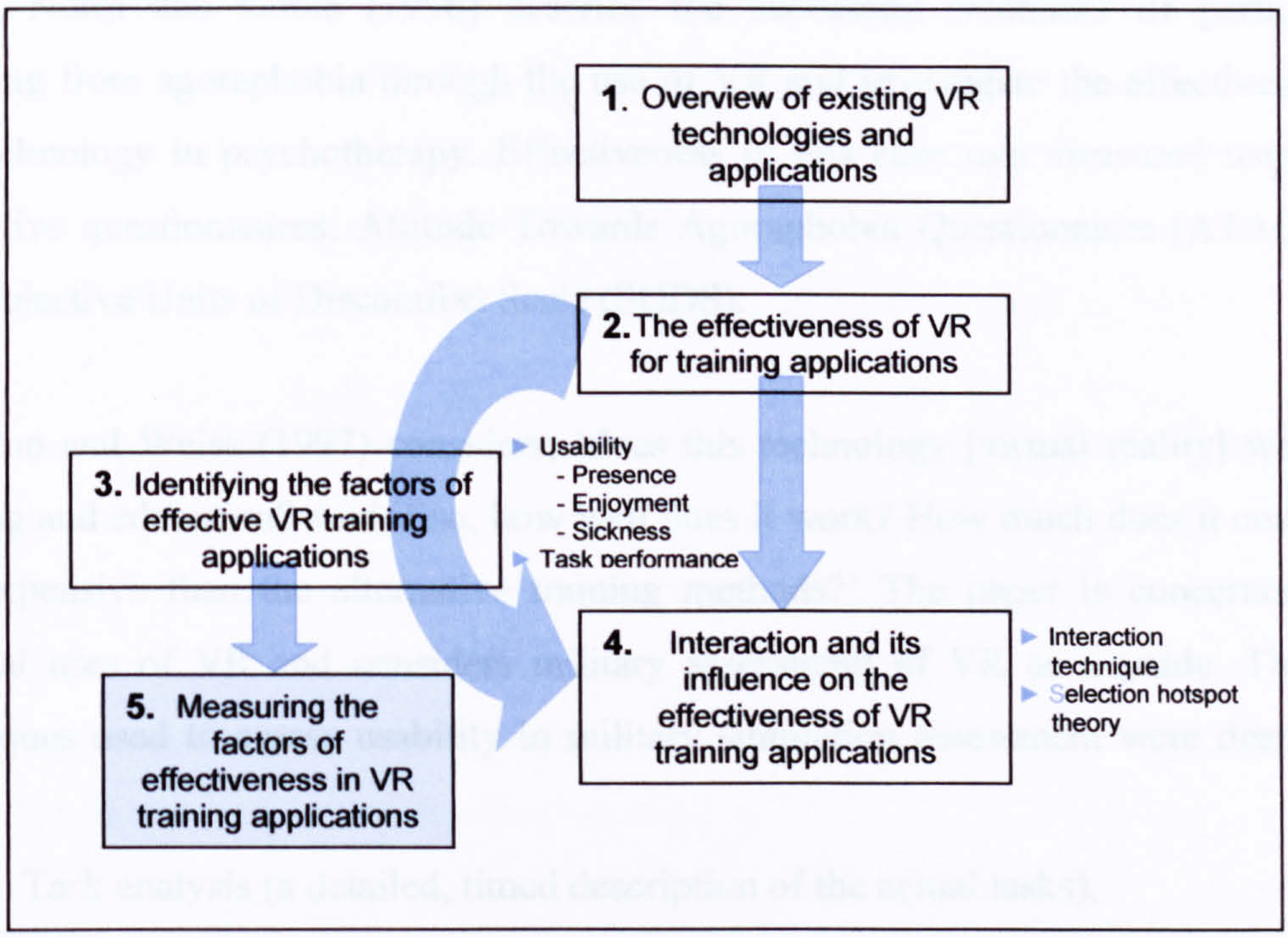


Figure 2-24: Literature review structure – interaction

The following section will review existing methods of measurement of the factors established to influence the effectiveness of VR training applications in '*Factors that Influence the Effectiveness of VR Training Applications*', section 2.3. This will provide a way of assessing the VR systems used within the research programme and how they are influenced by the adjustment of different variables being assessed.

2.5.1 Overview of measures of effectiveness

It has been established through the research presented that the factors of presence, involvement and enjoyment; usability and task performance are all intrinsically linked in influencing the effectiveness of a VE or VR system irrelevant of its application. As a result of this and the evident uncertainty as to the direction of influence between these factors in determining their importance it is thought that methods of measuring all the factors should be explored.

As effectiveness can mean so many things in so many environments a selection of experiments has been examined to establish how the method of measuring effectiveness has been approached in previous research.

North, North and Coble (1996) describe the successful treatment of participants suffering from agoraphobia through the use of VR and investigate the effectiveness of VE technology in psychotherapy. Effectiveness in this case was measured using two subjective questionnaires; Attitude Towards Agoraphobia Questionnaire (ATAQ) and the Subjective Units of Discomfort Scale (SUDS).

Johnston and Weiss (1997) considers; 'does this technology [virtual reality] work for training and education? And if so, how well does it work? How much does it cost? Is it less expensive than the alternative training methods?' The paper is concerned with medical uses of VR and considers military assessment of VR as a guide. The four techniques used to assess usability in military simulation assessment were deemed to be:

- Task analysis (a detailed, timed description of the actual tasks),
- Standard experimental designs (i.e. the pre-test, post-test control group design),
- Transfer-of-training experiments (where the evaluation metric is the actual task),
- Combinations of the above three.

Currently task analysis is used in the assessment of medical applications of VR training.

Hoffman et al. (2001) studied immersive VEs, assessing their ability to control pain for burn victims via distraction. Effectiveness assessment was measured in the form of subjective 'visual analogue pain scores' for each treatment condition demonstrating the successful use of subjective ratings to assess the effectiveness of VR.

Boud, Baber and Steiner (2000) examine the use of VR in a manufacturing environment and the resulting limitations of that use, mainly lack of haptic feedback from input devices. A solution to this was considered with the use of an 'instrumented object' (IO) that allowed manipulation of a representation of the component within the VE. This resulted in faster times indicating that haptic feedback improves assembly effectiveness in this example effectiveness measures were made with respect to the influence of changes made to task performance measured.

The main methods of assessing effectiveness in VEs used to date suggest the use of a subjective questionnaire and/or rating scales relevant to the environment being used, or objective measurements of task performance. Typical methods used include task analysis and standard experimental designs (i.e. the 'pre-test, post-test control group' design). It was suggested by Jordan (1998) that effectiveness be measured by breaking down a task into sub tasks and measure the success or failure of each of these sub-tasks.

It has been shown that factors involved with the assessment of the effectiveness of a VR system are numerous and usually specific to the VR system application being examined. Through further research into the areas of presence, usability and task performance within VR it was found that the influence of these factors is influential on the effectiveness of a system, thereby making them suitable aspects of VR use to examine to obtain a measure of a systems effectiveness.

2.5.2 The Measurement of Task Performance

The measurement of task performance is difficult to quantify as it is almost impossible to form general guidelines; each VR system and VE will vary so greatly with what it is aiming to achieve. General measures can be suggested (Gawron, 2000):

- Time taken – faster time to perform a task may mean an improved task performance
- Errors made – this would require further classification for specific environments as to which form the errors will take, such as collisions within the environment or errors within the task being performed etc.

Kalawsky, Bee and Nee (1999b) state that the entire virtual reality system needs to be considered to evaluate what properties of the system relate to overall task performance. The influence of the prospective application of the VR system should also be considered, for example a training VE must provide the user with the ability to apply the information gained from the environment to the real world.

The measure of task performance may also occur in the form of other influencing factors in the use of a VR system for example the usability or presence experienced by the user, as discussed in 'Factors that influence task performance', section 2.3.3.2..

2.5.3 The Measurement of Usability

There are two distinct considerations with methods of usability testing - reliability and validity. Reliability problems usually occur due to variability in individual characteristics that can not all be easily accounted for, shown to be a potentially large area of concern in the use of VR and a potential stumbling block in their 'take-up' for many applications. Validity relates to the value of the results obtained, how much does the test relate to the real system or object being measured? Existing methods of measuring usability in VR were examined to provide a background into measuring usability in practice.

Neale and Nichols (2001) provide an evaluation method that overcomes problems of 'time consuming' data analysis of iterative continual evaluation and user involvement in the design process and also difficulties in relaying results to designers. Theme Based Content Analysis (TBCA) is a qualitative, flexible method that allows the use of a variety of different data collection methods and the analysis is less time consuming allowing for summarisation and retention of raw data. It allows easy feedback to developers on usability problems from evaluation.

There are many established methods of usability measurement and assessment of a system such as expert walkthroughs, observation of users, verbal protocol and so on which can be carried out pre, during and post system use most of which can and have in someway been applied to the measurement of the usability of a VR system. Areas of usability assessment include areas such as how often it is used, problems in its use such as confusion with how it operates and how effective the outcome of its use is, for example does it supply adequate information?

The following review examines existing methods of subjective measurement, one of the most common and established methods of usability measurement, with respect to VR systems.

Subjective Measurement:

In the usability questionnaire presented by Kalawsky (1999a) the usability factors are split into 10 areas. Table 2-11 demonstrates the goal for each of these factors.

Table 2-11: Key usability factors and goals (Kalawsky, 1999a)

	Usability Factors	Goal
Part 1:	Functionality	The interface should be able to provide the level of functionality (control) the user expects in order to complete the task
Part 2:	User Input	The user should be able to interact with and control the environment in a natural manner
Part 3:	System Output (display)	Information displayed to the user should be understood, unambiguous and necessary
Part 4:	User Guidance and Help	The user should be able to request help via online assistance
Part 5:	Consistency	The operation of the VR system should be consistent with the users understanding and convention
Part 6:	Flexibility	The VR system should not constrain the user who should be able to interact with the system in a flexible manner
Part 7:	Simulation Fidelity	In order to be useful a VR system needs an underlying model or simulation to control the VE
Part 8:	Error Correction / Handling & Robustness	All computer systems should provide error correction and recovery before a permanent change is made
Part 9:	Sense of Immersion / Presence	A VR system should allow a user to feel part of (or immersed in) a VE
Part 10:	Overall System Usability	Overall a VR system should be intuitive and easy to use

100 questions were asked across these 10 parts with answer options of 5 possible responses for each question ranging from 'strongly agree' to 'strongly disagree'. The aim was to establish the level of usability achieved by the environment being tested. The majority of the usability factors examined concern the design of the VE itself and the interaction device.

In a study by Barone (2001) a similar style of questionnaire was designed with the same answer options on a rating scale. Three questionnaires were used, one was in reference to the usability of the environment, one to the usability of the input device used and finally two open ended questions that asked about the user's likes and dislikes again in reference to the environment and the input device used. It was found that different input devices did not affect the task performance times but the accuracy of those performances.

Marsh and Wright (1999) use a method of measurement called co-operative evaluation that combines 'think-aloud' verbal protocol where the user is encouraged to ask questions of the experimenter and vice-versa throughout the experiment.

2.5.4 The Measurement of Presence

Nichols et al. (2000) suggest that the reason presence has no universally accepted measures is that like other manifestations such as mental workload and mental models it is multifactorial and may be physiologically displayed in different ways to different people and consequently it is 'not easily amenable to definition, physiological measurement and even self-report' p.474.

Sheridan (1996) presents the concept of presence as 'natural (expected) responses of human and environment to each other'. This concept has been developed into assessing physical responses by movement or sound into a measure of presence, for example would the human react to a loud noise or swift movement in a VE as they would in the real world? The measure of reflexive responses as an indicator of presence is studying the response of the subject in comparison with a real life reflex response, for example ducking to avoid a missile coming towards the face, explored in Nichols et al., (2000). It has been suggested that this indicates a feeling of presence as the participant reacts to the situation as they would in the real world suggesting they feel to some extent that they are 'there' in the virtual world.

Barfield and Weghorst (1993) acknowledged the need for a set of metrics that can be used to measure performance within VEs and to quantify the level of presence experienced by participants of virtual worlds. Potential indicators of presence were suggested that include virtual world task performance, subjective assessment and degree of disorientation although they do not consider them conclusive. Within this paper it is noted that subjective rating of presence is not entirely dependable but is used in lieu of a suitable and more reliable alternative and provides a good initial indicator for initial exploration. Alternative 'more robust' metrics that are being developed and researched are commented on, for example physiometric indicators such as posture, muscle tension and cardiovascular responses to virtual events, such as heart rate evoked by looming of virtual objects. It was also noted that speed and accuracy on tasks performed solely within the VE might also be influenced by the sense of virtual presence. The possibility of using a secondary task method for measuring presence similar to that used to measure mental workload is considered, where the quality of performance of the secondary task is an indication of the presence experienced by the subject (i.e. poor performance indicates high presence as resources are concentrated on the environment not the secondary task).

Bystrom, Barfield and Hendrix (1999) present the Immersion, Presence, Performance (IPP) model for the measurement of presence. It provides a guide determining the factors that influence presence, aid research into the relationship between immersion, presence and performance in VEs and to help designers of virtual worlds select appropriate display features when they design VEs. Immersion in this case is defined as 'the quantifiable aspect of display technology, primarily determined by the extent to which displays are:

- inclusive, stimuli from the real world is excluded from the user
- Extensive, the number of sensory modalities accommodated by the system
- Surrounding, how panoramic the displays are and
- Vivid, the resolution of the displays.' (p.241)

Slater and Wilbur (1995) argue that a sense of presence in a VE will contribute to user behaviour that more closely matches real world behaviour, such as reflex responses to suitable stimuli. For example an object looming towards the user's head and even to the extent of the user avoiding obstacles even though intellectually they know they do not actually exist.

Freeman (1999) assesses presence by using a hand held slider and participants were asked to continually rate their feelings of presence with continually changing display stimulus.

In Kalawsky, Bee and Nee (1999b) it is suggested that the measurement of presence involves dealing with the following range of measures, *Table 2-12.*

Table 2-12: Measuring presence – Kalawsky et al. (1999b)

Measurement Type	Examples
Objective measures	Task demands Task results Correlated measures- error numbers, achieved task levels etc
Subjective measures	On-line evaluations Post-test evaluation Questionnaires Explanation of high stress
Physiological measures	Heart rate Blood pressure Respiration rate ECG
Task performance	
Learning efficiency	

This is one of the most inclusive lists of possible measurement methods of presence and although a combination of all these measures may provide the most comprehensive measure of the concept of presence that can be achieved realistically it is not possible to measure all these variables with respect to every system. As a result of this most research in the area has concentrated in the use of subjective questionnaires for such a measure or the use of other measures to corroborate the effectiveness of a subjective questionnaire.

Subjective measurement

The following research explores in more detail the existing opinions and methods of research into the area of subjective measurement of presence, the use of questionnaires the most common and often used approach to presence measurement. Existing questionnaires are investigated including how and why they were designed and how they are assessed.

'Subjective assessment, while typically problematic can be useful for initial exploration and hypothesis generation.' (Barfield & Weghorst, 1993, p.701)

Slater and Usoh (1993) assessed 'internal' (factors affecting individual's responses and perceptions to identical external stimuli) and 'external' (parameters of the VE i.e. field of vision) factors on the reported level of presence in a post experiment questionnaire, participants were asked to rate:

- Their sense of 'being there' (in the VE)
- The extent to which there were times during the experiment when the computer generated world became 'reality' for the participants (i.e. almost forgot the real world outside), and
- Whether they thought the computer generated world as something they had seen or somewhere they had visited.

Ratings were on Likert scales (1-7) and a presence score for each participant was a count of the number of 6 or 7 ratings for the response to the three questions, so had a range of 0 to 3. It was found that there was some 'association between a participant's dominant representational style (internal factors i.e. visual, auditory and kinesthetic) and their reported sense of presence'. In this case questionnaires successfully show that individual's characteristics influence their experience of presence when using a VE.

Hendrix and Barfield (1996) used the effect of display parameters on presence ratings within VEs; the same method was used for perceptions of presence within auditory VEs. The two questions used to determine the participant's levels of presence were (p.296):

- 'If your level of presence in the real world is '100' and your level of presence is '1' if you have no presence, rate your level of presence in this virtual world.'
- 'On a scale of 1 to 5, how strong is your sense of presence, 'being there,' in the VE? (Where 1 = very much so, and 5 = not at all).'

They found that responses to the questions were relatively consistent and concluded that 'direct subjective evaluation of presence is an adequate means of assessment' p.300.

Welch (1996) asks for the comparison of paired, visually different VEs (one of high realism and one of low realism) to rate which created the greater sense of presence. On a rating scale of 1 – 100 the participant rated their perceived difference in presence felt within the two environments. Presence was defined as the participants feeling of being physically located within the visual world. It was found that pictorial realism played less of a role in judgements of presence than interactivity or delay feedback (p.270). It is suggested that this is a result of the problem of defining pictorial realism and 'an unconfounded examination of this variable will require keeping complexity constant while varying the degree to which the graphical representation as similar to the real world' (p.270).

Witmer and Singer (1998) produced two questionnaires with the aim of measuring levels of presence within VEs. These were the Presence Questionnaire (PQ), that measures the degree that the individual's experiences presence in the VE and the influence of possible contributing factors, and the Immersive Tendencies Questionnaire (ITQ), that measures the capability or tendency of individuals to be involved or immersed in the VE. The questions have a seven point scale format as used in Slater and Usoh (1993), each item being anchored by opposing descriptors and include a mid-point anchor all based on the content of the question. The main question categories (relating to factors that influence presence) being; Control factors, sensory factors, distraction factors and realism factors. The sub-scales within the questions for the PQ were; involvement/control, natural, auditory, haptic, resolution and interface quality. It was concluded that these factors formulate a base in establishing what influences presence and that the questionnaires are internally consistent with high reliability. Slater (1999) disputes the validity of the questionnaire stating that 'We cannot separate out two different types of entity: a measure of presence and independently a measure of factors that might influence it. Changes in the latter automatically cause changes in the measured response because that is how the measured response is constructed' (p.563).

Barfield and Weghorst (1993) devised a '10 point questionnaire', questions used a 10 point scale anchored at each end, this included an 'embedded sub-scale' that covered the three areas:

- Sense of being there
- Sense of inclusion in the virtual world
- Sense of presence in the virtual world

Areas of questioning included:

- Ease of navigation
- Overall enjoyment and comfort
- Display clarity

They found that 'ease of interaction and indicators of display comfort and quality were shown to be slightly more predictive of the sense of virtual presence than other factors studied given a navigation task.'

Nichols, Haldane and Wilson (2000) used observational measures, recall and self-report to assess levels of presence. Nine questions were produced that used a rating scale of 1 – 7 for the self report, three questions were selected from Slater, Usoh and Steed (1994) that are known to directly relate to presence 'being there', 'somewhere visited or somewhere seen' and 'became more real or present than the real world'. The remaining questions covered areas that could possibly influence presence such as; awareness, depth of world, enjoyable, distraction of the controls, attention and exhilaration.

In Prothero et al. (1995) presence was measured in relation to changes in visual display. Ratings of presence were made on five questions that related to:

- If the participant felt they were in a room using the VE or they were within the environment.
- How real the environment felt.
- To what extent the virtual world become reality and the real world was forgotten.
- If the virtual world felt more like somewhere seen or somewhere visited.
- If the virtual world felt more like a picture or a scene looked at through a window.

Answers were on 1 – 7 rating scales, with larger response values indicating greater presence. Possible options related to the main component in each environment. The results obtained were established to be valid and reliable. It was suggested that the strongest evidence for the validity of subjective measures of presence is the fact that similar questionnaires often lead to predictable results from many studies in a variety of areas of research.

Schubert, Friedmann and Regenbrecht (1999) used a three-dimensional computer game and 75 questions to establish that three components related to presence: 'spatial presence', 'involvement' and 'realness' comparing the VE to the real world. Lessiter et al. (2001) created a general cross-media presence questionnaire this was a 44 item questionnaire using a five part Likert rating scale. Content areas included; a sense of space, involvement, attention, distraction, control, manipulation (i.e. autonomy), realness, naturalness, time, behavioural realism, para-social presence, co-presence, personal relevance, arousal and negative affects. Freeman (1999) recorded responses to questions 'on-line' during the experiment via a hand-held potentiometer.

The main problem in establishing a suitable set of factors to base a questionnaire on, that will be valid and reliable according to previous research, is that few researchers use the same set of measures so comparison across studies is difficult. More recently presence questionnaires have been and are currently being developed that may be valid and reliable across different participant groups, experimental conditions and stimuli (Witmer and Singer 1998; Freeman et al. 2000; Lessiter et al. 2001).

As it has been established there is no acknowledged reliable measure of presence within VEs, because of this questionnaires are the most used though little agreed method of measurement. Existing questionnaires and suggestions from research within this field have been studied and evaluated. Questions that require the subject to write a sentence i.e. open ended questions, (Slater and Usoh 1993) provide broader answers but may reduce the number, and relevance, of the responses and as with most qualitative data it is that it is difficult to analyse accurately.

The main themes that questionnaires have been based on to date that are used to measure presence are as follows, Table 2-13.

Table 2-13: Review of questionnaire themes for measuring presence

Theme	Author
Sense of being there	(Barfield and Weghorst 1993; Slater and Usoh 1993; Hendrix and Barfield 1996; Slater 1999; Lessiter et al. 2001)
Reality of the VE	(Slater and Usoh 1993; Slater, Usoh and Steed 1994; Prothero et al. 1995)
Involvement in the VE	(Witmer and Singer 1998; Schubert, Friedmann and Regenbrecht 1999; Lessiter et al. 2001)
Belief of the VE	(Prothero et al. 1995)
Was the environment able to startle or distract	(Witmer and Singer 1998)
Enjoyment of the VE	(Barfield and Weghorst 1993; Nichols, Haldane and Wilson 2000; Lessiter et al. 2001)
The environment was like a place visited rather than images seen	(Slater and Usoh 1993; Prothero et al. 1995; Slater 1999)
Extent VE becomes dominant and users respond to VE events not RW	(Slater 1999)

The review also demonstrated that a rating scale of possible answers to questions is the most regularly used method of designing a questionnaire, most of which have provided significant results with respect to presence. Ratings tended to range from 'not at all' to 'totally' with 5 –7 options in relation to the most common themes as noted above.

Objective Measurement

Presence is a subjective mental state and because of this it could be said that subjective measures are a more appropriate method of measuring levels of presence experienced within a VE. With this in mind it has still proven difficult to find a reliable subjective method of measurement and as a result objective measures are now slowly being developed that can be used as indicators of presence. As noted by Welch (1996) 'neither of the two types of measures is sufficient by itself' and 'Ideally, then, one should employ both measures in order to avoid the limitations of either by itself.' (p.264)

In Nichols, Haldane and Wilson (2000) a pre-programmed startle event was randomly timed to occur during the experiment and the participants response was classified into three categories – No reaction, verbal report of a reaction or a physically noticeable reaction. The experiment indicated statistically that there was some correlation between direct measure of this reaction and self-report measures of presence.

Barfield and Weghorst (1993) noted that subjective measures, though useful, will eventually be supplanted by more robust metrics which may include physiometric indicators (posture, muscle tension, ocular responses). 'The basic idea behind these measures is as follows: Just as humans experience changes in physiological parameters in response to novel or unusual stimuli, as the sense of presence increases within a VE, the participant should experience similar physiological changes.' (p.702). It is suggested an example of measuring the blink response to an object on a collision course with the participants virtual eye, though they do not use any such measures in the experiment that they conducted. It was also suggested that the introduction of a secondary task (as in the measurement of mental workload) and measuring the performance of that task indicates the level of attentional resources allocated to the primary task and therefore level of presence (i.e. lower performance means a higher level of presence).

Slater, Usoh and Steed (1994) made the point that within their experiment almost all the participants carefully avoided collisions with virtual objects even though they knew there were no real objects, and as a result most of the participants are feeling a strong sense of presence but do not exhibit or report it as they do not see anything out of the ordinary in what is happening. This aspect of possible discrepancy between presence shown and presence reported can be reduced by observing the behaviour of the subject within the environment and taking this into account when assessing the level of presence that was experienced.

In Freeman (1999) participants were required to rate their level of presence continually using a hand held slider with respect to varying television picture quality and a feeling of presence. This introduces the concept of measuring presence continually during the experiment but not disturbing the participant and their possible level of presence by asking questions or requesting continual verbal protocol. This theory can be adapted for objective measurement during experimentation.

Slater and Usoh (1993) suggested approaches of measuring presence that included observations of the user's behaviour, taking observational reactions to certain situations as confirmation of the user's presence, for example shying away from looming objects or replying to a 'hello' message (p.226). Informal investigations were performed into objective measures of presence by studying reactions of participants when simulated objects fly towards their face, though no conclusions were drawn from the data collected. The data demonstrated that those who had an adverse effect to being on a plank over an abyss in part of the environment tested did not rate themselves as being present. It was suggested that this may be as the participants were rating their overall impression and their sense of presence varied over time.

A proposed measure discussed in Nash et al. (2000) is the direction of conflict resolution when two separate stimuli (one from the real world and one from the virtual world) present different information. This type of measure may entail the ability to recall and describe the event and the speed of reaction to an event. Slater and Usoh (1993) looked informally at how people reacted to someone dropping a cup in the background in the real world and the participants reaction when asked the time whilst wearing a HMD so could not see their wrist (i.e. natural reaction would be to look at their wrist), no conclusive results were reported. Draper, Kaber and Usher (1998) suggest measuring objective or physiological and subjective measures to see how much they correlate.

It is clear that there are currently few established methods of the objective or subjective measurement of presence. As suggested by Welch (1996) using both subjective and objective methods to assess presence would improve the validity of the results. The main methods of achieving this are observing participants with respect to their responses, and if the responses are as they would respond in the real world. This is can be separated into vocal and visual responses to stimuli within the environment as shown in Nichols, Haldane and Wilson (2000).

2.6 *Discussion*

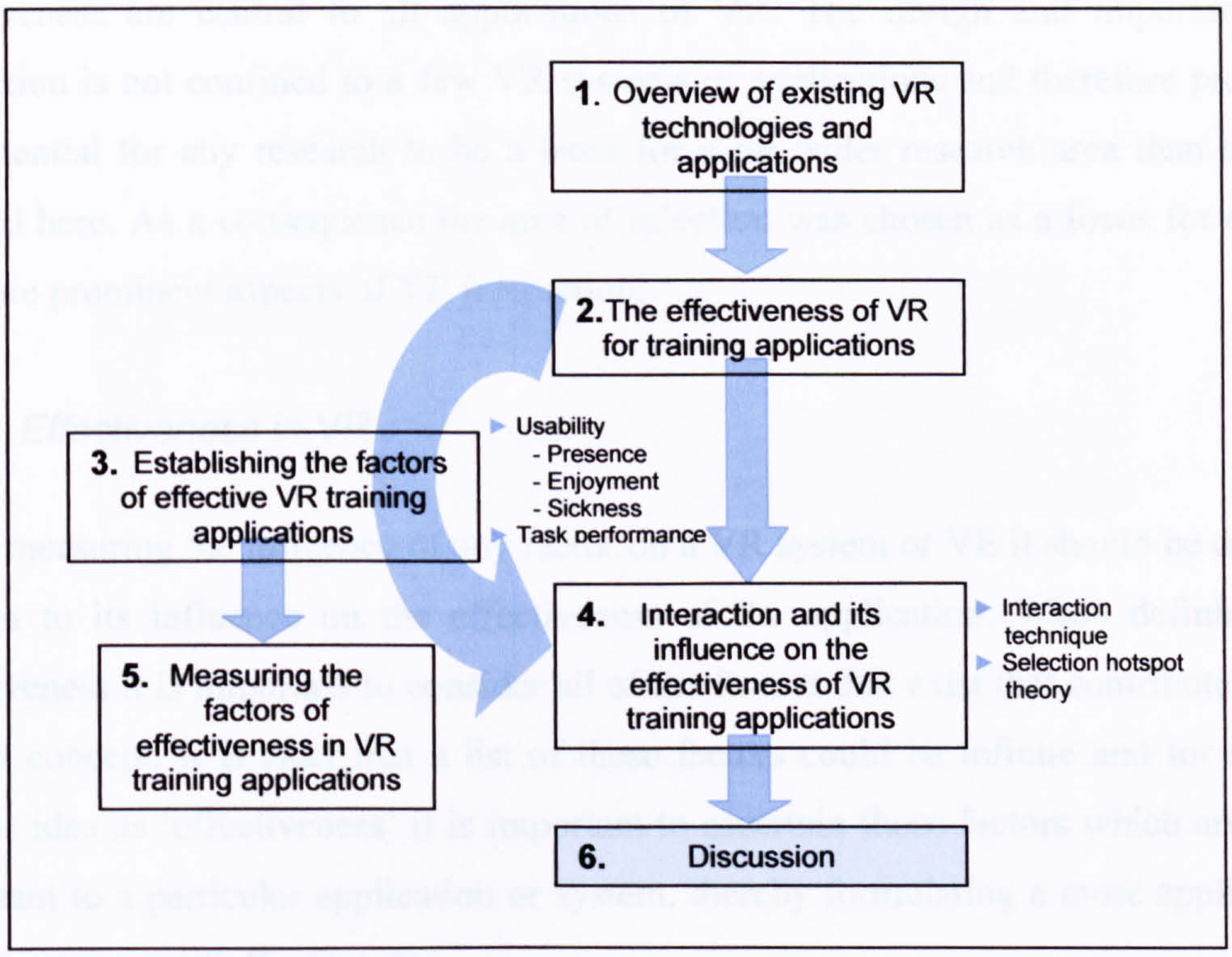


Figure 2-25: Literature review structure – discussion

The discussion will include the choice made for this research programme with respect to the direction of research, taking into consideration the application of VR for training, factors of VR use chosen to measure the effectiveness of a VR training system, how the factors are measured and the technology used to assess them.

2.6.1 *Identifying the Research Area*

'Interactivity is the critical, distinguishing attribute of VEs that defines the difference between VEs and other 3D modelling systems' Tromp et al.,(2003)

Interaction with a virtual environment, in this case, is defined as 'any action on the part of the participant that results in a change in the VE' (Tromp et al., 2003) which includes both selection and navigation and is a defining concept of VR. For a fundamental aspect of VR the research area of designing interaction and establishing its influence on the effectiveness of a VR application has had very little attention.

Interactivity has been selected as an elemental concept within VR that has been little explored. Aspects such as how and when it should be applied to achieve the greatest effectiveness are central to all applications of VR. The design and importance of interaction is not confined to a few VR systems or applications and therefore provides the potential for any research to be a basis for a far wider research area than can be covered here. As a consequence the area of selection was chosen as a focus for one of the more prominent aspects of VR interaction.

2.6.2 Effectiveness in VR

When measuring the influence of any factor on a VR system or VE it should be done in relation to its influence on the effectiveness of the application. When defining the effectiveness it is important to consider all of the factors that exist that contribute to the overall concept. It is clear that a list of these factors could be infinite and for such a generic idea as 'effectiveness' it is important to ascertain those factors which are most important to a particular application or system, thereby formulating a more application specific measure of effectiveness.

As discussed ('Defining Effectiveness', section 2.3.1) effectiveness can be defined as the extent to which a specific goal or task was achieved, or if a user experienced success or failure at a given task. When applying this concept to VR systems it can be interpreted as the goal or task to be achieved according to the desired outcome of the systems use, for example how much is recalled from a training VE? From previous research it has become evident that the concept of effectiveness does not stand alone as a measure of task performance in a VR system, other factors have an influence concerning both the system and the user. System effectiveness is influenced by its usability and user effectiveness is influenced by both usability and presence. Figure 2-26 illustrates the influence of the factors of usability and presence on task performance and consequent effectiveness of the VR system.

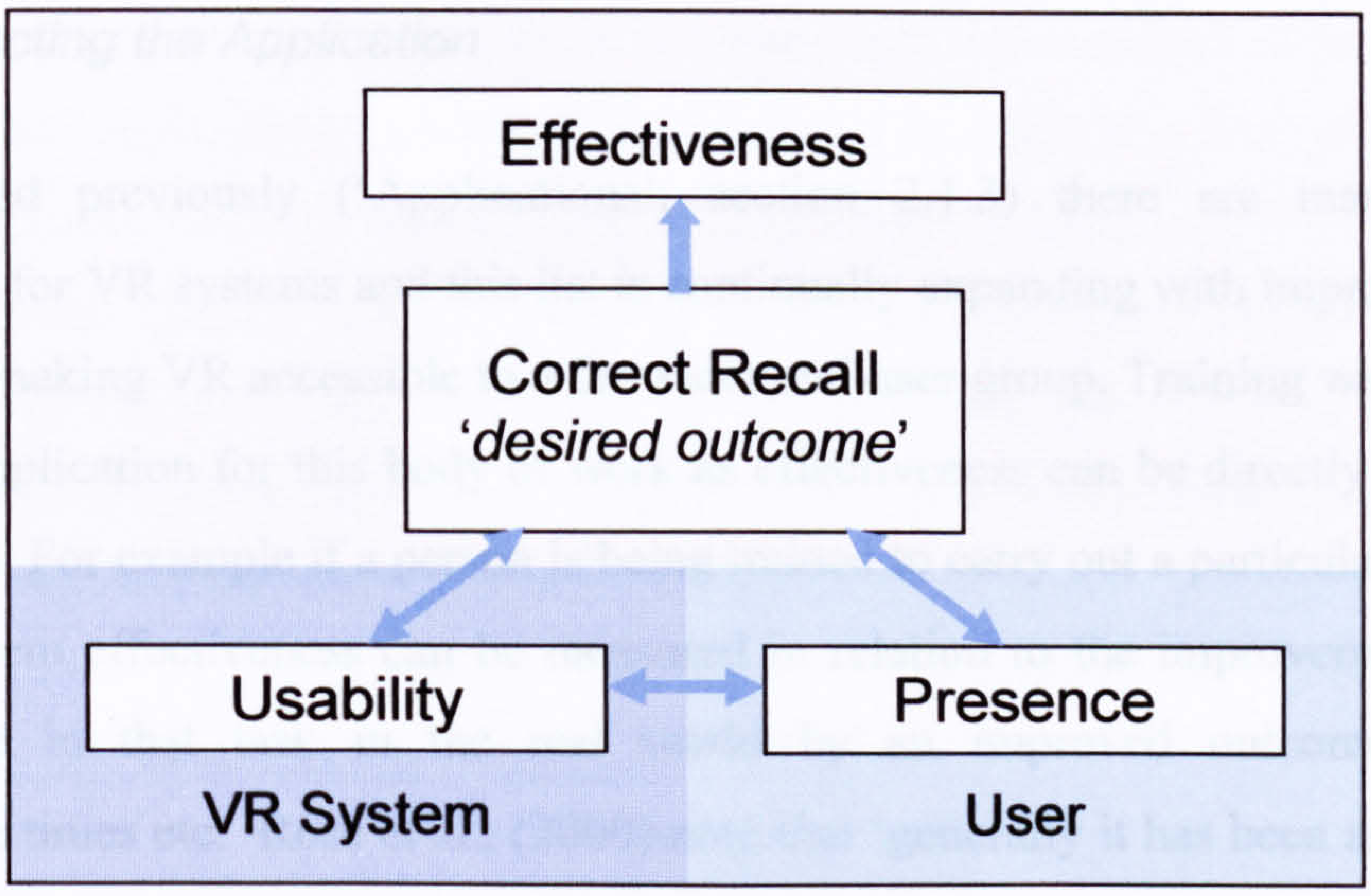


Figure 2-26: The elements of VR effectiveness

The effectiveness of a VR system or VE can be defined as the level of task performance achieved within it. The link between presence and task performance has been observed in Barfield et al., 1995; Romano et al., 1998; Bystrom et al., 1999 and Mania and Chalmers, 1999. Usability defined by ISO, 1995; Preece, 1994 and Nielson, 1993 includes task performance and effectiveness as a measure suggesting that the number of errors made, the efficiency of the system etc. all indicate the usability of that system. There is also a link evident in previous research between presence and usability, Witmer and Singer (1998) state interface awareness, immediacy of control, separation anxiety/disorientation among others as defining aspects of presence all of which would also contribute to the usability of a system. Many aspects of the usability of a VE (Lindgaard, 1994; Preece, 1994; Nielson, 1993) are directly comparable to the concept of effectiveness, for example the following.

- What is learnt/remembered from the VE use
- How effective/efficient the VR system is at achieving its aim
- The user's attitude towards the VR system

It is evident that there is a need to measure the presence experienced by the user and usability of a system as well as effectiveness measures deemed necessary for the VR application being studied to achieve an overall effectiveness assessment.

2.6.3 Selecting the Application

As examined previously ('Applications', section 2.1.3) there are many existing applications for VR systems and this list is continually expanding with improvements in technology making VR accessible to a far wider end-user group. Training was chosen as a suitable application for this body of work as effectiveness can be directly assessed in relation to it. For example if a person is being trained to carry out a particular task using the VR system effectiveness can be measured in relation to the improvement of their performance in that task in the real world by an improved outcome or faster performance times etc. Rose et al., (2000) note that 'generally it has been assumed that training in VEs will transfer to subsequent real world performance.' (p.295) Indicating that this is a suitable measure of effective training. It should also be acknowledged that performing research into training applications makes the findings directly applicable and relevant to training VE and VR systems as one of the most diverse and well used existing applications of VR.

The suitability of VR as a training tool has often been researched and many studies have been performed to examine the effectiveness of training transfer from the VE and VR system to the real world. It has been shown that the transfer of knowledge from VR to the real world does occur with respect to spatial knowledge transfer (Regian, Shebilske and Monk, 1992; Waller et al., 1998 and Brooks et al., 1999). To some extent procedural knowledge transfer has been shown to be effective (Regian et al., 1992; Brooks et al., 1999) though it is not an area that has received a vast amount of study and consequently neither type of effective knowledge transfer occurring from VR training can be stated emphatically.

Rose et al., (2000) note that the benefit of VR training could be as a result of the 'VE affording the participant a general familiarity with the associated real world situation. Alternatively, it could be due to the salience of particular cues being increased, specific sequences of actions being rehearsed or ... spatial memories being laid down procedurally' (p.495). This suggests that using VR for training purposes is both a valid and effective application of the medium. Although Waller et al., (1998) state that 'In fact, virtual training simulators are effective only to the degree that they enable a user to apply knowledge or skills acquired in the VE to their real world counterparts.' (p.129)

This indicates that generic information is not learnt and systems need to be specialised to the particular application. Consideration must also be made to a final point made in Rose et al., (2000) that 'the overall beneficial effect of training in a VE will mask a mixture of more specific effects, some of which will facilitate correct real world performance (positive transfer) and some of which will hinder it (negative transfer)' (p.496). It is possible that the factors researched will have both a positive and negative effect on the effectiveness measures recorded.

2.6.4 Selecting Measurement Methods

It has been established that to measure the effectiveness of a VR system its usability, presence and task performance should be examined (*'Factors that Influence the Effectiveness of VR Training Applications'*, section 2.3). There are many ways in which these factors can be measured, an effective method of measuring presence and usability has been subjective questionnaires (usability: Barfield et al., 1998; Kalawsky, 1999. Presence: Slater et al., 1994; Witmer and Singer, 1998; Nichols et al., 2000a). Main influences on these factors such as sickness experienced in relation to the systems used should also be measured (Nichols et al., 2000). The measures of task performance should be developed in relation to the VR application and the desired outcome of its use.

2.6.4.1 Usability

It was decided that usability would be measured through the use of a questionnaire. This is a tried and tested method of measurement that provides directly comparable results between systems and VEs ('Usability', section 2.3.2). The questionnaire used was designed as part of the VIEW project (Patel et al. 2001) and were administered post immersion. Development of the questionnaire occurred through expert discussion and by adaptation of questions and themes from existing questionnaires (Barfield et al., 1998; Kalawsky, 1999). For questions see appendix '*All Experiments - Usability Questionnaire*', p. 267.

2.6.4.2 Presence

Presence is most commonly measured through the use of questionnaires and although objective measures are being developed, current thinking is that the most reliable method of assessing this elusive concept is through a subjective questionnaire. The questionnaire used was developed for use through the VIEW project (Patel et al. 2001) and were administered as soon as the participant had completed their task using the VR system, thereby ensuring that responses were as true as possible to the experience and limiting the chance of distraction. Development of the questionnaire occurred through expert discussion and adaptation of questions and themes from existing questionnaires (Barfield and Weghorst, 1993; Lessiter et al., 2000; Nichols et al., 2000a; Prothero et al., 1995b; Schubert et al., 1999; Slater et al., 1994; Welch et al., 1996; Witmer and Singer, 1998). For questions see appendix '*All Experiments - Presence Questionnaire*', p. 266.

It is noted that the experience of VR systems may induce sickness effects, usually common in more immersive systems. This may have a detrimental effect on both the usability of the system for the user and for their experience of presence. To monitor this possible influencing factor the 'short symptoms checklist (SSC)' (Nichols et al., 2000) was administered at the start, every 10mins during immersion and at the end of the VR immersion for each participant. It was thought that administering the SSC would not have a vastly negative effect on the presence experienced by the participant if the system used was not very immersive and outside influence (visual and audible) is possible. See appendix '*All Experiments - Short Symptom Checklist*', p. 269.

2.6.4.3 Task performance

The chosen application for this research is training, as a consequence the measure of task performance must relate to how well the information being trained is learnt (recalled) by the participant. To apply this a training task should be formulated for the participant to carry out whilst using the VE where performance can be related to the real world that is meaningful to all participants and that can be tested in the real world upon which it is based. As reported in Nichols et al., (2000) VR system exposure should ideally not exceed 40-60mins to minimise the possibility of sickness symptoms being experienced. It was decided that a task should be taught by a VE based on the real world so it can be established if knowledge learnt can be transferred to the real world. As this is a realistic commercial application, findings would be relevant to real VR applications. It will also provide meaningfulness to the participants VR experience and as a result make a more interesting and enjoyable experience.

2.6.5 Selecting a VR system

There are many potentially suitable VR systems that can be used in VR training ranging from the basic desktop PC set-up to the hi-tech CAVE or aircraft simulator. Initially the fundamental deciding factor in the choice of system is cost. This will vary hugely between display systems used, interaction devices chosen and software the VE is developed on and so forth. A further consideration in system choice is the potential end user. It has been established that the application is training, it must therefore be considered who needs to receive the training, questions should then be asked such as; are they computer literate, and with what kind of interface? What is their physical ability? And so forth. Finally the specifics of the application should be considered if the task is to train a difficult physical task such as a surgical procedure for effective training a system with realistic visual, audible and tactile feedback will be required to provide adequate and useful training, whereas training procedures within a classroom a simple desktop system may be sufficient.

The use of a desktop PC VR system was chosen for the development of a suitable training VE as the software (i.e. Superscape ®) is readily available and does not have a long programming time, even for a non-expert to develop the VE initially and to maintain it. Whilst this software is no longer in active use in the VR world in general, it remains an excellent tool for prototyping VEs and the interaction methods supported are similar to those used with other more current systems. The PC is relatively inexpensive and is readily available, with no need to purchase specialised equipment, familiar and inexpensive interaction devices can be used with a desktop system such as a PC mouse for selection and joystick for navigation. These points are also directly applicable to a system being used in a commercial or industrial context, particularly with respect to financial factors. A desktop VR system provides a familiar interface to users of all levels of computer literacy, this familiarity reducing the chance of negative usability factors. The system is also not very immersive thereby reducing the chance of simulator sickness experienced by the user (Nichols et al, 2000). A PC may need additional graphics cards to run VR software (i.e. ATI, Nvida) this enables the upgrading of existing computers that can be done if and when required. Upgrades need not be brought all at once but if and when they are required and more can be easily added meaning initial financial outlays can be minimal.

Orr, Filigenzi and Ruff (2002) concluded that a 'low-cost, VR simulator can provide effective safety training for mine workers' and that 'this method provides a basis not just for gaining knowledge about job hazards but for changing unsafe behaviours in mine workers'. AIMS (2004) research at The University of Nottingham uses a software tool that can be easily programmed and run on a PC to train with the use of a VE. Claiming that the use of a PC makes the software more accessible to firms to include within their training package existing within the company without the need for the purchase of expensive equipment. Suggestions in Waller et al., (1998) are that 'immersive VE training may be no more effective than desktop VE'.

As discussed, desktop VR systems are not state of the art technology within this area of research but it can certainly be argued that fundamental interaction devices based on the mouse (2D or 3D) or joystick for separate selection and navigation using a projected image of a VE is the basis of many of the more advanced VR systems. The level of VE detail achievable is also certainly similar to other state of the art sophisticated VR technology experienced through the VIEW project at the Fraunhofer Institute, Stuttgart including a six walled CAVE system (Patel et al., 2003). This presents a strong case for the transferability of findings to more sophisticated systems that fundamentally use similar methods.

2.6.6 Conclusions

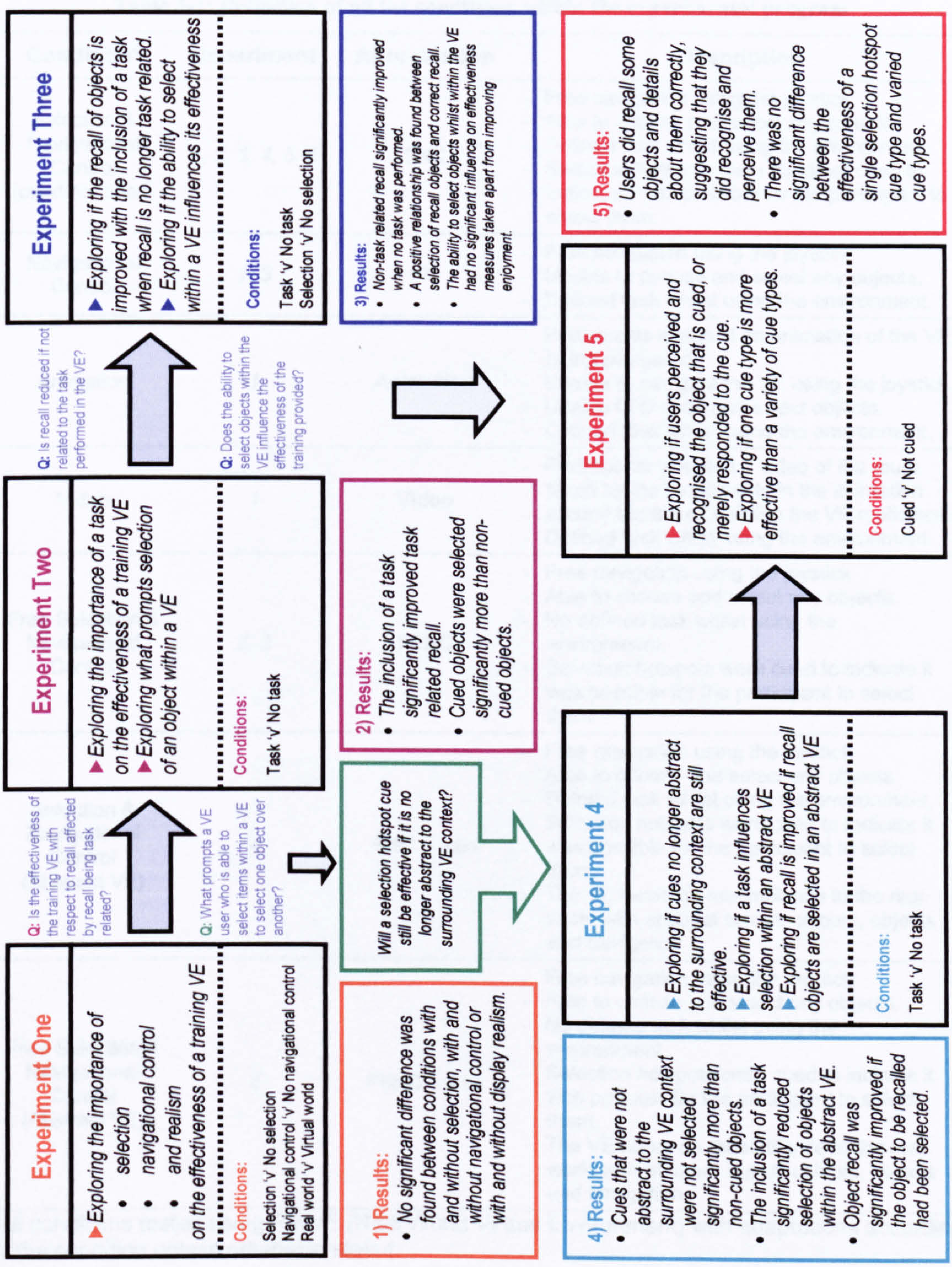
This discussion reviews the areas of VR that have been examined and assess the most appropriate area and method of study. It has been established that the area of object interaction within non-immersive desktop training environments will be examined with respect to its influence on effectiveness measured in the form of task performance, usability and presence.

Waller et al., (1998) state that 'researchers no longer need to question whether VEs can be effective in training spatial knowledge. Today's more pressing research questions involve examining the variables that mediate the training effects of VEs.' (p.130).

Chapter 3 - Programme of Experiments

The following diagram represents the experimental programme undertaken in this research indicating the order in which the experiments were performed and details of what was being examined and the main findings leading to further experimentation.

Figure 3-1: Experimental programme flow diagram



3.1 Experiment conditions

Table 3-1 provides details of the conditions explored in the experimental programme as shown in Figure 3-1. It can be seen that some conditions were repeated throughout to allow for comparison between experiments.

Table 3-1: Definition of all the conditions within the experimental program

Condition*	Experiment	Abbreviation	Description
Selection & Navigational Control (cued/not cued)	*1, 2, 3, 4, 5, 5*	**SNC**	- Free navigation using the joystick - Able to choose and select any objects. - Defined task whilst using the environment. - Selection hotspots were cued/not cued to indicate it was possible for the participant to select them.
Navigational Control	*1, 3*	**NC**	- Free navigation using the joystick - Unable to choose and select any objects. - Defined task whilst using the environment.
Animation	*1*	**Animation**	- Participants watched an animation of the VE being navigated. - Unable to navigate the VE using the joystick - Unable to choose and select objects. - Defined task whilst using the environment.
Video	*1*	**Video**	- Participants watched a video of the route taken by the participants in the animation around the actual building the VE replicates. - Defined task whilst using the environment.
Free Selection & Navigational Control	*2, 3*	**FSNC**	- Free navigation using the joystick - Able to choose and select any objects. - No defined task whilst using the environment. - Selection hotspots were cued to indicate it was possible for the participant to select them.
Selection & Navigational Control (Abstract VE)	*4*	**SNC – Abs**	- Free navigation using the joystick - Able to choose and select any objects. - Defined task whilst using the environment. - Selection hotspots were cued to indicate it was possible for the participant to select them. - The VE bears no resemblance to the real world with abstract layout, colours, objects and navigation
Free Selection & Navigational Control (Abstract VE)	*4*	**FSNC – Abs**	- Free navigation using the joystick - Able to choose and select any objects. - No defined task whilst using the environment. - Selection hotspots were cued to indicate it was possible for the participant to select them. - The VE bears no resemblance to the real world with abstract layout, colours, objects and navigation

*all conditions tested using RWVE (Real World Virtual Environment) with adaptations according to the condition unless otherwise stated.

3.2 Experiment Design

The following section describes in detail the equipment, procedure and measures used within the experimental programme. A detailed description of which is given here to avoid repetition of details throughout the thesis.

3.2.1 Experiment Equipment

All experiments were run on a PC (Desktop Pentium 400 PC with 17" monitor running Superscape VRT with speakers) with a joystick for navigation control (where applicable) and a mouse for selection (where applicable). The participant interaction with the VE using the joystick with 4 DOF (degrees of freedom) and the mouse was observed for analysis using a digital camcorder, a quad mixer and scan converter on a TV/video combination[1], see Figure 3-2.

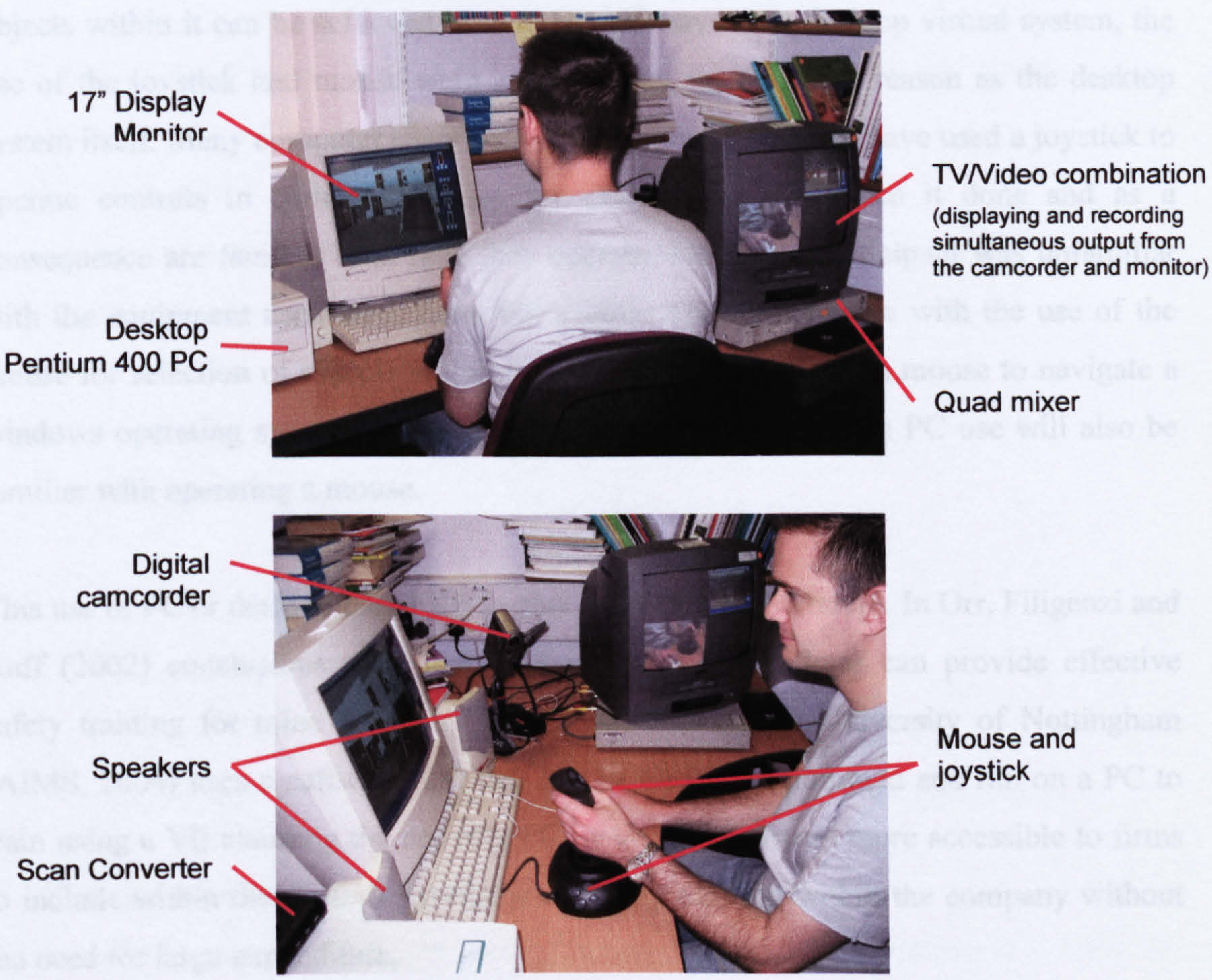


Figure 3-2: Photograph of experiment equipment set up

[1] As seen in Figure 3-2 the scan converter and quad mixer enable the simultaneous viewing (and recording) of the video camcorder output and monitor display on the TV/video combination.

A video recorder was used to make the video of the real world and the TV video combination was used to show the video to participants for condition 4 (Video condition). A minidisk recorder was used for the real world testing to support written notes.

The equipment on which the environment was displayed was carefully selected. It was reasoned that for the training to be accessible to as many potential end users as possible then a normal desktop PC set-up that is familiar and consequently user friendly would be most appropriate to cater for possible varying degrees of computer literacy. A desktop system also has the additional benefit of requiring little financial outlay on top of hardware that a user is likely to already have, particularly initially when potential users are usually most wary of paying for new systems such as this where they have not yet proven to be effective in their particular organisation. Navigating a VE and selecting objects within it can be achieved in a variety of ways on a desktop virtual system, the use of the joystick and mouse were again chosen for the same reason as the desktop system itself. Many computer users with only limited experience have used a joystick to operate controls in computer games for example or have seen it done and as a consequence are familiar with how they operate. No single participant was unfamiliar with the equipment used throughout the testing. This is the same with the use of the mouse for selection of objects within the VE. PC users will use a mouse to navigate a windows operating system and therefore if they are familiar with PC use will also be familiar with operating a mouse.

This use of PC or desktop based VR is also supported by literature. In Orr, Filigenzi and Ruff (2002) conclusions were that a 'low-cost, VR simulator can provide effective safety training for mine workers'. AIMS research at The University of Nottingham (AIMS, 2004) uses a software tool that can be easily programmed and run on a PC to train using a VE claiming the use of a PC makes the software more accessible to firms to include within their training package currently existing within the company without the need for large expenditure.

3.2.2 Experiment Procedure

Before the start of the experiment participants were required to complete a number of consent forms and demographic questionnaires. This was to ensure adherence to University of Nottingham ethical review committee requirements and to obtain suitable measures in the varying experimental conditions (see appendix, p.262). Participants were also given written instructions concerning what they would be required to do (appendix, p. 263) during the experiment and were given a short demonstration on how the equipment works. They were then given the opportunity to ask questions before carrying out the task using the desktop VE described according to the condition. At the start, end and every 10 minutes during experiment the short symptoms checklist (SSC) was applied (appendix, p.269). Symptoms were not analysed after experiment one where very low measures were recorded but the SSC continued to be applied to ensure no adverse effects were experienced by participants and to meet ethical requirements.

Participants were asked to complete the following measures after the experiment:

- Presence questionnaire (appendix, p. 266)
- Usability questionnaire (appendix, p. 267)
- Enjoyment questionnaire (experiments 3, 4 and 5 only – Appendix, p. 268)
- Recall test, these varied for different experiments (see *Table 3-2*)

Table 3-2: Recall tests performed in each experiment

Experiment Number	Recall Test performed*
1	Real world (RW) recall
2	RW recall
3	Object position recall (pictorial)
4	Object recall (written)
5	Missing Objects recall (pictorial)

For details of methods of recall testing refer to appropriate experiment chapter

- Participant record (appendix, p.270)

All the experiments were recorded on split screen video analysis equipment to allow for post experimental analysis of the objects that were selected by the participants. All participants were paid for their time.

3.2.3 Experiment Measures

The same measures were taken across all conditions in all experiments as far as was possible, according to the experimental condition, see Table 3-3.

Table 3-3: Measures taken in each experiment

Experiment Number	Measures Taken
1	Recall, Presence, Involvement, Usability, SSC, Time Taken
2	Recall, Presence, Usability, Selection, SSC
3	Recall, Presence, Usability, Enjoyment, Selection, SSC
4	Recall, Presence, Usability, Enjoyment, Selection, SSC
5	Recall, Presence, Usability, Enjoyment, Selection, SSC

The following sections describe the development and selection of the measures applied, for details of reasons for methods chosen please refer to 'Selecting Measurement Methods', section 2.6.4 and for questionnaires see appendix, p.262.

3.2.3.1 Presence Measurement

The presence questionnaire used was developed by VIRART as part of the 'VIEW of the future' project (Patel et al., 2001). This consisted of questions aimed at examining the participants' level of presence whilst within the VE and was administered post-immersion. The questionnaire was based on work previously performed by Barfield and Weghorst, 1993; Lessiter et al., 2000; Nichols et al., 2000a; Prothero et al., 1995b; Schubert et al., 1999; Slater et al., 1994; Welch et al., 1996 and Witmer and Singer, 1998. The responses were measured on a five point scale ranging from 'strongly agree' to 'strongly disagree' with a value of five being allocated for the most positive possible answer that could be given (this varied as some questions were ask positively and some negatively) and one to the least. A presence score was then awarded to each participant as a total of each score for each question – the higher the score the higher the indicated sense of presence reported by the participant.

The presence questionnaire (appendix, p. 266) was adapted slightly for conditions 'animation' and 'video' in experiment one as some questions referring to interaction within the VE were not applicable (throughout the words 'virtual environment' were replaced with 'display' and wording adjusted accordingly to make it generally applicable, questions 8, 10-12 and 15 were removed).

3.2.3.2 Usability Measurement

Usability was measured using a usability questionnaire (appendix, p.267) developed for the 'VIEW of the future' project (Patel et al, 2001) based on work by Barfield et al., (1998) and Kalawsky, (1999). Questions were asked of each participant concerning their opinion on the usability of the VE that they had just experienced. Again responses were made on a five point scale ranging from 'strongly agree' to 'strongly disagree', the most positive response being awarded 5 and the least 1 producing a final usability score per participant.

For the 'animation' condition in experiment one the usability questionnaire was adapted as it also referred to interaction (questions 6-8, 12-14, 16-19, 21, 24-30 were removed).

3.2.3.3 SSC – Short Symptoms Checklist

It has been recognised that sickness is a possible outcome of the use of some VR systems (Nichols et al., 1997; Nichols et al., 2000) influencing the experience of the VE for the participant and possibly the effectiveness of the VR application. A training VE may be used by a wide variety of users who will spend varying amounts of time using the medium depending on their ability. As a result of the potentially hugely variable end user group a desktop VR system was chosen for this research to limit the influence of these effects as it has been shown to have a less adverse effect on participant sickness than more immersive mediums such as headsets or 3D displays (Nichols et al, 2000). To confirm that this medium did not promote high levels of symptoms the short symptoms checklist (Nichols, 1997, see appendix, p.269) was administered to all participants in all conditions before, during (every 10mins) and after immersion in each experiment to monitor participant sickness symptoms throughout the experimental programme. This also met ethical requirements and participants where informed that they could withdraw at anytime during the experiment if they felt any negative effects, though no participants did. The SSC consists of six common sickness symptoms experienced by VR users (headache, eyestrain, blurred vision, dizziness (eyes open), dizziness (eyes closed) and sickness) a list of which were shown to the participants who were then asked to rate their feelings of each symptom a rating scale of 0 (no symptom) to 10 (severe symptom).

3.2.3.4 Enjoyment Measurement

Enjoyment was measured from experiment three onwards (appendix, p.268) as it was considered a further motive for the inclusion of interaction (selection and navigational control) within a training VE, as it is possible that if a participant enjoys using a training environment they may recall more information about it thereby making it more effective.

A question relating to the user's enjoyment whilst within the VE was already asked in the presence questionnaire but it was thought that enjoyment should be measured as a separate entity after the completion of experiment two. The method used to examine participants' enjoyment as a consequence of their VE experience was the enjoyment questionnaire (Nichols, 1997). This consisted of a checklist of adjectives (such as 'happy' and 'bored' and 'panicked'), where participants rated on a five point scale ranging from 'never' to always describing the degree to which they felt various emotions during the VE experience. The questionnaire consisted of six positive and six negative adjectives and scores were applied to each participant response, 5 being the most positive response possible and 1 being the most negative response possible. Participants were then given an overall enjoyment score. As enjoyment is considered an aspect of presence and usability (Nichols, 1999) within a VE it was anticipated that the scores obtained would have a positive relationship with those of presence and usability.

3.2.3.5 Selection Measurement

Participant selection of objects whilst within the VE was measured as a possible influencing factor on the effectiveness of the training provided by the VE and was considered in a variety of ways, see *Table 3-4*.

Table 3-4: Selection measures taken in each experiment and research questions asked

Exp. #	Selection Type Measured	Definition	Selection Research Questions
1	None		-
2	All objects	Every item selected by the user.	- Does a cue increase the likelihood of selection of an object? - Which is the most effective (most selected) cue type?
3	Cued recall objects	Every item selected by the user they were required to recall after the experiment.	- Does the selection of non-task recall objects increase the chance of their recall?
4	Cued objects	Every item selected by the user that was in some way cued.	- Does a cue increase the likelihood of selection of that object if cue is no longer abstract to the surrounding VE context? - Which is the most effective (most selected) cue type? - Does the selection of non-task recall objects increase the chance of their recall?
5	Cued recall objects	Every item selected by the user they were required to recall after the experiment.	- Does a cue increase the likelihood of selection of that object? - Is a single cue design more effective (more selected) than varied cue designs? - Does the selection of non-task recall objects increase the chance of their recall?

Selection was defined as the participant clicking on an object in the VE using the mouse. It was measured using split screen recording of the computer monitor as the participant viewed it and a video recording of their hands as they interacted with the environment using the mouse and the joystick.

3.2.3.6 Recall Measurement

Recall was measured as an important indicator of the effectiveness of a training VE as if a participant fails to recall details about a VE then it can be considered a failure with respect to the training it has aimed to provide. Methods of recall varied according to the condition being examined (reference *Table 3-2*) and the research question being asked. Details of the different methods can be found in the corresponding experiment chapter.

3.2.4 Participant Sample

Participant groups varied only slightly in size and composition as can be seen in *Table 3-5.* This variation was kept to a minimum to allow for direct comparisons across conditions within the experiments.

Table 3-5: Participant group breakdown for all experiments

Exp. Number	Total participants	Total in each condition	Age range	Gender (M=Male, F=Female)	Mean age
1	32	8	21 – 38	M=16, F=16	≈ 27yrs 2 months
2	16	8	21 – 37	M=8, F=8	≈ 26yrs 7 months
3	45	15	20 – 39	M=29, F=16	≈ 24yrs 10 months
4	36	10 AbsVE / 8 RWVE	18 – 37	M=13, F=7	≈ 24yrs 2 months
5	30	12 cued / 18 non-cued	18 – 54	M=19, F=11	≈ 26yrs 1 month

All participants were drawn from the population of staff and students at the University of Nottingham, aged 18 + who were not familiar with the building that the RWVE was based on, and had not participated in any of the previous experiments. An assumption of a basic level of computer literacy and competence was made as a result of the participant population used.

The specific characteristics of potential end users of the VE were considered in all aspects of the VE design and use. The main sectors of users as defined by Jordan (1998) can be seen in *Table 3-6.*

Table 3-6: VE user sectors and influence (Jordan, 1998)

User Sector	Influence
Experience:	- With the product itself, it is likely that if the user has performed the task with the product before he or she is likely to find the task easier on subsequent attempts.
Domain Knowledge:	- Knowledge related to the task, independent of the product being used. In the case of virtual reality this could refer to real world knowledge.
Cultural Background:	- Can be affected by population stereotypes, i.e. in the US lettering for emergency signs is red whereas in Europe it is green. Also details such as size vary between cultural groups.
Disability:	- Products usable to able bodied may not be so for disabled bodied users, this includes factors such as speech and learning difficulties with respect to speech recognition and the provision of instructions.
Age and Gender:	- These factors can have strong effects on strength required to perform a task, age will be a particularly influencing factor on the receptiveness on the users to the technology depending on the exposure they grew up with and are used to.

These five sectors (*Table 3-6*) were considered with respect to the user groups tested and in the development of the VE itself. Participants were chosen who had no previous experience with VE training, they did not have any previous domain knowledge of the building the RWVE was based on, all worked or studied within the UK ensuring familiarity with UK population stereotypes, were all students and staff at the University of Nottingham to ensure a certain level of computer literacy and familiarity and were of a working age of both genders. These requirements for each user sector being met by all the participants reduced their influence on the outcome of the training effectiveness measured, and any influence they may have would be directly comparable to the training application of the VE in practice as opposed to during research testing.

Chapter 4 - The Virtual Environments

4.1 Background

From research performed in '*Literature Review*' and referring to '*Figure 3-1: Experimental programme flow diagram*' (p.85) it was established that a VE needed to be developed that fulfilled the following requirements.

- Based on the real world to enable the testing of virtual to real world knowledge transfer by testing in the real world on which it is built. The relation to the real world also providing a familiar, realistic and recognisable environment for the user.
- A realistic task could be performed within it to provide a meaningful and interesting experience for users and enable the direct application of findings to realistic commercial VR applications.
- It should also be possible to provide an option for task and non-task related interaction.
- The environment should be relatively simple to build as VE programming is not the main focus of this research.
- The environment should be suitable for viewing on a desktop VR system.

It is important to consider what should and should not be included in any environment built. For an environment specific to a particular area not every detail of the real environment needs to be modelled as the development time and speed of the rendering within the environment would be too greatly compromised. In this situation it is important to identify which features should be included and why. It was decided that the VE would initially be built, as far as was possible, to replicate the real world environment on which it was based to make knowledge transfer from the VE to the real world as easy and intuitive as possible for the participant. Changes would then be made in an evolutionary way as design problems evolved through observation of the environment in use.

4.2 The Real World Virtual Environment (RWVE)

4.2.1 RWVE Design & Development

The RWVE design was based on an existing manufacturing laboratory at the University of Nottingham. This building was chosen as it had a number of rooms that could be entered, making it suitable for a search task to fulfil the above requirements. Many of the rooms had different functions and layout making it interesting for the user to explore. It was also possible to perform RW recall with the participants within the actual building. The layout of rooms was developed from floor plans of the building and as close as was possible matching positions and colours of major objects within the building (see Table 4-2 and Table 4-3).

Figure 4-1 shows the layout of the ground floor of the building, the white numbers indicate individual rooms or corridors (1 and 2 are two linked entrance foyer rooms and 4 and 5 are two linked lecture rooms).

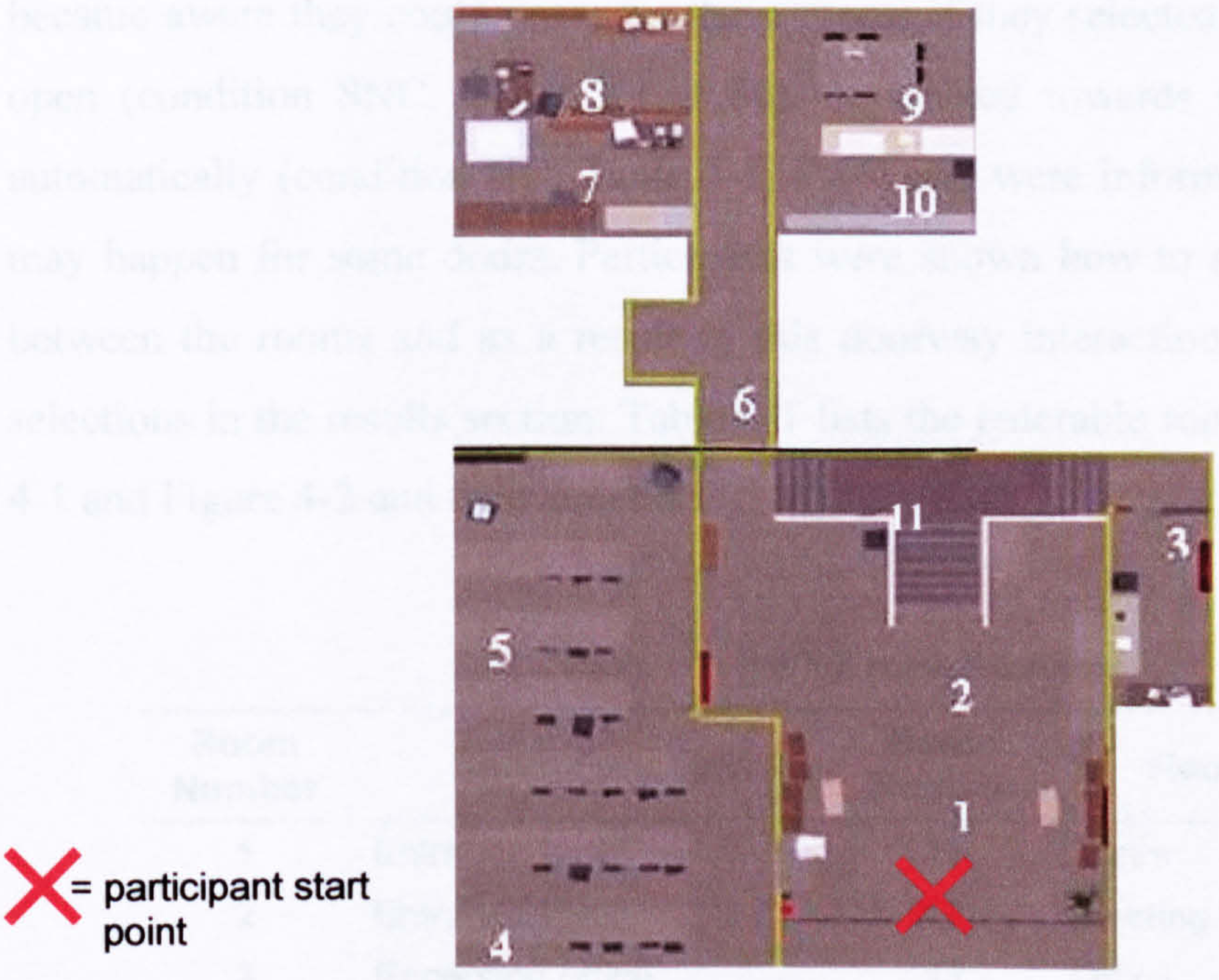


Figure 4-1: Birds eye view of the ground floor of the RWVE

Figure 4-2 shows the floor plan of the first floor of the building, again the white numbers indicate different rooms or corridors or stairways.

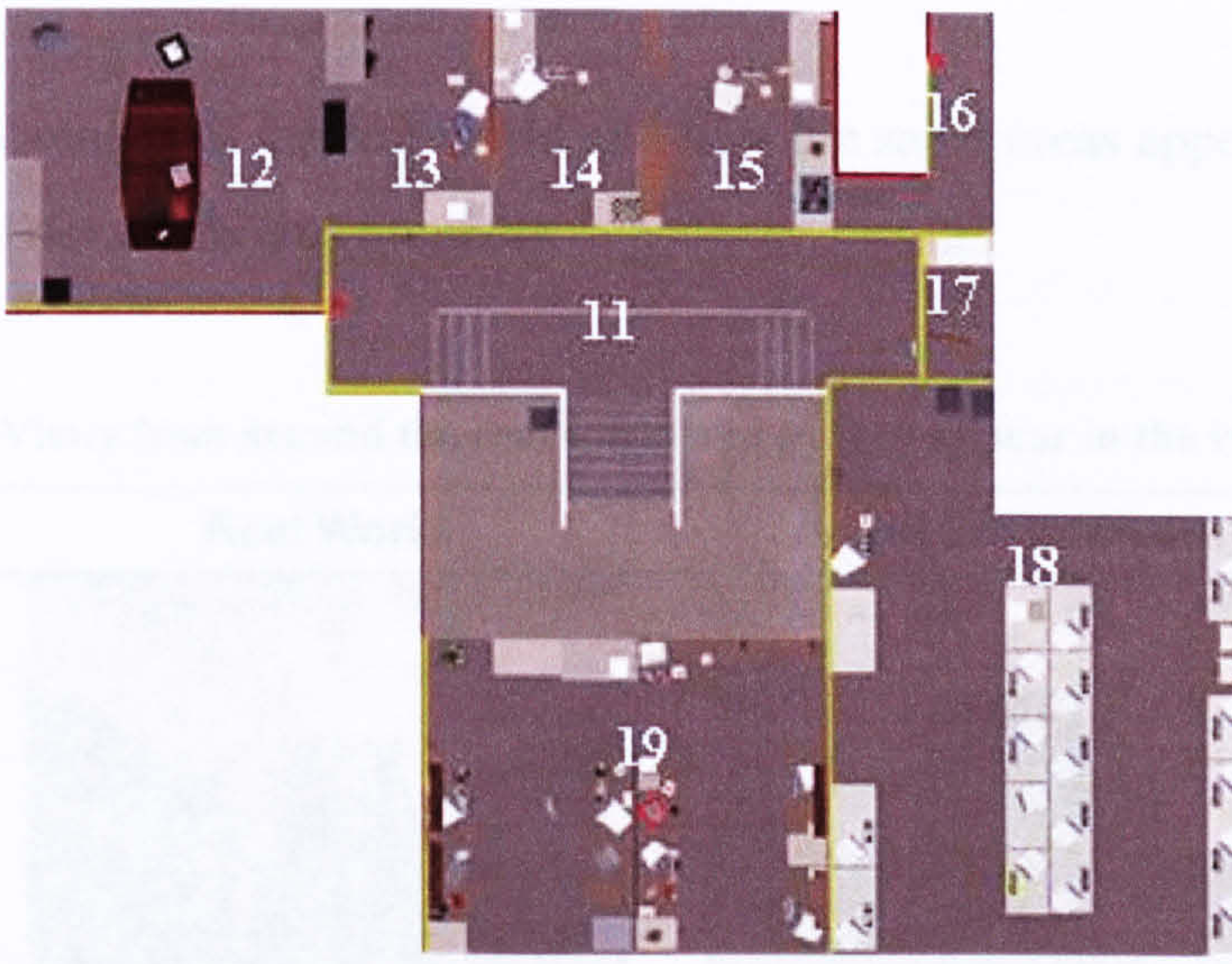


Figure 4-2: Birds eye view of the first floor of the RWVE

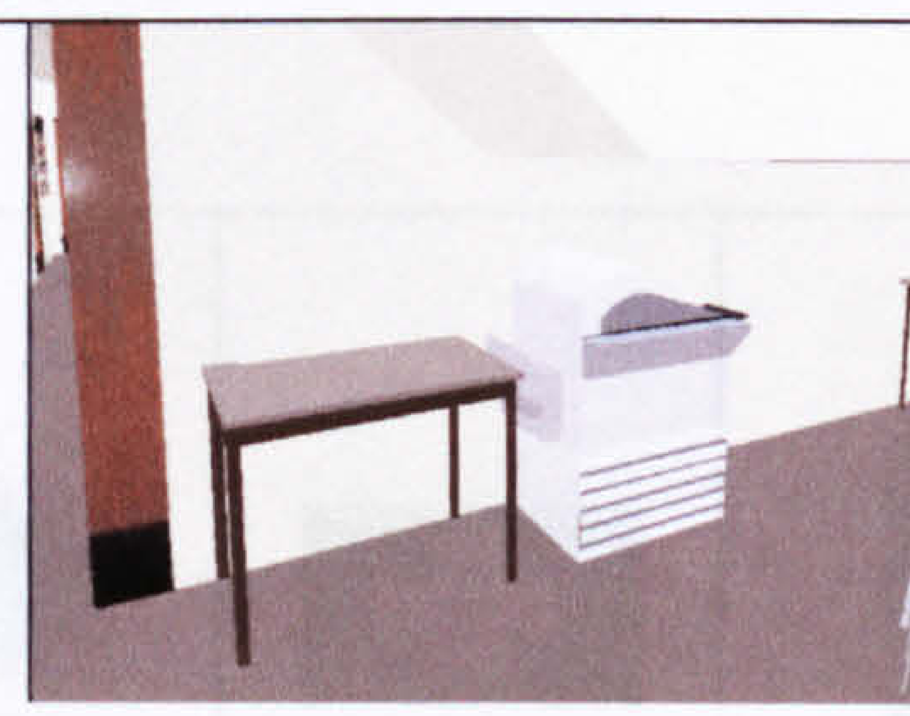
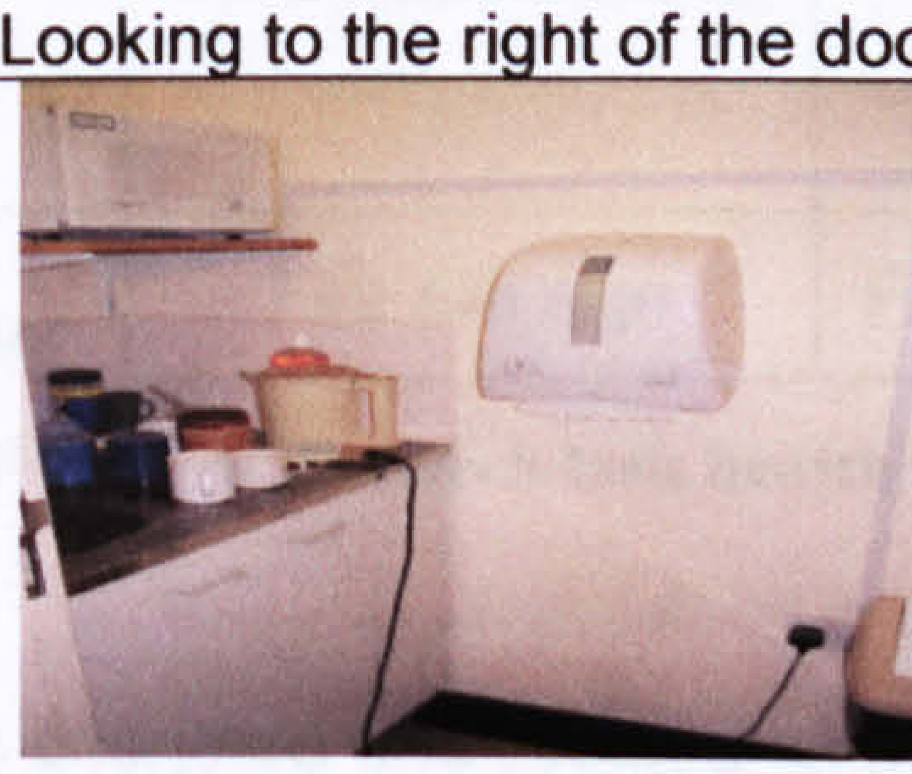
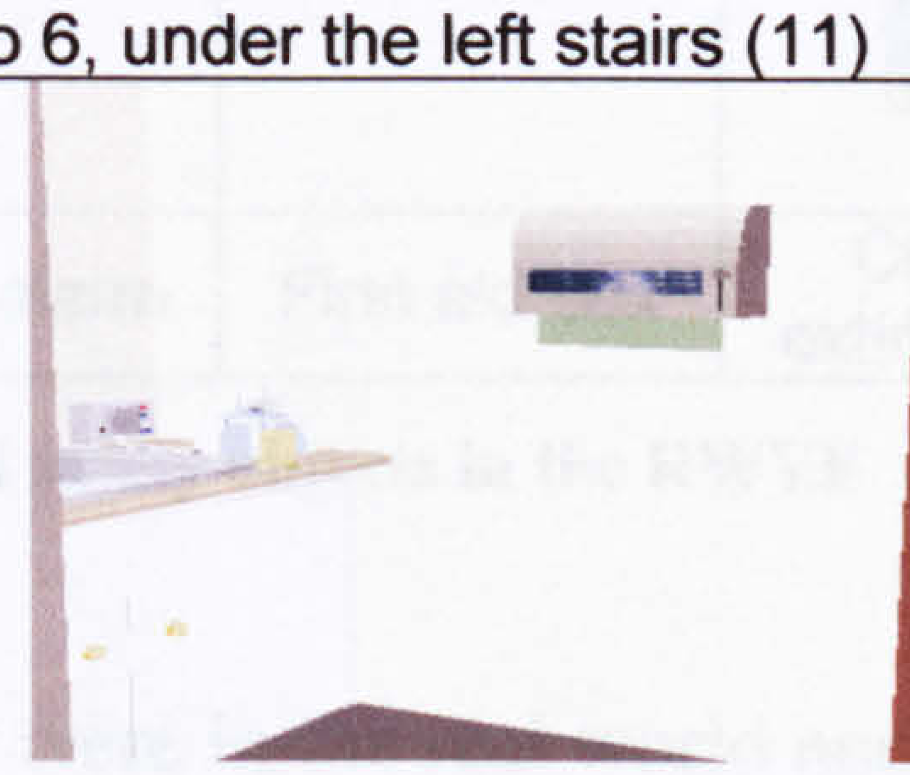
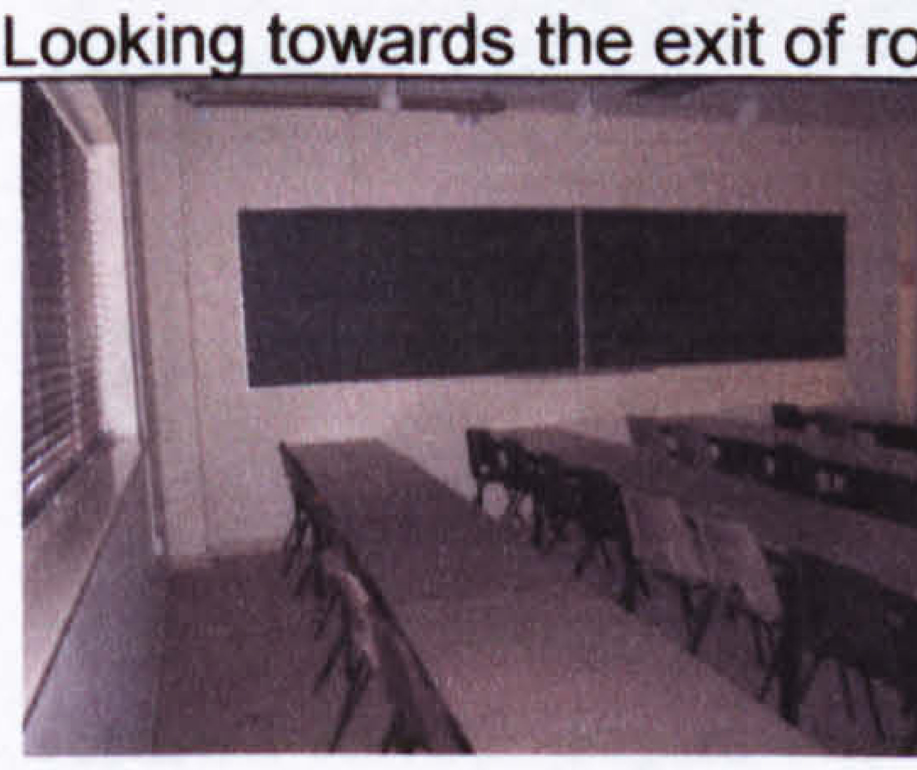
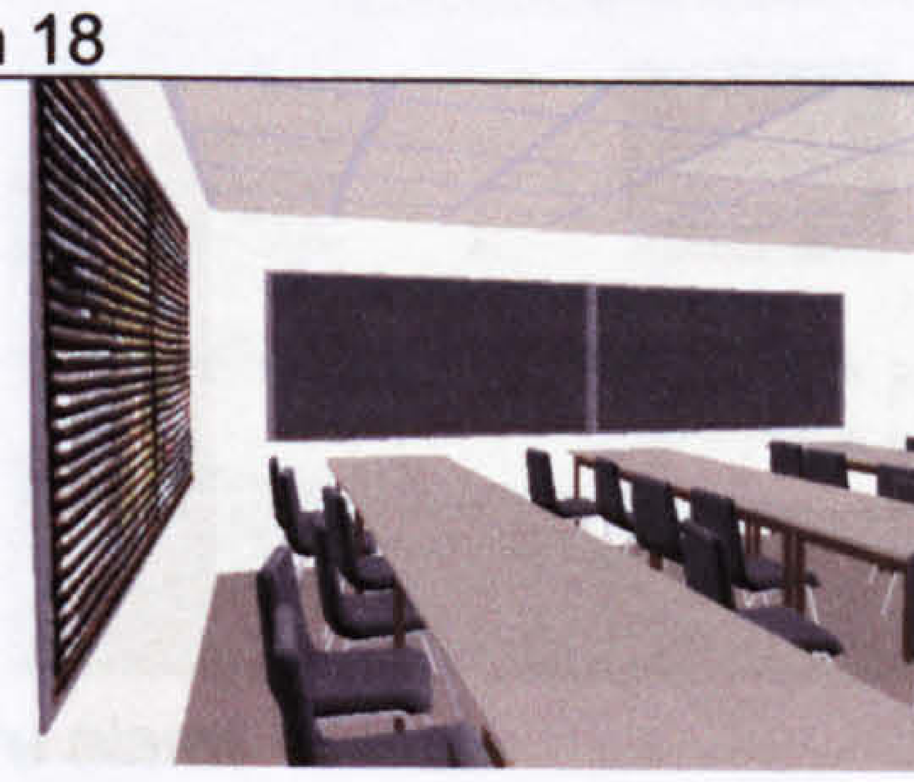
The RWVE consisted of nineteen rooms, foyers, stairways and corridors on two floors. Areas that could not be entered included toilets, safety critical areas such as the main manufacturing workshop in the building and storerooms which a visitor would not be allowed to enter in the real world without suitable safety equipment. The participant became aware they could not enter these rooms if they selected the door and it did not open (condition SNC, Table 3-1, P.86), or walked towards it and it did not open automatically (condition NC, Table 3-1, P.86) and were informed in advance that this may happen for some doors. Participants were shown how to select doors to navigate between the rooms and as a result of this doorway interactions were not included as selections in the results section. Table 4-1 lists the enterable rooms numbered in Figure 4-1 and Figure 4-2 and their function.

Table 4-1: RWVE room functions

Room Number	Room Function	Room Number	Room Function
1	Entrance foyer	**11**	Stairs
2	Entrance foyer	**12**	Meeting room
3	Reception office	**13**	Office
4	Lecture room	**14**	Office
5	Lecture room	**15**	Office
6	Corridor	**16**	Corridor to fire exit
7	Office	**17**	Staff kitchen
8	Office	**18**	Computer laboratory
9	Technicians' kitchen	**19**	PhD researchers room
10	Technicians' locker room		

Table 4-2 shows images of the real world and how the same areas appear in the RWVE, refer to Table 4-1 for room/area numbers.

Table 4-2: Views from around the real world and as they appear in the virtual world

	Real World	Virtual Environment
One		
	Looking up the stairs (11) from room 2	
Two		
	Looking to the right of the door to 6, under the left stairs (11)	
Three		
	The kitchen, room 17	
Five		
	Looking towards the exit of room 18	
Six		
	Room 4	

4.2.2 The RWVE Task

A search and select task was designed for the real world virtual environment (RWVE) which would be both a realistic training task to be performed in such an environment and would also give reason to the user to explore all areas of the environment. Griffiths (2001) suggests an important consideration when implementing usability into a VE is virtual task awareness, claiming if the VE is based on task based interactions it is important that the task is clear to reduce boredom or frustration. The task was to search for and select fourteen health and safety (H&S) objects located around the environment that appeared as shown in Figure 4-3. Participants were told they would be performing the task of an H&S officer performing a routine safety check to ensure all the objects were in place (see appendix, p.263).

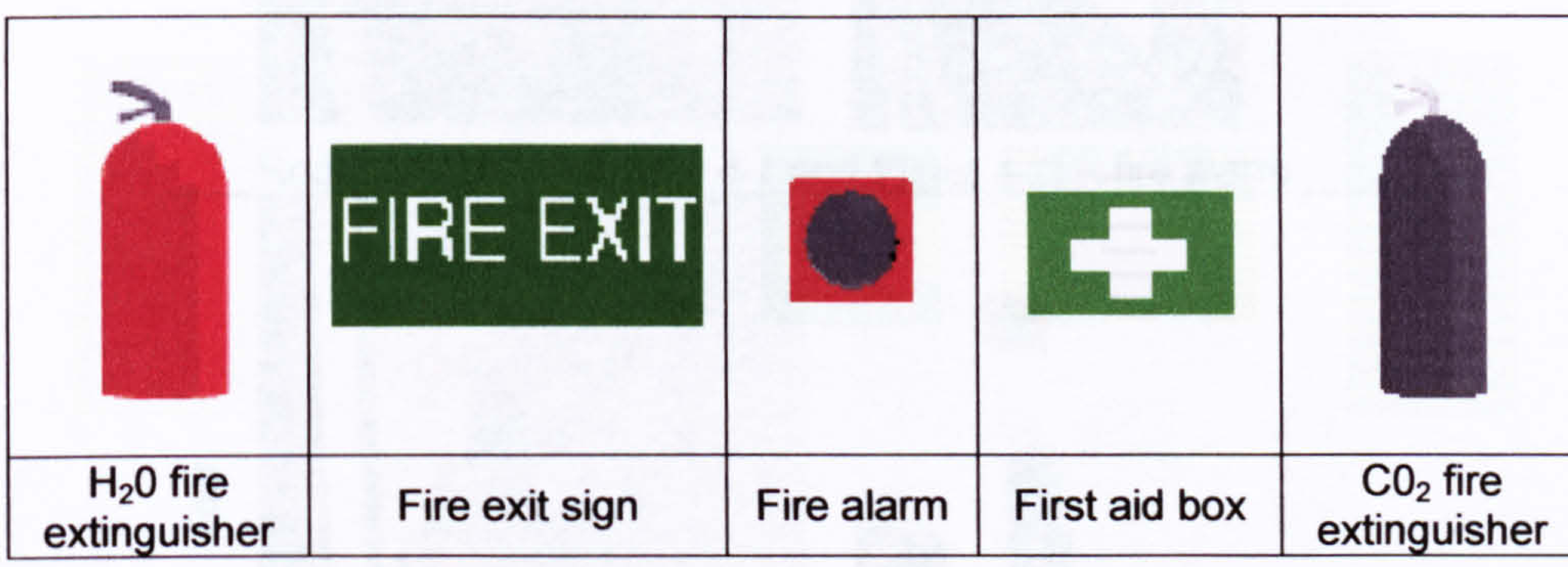
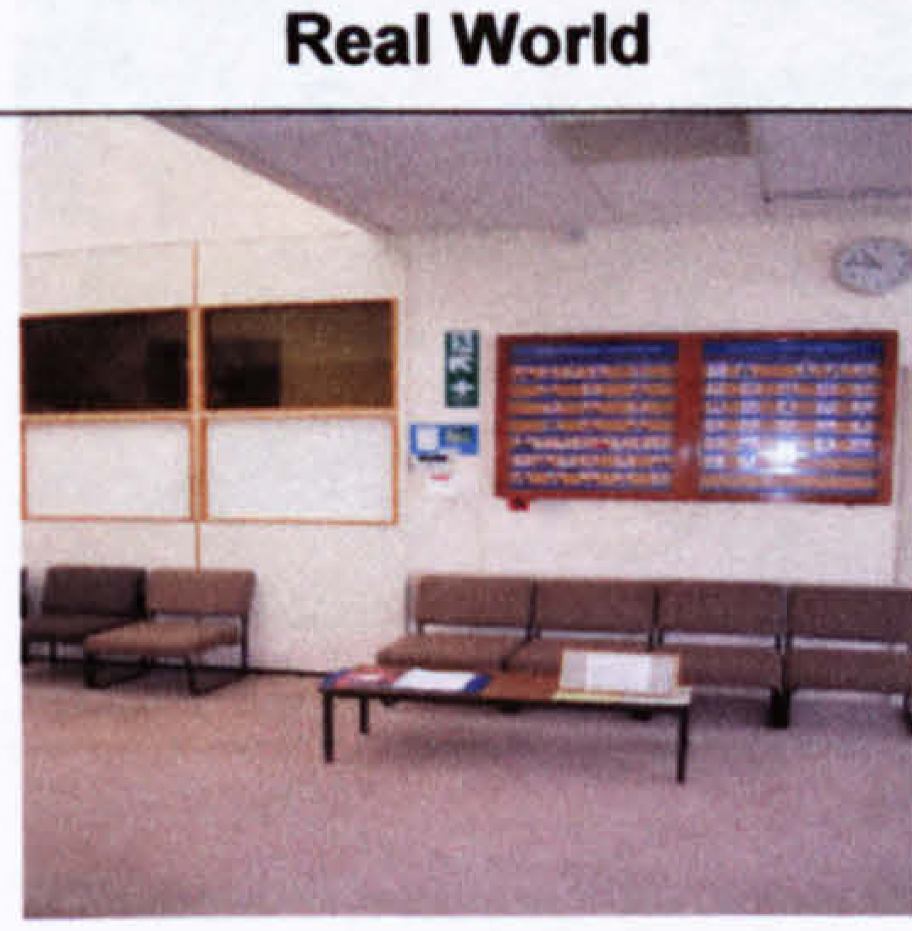
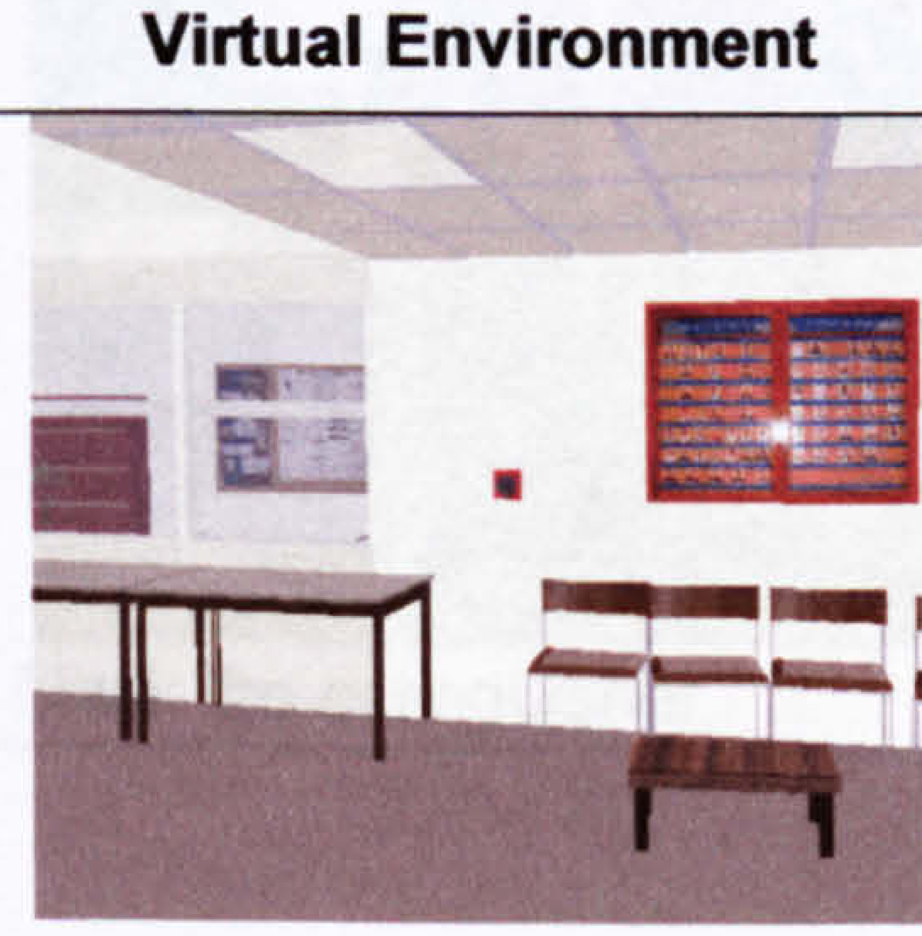
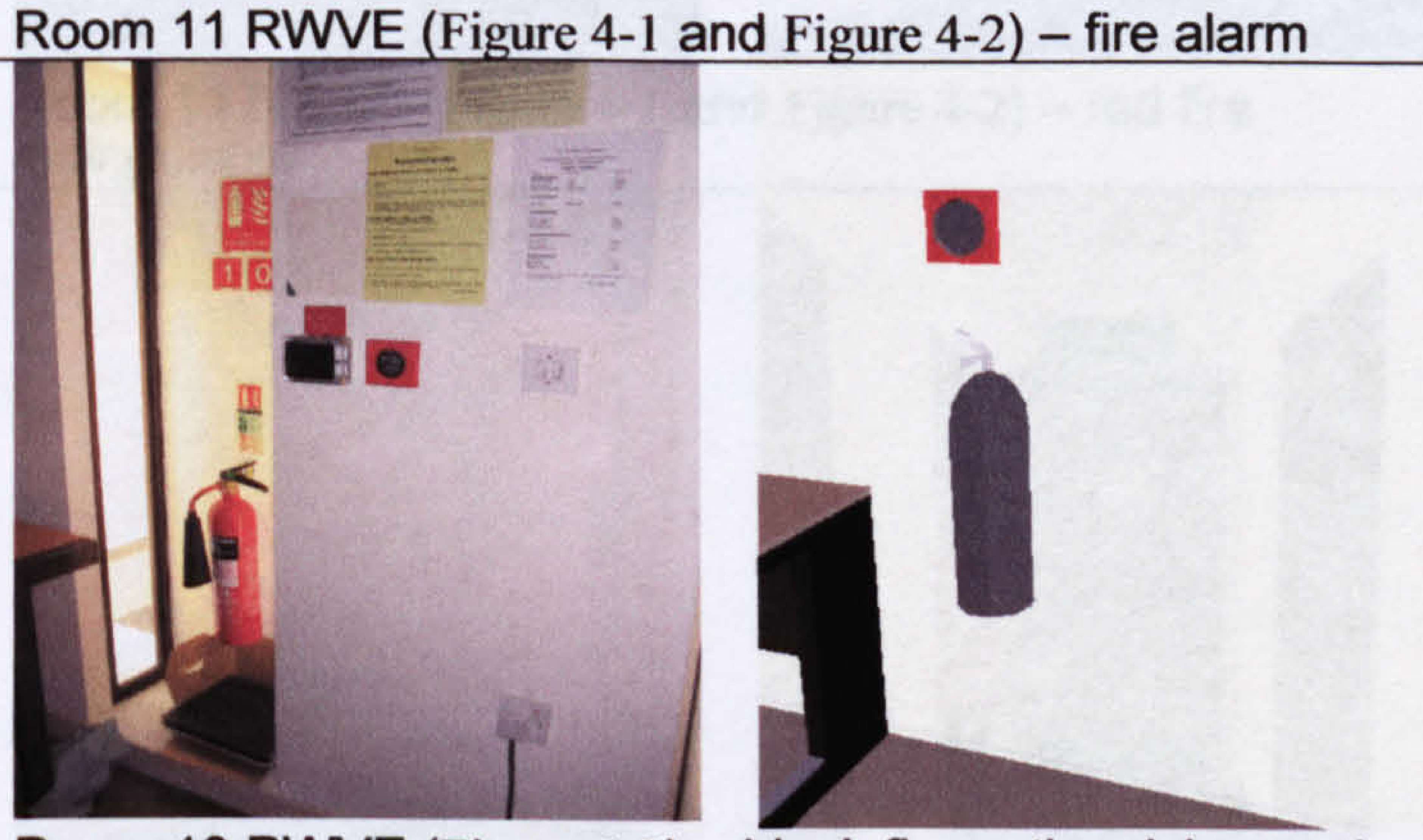


Figure 4-3: Search task health and safety objects in the RWVE

The objects were designed and located as they were in the real world and can be seen in Table 4-3.

Table 4-3: Search task objects as they appear in the real world and in the RWVE

	Real World	Virtual Environment
One		
	Room 1 RWVE (Figure 4-1) – fire alarm	

Two	 Room 1 RWVE (Figure 4-1) – fire alarm
Three	 Room 11 RWVE (Figure 4-1 and Figure 4-2) – fire alarm
Four	 Room 18 RWVE (Figure 4-2) – black fire extinguisher and fire alarm
Five	 Room 19 RWVE (Figure 4-2) – black fire extinguisher

Six

Room 1 RWVE (Figure 4-1) – red and black fire extinguisher

Seven

Room 11 RWVE (Figure 4-1 and Figure 4-2) – red fire extinguisher

Eight

Room 16 RWVE (Figure 4-2) – fire exit and red fire extinguisher

Nine

Room 1 RWVE (Figure 4-1) – fire exit

Ten	 Room 6 RWVE (Figure 4-1) – fire exit
Eleven	 Room 11 RWVE (Figure 4-1 and Figure 4-2) – first aid box

It can be seen that the $C0_2$ fire extinguishers appeared red in the real world and black in the RWVE (Pictures four, five and six in Table 4-3). Participants were informed of this when performing real world recall and whilst using the video training condition (Table 3-1: Definition of all the conditions within the experimental program, P.86). This was to enable easy distinction between the two types of extinguishers to be found by the participant, and as $C0_2$ extinguishers are commonly black in colour. The movement of the fire alarm (picture one and also four, Table 4-3) just slightly indicates how a VE can be used to simplify and clarify a real world environment for training and to make the learning aspects of that environment apparent. In picture eleven (Table 4-3) the first aid box appears on the opposite side of the upstairs kitchen door due to VE modelling restrictions. It is also evident, for example in picture five, that there is far less clutter in the VE than in the real world with only main aspects of the real world being modelled in the VE.

Once the participant had found the object in the VE they selected it with the mouse, or ticked it off a list, depending on the condition in which they were participating (Table 3-1: Definition of all the conditions within the experimental program, P. 86). Participants in the SNC condition were able to select the object with a mouse and a tick appeared below the corresponding icon of the object on an on screen tick list to the side of their viewing screen. This can be seen in Figure 4-4. The ticks show how many of each of the search task objects have already been found and selected and the white boxes show how many there are still to find.

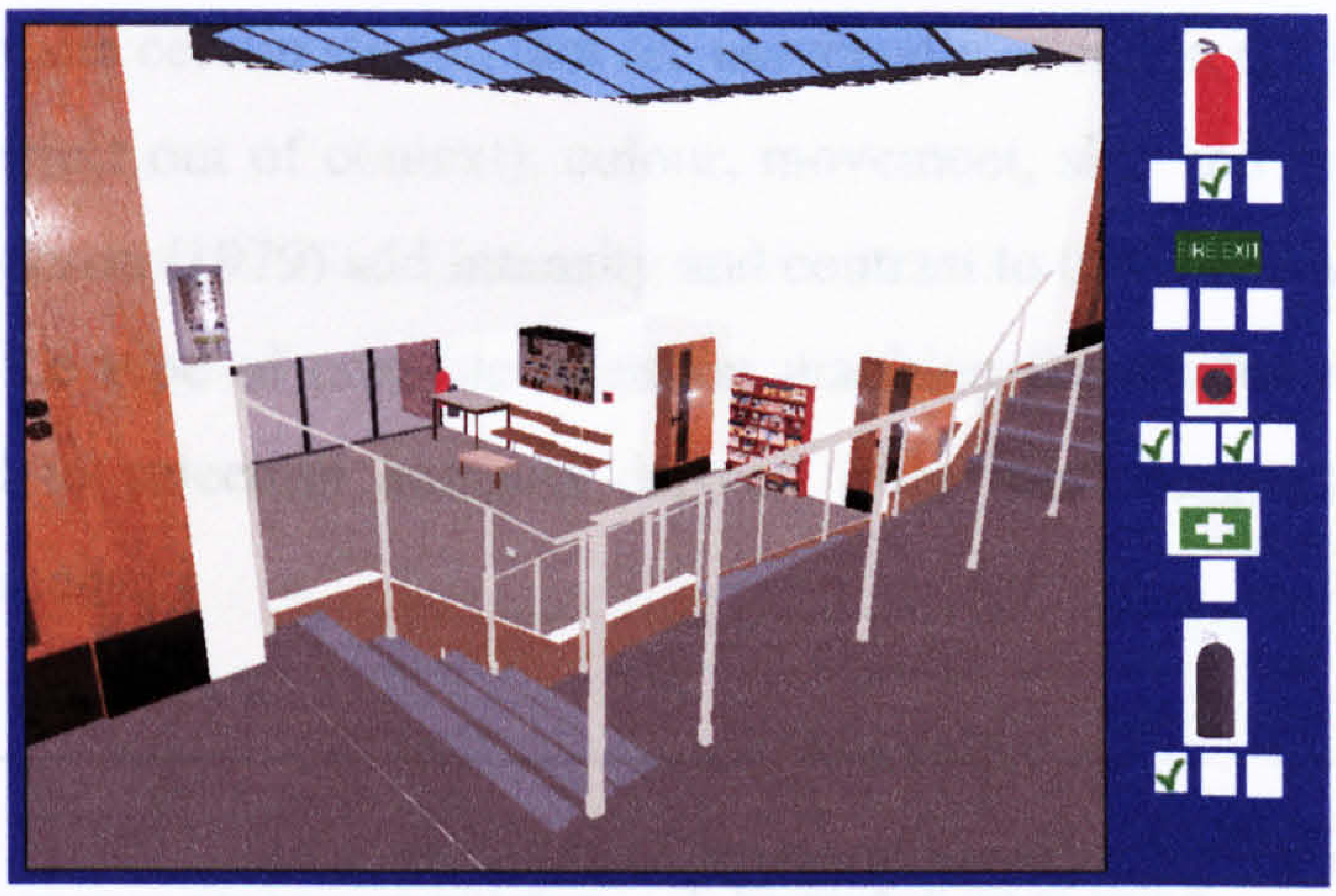


Figure 4-4: View of RWVE 'SNC' condition search task screen.

The participant could take as long as they wished to explore the environment to find the objects and could stop once all fourteen had been found.

4.2.3 RWVE Selection Hotspot Cues

For all of the experiments in which the participants were able to choose and select any objects (*Table 3-1: Definition of all the conditions within the experimental program*, P.86) the question 'what prompts a user to select one object in a VE over another' was considered. The concept of selection hotspots evolved as a method of describing points in a VE that are interactive, in that when they are selected they will provide feedback in some way (visually or audibly) as recommended by Pouyrev et al., (1998). The manner in which these hotspots are cued within a VE to encourage selection was considered a 'selection hotspot cue'.

Considering how to design the selection hotspot cues within the environment led to a second question 'what will prompt a user to notice and interact with a specific point in a VE?' This is a question that can be approached and answered in a number of ways.

Eastgate (2001) defines a selectable object as a 'device' – any object that affords selection, and provides recommendations for the use of cueing within the design of selectable objects to draw attention the object and to entice the user to interact with the environment (p.174). According to Benjamin, Hopkins and Nation (1987) in the process of attention certain stimuli are selected over others in our perceptual world. It can also be noted that there are certain stimuli that are universally attention drawing, for example novelty (i.e. an object out of context), colour, movement, size and repetition. Hilgard, Atkinson and Atkinson (1979) add intensity and contrast to this list. *Figure 4-5* provides an indication of the type of possible attention grabbing factors for users of VEs that could be applied to selection hotspots derived from these suggestions of attention drawing features made.

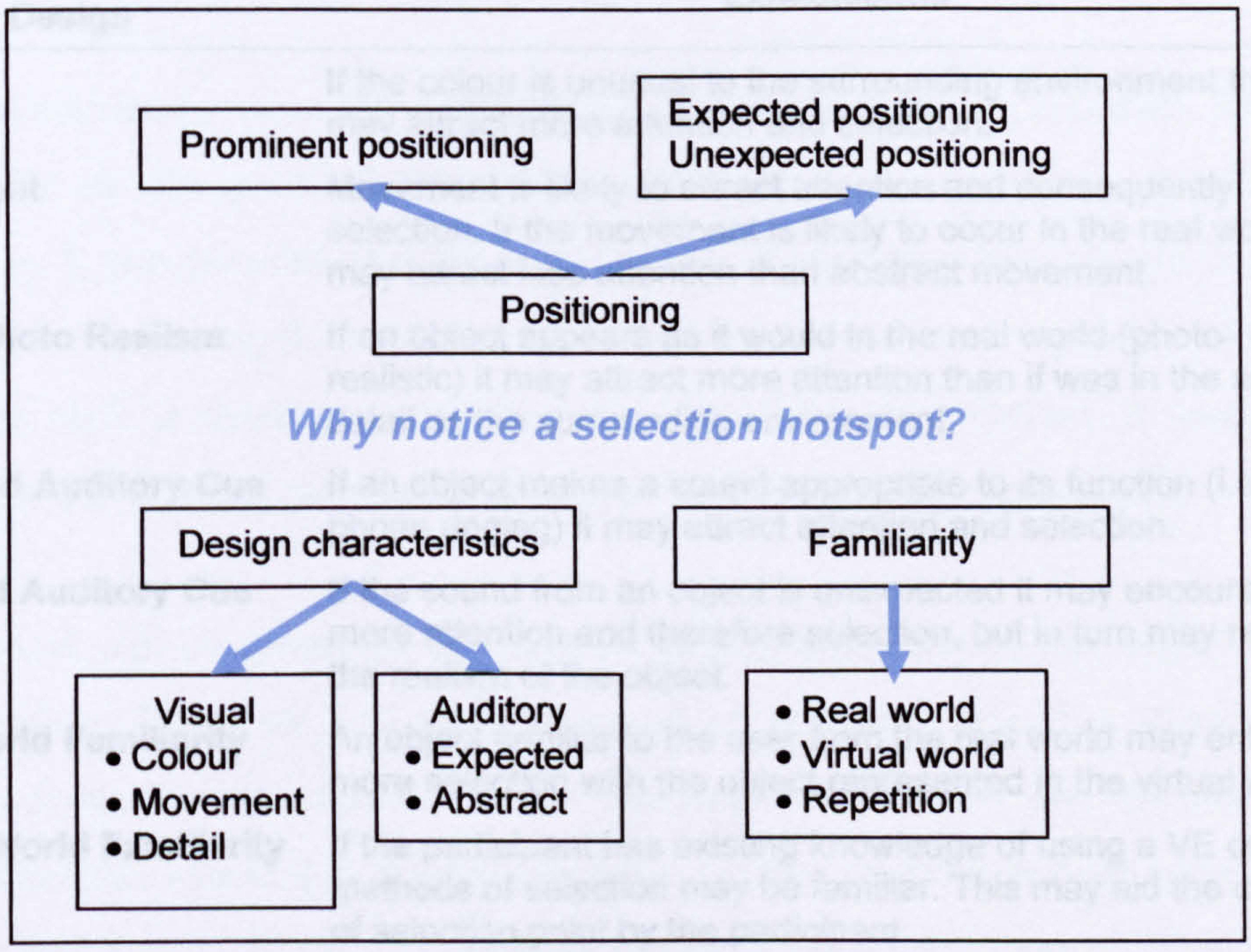


Figure 4-5: Noticing Selection Hotspots

Figure 4-5 suggests that a selection hotspot cue is likely to be noticed depending upon its positioning within the VE, how familiar the objects are to the user and their visual or auditory design characteristics. There are obvious limitations in the implementation of the design of some of these cues, for example it will be difficult to explore the importance of position on the selection of a hotspot cue if a VE is designed to replicate the real world. This is because objects will need to be placed as they are in the real world and the effectiveness of the VE application may be limited if objects are moved to unexpected or prominent positions to prompt selection. This is also the case for the familiarity of objects portrayed in the VE, if the VE in question is based on the real world and is to be used by a variety of end users with a vast knowledge base then you cannot influence the familiarity of the objects within it to prompt their selection. It is for this reason that the main focus of selection hotspot development will be on the design characteristics of potential selection hotspot cues, both visual and auditory.

Table 4-4 demonstrates the author's expectations derived from literature with respect to the design of selection hotspots within a VE in reference to *Figure 4-5*.

Table 4-4: Expectations from the design of selection hotspot cues (Marshall and Nichols, 2004)

Selection Hotspot Design	Expectations
Colour	If the colour is unusual to the surrounding environment then it may attract more attention and selection.
Movement	Movement is likely to attract attention and consequently selection. If the movement is likely to occur in the real world it may attract less attention than abstract movement.
Detail/Photo Realism	If an object appears as it would in the real world (photo-realistic) it may attract more attention than if was in the same detail as the surrounding environment.
Expected Auditory Cue	If an object makes a sound appropriate to its function (i.e. a phone ringing) it may attract attention and selection.
Abstract Auditory Cue	If the sound from an object is unexpected it may encourage more attention and therefore selection, but in turn may reduce the realism of the object.
Real World Familiarity	An object familiar to the user from the real world may entice more selection with the object represented in the virtual world.
Virtual World Familiarity	If the participant has existing knowledge of using a VE certain methods of selection may be familiar. This may aid the choice of selection point by the participant.
Repetition	The repetition of a task could result in learning by the user as to which objects are interactive and may therefore increase the attention drawn to such an object.
Prominent Positioning	If an object is placed in the users line of vision it may attract more attention and imply selection than if it were not.
Expected Positioning	An object placed in a position that it would be expected to be seen in it is less likely to attract attention and encourage selection.
Unexpected Positioning	An object placed entirely out of context is likely to attract more attention and selection.

Selection hotspot cue inclusion within a VE may have an influencing effect on the usability of the environment. This may be dependent on many factors concerning the use and design of that environment. For example if the task to be completed within the environment involves the manipulation of many objects then the use of selection hotspot cues may be a highly influential factor. If the task requires navigation but little selection then the influence of selection hotspot cues may be greatly reduced. It may also be the case that if an object is required to perform the set task (i.e. it is dark and the participant needs to find a light switch to see what they are doing) they will actively seek out that object to interact with it if it is cued or not, it is therefore less likely that the appearance of the object within the environment will be the influencing factor; it is more likely that the location of the object relative to expectations from the real world will be.

Other considerations were the combination of two or more expectations such as an auditory cue and the position of the object within the environment, or a detailed object that moves. It was possible that the combination of cues may have conflicting effects. For example, increasing the realism of an image may reduce the brightness of its colour (as effects such as shading come into play) within the environment. It was not clear which factors will prove most influential or even if it is possible to quantify.

A participant will be prompted to select an object as a result of that object attracting their attention. There are two main divisions of attention, selective attention is the ability to focus on one stimulus whilst ignoring other stimuli that are present, and divided attention where it is possible to focus on two or more stimuli simultaneously (Eysenck and Keane, 1995). An example of this is the cocktail party effect when you can be listening intently in a conversation with the person next to you in a crowded room, but your attention can be drawn to another conversation if you hear your name across the room (Wickens et al., 1998). The fact that your name was heard indicates that on some level attention was being paid to that secondary conversation. It is easier to divide attention if different senses are stimulated, for example, visual and auditory (Hampson, 1989). This suggests that a variety of cues within an environment will encourage more selection as attention may be divided between them if they stimulate a variety of senses.

Usability is another aspect considered in the design of selection points. In work by Kaur (1999) four points are made with respect to the design of objects within a VE to ensure usability;

- Make the objects easy to distinguish
- Make the objects easy to identify
- Make the interactivity and significance of the objects clear
- Make the objects easy to access

These factors in turn affect the design of hotspots because they limit the possible use of incongruous colour, detail, movement, or positioning. With this in mind the following list of cue types was developed, see *Table 4-5*.

Table 4-5: Description of selection hotspots used

Cue Type	Description
Highlighted	red, yellow, grey and blue
Flashing highlighted	red, yellow, grey and blue
Photo realistic	in contrast to 'blocky' appearance of the rest of the VE
Textured	non flat colour relevant to the object
Sound	expected auditory cues such as phones ringing
Movement	expected and similar to the real world

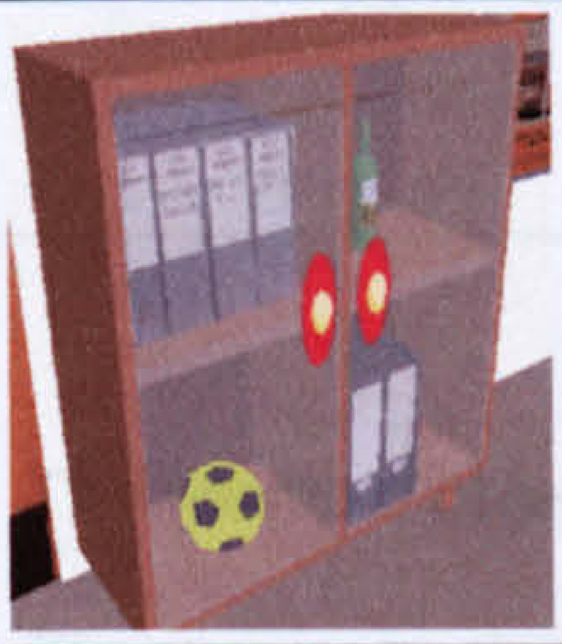
These cues were chosen as they combined attention grabbing features that would not distract from the distinguishable and identifiable features of the environment as recommended by Kaur (1999). *Table 4-6* lists the cues used within the RWVE, the number that appeared and of this number how many would react if selected.

Table 4-6: Selection hotspot cues in the RW environment – RWVE experiments 1, 2 & 3

Selection hotspot cue types	Number in RWVE	Number reactive
Red	14	14
Blue	14	14
Grey	14	14
Yellow	14	14
Textured/Photo Realistic	115	12
Movement	20	0
Sound	4	3
Flashing	28	28
Highlighted	28	28

Table 4-7 illustrates examples of how the cues appeared within the RWVE.

Table 4-7: Examples of selection hotspot cue types in the RWVE

RWVE Image	Description
	This picture provides an example of a *blue highlighted* keyboard (click on it and the monitor screen changes) and *yellow highlighted flashing* phone (click on it and it lifts and it emits an engaged tone). The mouse on the screen followed the *movement* of the real mouse (when clicked started a printer positioned to the right).
	This picture demonstrates the use *of photo realism* to prompt interaction. The only drawer in these filing cabinets that opens when clicked on is the one with the photo image on the front.
	This picture demonstrates both a *red highlighted flashing* cue and the inclusion of objects placed out of context with the rest of the surrounding area, (the *flashing yellow* football and the wine bottle).
	*This picture demonstrates a variety of cues, the* blue highlighted *plug socket (switches on the microwave) the* blue *button (opens the microwave door) the* photo realistic *fridge door and the* textured *cupboard door both open when clicked on.*

4.2.4 Coloured Cue Design

The coloured cues (red, blue, grey and yellow) differed from the other cues in the RWVE in their design within the environment. The cues were necessary additions to the VE and three methods of including them were used – all, part and surround. These are shown in Table 4-8.

Table 4-8: Examples of coloured cue design types in the RWV

Cue Design	Description	Example
All	The entire object is cued. The example shows a laptop mouse with an all red (flashing) cue. Once selected the laptop screen changes from a 'clouds' screen saver to the image shown, the laptop is in effect being reactivated by the user.	
Part	Only a part of the object is cued. The example shows a chair with a part red (highlighted) cue. Once selected the chair spins, it is in effect being moved round by the user.	
Surround	The reactive object is surrounded by the cue. The example shows a video player button with a surround red (flashing) cue. Once selected the TV screen changes from grey to the image shown, the TV is in effect being switched on by the user.	

The following table (Table 4-9) demonstrates how and where the differing coloured cue designs featured within the RWVE and if they were flashing or highlighted.

Table 4-9: Coloured cue design featured within the RWVE

Room	Object Name	Cue Design	F / H	Room	Object Name	Cue Design	F / H
12	Laptop	A	F	12	OHP	A	H
19	mouse	A	F	7	Drawing board	P	H
15	Disk box	P	F	8	Chair	P	H
2	Cabinet	P	F	14	Chair	P	H
3	Printer	S	F	19	Keyboard	P	H
5	TV	S	F	19	Filing cabinet	S	H
19	Joystick	S	F	19	Laptop	S	H
5	OHP	A	F	19	Chair	A	H
9	Microwave	A	F	19	Disk box	P	H
18	Mouse	A	F	7	Filing cabinet	P	H
7	Cabinet	P	F	14	Cabinet	P	H
8	Cabinet*	P	F	3	Computer	S	H
9	Switch	S	F	17	Switch	S	H
19	Laptop	S	F	13	Keyboard	S	H
7	Computer	A	F	9	Tap	A	H
9	Fridge drawer*	P	F	15	Filing cabinet	A	H
14	Monitor	P	F	15	Filing cabinet	A	H
18	Keyboard	P	F	18	Chair	A	H
18	Chair	P	F	19	Filing cabinet	A	H
12	TV	S	F	19	Filing cabinet	A	H
17	Towel dispenser	S	F	9	Microwave door*	P	H
13	Phone	A	F	19	Mouse	A	H
19	Computer	A	F	9	Tap head	P	H
2	Football	A	F	10	Locker	P	H
8	Chair	P	F	10	Locker	P	H
9	Cupboard	P	F	10	Locker	P	H
17	Cupboard	P	F	13	Cupboard	S	H
19	Laptop	S	F	18	Keyboard	S	H

*Cue not immediately visible, another object had to be moved before the participant could see/select it.
F = Flashing cue (intermittently appeared and disappeared) A = All Cued
H = Highlighted cue (constantly visible) P = Part Cued
S = Surrounded by cue

4.3 The Abstract VE (AbsVE)

4.3.1 AbsVE Design & Development

The AbsVE was developed specifically for experiment four to be unrelated to the real world so that the selection hotspots appeared less incongruous to the surrounding VE context. The VE consisted of one room that the participant navigated by flying about using the joystick and selected objects using a mouse as with the RWVE. The objects within the room consisted of mainly geometrical shapes. Examples can be seen in Figure 4-6 and Figure 4-7.

Figure 4-6: View within the AbsVE

4.3.2 The AbsVE Task

The Abstract virtual environment (AbsVE) was developed to establish if selection hotspot cues were still effective when they were integrated rather than incongruous to the surrounding virtual context, and whether there was a difference between recall from an abstract rather than ecologically valid VE.

The task to be performed whilst within the environment encouraged the participants to explore the whole area from a variety of angles to ensure that all the selection hotspot cue types were seen by the participant.

Participants were asked to follow a numbered arrangement of targets (arrows directed them from the target they were at, to the next target in the sequence) from target one to target ten. Upon seeing a target they had to navigate into the target until they heard an auditory response and a visual response in the form of a tick appearing below the corresponding target number on the on screen tick list to the right of the screen, before moving to the next. A selection of task targets and the on screen tick list can be seen in Figure 4-7, the ticks indicating targets already selected and the white squares the targets still to select.

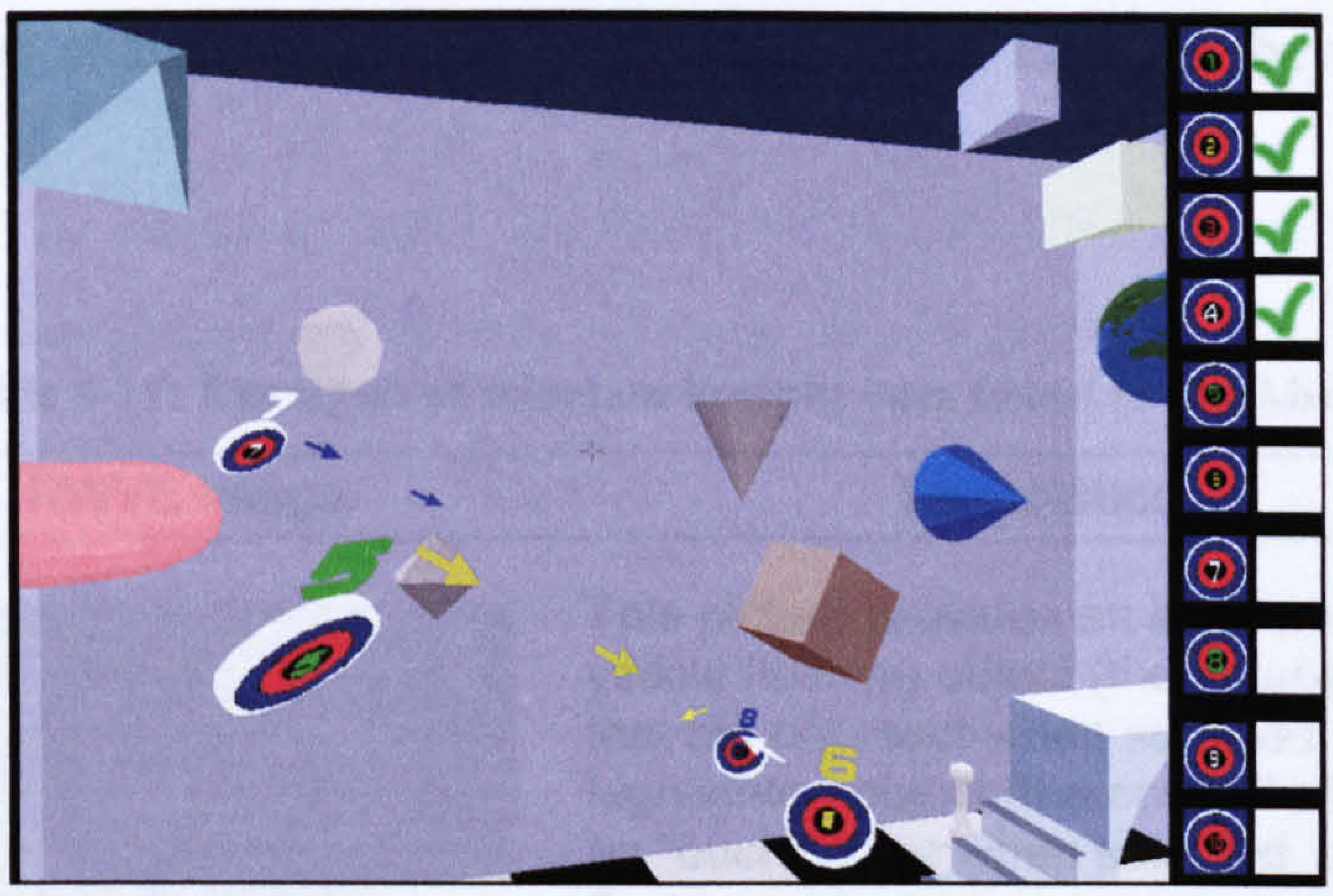


Figure 4-7: View of task targets within the AbsVE

The participant could take as long as they wished to explore the environment and complete the navigation task. Whilst performing the task they were also told they may interact with whatever objects they wished

4.3.3 AbsVE Selection Hotspot Cues

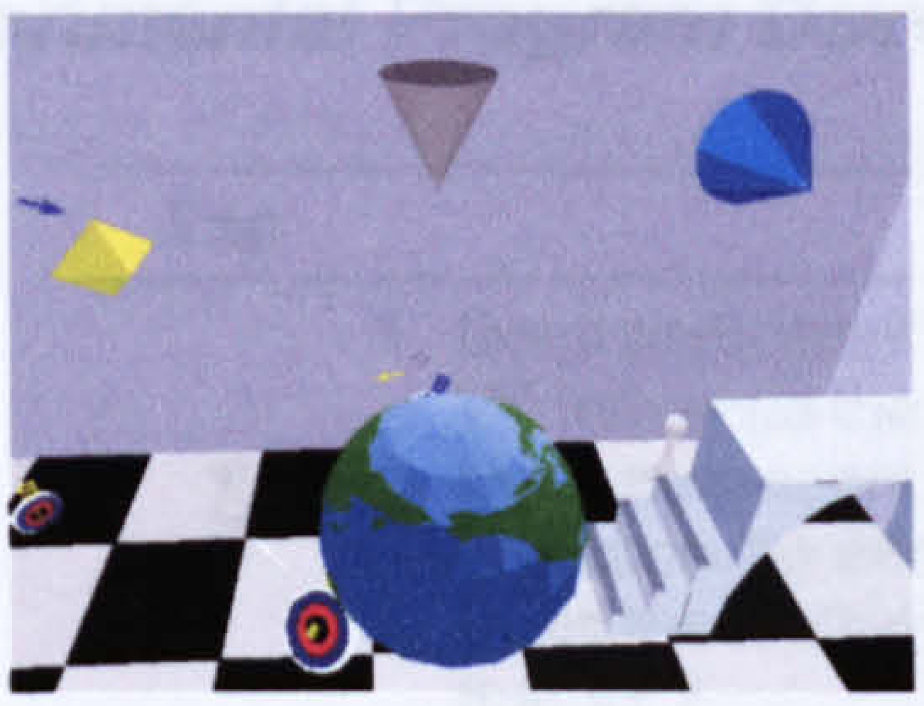
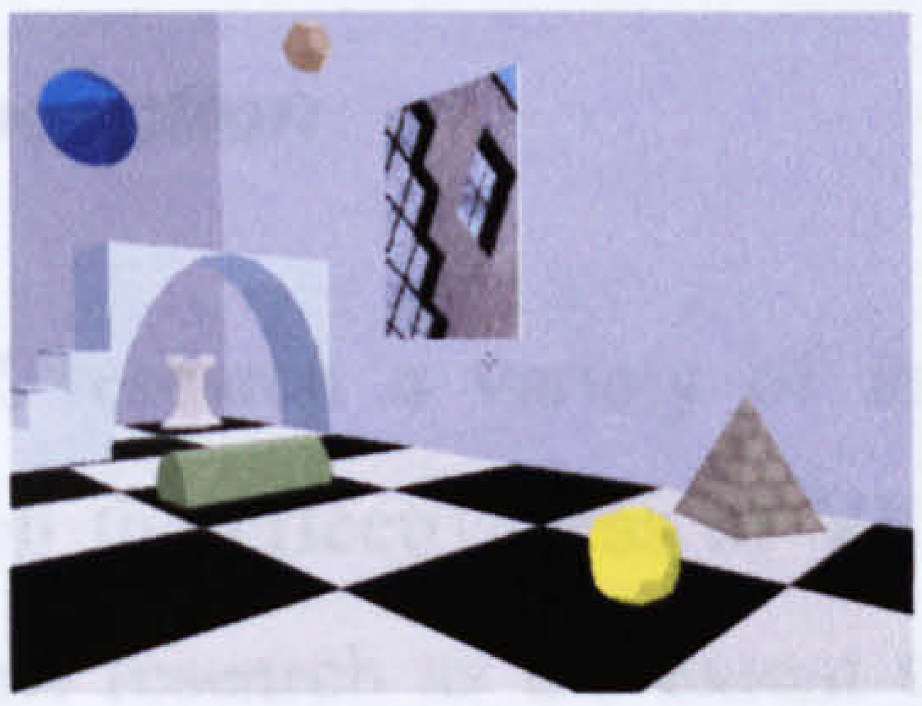
The AbsVE was designed to have the same selection hotspot cues as the RWVE to enable a comparison between the two when they are incongruous to the surrounding VE context (RWVE) and when they are not (AbsVE). The same cue types as described in '*Table 4-5: Description of selection hotspots used*', p.108 were used and Table 4-10 indicates how many were incorporated into the environment design.

Table 4-10: Selection hotspot cue types in the Abstract environment – AbsVE exp 4

Selection hotspot cue types	Number in AbsVE	Number reactive
Red	2	1
Blue	2	2
Grey	2	1
Yellow	2	1
Textured/Photo Realistic	4	1
Movement	3	1
Sound	2	2
Flashing	4	2
Highlighted	4	3

Table 4-11 shows examples of these selection hotspot cues as they appeared in the AbsVE.

Table 4-11: Examples of selection hotspot cues found in the AbsVE

RWVE Image	Description
	This picture provides an example of a yellow flashing object (the octahedron) that did not react when selected, a blue highlighted object (the cone) that made an "ouch" noise when selected, a grey flashing object (the cone) that made a "bang" noise when selected and the globe which rotated but did not react when selected.
	This picture provides an example of a yellow highlighted object (the sphere) that rolled around when selected, a blue highlighted object (the cone) as before, a sound emitting object (the green curve) that made a "dripping" noise until selected, the abstract photo that made a "tweet" noise when selected and the textured pyramid that did not react when selected.

4.4 VE development tool

Both VEs (RWVE and AbsVE) and condition variables of them were designed and adapted by the author on Superscape® virtual reality software, version 5.60. Programming time was approximately 3 months for both VEs.

Chapter 5 - Experiment 1

Establishing the factors that influence virtual reality training; participant selectivity, control of movement and realism

5.1 Experimental Program Development

Exp	Questions asked
One	1. Does participant ability to control their navigation around a VE influence the effectiveness of that VE? 2. Does participant ability to select objects within a VE influence the effectiveness of that VE? 3. Does the realism of the VE influence the effectiveness of that VE?

5.2 Introduction

Within VR research a variety of factors have been explored as having a possible influence on the effectiveness of VE training. Effectiveness has been defined for the scope of this research as the extent to which a specified goal or task is achieved and may be quantified by factors such as presence, usability and task performance achieved by the user.

Griffiths (2001) suggests the user's experience of realism, familiarity, selection and exploring as freely as possible are important considerations when implementing usability into the design of VEs. Zeltzer, (1992) defined interaction as one of the key components of VR and Kaur, Sutcliffe & Maiden, (1998) explored selection within VEs and provided guidelines for suitable selection hotspot cue design stating, failure to understand and find existing selections result in '*user frustration and poor usability*'. Realism is considered an important factor in the formation of a sense of presence within a virtual environment although too much can result in a slowing down of the environment rendering to such an extent that it has a negative effect on presence (Nichols, Haldane & Wilson 2000; Barfield and Weghorst 1993).

It has also been suggested that the type of task performed in the VE will affect the presence experienced as a more engaging and interesting task may result in increased presence (Nichols et al., 2000; Bystrom, Barfield and Hendrix 1999). Increased realism and selection may improve both the interest in the task and as a result the experience for the participant. The ability to navigate around a virtual environment as desired by the user is not only a defining aspect of a virtual environment but also an important influencing factor in both its usability and the presence experienced by the user. Sheridan (1992) puts the ability to modify the physical environment (this includes both control of movement and selection) and the control of relations between sensors and display as two of the three major aspects that determine the level of presence within a VE. It has also been suggested that presence is an influencing factor on task performance (Nash et al., 2000; Bystrom et al., 1999; Barfield, Zeltzer, Sheridan & Slater, 1995; Barfield & Weghorst 1993), real world knowledge transfer (Mania & Chalmers, 1999) and usability (Kalawsky, Bee & Nee, 1999a; Stanney, Mourant and Kennedy, 1998; Barfield & Weghorst 1993;).

The aim of this experiment was to establish if a VR training tool is an effective alternative when real world training is not possible, is too expensive to practice with the required regularity or if it is just not possible to practice as frequently as required. The experiment was designed to help establish if memory recall (i.e. fire exit location, safety equipment location) are sufficiently learnt from using a VE. The following experimental conditions considered if selection, navigational control and realism are required for the most effective training possible using VR. This was done by testing participants in the extremes of each condition i.e. full selection and no selection, full control of movement and no control, virtual world and real world. Effective memory recall was measured by participants visiting the real world building that the virtual environment replicated and were asked to recall the location of the safety search task objects they had been asked to find during the training. This would enable two factors to be examined, firstly whether memory recall from the VE training decays over time and if VE training is a suitable replacement to Video or animation training.

5.3 Research Questions

The research questions within this experiment evolved from the review of literature. Expectations with respect to the findings from these questions were derived from literature and the author's own experience[2].

1. Does selection influence the effectiveness of VE training for the user?
- **Expectation:** Selection will lead to improved results in effectiveness measures.
- **Reasoning:** Selection will make the VR experience more interesting for the participant (Bystrom et al., 1999) and the process of selection will increase the attention given to the recall objects increasing the likelihood of them being recalled (Eysenck and Keane, 1995).

2. Does realism influence the effectiveness of VE training for the user?
- **Expectation:** Increased realism will lead to improved results in effectiveness measures.
- **Reasoning:** Improved realism will enable the easier transfer of knowledge gained from the VE to the real world on which it is based if the real world is familiar from using the VE (Rose et al., 2000).

3. Does navigation control influence the effectiveness of VE training for the user?
- **Expectation:** Navigational control will lead to improved results in effectiveness measures.
- **Reasoning:** navigational control will make the VR experience more interesting for the participant (Bystrom et al., 1999) and enable greater familiarisation with the VE if self navigated thereby facilitating easier knowledge transfer.

[2] Providing expectations can suggest the use of one tailed statistical testing, however it was decided that expectations were not strong enough to warrant this, consequently two tailed testing was used throughout.

5.4 The Experiment

5.4.1 Conditions

The environment used was the RWVE as described in '*The Real World Virtual Environment (RWVE)*', section 4.2. The VE was ecologically valid in that it was based on the real world in appearance, furniture and décor was as close as was possible to how it appeared in the real world. The RWVE also reacted as the real world would have, for example rules of gravity were applied. An example of the appearance of the real world and of the RWVE can be seen in Figure 5-1.

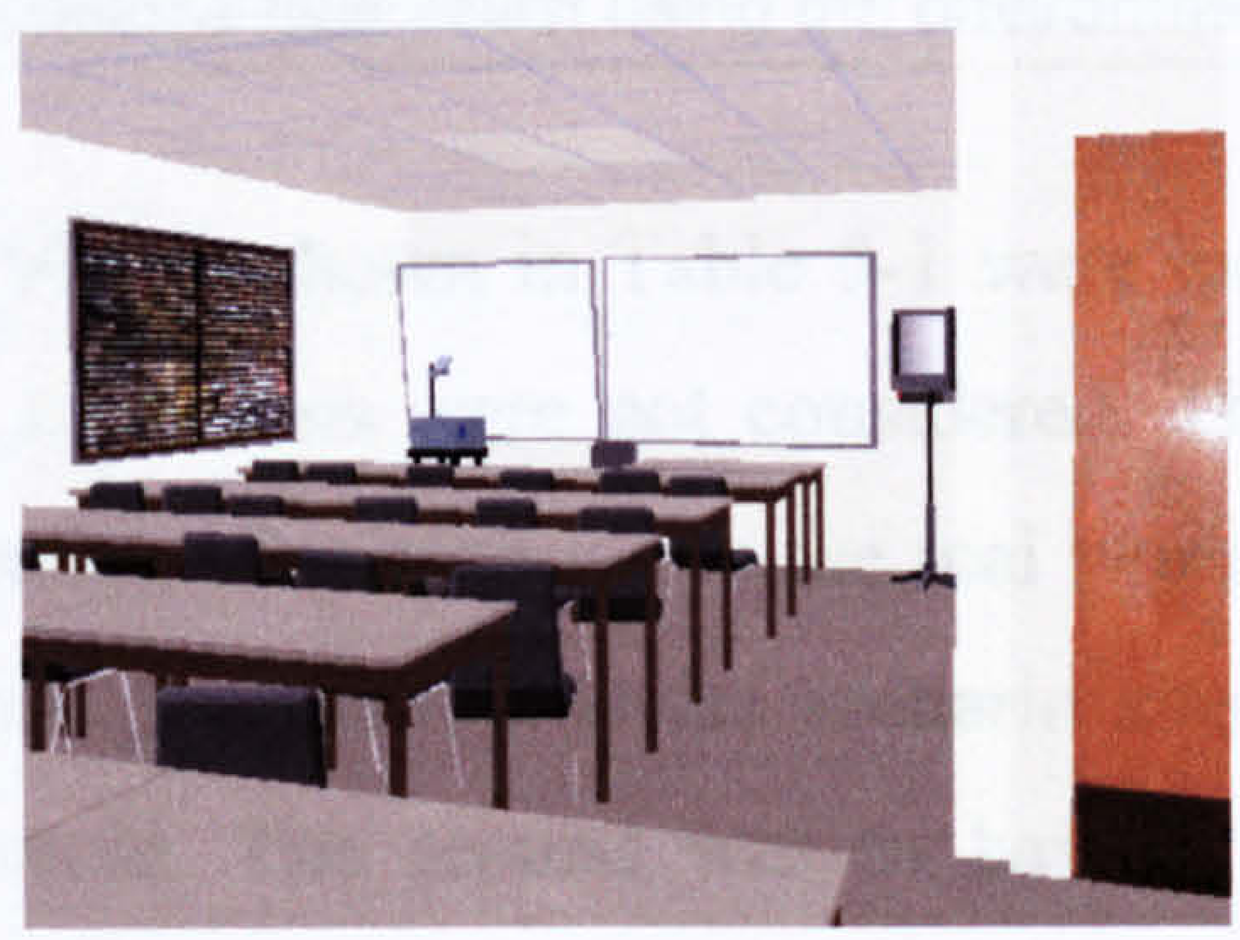
Real World	RWVE
	

Figure 5-1: Example of the appearance of the real world and the RWVE model

Four conditions were examined in this experiment to explore the importance of selection, navigational control and realism on the effectiveness of VE training using the measures taken. Table 5-1 provides details of the conditions used.

Table 5-1: Conditions explored within experiment one

Condition	Abbreviation	Description
Selection & Navigational Control	**SNC**	- Free navigation using the joystick - Able to choose and select any objects. - Defined task whilst using the environment. - Selection hotspots were cued to indicate it was possible for the participant to select them.
Navigational Control	**NC**	- Free navigation using the joystick - Unable to choose and select any objects. - Defined task whilst using the environment.
Animation	**Animation**	- Participants watched an animation of the VE being navigated. - Unable to navigate the VE using the joystick - Unable to choose and select objects. - Defined task whilst using the environment.
Video	**Video**	- Participants watched a video of the route taken by the participants in the animation around the actual building the VE replicates. - Defined task whilst using the environment.

Four conditions (SNC, NC, Animation and Video) shown in Table 5-1 were explored within this experiment. Two other possible conditions were not considered. The first was complete reality with the training and testing all performed in the real world (with or without selection and control) that was not done as this is the scenario alternative training methods are being developed to avoid. The second was to have a virtual environment where selection is possible but not control over movement. This was not possible to test as participants could not then independently choose where to go and therefore what to select and does not make sense with any VR interaction paradigms.

5.4.2 The Task

The task performed in each condition was as described in 'The RWVE Task', section *4.2.2.* Each participant was asked to explore the environment in search of fourteen health and safety (H&S) objects (red and black fire extinguishers, fire exits, fire alarms and a first aid box) located in the same position as in the real world (see Figure 5-2).

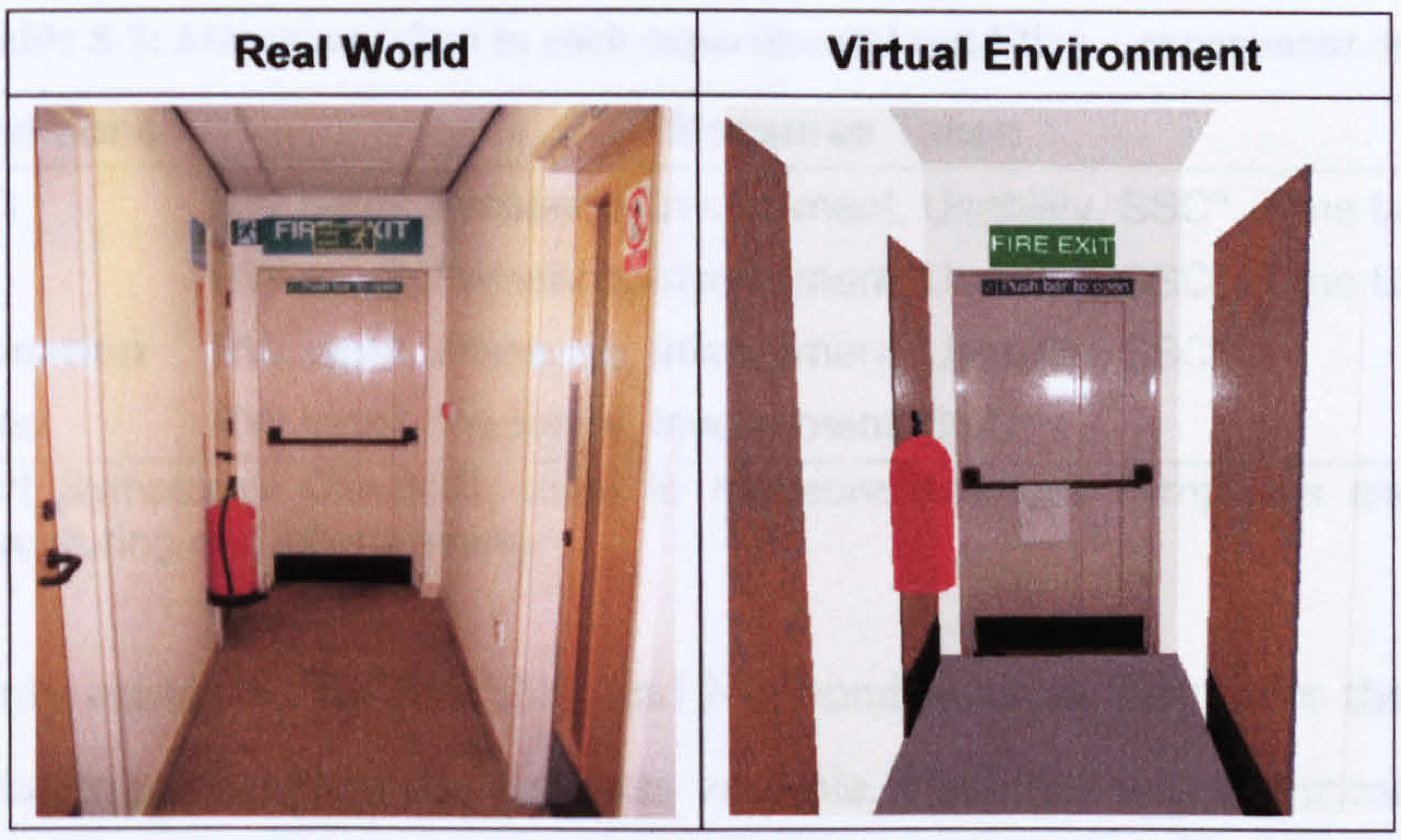


Figure 5-2: H&S objects (red fire extinguisher and fire exit) as they appear in the RW and the RWVE

In the SNC condition when the H&S objects were found by the participant they were selected and a tick appeared on an onscreen tick list so they could keep track of how many objects had been found and how many of what type were still to be found (see, '*Figure 4-4: View of RWVE 'SNC' condition search task screen.*' P. 104). In all the other conditions participants marked on a tick sheet by hand when they saw one of the search H&S objects as they were not able to select. In the conditions with participant navigational control (SNC and NC) participants explored the environment at their own speed, could go where they wish and return to an area they had already visited, whereas in the other two conditions they watched the animated display of the VE (animation) or video of the real world (video) only once which 'walked' round the environment into each room passing all the H&S objects en route and ticked them off on their list when or if they saw them.

5.4.3 Measures Taken

The following measures (Table 5-2) were taken for each condition. For details of measurement measures see 'Experiment Measures' section 3.2.3. The equipment set up was as described in 'Experiment Equipment' section 3.2.1.

Table 5-2: Measures taken in each experimental condition – experiment one

Conditions	Measures Taken
SNC	RW recall, Presence, Involvement, Usability, SSC*, Time taken
NC	RW recall, Presence, Involvement, Usability, SSC*, Time taken
Animation	RW recall, Presence, Involvement, Usability, SSC*
Video	RW recall, Presence, Involvement, SSC*

*SSC – Short Symptoms Checklist, used to measure sickness symptoms experienced by trainees before during and after training.

Time was only measured for the SNC and NC conditions as they were they only ones where time taken to complete the task was variable. Usability was not measured for the video condition.

5.4.4 RW Recall

Real world memory recall (RW recall) was created as a measure to determine whether participants were able to transfer knowledge they had gained from training (refer to Table 5-1 for details of training conditions) and relate it to the real world. Participants were asked to find fourteen health and safety objects during training in all the conditions measured and were then taken to the actual building that the training was based on, either one day or one week later (for details of the task refer to 'The Task', page 119). Participants were not told that they would be required to recall information about the VE at any point until they arrived at the real world building. The recall task required them to recall the location of the same objects they found during training either by walking to the objects or describing their location to the experimenter.

Recall was performed one day or one week later to examine if memory recall varies over time after training was performed. This was an explicit memory test as the task they performed during training was directly related to the memory recall they were asked to perform post-training.

Sickness Symptoms

It has been acknowledged that sickness symptoms have a possible negative influence on the VR users experience of the VE and as a consequence the short symptoms checklist developed by Nichols et al., (1997) see, 'SSC – Short Symptoms Checklist' (section

3.2.3.3) was administered to all participants before, during (every 10mins) and after each experiment to ensure if any sickness symptoms were being experienced they were monitored. Participants were informed that they may withdraw from the experiment at any time of they wished.

5.5 Research Hypotheses

Hypotheses derived from experiment research:

1. There will be a difference in real world (RW) recall one day and one week after the VE training has taken place.
2. There will be a difference in RW recall between conditions (SNC, NC, Animation and Video).

Hypotheses derived from research questions:

- *Does selection influence the effectiveness of VE training for the user?*
  3. There will be a difference in the effectiveness measures taken between selection (SNC) and no selection (NC) conditions.
- *Does realism influence the effectiveness of VE training for the user?*
  4. There will be a difference in the effectiveness measures taken between realism (video) and low realism (animation) conditions.
- *Does navigation control influence the effectiveness of VE training for the user?*
  5. There will be a difference in the effectiveness measures taken between participant navigational control (NC) and no participant navigational control (animation) conditions.

Further hypothesis derived from research questions:

6. There will be a relationship between the time taken and RW recall when participants were able to use the training VE as long as they wished (SNC and NC conditions).

5.6 Experimental Structure

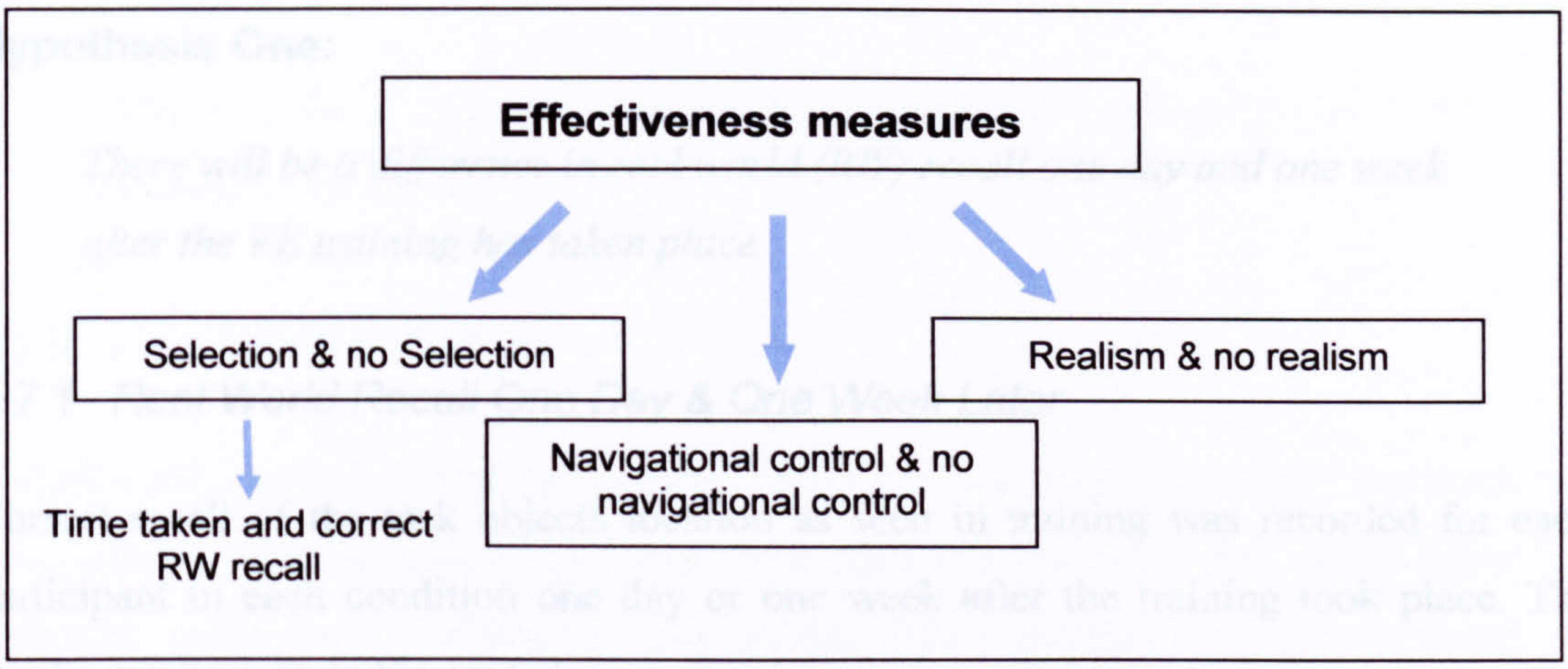


Figure 5-3: Experiment one structure

5.6.1 Participant Group

Table 5-3 shows the experimental group details.

Table 5-3: Participant group

Total	Age Range	Mean	Background
32	21 – 38	27yrs 2 months	Students and staff at the University of Nottingham. No previous knowledge of the real world building. VE novices.

The breakdown of participants in each condition within the group is shown in Table 5-4.

Table 5-4: Experimental conditions breakdown – number of participants

Condition	RW recall – 1 day later	RW recall – 1 week later
SNC	4	4
NC	4	4
Animation	4	4
Video	4	4

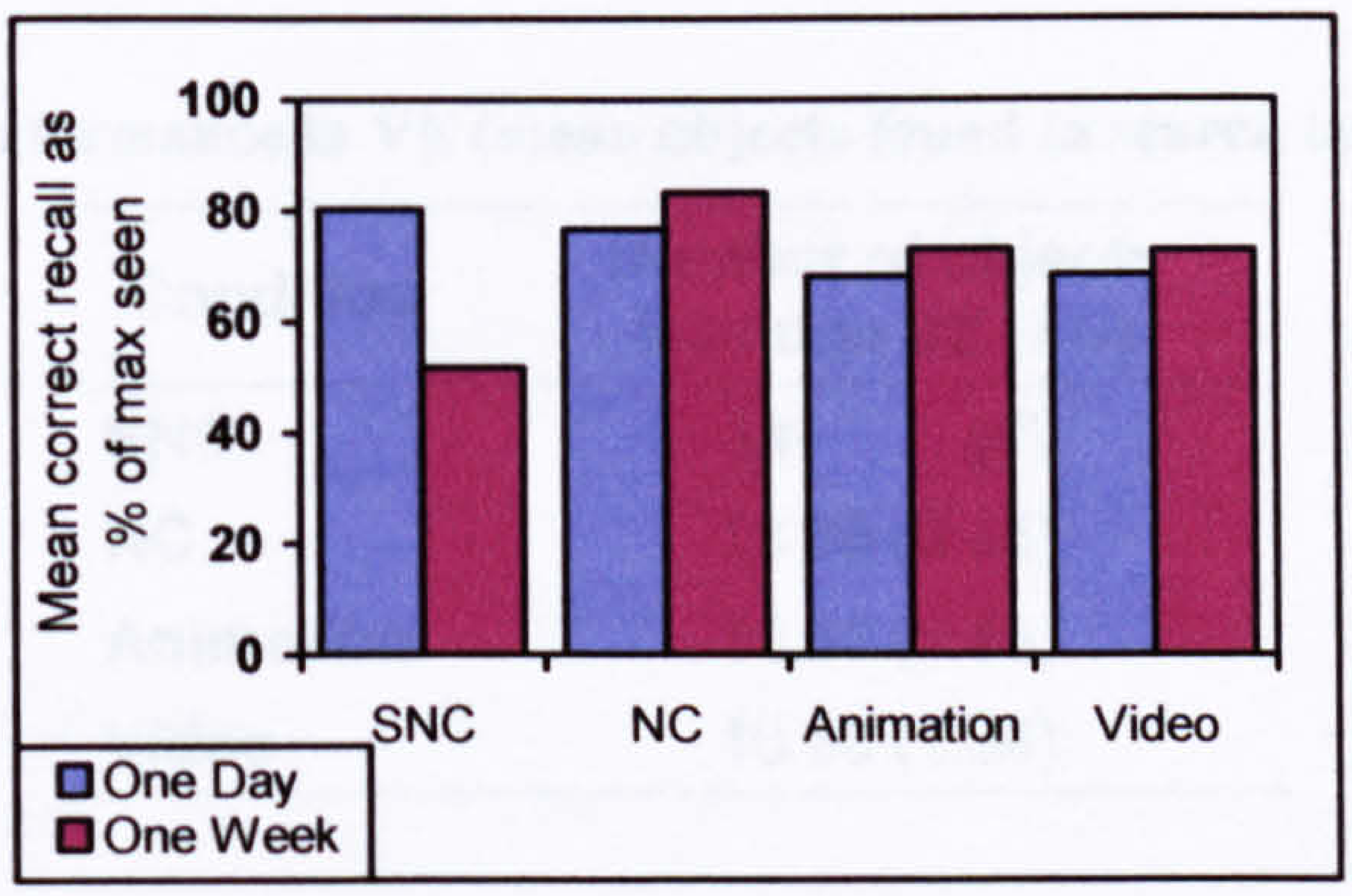
5.7 *Results and Discussion*

Hypothesis One:

There will be a difference in real world (RW) recall one day and one week after the VE training has taken place.

5.7.1 Real World Recall One Day & One Week Later

Correct recall of the task objects location as seen in training was recorded for each participant in each condition one day or one week after the training took place. The results can be seen in Figure 5-4.



Condition	One day (SD)	One week (SD)
SNC	80.36 (20.52)	51.79 (22.87)
NC	76.79 (12.20)	83.38 (12.97)
Animation	68.28 (19.52)	73.26 (13.22)
Video	68.58 (9.88)	72.89 (14.52)

Figure 5-4: Correct recall one day and one week after VE training – all conditions

(SNC, 'day' and 'week': t= 1.860, df=6, p>0.05; NC, 'day' and 'week': t= -0.740, df=6, p >0.05; Animation, 'day' and 'week': t=-0.422, df=6, p >0.05; Video, 'day' and 'week': t=-0.491, df=6, p >0.05).[3]

There was no significant difference found between recall for any of the conditions if the participants performed the recall task one day or one week after training. As there was insufficient evidence of deterioration shown in the measures taken it was possible for further calculations using recall data to include results from recall performed both one day and one week later.

[3] All raw data for all experiments can be found in 'Appendix II'

Hypothesis Two:

There will be a difference in RW recall between conditions (SNC, NC, Animation and Video).

5.7.2 Real World Recall

Not all participants found all the objects during training which obviously put them at a disadvantage when it came to recalling those same objects in the real world. Table 5-5 indicates mean task performance (as in the mean number of objects found by participants) in each condition.

Table 5-5: Task performance in VE (mean objects found in search task) – all conditions

Condition	Number of objects found in VE (SD)
SNC	14 (0)
NC	13.88 (0.35)
Animation	12.88 (1.13)
Video	10.88 (1.64)

One-way ANOVA was performed on the data obtained for task performance (Table 5-5) and there was shown to be a significant difference between the level of task performance in the four conditions ($F_{(3,28)} = 16.333$; $p<0.05$). Post-hoc analysis revealed a significant difference between the video condition and the SNC, NC and animation conditions ($p<0.05$)[4].

It can be seen that task performance decreases on average as control over the environment is removed from the participant, from full control in the SNC condition with highest task performance to least control in the animation and video conditions that recorded the lowest task performance results. Participants in the animation and video conditions may have had lower task performance as they were unable to navigate themselves and therefore when they did not see a search task object the first time they were unable to recheck areas to find them. This was commented on by participant 32, video condition:

[4] Non-significant post hoc results are not reported throughout.

"It [the video] *might hover in a room and then disappear again and I'd go wait I haven't finished looking whereas if it was you, you would stay until you felt comfortable you had seen everything you wanted to"*

This highlights a possible advantage of using VE for training over other methods.

RW recall results recorded were considered in each condition in relation to the number of search task objects that were found during the training for each participant. Table 5-6 shows the mean number of objects found in the VE per participant and the mean correct recall in the RW per participant.

Table 5-6: Mean number of search objects found in VE and mean number correctly recalled in the RW – all conditions

Condition	Number of objects found in VE (SD)	Mean correctly Recalled (SD)
SNC	14 (0)	9.25 (3.54)
NC	13.88 (0.35)	11.13 (1.81)
Animation	12.88 (1.13)	9.13 (2.23)
Video	10.88 (1.64)	7.63 (1.3)

Figure 5-5 shows the mean correct recall as a percentage of the number of search objects found in the VE per participant.

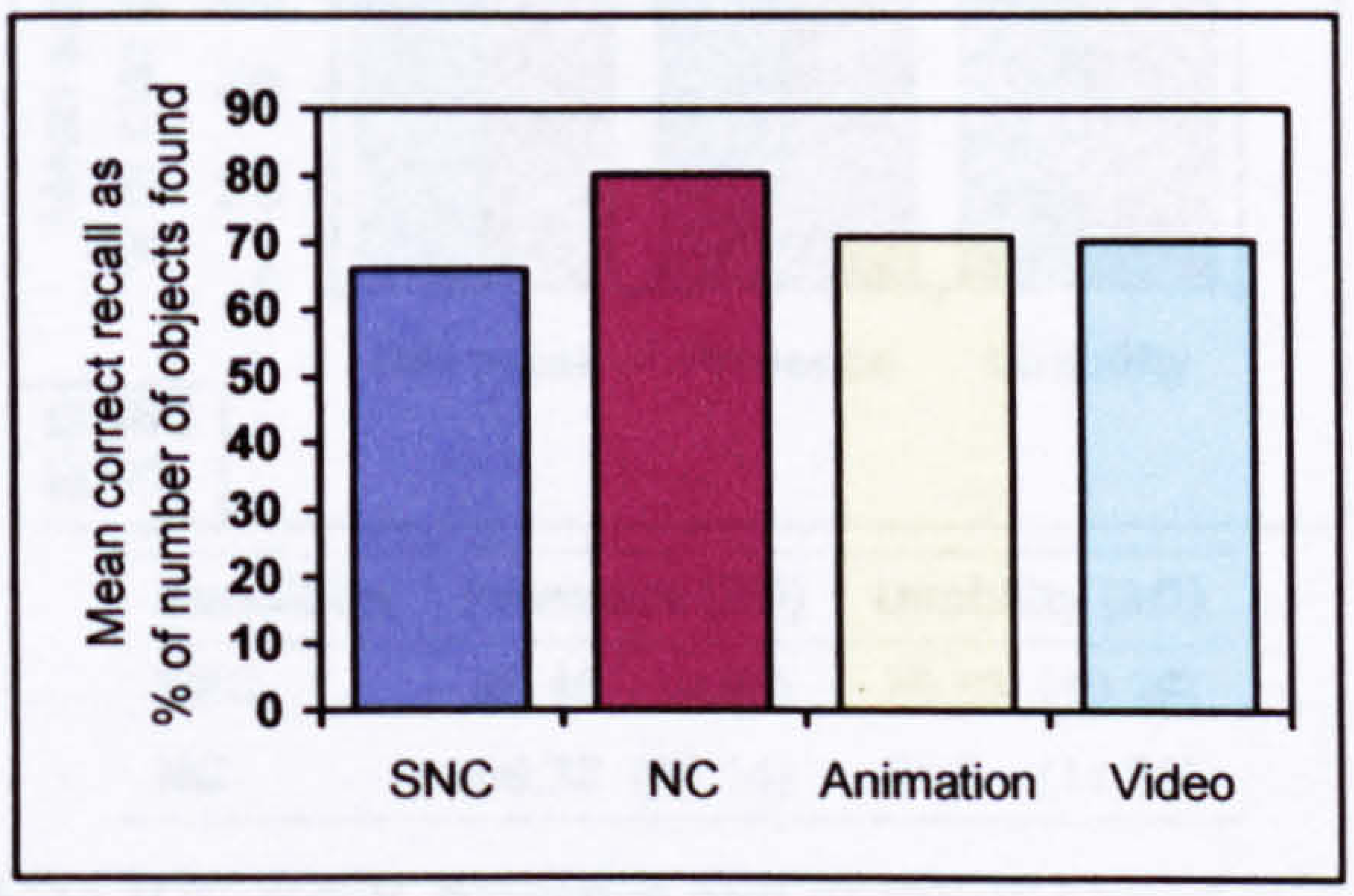


Figure 5-5: Mean correct recall as a percentage of max recall objects found in VE – all conditions

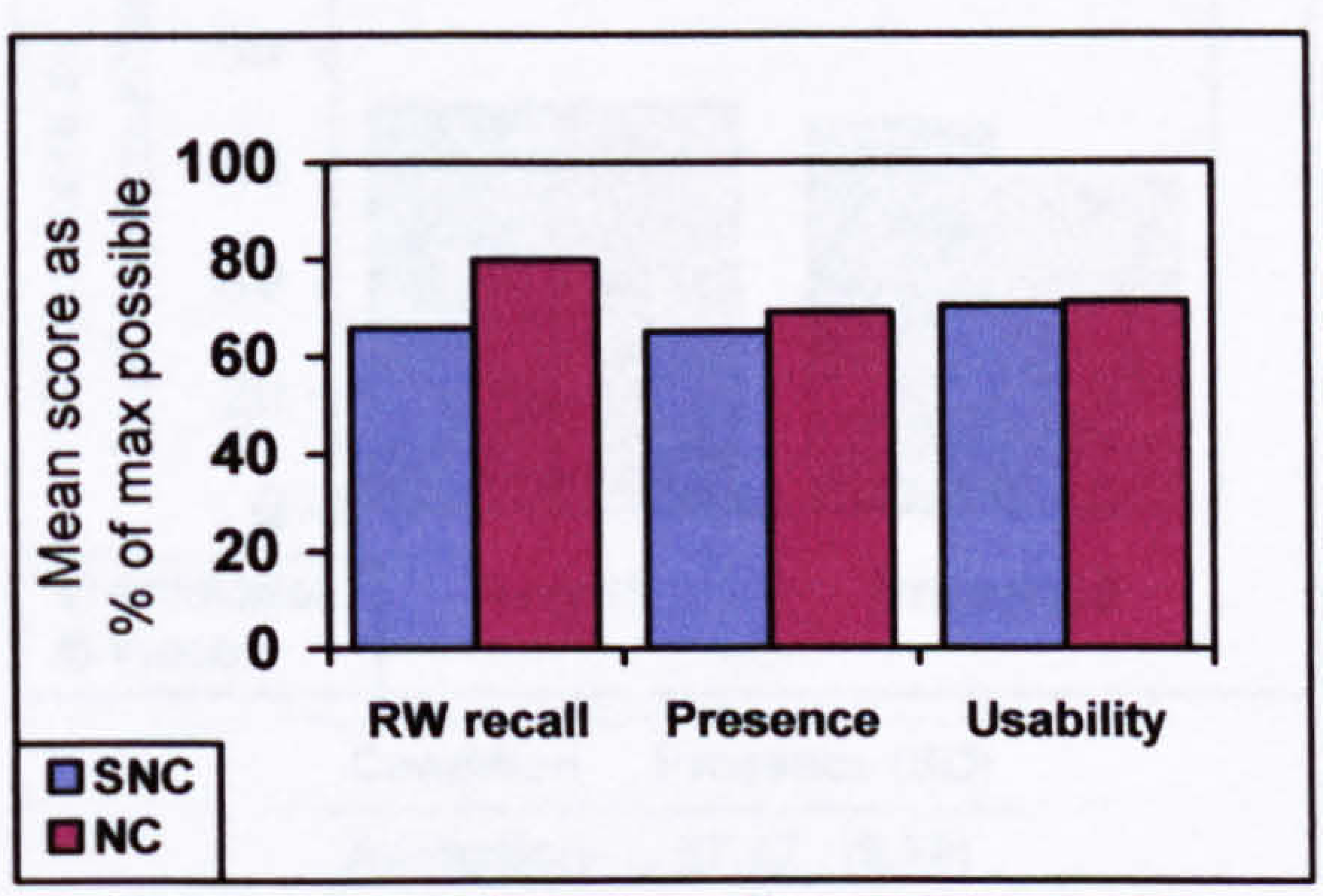
The percentage values were obtained by finding the percentage of correct recall from the mean task performance values obtained. For example if a participant found ten items in the task and recalled eight of those items the percentage would be 80%. One-way ANOVA was performed on the data obtained for correct recall (Table 5-6) and there was shown to be no significant difference between the level of correct recall in the four conditions ($F_{(3,28)} = 2.931$; $p>0.05$). Post-hoc analysis revealed no significant difference between any two conditions. This indicates that the use of VE training does not result in any worse performance than the other conditions examined and may have other cost and attitude advantages and consequently is worth providing research into the area.

Hypothesis Three:

There will be a difference in the effectiveness measures taken between selection (SNC) and no selection (NC) conditions.

5.7.3 RW recall, Presence and Usability – Selection & No Selection

Results were compared for the effectiveness measures taken (recall, presence and usability) in the selection (SNC) and no selection (NC) conditions, see Figure 5-6.



Condition	Presence (SD)	Usability (SD)
SNC	65.46 (9.96)	70.58 (10.29)
NC	69.32 (11.14)	71.5 (11.83)

Figure 5-6: Mean RW recall, presence and usability scores as a percentage of the maximum possible – 'SNC – selection' and 'NC – no selection'

(Recall data is repeated here from hypothesis two for ease of reference. RW Recall, 'SNC – selection' and 'NC – no selection': t=-1.413, df=10.089, $p>0.05$; Presence, 'SNC – selection' and 'NC – no selection': t=-0.709, df=14, $p>0.05$; Usability, 'SNC' and 'NC': t=-0.165, df=14, $p>0.05$).[5] [6]

[5] The use of parametric statistics on likert scale questionnaire data is justified in Oppenheim (1992) p.195

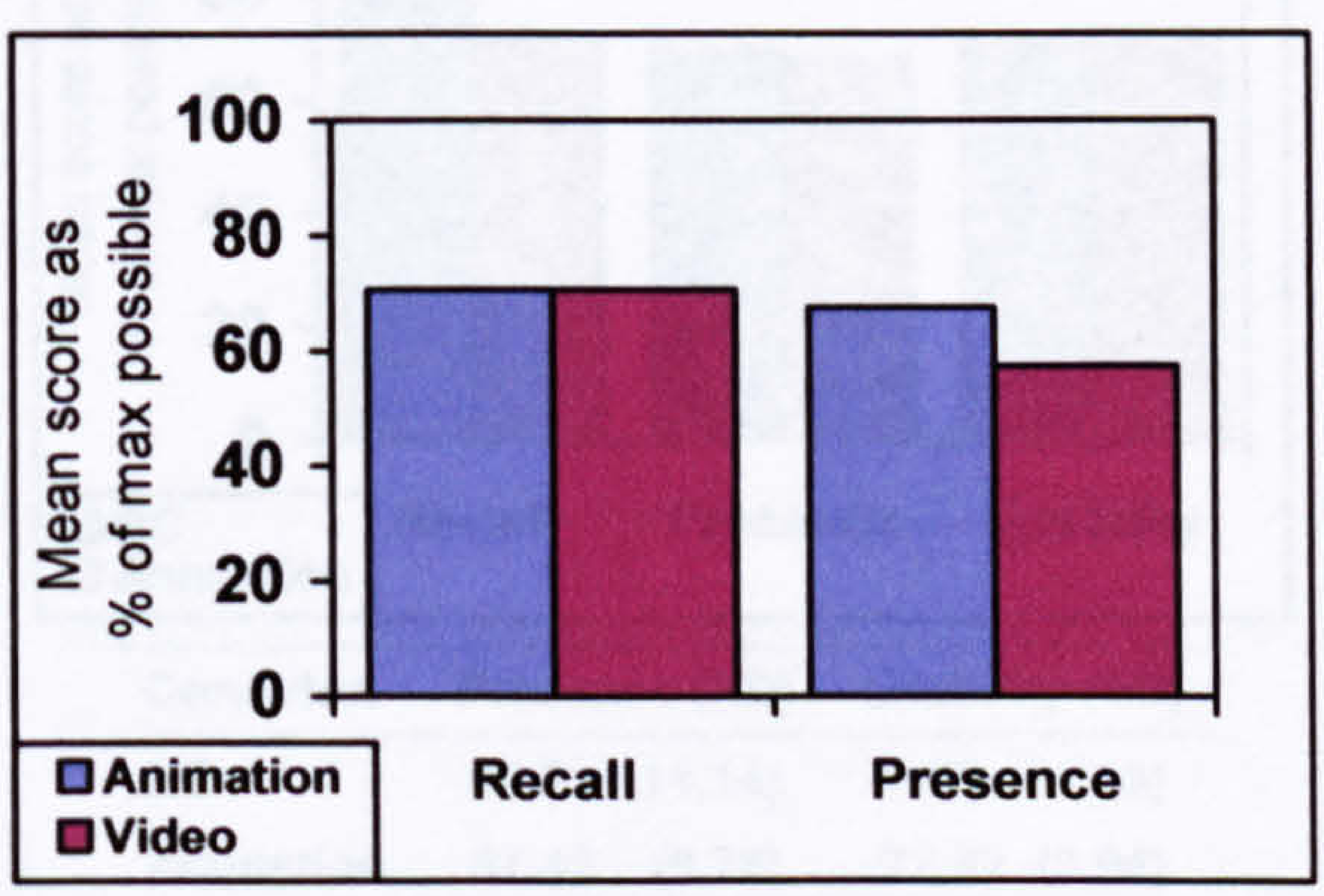
No significant difference is evident between RW recall measures for both conditions, indicating that selection is not an important inclusion in a training VE to ensure increased recall from the task performed within that VE. Presence and usability also showed no significant difference between the two conditions suggesting that they are not influenced by the participants' ability to select whilst within a VE. This is a surprising outcome and will need further examination to establish why this may be the case.

Hypothesis Four:

There will be a difference in the effectiveness measures taken between realism (video) and low realism (animation) conditions.

5.7.4 Real World Recall and Presence – Realism & Low Realism

Results were compared for the effectiveness measures taken (recall, presence and usability) in the real (Video) and VE (Animation) conditions, see Figure 5-7.



Condition	Presence (SD)
Animation	67.42 (8.78)
Video	57.5 (11.06)

Figure 5-7: Mean RW recall and presence scores as a percentage of the maximum possible – 'animation' and 'video'

(Recall data is repeated here from hypothesis two for ease of reference. RW Recall, 'Animation' and 'Video': t=0.006, df=14, *p*>0.05; Presence, 'Animation' and 'Video': t=2.066, df=14, *p*>0.05).

No significant difference was found between the measures of RW recall or presence for the virtual environment realism (Animation) and total realism (Video) conditions

[6] Adjusted number used for degrees of freedom throughout when equal variances not assumed.

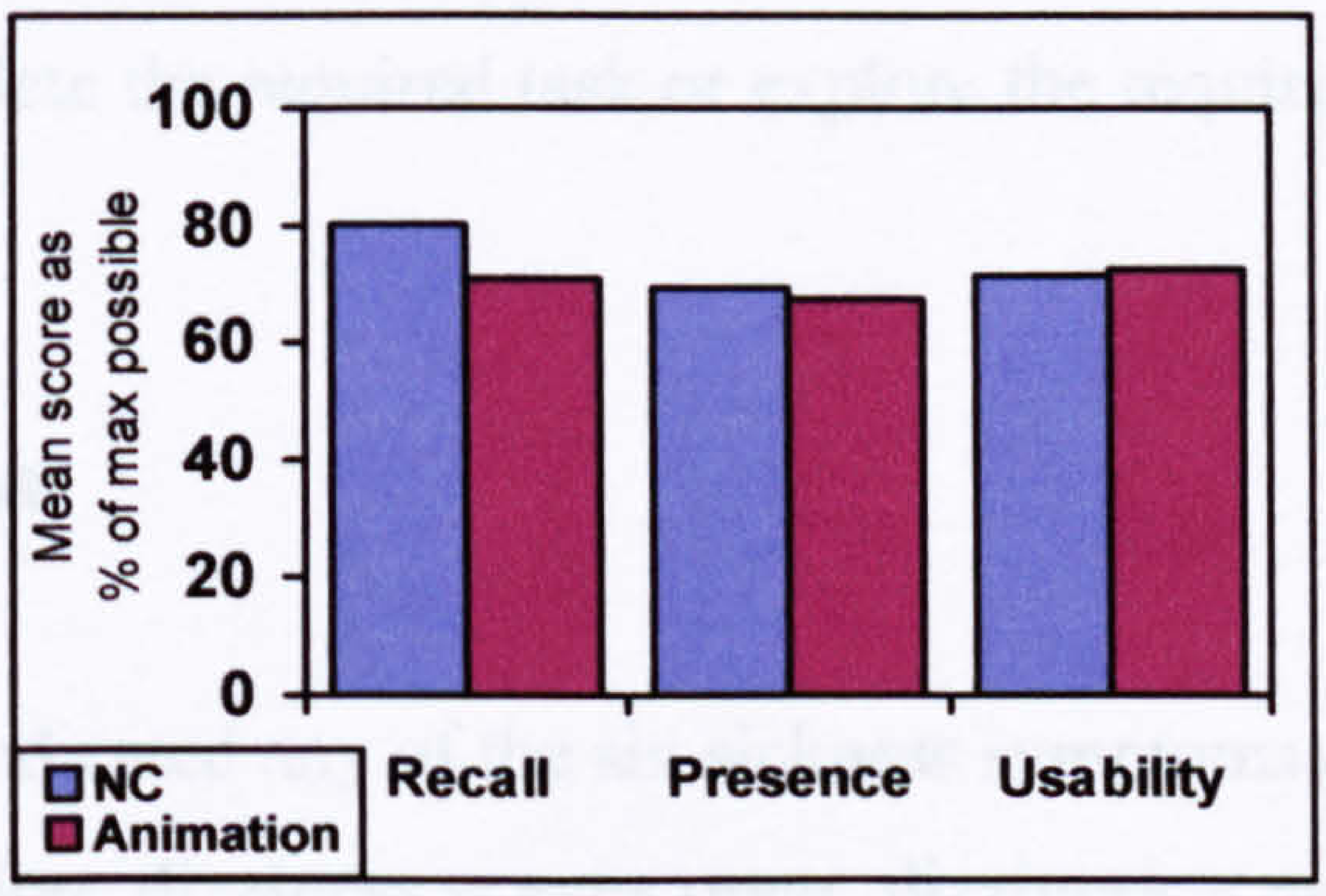
indicating that realism is not essential for effective VE training and consequently that VE training is a suitable equivalent to the other methods tested. Possible cost and user attitude benefits may be evident and would require further examination.

Hypothesis Five:

There will be a difference in the effectiveness measures taken between participant navigational control (NC) and no participant navigational control (animation) conditions.

5.7.5 Real World Recall, Presence and Usability – Navigational Control & No Navigational Control

Results were compared for the effectiveness measures taken (recall, presence and usability) in the navigational control (NC) and no navigational control (Animation) conditions, see Figure 5-8.



Condition	Presence (SD)	Usability (SD)
NC	69.32 (11.14)	71.5 (11.83)
Animation	67.42 (8.78)	72.67 (3.94)

Figure 5-8: Mean RW recall, presence and usability scores as a percentage of the maximum possible – NC and Animation

(Recall data is repeated here from hypothesis two for ease of reference. RW Recall, 'NC' and 'Animation': t=1.327, df=14, P>0.05; Presence, 'NC' and 'Animation': t=0.374, df=14, p>0.05; Usability, 'NC' and 'Animation': t=-0.224, df=14, p>0.05).

No significant difference was found between the measures of RW recall, presence or usability for total participant navigational control (NC) and no navigational control (VE) conditions indicating that selection is not essential for effective VE training.

Hypothesis Six:

There will be a relationship between the time taken and RW recall when participants were able to use the training VE as long as they wished (SNC and NC conditions).

5.7.6 Time Taken – Selection & No Selection

It was possible for participants to spend as long as they wished in the conditions they had navigational control over (SNC and NC) and as a result the possible influence that this may have had on correct RW recall was explored. For correct recall and time spent in the SNC condition ($r=0.264$, $n=8$, $p>0.01$) no significant relationship was found. For correct recall and time spent in the NC condition ($r=-0.347$, $n=8$, $p>0.01$) no significant relationship was found. This indicates time is not a factor in the effectiveness of the virtual environment training and does not need to be considered when developing training environments to ensure participants spend a certain length of time in them, merely that they complete the required task or explore the required area however long it takes them.

Sickness Symptoms

Only six participants indicated any of the six sickness symptoms on the SSC (head ache, eye strain, blurred vision, dizziness – eyes open, dizziness – eyes closed, sickness) at any point during the experiment in all four conditions. Of these two stated their symptoms stayed the same before during and after using the VE (an indication that it is possible that the symptoms were in no way related to the use of the VE), three indicated an increase in symptoms in dizziness with eyes open and eyes closed and also sickness. No participants felt at any point unable to continue with the experiment and reported a return to normal after its completion. One participant indicated that blurred vision decreased whilst using the environment. Of the three participants indicating a worsening of symptoms two used the SNC condition, the other NC. The presence and usability values calculated for each of the participants experiencing an increase in symptoms were all greater than or equal to the equivalent mean values calculated for the entire participant group.

This indicates that the symptoms of sickness had no obvious influence on either presence or usability for any of the three participants. It is also possible that symptoms of sickness were increased due to high levels of presence experienced, as the experience of virtual reality was more real to the participants.

This may have occurred for many reasons, for example it is possible that these participants had a greater dissociation between virtual and real experience and a greater conflict between visual and balance senses, which could lead to feelings of sickness. As none of the reported symptoms were in any way severe it is possible to state that the desktop VE medium used (with joystick and mouse to navigate and select where appropriate) would be suitable for most potential end users of such training and it was felt that desktop VE would be a suitable platform for continuing the research.

5.8 Main Findings

Table 5-7: Main Findings – experiment one

	Hypothesis	Finding
H_1	There will be a difference in real world (RW) recall one day and one week after the VE training has taken place.	There was no significant difference between the RW recall one day or one week after training in any condition (SNC, 'day' and 'week': t= 1.860, df=6, *p*>0.05; NC, 'day' and 'week': t= -0.740, df=6, *p*>0.05; Animation, 'day' and 'week': t=-0.422, df=6, *p*>0.05; Video, 'day' and 'week': t=-0.491, df=6, *p*>0.05).
H_2	There will be a difference in RW recall between conditions (SNC, NC, Animation and Video).	There was no significant difference in RW recall between any conditions (F=0.945; df=3; *p*>0.05). Post-hoc analysis revealed no significant difference between any two conditions.
H_3	There will be a difference in the effectiveness measures taken between selection (SNC) and no selection (NC) conditions.	There was no significant difference between the effectiveness measures taken between SNC – selection and NC – no selection conditions (RW Recall, 'SNC – selection' and 'NC – no selection': t=-1.413, df=10.089, *p*>0.05; Presence, 'SNC – selection' and 'NC – no selection': t=-0.709, df=14, *p*>0.05; Usability, 'SNC' and 'NC': t=-0.165, df=14, *p*>0.05).
H_4	There will be a difference in the effectiveness measures taken between realism (video) and low realism (animation) conditions.	There was no significant difference between the effectiveness measures taken between video – realism and animation – no realism conditions (RW Recall, 'Animation' and 'Video': t=0.006, df=14, *p*>0.05; Presence, 'Animation' and 'Video': t=2.066, df=14, *p*>0.05).
H_5	There will be a difference in the effectiveness measures taken between participant navigational control (NC) and no participant navigational control (animation) conditions.	There was no significant difference between the effectiveness measures taken between NC – navigational control and animation – no navigational control conditions (RW Recall, 'NC' and 'Animation': t=1.327, df=14, *p*>0.05; Presence, 'NC' and 'Animation': t=0.374, df=14, *p*>0.05; Usability, 'NC' and 'Animation': t=-0.224, df=14, *p*>0.05).
H_6	There will be a relationship between the time taken and RW recall when participants were able to use the training VE as long as they wished (SNC and NC conditions).	There was no significant relationship between time taken within the VE training and correct RW recall SNC (r=0.264, n=8, *p*>0.01) NC (r=-0.347, n=8, *p*>0.01)

Sickness symptoms: Very low sickness symptoms were reported during the experiment (only 6/32 participants), of these 3 reported a worsening of symptoms, though none felt that they were unable to continue with the experiment and reported a return to normal after its completion.

5.9 Experimental Program Development

As none of the display and interaction conditions explored in this experiment indicated a significant influence on the effectiveness measures taken (RW recall, presence, usability) it is possible to suggest VR training was not found to be significantly inferior to video and animated training displays and the development of an effective method of implementing this training application of VR can continue to be explored. The Animation and Video conditions will no longer be considered within this research as the main focus of research is on VE design.

Time has been eliminated as an influencing factor on the training effectiveness measures taken and consequently the use of a task to ensure that the user spends a certain amount of time in the VE is not a requirement. As all conditions in experiment one required the participant to perform a task whilst within the environment when considering how to make a VE as effective as possible for a training application the task and its importance on the effectiveness measures taken should be examined.

No sickness symptoms that were reported were lasting or resulted in the discontinuation of training again justifying the continued use of desktop VE as a medium for this application.

Chapter 6 - Experiment 2

Establishing the most effective design of selection hotspots in task directed and non task directed environment exploration

6.1 Experimental Program Development

Exp	Questions asked	Main findings	What next?
One	1. Does participant ability to control their navigation around a VE influence the effectiveness of that VE? 2. Does participant ability to select objects within a VE influence the effectiveness of that VE? 3. Does the realism of the VE influence the effectiveness of that VE?	1. There was no significant difference between measures with total participant navigational control and no participant navigational control. 2. There was no significant difference between measures with participant selection and no participant selection. 3. There was no significant difference between measures with total realism and no realism.	As none of the display and interaction conditions explored in experiment one indicated a significant influence on VE training effectiveness indications are VR training is a suitable replacement for video and animated training. What other factors may influence the effectiveness measures of VE training, in particular RW recall as a fundamental aspect of VE training? Explore these factors and examine their importance.
Two	1. Does the inclusion of a task influence the effectiveness of VE training, specifically with respect to task related RW recall? 2. What prompts a participant to select a specific object within a VE?		

6.2 Introduction

From the findings of experiment one it appeared that the manner in which information is displayed about an environment (a VE with or without participant navigational control, and animation or a video of the real world environment) did not significantly influence the recall of task related information from that environment ('*Figure 5-5: Mean correct recall as a percentage of max recall objects found in VE – all conditions*', P. 126). Consequently it is possible to state that VR training is a suitable replacement to video or animated training and it was therefore justified that research into VR as a training tool continued. As retaining information about a VE is obviously a basic requirement of creating an effective training VE other factors were considered that may have an effect on the measures taken, in particular recall.

All of the conditions examined in experiment one required the participant to perform a task and recall was measured in the real world environment about that task. It is possible in this case that the inclusion of a task influenced real world recall and therefore it was decided that in this experiment a task and no task condition would be compared to investigate any possible effect on the measures taken.

A distinguishing feature of VR from other computer based displays is that it can be manipulated by the user in real time (either through navigation – changing FOV, or selection of objects and possible reactions from those objects as a result of that selection) and is not merely a non interactive display. This, and the fact it was shown in experiment one that VE training was a suitable equivalent to video and animated training (one day and one week after training took place) from the measures taken, a decision was taken that the animation and video conditions would no longer be considered in this research programme.

After investigating the importance of the ability to select or not within a VE in experiment one and finding it to have no significant influence on the effectiveness of the VE training environment it was thought that what prompts a participant to select a specific object within a VE should be explored. A variety of cues were used in experiment one to examine this though results were not examined in detail.

Selection is a fundamental feature of VR but little research has been performed into how this selection should be designed and developed and as the power of the PC increases and software improves, the capability to involve selection when designing a VE is almost inexhaustible with minimal negative effects on the VE itself such as slower rendering speeds. Factors that then become limiting in the development of selection within a VE are more likely ones of time and ultimately cost of its development and maintenance. As a result it is still important to establish which selection is most important for the user and effective for the goal of the VE use, with respect to the task they are performing and the consequences of the VE use. This is for many reasons, for example, within a training VE it may be a requirement to encourage the participant to use certain objects within a VE as part of the training and therefore select it, or to entice them to important areas of the environment they are required to explore. This experiment aims to explore all these options to establish which features of the environment are most likely to be selected by participants, this information can then be used to reduce the design and development of non-useful environment features that can result in less time efficient development and less effective environments.

The points to be selected within the VE will be referred to as selection hotspots and the method used to encourage this selection as selection hotspot cues. It was also considered whether using a variety of selection hotspot cues would cause some cue types to be selected more or less than others and if this differed according to whether the participant performed a task or not within the VE.

The aim of this experiment therefore was to explore the importance of a task on task related recall and other effectiveness measures (presence and usability) and if this recall is affected by a delay after training (one week or one day), also, what prompts a user to select a specific object within a VE in both the task and no task conditions. For details of cue designs used and the underlying cognitive reasoning behind the designs refer to '*Table 4-4: Expectations from the design of selection hotspot cues (Marshall and Nichols, 2004)*'.

6.3 Research Questions

Task 'v' No task

1. Does the inclusion of a task influence task related RW recall?

- **Expectation:** A task will improve task related recall.
- **Reasoning:** The process of actively searching for and selecting the task items will increase the attention paid to those objects and consequently increase the likelihood of their being recalled (Kaur et al., 1999).

2. Does the inclusion of a task influence the other measures of the effectiveness of VE training taken (presence and usability)?

- **Expectation:** A task will improve effectiveness measures taken

- **Reasoning:** The process of actively searching for and selecting the task items will provide purpose, interest and context for the participant increasing the measures of presence and usability recorded (Kaur et al., 1999).

Selection Hotspot Cues

3. Do selection hotspot cues prompt increased selection?

- **Expectation:** Selection hotspot cues will prompt increased selection.
- **Reasoning:** Selection hotspot cues will attract more attention than the surrounding VE thereby prompting increased selection (Kaur, et al., 1999b).

4. Do some selection cue types prompt different amounts of selection than others?

- **Expectation:** Some selection hotspot cues will prompt more selection than others.
- **Reasoning:** Different cue types will attract different amounts of selection as a result of their appearance according to the surrounding VE context; the more out of context the more likely they will be selected (Kaur, et al., 1999b).

6.4 The Experiment

6.4.1 Conditions

The environment used was the RWVE as described in '*The Real World Virtual Environment (RWVE)*', section 4.2. The RWVE design was based on an existing building and consisted of 14 enterable rooms on two floors including offices, kitchens, computer rooms and lecture rooms that all appeared with respect to colours, main pieces of furniture and layout as close as was possible to the real world building. Two conditions were examined in this experiment, the first where the participants had to complete a task and the second where they did not. Table 6-1 provides details of these conditions.

Table 6-1: Conditions explored within experiment two – task and no task

Condition	Abbreviation	Description
Selection & Navigational Control - task[7]	**SNC – task**	- Free navigation using the joystick - Able to choose and select any objects. - Defined task whilst using the environment. - Selection hotspots were cued to indicate it was possible for the participant to select them.
Free Selection & Navigational Control - no task	**FSNC – no task**	- Free navigation using the joystick - Able to choose and select any objects. - No defined task whilst using the environment. - Selection hotspots were cued to indicate it was possible for the participant to select them.

6.4.2 The Task

The task in the 'SNC – task' condition was as described in '*The RWVE Task*', section 4.2.2 and required the participants to find 14 health and safety objects around the environment including red and black fire extinguishers, fire alarms, fire exits and a first aid box all of which were located as they were in the actual building. Once the objects were found the participant had to select them with the mouse and a tick appeared on an onscreen list so the participant could keep track of what they had found and how many they had still to find, see '*Figure 4-4: View of RWVE 'SNC' condition search task screen.*' P.104. The same RWVE (aside from the on screen tick list for the task in the 'SNC – task' condition) was used for both conditions with the same selection hotspot cues. The data from the 'SNC – task' condition used in this experiment was from the SNC participant group, experiment one.

6.4.3 Measures Taken

The following measures (*Table 6-2*) were taken for both conditions, for details of measurement methods see '*Experiment Procedure*', section 3.2.2 and '*Experiment Measures*', section 3.2.3, using the equipment and set up as described in '*Experiment Equipment*', section 3.2.1.

[7] Data used from SNC participant group in experiment one

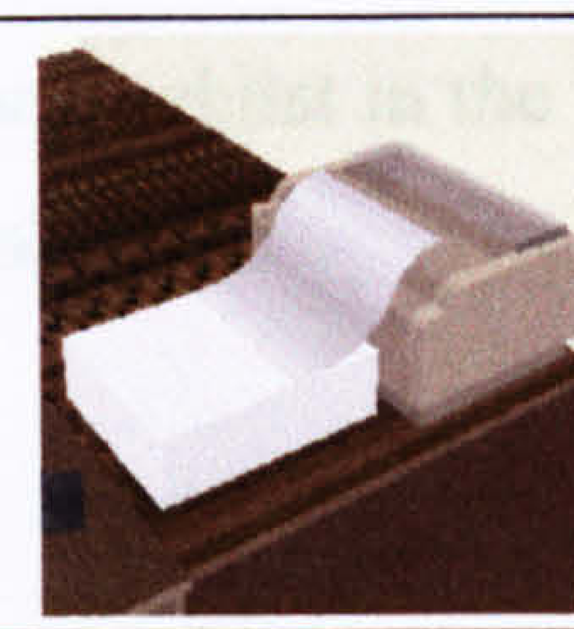
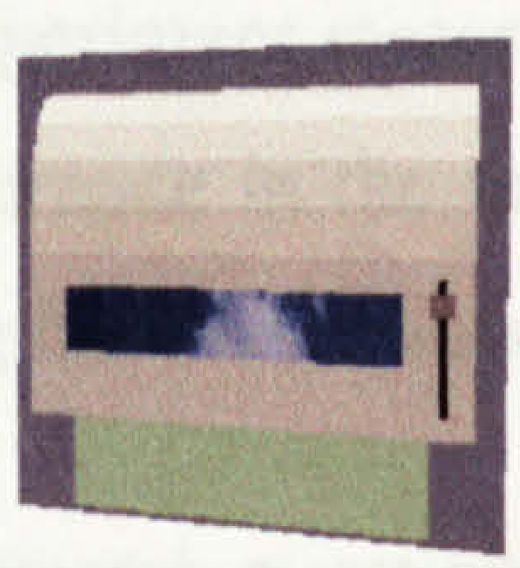
Table 6-2: Measures taken for each experimental condition – experiment two

Conditions	Measures Taken
SNC – task	RW recall, Presence, Usability and Selection
FSNC – no task	RW recall, Presence, Usability and Selection

6.4.4 Selection Hotspot Cues

The variety of selection cues used can be seen in *Table 6-3* with examples of how they appeared within the RWVE, the choice of cue design was based on research shown in '*RWVE Selection Hotspot Cues*', section 4.2.3.

Table 6-3: Selection Hotspot Cue Types and Examples

Selection Hotspot Cue Types	Example	Selection Hotspot Cue Types	Example
a) Red (flashing & highlighted) - The chair spins if selected.		**e) Textured – Photo Realistic** - The filing cabinet drawers open if selected.	
b) Blue (flashing & highlighted) - The kettle boils if the switch is selected.		**f) Movement** - The paper continually comes out of the printer as if it were printing.	
c) Grey (flashing & highlighted) - The dispenser dispenses towels if selected.		**g) Sound** - The tap makes a dripping noise when close to.	
d) Yellow (flashing & highlighted) - The phone handset lifts and emits a dialling tone if selected.			

A variety of cues were used to establish which were the most successful in that they prompted the most selection.

The appearance of the coloured cues (red, blue, grey and yellow both flashing and highlighted) was analysed further and was split into three categories; 'all', 'part' and 'surround'. The 'all' cue design was when the entire reactive aspect of the object was cued ('d' *Table 6-3*), 'part' was when only part of the reactive aspect of the object was cued ('a' *Table 6-3*) and 'surround' was when the reactive aspect of the object was surrounded by the cue ('b' *Table 6-3*).

6.4.5 Real World Recall

The same RW memory recall test was performed as described in experiment one (*'RW Recall'*, section 5.4.4). Participants were taken to the real world building that the RWVE was based on either one day or one week after the training to examine any possible degradation of the knowledge retained from the VE training over time and they were asked to recall the location of the objects they had been required to find in the 'SNC – task' condition. Participants' were not told at any point that they would be required to recall information about the VE until they arrived at the real world building. The participants in the 'FSNC – no task' condition were asked to find the same objects in the real world building although they were not required to find them whilst in the VE, this was to establish if recall was improved if it was of task related objects.

6.5 Research Hypotheses

Hypothesis derived from experiment research:

1. There will be a difference in the real world (RW) recall one day and one week after the VE training has taken place.

Hypotheses derived from research questions:

- *Does the inclusion of a task influence task related RW recall?*
- *Does the inclusion of a task influence the other measures of the effectiveness of VE training taken (presence and usability)?*

2. There will be a difference in the effectiveness measures recorded between the 'SNC – task' condition and the 'FSNC – no task' condition.

- *Do selection hotspot cues prompt increased selection?*

3. Selection hotspot cues will influence the amount of selection in comparison to non cued objects.

- *Do some selection cue types prompt different amounts of selection than others?*

4. Some selection hotspot cues (with respect to type and coloured cue design) will have a different influence on the amount of selection than others.

6.6 *Experiment Structure*

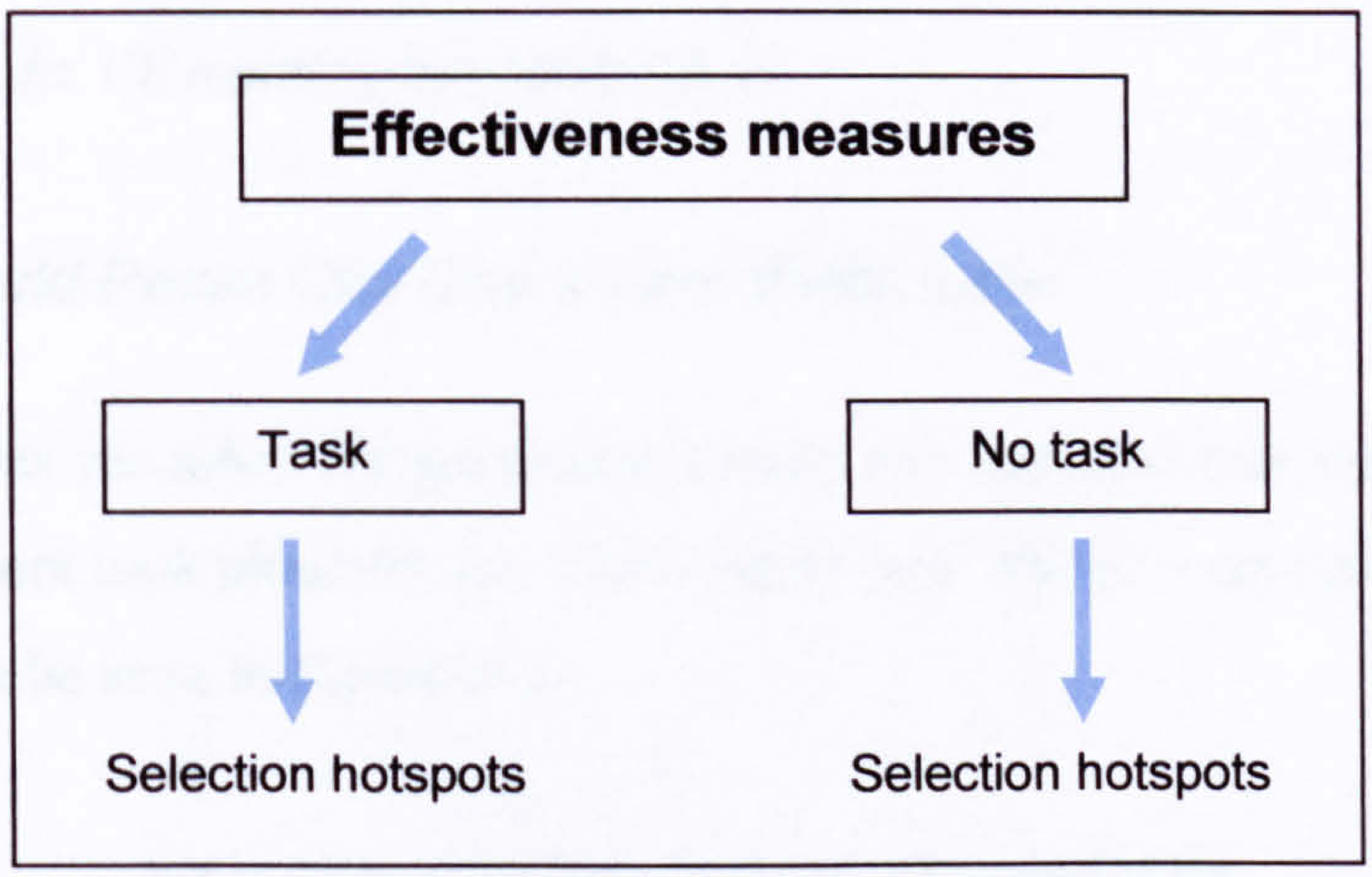


Figure 6-1: Experiment two structure

6.6.1 Participation Group

Table 6-4 shows the experimental group details[8].

Table 6-4: Participant group

Total	Age Range	Mean	Background
16	21 – 37	27yrs 7 months	Students and staff at the University of Nottingham. No previous knowledge of the real world building. VE novices.

The breakdown of participants in each condition within the group is shown in *Table 6-5*.

Table 6-5: Experimental conditions breakdown – number of participants

Condition	RW recall - 1 day later	RW Recall - 1 week later
SNC – task	4	4
FSNC – no task	4	4

[8] Participants in 'SNC – task' condition as in experiment one

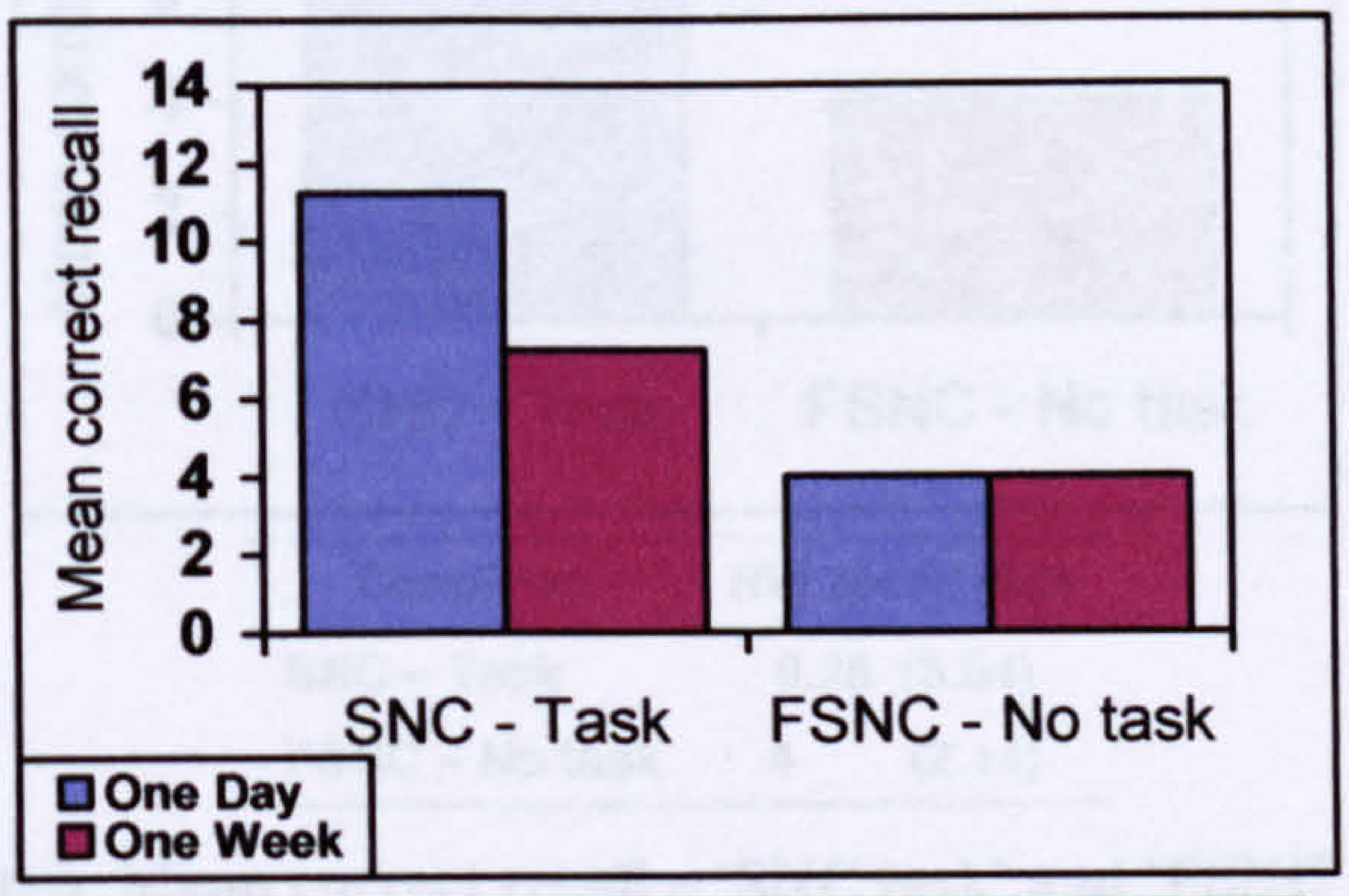
6.7 Results and Discussion

Hypothesis One:

'There will be a difference in the real world (RW) recall one day and one week after the VE training has taken place.'

6.7.1 Real World Recall One Day & One Week Later

Correct recall was recorded for participants both one day and one week after the VE training experiment took place for the 'SNC –task' and 'FSNC – no task' condition. The values found can be seen in Figure 6-2.



Condition	One day (SD)	One week (SD)
SNC – Task	11.25 (2.87)	7.25 (3.2)
FSNC – No task	4 (1.41)	4 (2.94)

Figure 6-2: Correct recall one day and one week after VE training – 'SNC – task' and 'FSNC – no task'

(SNC – Task, 'day' and 'week': t=1.860, df=6, $p>0.05$; FSNC – No task, 'day' and 'week': t=0, df=6, $p>0.05$)[9]

Figure 6-2 illustrates that there was no significant difference between recall one day and one week after training (as was also shown in experiment one 'Real World Recall One Day & One Week Later', section 5.7.1) and as a result of this recall from both will be used together in all further analysis. This provides positive evidence that recall does not appear to deteriorate over a week from VE training and is retained by the participant. As a result of this it was concluded that recall did not deteriorate directly after VE training

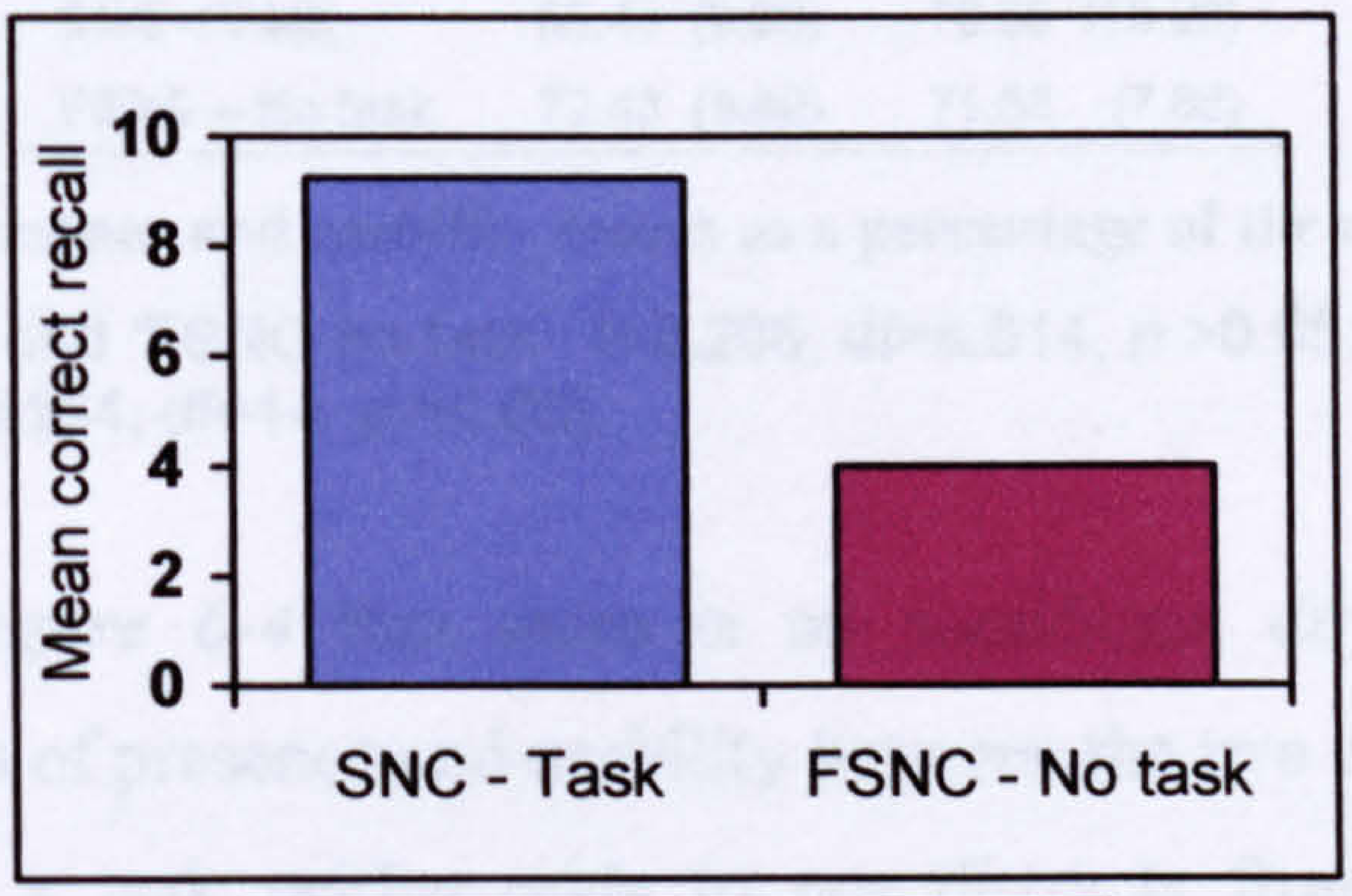
[9] Correct recall could not be examined here as a percentage of task performance as in experiment one as for the 'FSNC – No task' condition there was no task to measure the task performance from.

and any deterioration over time was not significant, therefore was no longer examined within this research.

Hypothesis Two:

'There will be a difference the effectiveness measures recorded between the 'SNC – task' condition and the 'FSNC – no task' condition.'

6.7.2 Real World (RW) Recall – Task & No Task



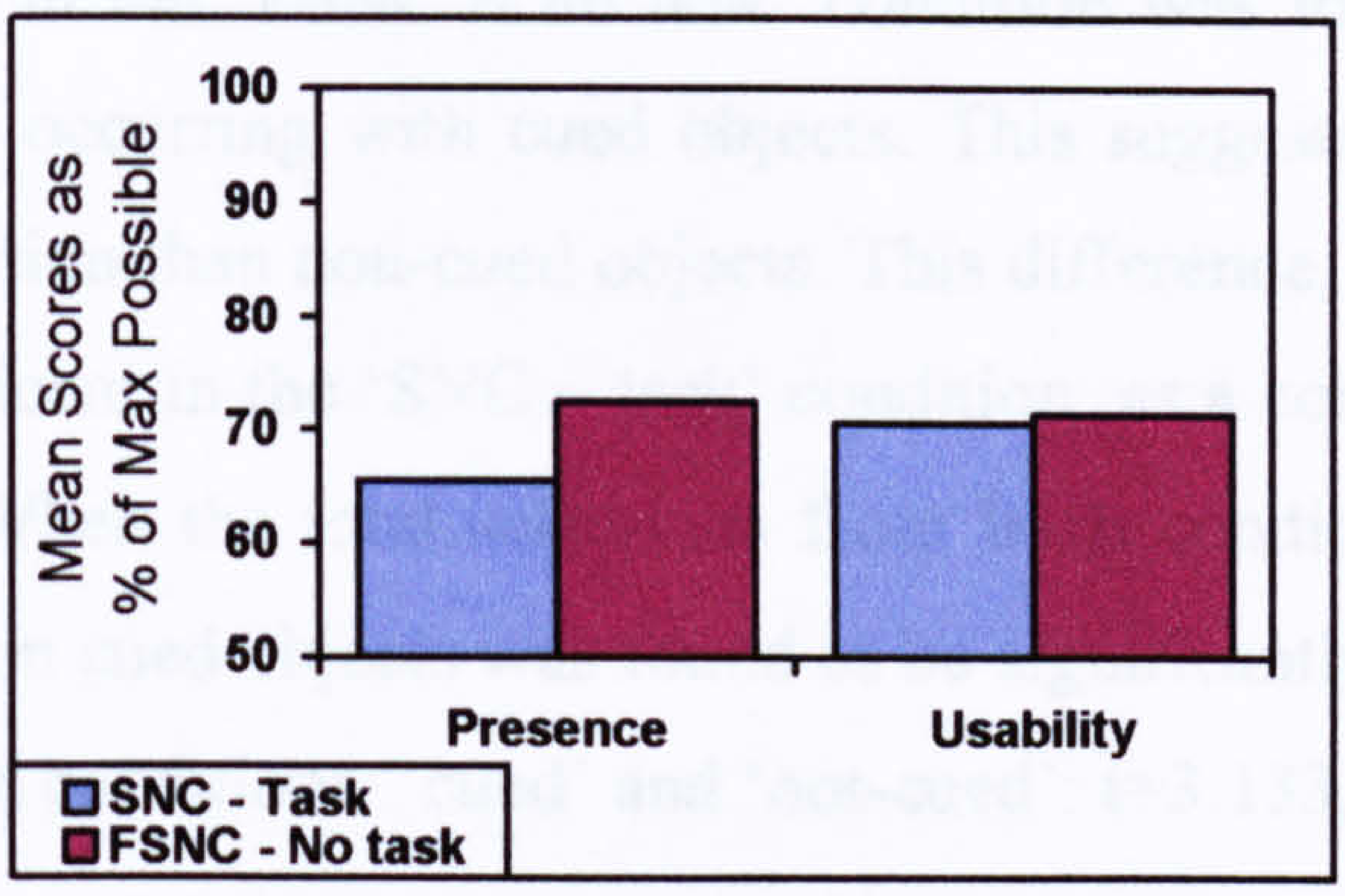
Condition	RW recall (SD)
SNC – Task	9.25 (3.54)
FSNC – No task	4 (2.14)

Figure 6-3: Mean correct recall – 'SNC task' and 'FSNC no task'
(Correct recall, 'SNC – task' and 'FSNC – no task': t=3.594, df=14, $p<0.05$).

Figure 6-3 shows that there was a significantly higher recall in the 'SNC – task' condition than the 'FSNC – no task' condition. This suggests that when the participant is required to recall information from the VE this recall is significantly improved if the information to be recalled was part of the task they were required to perform.

As participants were required to select the recall objects as part of the task in the 'SNC – task' condition it is also possible to say that selection may improve recall, this will be isolated in later experiments and its importance explored further.

6.7.3 Presence and Usability – Task & No Task



Condition	Presence (SD)	Usability (SD)
SNC – Task	65.46 (9.96)	70.58 (10.29)
FSNC – No task	72.43 (4.89)	71.33 (7.88)

Figure 6-4: Mean presence and usability scores as a percentage of the max scores possible
(Presence, 'SNC – task' and 'FSNC no task': t=0.298, df=8.614, $p > 0.05$: Usability, 'SNC – task' and 'FSNC no task': t=-0.164, df=14, $p > 0.05$).

It can be seen in *Figure 6-4* that there is no significant difference between the effectiveness measures of presence and usability between the two conditions, suggesting that the inclusion of a task neither adds to nor distracts from these effectiveness measures.

Hypothesis Three:

'Selection hotspot cues will influence the amount of selection in comparison to non cued objects.'

6.7.4 Selection of Cued & Non Cued Objects

Table 6-6: Selections of cued and non-cued objects (all participants) – 'SNC task' and 'FSNC no task'

Condition	Mean cued objects selected (SD)	Mean non-cued objects selected (SD)	t-test
SNC – Task	13 (18.68)	3.88 (6.17)	t=2.031, df=7, $p>0.05$
FSNC – No task	34.13 (27.05)	28 (27.03)	t=2.739, df=7, $p<0.05$
t-test	t=-1.818, df=14, $p>0.05$	t=-2.461, df=7.729, $p<0.05$	

(Total selections, 'SNC – task' and 'FSNC – no task': t=-2.163, df=9.841, $p>0.05$)

It can be seen in Table 6-6 that the difference between the number of selections of cued and non-cued objects in the 'FSNC – no task' condition was found to be significant, with greater selection occurring with cued objects. This suggests that cued objects do prompt greater interaction than non-cued objects. This difference, although evident, was not found to be significant in the 'SNC – task' condition, as a consequence of the large individual variance. When the total selections from **both** conditions were studied the amount of selections on cued objects was found to be significantly higher than those on non-cued objects (both conditions: 'cued' and 'not-cued': t=3.133, df=15, $p<0.05$).

The selection of cued and non-cued objects between the 'SNC – task' and 'FSNC – no task' conditions demonstrated a difference in the amount of selection of non-cued objects with significantly greater selection in the 'FSNC – no task' condition and although the same trend was evident for cued object selection it was not found to be significant.

Total selections of all objects were found to be greater in the 'FSNC – no task' condition although due to large individual variances it was not found to be significant.

Hypothesis Four:

> *'Some selection hotspot cues (with respect to type and coloured cue design) will have a different influence on the amount of selection than others.'*

6.7.5 Selection Cue Type & Selection

The mean number of selections per participant on each cue type is shown in *Table 6-7* and selections as a percentage of the maximum possible within the environment was calculated for both conditions and can be seen in *Figure 6-5.*

Table 6-7: Mean selections per participant on each cue type (SD)

Condition	R	B	G	Y	M	S	T/P	H	F
SNC – Task	2.25 (3.33)	2.63 (4.87)	1.75 (2.55)	2.75 (3.06)	0.63 (1.41)	0.25 (0.71)	2.75 (3.96)	4.13 (6.27)	5.25 (7.38)
FSNC – No task	5.5 (4.87)	6.5 (3.89)	5 (4.54)	4.63 (3.85)	4.13 (4.45)	1.63 (1.6)	6.75 (5.85)	9.5 (8.04)	12.13 (8.66)

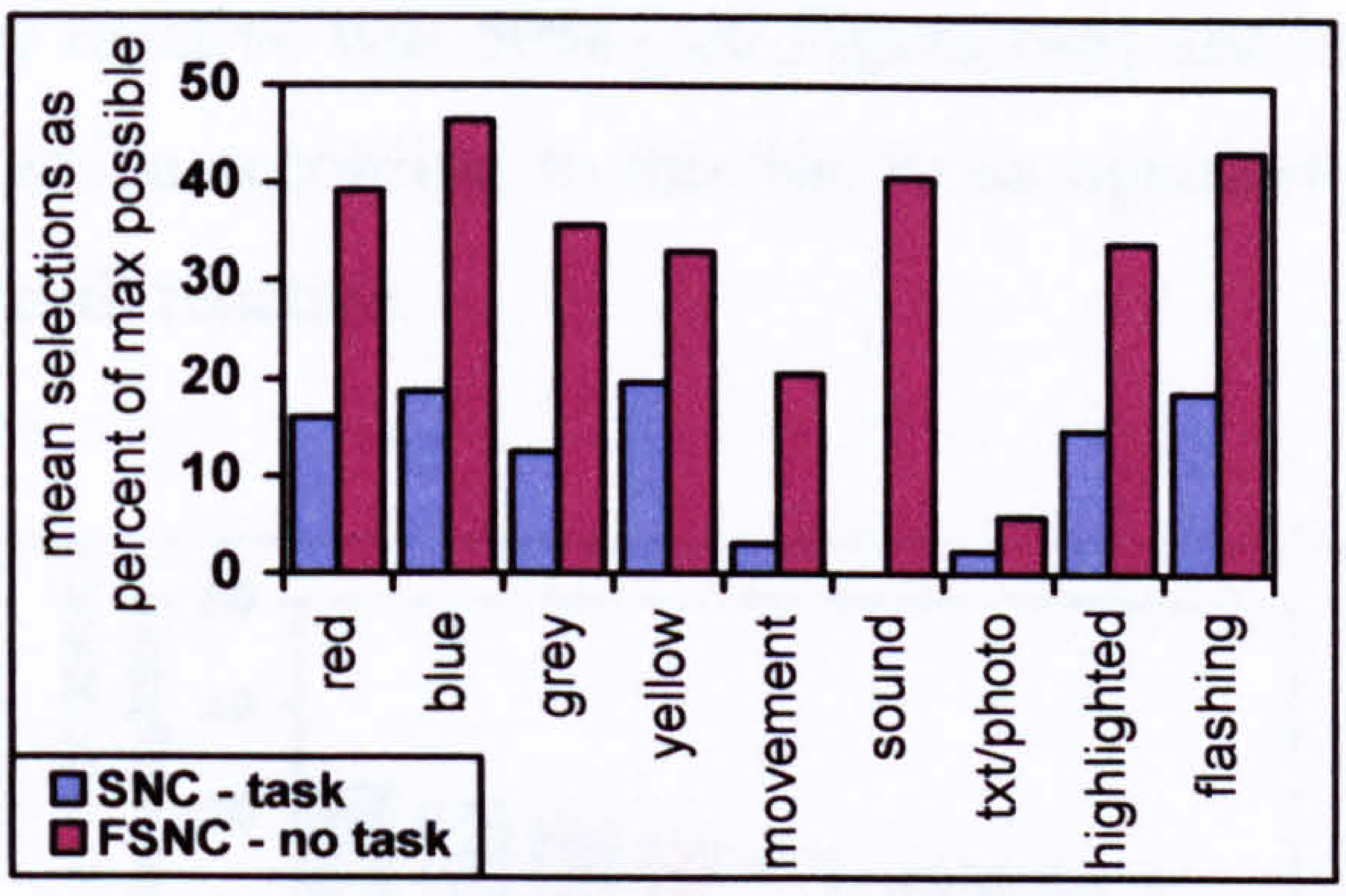


Figure 6-5: Mean selections per participant on each cue type as a percentage of the maximum possible

One-way within-subjects ANOVAs were performed on the data for the number of selections of each cue type (Figure 6-5). There was shown to be a significant difference in the number of selections on each cue type in both conditions ('SNC – task', $F_{(8,56)} = 3.262$, $p<0.005$; 'FSNC – no task', $F_{(8,56)} = 5.868$, $p<0.005$).

It can be seen from Figure 6-5 that the cues least selected and therefore least effective were in both conditions movement and textured/photo realistic cues. It is possible that this was as a consequence of them being congruous to the surrounding VE where other cues were not, such as the coloured cues, and therefore less 'noticeable' or 'attention grabbing' (Table 6-3, P. 139).

It was thought that a possible reason for the variety in number of selections for each cue type may be as a result of the fact that different numbers of each cue type were reactive. So if a participant tried a few photo realistic or textured objects for example, and they did not react they may have stopped selecting them. On the other hand the flashing objects would all react so they were more likely to try all that they came across to test for any possible reaction.

The influence of the reactivity of a cued object on the amount it was selected was taken into account with respect to the influence of the percentage of each cue type that was reactive on the mean percentage of each cue type selected. Extra weighting was given to the cue types that were not 100% reactive (txt/photo 10.43% reactive, sound 75% reactive and movement 0% reactive) to see if this influenced their effectiveness, for example if there were 14 moving cues and 7 of them would react in some way if selected the percentage reactive was 50% (see Figure 6-6) and the mean percentage of cue type selected would be according to this figure as opposed to 100% used for the coloured cues that were all reactive.

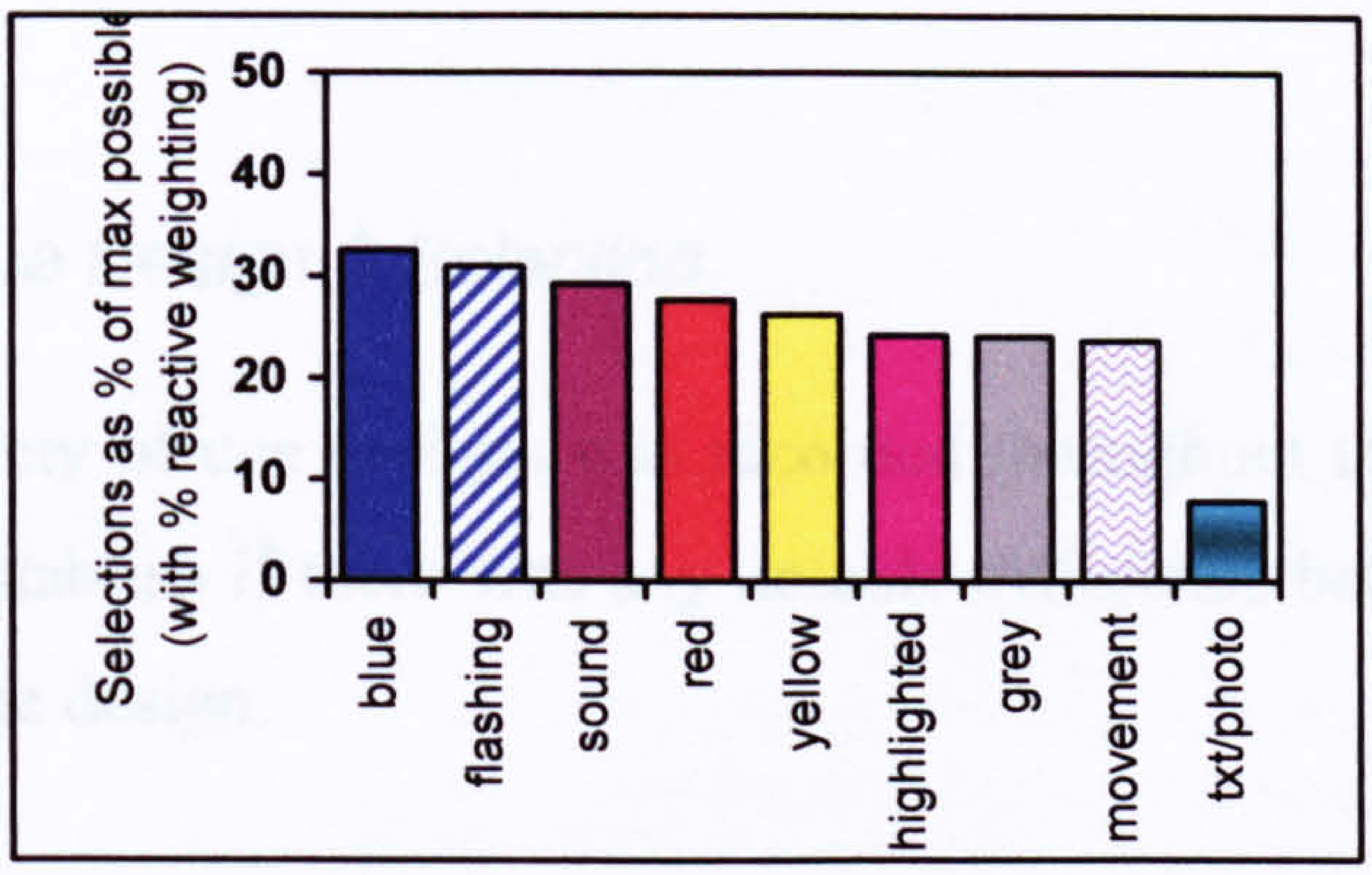


Figure 6-6: Mean number of selections made by all participants as a percentage of the maximum possible with extra weighting according to the number of each cue type that were reactive

A matrix of 't-test' values between each cue type for the data in Figure 6-6 is provided in Table 6-8 to examine the difference in selection between each cue type. The red highlighted values are those found to be significant at $p<0.05$.

Table 6-8: T-test results matrix for the number of selections made by all participants with extra weighting according to the number of each cue type that were reactive

	B	F	S	R	Y	H	G	M	T/P
B	X	0.778	0.41	1.546	1.754	2.873	2.162	1.502	3.621
F	X	X	0.222	2.167	2.039	4.118	2.584	1.462	3.884
S	X	X	X	0.206	0.332	0.665	0.804	0.831	2.326
R	X	X	X	X	0.495	1.724	1.225	0.746	3.175
Y	X	X	X	X	X	1.09	0.675	0.449	3.868
H	X	X	X	X	X	X	0.12	0.118	3.265
G	X	X	X	X	X	X	X	0.09	3.115
M	X	X	X	X	X	X	X	X	2.202
T/P	X	X	X	X	X	X	X	X	X

It becomes clear from this graph that the only cue type that appears to remain less effective than the rest when reactivity is taken into account is the texture/photo realistic cue type. Table 6-8 shows that this difference is significantly different from all the other cue types. There are many possible reasons for this, such as the photos and textures added to the environment are assumed by the participant to be there purely to add realism to its appearance and therefore they are not perceived as selection cues, or, due to so few of this cue type being reactive because of its prevalence in the VE (10.43%) the chances of participants selecting a reactive object initially (therefore realising that some such cue types do result in a reaction) is low and consequently they do not attempt to again.

6.7.6 Coloured Cue Design & Selection

Selection of the variety of cue designs was recorded throughout the experiment for all the participants to establish if there was any notable difference between the number of selections on each cue design.

Table 6-9: Mean number of each coloured cue design type selected by participants – SNC (task) and FSNC (no task) as a percentage of the maximum possible

Coloured Cue Design	Mean # Cues Selected SNC – task (SD)	Mean # Cues Selected FSNC – no task (SD)
'all'	13.89 (21)	34.72 (29.36)
'part'	18.48 (24.12)	39.67 (28.5)
'surround'	17.50 (30.43)	41.67 (33.38)

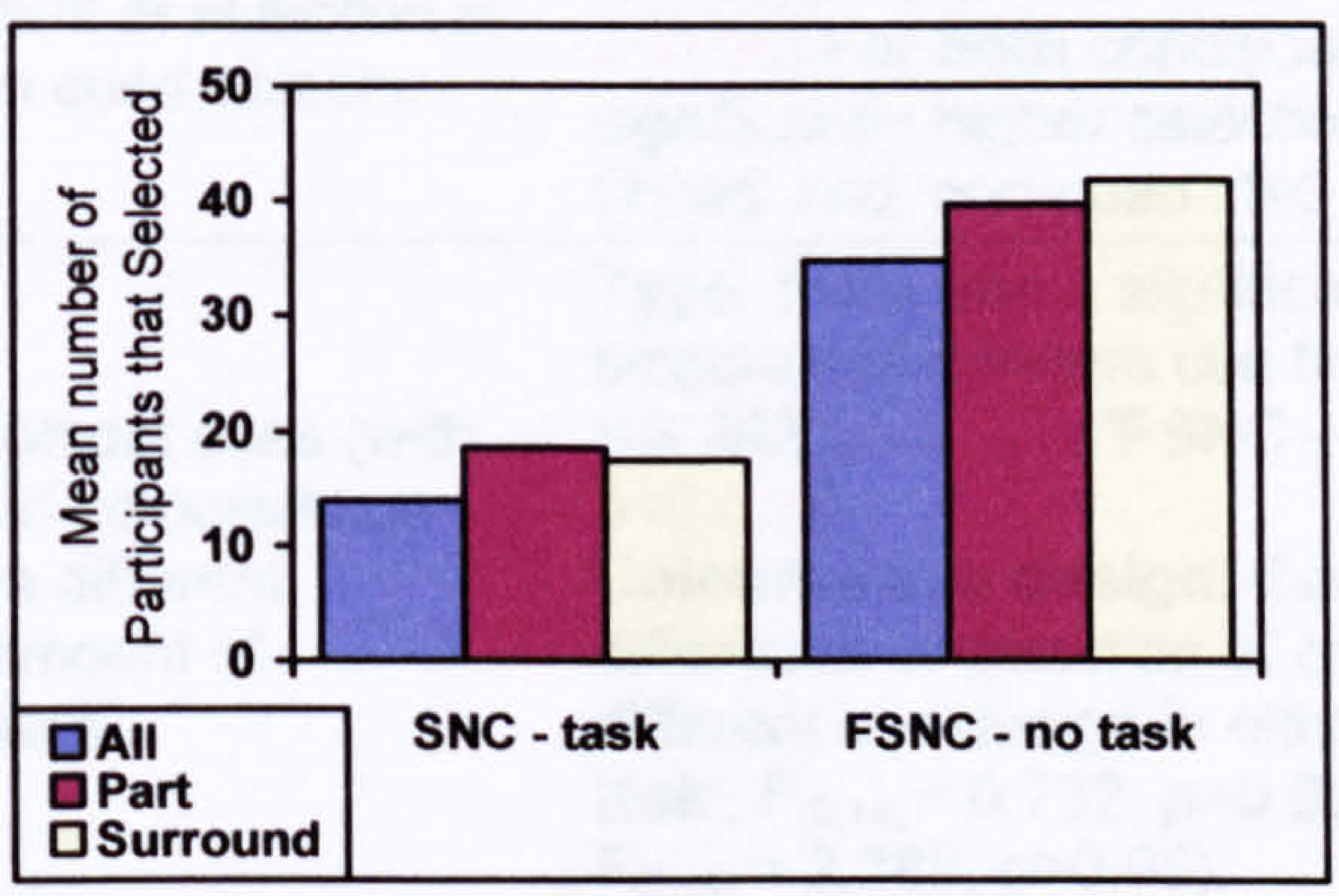


Figure 6-7: Mean number of selections by participants in the 'SNC – task' and 'FSNC – no task' conditions for 'all', 'part' and 'surround' cue designs

One-way within-subjects ANOVA was performed on the data for the number of selections of each coloured cue design (Figure 6-7)[10]. There was shown to be no significant effect of the number of selections on each coloured cue design in both conditions ('SNC – task', $F_{(2,14)} = 0.732$, $p>0.05$; 'FSNC – no task', $F_{(2,14)} = 2.388$, $p>0.05$). This indicated that no particular coloured cue design prompted greater

[10] One-way ANOVA was used as two-way ANOVA was not appropriate. A comparison between 'SNC – task' and 'FSNC - no task' conditions was not applicable to the effectiveness of coloured cue design.

interaction and consequently all designs ('all', 'part' and 'surround') can be used in selection hotspot cue design.

6.8 *Main Findings*

Table 6-10: Main Findings – experiment two

	Hypothesis	Finding
H_1	There will be a difference in the real world (RW) recall one day and one week after the VE training has taken place.	There was no significant difference between the RW recall one day or one week after VE training in either condition (SNC – Task, 'day' and 'week': t=1.860, df=6, $p>0.05$; FSNC – No task, 'day' and 'week': t=0, df=6, $p>0.05$).
H_2	There will be a difference in the effectiveness measures recorded between the 'SNC – task' condition and the 'FSNC – no task' condition.	**Recall**: 'SNC – task' condition showed a significantly higher RW recall than the FSNC – no task' condition (Correct recall, 'SNC – task' and 'FSNC – no task': t=3.594, df=14, $p<0.05$). **Presence and Usability**: There was no significant difference between the effectiveness measures of presence and usability recorded between both conditions (Presence, 'SNC – task' and 'FSNC – no task': t=0.298, df=8.614, $p>0.05$: Usability, 'SNC – task' and 'FSNC no task': t=-0.164, df=14, $p>0.05$).
H_3	Selection hotspot cues will influence the amount of selection in comparison to non cued objects.	There was significantly higher selection of cued objects in the 'FSNC – no task' condition (FSNC – No task, 'cued' and 'non-cued': t=2.739, df=7, $p<0.05$).For **both** conditions combined there was significantly higher selection of cued objects ('cued' and 'non-cued': t=3.133, df=15, $p<0.05$).
H_4	Some selection hotspot cues (with respect to type and coloured cue design) will have a different influence on the amount of selection than others.	**Type**: there was a significant difference of selection of different cue types ('SNC – task', $F_{(8,56)}$ = 3.262, $p<0.005$; 'FSNC – no task', $F_{(8,56)}$ = 5.868, $p<0.005$). **Coloured cue design**: there was no significant difference of selection of coloured cues with different cue design in either condition ('SNC – task', $F_{(2,14)}$ = 0.732, $p>0.05$; 'FSNC – no task', $F_{(2,14)}$ = 2.388, $p>0.05$).

6.9 *Experimental Program Development*

The first main finding from this experiment indicated that recall is improved when participants who used the VE performed a task, if recall is task related. Development of this finding would be to establish if this was the case when recall was not task related.

It was also noted that recall being higher in the task condition may have been as a consequence of participants having selected the recall objects (see section 'Real World

(RW) Recall – Task & No Tas*k'*, P 143) so the importance of selection on object recall was a further consideration in future experimental design.

As the use of cues suggested an increase in selection from the findings of this experiment it was decided that they should continue to be used in further experiments to encourage the selection of non-task related objects within the VE, including those objects that will be recalled as the recall measure after the training has taken place. It was also found that selection was significantly increased if there was no task for the participant to perform. A possible reason for this is that when performing a task the participant became focused on that task and did little else. This should be considered when developing a VE as if it is a requirement of the participant to recall certain aspects of the VE it is possible they should either be incorporated into a task or there should be no task and preferably these points will be cued in some way to encourage attention.

One final point that was observed worth note and further exploration, was that the cues least selected were those which were least abstract to the surrounding VE context (Figure 6-5, P.146), the movement and photo realistic or textured cues. It is possible that as their appearance within the VE was congruent to the surrounding appearance ('Table 4-7: Examples of selection hotspot cue types in the RWVE*'*, P.109) they were consequently less effective than the more incongruent cues such as the coloured cues (Table 6-3, P. 139).

Chapter 7 - Experiment 3

Establishing the importance of object selection and task directed environment exploration on non task directed recall

7.1 Experimental Program Development

Exp	Questions asked	Main findings	What next?
One	1. Does participant ability to control their navigation around a VE influence the effectiveness of that VE? 2. Does participant ability to select objects within a VE influence the effectiveness of that VE? 3. Does the realism of the VE influence the effectiveness of that VE?	1. There was no significant difference between measures with total participant navigational control & no participant navigational control. 2. There was no significant difference between measures with participant selection & no participant selection. 3. There was no significant difference between measures with total realism & no realism.	As none of the display and interaction conditions explored in experiment one indicated a significant influence on VE training effectiveness indications are VR training is a suitable replacement for video and animated training. What other factors may influence the effectiveness measures of VE training, in particular RW recall as a fundamental aspect of VE training?
Two	1. Does the inclusion of a task influence the effectiveness of VE training, specifically with respect to task related RW recall? 2. What prompts a participant to select a specific object within a VE?	1. The inclusion of a task resulted in significantly increased recall of task related objects 2. Cues suggested increased selection over non-cued objects	As recall was improved with a task when task related it should be explored if this is also the case when recall is not task related. Recall performance may not have been related to the task but as a result of the selection of recall objects that occurred as part of that task, the importance of selection should therefore also be examined.
Three	1. Is the recall of objects within a training VE improved *when no longer related to the task* performed in the VE? 2. Does the selection of objects whilst in a VE influence the effectiveness of that training VE?		

7.2 Introduction

It was evident from the results of experiment two that recall of task related objects is significantly improved if the participant performed the task to which the objects relate. It is important now to consider if other aspects of the VE training that are not task related are also recalled, how this is affected by the inclusion of a task and to what extent. For example does the inclusion of a task prevent the participant noticing non-task related aspects of the VE because they are too task focused. This was suggested in experiment two when it was noted that selection was notably increased when there was no task for the participants to perform as a result they explored the environment more, possibly noticing more aspects of it as a consequence. It should also be asked; if a task is required to create an effective training VE must it relate to the recall required from the VE?

A second factor that should also be examined as a consequence of the findings of experiment two is the importance of selection of specific objects on their recall. As noted the inclusion of a task improved recall in experiment two, and as part of that task participants were required to select the health and safety (H&S) objects that they were later to recall. It should therefore be examined if this selection of objects in itself improves the recall of them, thereby giving a further reason for the inclusion of selection hotspot cues (that were shown in experiment two to increase selection of cued objects significantly) for important objects in training VEs. For example if a participant selected a cupboard door and it reacted to that selection in some way, such as opening, they may be more likely to recall details about that cupboard and its location than if it were merely a cupboard in the corner of a room.

Particularly in the case of training VEs it is also important to reduce the levels of incorrect recall as far as is possible. For a training VE to be as effective as possible correct recall must obviously be as high as is possible however it could be equally bad in a training context, if not more so, for incorrect recall to be high.

It is more expensive to include selection within a VE with respect to time taken to design and develop the environment to be used so the importance of its inclusion and how to make it most effective should be examined thoroughly. Therefore the ability to select can be limited to where it is most effective according to the requirements of the VE

An aspect of effectiveness with respect to the user that was not previously explored in experiments one or two as a separate entity is enjoyment. As a consequence of informal debriefs with participants after experiments one and two it was suspected that enjoyment was an influencing factor on the effectiveness measures that were recorded, consequently it was thought that this possibility should be examined formally to asses any possible influence. It was found in Nichols (1997) that participants' attitude towards conventional computers was associated with their enjoyment and their sense of presence, obviously an aspect of developing effective VE training should consider user attitude towards the system with which they are being trained. If they find it frustrating and ineffectual they will be less receptive to what it teaching them and consequently less likely to use it.

A question relating to the user's enjoyment whilst within the VE was asked in the presence questionnaire but it was thought that enjoyment should be examined in more depth as a separate entity. The method used to examine participants' enjoyment as a consequence of their VE experience was the enjoyment questionnaire (Nichols, 1997), this consisted of a checklist of adjectives (such as 'happy' and 'bored' and 'panicked'), where participants rated on a five point scale ranging from 'never' to always describing the degree to which they felt various emotions during the VE training. The scale consisted of six positive and six negative adjectives and scores were applied to each participant response, 5 being the most positive response possible and 1 being the most negative response possible. Participants were then given an overall enjoyment score. As enjoyment is considered an aspect of presence and usability (Nichols, 1999) within a VE it is thought that the scores obtained would have a positive relationship with those of presence and usability.

7.3 Research Questions

Task 'v' No task

1. Does the inclusion of a task influence the recall of non-task related objects?

- **Expectation:** A task will not improve the recall of non-task related objects
- **Reasoning:** The inclusion of a task has been shown to decrease the selection of objects within the VE (experiment two, '*Selection of Cued & Non Cued Objects*', section 6.7.4) as a consequence non-task related recall objects are less likely to be

selected and therefore be attended to if there is a task and therefore are less likely to be recalled

2. Does the inclusion of a task influence the effectiveness of VE training (presence, usability and enjoyment)

- **Expectation:** A task will improve the effectiveness of VE training.
- **Reasoning:** A task provides a reason and purpose to the participant's use of the VE and enables them to put the VE into context as opposed to exploring the VE with no specific goal. As a result there will be greater VE training effectiveness (measured by presence, usability and enjoyment) when completing a task within the VE. No significant findings were found with respect to the measures of presence and usability with and without a task in experiment two, consequently warranting further investigation and the inclusion of a further measure (enjoyment) to establish the influence it may have on effectiveness. See '*Figure 6-4: Mean presence and usability scores as a percentage of the max scores possible*'.

Selection 'v' No selection

3. Will participants be more likely to recall object position after VE training if they selected that specific object whilst in the VE?

- **Expectation:** Participants will be more likely to recall object position if they select that object during VE training.
- **Reasoning:** The process of selecting a specific object will encourage the participant to recall that object, this was suggested as a possibility in experiment two when the selection of objects to be recalled was part of the task the participants performed and resulted in increased recall. See '*Real World (RW) Recall – Task & No Task*', section 6.7.2.

4. Will enjoyment be improved when the participant is able to select objects or perform a task whilst within the VE thereby establishing a reason for the inclusion of selection within a VE?

- **Expectation:** Enjoyment will be improved when a participant is able to select objects as opposed to when they can not, enjoyment will also be improved when a participant performs a task within a VE.

- **Reasoning:** Through observation of participants using VR the inclusion of a task provides reason and purpose for the participant's use of the VE and consequently they may enjoy it more, the ability to select within the VE may also improve enjoyment as the reaction of objects to that selection will provide more depth to the environment and in so doing make it more enjoyable. Experiment one found no significant influence of selection on the measures of presence and usability (see, *'Figure 5-6: Mean RW recall, presence and usability scores as a percentage of the maximum possible – 'SNC – selection' and 'NC – no selection'*) thereby warranting further investigation into its possible influence on effectiveness with respect to presence, usability and enjoyment.

7.4 The Experiment

7.4.1 Conditions

The environment used was the RWVE as described in '*The Real World Virtual Environment*', section 4.2 with some usability design adaptations. Based on an existing building the VE was developed to visually represent the real buildings appearance as close as possible with the same room lay out, furniture and décor. Participants walked around the environment, navigating using a joystick, viewing it as they would the real world. Three conditions were examined in this experiment to explore the questions posed, the influence of a task on recall of non-task related objects required a task and non-task condition and the importance of selection on this question required a no selection condition. Details of these conditions can be found in Table 7-1.

Table 7-1: Conditions explored within experiment three – task and no task, selection and no selection

Condition	Abbreviation	Description
Selection & Navigational Control - with task & Selection	**SNC – task**	- Free navigation using the joystick - Able to choose and select any objects. - Defined task whilst using the environment. - Selection hotspots were cued to indicate it was possible for the participant to select them.
Free Selection & Navigational Control - no task	**FSNC – no task**	- Free navigation using the joystick - Able to choose and select any objects. - No defined task whilst using the environment. - Selection hotspots were cued to indicate it was possible for the participant to select them.
Navigational Control - no selection	**NC – no selection**	- Free navigation using the joystick - Unable to choose and select any objects. - Defined task whilst using the environment. - Selection hotspots were cued although participants were unable to select them to make them comparable.

The same selection hotspot cues were used in all the conditions, even when participants were unable to select within the environment (NC – no selection) to give participants an equal chance of recalling the objects in the recall test after the VE use took place.

7.4.2 RWVE Design Changes

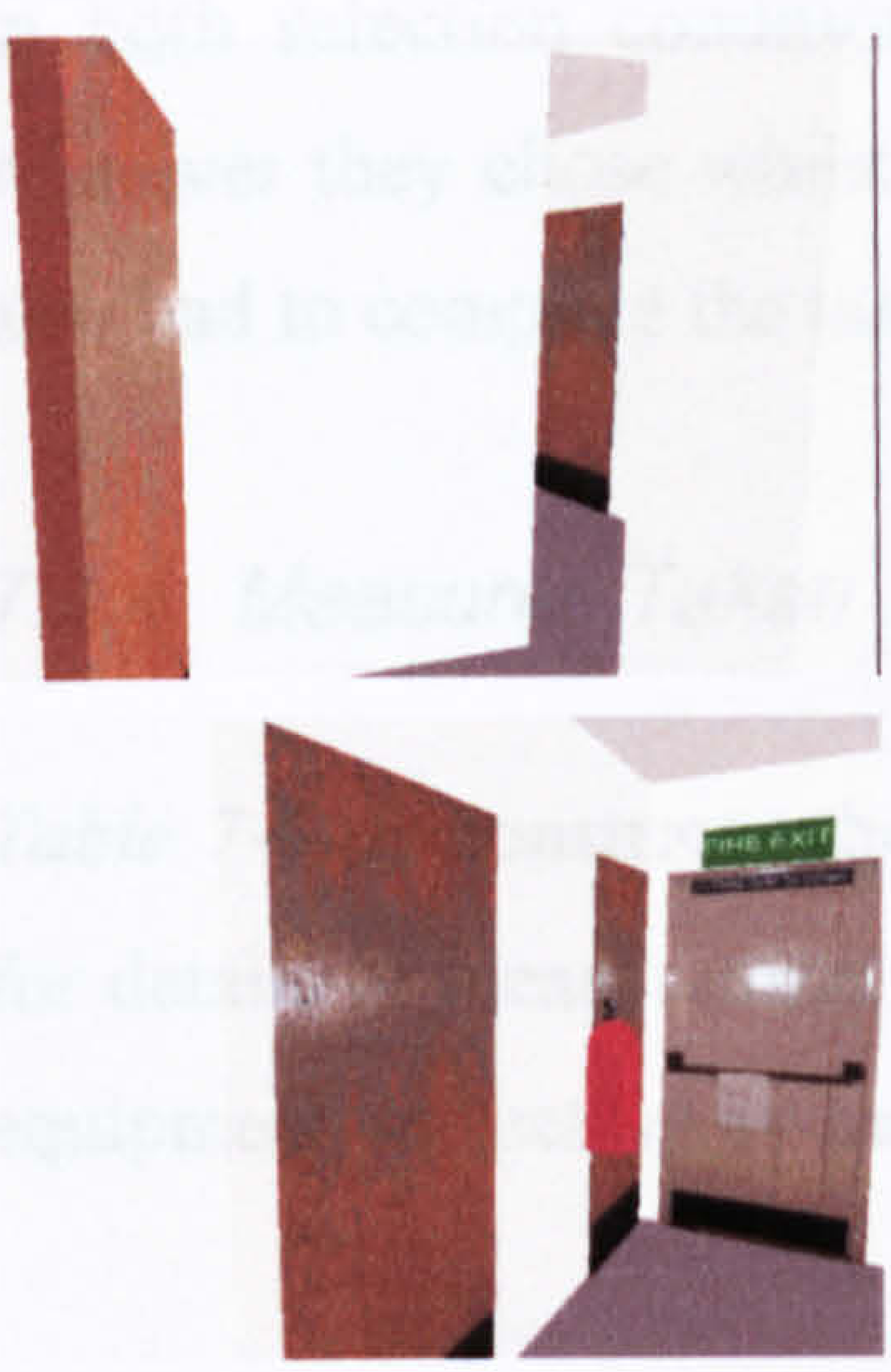
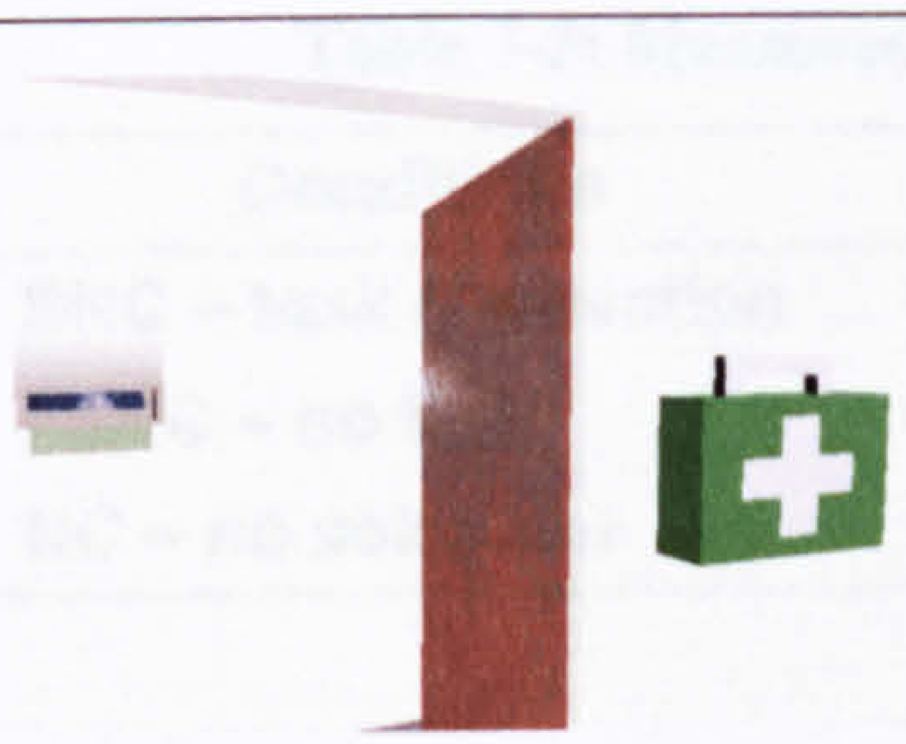
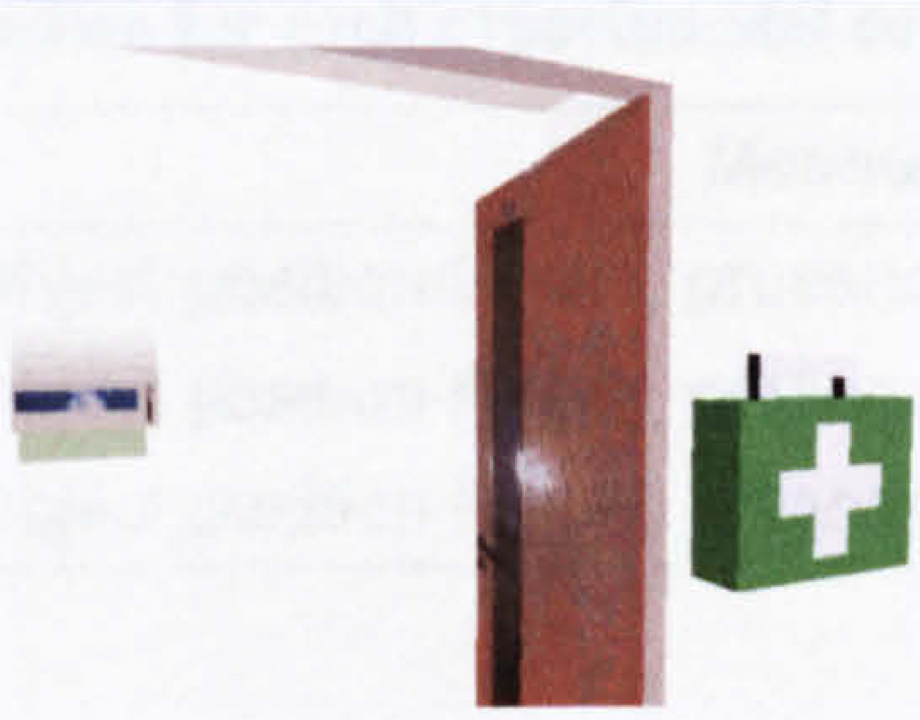
The VE used was adapted from the original design which was developed purely to represent the real world. This was because through observing participants in previous experiments it was noted persistent usability issues with aspects of the VE design occurred. There were, for example, areas where many participants got stuck in a small space or could not move in the direction they wanted and did not understand why as there was no obvious visual reason for it, such as under the stairs. The actual reason was that their VE body representation was too large to fit in the gap. In the real world a person would have crouched to get in the space but this was not possible in the virtual world. To address this the VE was adapted from its original design (see '*The Real World Virtual Environment (RWVE)*', section 4.2) to avoid common usability and selection problems as described by Kaur (1999) p.404.

- Maintaining a suitable viewing angle
- Navigating tight areas
- Losing whereabouts once too close to objects
- Recognising reactive hotspots.

Kaur (1999) was used as a practical guideline to designing environments to consider usability requirements.

The navigation of tight areas was prevented in all the rooms where it was possible by moving objects to cover openings into such areas. Using invisible barriers a short distance from the building walls prevented participants getting too close to the walls and non-reactive objects. Examples of design changes made and reasons for those changes can be seen in Table 7-2.

Table 7-2: Design changes made to the RWVE

Before Design Changes	After Design Changes	Details of Changes
		*Room 2* **Change:** tables moved under the stairs **Preventing:** getting stuck trying to navigate under the stairs and getting too close to the wall
		*Rooms 4 and 5:* **Change:** table removed **Preventing:** getting stuck moving from one door to another. **Action:** chairs moved. **Preventing:** getting stuck in-between the rows of tables & get too close to the wall
		*Room 16* **Change:** texture & colour variance added to the walls **Preventing:** disorientation as the similar colour of all the walls in this area had led to this in previous experiments.
		Room 17 ***Change:*** *texture on the doorframe (this occurred in many doorways throughout the environment),* ***Preventing:*** *paler colours used previously not being clearly distinguishable against the pale colour of the walls.*
		Room 18 ***Change:*** *stacks of chairs at the end of the desks* ***Preventing****: getting stuck* ***Change:*** *computer chairs moved closer to desks* ***Preventing:*** *Difficulties navigating round room.*

7.4.3 The Task

The task performed in the two task conditions ('SNC – selection' and 'NC – no selection') was as described in '*The RWVE Task*', section 4.2.2, participants could freely explore the RWVE navigating using the joystick in search of fourteen health and safety (H&S) objects (red and black fire extinguishers, fire alarms, fire exits and a first aid box) located as they were in the real world building. Participants were able to keep track of how many of these objects had been found and were still to be found during the SNC condition by selecting the objects with the mouse and a tick appearing on the onscreen tick list under a picture of the corresponding object (see '*Figure 4-4: View of RWVE 'SNC' condition search task screen.*' P.104). As participants in the NC condition were unable to select they used the same tick list but completed it by hand. Participants in both selection conditions (SNC and 'FSNC) were told they could interact with whatever they chose whilst within the environment; though in the SNC condition they also had to complete the task.

7.4.4 Measures Taken

Table 7-3 demonstrates the measures taken for each condition within this experiment, for details of measurement methods see '*Experiment Measures*', section 3.2.3 using the equipment and set up as described in '*Experiment Equipment*', section 3.2.1.

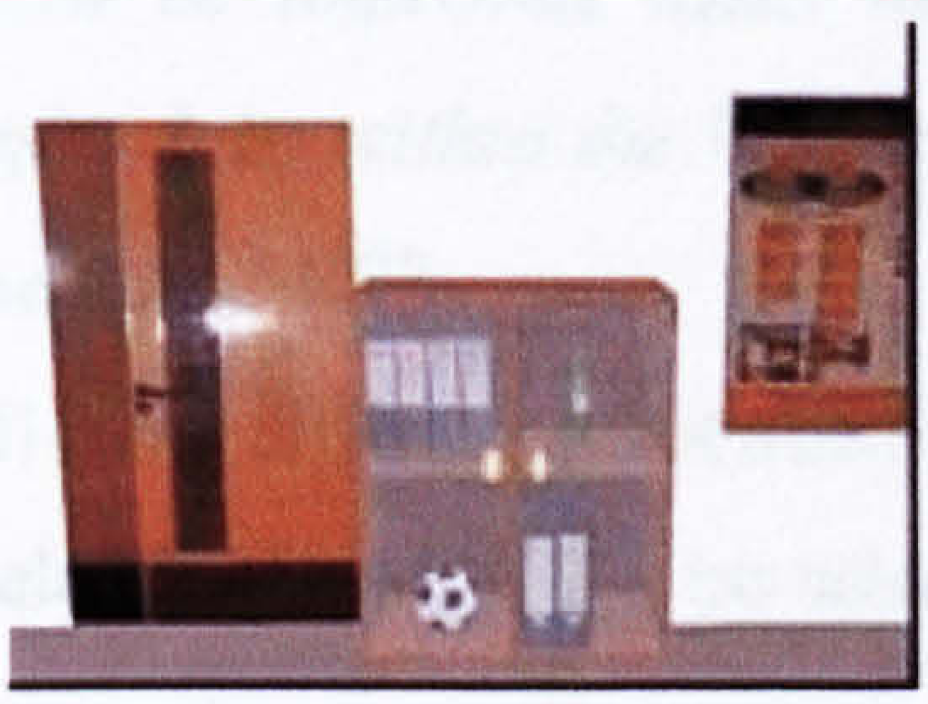
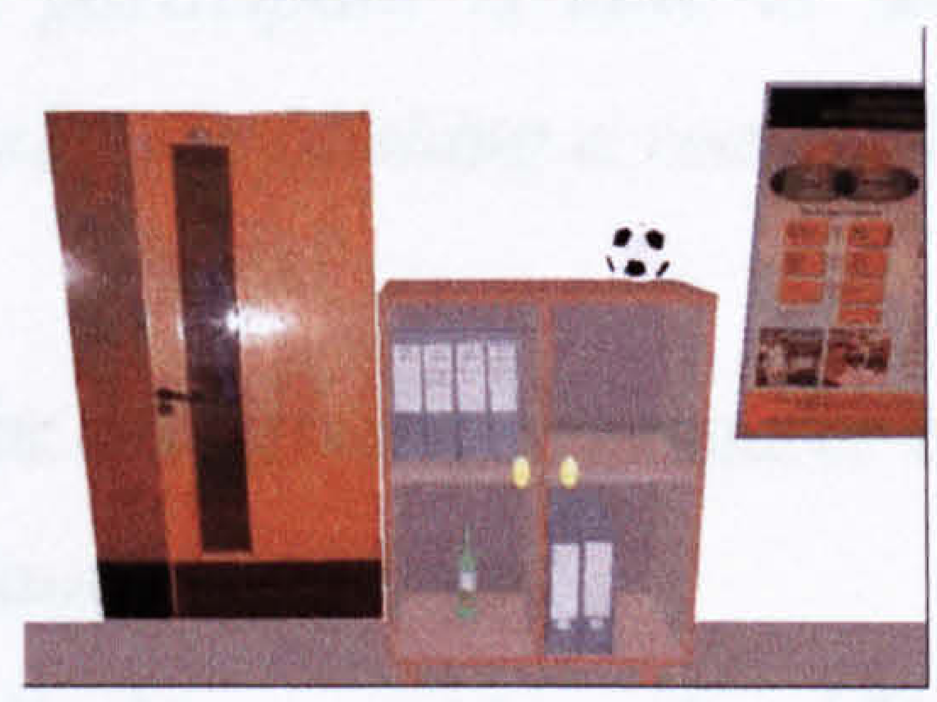
Table 7-3: Measures taken for each experimental condition – experiment three

Conditions	Measures Taken
SNC – task & selection	Object position Recall, presence, Usability, Enjoyment, Selection
FSNC – no task	Object position Recall, presence, Usability, Enjoyment, Selection
NC – no selection	Object position Recall, presence, Usability, Enjoyment

7.4.5 Object position recall

The method of measuring recall was adapted from that used in experiments one and two as it had been established from those experiments that recall did not significantly deteriorate over time and it was necessary for this experiment to establish a means of assessing if participants recalled congruent objects other than those they were required to search for during the task. Object position recall was designed to do this and also to ascertain if this recall was improved if they had selected the object. Eight images from the VE were taken and the cued objects [cued objects were chosen as they were more likely to be selected, as found in experiment two] within the picture were moved around (see appendix, p.271). Participants were not informed before they used the VE that they would be asked questions about its appearance afterwards. The participant was then shown the adapted pictures and the ones of the environment as they saw it and were asked to state which they thought was correct. Table 7-4 shows examples of the images for the recall test that took place after the VE training took place as they were shown to the participant during the experiment.

Table 7-4: Examples of images used in picture recall test

Correct Image of RWV	Incorrect Image of RWVE
	
	
	
	

7.5 Research Hypotheses

Hypotheses derived from research questions:

- *Does the inclusion of a task influence the recall of non-task related objects?*
- *Does the inclusion of a task influence the effectiveness of VE training (presence, usability and enjoyment)*
  1. There will be a difference between the effectiveness measures recorded for the 'SNC – task' condition and the 'FSNC – no task' conditions.
- *Will participants be more likely to recall object position after VE training if they selected that specific object whilst in the VE?*
  2. There will be a relationship between the general level of selection of recall objects and overall correct recall.
- *Will enjoyment be improved when the participant is able to select objects or perform a task whilst within the VE thereby establishing a reason for the inclusion of selection within a VE?*
  3. There will be a difference between the effectiveness measures recorded for the 'SNC – selection' and 'NC – no selection' conditions.
- *Will participants be more likely to recall object position after VE training if they selected that specific object whilst in the VE?*
  4. There will be a difference in object position recall between objects that were seen and selected and those which were seen but not selected.

Hypothesis derived from experiment research:

5. There will be a difference between explicit recall (task related – experiment two) and implicit recall (non-task related – experiment three).

7.6 Experiment Structure

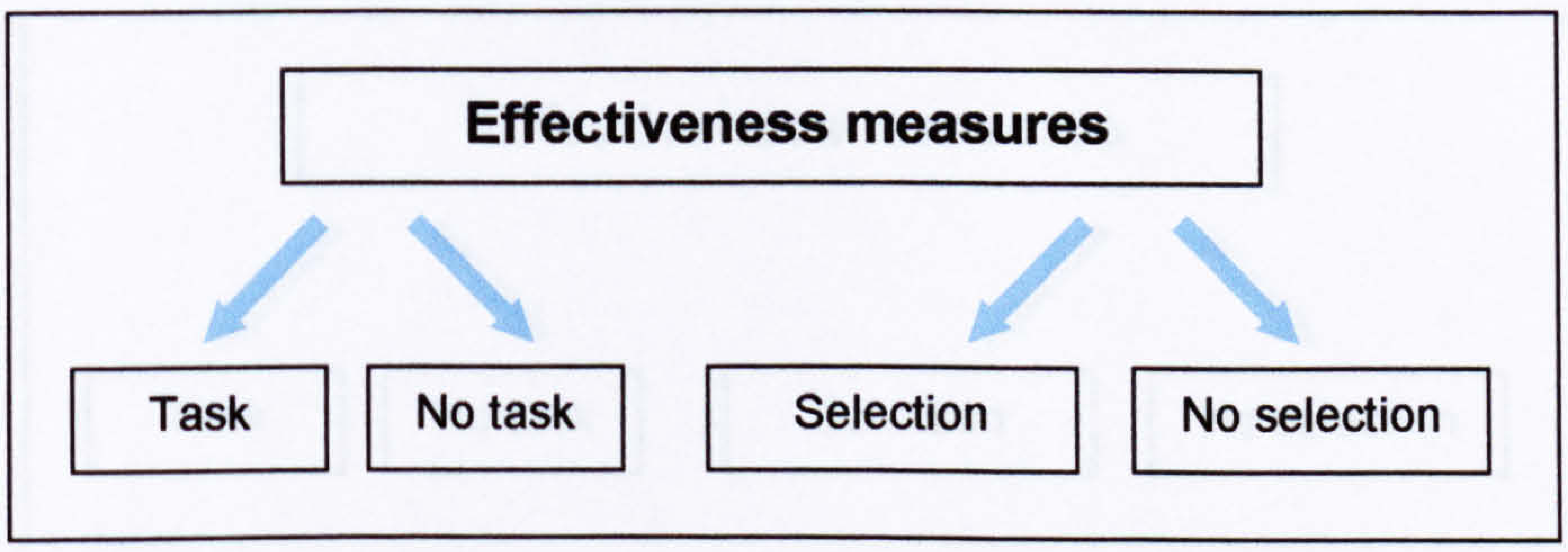


Figure 7-1: Experiment three structure

7.6.1 Participant Group

Table 5-3 shows the experimental group details.

Table 7-5: Participant group breakdown

Total	Age Range	Mean	Background
45	20 – 39	24yrs 10 months	Students and staff at the University of Nottingham. No previous knowledge of the real world building. VE novices.

The breakdown of participants in each condition within the group is shown in Table 7-6.

Table 7-6: Experimental conditions breakdown – number of participants

Condition	Participants
SNC – task & selection	15
FSNC – no task	15
NC – no selection	15

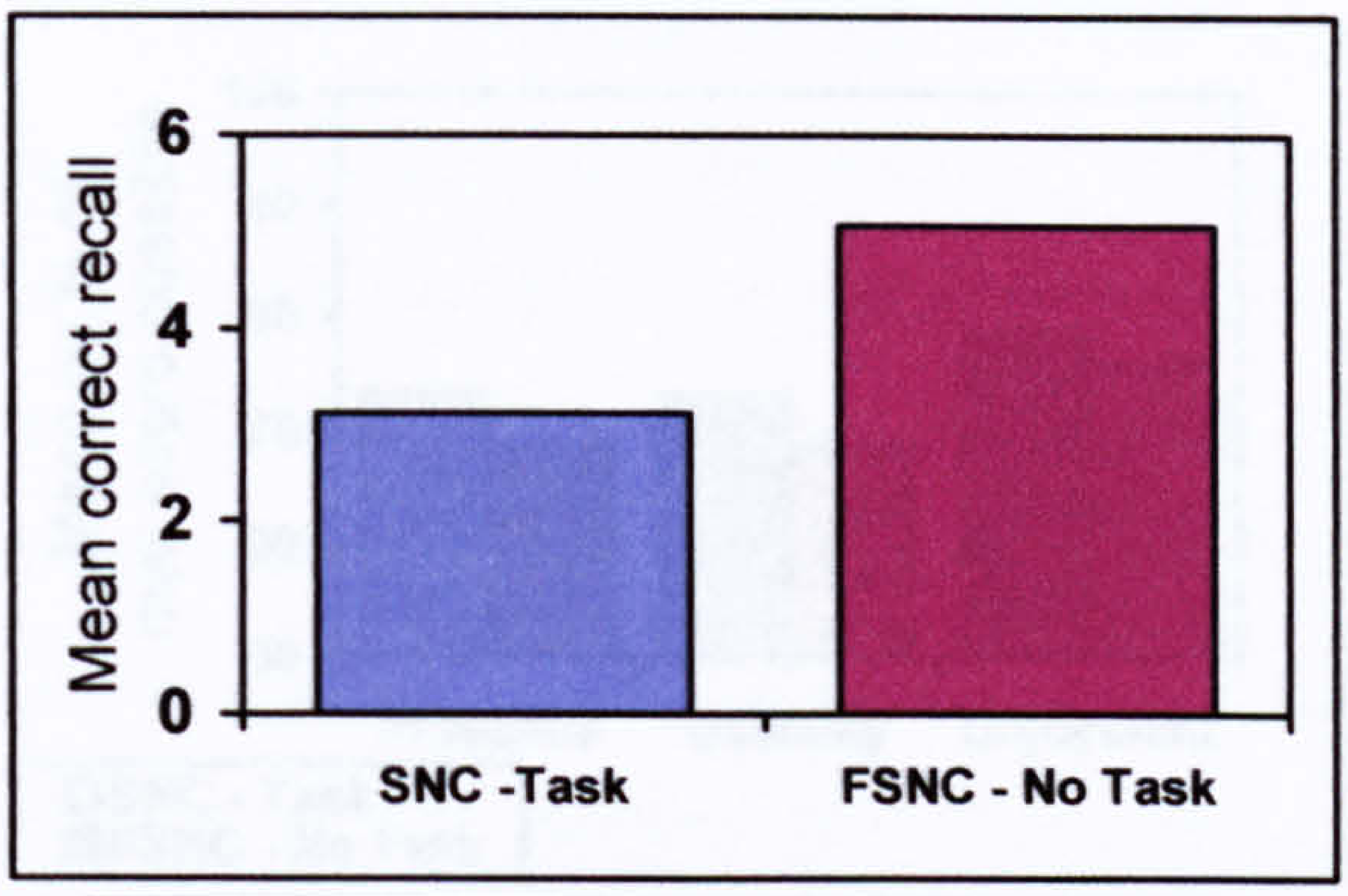
7.7 Results and Discussion

Hypothesis One:

> *'There will be a difference between the effectiveness measures recorded for the 'SNC – task' condition and the 'FSNC – no task' conditions.'*

7.7.1 Object Position Recall – Task & No Task

Correct recall for 'SNC – task and 'FSNC – no task conditions can be seen in Figure 7-2.



Condition	Object Position Recall (SD)
SNC – Task	3.13 (1.13)
FSNC – No task	5.13 (1.79)

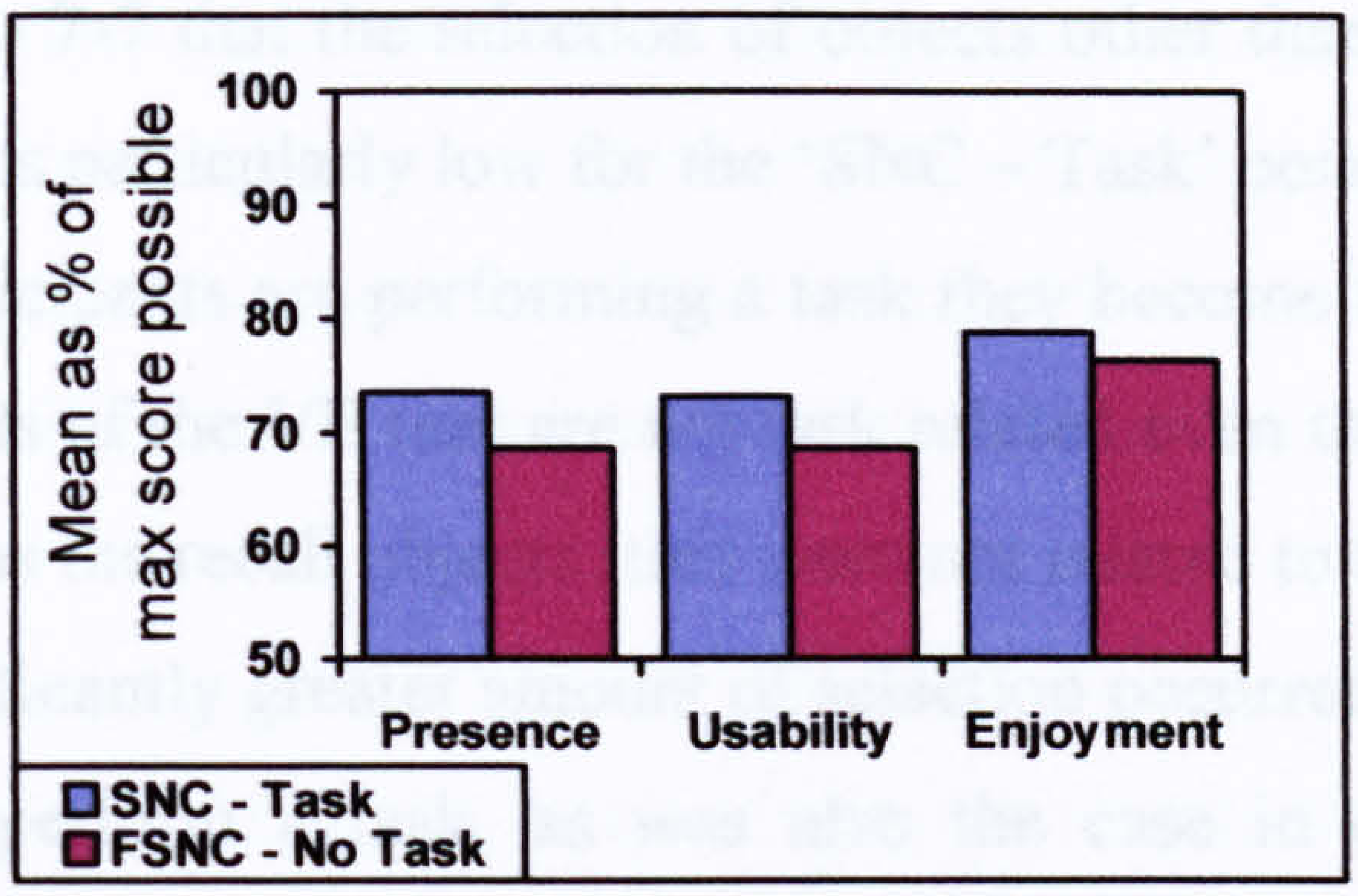
Figure 7-2: Mean correct recall – SNC – task and FSNC – no task

(Correct recall, 'SNC – task' and 'FSNC – no task': t=-3.539, df=23.561, $p<0.05$).

It can be seen that correct non-task related recall was found to be significantly higher when participants had no task to perform in the FSNC condition. It is possible that this is as a result of greater selection within this condition. This was found to be significantly higher (see, 'Selection & Correct Recall', section 7.7.3.). The difference in the recall of task related and non-task related objects in task and non-task conditions can be clearly seen. In this case when recall is not related to the task performed by the participant the non-task condition shows significantly higher recall indicating that when there is no task participants pay more attention to the surrounding objects whereas when performing a task they do not. When recall was task related it was found to be significantly higher in the task condition (see, 'Figure 6-3: Mean correct recall – 'SNC task' and 'FSNC no task'), as the participants attention is focused on the objects they are later to recall.

7.7.2 *Presence, Usability & Enjoyment – Task & No Task*

Effectiveness measures of presence, usability and enjoyment were recorded for all participants in the SNC – task and FSNC – no task conditions, *Figure 7-3*.



Condition	Presence (SD)	Usability (SD)	Enjoyment (SD)
SNC – Task	73.58 (9.72)	73.24 (8.99)	78.78 (9.56)
FSNC – No task	68.61 (5.69)	68.58 (7.19)	76.44 (8.23)

Figure 7-3: Presence, usability and enjoyment – task and no task

(Presence, 'SNC – task' and 'FSNC – no task': t=1.695, df=28, $p>0.05$; usability, 'SNC – task' and 'FSNC – no task': t=1.571, df=28, $p>0.05$; enjoyment, 'SNC – task' and 'FSNC – no task': t=0.716, df=28, $p>0.05$)

Figure 7-3 shows that none of the differences between the task and no task conditions were significant. This suggests that the inclusion of a task neither increases nor decreases the measures taken and therefore the decision to include a task in a training VE can depend on other factors such as recall without the concern of decreasing user effectiveness factors.

Hypothesis Two:

'There will be a relationship between the general level of selection of recall objects and overall correct recall.'

7.7.3 Selection & Correct Recall

Table 7-7 shows the total number of selections on cued objects for the task and no task conditions for all participants.

Table 7-7: Selection of recall objects – SNC task and FSNC no task

	Mean (SD) Selections
SNC – task	1.2 (1.74)
FSNC – no task	6.47 (1.85)

(Selections, 'SNC – task' and 'FSNC – no task': t=-8.039, df=28, $p<0.05$).

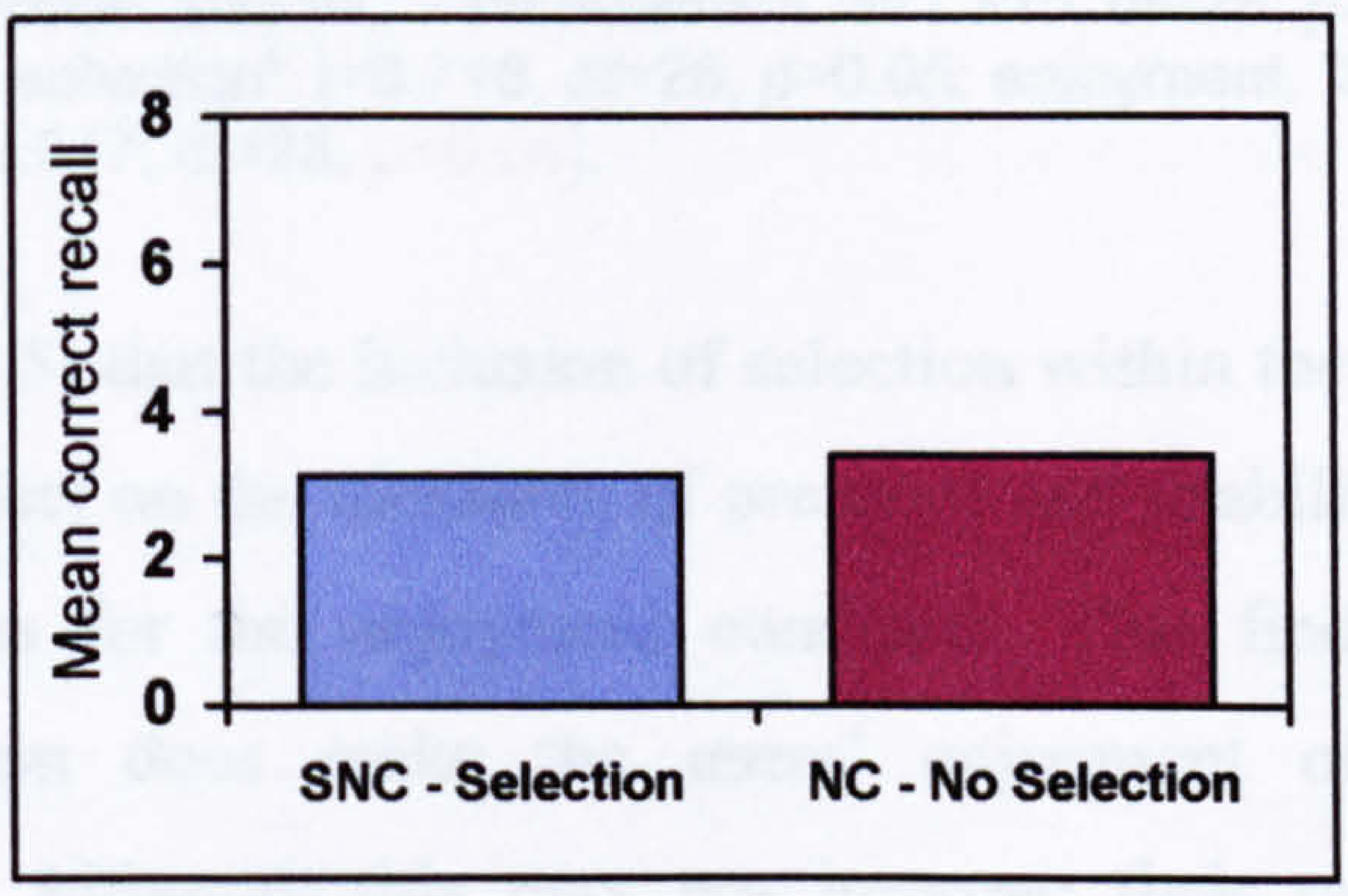
It can be seen in Table 7-7 that the selection of objects other than those required to be selected by the task was particularly low for the 'SNC – Task' condition, reinforcing the theory that whilst participants are performing a task they become focused on it and pay less attention to aspects of the VE that are not task related even though in both the task and non-task conditions the recall objects (that were not related to the task) were cued in the same way. A significantly greater amount of selection occurred when the participant was not required to perform a task, as was also the case in experiment two. The relationship between selections on cued objects and general performance in the non-task related recall was found to be significant (r=0.648, n=30, $p<0.01$). This suggests that the selection of objects increases the chance of correctly recalling them when the objects to be recalled are not task related.

Hypothesis Three:

'There will be a difference between the effectiveness measures recorded for the 'SNC – selection' and 'NC – no selection' conditions.'

7.7.4 Object Position Recall – Selection & No Selection

Correct recall for 'SNC – selection' and 'NC – no selection' conditions can be seen in Figure 7-4.



Condition	Object Position Recall (SD)
SNC – Selection	3.13 (1.13)
NC – No selection	3.4 (1.45)

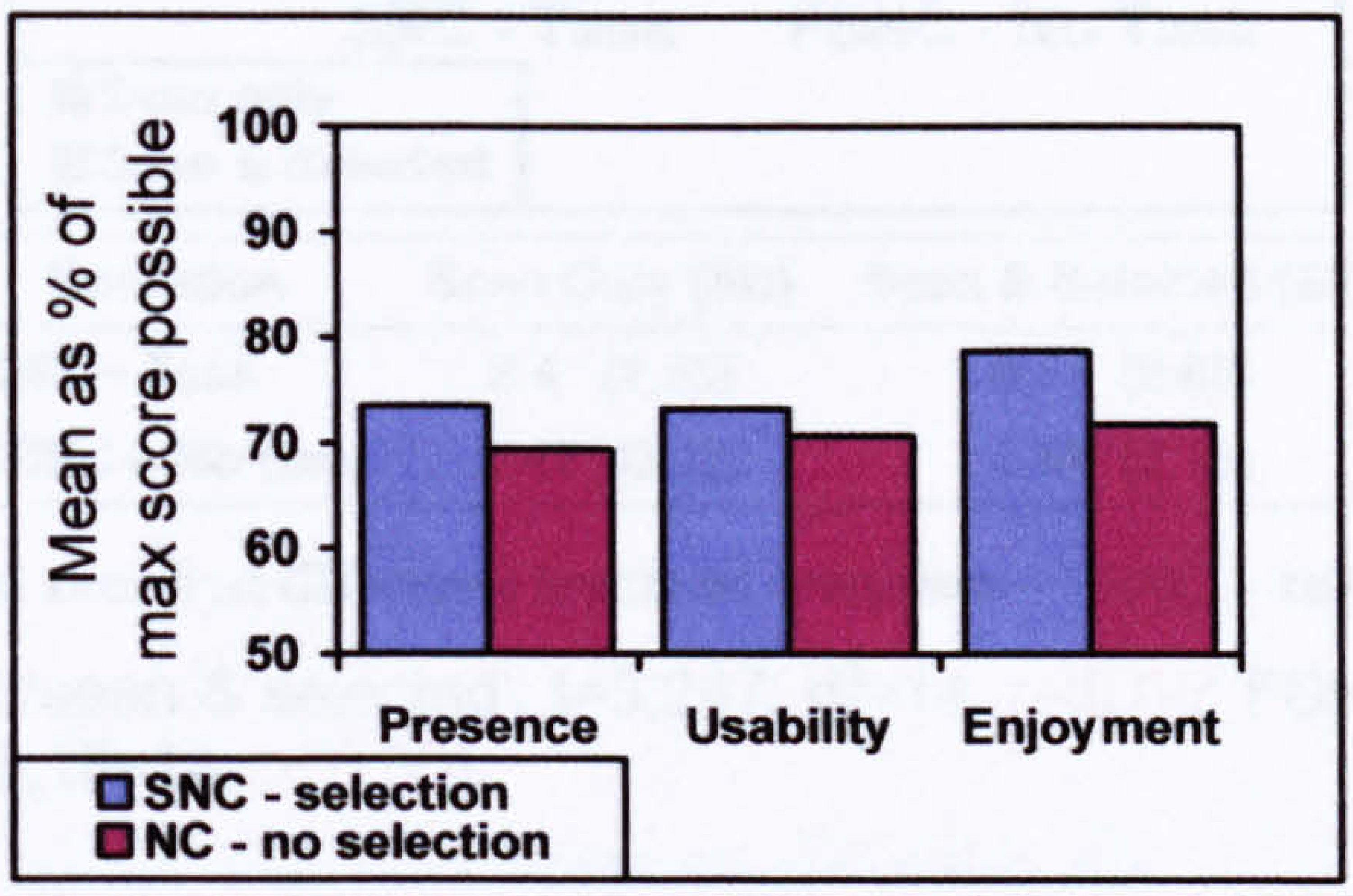
Figure 7-4: Mean correct recall – SNC – selection and NC – no selection

(Correct recall, 'SNC – selection' and 'NC – no selection': t=-0.562, df=28, $p>0.05$).

Figure 7-4 shows no significant difference between correct recall of object position when the participants can and cannot select objects of their choice whilst in the VE. This indicates the inclusion of selection is not essential to improve recall, and suggests that it is the type of selection cue that is important as opposed to simply the ability to select.

7.7.5 Presence, Usability & Enjoyment – Selection & No Selection

Effectiveness measures of presence, usability and enjoyment were recorded for all participants in the SNC – selection and NC – no selection conditions, and can be seen in Figure 7-5.



Condition	Presence (SD)	Usability (SD)	Enjoyment (SD)
SNC – Selection	73.58 (9.72)	73.24 (8.99)	78.78 (9.56)
NC – No selection	69.33 (7.74)	70.67 (10.6)	71.78 (9.16)

Figure 7-5: Presence, usability and enjoyment – selection and no selection

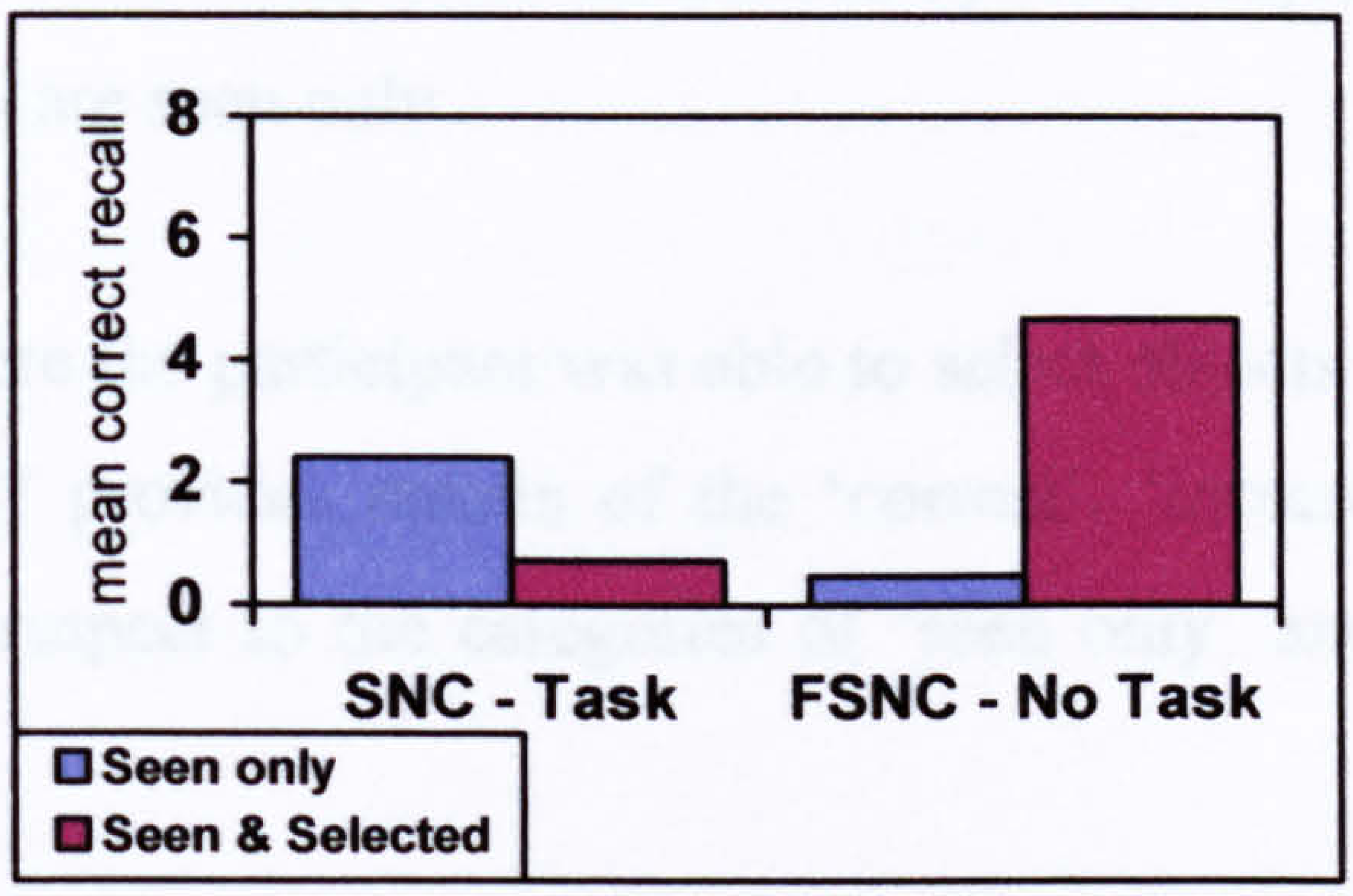
(Presence, 'SNC – selection' and 'NC – no selection': t=1.315, df=28, $p>0.05$; usability, 'SNC – selection' and 'NC – no selection': t=0.718, df=28, $p>0.05$; enjoyment, 'SNC – selection' and 'NC – no selection': t= 2.047, df=28, $p<0.05$).

It is shown (Figure 7-5) that the inclusion of selection within the VE for the participant has no significant effect on the measures of presence and usability, the only significant difference found was for the enjoyment condition. This finding suggests that the inclusion of selection does make the users' enjoyment of the VE experience significantly higher. Although this may not improve their performance within the training VE or even the effectiveness of that training with respect to recall from it, it is important as it may encourage a positive attitude towards VE and encourage its use if it were used in a training context.

Hypothesis Four:

'There will be a difference in object position recall between objects that were seen and selected and those which were seen but not selected.'

7.7.6 Object position Recall – Objects Seen & Objects Selected



Condition	Seen Only (SD)	Seen & Selected (SD)
SNC – Task	2.4 (1.35)	0.73 (0.88)
FSNC – No task	0.47 (0.92)	4.67 (2.13)

Figure 7-6: Mean correct recall at different levels of selection – 'SNC – task' and 'FSNC – no task' (SNC – task, 'seen' and 'seen & selected': t=3.247, df=14, $p<0.05$; FSNC – no task, 'seen' and 'seen & selected': t= -5.9, df=14, $p<0.05$).

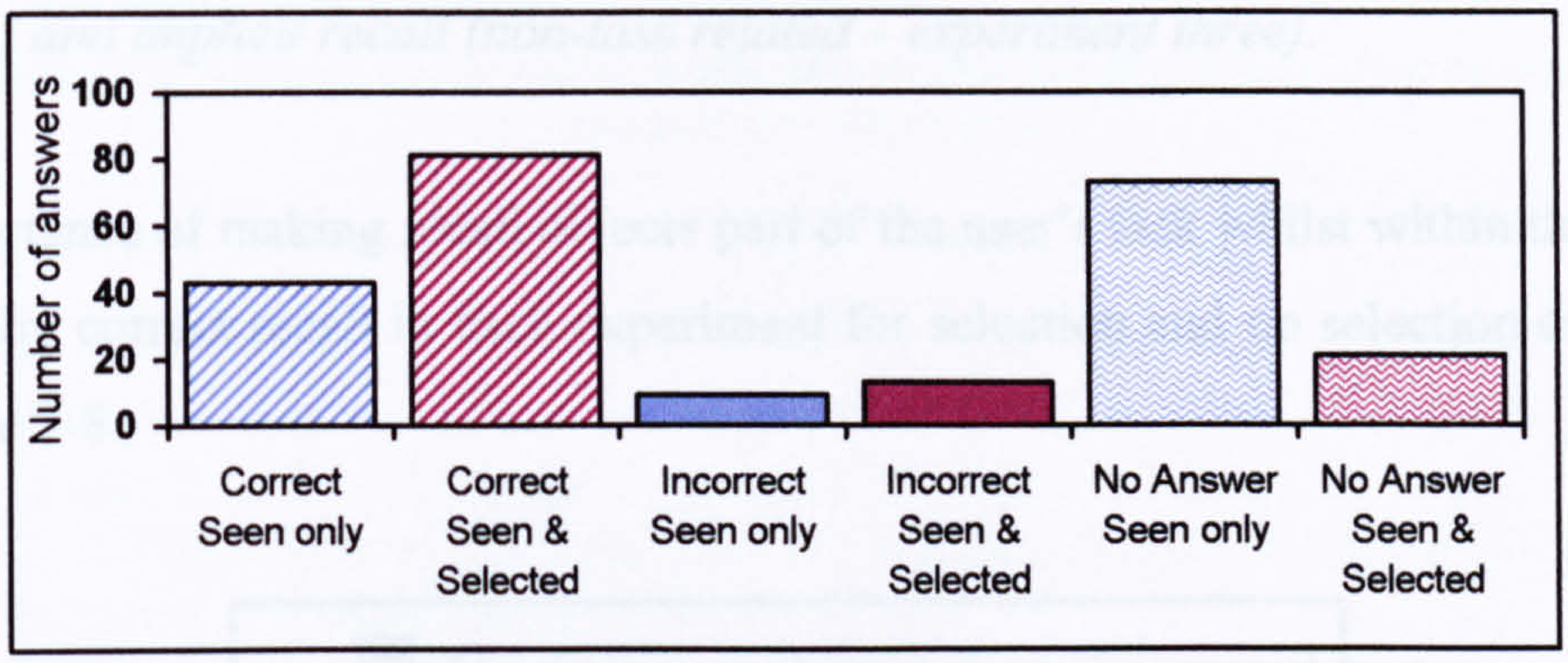
It can be seen in Figure 7-6 that there is a significant difference between the level of objects correctly recalled that were only seen and the number that were seen and selected by the participants in both the 'SNC – task' and 'FSNC – no task' condition. The greater correct recall for selected objects in the no task condition may be as a result of greater selection of recall objects that occurred in this condition generally, as can be seen in Table 7-7, P.164.

It is possible that in the 'SNC – task' condition participants were concentrating on the task and finding the task H&S objects, therefore selected fewer non-task objects and noticed the rest of the RWVE less. Consequently, their performance on a recall task that was not task related was less than that of the 'FSNC – no task' condition.

7.7.7 Object Position Recall – Correct & Incorrect

When considering VE training it is important to examine not only correct information learnt from the VE but also information that is incorrectly learnt. This is as incorrectly recalled information applied in the real world could be potentially worse than no recall at all. To consider this 'incorrect' and 'no answers' provided by participants were examined with respect to how they were influenced by recall objects that were seen and selected and when they are seen only.

For the conditions where the participant was able to select objects as they wished (SNC and FSNC) Figure 7-7 provides results of the 'correct', 'incorrect' and 'no answer' recall responses with respect to the categories of 'seen only' and 'seen and selected' objects.



	Correct* (SD)	Incorrect* (SD)	No answer* (SD)
Seen only	1.43 (1.5)	0.3 (0.53)	2.43 (2.06)
Seen and Selected	2.7 (2.56)	0.43 (0.68)	0.7 (0.92)

* mean per participant

Figure 7-7: Correct, incorrect and no answer recall for objects 'seen' and 'selected'

(Correct, 'seen' and 'seen & selected': t=-1.823, df=29, $p>0.05$; incorrect, 'seen' and 'seen & selected': t=-0.750, df=29, $p>0.05$; no answer, 'seen' and 'seen & selected': t=3.546, df=29, $p<0.05$).

The difference between the types of recall (correct, incorrect and no answer) were then compared to establish any significant differences between them when objects are selected and when they are just seen. There was no significant difference between the correct recall between recall objects being selected or seen. There was very little difference with incorrect answers between the two levels of selection and as would be expected there was a significant increase in no answer when the object were seen as opposed to selected.

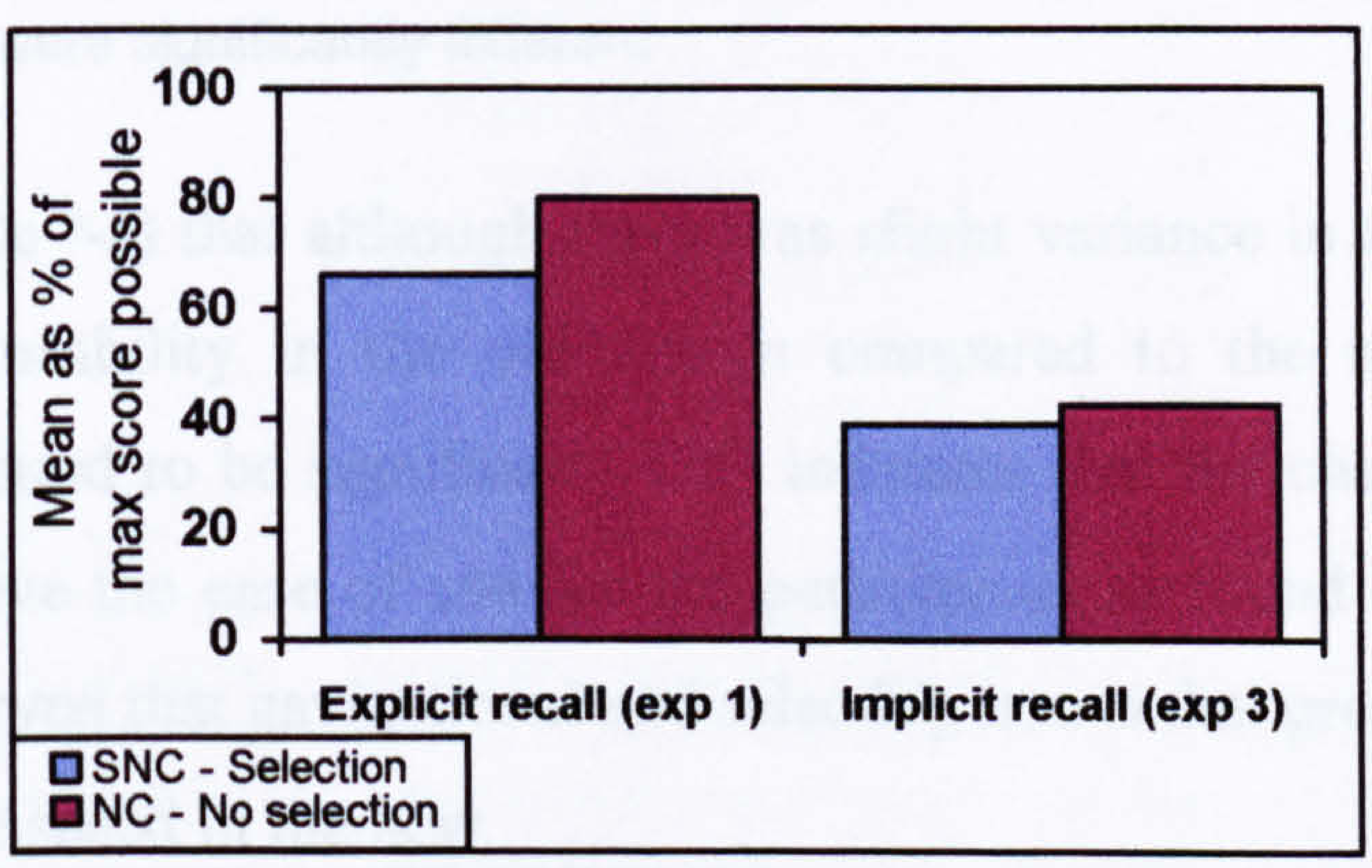
Hypothesis Five:

Implicit and Explicit Recall

In experiment one the participant was asked to recall objects that they had been explicitly asked to find and select within the environment. In experiment three they were instead asked to recall objects that they were not explicitly asked to find whilst using the environment and may or may not have seen or selected. From this the following hypothesis was established:

> *'There will be a difference between explicit recall (task related – experiment two) and implicit recall (non-task related – experiment three).'*

The importance of making recall objects part of the user's task whilst within the VE was explored by correct recall in each experiment for selection and no selection conditions, see Figure 7-8.



Condition	Explicit recall (SD)	Implicit recall (SD)
SNC – Selection	66.07 (25.25)	39.17 (14.17)
NC – No selection	28.57 (15.3)	42.5 (18.18)

Figure 7-8: Correct recall for explicit and implicit testing – selection and no selection

It can be seen (Figure 7-8), that there is an improvement in recall if the objects recalled were explicitly part of the task rather than unconnected to it. This was the same for both the condition that enabled participant selection within the VE and the condition that did not. Although values have not been compared statistically as the method of recall for both experiments was different it is interesting that a notable difference was evident between the values recorded.

RWVE Design Changes

The environment was altered from its original design based on the real life building to avoid common usability and selection problems observed in experiments one and two. Details of these changes can be found in section 'RWVE Design Changes', section 7.4.2. To investigate if these alterations had an influence on presence and usability the results recorded in previous experiments (with the same conditions) were compared, see Table 7-8.

Table 7-8: Presence and usability scores as a percentage of the maximum possible – old and new VE design

Condition	Presence - old	Presence - new	Sig?*	Usability - old	Usability - new	Sig?*
SNC – task and selection	65.45	73.58	No	70.58	73.24	No
NC – no selection	71.33	68.58	No	71.33	68.58	No
FSNC – no task	71.50	70.67	No	71.50	70.67	No

***Sig,** a t-test was performed to see if the difference between results recorded in the old and the new RWVE designs were significantly different

It can be seen (Table 7-8) that although there was slight variance in the scores recorded for presence and usability in the old design compared to the new none of these differences were found to be significant. This indicates that the changes made did not significantly improve the ease of use for the participants as found by these measures, though it was observed that navigational and selecting issues that previously arose in the old RWVE were lessened in the new.

7.8 *Main Findings*

Table 7-9: Main findings – experiment three

	Hypothesis	Finding
H_1	There will be a difference between the effectiveness measures recorded for the 'SNC – task' condition and the 'FSNC – no task' conditions.	**Recall**: 'FSNC – no task' condition showed a significantly higher object position recall than the 'SNC – task' condition (correct recall, 'SNC – task' and 'FSNC – no task': t=-3.539, df=23.561, l<0.05). **Presence, Usability and Enjoyment**: There was no significant difference in effectiveness measures between the 'SNC – task' condition and the 'FSNC – no task' condition (presence, 'task' and 'no task': t=1.695, df=28, *p*>0.05; usability, 'task' and 'no task': t=1.571, df=28, *p*>0.05; enjoyment, 'task' and 'no task': t= 0.716, df=28, *p*>0.05).
H_2	There will be a relationship between the general level of selection of recall objects and overall correct recall.	There was a significant positive relationship between amount of selection of recall objects and correct recall (r=0.648, n=30, *p*<0.01).
H_3	There will be a difference between the effectiveness measures recorded for the 'SNC – selection' and 'NC – no selection' conditions.	**Recall:** There was no significant difference in non-task related object position recall measures between the 'SNC – task' condition and the 'FSNC – no task' condition (correct recall, 'selection' and 'no selection': t=-0.562, df=28, *p*>0.05). **Presence, Usability and Enjoyment**: There was no significant difference in effectiveness measures between the 'SNC – selection' condition and the 'FSNC – no selection' condition except for enjoyment, 'SNC – selection' = significantly higher (Presence, 'selection' and 'no selection': t=1.315, df=28, *p*>0.05; usability, 'selection' and 'no selection': t=0.718, df=28, *p*>0.05; enjoyment, 'selection' and 'no selection': t= 2.047, df=28, *p*≤0.05).
H_4	There will be a difference in object position recall between objects that were seen and selected and those which were seen but not selected.	**Correct Recall**: In the 'SNC – task' condition object position recall was significantly higher if the objects were *seen*, for the 'FSNC – no task' condition objects *selected* were significantly higher (SNC – task, 'seen' and 'selected': t=3.247, df=14, *p*<0.05; FSNC – no task, 'seen' and 'selected': t= -5.9, df=14, *p*<0.05). **Incorrect and No Answer Recall**: The only significant difference was found in the no answer category where *seen* objects were significantly less likely to be answered than *selected* ones (Correct, 'seen' and 'selected': t=-1.823, df=29, *p*>0.05; incorrect, 'seen' and 'selected': t=-0.750, df=29, *p*>0.05; no answer, 'seen' and 'selected': t=3.546, df=29, *p*<0.05).
H_5	There will be a difference between explicit recall (task related – experiment two) and implicit recall (non-task related – experiment three).	Recall in the explicit recall experiment (experiment two) appeared to be higher than that in the implicit memory recall experiment (experiment three).

RWVE Design Changes: No significant differences were found between comparable measures in the old RWVE design and the new RWVE design.

7.9 Experimental Program Development

The main finding of this experiment was that recall that was not task related was significantly improved when there was no task and a positive relationship was found between the amount of selection (which was significantly higher in the no task condition) and the amount of correct recall. There was no difference found in the user effectiveness measures of presence and usability measured.

The ability to select objects within a VE had no notable influence on any of the effectiveness measures taken other than improving participants' enjoyment of the VE experience that they had. In the no task condition the specific selection of objects that were later to be recall had a significant improving effect on recall though the opposite was the case for the task condition.

It was also suggested when results were compared of recall (as a percentage of the maximum score possible) from experiment one where recall was explicitly related to the task performed and experiment three, when it was not, that recall was higher when explicitly task related.

It has therefore been found through experimentation to this point that the inclusion of a task improves task related recall and reduces selection within a VE. If a task is not included selection is increased as is recall of cued/selected objects within the VE. If an object has been selected it is more likely to be recalled if there is no task, whereas if there is a task, non task related recall is higher if the object was seen and not selected. Overall recall of non task related objects is significantly higher in the no task condition, though the opposite is true if recall is task related. The inclusion of selection hotspot cues increased selection of those cued objects.

There are two developments from this point that are now explored in two separate experiments. Firstly, how effective are selection hotspot cues when they are no longer congruent to the VE context in which they are used? Will they still prompt increased selection in comparison to non-cued objects and will this increased selection have the same effect? Secondly, considering the findings from all previous experiments, are users perceiving and recognising the object that is cued and therefore are learning from the training VE, or are they merely responding to the cue?

Chapter 8 - Experiment 4

Establishing the importance of selection hotspot cue design being incongruous to the virtual context

8.1 Experimental Program Development

Exp	Questions asked	Main findings	What next?
One	1. Does participant ability to control their navigation around a VE influence the effectiveness of that VE? 2. Does participant ability to select objects within a VE influence the effectiveness of that VE? 3. Does the realism of the VE influence the effectiveness of that VE?	1. There was no significant difference between measures with total participant navigational control & no participant navigational control. 2. There was no significant difference between measures with participant selection & no participant selection. 3. There was no significant difference between measures with total realism & no realism.	As none of the display and interaction conditions explored in experiment one indicated a significant influence on VE training effectiveness indications are VR training is a suitable replacement for video and animated training. What other factors may influence the effectiveness measures of VE training, in particular RW recall as a fundamental aspect of VE training?
Two	1. Does the inclusion of a task influence the effectiveness of VE training, specifically with respect to task related RW recall? 2. What prompts a participant to select a specific object within a VE?	1. The inclusion of a task resulted in significantly increased recall of task related objects 2. Cues suggested increased selection over non-cued objects	As recall was improved with a task when task related it should be explored if this is also the case when recall is not task related. Recall performance may not have been related to the task but as a result of the selection of recall objects that occurred as part of that task, the importance of selection should therefore also be examined.
Three	1. Is the recall of objects within a training VE improved when no longer related to the task performed in the VE? 2. Does the selection of objects whilst in a VE influence the effectiveness of that training VE?	1. Non task related recall was significantly improved when there was no task, a positive relationship was found between selection of recall objects and correct recall. 2. The ability to select objects whilst within the VE had no significant effect on effectiveness apart from improving participants' enjoyment.	Explore if selection hotspot cues result in the same effects as found in experiments 2 and 3 (increased selection over non-cued objects, decreased selection in task conditions, improved recall if selected) if no longer incongruous to the VE context in which they are placed? When recalling objects as in experiments I, 2 and 3 are participants' merely responding to the cue or performing the set task or are they perceiving the objects and learning form them, thereby creating an effective training VE?

Four	1. Do cues that are no longer incongruous to the surrounding VE context still result in increased selection over non-cued objects? 2. Is the selection of cued objects influenced by the inclusion of a task within that VE? 3. Is recall of cued objects improved if they are selected?

8.2 Introduction

It was found in experiment two that the least selected cues were those that were most congruent to the surrounding VE context, such as textured or photo realistic cues and movement cues. These cues were more prolific within the environment and in contrast to the other cue designs appeared more as you would expect objects to appear in the real world (you would not expect a desk drawer to flash red in the real world for example, but it would be less unusual to see a photo realistic or wood textured/coloured drawer). It had to therefore be established if the increased selection of the incongruous cues was as a result of their lack of ecological validity to the RWVE or whether the cue type itself was effective in any context. This would provide a guideline for the development of generic selection hotspot cue designs in both abstract and real world based training VEs. Experiment two demonstrated a significantly higher total number of selections on all types of cued objects over non-cued objects ('*Selection Cue Type & Selection*', section 6.7.5).

To examine if it was the incongruous nature of certain cue types (the coloured red, blue, grey and yellow flashing and highlighted cues) that improved the cue effectiveness a VE was developed that bore no resemblance to the real world in both appearance and the method of participant navigation within it. Consequently the cues experienced a reduction of aesthetic distinction from the surrounding VE and their resultant effectiveness could be examined in light of that.

Experiment three demonstrated that non-task related recall was significantly lower in the task condition, and that the amount of selection on task-related objects demonstrated a significant positive relationship with correct recall. It was decided that the influence of a task and the importance of object selection on recall should be examined with respect to selection hotspot cues in an abstract VE (AbsVE) that does not adhere in either appearance of method of exploration to the real world. There is an evident relationship between selection cues and selection within a RWVE and also the inclusion of a task and selection shown in previous experimentation to explore in an AbsVE context.

For the scope of this research the term 'abstract virtual environment' (AbsVE) refers to a VE that does not represent the real world both in the way it appears to the user visually, for example a lack of familiar or expected objects within it behaving according to rules within the real world such as gravity. Also the manner in which the user explores the AbsVE does not represent the real world again, rules of the real world need not apply so the user may be able to fly or walk on the ceiling for example as they would obviously not be able to do in a VE that represented the real world. This enables the development of a VE with red or blue flashing cues will not appear incongruous.

Abstract virtual environments have real VE applications for example in education the teaching of cell structure can be performed through the medium of VE where the user is able to fly around and walk within cells to examine and learn their structure which obviously would not be possible in the real world. The ability to 'fly' within a VE also has applications in VEs that are based on the real world. In architecture or sales potential buyers can 'fly' around virtual representations of their future purchases to examine their appearance from a variety of angles within context (i.e. viewing a potential new building and its appearance from surrounding existing buildings).

8.3 Research Questions

1. Do selection hotspot cues encourage increased interaction when no longer incongruous to the virtual context they are in?

- **Expectation**: Selection hotspot cues will no longer encourage increased selection when no longer incongruous VE context.
- **Reasoning**: Participants are prompted to select cued objects as the cues attract their attention. This attention is primarily drawn by the fact that the cues are out of place

with respect to the rest of the VE as in experiment two where cues were incongruous to the surrounding real world VE context ('*Table 4-4: Expectations from the design of selection hotspot cues (Marshall and Nichols, 2004)*', p.106).

2. Will participants be more likely to recall objects within the abstract VE if the object to be recalled was selected whilst within the VE?

- **Expectation**: Participants will be more likely to recall objects that they have selected whilst within the VE than those which they have not.
- **Reasoning**: The process of selection and also reaction to that selection will aid the consolidation of that object to memory for the participant. A positive significant relationship was found between the level of selection of objects to be recalled and correct recall in experiment three ('*Selection & Correct Recall*', section 7.7.3).

Task 'v' No task

3. Does the inclusion of a task influence the amount selection of cued objects in an abstract environment?

- **Expectation**: A task will decrease the amount of selection of cued objects.
- **Reasoning**: It was shown in experiment two ('*Selection of Cued & Non Cued Objects*', section 6.7.4) and three ('*Selection & Correct Recall*', section 7.7.3) that appeared to be the case as participants become more focused on the task and consequently explore the VE less therefore it is likely this will be the case in the abstract VE.

4. Does the inclusion of a task influence the recall of non-task related objects in an abstract environment?

- **Expectation**: The inclusion of a task will reduce the correct recall of non-task related objects.
- **Reasoning**: If the participants perform a task they are more likely to concentrate on that as opposed to explore the rest of the environment and consequently are less likely to recall aspects of the VE that are not related to that task, this was shown to be the case in experiment three ('*Object Position Recall – Task & No Task*', section 7.7.1).

5. Does the inclusion of a task influence the measures of effectiveness in an abstract environment (presence, usability and enjoyment)?

- **Expectation:** A task will improve the measures of user effectiveness taken.
- **Reasoning:** A task provides a reason and purpose to the participant use of the VE and enables them to put the VE into context as opposed to exploring the VE with no specific goal. As a result there will be greater user satisfaction and enjoyment from completing a task improving effectiveness measures recorded although no significant improvement was reported in the measures recorded in experiment three ('*Presence, Usability & Enjoyment – Task & No Task*', section 7.7.2) a slight increase was evident.

8.4 The Experiment

8.4.1 Conditions

The environment used was the Abstract VE (AbsVE) as described in '*The Abstract VE*', section 4.3. The AbsVE was designed to in no way represent the real world, in its appearance or how it was navigated and as such was not limited by ecological constraints. Although the same equipment was used to interact with the AbsVE as in the RWVE experiments (Experiments 1 to 3), with the joystick to navigate and the mouse to select, the participant was not restricted as they were in the RWVE to move around as they would in the real world, instead they were able to fly about the environment as they liked. The environment itself consisted of one room full of random objects that were mainly unrecognisable as objects from the real world (such as geometrical shapes), these objects were cued in the same way that the RWVE were cued to enable a comparison between their effectiveness in both types of environment.

Two conditions were examined in this experiment, details can be found in Table 8-1.

Table 8-1: Conditions explored within experiment four – task and no task

Condition	Abbreviation	Description
Selection & Navigational Control (Abstract VE)	**SNC(Abs) - Task**	- Free navigation using the joystick - Able to choose and select any objects. - Defined task whilst using the environment.

		- Selection hotspots were cued to indicate it was possible for the participant to select them. - The VE bears no resemblance to the real world with abstract layout, colours, objects and navigation
Free Selection (Abstract VE)	**FSNC(Abs) - No task**	- Free navigation using the joystick - Able to choose and select any objects. - No defined task whilst using the environment. - Selection hotspots were cued to indicate it was possible for the participant to select them. - The VE bears no resemblance to the real world with abstract layout, colours, objects and navigation

8.4.2 The Task

The task in the 'SNC(Abs) – task' condition was as described in 'The AbsVE Task', section 4.3.2 and required the participant to follow a numbered arrangement of targets (arrows directed them from the target they were at, to the next target in the sequence) positioned around the environment. When a target was reached the participant navigated into it and, heard an auditory response and saw a visual response in the form of a tick appearing below the corresponding target number on the on screen tick list to the right of the screen the search and find nature of the task and the feedback from the VE was designed in an attempt to make the task as similar in form and structure as the concrete task in the RWVE. A selection of task targets and the on screen tick list can be seen in Figure 8-1, the ticks indicating targets already selected and the white squares the targets still to select.

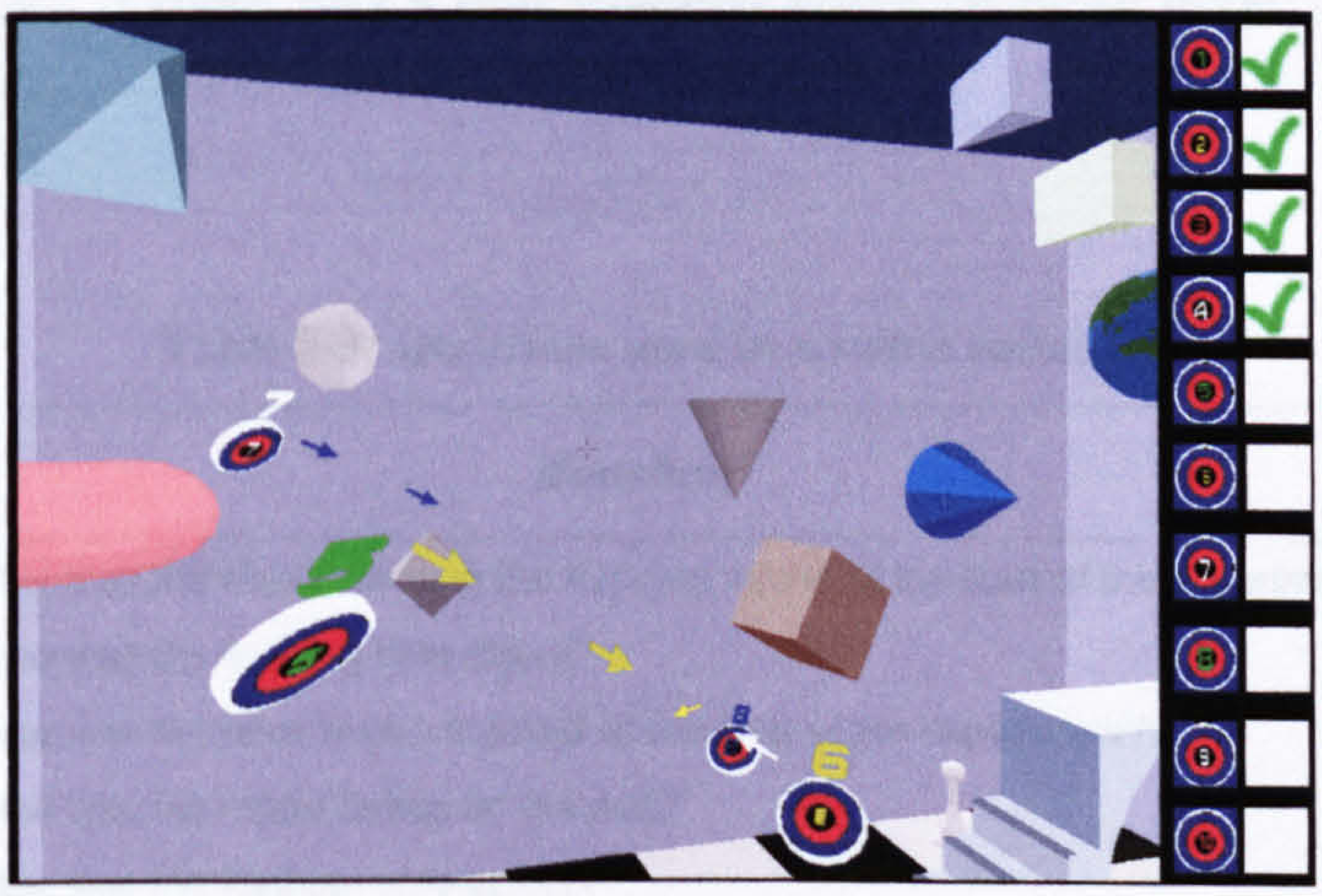


Figure 8-1: View of task targets within the AbsVE

8.4.3 Measures Taken

The following measures (Table 8-2) were taken for each condition. For details of measurement methods see 'Experiment Measures', section 3.2.3 using the equipment and set up as described in 'Experiment Equipment', section 3.2.1. The measure of the selection of objects was split into three levels, firstly if the objects was seen and not selected (Seen), secondly if the object was selected (Select) and finally if the object was selected and it reacted to that selection (S&R).

Table 8-2: Measures taken for each experimental condition – experiment four

Conditions	Measures Taken
SNC(Abs) – task	Object recall, Presence, Usability, Enjoyment, Selection
FSNC(Abs) – no task	Object recall, Presence, Usability, Enjoyment, Selection

8.4.4 Object Recall

The participants were asked to answer questions concerning their recall of details about the VE after they had completed their use of it, they were not told before using the VE that they would be asked questions about its appearance afterwards. Table 8-3 shows the questions asked and the correct answers. The questions related to the cued objects within the environment and were used to establish the participants' inadvertent observation of them. Five of the questions asked referred to the objects colour and five to their shape to see if there was a bias towards either of these details recalled over the other.

Table 8-3: Questions used in written recall test

Question Number	*Question*	*Answer*
1	What colour was the object emitting the beeping sound at the start of the experiment?	*Green*
2	What shape was the flashing blue object?	*Sphere*
3	What shape was the brick textured object at the start of the experiment?	*Pyramid*
4	What colour was the round button on the wall?	*Red*
5	What shape was the flashing grey object?	*Cone*
6	What colour was the moving doughnut shaped object?	*Brown*
7	What shape was the red flashing object?	*Cylindrical*
8	What shape was the yellow object at the start of the experiment?	*Sphere*
9	What colour were the chess pieces on the floor of the environment?	*White/grey*
10	What colour was the flashing octahedron (double pyramid)?	*Yellow*

8.5 Research Hypotheses

- *Do selection hotspot cues encourage increased interaction when no longer incongruous to the virtual context they are in?*
  1. There will be a difference in the effectiveness of selection hotspot cues when incongruent with the VE (RWVE, experiment two) and when they are not (AbsVE).
  2. Some selection hotspot cue types will have a difference influence on the amount of selection than others.
- *Will participants be more likely to recall objects within the abstract VE if the object to be recalled was selected whilst within the VE?*
  3. There will be a difference in the recall (correct, incorrect and no recall) of objects that were selected and not selected.
  4. There will be a difference between the correct recall of colours and shapes.
- *Does the inclusion of a task influence the amount selection of cued objects in an abstract environment?*
  5. There will be a difference in the amount of selection in the 'SNC(Abs) – task' condition and 'FSNC(Abs) – no task' condition.

- *Does the inclusion of a task influence the recall of non-task related objects in an abstract environment?*
- *Does the inclusion of a task influence the measures of effectiveness in an abstract environment (presence, usability and enjoyment)?*
  6. There will be a difference in effectiveness measures in the 'SNC(Abs) – task' condition and 'FSNC(Abs) – no task' condition.

8.6 Experiment Structure

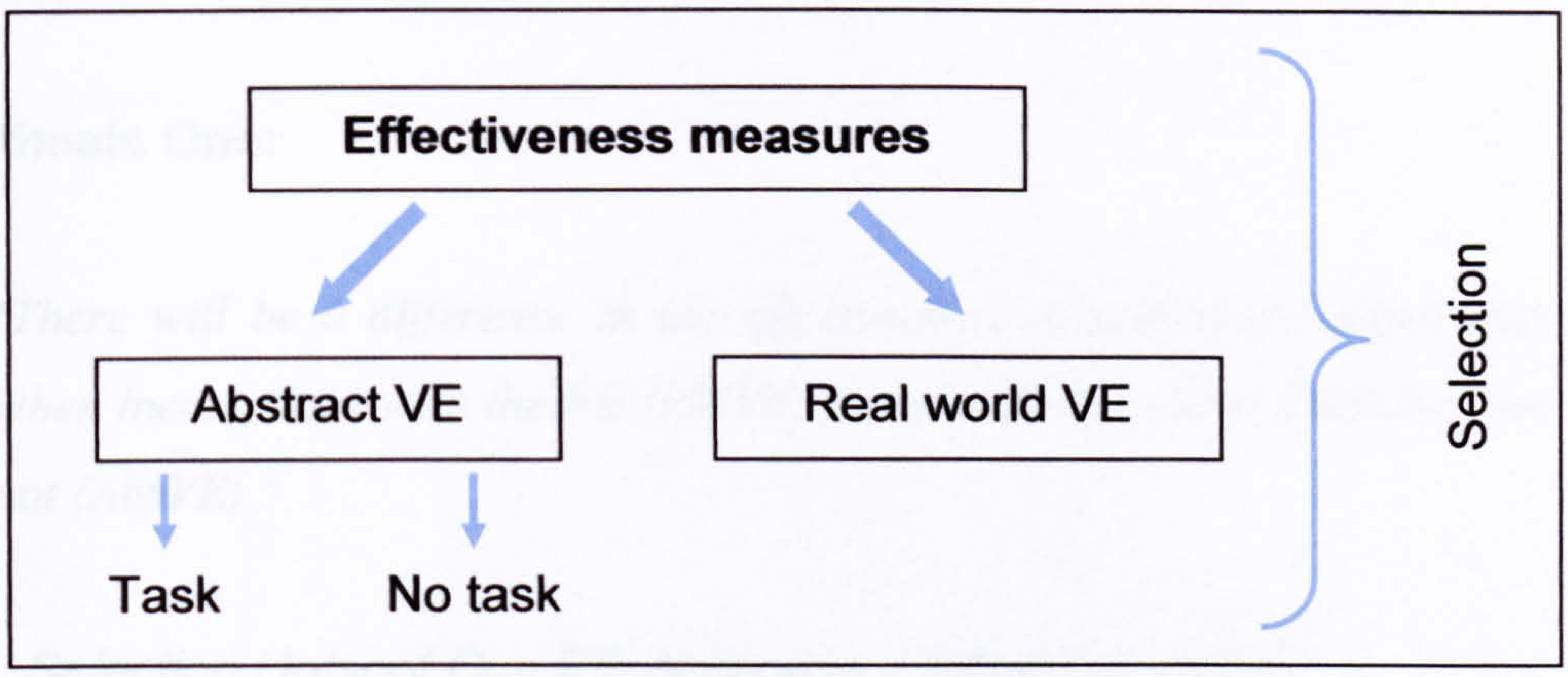


Figure 8-2: Experiment four structure

8.6.1 Participant Group

Table 8-4 shows the experimental group details

Table 8-4: Participant group breakdown

Total	Age Range	Mean	Background
36	18 – 37	24yrs 2 months	Students and staff at the University of Nottingham. No previous knowledge of the real world building. VE novices.

The breakdown of participants in each condition within the group is shown in Table 8-5.

Table 8-5: Experimental conditions breakdown – number of participants

Condition	Task	No Task
Real World (exp 2)	8	8
Abstract World	10	10

8.7 Results and Discussion

Hypothesis One:

'There will be a difference in the effectiveness of selection hotspot cues when incongruent with the VE (RWVE, experiment two) and when they are not (AbsVE).'

8.7.1 Selection Hotspot Cue Effectiveness – RWVE & AbsVE

Selections of cued and non-cued objects were recorded for all participants in the RWVE and the AbsVE, Table 8-6.

Table 8-6: Selections on cued and non-cued objects (all participants all conditions) – RWVE and AbsVE

Condition	Mean cued objects selected (SD)	Mean non-cued objects selected (SD)	t-test
RWVE	24.06 (25.46)	15.44 (22.08)	t=3.133, df=15, $p<0.05$
AbsVE	7.75 (5.17)	7.5 (6.12)	t=0.327, df=19, $p>0.05$

It can be seen that the selection of cued objects is significantly higher in the RWVE where the cues themselves are abstract to the surrounding environment, whereas in the AbsVE the selection of cued and non-cued objects is almost equal. This suggests that for selection hotspot cues to be effective by prompting selection they should appear incongruous to the VE context in which they appear.

Hypothesis Two:

'Some selection hotspot cue types will have a difference influence on the amount of selection than others.'

8.7.2 Selection of Cue Type & Amount of Selection

Selection of each cue type was measured from both conditions using the abstract environment ('SNC – Abs' and 'FSNC – Abs') and the number of selections of each cue type as a percentage of the total number of each cue type available was recorded, (*Figure 8-3*). It should be noted that no distinction was made between the task and no task condition experiments as it was not the focus of this hypothesis.

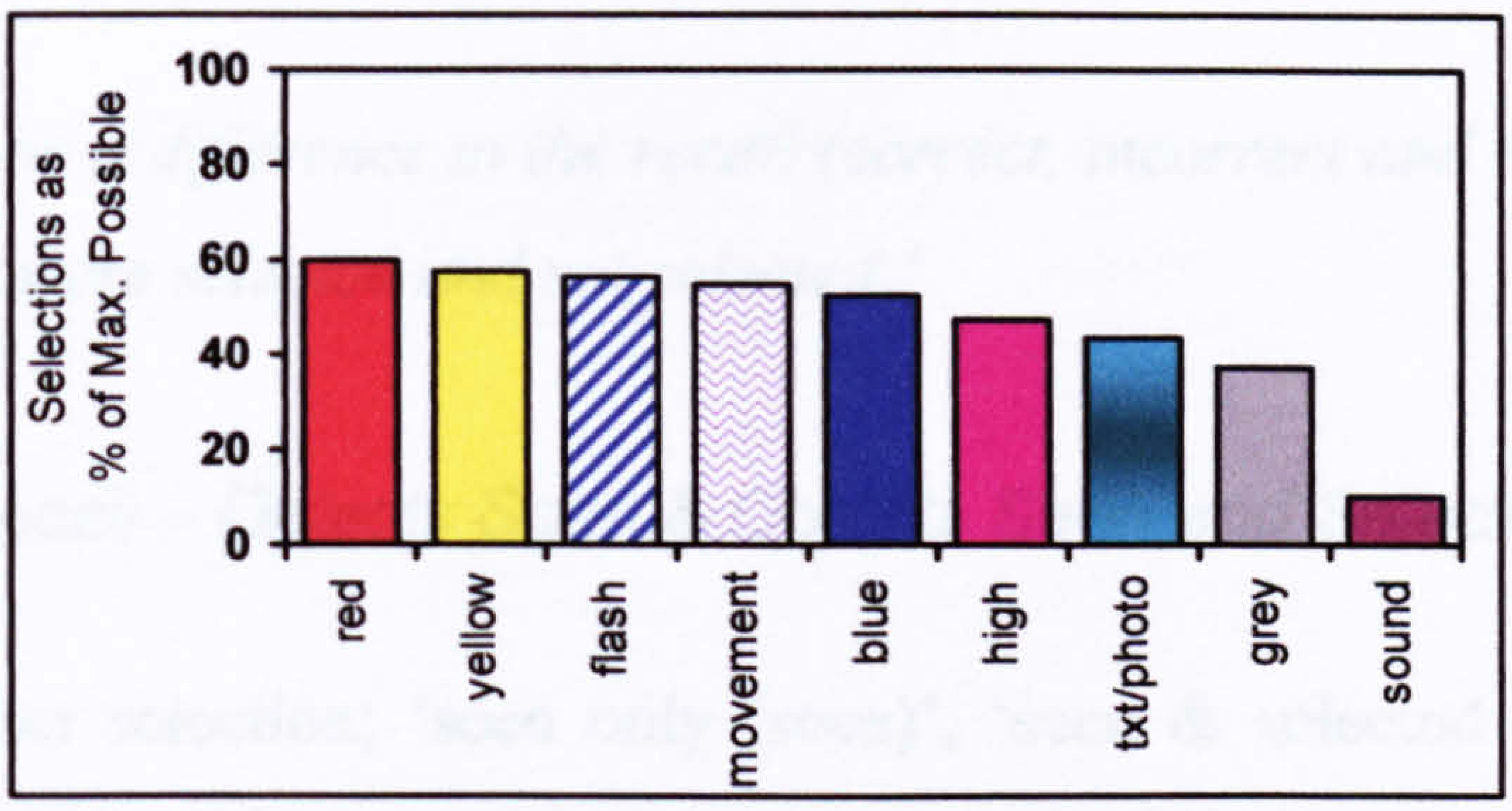


Figure 8-3: Mean number of selections on each cue type as a percentage of the maximum possible

One-way within-subjects ANOVA was performed on the data for the number of selections of each cue type (Figure 8-3). There was shown to be a significant difference in the number of selections on each cue type (cue type selections, $F_{(8,152)} = 8.58$, $p<0.05$). The difference between each cue type was examined and results can be seen in the t-test results matrix, Table 8-7.

Table 8-7: T-test results matrix for the number of selections made by all participants as a percentage of the maximum possible

	R	Y	F	M	B	H	T/P	G	S
R	X	0.438	0.616*	0.754	0.825	2.517*	2.668	2.269*	5.627*
Y	X	X	0.252	0.364	0.49	1.902	2.342	2.629*	5.596*
F	X	X	X	0.227	0.567	1.677*	2.236	3.000	6.135*
M	X	X	X	X	0.276	1.027	1.624*	1.909	5.542*
B	X	X	X	X	X	0.698*	1.129*	1.552*	5.101*
H	X	X	X	X	X	X	1.000*	1.566	4.943*
T/P	X	X	X	X	X	X	X	0.893*	4.477
G	X	X	X	X	X	X	X	X	2.773*
S	X	X	X	X	X	X	X	X	X

* Found to be significantly different in experiment two Table 6-8
* Not found to be significantly different in experiment two Table 6-8

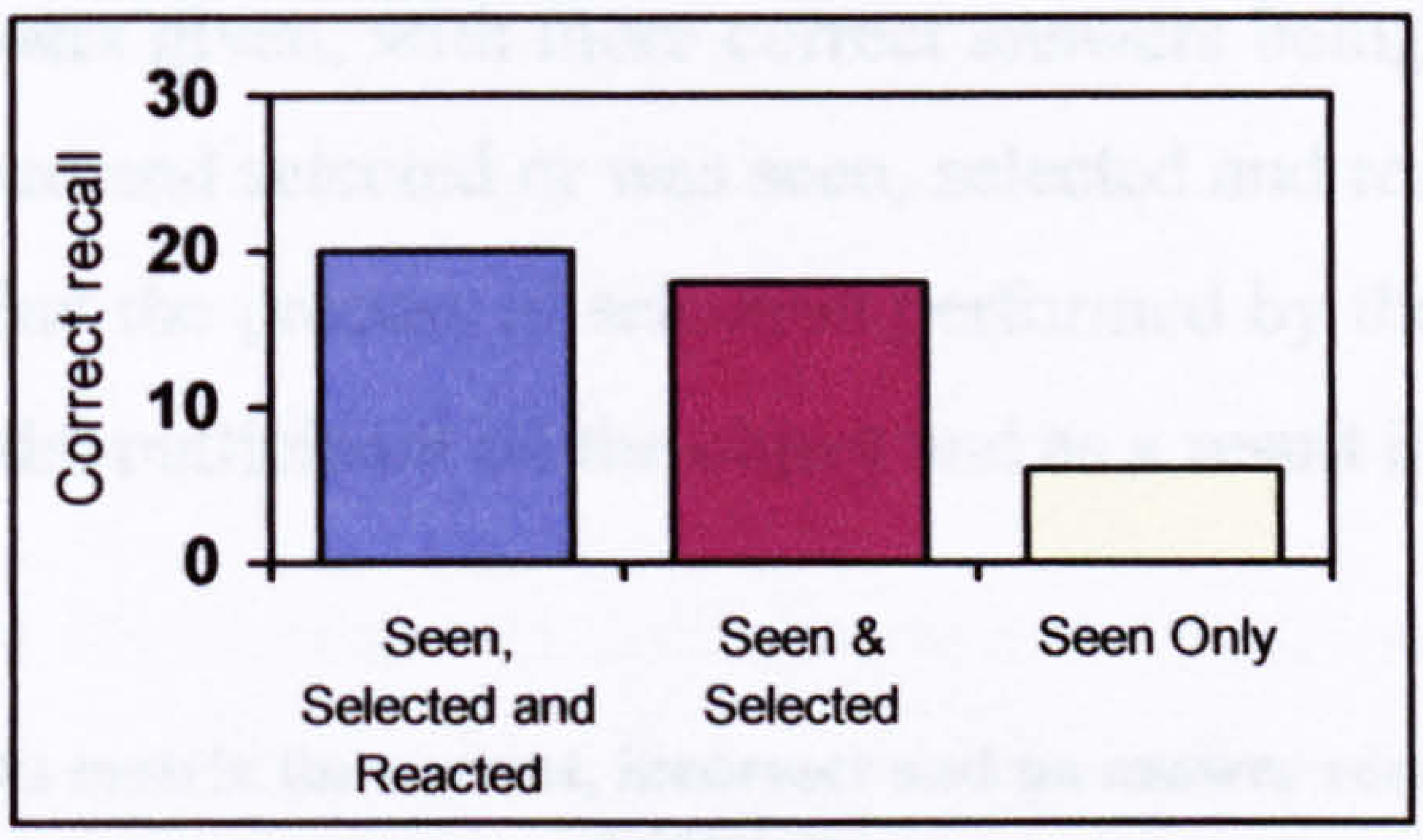
It can be seen in Table 8-7 that there are three cue types that were selected significantly more than the three cue types that were selected the least, this suggests a tier system for the effectiveness of each cue design. The top tier cue types being 'red', 'yellow' and 'flashing' the lowest tier being 'textured/photo realistic', 'grey' and 'sound'.

Hypothesis Three:

'There will be a difference in the recall (correct, incorrect and no recall) of objects that were selected and not selected.'

8.7.3 Object Recall – Objects Seen & Objects Seen and Selected

The level of object selection; 'seen only (seen)', 'seen & selected (S/S)' and 'seen, selected & reacted'(S/S/R) of recall objects was recorded with respect to correct recall (Figure 8-4).



	Recall* (SD)
Seen, Selected and Reacted	1 (1.03)
Seen & Selected	0.9 (1.07)
Seen only	0.3 (0.47)

*Mean recall per participant

Figure 8-4: Correct recall and level of selection abstract environment – all conditions

('level of selection', $F_{(2,38)} = 3.76$, $p<0.05$)

One-way within-subjects ANOVA was performed on the data for correct recall at different levels of selection (Figure 8-4) and a significant difference was found. 'seen, selected & reacted' and 'seen & selected' objects were correctly recalled significantly more than 'seen only' objects, see Table 8-8. This suggests that there was a significantly higher chance of objects being correctly recalled if they had been selected by the participant whilst within the environment.

8.7.4 Object Recall – Correct, Incorrect & No Answer

The level of selection of recall objects were measured with respect to correct, incorrect and no answer recall, *Table 8-8.*

Table 8-8: Correct, incorrect and no answer recall at different levels of selection

Level of Selection	Correct	Incorrect	No Answer
Seen Only	6	19	72
Seen & Selected	18	7	24
Seen, Selected and Reacted	20	7	27

A Chi-square test[11] was performed on the data in Table 8-8, $\chi^2 = 27.64$, df=4, P<0.001 ($\chi^2_{crit} = 18.46$). It was found that the answers given and the type of selection performed results were significantly dependent on each other implying that the level of selection did influence the answers given, with more correct answers being given if the object in question was either seen and selected or was seen, selected and reacted to that selection. This result indicates that the process of selection performed by the participant served to focus the attention of the participant on the object and as a result improving recall.

Table 8-9: T-test results matrix for correct, incorrect and no answer recall at different levels of selection

Correct

	S/S/R	S/S	Seen
S/S/R	X	0.335	2.666
S/S	X	X	2.259
Seen	X	X	X

Incorrect

	S/S/R	S/S	Seen
S/S/R	X	0	2.565
S/S	X	X	2.179
Seen	X	X	X

No answer

	S/S/R	S/S	Seen
S/S/R	X	0.616	2.906
S/S	X	X	3.040
Seen	X	X	X

[11] Although χ^2 is generally used on between subject designs it is useful here to ascertain whether answer and selection behaviour are independent.

The difference between the correct, incorrect and no answer recall was considered with respect to different levels of selection and it can be seen that objects selected (S and S&R) resulted in a significantly greater number of correct responses and significantly lower number of incorrect and no answer responses (Table 8-9). This suggests that the selection of objects within VE results in better recall performance as would be the required outcome, with respect to recall, of a training VE. There was no significant difference found between the 'selected' objects and the 'selected and reacted' objects suggesting that a reaction from a selected object did not improve its effectiveness in this experiment.

Hypothesis Four:

'There will be a difference between the correct recall of colours and shapes.'

8.7.5 Correct Recall – Colour & Shape

Table 8-10: Mean correct recall – object colour & object shape

	Colour Recall (SD)	Shape Recall (SD)
Mean Correct Recall	1.65 (1.18)	0.6 (0.88)

(Correct recall, 'colour' and 'shape': t=3.943, df=19, $p<0.005$)

Table 8-10 suggests that colour is far more memorable to the participant than the objects shape. This raises interesting questions with respect to if participants are observing the objects themselves or merely the cue and are responding to that primarily, in that they are recalling it. This is an important consideration in the development of a VE in particular for training, as users will be required to retain information provided, most commonly about the objects within it, and apply this information to their real world situation. If the use of coloured cues results in recall of the cues as opposed to the objects themselves this would obviously have a negative effect on the effectiveness of the training provided by the VE.

Hypothesis Five:

'There will be a difference in the amount of selection in the 'SNC(Abs) – task' condition and 'FSNC(Abs) – no task' condition.'

8.7.6 Selection – Task & No Task

Selection was recorded for both conditions, Table 8-11.

Table 8-11: Total selections in the AbsVE – 'SNC(Abs) – task' and 'FSNC(Abs) – no task'

	Mean Selections (SD)
SNC(Abs) –Task	21 (18.4)
FSNC(Abs) – No Task	69.1 (43.3)

(Total number of selections, 'SNC(Abs) – task' and 'FSNC(Abs) – no task': t:-3.234, df=18, $p<0.05$)

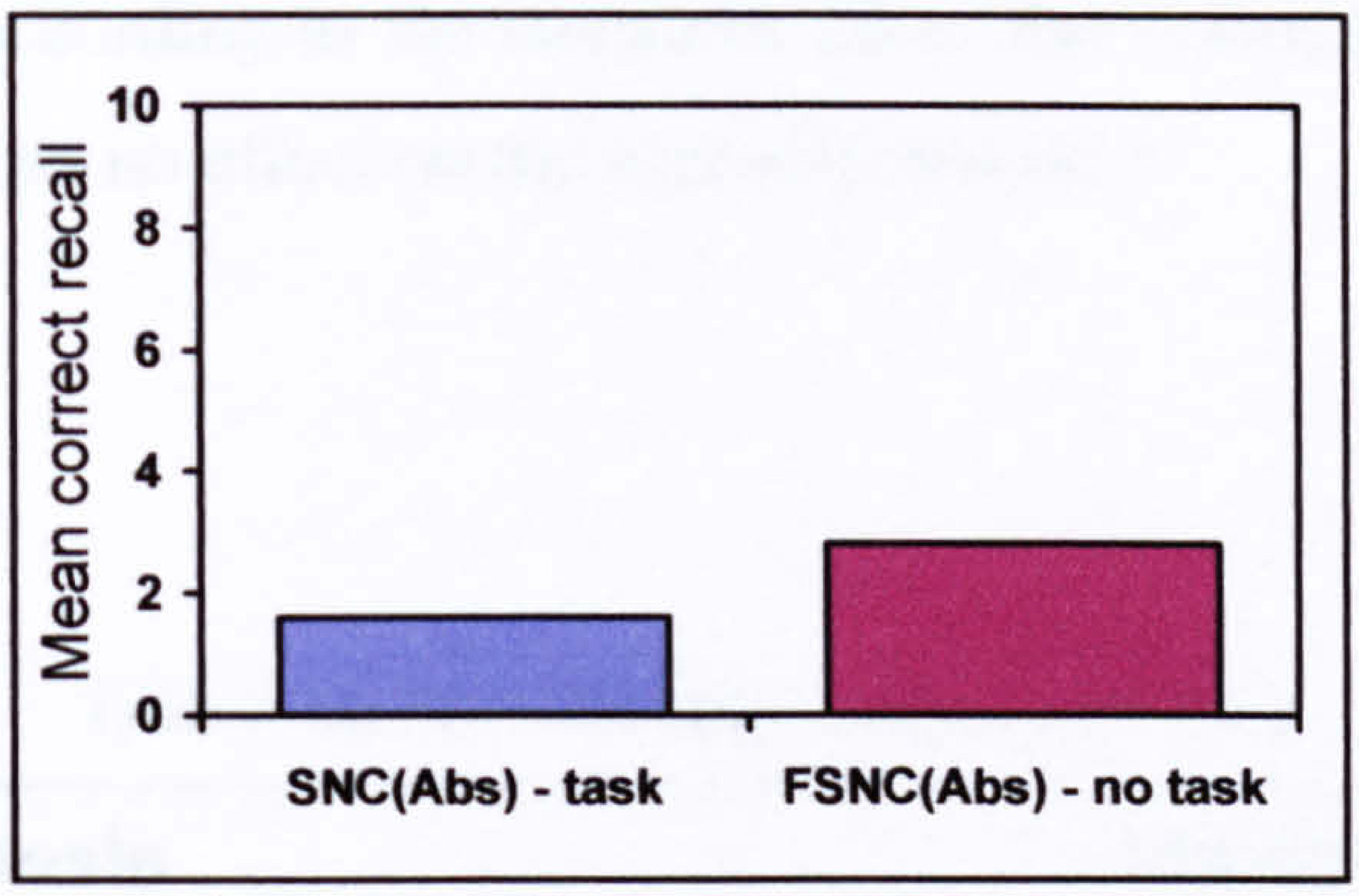
It can be seen that the number of selections was significantly higher when the participant did not have to perform a task. This may be as a result of not having the focus of the task meant that participants investigated their surroundings more and consequently notice more objects to select than when they were concentrating on completing the task.

Hypothesis Six:

'There will be a difference in effectiveness measures in the 'SNC(Abs) – task' condition and 'FSNC(Abs) – no task' condition.'

8.7.7 Object Recall – Task & No Task

Correct object recall was recorded for the 'SNC(Abs) – task' and 'FSNC(Abs) – no task' conditions, Figure 8-5.



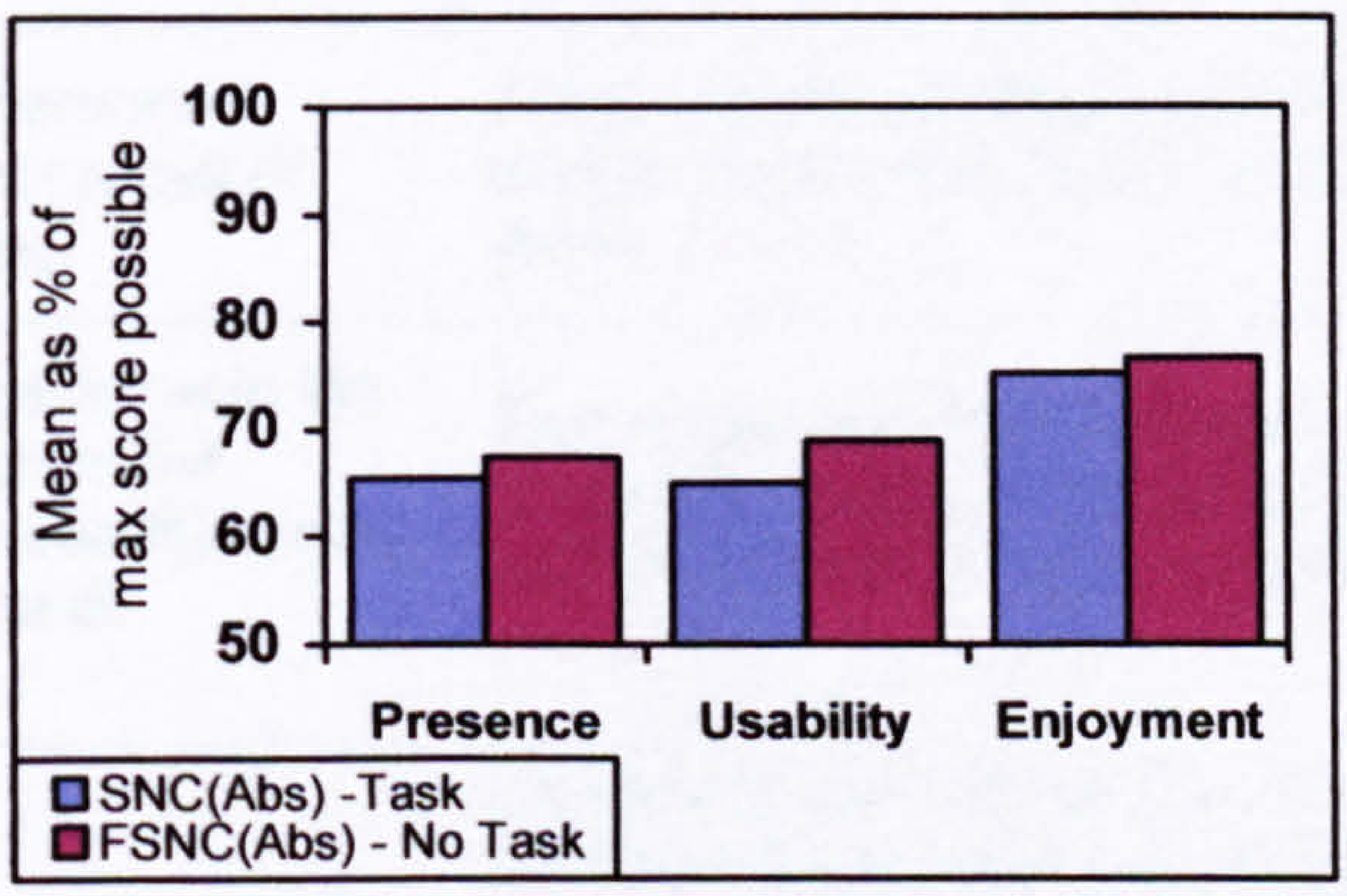
Condition	Recall (SD)
SNC(Abs) – Task	1.6 (1.26)
FSNC(Abs) – No task	2.8 (1.81)

Figure 8-5: mean correct recall – task and no task

(Correct recall, 'SNC(Abs) – task' and 'FSNC(Abs) – no task': t=-1.716; df; 18; $p>0.05$).

It is shown that the level of recall was not significantly different between the task and no task conditions (*Figure 8-5*). This suggests that recall performance is not influenced by the inclusion of a task within an abstract VE.

8.7.8 Presence, Usability & Enjoyment – Task & No Task



Condition	Presence (SD)	Usability (SD)	Enjoyment (SD)
SNC(Abs) – Task	65.45 (8.35)	65.07 (8.65)	75.17 (8.66)
FSNC(Abs) – No task	67.45 (10.92)	69 (9.37)	76.67 (9.13)

Figure 8-6: Presence, usability and enjoyment in the abstract environment – SNC(Abs) – task and FSNC(Abs) – no task

(Presence – 'SNC(Abs) – task' and 'FSNC(Abs) – no task': t=-0.460, df=18, $p>0.05$; Usability – 'SNC(Abs) – task' and 'FSNC(Abs) – no task': t=-0.975, df=18, $p>0.05$; Enjoyment – 'SNC(Abs) – task' and 'FSNC(Abs) – no task': t=-0.377, df=18, $p>0.05$).

No significant difference was found between the task and no task condition for the measures of effectiveness (presence, usability and enjoyment), *Figure 8-6*. It is possible to say therefore that according to the measures taken the inclusion of a task within the abstract environment has no effect on the user effectiveness.

8.8 Main findings

Table 8-12: Main findings – experiment four

	Hypothesis	Finding
H_1	There will be a difference in the effectiveness of selection hotspot cues when incongruent with the VE (RWVE, experiment two) and when they are not (AbsVE).	When the selection hotspot cues were abstract to the VE (RWVE) selection of them was significantly higher than of non-cued objects. When cues were no longer abstract (AbsVE) there was no difference in selection of cued and non-cued objects (Total RWVE, 'cued' and 'non-cued': t=2.965, df=15, $p<0.05$; Total AbsVE, 'cued' and 'non-cued': t=0.327, df=19, $p>0.05$).
H_2	Some selection hotspot cue types will have a difference influence on the amount of selection than others.	There was a significant difference of selection of different cue types (cue type selections, $F_{(8,152)} = 8.58$, $p<0.05$).
H_3	There will be a difference in the recall (correct, incorrect and no recall) of objects that were selected and not selected.	Selected objects were recalled significantly more than seen objects (correct recall, 'Seen, Selected & Reacted' and 'seen only': t=2.68, df=19, $p<0.05$; correct recall, 'Seen & Selected' and 'seen only': t=2.259, df=19, $p<0.05$).
H_4	There will be a difference between the correct recall of colours and shapes.	Colours were recalled significantly more than shapes of objects (Correct recall, 'colour' and 'shape': t=3.943, df=19, $p<0.005$).
H_5	There will be a difference in the amount of selection in the 'SNC(Abs) – task' condition and 'FSNC(Abs) – no task' condition.	There was significantly higher selection in the no task condition (Total number of selections, 'SNC(Abs) – task' and 'FSNC(Abs) – no task': t:-3.234, df=18, $p<0.05$).
H_6	There will be a difference in effectiveness measures in the 'SNC(Abs) – task' condition and 'FSNC(Abs) – no task' condition.	**Correct Recall**: There was no significant difference between correct recall in the task and no task conditions (Correct recall, 'SNC(Abs) – task' and 'FSNC(Abs) – no task': t=-1.716; df; 18; $p>0.05$). **Presence, Usability & Enjoyment**: there was no significant difference between correct recall in the task and no task conditions (Presence – 'SNC(Abs) – task' and 'FSNC(Abs) – no task': t=-0.460, df=18, $p>0.05$; Usability – 'SNC(Abs) – task' and 'FSNC(Abs) – no task': t=-0.975, df=18, $p>0.05$; Enjoyment – 'SNC(Abs) – task' and 'FSNC(Abs) – no task': t=-0.377, df=18, $p>0.05$).

8.9 Experimental Program Development

The main finding of this experiment was that the use of cues with coloured or flashing characteristics for example that are congruous to the surrounding AbsVE context do not prompt significantly more selection than non-cued objects, whereas when these same cues are incongruous to the surrounding VE context, as shown in experiment two using the RWVE, selection was significantly greater of these cued objects than those that were not. Although the effectiveness with respect to selection was not influenced by cues in the AbsVE it was still the case that recall was improved when objects had been selected as opposed to when they had not. This reinforces previous findings in experiment three using the RWVE and it is consequently possible to say that selection has a positive influence on effectiveness if particular objects need to be recalled from a training VE and that selection hotspots prompt selection when they are abstract from the surrounding VE context.

From experiment two it was found that the inclusion of a task improves recall of task related objects, though decreased selection within the environment generally. In experiment three it was found selection is again increased when there is no task and that selection has a positive influence on recall of the objects selected and that a task reduces selection generally and does not improve recall of non-task related objects, these findings all relate to a VE that is based in appearance on the real world environment. It was found from this experiment that when the VE was abstract from the real world in appearance and navigation the inclusion of a task reduced selection generally within the environment and that selection (with or without reaction as a result of that selection) of objects significantly improved the recall of those objects.

Another notable finding from this experiment that was not explored within previous experiments was that there was a significant bias to the recall of colours relating to objects recall rather than their shape. As a consequence of this finding the question was raised – what it is that the participants are recalling, the object or the cue to prompt selection of that object (examined here as the object being recalled with respect to shape or the cue being recalled with respect to colour)? If it is the former then that is obviously what is required from a training VE, if it is the latter then the inclusion of selection hotspots cues may have a negative effect on the effectiveness of a training VE as participants are not recalling details from the VE to relate to the real world. This reiterated the questions posed in experiment three, 'are users perceiving and recognising the object that is cued and are therefore learning from the training VE, or are they merely responding to the cue?'

Chapter 9 - Experiment 5

Are users perceiving and recognising the object that is cued or merely responding to the cue?

9.1 Experimental Program Development

Exp	Questions asked	Main findings	What next?
One	1. Does participant ability to control their navigation around a VE influence the effectiveness of that VE? 2. Does participant ability to select objects within a VE influence the effectiveness of that VE? 3. Does the realism of the VE influence the effectiveness of that VE?	1. There was no significant difference between measures with total participant navigational control & no participant navigational control. 2. There was no significant difference between measures with participant selection & no participant selection. 3. There was no significant difference between measures with total realism & no realism.	As none of the display and interaction conditions explored in experiment one indicated a significant influence on VE training effectiveness indications are VR training is a suitable replacement for video and animated training. What other factors may influence the effectiveness measures of VE training, in particular RW recall as a fundamental aspect of VE training?
Two	1. Does the inclusion of a task influence the effectiveness of VE training, specifically with respect to task related RW recall? 2. What prompts a participant to select a specific object within a VE?	1. The inclusion of a task resulted in significantly increased recall of task related objects 2. Cues suggested increased selection over non-cued objects	As recall was improved with a task when task related it should be explored if this is also the case when recall is not task related. Recall performance may not have been related to the task but as a result of the selection of recall objects that occurred as part of that task, the importance of selection should therefore also be examined.
Three	1. Is the recall of objects within a training VE improved when no longer related to the task performed in the VE? 2. Does the selection of objects whilst in a VE influence the effectiveness of that training VE?	1. Non task related recall was significantly improved when there was no task, a positive relationship was found between selection of recall objects and correct recall. 2. The ability to select objects whilst within the VE had no significant effect on effectiveness apart from improving participants' enjoyment.	Explore if selection hotspot cues result in the same effects as found in experiments 2 and 3 (increased selection over non-cued objects, decreased selection in task conditions, improved recall if selected) if no longer incongruous to the VE context in which they are placed? When recalling objects as in experiments I, 2 and 3 are participants' merely responding to the cue or performing the set task or are they perceiving the objects and learning form them, thereby creating an effective training VE?

Four	1. Do cues that are no longer incongruous to the surrounding VE context still result in increased selection over non-cued objects? 2. Is the selection of objects influenced by the inclusion of a task within that VE? 3. Is recall of cued objects improved if they are selected?	1. Cues that were not incongruent to the surrounding VE context were not found to increase selection significantly over non – cued objects. 2. The inclusion of a task significantly reduced the selection of objects within the abstract VE. 3. Object recall was significantly improved if the object was selected	The most effective cue type has been established, what effect the inclusion of a task within the VE has and the effect of selection on recall in training VEs. Further research should examine the 'so what' angle of these findings, if cues improve selection and selection improves recall are participants recalling the cue or the objects selected? This has important influence on the effectiveness of the training provided by the VE.
Five	1. Are participants merely recalling the cue that was selected or attending to the object that is cued, selecting it and then recalling it? 2. Is the use of one cue more effective than the use of a variety of cues as used in experiments two and three?		

9.2 *Introduction*

Findings have been made concerning the inclusion of a task, selection hotspot cues and the level of control a participant has over the VE to establish the most important design aspects to be included in a desktop VE with respect to the effectiveness of the training it provides. However, yet to be established are the consequences of these findings. The effectiveness of the training aspect of the VE use has been examined with respect to recall in a variety of ways; in the real world over a period of time in relation to the task performed (experiment one and two), pictorial testing removed from the task performed (experiment three) and written testing removed from the task performed in an abstract context (experiment four).

There is little doubt that learning has occurred from the participant's use of the VEs be it from the informal observation by the experimenter in experiments one and two that all participants without exception recognised the real world (that they had never been to before) on which the RWVE was based when they entered it. This indicates even if only on a basic level of familiarity the training VE was to some extent successful. Successful training has also been shown with participants recalling particular details about the environment from the recall of object location participants had been asked to find as part of their task within the VE and also the recall of objects that were not part of the task participants had to perform. What is important to establish is what has been learnt and whether that learning has been as a result of the participant interaction with the VE.

Experiment three demonstrated that objects with selection hotspot cues prompted significantly higher selection than non-cued objects, so it is clear that on a basic level the use of a variety of selection hotspots is effective. No significant difference between the effectiveness of each cue type was found and so it was thought that the same cue type should be used throughout the environment to examine if this, as opposed to varied cue types, has an influence on cue effectiveness. Experiment four suggested that the objects themselves are not what the participants recall but the cues, as a significantly higher recall was found for questions relating to colour (of the cues) than about the shapes of the objects themselves (see, 'Correct Recall – Colour & Shape', section 8.7.5).

Although the use of a task was shown to decrease selection generally within the a VE (Experiment two, three and four) it is a way to control the exploration of participants around a VE (ensuring they explore all the relevant areas) to some extent for the sake of experimentation, so it was decided that a task would be used for this reason within this experiment.

This experiment aims to establish if the process of a user in VE selecting a cued object whilst within a VE is merely a response to the stimulus with no cognitive recognition of the object (the green arrows in 'Figure 9-1', p.197) or the user perceives and recognises the object selected (the blue arrows in 'Figure 9-1', p.197). There are other points to consider, will the user perceive and recognise the cued object even if they do not interact with it? Will the user perceive and recognise the object with or without interacting with it if it is non-cued?

When designing a VE that requires users to recall the objects that they select whilst within it (either performing a task or in response to a cue), the importance of them recognising the objects and not merely reacting to the stimulus of the cue is great. A spontaneous response to a stimulus without recognition is likely to result in a less effective training environment.

This experiment will combine the use one of the most effective cue type from previous experiments, red flashing (see experiment two and experiment four results for the effectiveness of coloured cue and abstract cue design respectively), to prompt object selection and to establish if the user perceives and recognises the objects selected. Perception and recognition provides meaning to the information provided by the object, i.e. what the object is, where it is located relative to other recognisable objects within the VE and its purpose within the VE and also in relation to the real world. For example will a user just click on a cupboard door because it is flashing red and only recall that an object was flashing red or will they click on the cupboard, realise that it is a cupboard and attend to details about it such as where the cupboard was and possibly further information gained from selecting it such as its contents. This would be done by comparing the information provided by the representation of the cupboard object in the VE to information in the long term memory enabling VE object recognition in relation to real world objects or objects previously encountered in VR.

9.2.1 Information processing

Wickens, C. D., Gordon, S. E. & Liu, Y. (1998) developed a generic model of human information processing, a simplified version of this model used for demonstrating this theory and its importance in the context of this experiment can be seen in *Figure 9-1*.

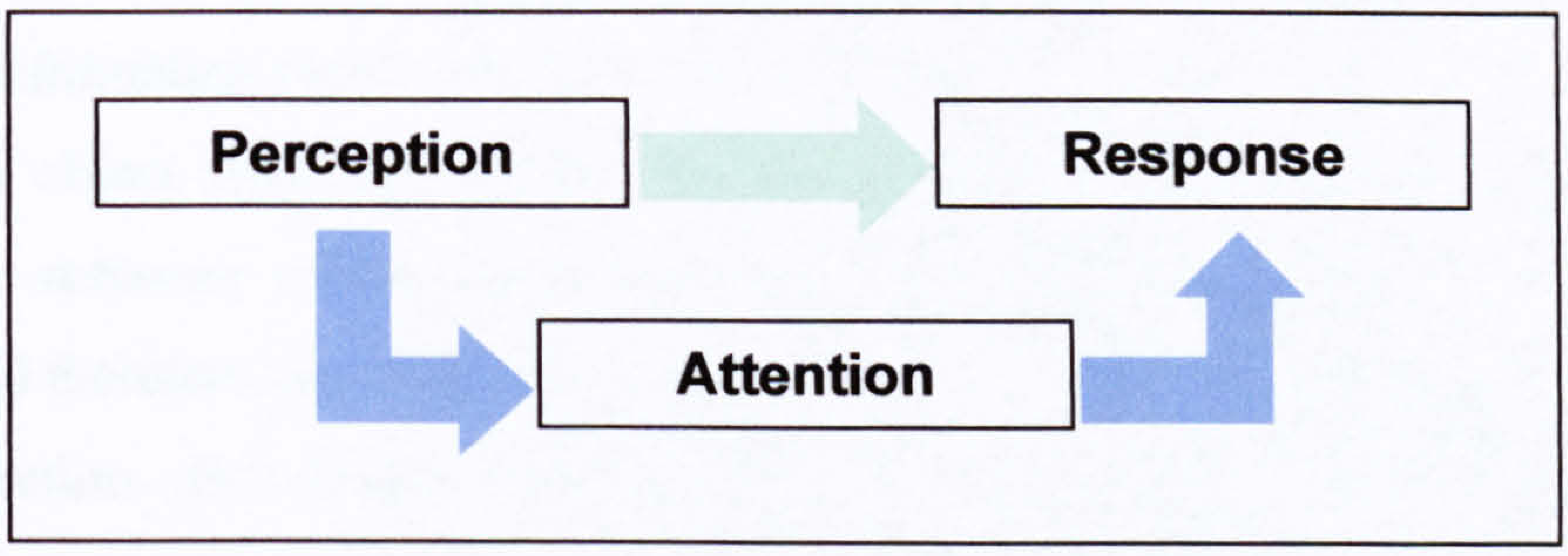


Figure 9-1: Basic human information processing based on Wickens et al., (1998)

Figure 9-1 in the context of research performed previously it has been shown that the information from the VE is perceived and then responded to (the green arrow route). What it is important for this experiment to explore is the concept as explained in Wickens et al. (1998) p.147 that 'any information receiving attention is processed further in the perception stage' by the process of *adding meaning* to the information or *attending* to it. In this case the object is given attention by the participant as a result of visual or auditory sensory information from the object or the cue, meaning is applied to its appearance or the sound it makes (i.e. "it looks like a button so I will press it", or "it sounds like a phone ringing so I will answer it") and a response is made by the process of object selection. This meaning is applied by comparing the information provided by the object representation in the VE to the information that exists in relation to it in the long term memory. This means, theoretically, that the object selected in the environment by the participant will be compared with similar/familiar objects from the real or virtual world the participant has previously encountered and appropriate meaning will be applied to that object (blue arrows ref. *Figure 9-1*). For the purpose this experiment, the process of information receiving attention in the working memory and reference to the long-term memory of objects/aspects within a VE is defined as 'recognition'. This process is important to determine the effectiveness of the training environment as a) the environment and the objects selected within it are acknowledged and b) they are compared to existing knowledge (most likely from the real world) and meaning is applied. This has further implications as to the importance of object selection and manipulation being included within VE design. If this process does prove to aid the perception and recognition of specific aspects of a VE it will improve the effectiveness of that VE.

Alternatively, if the selection of the object the process of 'response' within this model of human information processing and the recognition and perception of the object is not in fact the object itself but of the cue (red flashing), that is recognised as having produced a response within the environment when previous similar cues have been selected and therefore the object itself is of no consequence to the participant, merely its cue for selection. An example of this is when an oven timer goes off and you press it to stop the alarm but forget to switch the oven off or remove the food and it gets burnt. In this example the alarm has been responded to but its meaning not properly perceived. In this case the information has not been sent to the working memory for further processing and is instead an immediate reaction to perception (green arrow ref. *Figure 9-1*). If this is the case with respect to the inclusion of cues in a VE to prompt object selection and possibly the ability of the user to select objects within a VE at all may, in fact, have no impact or a negative impact on the effectiveness of a VE.

9.3 Research Questions

1. Will cued objects encourage increased object selection?

- **Expectation:** Users are more likely to select cued objects than non-cued objects.
- **Reasoning:** The cue makes the object more noticeable within the VE and draws attention to it specifically increasing the chance of that object being selected, as shown in experiment two ('Selection of Cued & Non Cued Objects', section 6.7.4).

2. Are usability, presence, enjoyment and recall influenced by the inclusion of object cues?

- **Expectation:** Effectiveness measures will not be influenced by the inclusion of selection hotspot cues.

- **Reasoning:** Earlier findings have shown no influencing factor on the effectiveness measures taken, including the inclusion of a task, the ability of the user to select within the VE and the method of viewing the VE itself suggesting there will be no notable influence of the selection hotspot cues.

3. Will the use of one cue type, as opposed to many, have a positive influence on the effectiveness of the cue?

- **Expectation:** One cue type will be more effective than a variety.
- **Reasoning:** The one cue type used was effective in previous experiments and participants will learn whilst within the VE that cued objects react when selected and they are easier to identify as they are all the same.

4. Are users more likely to perceive/recognise *cued* or *non-cued* objects if they have selected or manipulated them?

- **Expectation:** Users are more likely to perceive/recognise *cued* objects than non-cued objects that they have only seen and not selected.
- **Reasoning:** The cue makes the object more noticeable within the VE and draws attention to it specifically increasing the chance of that object being attended to and consequently recalled (Wickens et al., 1998).

5. Will Users be more likely to perceive/recognise the objects that they have selected or manipulated?

- **Expectation:** Users are more likely to perceive/recognise objects that they have selected.
- **Reasoning:** Earlier findings (experiment three, 'Object Recall – Objects Seen & Objects Seen and Selected', section 8.7.3) have suggested that this is the case and the process of selection and reaction may improve recall by making the object selected 'stick out' more.

9.4 The Experiment

9.4.1 Conditions

The environment used was the RWVE as described in '*The Real World Virtual Environment*', section 4.2 as was used in experiment one, two and three (to enable comparison of findings across experiments) except that all cues on interactive objects will be the cued flashing red, one of the most favoured in previous experiments, in the cued condition. This was to establish if one cue type would be equally effective instead of using a variety of cue types as in previous experiment, as a single cue type will result in easier VE development. The RWVE was based on an existing building with the same room layout, furniture and décor. Participants viewed the environment as they would the real world with a 'humans eye view' and used a joystick to navigate around the room and a mouse to select objects within it. Two conditions were examined within this experiment, firstly a cued environment where reactive objects were cued flashing red to prompt selection and secondly where no objects were cued, to examine the influence of cues on the effectiveness measures taken and the effectiveness of a single cue type over a variety of cue types (experiment two and three).

Table 9-1: Conditions explored within experiment five – cued and non-cued

Condition	Abbreviation	Description
Selection & Navigational Control - cued	**SNC - cued**	- Free navigation using the joystick - Able to choose and select any objects. - Defined task whilst using the environment. - Selection hotspots were cued to indicate it was possible for the participant to select them.
Selection & Navigational Control - non-cued	**SNC - non-cued**	- Free navigation using the joystick - Able to choose and select any objects. - Defined task whilst using the environment. - Selection hotspots were non-cued to indicate it was possible for the participant to select them.

9.4.2 The Task

A task was used within both experimental conditions to encourage exploration of the same areas within the environment and encourage consistency between conditions, even though selection has been shown to be less in a task directed VE. The task was as described in '*The RWVE Task*', section 4.2.2 and required participants' to explore the environment searching for fourteen health and safety (H&S) objects within it (red and black fires extinguishers, fire exits, fire alarms and a first aid box). When the object was found it was selected using the mouse and a tick appeared below the corresponding on screen tick list (see '*Figure 4-4: View of RWVE 'SNC' condition search task screen.*' P104) to enable participants to keep track of what they found and what they had still to find. In both conditions participants were encouraged to select any objects they wished as well as completing the task.

9.4.3 Measures Taken

Table 9-2 shows the measures taken for participant in each condition within this experiment, for details of measurement methods see 'Experiment Measures', section 3.2.3 the equipment set up was as described in 'Experiment Equipment', section 3.2.1.

Table 9-2: Measures taken for each experimental condition – experiment five

Conditions	Measures Taken
SNC – cued	Missing Object Recall, Presence, Usability, Enjoyment, Selection
SNC – non-cued	Missing Object Recall, Presence, Usability, Enjoyment, Selection

Selection was measured with respect to three selection levels; 'selected & reacted', 'selected' and 'seen' as opposed to merely if the objects have been selected or not. This was to examine if the reaction of the objects influence if the participant recalled the object or not. Selection occurred when the participant clicked on an object with the mouse, selection and reaction is when that object provided some kind of feedback to the participant, such as a visual or audible change in the environment.

9.4.4 Missing Object Recall

Missing objects recall was designed to establish if participants were recognising the cued object that they were selecting as opposed to merely responding to the cue. This was done by removing the cued objects completely from images of the RWVE as the participants' had seen them and asking if they could recall the object itself and specific details about it, such as its colour and location (see appendix, p. 273). This was then to be compared with the same RWVE with no cues to establish if the inclusion of a cue aided or hindered this missing objects recall. Table 9-3 demonstrates a selection of the images used for this missing objects recall test where the first picture in each pair represents the environment as the participant saw it, with all the missing cued objects in place. The second represents the picture that they will be shown in the missing objects recall test with the cued objects removed. They were asked to identify the missing objects, their colour and their position on the picture and how confident they were with their answers on a scale of one (not at all confident) to 5 (totally confident). Fifteen images with objects missing were shown to the participant.

Table 9-3: Examples of images from the RWVE as used in the missing object recall test

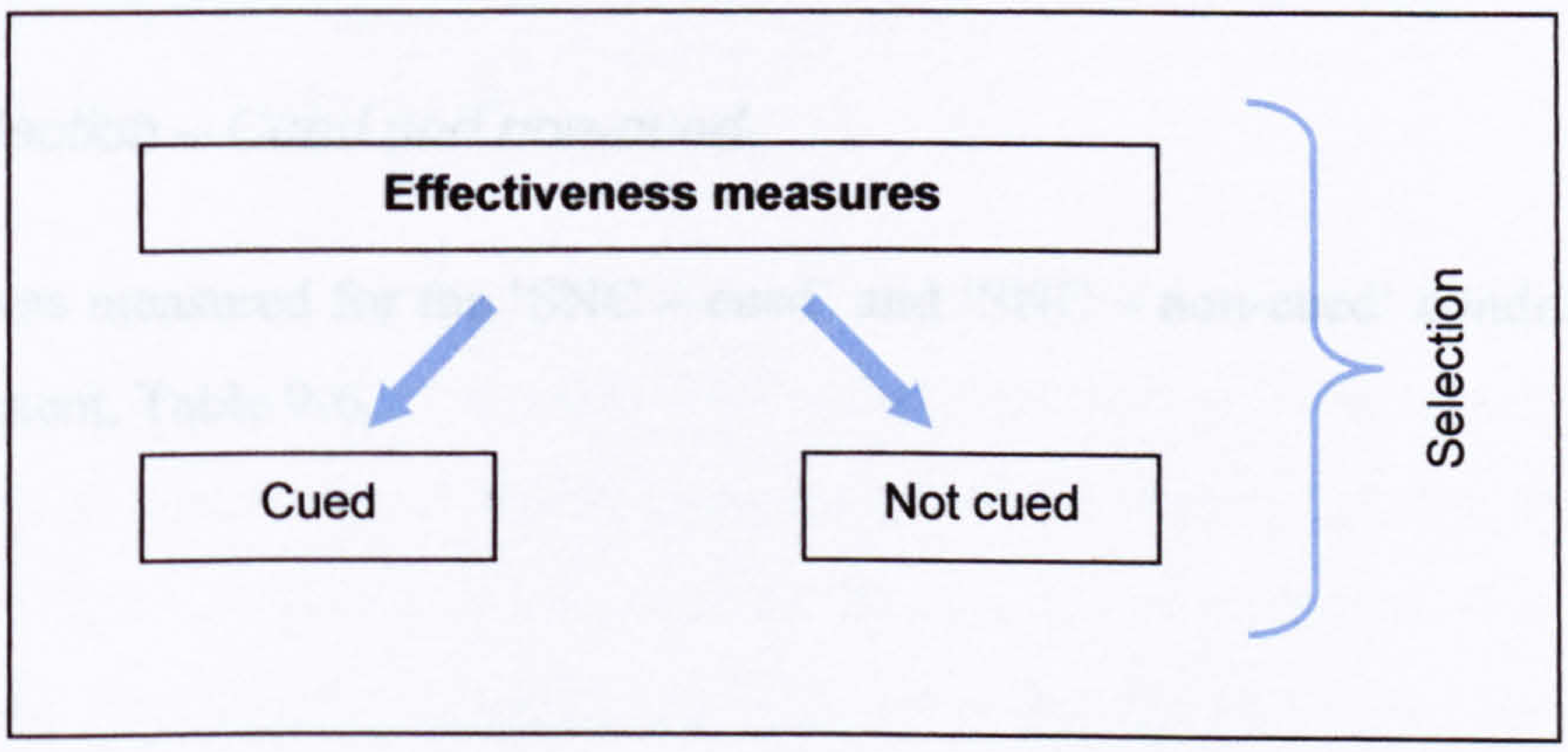
RWVE as Participant saw it	Test images (cued objects missing)
	 Missing objects: Computer, Printer
	 Missing objects: Microwave, Plug, Cupboard, Tap, Fridge door
	 Missing objects: OHP, TV, Laptop
	 Missing objects: Filing cabinets, Keyboard, Telephone

9.5 Research Hypotheses

Hypotheses derived from research questions:

- *Will cued objects encourage increased object selection?*
  1. There will be a difference in the amount of selection between the 'SNC – cued' and 'SNC – not conditions.
- *Are usability, presence, enjoyment and missing objects recall influenced by the inclusion of object cues?*
  2. There will be a difference in usability, presence, enjoyment and missing objects recall between the 'SNC – cued' and 'SNC – non-cued' conditions.
- *Will the use of one cue type, as opposed to many, have a positive influence on the effectiveness of the cue?*
  3. There will be a difference between the selection of one cue type (experiment five, SNC – cued) and a variety of cue types (experiment three SNC – task & selection).
- *Are users more likely to perceive/recognise cued or non-cued objects if they have selected or manipulated them?*
  4. There will be a relationship between selection and correct recall of specific missing objects.
- *Will Users be more likely to perceive/recognise the objects that they have selected or manipulated?*
  5. 'There will be a difference between correct missing objects recall and level of selection (levels – 'seen only', 'seen & selected' and 'seen, selected & reacted')'

9.6 Experiment Structure



9.6.1 Participant group

Table 9-4 shows the experiment group details.

Table 9-4: Participant group breakdown

Total	Age Range	Mean	Background
30	18 – 54	26yrs 1month	Students and staff at the University of Nottingham. No previous knowledge of the real world building. VE novices.

The breakdown of participants in each condition within the group is shown in Table 9-5.

Table 9-5: Experimental conditions breakdown – number of participants

Condition	Participants
SNC – cued	12
SNC – non-cued	18

Cued objects have been shown to encourage increased selections by participants in previous experiments. The unequal number of participants in each condition was for there to be a useful comparable result with an equivalent amount of selections needed to occur in the non-cued condition and the cued condition.

9.7 Results and Discussion

Hypothesis One:

'There will be a difference in the amount of selection between the 'SNC – cued' and 'SNC – not conditions.'

9.7.1 Selection – Cued and non-cued

Selection was measured for the 'SNC – cued' and 'SNC – non-cued' conditions within this experiment, Table 9-6.

Table 9-6: Total number of missing objects selected – cued and non-cued

	Total	Mean per participant (SD)
SNC – cued	148	12.33 (11.18)
SNC – non-cued	95	5.28 (6.09)

(Selections, 'SNC – cued' and 'SNC – non-cued': t=1.998, df=15.387, *p*>0.05).

This indicates that the cued condition prompted an increased level of selection with cued objects, though this difference was not found to be significant. Once they had completed the missing objects recall task all participants were asked:

- *Do you recall anything specific about the missing objects?*

Responses were categorised according to the main reason provided in a participants statement, for example participant four (not cued) stated "the football was the first thing I saw" which would fall in the 'first thing seen/selected/reacted category' and participant five stated "I played with them" which would fall into the 'objects selected/reacted' category and so forth. It was possible for participants to provide more than one reason and for this reason percentages in Table 9-7 were calculated according to the total number of responses provided by all participants and not according to the total possible. Table 9-7 shows the results given to this question (excluding responses that the answer was guessed and when no answer was provided).

Table 9-7: Verbal responses to 'why recall missing objects?' – cued and non-cued

Response	Responses as % of max possible* - Cued	Responses as % of max possible* - Non-cued
red flashing objects	28.57	-
curiosity about objects	9.52	17.86
task focused (didn't recall)	4.76	7.14
first thing seen/selected/reacted	-	10.71
unexpected/out of place objects	19.05	28.57
objects selected/reacted	38.1	35.71

*Total responses: cued = 21, not-cued = 28

28.57% of participants in the cued condition stated that they recalled the red flashing cues as a specific detail of the missing objects that they were asked to recall, the greatest response to this question was that they had selected the object, (38.1%) though it has been shown that selection was increased if the object was cued than if it was not in Table 9-6. In the non-cued condition 35.71% stated that the fact they had selected the objects was what they recalled, the highest percentage from the answers provided. This suggests that although the participants were prompted to select cued objects because they are cued, it is not the cue that they recall the most but the fact that they selected that object. These numbers provide an indication as to what a participant recalls about the use of a VE and why, further research would be required to define this specifically.

Participants were asked a further question:

- *What, if anything, prompted you to select certain objects?*

Table 9-1 shows the results given to this question (excluding responses that they selected an object as they had been shown it reacted in the pre-experiment demonstration).

Table 9-8: Verbal responses to 'why select missing objects?' – cued and non-cued

Response	Responses as % of max possible* - Cued	Responses as % of max possible* - Non-cued
unexpected/out of place objects	6.67	5
task focused (didn't recall)	6.67	15
expectations from previous objects reacting	6.67	5
curiosity about objects/playing	20	35
objects looked like they did things	-	30
No reaction first time, did not select again	20	10
red flashing/cued objects	40	-

*Total responses: cued = 15, not-cued = 20

The inclusion of a cue is shown to be the most influential conscious factor in object selection for participants in the cued condition (40%), whereas in the non-cued condition the reasoning for selection objects is far less directed and seemed to be pot luck with no conscious reasoning but a general curiosity about the environment and affordances of the objects themselves.

Hypothesis Two:

> *'There will be a difference in effectiveness measures between the 'SNC – cued' and 'SNC – non-cued' conditions.'*

9.7.2 Missing Object Recall – Cued and non-cued

For the following results correct missing objects recall constitutes all three questions asked about each VE image (recalling the missing objects itself, its location and its colour) being recalled correctly. Answers that were only partially correct (i.e. colour and location were correct but object was not and so forth) were not included as to examine evidence of participants perceiving and recognising objects all aspects of that object should be correctly recalled to demonstrate this. Conversely for incorrect recall all three answers must be incorrect (no recall will be examined separately).

Correct missing objects recall was recorded for each condition as a percentage of the maximum correct recall score possible (39 missing objects in fifteen RWVE images) Table 9-9.

Table 9-9: Mean correct recall of missing objects as a percentage of maximum possible – SNC – cued and SNC – non-cued

	Mean Correct Recall
Cued	13.89 (12.87)
Not Cued	9.4 (7.46)

(Correct recall – 'SNC – cued' and 'SNC – non-cued': $t=1.211$, $df=28$, $p>0.05$)

Correct missing objects recall was found to be higher on average in the cued condition but this difference was not significant. This is the first time within this research the influence of cues and no cues have been directly compared and previous findings of selection being higher with cued objects and selected objects being more likely to be recalled would imply that the correct recall of cued objects would be higher. Although the difference found is large it was not significant due to the high standard deviation values obtained.

Levels of incorrect missing objects recall are equally important if not more so for a training VE if incorrect information is recalled and implemented in the real world.

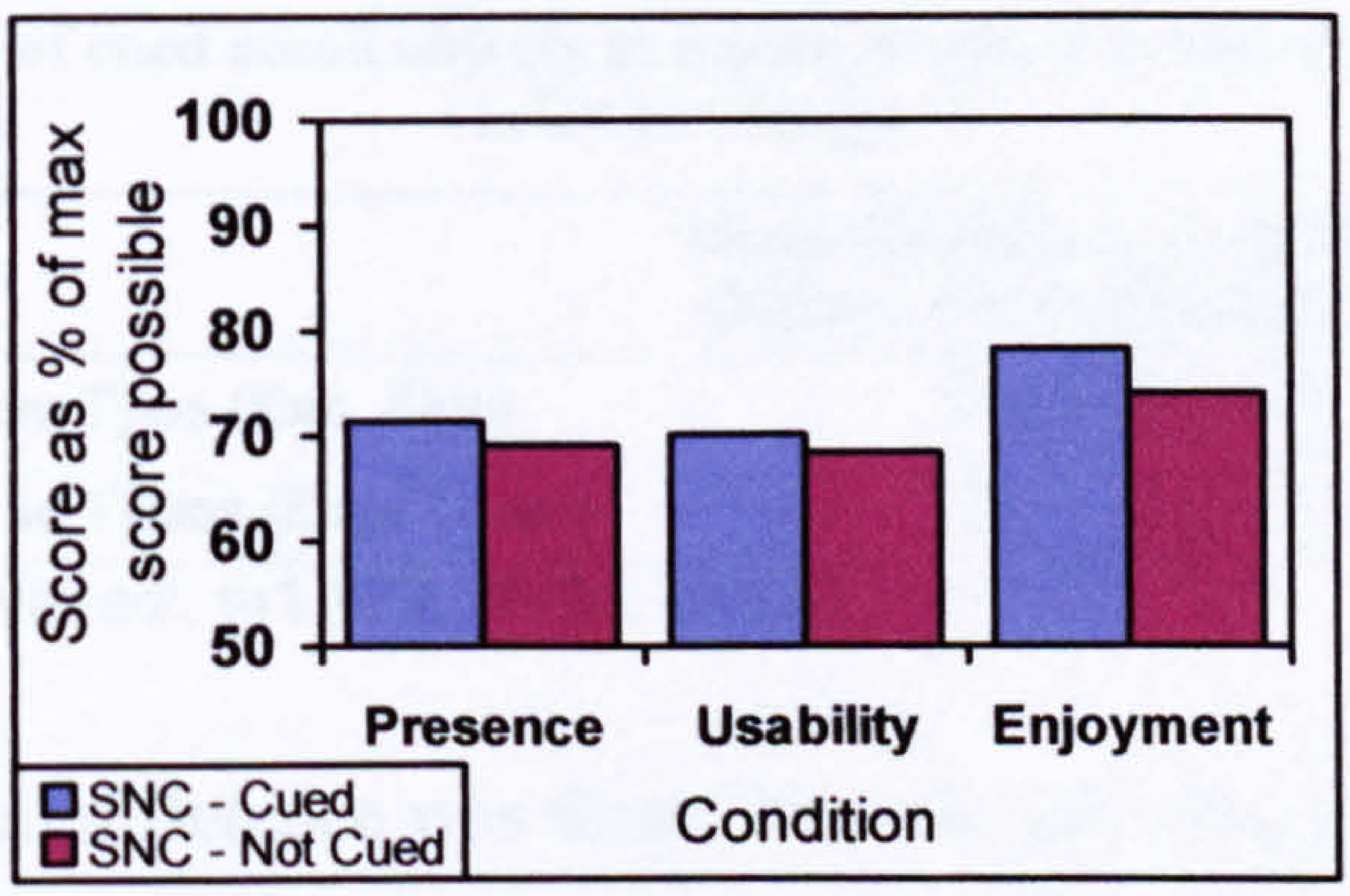
Table 9-10: Mean incorrect recall of missing objects as a percentage of maximum possible – SNC – cued and SNC – non-cued

	Mean Incorrect Recall
Cued	5.13 (4.05)
Not Cued	7.26 (7.42)

(Incorrect recall – 'SNC – cued' and 'SNC – non-cued': t=-0.901, df=28, $p>0.05$)

Incorrect missing objects recall was found to be highest in the non-cued condition, again this difference was not found to be significant. In the cued condition correct missing objects recall was found to be significantly higher than incorrect missing objects recall (SNC – cued, 'correct' and 'incorrect': t=2.367, df=11, $p<0.05$), though in the non-cued condition this was not the case (SNC – non-cued, 'correct' and 'incorrect': t=0.940, df=17, $p>0.05$).

9.7.3 Presence, Usability and Enjoyment – Cued and non-cued



	Presence (SD)	Usability (SD)	Enjoyment (SD)
SNC – Cued	71.52 (10.44)	70.17 (9.71)	78.33 (8.44)
SNC – Not cued	69.09 (9.7)	68.41 (7.25)	74.07 (11.39)

Figure 9-2: Presence, usability and enjoyment measures – cued and non-cued

(Presence, 'SNC – cued' and 'SNC – non-cued': t=0.651, df=28, $p>0.05$; Usability, 'SNC – cued' and 'SNC – non-cued': t=0.569, df=28, $p>0.05$; Enjoyment, 'SNC – cued' and 'SNC – non-cued': t=1.106, df=28, $p>0.05$).

There was no significant difference between the levels of presence, usability and enjoyment measured in the two conditions (cued and non-cued) as shown in Figure 9-2.

Hypothesis Three:

'There will be a difference between the selection of one cue type (Experiment five, SNC – cued) and a variety of cue types (experiment three SNC – task & Selection).'

9.7.4 Single and Varied Cue Types

In experiments three (condition SNC – task) and five (condition SNC – cued) the participants performed the same task that required them to search and select H&S objects within the same RWVE. Both experiments later required the participants to recall objects that had been cued within the VE that had just explored that were not related to the task. In experiment three the cues were of eleven different types (red, blue, grey, yellow highlighted and flashing and sounds, photo realistic or textured and movement) and in experiment five these objects were all cued the same (red flashing). Table 9-11 demonstrates the influence that this had on the selection of these objects.

Table 9-11: Selections of cued recall objects as a percentage of maximum possible – single and varied cue design

	Mean Selections on Cued Recall Objects Per Participant, % (SD)
Single Cue Type (Exp. Five)	31.62 (28.66)
Varied Cue Types (Exp. Three)	15 (21.75)

(Selection, 'single' and 'varied': t=1.175, df=25, p>0.05).

Although no significant difference was found between the selection of a single cue type or a variety of cue types a greater selection was found for the single cue type RWVE, this suggests that using a single cue type will prompt greater selection. The lack of significant difference is a consequence of high standard deviations for the results recorded.

Hypothesis Four:

'There will be a relationship between selection and correct recall of missing objects.'

9.7.5 Selection and Correct Missing Objects Recall

The number of recall objects correctly recalled and the number of selections made on recall objects was recorded for both conditions, Figure 9-3.

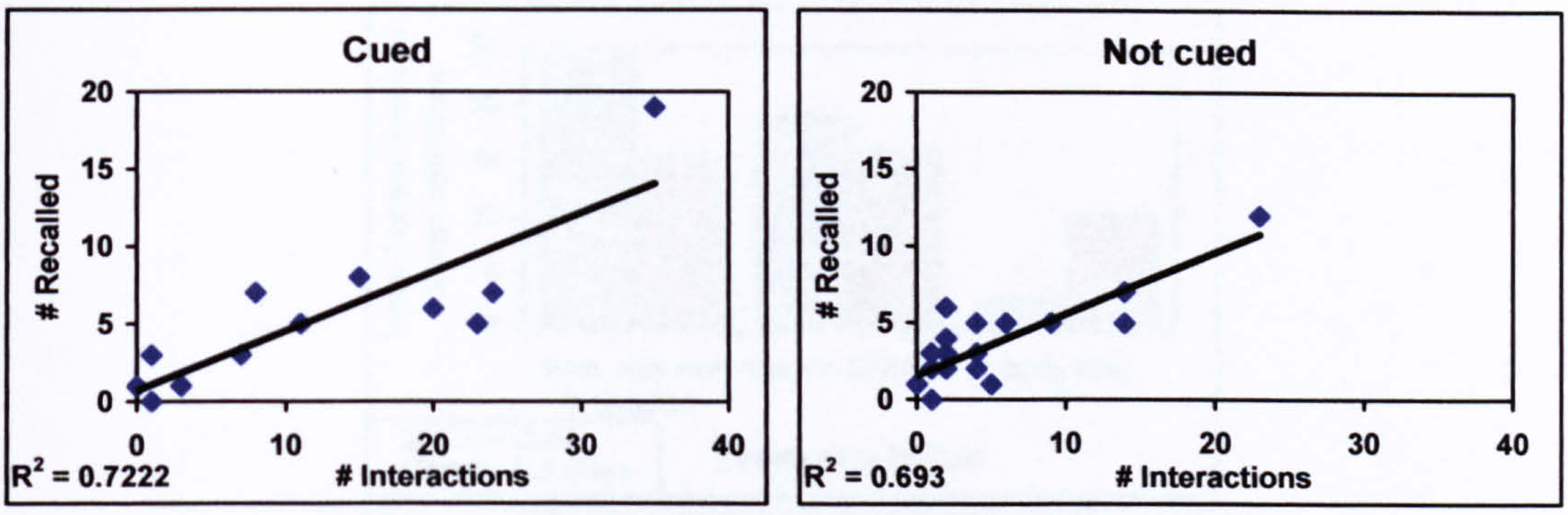


Figure 9-3: Correlations of the selection of task objects and number of missing task objects correctly recalled – cued and non-cued

(Cued, 'recalled' and 'interactions': r=0.850, n=12, $p<0.05$: non-cued, 'recalled' and 'interactions': r=0.833, $p<0.05$).

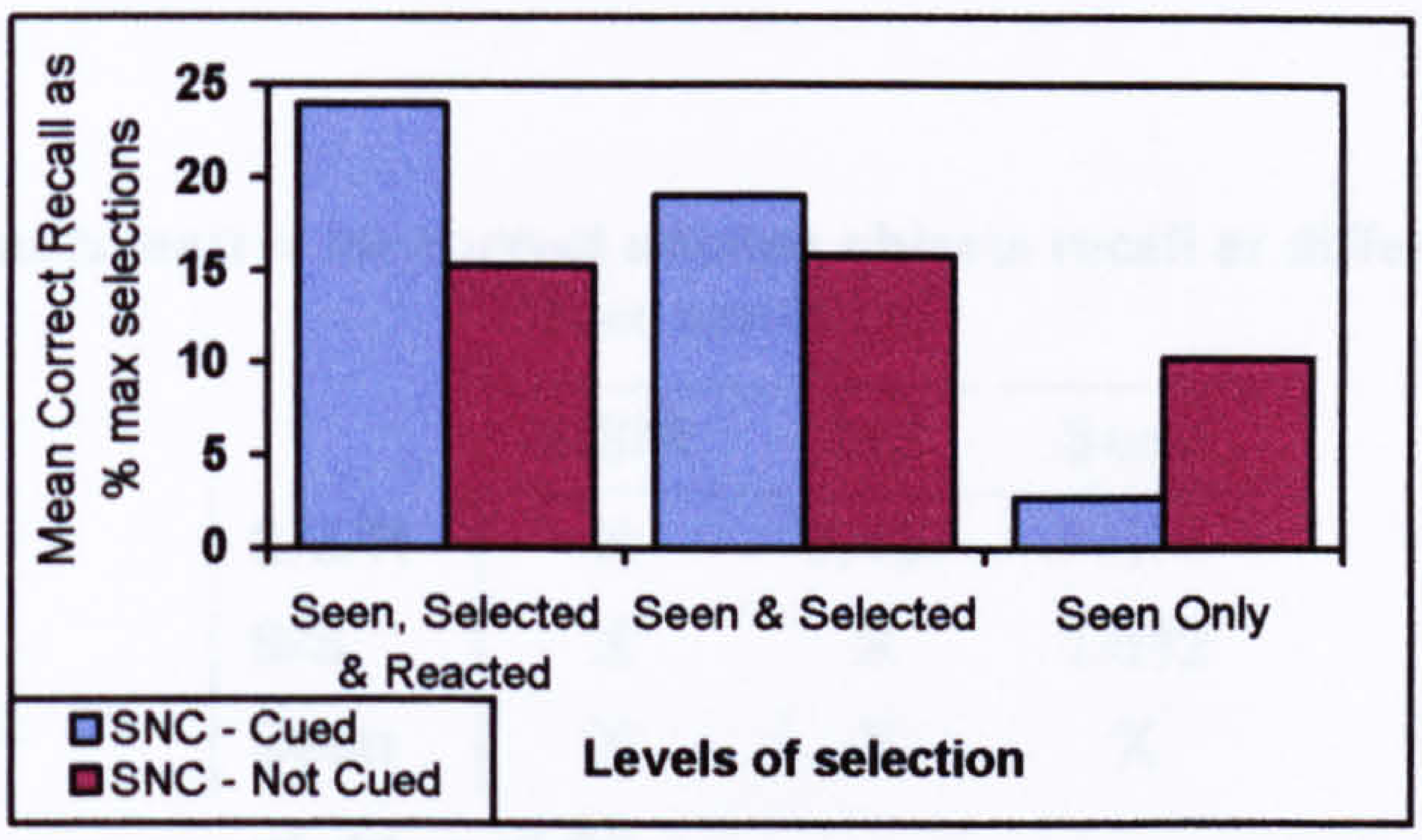
It can be seen in Figure 9-3 that there is a significant relationship between the number of selections in each condition and the number of missing objects correctly recalled suggesting that increased selection results in increased recall. It is possible that individual differences in 'inquisitiveness' could explain this as the more a participant explored the environment and interacted within it the greater their observation of it and consequently their correct recall of it. This is another indication that the inclusion of selection and prompts to encourage that selection within an environment is a positive factor in this case with respect to recall of details within that environment.

Hypothesis Five:

> *'There will be a difference between correct missing objects recall and level of selection (levels – 'seen only', 'seen & selected' and 'seen, selected & reacted')'*

9.7.6 Missing Object Recall – Level of Selection

The mean number of objects correctly recalled as a percentage of the total selection at each level made by each participant was recorded for both test conditions, Figure 9-4.



	Recall (SD) SNC – Cued	Recall (SD) SNC – Not cued
Seen, Selected and Reacted	23.93 (20.08)	15.22 (21.98)
Seen & Selected	19.05 (38.69)	15.74 (33.56)
Seen only	2.78 (3.36)	10.24 (9.62)

Figure 9-4: Mean number of correct missing object recall as a percentage of the maximum correct recall possible at different levels of object selection – SNC – cued and SNC – non-cued

(Seen, Selected & Reacted, 'SNC – cued' and 'SNC – non-cued': t=1.099, df=28, $p>0.05$; Seen & Selected, 'SNC – cued' and 'SNC – non-cued': t=0.249, df=28, $p>0.05$; Seen Only, 'SNC – cued' and 'SNC – non-cued': t=-2.572, df=28, $p<0.05$)

An ANOVA test was not used in this case as with the high standard deviations evident it is not a robust test.

It can be seen that in the 'SNC – cued' condition the majority of correct recall (as a percentage of the total selections made per participant) resulted from the participant selecting objects and those objects reacting to the selection, for the 'SNC – non-cued' condition the value of correct missing objects recall is virtually identical for both selected and reacted objects and selected objects. The only significant difference found between conditions was in the 'seen' level of selection where correct missing object recall was greater for non-cued objects than for cued, this may be as a result of there being less selection in the non-cued condition generally and with no cue to draw additional attention to the objects in the non-cued condition there is less difference in recall between them being seen and them being seen and selected. This indicates that without a cue the effectiveness of selection in improving recall of an object is less than if that object is cued. Consequently it may be the case that for recall to be greatest cues should be used to prompt selection of significant aspects of the VE that users are required to recall.

The difference between the correct missing objects recall and the levels of selection for the 'SNC – cued' condition was recorded, Table 9-12.

Table 9-12: T-test results matrix for correct missing objects recall at different levels of selection – cued condition

	S/S/R	S/S	Seen
S/S/R	X	0.467	3.676
S/S	X	X	1.512
Seen	X	X	X

df=11, $p<0.05$

The only significant difference was found between the 'seen, selected and reacted' and 'seen only' values of correct missing objects recall. The difference between the correct recall and the levels of selection for the 'SNC – non-cued' condition was recorded, Table 9-13.

Table 9-13: T-test results matrix for correct missing objects recall at different levels of selection – non-cued condition

	S/S/R	S/S	Seen
S/S/R	X	0.056	1.008
S/S	X	X	0.693
Seen	X	X	X

df=11, $p< 0.05$

It is shown that selection and reaction prompted the greatest recall in the 'SNC – cued' condition, significantly greater than objects that were seen and not selected. It is possible therefore to suggest that there is a greater chance of participants recalling objects that have been selected than those which have not and that this chance is improved if those objects responded to that selection. A similar trend was shown in the 'SNC – non-cued' condition although the importance of the objects reacting to the selection appears lessened.

9.7.7 Missing Object Recall – Confidence in Recall

Table 9-14 demonstrates the mean confidence ratings recorded by participants when they only saw the objects that they recalled (Seen), when they saw the objects and selected them (S/S) and when they saw them, selected them and they reacted in some way (visually or audibly) to that selection (S/S/R). This aimed to establish if participants had varied confidence in their correct answers provided about specific objects depending on the level of selection ('S/S/R', 'S/S' or 'Seen') that occurred with that object within the VE.

Table 9-14: Mean confidence in correct answers given for each level of selection – cued and non-cued

		Object – O (SD)	Position – P (SD)	Colour – C (SD)
Cued	S/S/R	4.43 (0.84)	4.46 (0.84)	4.38 (0.80)
	S/S	4.25 (0.50)	4.00 (1.00)	3.75 (0.96)
	Seen	3.78 (1.20)	4.00 (1.00)	3.38 (1.30)
Not Cued	S/S/R	4.71 (0.83)	4.75 (0.87)	4.50 (1.09)
	S/S	3.80 (1.30)	4.00 (1.41)	4.40 (0.89)
	Seen	3.95 (1.28)	4.20 (1.15)	4.05 (1.00)

1 = Not at all confident
2 = Slightly confident
3 = Moderately confident
4 = Very confident
5 = Extremely confident

As not all participants provided confidence ratings with correctly recalled objects no statistical test was performed on this data. It has been included here to demonstrate that confidence tended to be greater when the object to be recalled had been selected and that selection resulted in a reaction as opposed to when it had not. This suggests that the process of selection reinforces the memory of the object for the participant increasing their confidence that they have correctly answered the recall question. This has valuable implications for training VEs and the inclusion of selection and is an area that requires further research.

9.8 *Main Findings*

	Hypothesis	Finding
H_1	There will be a difference in the amount of selection between the 'SNC – cued' and 'SNC – non-cued' conditions.	There was greater selection in the 'SNC – cued' condition but this was not found to be significant (Selections, 'SNC – cued' and 'SNC – non-cued': t=1.998, df=15.387, $p>0.05$).
H_2	There will be a difference in effectiveness measures between the 'SNC – cued' and 'SNC – non-cued' conditions.	There was no significant difference found between the conditions for all measures of effectiveness (Correct recall, 'SNC – cued' and 'SNC –non-cued': t=1.211, df=28, $p>0.05$; Presence, 'SNC – cued' and 'SNC –non-cued': t=0.651, df=28, $p>0.05$; Usability, 'SNC – cued' and 'SNC –non-cued': t=0.569, df=28, $p>0.05$; Enjoyment, 'SNC – cued' and 'SNC –non-cued': t=1.106, df=28, $p>0.05$).
H_3	There will be a difference between the selection of one cue type (experiment five, SNC – cued) and a variety of cue types (experiment three SNC – task & selection).	Selection was greater in the 'single cue' condition but this was not found to be significant (Selection, 'single' and 'varied': t=1.175, df=25, $p>0.05$).
H_4	There will be a relationship between selection and correct recall of objects.	In both the cued and non-cued condition there was a significant positive relationship found between the number of selections and correct recall (Cued, 'recalled' and 'interactions': r=0.850, n=12, $p<0.05$: Non-cued, 'recalled' and 'interactions': r=0.832, $p<0.05$).
H_5	There will be a difference between correct recall and level of selection (levels – seen only, seen & selected and seen, selected & reacted).	There was a significant difference found between selected & reacted and selected and selected and seen in both conditions, **Cued condition correct Recall:** (Seen, Selected & Reacted and Seen & Selected: t=0.467, df=11, $p>0.05$; Seen, Selected & Reacted and Seen Only: t=3.676, df=11, $p<0.05$; Seen & Selected and Seen Only: t=1.512, df=11, $p>0.05$) **Not cued condition correct Recall:** (Seen, Selected & Reacted and Seen & Selected: t=-0.056, df=17, $p>0.05$; Seen, Selected & Reacted and Seen Only: t=1.008, df=17, $p>0.05$; Seen & Selected and Seen Only: t=0.693, df=17, $p>0.05$) **Confidence:** Shown to increase if objects have been selected. No statistical test possible.

9.9 *Experimental Findings*

The fact that missing objects were recalled at all in both conditions suggests that participants perceived and recognised the objects as they were able to identify them and their location correctly with out any prompt. When considering if this perception and recognition of the missing objects was improved if the objects themselves were cued or if they had been selected findings were not as clear, though the results recorded suggest trends the large variances between participants prevent significant statistical results.

When asked directly why they recalled the objects the majority of responses from participants in both conditions stated that they had selected the objects being the reason they recalled them. When asked why they had selected the objects that they did in the cued condition the majority of participants stated the reason as the objects had been cued, in the non-cued condition participants stated curiosity and a desire to play with objects was what had prompted them to select them, and a close second to that the affordances of the objects, that the 'looked like they did things'. Selection was shown to be greater (though not significantly) in the cued condition suggesting that the cues do prompt increased selection. As previously within this research selection has been compared between task and non-task conditions it is interesting to see that when a task is performed with cues and without that the cued condition does prompt increased selection.

These findings suggest firstly and most importantly that objects within the VE are perceived and recognised by VE users as they are able to recall them and details about them. Secondly that recall is improved as a consequence of the participant either selecting the object or that the object is cued thereby prompting selection. In the cued condition correct recall was found to be significantly higher than incorrect recall and further reinforcing these findings a positive relationship in both conditions was found between the number of selections made by participants and the number of objects correctly recalled. Selected objects in the cued condition were recalled significantly more than objects that were only seen.

A further interesting find here is with respect to the cues themselves as missing objects recall was improved when the objects had been selected. This suggests that the selection of objects means that participants are not merely responding to the cue (in the cued condition) but are attending to the object itself to be able to then correctly recall it.

It was thought that the use of the same cue type throughout the VE would prompt greater selection than the use of a variety of cue types within one environment as participants would 'learn' that the selection of, in this case red flashing, cued objects resulted in the VE reacting in some way. Although by comparing the amount of selection with experiment three where the same environment was used with a variety of cue types the single cue type showed greater selection again the high variances prevented this finding being statistically significant.

Chapter 10 - Discussion and Conclusions

Research Aim

> *The overall aim of this research was measure the influence of interaction on the effectiveness of a VE. This was achieved using a training application on a desktop VR system. Examined was what prompts user object selection, the influence of guiding user VE exploration and the level of control the user has within a VE. This will help to define how interaction should be designed by VE programmers most effectively. Effectiveness of a desktop training VE was determined by measuring the usability of the VR system and the task performance of participants under varying conditions for each factor.*

The above aim of this research was developed through reviewing literature and achieved through a series of experimental studies. An overview of each experiment, main findings and interpretation is given in section 10.1. Section 10.2 discusses the implications of these experimental results with regard to design for effective interaction in a training VE and recommendations for VE designers are provided in light of these findings.

10.1 Experimental Programme Overview

Experiment One

Experiment one considered the influence of the participant's ability to select objects within the VE, whether or not they had control over their navigation whilst within the VE and the level of realism of the training they received on the measures of effectiveness taken. This aimed to ascertain the appropriateness of the desktop VR system for the chosen application so that the above aims could be examined. Participants in each condition performed the same task to maintain similarities between them.

Table 10-1 shows the research questions proposed in experiment one, the expectations for results prior to experimentation and the actual findings from experimentation.

Table 10-1: Experiment one research questions expectations and actual findings

Expectation	Reasoning	Finding
1. Does selection influence the effectiveness of VE training for the user?		
Selection will lead to improved results in effectiveness measures. Unsupported	Selection will make the VR experience more interesting for the participant (Bystrom et al., 1999) and the process of selection will increase the attention given to the recall objects increasing the likelihood of them being recalled (Eysenck and Keane, 1995).	No significant difference was found for the measures of recall, usability or presence between selection and no selection conditions (Figure 5-6 p.127).
2. Does realism influence the effectiveness of VE training for the user?		
Increased realism will lead to improved results in effectiveness measures. Unsupported	Improved realism will enable the easier transfer of knowledge gained from the VE to the real world on which it is based if the real world is familiar from using the VE (Rose et al., 2000).	No significant difference was found for the measures of recall, usability or presence between realism and low realism conditions (Figure 5-7 p. 128).
3. Does navigation control influence the effectiveness of VE training for the user?		
Navigational control will lead to improved results in effectiveness measures. Unsupported	Navigational control will make the VR experience more interesting for the participant (Bystrom et al., 1999) and enable greater familiarisation with the VE if self navigated thereby facilitating easier knowledge transfer.	No significant difference was found for the measures of recall, usability or presence between navigational control and no navigational control conditions (Figure 5-8 p.129).

Q1: Recall significantly different to $p<0.2$
Q2: Presence significantly different to $p<0.1$

As none of the display and interaction conditions explored within this experiment indicated a significant influence on VE training effectiveness measures indications were that VR training is a suitable equivalent to video and animated training. The main question arising from these findings was what other factors may influence the effectiveness measures of VE training, in particular RW recall? This was explored and examined in the following experimentation.

Experiment Two

Experiment two examined the importance of a task on the amount of correct recall achieved by participants and the measures of effectiveness recorded when all other experimental conditions remained constant. It also closely examined the influence of selection hotspots (prompts to encourage selection within the VE) on effectiveness measures taken and which selection cue types were shown to be most effective (encouraged the most selection). This aimed to establish whether the inclusion of a task had an influence on recall related to that task and also if it is possible to prompt a user to select one object in a VE over another through the use of selection hotspots.

Table 10-2 shows the research questions proposed in experiment two, the expectations for results prior to experimentation and the actual findings from experimentation.

Table 10-2: Experiment two research questions expectations and actual findings

Expectation	Reasoning	Finding
Task 'v' No task		
1. Does the inclusion of a task influence task related RW recall?		
Expectation	**Reasoning**	**Finding**
A task will improve task related recall Supported	The process of actively searching for and selecting the task items will increase the attention paid to those objects and consequently increase the likelihood of their being recalled (Kaur et al., 1999).	Task related recall was significantly improved in the task condition (Figure 6-3, p.143).
2. Does the inclusion of a task influence the other measures of the effectiveness of VE training taken (presence and usability)?		
Expectation	**Reasoning**	**Finding**
A task will improve effectiveness measures taken Unsupported	The process of actively searching for and selecting the task items will provide purpose, interest and context for the participant increasing the measures of presence and usability recorded (Kaur et al., 1999).	No significant difference was found for the measures of usability or presence between task and no task conditions (Figure 6-4, p. 144)
Selection Hotspot Cues		
3. Do selection hotspot cues prompt increased selection?		
Expectation	**Reasoning**	**Finding**
Selection hotspot cues will prompt increased selection. *Partly* supported	Selection hotspot cues will attract more attention than the surrounding VE thereby prompting increased selection (Kaur, et al., 1999b).	In the no task condition cued objects were selected significantly more than non-cued objects, there was no significance difference in the task condition (Table 6-6, p.144).
4. Do some selection cue types prompt different amounts of selection than others?		
Expectation	**Reasoning**	**Finding**
Some selection hotspot cues will prompt more selection than others. Supported	Different cue types will attract different amounts of selection as a result of their appearance according to the surrounding VE context; the more out of context the more likely they will be selected (Kaur, et al., 1999b).	Coloured flashing cues were found to prompt the greatest selection (blue flashing significantly more than other cue types - Figure 6-6, p.147).

Q3: Task condition significantly different to $p < 0.1$

As recall was improved with a task when task related further experimentation examined if this was also the case when recall was no longer related to the task. It was also unclear from this experiment if recall was related to the task but as a result of the selection of the recall objects that occurred as part of the task. Consequently the importance of selection on recall was also examined in further experimentation.

Experiment Three

Experiment three aimed to establish if the inclusion of a task to guide the participant exploration of the VE and ability of the participant to select items within the VE influenced the measures of effectiveness recorded. The experiment also identified whether recall improved when related to the task (as in experiment one and two) or not. Also examined was the importance of selection on recall when no longer task related. All the objects to be recalled were cued to prompt selection.

Table 10-3 shows the research questions proposed in experiment three, the expectations for results prior to experimentation and the actual findings from experimentation.

Table 10-3: Experiment three research questions expectations and actual findings

Task 'v' No task		
1. Does the inclusion of a task influence the recall of non-task related objects?		
Expectation	**Reasoning**	**Finding**
A task will not improve the recall of non-task related objects. Supported	The inclusion of a task has been shown to decrease the selection of objects within the VE (experiment two, 'Selection of Cued & Non Cued Objects', section 6.7.4) as a consequence non-task related recall objects are less likely to be selected and therefore be attended to if there is a task and therefore are less likely to be recalled.	Recall was significantly lower in the task condition (Figure 7-2, p.163)
2. Does the inclusion of a task influence the effectiveness of VE training (presence, usability and enjoyment)		
Expectation	**Reasoning**	**Finding**
A task will improve the effectiveness of VE training. Unsupported	A task provides a reason and purpose to the participant's use of the VE and enables them to put the VE into context as opposed to exploring the VE with no specific goal. As a result there will be greater VE training effectiveness (measured by presence, usability and enjoyment) when completing a task within the VE. No significant findings were found with respect to the measures of presence and usability with and without a task in experiment two, consequently warranting further investigation and the inclusion of a further measure (enjoyment) to establish the influence it may have on effectiveness. See 'Figure 6-4: Mean presence and usability scores as a percentage of the max scores possible'.	There was no significant difference between the measures of usability, presence and enjoyment for the task and no task conditions (Figure 7-3, p.164)
Selection 'v' No selection		
3. Will participants be more likely to recall object position after VE training if they selected that specific object whilst in the VE?		
Expectation	**Reasoning**	**Finding**
Participants will be more likely to recall object position if they select that object during VE training. *Partly* supported	The process of selecting a specific object will encourage the participant to recall that object, this was suggested as a possibility in experiment two when the selection of objects to be recalled was part of the task the participants performed and resulted in increased recall. See 'Real World (RW) Recall – Task & No Task', section 6.7.2.	Selection of an object was found to significantly improve recall in the no task condition but significantly lessen it in the task condition (Figure 7-6, p.167).
4. Will enjoyment be improved when the participant is able to select objects or perform a task whilst within the VE thereby establishing a reason for the inclusion of selection within a VE?		
Expectation	**Reasoning**	**Finding**
Enjoyment will be improved when a participant is able to select objects as opposed to when they can not, enjoyment will also be improved when a participant performs a task within a VE. *Partly* supported	Through the observation of participants using VR the inclusion of a task provides reason and purpose for the participant's use of the VE and consequently they may enjoy it more, the ability to select within the VE may also improve enjoyment as the reaction of objects to that selection will provide more depth to the environment and in so doing make it more enjoyable. Experiment one found no significant influence of selection on the measures of presence and usability (see, 'Figure 5-6: Mean RW recall, presence and usability scores as a percentage of the maximum possible – 'SNC – selection' and 'NC – no selection') thereby warranting further investigation into its possible influence on effectiveness with respect to presence, usability and enjoyment.	There was no significant increase in enjoyment experienced in the task condition than the no task condition (Figure 7-3, p.164). Enjoyment was significantly greater in the selection condition than the no selection condition (Figure 7-5, p.166).

Q2: Presence significantly different to $p < 0.2$.
Usability significantly different to $p < 0.2$.

As selection cues resulted in increased selection over non-cued objects and improved recall of cued objects in experiments two and three further experimentation needed to examine if this was still the case if cues were no longer incongruous to the surrounding RWVE. It was also noted that when recalling objects in experiments three it was possible that the participant was merely responding to the cue and not perceiving and recalling the object itself and thereby making it an effective VE it was therefore examined in further experimentation exactly what the participant was recalling.

Experiment Four

Experiment four investigated the effectiveness of selection hotspot cues when no longer incongruous to the surrounding VE context. The same cues as used in the ecologically valid real world VE (RWVE) were used in an Abstract VE (AbsVE) and their effectiveness in prompting selection were examined. The influence of task directed VE exploration in the AbsVE was also explored and whether the selection of objects improved the recall of those objects when the object cues were no longer incongruous to the surrounding VE context.

Table 10-4 shows the research questions proposed in experiment four, the expectations for results prior to experimentation and the actual findings from experimentation.

Table 10-4: Experiment four research questions expectations and actual findings

Expectation	Reasoning	Finding
1. Do selection hotspot cues encourage increased interaction when no longer incongruous to the virtual context they are in?		
Selection hotspot cues will no longer encourage increased selection when no longer incongruous VE context. Supported	Participants are prompted to select cued objects as the cues attract their attention. This attention is primarily drawn by the fact that the cues are out of place with respect to the rest of the VE as in experiment two where cues were incongruous to the surrounding real world VE context ('Table 4-4: Expectations from the design of selection hotspot cues (Marshall and Nichols, 2004)', p.106).	There was no significant difference between the selection of cued and non-cued objects in the AbsVE (Table 8-6, p.183).
2. Will participants be more likely to recall objects within the abstract VE if the object to be recalled was selected whilst within the VE?		
Participants will be more likely to recall objects that they have selected whilst within the VE than those which they have not. Supported	The process of selection and also reaction to that selection will aid the consolidation of that object to memory for the participant. A positive significant relationship was found between the level of selection of objects to be recalled and correct recall in experiment three ('Selection & Correct Recall', section 7.7.3).	Objects that were selected (and those which were selected and reacted to that selection) were recalled significantly more than objects that were seen only (Table 8-9, p.186).
Task 'v' No task		
3. Does the inclusion of a task influence the amount selection of cued objects in an abstract environment?		
A task will decrease the amount of selection of cued objects. Supported	It was shown in experiment two ('Selection of Cued & Non Cued Objects', section 6.7.4) and three ('Selection & Correct Recall', section 7.7.3) that appeared to be the case as participants become more focused on the task and consequently explore the VE less therefore it is likely this will be the case in the abstract VE.	The total number of selections was significantly higher in the no task condition than the task condition (Table 8-11, p.188).
4. Does the inclusion of a task influence the recall of non-task related objects in an abstract environment?		
The inclusion of a task will reduce the correct recall of non-task related objects. Unsupported	If the participants perform a task they are more likely to concentrate on that as opposed to explore the rest of the environment and consequently are less likely to recall aspects of the VE that are not related to that task, this was shown to be the case in experiment three ('Object Position Recall – Task & No Task', section 7.7.1).	There was no significant difference between the recall between the task and the no task conditions (Figure 8-5, p.189).
5. Does the inclusion of a task influence the measures of effectiveness in an abstract environment (presence, usability and enjoyment)?		
A task will improve the measures of user effectiveness taken. Unsupported	A task provides a reason and purpose to the participant use of the VE and enables them to put the VE into context as opposed to exploring the VE with no specific goal. As a result there will be greater user satisfaction and enjoyment from completing a task improving effectiveness measures recorded although no significant improvement was reported in the measures recorded in experiment three ('Presence, Usability & Enjoyment – Task & No Task', section 7.7.2) a slight increase was evident.	There was no significant difference between the measures of usability, presence and enjoyment for the task and no task conditions (Figure 8-6, p.189).

Q4: Recall significantly different to $p<0.2$

It is evident that a selection cue being incongruous to the surrounding VE context makes it more effective. The importance of a task and selection on recall were examined up to this point and how to design a VE for the most effective selection. Further research needed to examine the 'so what?' aspect of these findings. Were participants recalling the cue or were they perceiving the object and recalling it?

Experiment Five

Experiment five examined whether participants were perceiving the objects that they selected and consequently recalling the object, or if they were merely reacting to the cue by selecting the object then recalling the cue. It was also explored whether a single cue type (as opposed to a variety of different cue types) prompted greater selection. This aimed to establish if recall through selection resulted in an effective training VE as participants were attending to the selected objects.

Table 10-5 shows the research questions proposed in experiment five, the expectations for results prior to experimentation and the actual findings from experimentation.

Table 10-5: Experiment five research questions expectations and actual findings

Expectation	Reasoning	Finding
1. Will cued objects encourage increased object selection?		
Users are more likely to select cued objects than non-cued objects. Unsupported	The cue makes the object more noticeable within the VE and draws attention to it specifically increasing the chance of that object being selected, as shown in experiment two ('Selection of Cued & Non Cued Objects', section 6.7.4).	There was no significant difference between the selection of missing recall objects in the cued and the non-cued conditions (Table 9-6, p.205).
2. Are usability, presence, enjoyment and recall influenced by the inclusion of object cues?		
Effectiveness measures will not be influenced by the inclusion of selection hotspot cues. Supported	Earlier findings have shown no influencing factor on the effectiveness measures taken, including the inclusion of a task, the ability of the user to select within the VE and the method of viewing the VE itself suggesting there will be no notable influence of the selection hotspot cues.	There was no significant difference between the effectiveness measures in the cued and non-cued conditions (Figure 9-2, p.208).
3. Will the use of one cue type, as opposed to many, have a positive influence on the effectiveness of the cue?		
One cue type will be more effective than a variety. Unsupported	The one cue type used was effective in previous experiments and participants will learn whilst within the VE that cued objects react when selected and they are easier to identify as they are all the same.	There was no significant difference between the number of selections of one cue type and a variety of cue types (Table 9-11, p.209).
4. Are users more likely to perceive/recognise cued or non-cued objects if they have selected or manipulated them?		
Users are more likely to perceive/ recognise *cued* objects than non-cued objects that they have only seen and not selected. Unsupported	The cue makes the object more noticeable within the VE and draws attention to it specifically increasing the chance of that object being attended to and consequently recalled (Wickens et al., 1998).	Seen only objects were recalled significantly less in the cued condition than the non-cued condition (Figure 9-4, p.211).
5. Will Users be more likely to perceive/recognise the objects that they have selected or manipulated?		
Users are more likely to perceive/recognise objects that they have selected. *Partly* supported	Earlier findings (experiment three, 'Object Recall – Objects Seen & Objects Seen and Selected', section 8.7.3) have suggested that this is the case and the process of selection and reaction may improve recall by making the object selected 'stick out' more.	Recall was significantly higher for objects that were seen, selected and reacted to that selection than objects that were only seen in the cued condition, this was not the case in the non-cued condition (Table 9-12, p.212).

Q1: Recall object selection (cued and non-cued conditions) significantly different to $p<0.1$.

Findings suggest that participants are in fact recalling the objects themselves and therefore that the VE as a training application is successful. Again it is evident that selection improves recall and that the use of cues does prompt greater selection. These findings enable the development of guidelines. The unexpected findings with respect to cue design are discussed further in section 10.2.

10.2 Selection within a VE

This section addresses the research objective to identify the most effective prompts supporting user interaction within a VE. Findings across all of the experiments are reviewed and recommendations to VE designers are made.

OBJECTIVE:

- Construct a suitable VE upon which the influence of stated factors on effectiveness can be measured for a given application.

As described in '*Chapter 4 -The Virtual Environments*' two virtual environments were developed with which to examine the following objectives.

  - The most effective prompts to selection of specific objects within a VE.
  - If selection and task guided exploration within a VE have any influence on the measures of effectiveness recorded.

One VE being based on the real world in appearance and use (i.e. it followed rules of the real world such as gravity and not being able to walk through walls etc) to establish which selection prompts are more effective in a RWVE and, the influence of task guided VE exploration and the users ability to select within a VE on the measures of effectiveness taken. The second VE was designed to be entirely abstract to the real world in appearance and used to compare findings from the RWVE experiments. Findings from experiments using both types of VE are reviewed in the following sections.

OBJECTIVE:

- Use an experimental approach to establish:
  - The most effective prompts to selection of specific objects within a VE.

Selections were measured by filming participants whilst using the VR system on a split screen, showing the VE as they viewed it and the users hands (see, 'Figure 3-2: Photograph of experiment equipment set up', p.87), each selection was then recorded.

10.2.1 The Design and Influence of selection

The following section discusses the findings from the measures recorded and how they may or may not have been influenced by the design of the cue. Also considered was whether results show that selection was influenced by task directed VE exploration, the inclusion of selection hotspot cues and what influence selection had on the effectiveness of the VE training measured.

10.2.1.1 What is the Most Effective Cue Design?

RWVE

- Selection of cued objects was significantly greater than non-cued objects (experiment two, section 6.7.4).
- Selection of textured/photo realistic cues was significantly lower than all other cue types. Blue cues and flashing coloured cues were found to encourage the greatest selection (experiment two, section 6.7.5).
- Coloured selection cue *design* did not significantly influence the selection of cued objects (experiment two, section 6.7.6).
- Objects were selected more when there was one cue type than when there was a variety of cue types, though this difference was not significant due to high individual variance (experiment five, section 9.7.4).

In the design of a RWVE through experimentation it was found that cues are more effective if incongruous to the surrounding VE context this is in accordance with expectations from Hilgard et al., (1979) and Benjamin et al., (1987) that the incongruous nature of the cue would attract attention. Favoured cue designs were found to be primary coloured flashing cues. The design of the cue (part of the reactive object is cued, all of it is cued or the reactive object is surrounded by the cue, see 'Table 4-9: Coloured cue design featured within the RWVE', p.111) was not found to have a significant influence on the effectiveness of the cue.

Through a review of literature within section 4.2.3, Figure 4-5 (p. 105) was developed to establish what may influence the design of effective selection hotspot cues. Figure 10-1 demonstrates a development of this summary of literature with amendments according to findings from this research.

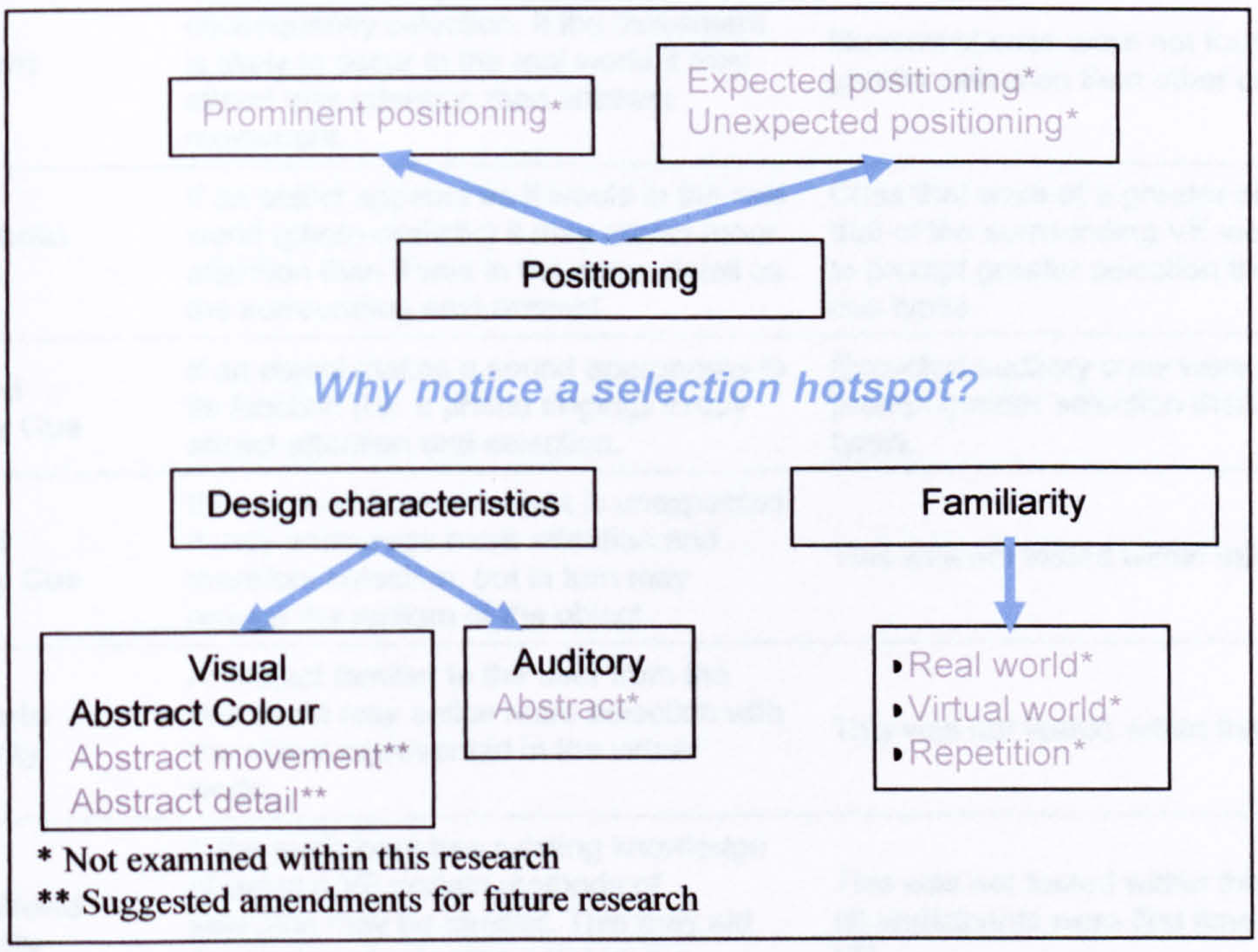


Figure 10-1: Noticing selection hotspots - developed in section 4.2.3 p. 104

From 'Figure 4-5: Noticing Selection Hotspots' p. 105 expectations as to the importance of each aspect of selection cue design were developed. Table 10-6 demonstrates how findings produced through experimentation compared to the original expectations.

Table 10-6: Findings from expectations of selection hotspot cue design
(see, Table 4-4 section 4.2.3 p. 104)

Selection Hotspot Design	Expectations	Findings
Colour	If the colour is unusual to the surrounding environment then it may attract more attention and selection.	Cues that were incongruous to the surrounding VE context (in particular flashing colour cues) were selected more than other cue types.
Movement	Movement is likely to attract attention and consequently selection. If the movement is likely to occur in the real world it may attract less attention than abstract movement.	Movement cues were not found to prompt greater selection than other cue types.
Detail/Photo Realism	If an object appears as it would in the real world (photo-realistic) it may attract more attention than if was in the same detail as the surrounding environment.	Cues that were of a greater detail than that of the surrounding VE were not found to prompt greater selection than other cue types.
Expected Auditory Cue	If an object makes a sound appropriate to its function (i.e. a phone ringing) it may attract attention and selection.	Expected auditory cues were not found to prompt greater selection than other cue types.
Abstract Auditory Cue	If the sound from an object is unexpected it may encourage more attention and therefore selection, but in turn may reduce the realism of the object.	This was not tested within this research.
Real World Familiarity	An object familiar to the user from the real world may entice more selection with the object represented in the virtual world.	This was not tested within this research.
Virtual World Familiarity	If the participant has existing knowledge of using a VE certain methods of selection may be familiar. This may aid the choice of selection point by the participant.	This was not tested within this research; all participants were first time users of VR.
Repetition	The repetition of a task could result in learning by the user as to which objects are interactive and may therefore increase the attention drawn to such an object.	This was not tested within this research; each participant performed only one experiment.
Prominent Positioning	If an object is placed in the users line of vision it may attract more attention and imply selection than if it were not.	As the VE used in experimentation was based on the real world all objects were positioned as would be expected not in prominent positions so it was not possible to establish if this expectation was correct or not.
Expected Positioning	An object placed in a position that it would be expected to be seen in it is less likely to attract attention and encourage selection.	As the VE used in experimentation was based on the real world all objects were positioned as would be expected so it was not possible to compare with unexpected object positioning to establish if this expectation was correct or not.
Unexpected Positioning	An object placed entirely out of context is likely to attract more attention and selection.	This was not tested within this research (see above).

Findings from this research indicate that cues that are incongruous to the surrounding VE context are most effective. As detail, movement and auditory cues within the

RWVE used were all designed to be as you would expect in the real world none of them resulted in increased selection over other 'out of context' cue designs. Eastgate (2001) recommended the use of cueing to draw the user's attention to select certain objects and this has been reinforced through this research. That the cues are designed to be attention drawing in ways detailed by Hilgard et al., (1979) and Benjamin et al,. (1987) has been shown to make them most effective.

AbsVE

- Selection of cued objects was not significantly greater than non-cued objects in the AbsVE (experiment four, section 8.7.1)

- Selection of red and yellow cues and flashing cues were significantly higher than Textured/photo realistic cues, grey cues and sound cues. Sound cues were significantly less effective than all other cues in an AbsVE (experiment four, section 8.7.2).

In the design of an AbsVE the use of selection cues was not shown to be effective, although again when selections on specific objects were examined it was shown that primary coloured flashing cues were favoured.

10.2.1.2 Is Selection Influenced by Task Directed VE Exploration?

- The amount of selection on all objects was not significantly influenced by the user performing a task (experiment two, section 6.7.4).
- The amount of selection of cued recall objects was significantly greater in the no task condition (experiment three, section 7.7.3).

- The amount of selection was significantly greater in the no task condition than the task condition in an AbsVE (experiment four, section 8.7.6).

Selection generally was not influenced by the inclusion of a task, though was found to be consistently higher when participants did not perform a task, suggesting that not having a task encourages the user to explore the VE to a greater extent resulting in increased selection. When the selection of only cued objects was considered it was shown that significantly more selection occurred when the participants were not required to perform a task reinforcing the point previously made. Selection generally was found to be higher when participants were not required to perform a task in the AbsVE.

10.2.1.3 What is the Influence of Cues on Selection?

- Selection of cued objects was significantly greater than non-cued objects (experiment two, section 6.7.4).
- The selection of cued object was significantly greater as a percentage of the total number of selections per participant (experiment two, section 6.7.4).
- The selection of cued objects, although higher, was not significantly greater than the selection of those same objects when not cued (experiment five, section 9.7.1).
- When questioned users indicated that objects were selected because they were cued (experiment five, section 9.7.1).

- Cued objects were not selected significantly more than non-cued objects in the AbsVE (experiment four, section 8.7.1).

It is indicated that when objects are cued they do encourage greater selection in the RWVE suggesting that the incongruous nature of the cue attracts the attention of the user as proposed by Benjamin et al., (1987). As the cues were not out of place in the AbsVE they did not result in significantly greater selection.

10.2.1.4 Does Level of Selection Influence Recall?

- Objects seen were recalled significantly more than objects seen and selected when there was a task (experiment three, section 7.7.6).
- Objects seen and selected were recalled significantly more than objects seen when there was no task (experiment three, section 7.7.6).

- No answer in response to questions was significantly greater if the object had been seen as opposed to seen and selected (experiment three, section 7.7.7).

- Seen only objects were recalled significantly more in the not cued condition (experiment five, section 9.7.6).

- Increased number of selections on objects to be recalled was positively correlated with correct recall (experiment five, section 9.7.5).

- Correct recall was significantly higher for 'seen, selected and reacted' objects and 'seen and selected' objects than just 'seen' objects in the AbsVE (experiment four, section 8.7.4).

- Incorrect recall and no answer recall was significantly higher for 'seen' objects than 'seen, selected and reacted' objects and 'seen and selected' objects in the AbsVE (experiment four, section 8.7.4).

- When questioned users indicated that objects were recalled largely because they had been selected (experiment five, section 9.7.1).

The greater the level of interaction the participant has with an object (they saw the object, they saw and selected the object or saw the object, selected it and it reacted) was found to increase the user's chance of recalling that object. This was not found to be the case when selection was generally lower with task directed VE exploration, as it is likely that participants were generally more focused on the task than other aspects of the VE. Findings show a positive correlation between the section of objects and the recall of those objects and user subjective opinion suggests that participants tended to believe they recalled objects because they had selected them.

10.2.2 Recommendations for the Design of Selection Cues in a VE

Figure 10-2 demonstrates the main findings from this research and provides checklist guidelines for the VE designer with respect to the development of selection hotspots (points within a VE that are cued in some way to prompt selection).

- Cue the parts of the VE object you wish the user to select (selection is likely to improve the recall of those objects post user VE immersion).
- Use cues incongruous to the surrounding VE context (flashing cues in primary colours).
- Selection of objects that are not part of the task are likely to be reduced generally if VE exploration is task directed.

Figure 10-2: Design guidance checklist RWVE – selection hotspot cues

With the aim of providing guidance to designing interactivity within a VE Eastgate (2001) developed a flow chart, Figure 10-3. Aspects of this guidance tool have been verified within this research as to its effectiveness in the context of VE training on a desktop VR system. The design guidance provided by the tool concerning the specific details of interactive object design examined within this work is highlighted blue.

Table 10-7, corresponds to the numbers shown in Figure 10-3 and demonstrates how findings from experimentation within this research support existing guidelines Eastgate (2001).

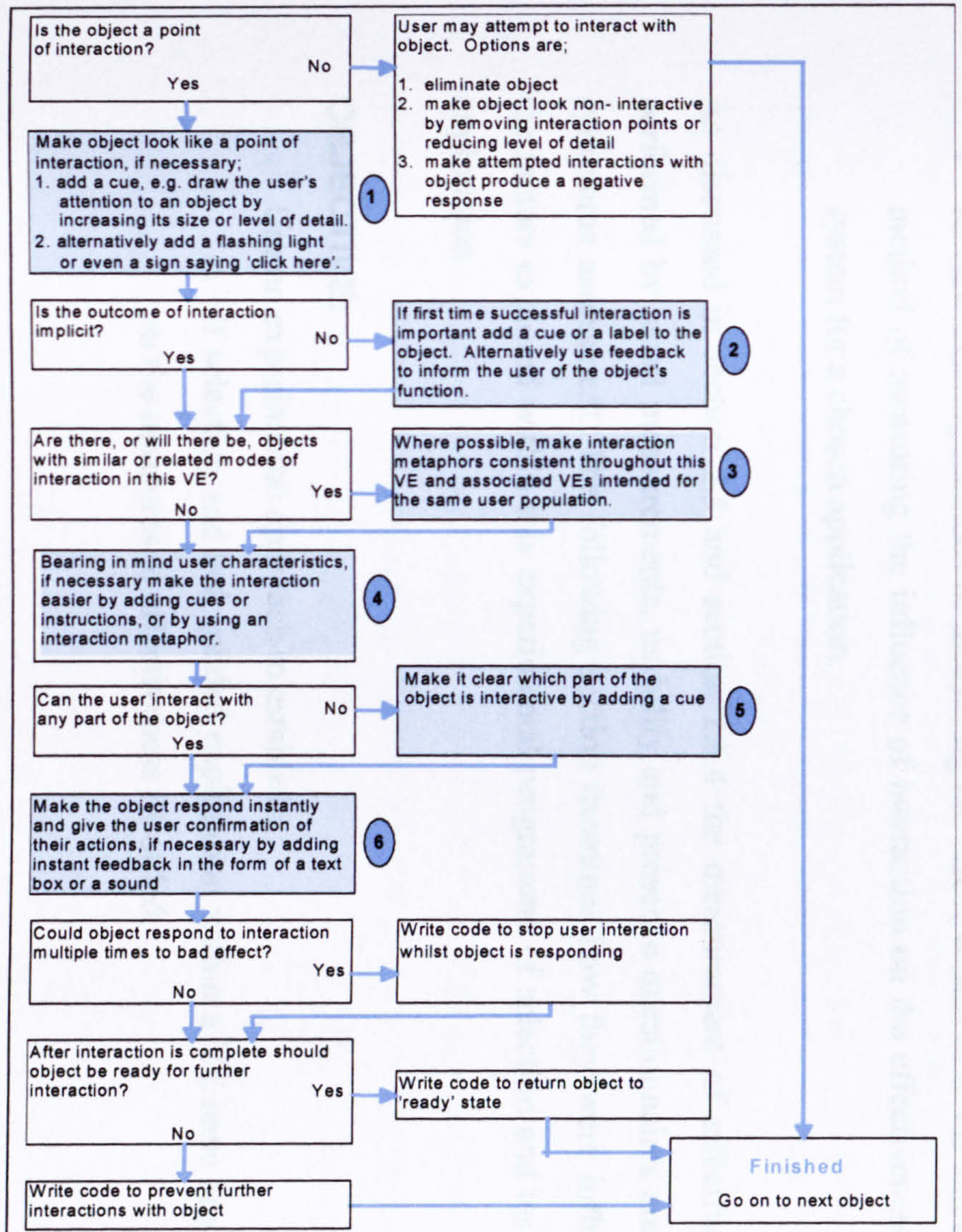


Figure 10-3: Flow chart of decisions to be made when designing interactivity into a VE (Eastgate, 2001)

Table 10-7: Experimental findings in support of Eastgate (2001)

1	This corresponds with the decision to use cues to prompt the selection of specific objects within a VE in this case for the purposes of training. It was found that the use of cues was effective, resulting in greater selection than non-cued objects.
2	The importance of selection and reaction of objects was assessed within this research with respect to the correct recall of the objects selected. It was suggested from findings that the selection of an object (as opposed to it being seen only) and the reaction of the object to that selection resulted in improved recall of the object post VE immersion if there was a high level of selection in the VE (when VE exploration was not task directed for example) and that no recall at all was significantly less likely if the object had been selected as opposed to seen only.
3	Although findings were not significant it was indicated that the use of the same cues throughout (experiment five, red flashing cues) prompted more selection than using a variety of cues.
4	Cued objects were shown to prompt greater selection than non-cued objects, suggesting that instructions or further details could be provided for an object once it has been selected, this selection being encouraged initially by the use of a selection cue.
5	The design of the selection cues, examined in this research through coloured cues covering all, part or surrounding the reactive aspect of the object were found to be equally effective in prompting selection.
6	Again as with point two findings suggest that an object reacting to selection improves recall.

10.2.3 Interaction Theory

The identification of a requirement to enable the VE user to find and understand available interactions was made by Kaur et al., (1999) and has been shown through the research performed to be influential to the effectiveness of a VE. Interactions with cued objects were shown to be significantly higher than those with non-cued objects (Table 6-6, p.144) demonstrating them to be an effective method of prompting selection and in turn recall of objects selected was found to be higher if that object had been selected (Figure 7-6, p.167). The findings made within this research are in support of the findings made by Kaur et al., (1999) and suggested outcomes made by Eastgate (2001) when designing interaction within a VE such as the use of cues to make an object look like a point of interaction, the use of constant interaction metaphors (i.e. one cue type as opposed to a variety) and the provision of feedback to generate more effective interaction (i.e. increase the likely recall of that object) see Figure 10-3, p.234.

10.3 Measures of Effectiveness

OBJECTIVE:

- Review existing methods of measuring the effectiveness of a VE and establish a method of measuring the influence of interaction on the effectiveness of a VR system for a chosen application.

As discussed in section 2.5 and section 2.6.4 the measurement of effectiveness was performed by recall measurements, usability and presence questionnaires and sickness symptoms assessment. The following section examines how they were influenced by the factors explored within this experimental programme of selection and task directed exploration.

OBJECTIVE:

- Use an experimental approach to establish:
    - If selection and task guided exploration within a VE have any influence on the measures of effectiveness recorded.

Effectiveness was measured through the assessment of the participant's experience of the experimental conditions within VE that they used. As discussed in '*Factors that Influence the Effectiveness of VR Training Applications*', section 2.3 the effectiveness of the VE was measured through recall of details of the VE, usability of the VE (including presence experienced and simulator sickness) and enjoyment experienced through its use. Methods of measurement were as discussed in '*Measurement of Effectiveness*', section 2.5. The following section discusses the findings from these measures and how they may or may not have been influenced by selection within the VE, if VE exploration was task directed and the level of control the participant had over their use of the VR system.

10.3.1 Recall

Recall was assessed in a variety of ways throughout the experimental programme according to the VE and the factors being examined. Methods used are described in detail in each corresponding experiment chapter and are reviewed in Table 10-8.

Table 10-8: Recall measurement methods

Experiment	Recall Measurement
One	*Real world (RW) recall*: Participants taken to the real world the VE was built to represent and are asked to recall the location of H&S items that were in the VE
Two	*RW recall*: As above
Three	*Object position recall (pictorial)*: Participants were shown pictures of the VE they used one as they saw it and one with the interactive objects moved, and were ask to identify which was correct.
Four	*Object recall (written):* Participants were asked questions about objects within the VE.
Five	*Missing Objects recall (pictorial):* Participants were shown images of the VE that they used with cued objects removed and were asked to identify the objects, their colour and position and how confident they were in their answers.

In establishing the appropriateness of desktop VR for training, recall was compared with and without user navigational control and non-real display (VE) and video display to establish if VR was a suitable equivalent.

- Task related recall was not significantly influenced by the realism of the training display (experiment one, section 5.7.4).

- Task related recall was not significantly affected by the user's ability to control their navigation whilst within the VE (experiment one, section 5.7.5).

Recall was examined with respect to user ability to select, task inclusion, the inclusion of selection hotspot cues, delayed recall and recall of shape or colour.

10.3.1.1 Was Recall Influenced by the Users Ability to Select?

- Task related recall was not significantly influenced by the user's ability to select objects within the VE (experiment one, section 5.7.3).
- Non-task related recall was not significantly influenced by the user's ability to select objects within the VE (experiment three, section 7.7.4).

It was found that the user's ability to select objects within the VE did not influence recall.

10.3.1.2 Did the User Performing a Task Influence Recall?

- Task related recall was significantly greater when there was a task than when there was not (experiment two, section 6.7.2).
- Non-task related recall was significantly greater when there was no task than when there was (experiment three, section 7.7.1).
- Non-task related recall was not significantly influenced by there being a task in an abstract VE (experiment four, section 8.7.7).

Recall was found to be significantly improved if task related when the participant performed a task. When recall was not task related it was found to be significantly greater when there was no task for the user to perform, this may be as a consequence of participants selecting objects more in non task directed exploration conditions and findings suggest that selection improved recall. Recall in the Abstract VE was not found to be influenced by a task.

10.3.1.3 Was Recall Influenced by the Recall Objects Being Cued?

- Non-task related recall was not significantly influenced by the recall objects being cued or not (experiment five, section 9.7.2).

10.3.1.4 Was Recall Influenced by a Delay After Training?

- Task related recall was not significantly different one day or one week after training took place (experiment one, section 5.7.1 and experiment two, section 6.7.1).

10.3.1.5 Was the Objects Colour or its Shape Recalled More?

- Non-task related recall was significantly greater for the colour of objects than the shape of objects in an abstract VE (experiment four, section 8.7.5).

10.3.1.6 Recall Design Decision Tree

As a result of these findings the following decision tree (Figure 10-4) was developed to aid a VE designer's choice in VE style with respect to the inclusion of a task and the ability for the user to select objects within a VE according to the type of recall required by the VE (task or non-task related recall). As noted by Eastgate (2001) 'any guidance has to be simple and quick to apply' and therefore should be kept brief and to the point and any further information that is required by the designer can be examined in greater depth if required.

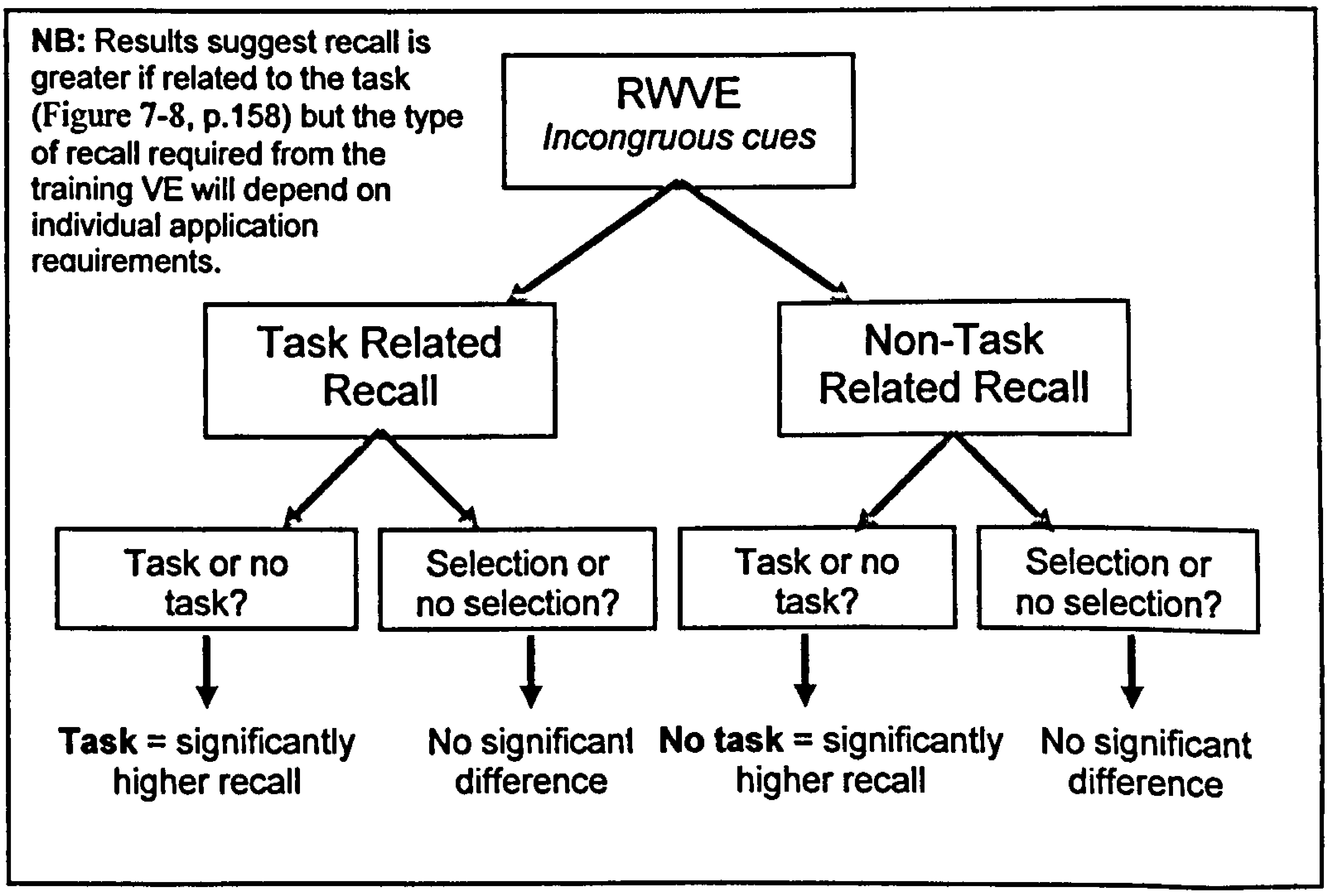


Figure 10-4: Design decision tree – recall RWVE (incongruous cues)

10.3.2 Usability, Presence and Enjoyment

As with recall measures discussed in section 10.3.1 establishing the appropriateness of desktop VR training measures of presence, usability and enjoyment (experiments three, four and five only) were compared with and without user navigational control and non-real display (VE) and video display to establish if VR was a suitable equivalent. Sickness symptoms were examined in each condition but reports of ill effects were extremely minimal, none resulting in participants requesting to stop VE use and any symptoms experience passed once the VE use had been completed.

- Presence was not significantly influenced by the realism of the training display (experiment one, section 5.7.4).
- Presence and usability were not significantly influenced by the user's ability to control their navigation whilst within the VE (experiment one, section 5.7.5).

Presence, usability and enjoyment (experiments three, four and five) were examined with respect to user ability to select, task inclusion and the inclusion of selection hotspot cues.

10.3.2.1 Were Usability and Enjoyment Influenced by the Users Ability to Select?

- Presence and usability were not significantly influenced by the user's ability to select objects within the VE (experiment one, section 5.7.3 and experiment three, section 7.7.5).
- Enjoyment was significantly greater when users were able to select objects within the VE (experiment three, section 7.7.5).

Presence and usability were not influenced by the participant's ability to select objects within the VE but the user's reported sense of enjoyment was improved, a positive reason for including interaction in a VR training environment as increased enjoyment is likely to result in increased use of the system.

10.3.2.2 Did the User Performing a Task Influence Usability and Enjoyment?

- Presence and usability (and enjoyment – experiment three) were not significantly influenced when there was a task than when there was not (experiment two, section 6.7.3 and experiment three, section 7.7.2).

- Presence, usability and enjoyment were not significantly influenced when there was a task than when there was not in an abstract VE (experiment four, 8.7.8).

Presence, usability and enjoyment were not influenced by the user performing a task within the VE, suggesting the inclusion of a task can be decided on other factors such as requiring participants to view particular aspects of the VE, the VE being use to train the task being performed or to ensure that they spend a certain length of time in the VE for example. Findings are contrary to expectations made by Kaur et al., (1999) who suggested that the effectiveness of a VE is influenced by the inclusion of a task and the proposal made be Nichols et al., (2000) the inclusion of a task may influence the presence that the user experiences.

10.3.2.3 Were Usability and Enjoyment Influenced by Cues in the VE?

- Presence, usability and enjoyment were not significantly influenced by objects being cued or not within the VE (experiment five, 9.7.3).

It was shown that the inclusion of cues did not have an adverse influence on the user's experience of the VE and as a consequence can be included in a VE for the purpose of encouraging the selection of specific objects to aid the recall of those objects for example or to guide exploration within a VE.

10.3.3 Questionnaire Discussion

Within the review of literature the limitations of using questionnaires to measure user experiences of VR have been acknowledged but currently they are the most widely used method and have been found to successfully imply presence experienced by participants by Slater and Usoh (1993); Prothero et al. (1995); Hendrix and Barfield (1996) and Witmer and Singer (1998). Slater (1999) in contrast did not agree that subjective questionnaires were a suitable method of measuring presence and made his point in response to Witmer & Singer (1998). Other measures have been explored such as physical responses (Nichols et al., 2000) or physiological measures (Kalawsky et al., 1999b) but have not been found to be any more effective. The use of questionnaires within this research was as a consequence of limited time and to enable the comparison of the measures taken between conditions.

The most common recommendation made within existing research is the use of a variety of measures including questionnaire and performance assessment of the participant's experience of the VE (Barfield and Weghorst, 1993; Welch, 1996; Draper et al., 1998; Kalawsky et al., 1999b; Nichols et al., 2000) to reinforce any measures taken using with each method individually. The approach within this research used a combination of measures, as recommended, to examine the effectiveness of a VE under a variety of conditions. Figure 10-5 shows the correlations between subjective questionnaire results.

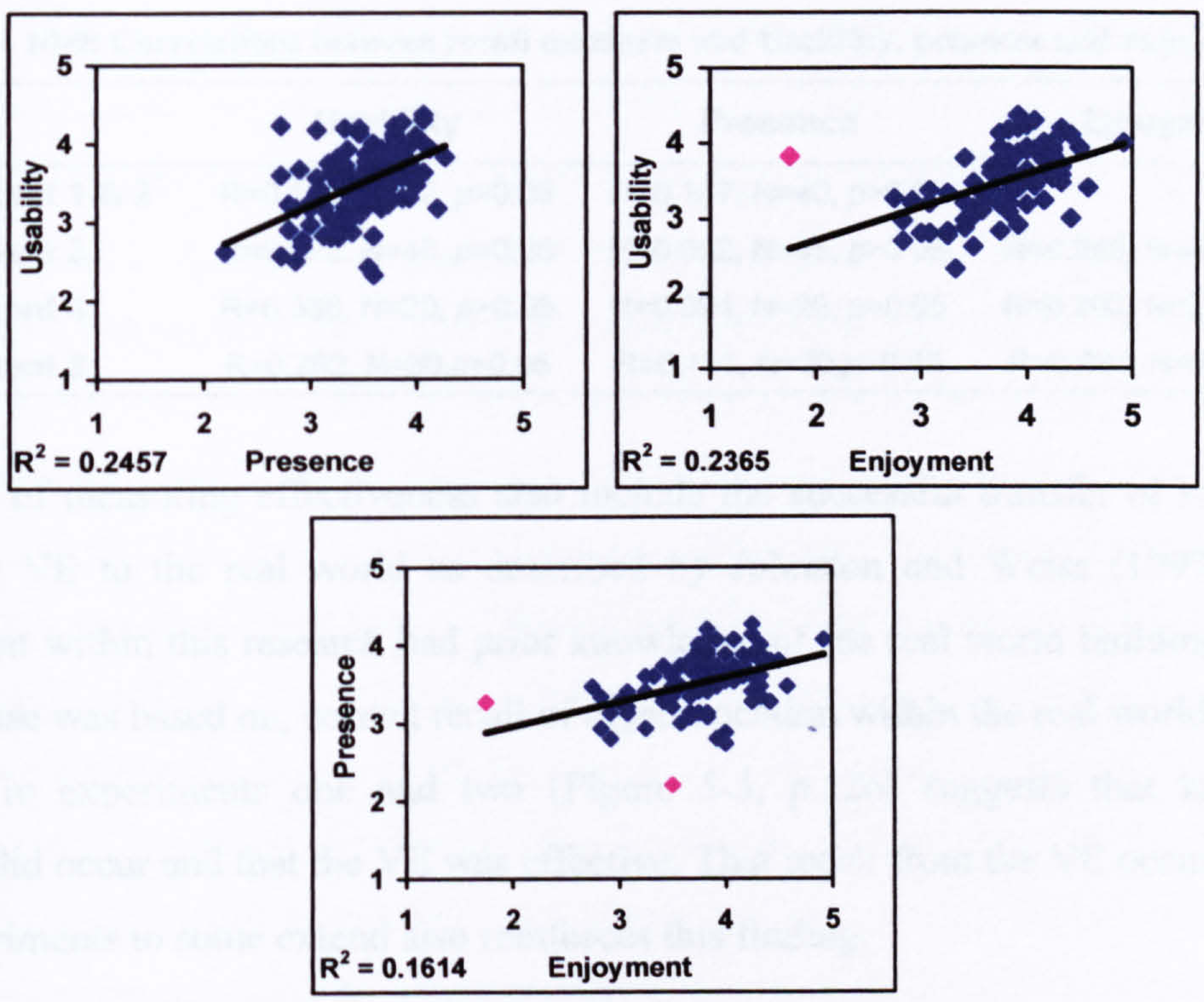


Figure 10-5: Correlations between subjective measures of presence, usability and enjoyment ('presence' and 'usability': r=0.496, n=127, $p<0.01$: ('enjoyment' and 'usability': r=0.0.486, n=95, $p<0.01$: 'presence' and 'enjoyment': r=0.402, n=95, $p<0.01$)

The clear relationships demonstrated suggest that the indications within literature that these factors are related (Stanney et al., 1998) are supported by the findings of this research and as correlations were evident it is possible to suggest that the measurement of each factor was successful.

Questionnaire results examined in relation to task performance within each condition did not show any significant relationships (Table 10-9), this suggests that theory presented in Barfield et al., (1994); Mania and Chalmers (1999) and Welch (1999) that task performance (in this case measured as recall) is related to the usability, presence and enjoyment experienced is not necessarily the case. Other factors such as the design of the VE and the method of prompting VE exploration have more of an influence on task performance and therefore measures of selection can be used as a measure of effectiveness instead. As all participants within each task condition within this research were required to complete the task before they finished using the VE, direct measures of how they performed within the VE were not used. It must therefore be made clear that existing theory on the relationship between these factors should be examined further.

Table 10-9: Correlations between recall measures and Usability, presence and enjoyment

Recall	Usability	Presence	Enjoyment
Experiment 1 & 2	R=0.121, N=32, *p*>0.05	R=0.167, N=40, *p*>0.05	-
Experiment 3	R=0.023, N=45, *p*>0.05	R=0.002, N=45, *p*>0.05	R=0.045, N=45, *p*>0.05
Experiment 4	R=0.336, N=20, *p*>0.05	R=0.094, N=20, *p*>0.05	R=0.202, N=20, *p*>0.05
Experiment 5	R=0.262, N=30,*p*>0.05	R=0.111, N=30,*p*>0.05	R=0.085, N=30,*p*>0.05

Methods of measuring effectiveness also include the successful transfer of knowledge from the VE to the real world as described by Johnston and Weiss (1997). As no participant within this research had prior knowledge of the real world building that the RWVE use was based on, correct recall of object location within the real world after VE training in experiments one and two (Figure 5-5, p.126) suggests that knowledge transfer did occur and that the VE was effective. That recall from the VE occurred in all the experiments to some extend also reinforces this finding.

10.3.3.1 Overview Analysis of Questionnaire Data

SNC	Selection and Navigational Control
NC	Navigational Control
FSNC	Free Selection and Navigational Control
Abs	Abstract VE

Figure 10-6 shows the mean presence scores recorded for each experimental condition within this research. It is not appropriate to use statistical assessment of data across experimental conditions to examine if differences are significant due to the variances in conditions between experiments.

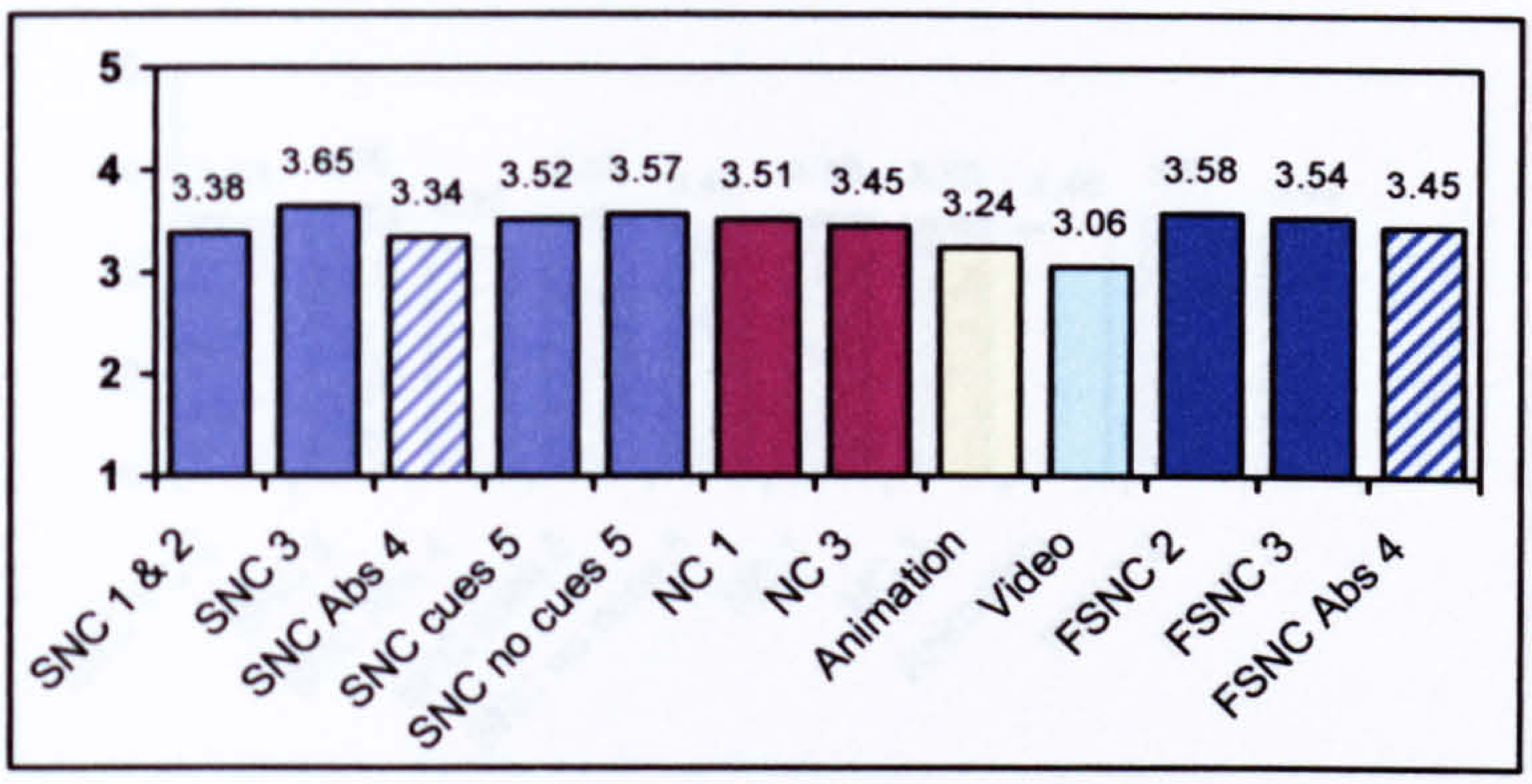


Figure 10-6: Mean presence scores for each condition

It can be seen that within the SNC sub group the abstract condition demonstrates the lowest presence scores, as is the case with the FSNC sub group. This reinforces the point made by Slater (1999) that the experience of presence is as having visited a place rather than just seen computer generated images, as this is more likely to occur in an environment that appears like a place that could be visited, as opposed to the abstract VE which did not. It can also be seen that presence tended to be higher where the participants were involved with the VE as opposed to watching an animation or a video of the real world. This may be as a result of the participant feeling involved with the VE prompting a feeling of 'being there' (Sheridan 1992b). The higher levels of presence in the 'no- task' or 'FSNC' conditions is contrary to Bystrom et al., (1999) who suggested that the inclusion of a task will increase the attentional resources paid to the VE and therefore develop a sense of presence. This may be as a consequence of the participant enjoying the experience more as they were able to 'play' as they wished in the FSNC conditions or that the task that they were required to perform in the SNC conditions was not suitably absorbing.

Figure 10-7 demonstrates the mean usability scores for all the experimental conditions within this research.

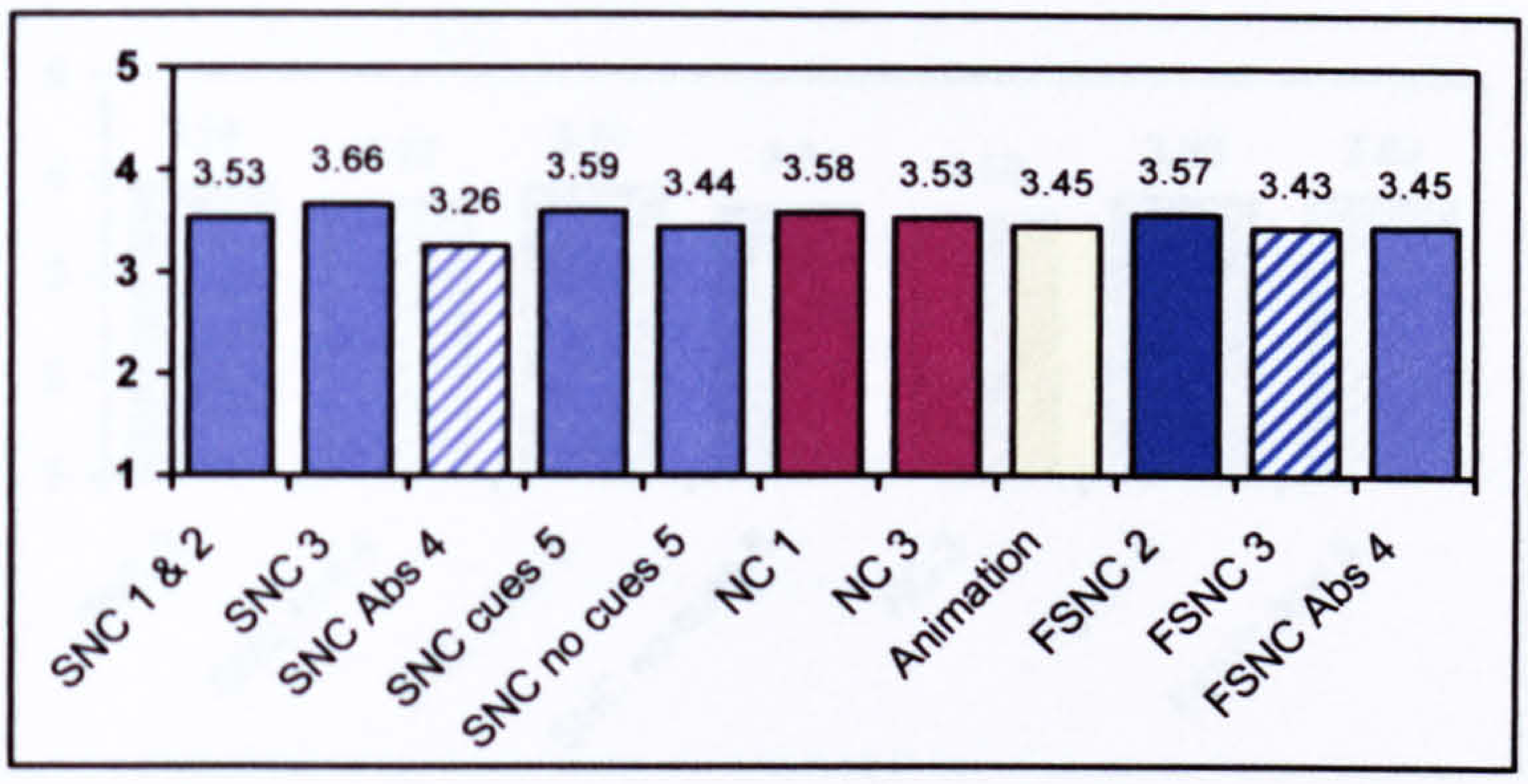


Figure 10-7: Mean usability scores for each condition

It can be seen that there is little variation between the means calculated, the lowest within each sub group (SNC and FSNC) being the abstract environments. This may be as a result of the interaction with the VE being less intuitive in the AbsVE as the participant was required to 'fly' around a room adding an extra degree of freedom (up and down) that was not in the RWVE. A further point as noted by Griffiths (2001) was that to aid usability a VE should be designed in a way that the user finds familiar and that it promotes a feeling of ease for the user, as is more likely the case for the RWVE than the AbsVE. As the same VE was used for all the other conditions with only minor alterations the similarity in findings is not surprising. This also suggests that the inclusion of the ability to select with a VE does not influence the usability of the VE as there are no notable differences between the NC conditions and the SNC and FSNC conditions. Usability being higher in the cued condition (SNC cues 5) than the non cued condition (SNC no cues 5) supports suggestion by Kaur (2002) that it should be made clear if an object can be interacted with when designing for usability within a VE.

Figure 10-8 demonstrates the mean enjoyment measures from each condition within the research.

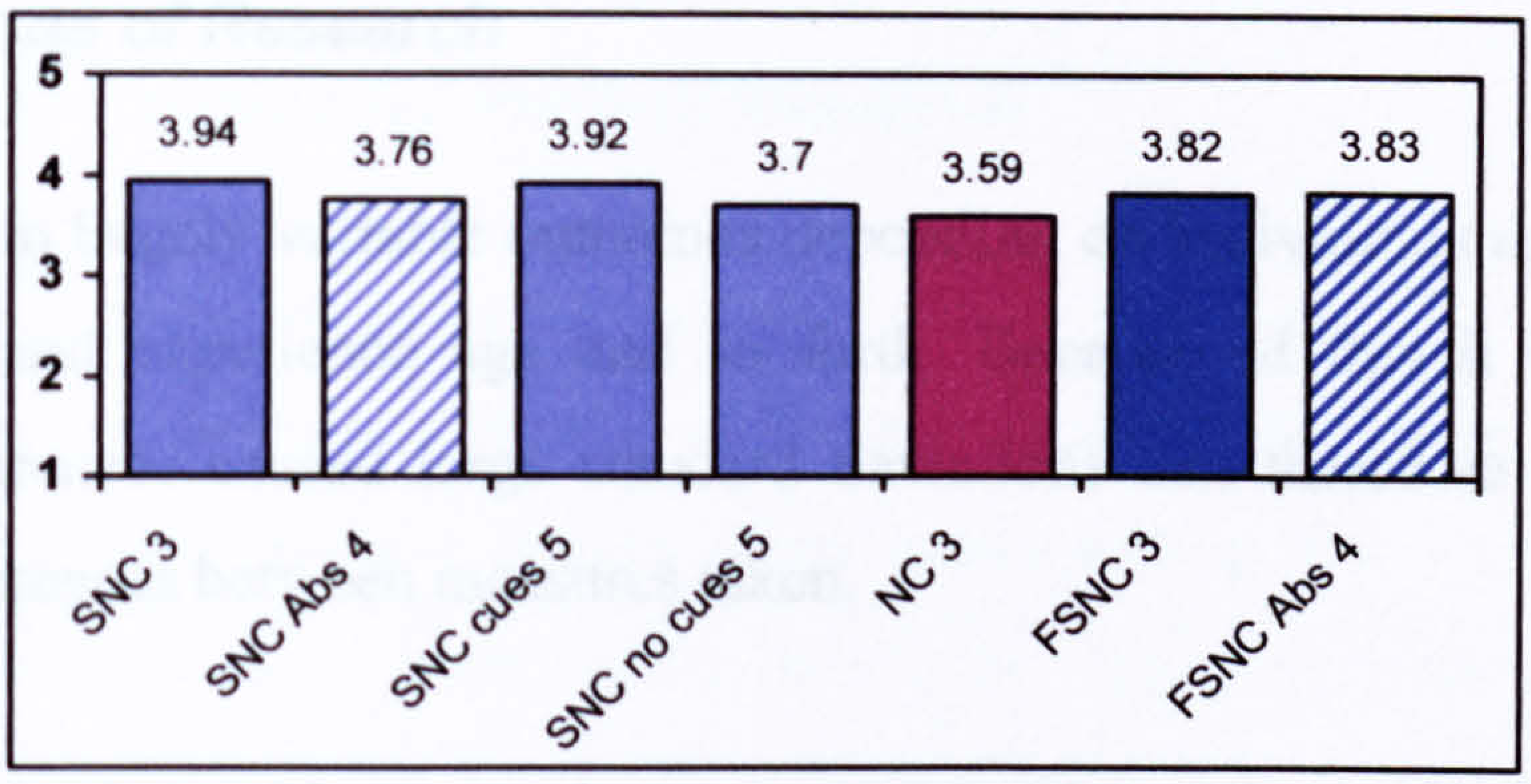


Figure 10-8: Mean enjoyment scores for each condition

It can be seen that there is little variation in the enjoyment figures. The lowest value is the NC condition where the participant is unable to select. This suggests that the ability to select within a VE has benefits not only to the design of that selection (i.e. cue prompted or task directed) but also generally as it provided a sense of enjoyment for the user.

10.3.3.2 Questionnaire Conclusions

It is not evident within this research if questionnaires are a valid measure of the effectiveness of a VE for a given application. A debate exists within literature as to their suitability and there is not enough evidence to support the argument either way. What is evident from this research is that selection of an object is a suitable indicator as to whether a user will recall that object from a VE thereby making that VE effective for its purpose.

Although it is not possible to demonstrate the validity of the questionnaires used within this research it is the author's belief that questionnaires are a valid method of measuring these factors within a VE, though should be used in conjunction with other measures. As the concept being measured is subjective it is appropriate to use subjective methods of assessment and findings suggest using a variety of these methods to support each other. What should be taken from this research is that to measure each concept of effectiveness within this study individually (usability, presence, enjoyment and recall) would require a greater range of measures to reinforce findings from any one source.

10.4 Limitations of Research

VR use results in hugely variable outcomes depending on individuals as a consequence of their skills and experience age and so forth. Because of this it is possible that individual differences caused large standard deviations and therefore resulted in non significant differences between measures taken.

The methods used in this research were mainly focused on distinct measurable variables; further qualitative analysis could be performed to establish to a greater extent the influence of user opinion of the design of VEs for training applications.

As the research performed was conducted under experimental research conditions the requirement of VE development in this case was a prototype (i.e. was not to actually test in the real world as a training device). It was therefore not necessary to develop an advanced VE, the main requirement being an easily learned software program that was trouble-free to adapt by the author to suit requirements. Although more advanced software is available on the market for such applications the use of Superscape suited the research requirements of the research performed.

A final limitation that should be noted is that all participants used were staff and students of the University of Nottingham and this suggests a certain level of computer familiarity. As a consequence participants may have had greater confidence using the VR system that may not exist to the same extent in other organisations. The use of computer literate users enabled experimentation to occur with little or no training to use the system itself and as this was not an element of this research it allowed focus of experimentation to be on the VE design not the system usability and therefore the use of such participants was justified in this case. Further research should examine if findings are still relevant to a wider spectrum of end users.

It was not possible through this research to examine all aspects of interaction design and as a consequence specific elements of cue design were focused on, as discussed in section 10.2 '*Selection within a VE*'. As a result of this any aspects it is felt should still be examined are discussed in the following section (10.5 *Recommendations for Further Research*).

10.5 Recommendations for Further Research

- Test findings in more advanced VR systems

Experimentation was limited to the use of desktop systems chosen for its affordability and familiarity, both important factors when implementing VR technology into an organisation which in most cases would be for the first time with no guarantee of success to warrant high initial financial outlay on more advanced technology. What therefore needs to be explored is if the findings from this research still apply when users are interacting with more advanced input devices such as the dataglove and more immersive displays such as the HMD or CAVE VR systems. Will the same VE features attract the user's attention in an immersive system and will the use of advanced input devices enhance or diminish the importance of a task in the users experience with the VR system and so forth?

- Test findings for a wider end user group.

All participants used within this research were staff and students of the University of Nottingham and although they had no experience with a desktop VR system such as the one used a certain level of computer experience enabled them to use the system with relative ease. This may not be the case in an organisation that involves less use of computers. It should therefore be examined if findings are applicable to a wider end user group with a greater range of computer familiarity, as for training to be effective within an organisation it must be possible for all members of that organisation to be trained.

- Test findings in real world training situations.

Findings from this research could now be taken and applied to a training VE application to establish their suitability.

- Test designers using the guidelines provided and resulting VEs developed.

Evaluation could be performed on the guidelines provided from the findings of this research to establish if VE designers can use and apply them as they work enabling the incorporation of design recommendations for more effective and usable training VE from the initial development stages. This will validate the guidelines provided; effective guidelines will reduce time and costs in VE development from using an iterative approach that involves the evaluation of VEs by end users then adapting VEs from this evaluation.

- Test findings for suitability to applications other than training.

All research performed was based on the use of the VR system and the VE design with respect to a training application. A possible extension of this work would be to apply findings to other applications such as rehabilitation, research and even entertainment to establish their transferability across applications.

- Examine the expectations of VE selection hotspot design not studied within this research.

In Table 10-6 (p.229) findings on the design of selection hotspot cues are reviewed from work performed within this research and compared to the expectations made prior to experimentation (Table 4-4, p.106). Not all the expectations developed through literature research were studied and an extension of this work would be to examine if these expectations are correct to provide further guidelines for selection hotspot design for VE developers. Further to this an examination of whether the same cue designs when used out of context are then more effective (as suggested to be the case from experimentation), for example movement of an object you would not expect, would it be selected more? This is already suggested in the case of auditory cues.

- Examine further the expectation presented in Eastgate (2001) that using a single interaction metaphor will be more effective than using a variety within the same VE.

Experimentation within this research did not show one cue type to be selected significantly more than a variety of cue types within the same VE. A large difference was not found to be significant due to large individual differences and consequently this aspect of cue design could be examined in greater depth.

- Examine in greater depth the relationship between measures of effectiveness and task performance.

Within this research the relationship between these factors was focused on task performance in the form of recall from the VEs used, not how well the individual using the VE performed a task whilst within the VE. No significant relationships were found between task performance in the form of recall and the VE effectiveness measures used. To examine the usefulness of measures of effectiveness in relation to task performance within the VE and if these factors are related further experimentation would be required.

10.6 Final Conclusions

The research performed within this study has formed a basis for the continual investigation into the previously under-examined design of selection within desktop training VEs, with respect to prompting users to select specific aspects of the VE and the importance of that selection on the VE experience for the user. Currently no comprehensive guidelines exist that inform VE designers how to design prompts for the selection of specific points within a VE. The development of the design guidelines produced within this research will enable the VE designer to effectively design cued objects for selection in a VE to support a training application.

This research is a foundation that can be built upon with further investigation into more technologically advanced VR systems, a greater range of end users and a wider scope of VR applications with the aim of changing the approach to design to enable the efficient development of effective selection within VEs from the outset.

Main design guidelines developed from this research can be seen in Figure 10-9.

- Cue the parts of the VE object you wish the user to select (selection is likely to improve the recall of those objects post user VE immersion).
- Use cues incongruous to the surrounding VE context (flashing cues in primary colours).
- Selection of objects that are not part of the task are likely to be reduced generally if VE exploration is task directed.

Figure 10-9: Design guidance checklist RWVE – selection hotspot cues

Guidelines on specific aspects of these points are provided within section 10.2, 'Selection within a VE'.

References

3Dconnexion. (2004). "*3Dconnexion*", http://www.3dconnexion.com/products.htm. 2004.

5dt. (2004). "*Fifth Dimension Technologies – Virtual Reality for the Real World*", http://www.5dt.com/products.html. 2004.

AIMS. (2004). "*AIMS Solutions Ltd.*", http://www.nottingham.ac.uk/aims/VRSite/HTML/SafeVR.html. 2004.

Ascension Technology. (2004). "*Ascension Technology Corporation*", http://www.ascension-tech.com/products/. 2004.

Barfield, W. and Weghorst, S. (1993). "*The Sense of Presence within Virtual Environments: A Conceptual Framework.*" Human Computer Interaction: Software and Hardware Interfaces: 699 – 704.

Barfield, W., Zeltzer, D., Sheridan, T. and Slater, M. (1995). "*Presence and Performance Within Virtual Environments*". New York, NY: Oxford University Press.

Barone, A. (2001). "*A Usability Comparison of Two Virtual Environments and Three Modes of Input*". Unpublished MSc dissertation. School of Mechanical, Materials, Manufacturing Engineering and Management. University of Nottingham.

Bayon, V. and Griffiths, G. (2003) "*Co-located Interaction in Virtual Environments via De-coupled Interfaces.*" Proceedings, HCI International 2003, Crete, Greece, Lawrence Erlbaum Associates.

Benjamin, L. T., Hopkins, R. J. and Nation, J. R. (1987). "*Psychology*". New York, Macmillan Publishing Company.

Botella, C., Banos, R., M., Villa, H., Perpina, C. and Garcia-Palacious, A. (2000). "*Virtual Reality in the Treatment of Claustrophobic Fear: A Controlled, Multiple Baseline Design.*" Behaviour Therapy 31(3): 583-595.

Boud, A. C., Baber, C. and Steiner, S. J. (2000). "*Virtual Reality: A Tool for Assembly.*" Presence: Teleoperators and Virtual Environments 9(5): 486-496.

Bowman, D. A. and Wingrave, C. A. (2001). "*Design and Evaluation of Menu Systems for Immersive Virtual Environments.*" VR: 149-156.

Bowman, D. A., Johnson, D. B. and Hodges, L. F. (2001). "*Test Bed Evaluation of Virtual Environment Techniques.*" Presence: Teleoperators and Virtual Environments 10(1): 75-95.

Bowman, D. A., Kruijff, E., LaViola Jr, J. J. and Poupyrev, I. (2001). "*An Introduction to 3-D User Interface Design.*" Presence: Teleoperators and Virtual Environments 10(1): 96-108.

Brooks, B. M., Attree, E. A., Rose, D. F., Clifford, B. R. and Leadbetter, A. G. (1999). *"The Specificity of Memory Enhancement During Interaction with a Virtual Environment."* Memory 7(1): 65-78.

Brown, D. J., Cobb, S. and Eastgate, R. (1995). *"Learning in Virtual Environments"*. Virtual Reality Applications. R. Earnshaw, A, J. Vince, A and H. Jones. London, Academic Press Limited: 245-252.

Brown, D. J., Kerr, S. J and Bayon, V (1998). *"The development of the Virtual City: A user centred approach"*. Proceedings: 2nd ICDVRAT 1998, 10-11th September, Skovde, Sweden, University of Reading.

Bryson, S. (1993). *"The Virtual Wind Tunnel"*. SIGGRAPH 93 Course, No 43, pp.2.1-2.10.

Bystrom, K., Barfield, W. and Hendrix, C. (1999). *"A Conceptual Model of the Sense of Presence in Virtual Environments."* Presence: Teleoperators and Virtual Environments 8(2): 241-244.

Case, M. M. (1999). *"Measuring the Cost Effectiveness of Journals: The Wisconsin Experience"*, Association of Research Libraries (ARL) Bimonthly Report from ARL, CNI, and SPARC. 2001.

Chu, C. C. P., Dani, T. H. and Gadh, R. (1998). *"Evaluation of Virtual Reality Interface for Product Shape Designs."* IIE Transactions 30(7): 629-643.

Cobb, S., Nichols, S., Ramsey, A. D. and Wilson, J. R. (1999). *"Virtual Reality-Induced Symptoms and Effects (VRISE)."* Presence: Teleoperators and Virtual Environments 8(2): 169-186.

Cobb, S. and Stanton, D (in press). *"Multimedia Learning in Virtual Reality."* In R. Mayer (ed.) The Cambridge Handbook of Multimedia Learning. New York: Cambridge University Press.

Crosbie, J. H., McDonough, S. M, Lennon, S., Pokluda and McNeill (2004) *'Virtual reality in the rehabilitation of the upper limb after stroke: the user's perspective'* Proceedings: 5th ICDVRAT 2004, 20-22nd September, Oxford, UK, University of Reading.

Crosier, J. K. (2000). *"Virtual Environments for Science Education: A Schools-Based Development"*. Virtual Reality Applications Research Team. Ph.D. Thesis. University of Nottingham.

Crosier, J. K., Nichols, S., Stedmon, A. W. and Patel, H. (2001). *"VIEW: State of the Art Market Analysis"*, University of Nottingham. Report: IST-2000-26089, D1.1

D'Cruz, M. (1999). *"Structured Evaluation of Training in Virtual Environments"*. Virtual Reality Applications Research Team, Ph.D. Thesis. University of Nottingham.

Doxford, D. and Judd, A. (2002). *"Army Training: The Environmental Gains Resulting from the Adoption of Alternatives to Traditional Training Methods."* Journal of Environmental Planning and Management 45(2): 245-265.

Draper, J. V., Kaber, D. B. and Usher, J. M. (1998). "*Telepresence.*" Human Factors 40(3): 354-375.

Eason, K., D (1984). "*Towards the Experimental Study of Usability.*" Behaviour and Information Technology 3(2): 133-43.

Eastgate, R. (2001). "*The Structured Development of Virtual Environments: Enhancing Functionality and Interactivity*". Virtual Reality Applications Research Team, Ph.D. Thesis. University of Nottingham.

Eysenck, M. W. and Keane, M. T. (1995). "*Cognitive Psychology A Students Handbook*". UK, Taylor & Francis Group.

Francis, G., A and Tan, H., S (1999). "*Virtual Reality as a Training Instrument.*" The Temasek Journal 7: 4 – 15.

Freeman, J. (1999). "*Effects of Sensory Information and Prior Experience on Direct Subjective Ratings of Presence.*" Presence: Teleoperators and Virtual Environments 8(1): 1-13.

Freeman, J., Avons, S. E., Pearson, D. E., Meddis, R. and Ijsselsteijn, W. A. (2000). "*Using behavioural Realism to Investigate Presence: A Study of the Utility of Postural Responses to Motion Stimuli.*" Presence: Teleoperators and Virtual Environments 9(2): 149-164.

Gowron, V. J., (2000). "*Human Performance Measures Handbook*". New Jersey – London, Lawrence Erlbaum Associates.

Greenhalgh, C., Bullock, A., Tromp, J. and Benford, S. (1997). "*Evaluating Network and Usability Characteristics of Virtual Reality Conferencing.*" BT Technical Journal 15(4): 101-119.

Griffiths, G. D. (2001). "*Virtual Environment Usability & User Competence: The Nottingham Assessment of Interaction Within Virtual Environments (NAIVE) Tool*". Virtual Reality Applications Research Team. Ph.D. Thesis. University of Nottingham.

Grove, J. (1996). "*VR and History – Some Findings and Thoughts.*" VR in the Schools 2(1): 3-9.

Hampson, P. J. (1989). "*Aspects of Attention and Cognitive Science.*" The Irish Journal of Psychology 10: 261-275.

Harris, S. R., Kemmerling, R. L. and North, M. M. (2002). "*Brief Virtual Reality Therapy for Public Speaking Anxiety.*" Cyber Psychology & Behaviour 5(6): 543-550.

Harrison, D. and Jaques, M. (1996). '*Experiments in Virtual Reality*'. Oxford, Butterworth-Heinemann.

Heeter, C. (1992). "*Being There: The Subjective Experience of Presence.*" Presence: Teleoperators and Virtual Environments 1(2): 262-271.

Hendrix, C. and Barfield, W. (1996). "*The Sense of Presence Within Auditory Virtual Environments.*" Presence: Teleoperators and Virtual Environments 5(3): 290-301.

Herndon, K. P., Van Dam, A. and Gleicher, M. (1994). "*The Challenges of 3D Interaction*". SIGCHI Bulletin.

Hilgard, E. R., Atkinson, R. L. and Atkinson, R. C. (1979). "*Introduction to Psychology*". New York, Harcourt Brace Jovanovich, Inc.

Hodges, L. F., Kooper, R., Meyer, T. C., Rothbaum, B. O., Opdyke, D., de Graaff, J. J., Williford, J. S. and North, M. M. (1995). "*Virtual Environments for Treating the Fear of Heights.*" Computer 28(7): 27-34.

Hodges, L. F., Watson, B. A., Kessler, G. D., Rothbaum, B. O. and Opdyke, D. (1996). "*Virtually Conquering Fear of Flying.*" Computer Graphics and Applications, IEEE 16(6): 42-49.

Hoffmann, H. and Stefani, O. (2002). '*VIEW: System Architecture*' University of Stuttgart. Report: IST-2000-26089, D5.1

Hoffman, H. G., Patterson, D. R., Carrougher, G. J. and Sharar, S. R. (2001). "*Effectiveness of Virtual Reality-based Pain Control With Multiple Treatments.*" Clinical Journal of Pain 17(3): 229-235.

Hoffman, H., G., Garcia-Palacious, A., Carlin, A., Furness, T., A. and Botella-Arbona, C. (2003). "*Interfaces That Heal: Coupling Real and Virtual Objects to Treat Spider Phobia.*" International Journal of Human-Computer Interaction 16(2): 283-301.

IAW (2004). "*Institute of Industrial Engineering and Ergonomics (IAW) – RWTH Aachen University*", http://www.iaw.rwth-aachen.de/projekte/arvika/index.html. 2004.

Immersion. (2004). "*Medical Overview*", www.immersion.com/medical/. 2004.

Inition (2004). "*Inition Innovative Graphics Solutions*", www.inition.co.uk. 2004.

ISO (1995). "*ISO/DIS 9241-13 Ergonomic Requirements for Office Work with Visual Display Terminals (VDT's) Part 13 (draft): User Guidance*". I. S. Organisation.

Jacobson, P. D. and Kanna, M. L. (2001). "*Cost-Effectiveness Analysis in the Courts: Recent Trends and Future Prospects*", University of Michigan School of Public Health. 2001.

Johnston, R. and Weiss, P. (1997). "*Analysis of Virtual Reality Technology Applied in Education.*" Minimally Invasive Therapy and Applied Technologies 6(2): 126-127.

Johnston, A. (2001). "*Theories of Visual Perception: Problems and Perspectives*", University College, London. 2003.

Johnson, M. J., Van der Loos, H. F. M, Burgar, C. G, Shor, P. C. and Leifer, L. J. (2003), *'Design and evaluation of driver's SEAT: A car steering simulation environment for upper limb stroke therapy'*, Robotica, 21, pp 13-23.

Jones, J. I. and Simonson, M. (1990). "*Cost Effectiveness of Distance Education In Iowa*", Iowa State University. 2001.

Jordan, P. (1998). "*An Introduction to Usability*". London, Taylor and Francis.

Kalawsky, R. S. (1999a). "*VRUSE – A Computerised Diagnostic Tool: for Usability Evaluation of Virtual/Synthetic Environment Systems.*" Applied Ergonomics 30(1): 11-25.

Kalawsky, R., S, Bee, S., T and Nee, S., P (1999b). "*Human Factors Evaluation Techniques to Aid Understanding of Virtual Interfaces.*" BT Technical Journal 17(1): 128-141.

Kaur, K. (1997). "*Designing Virtual Environments for Usability*". Proceedings: INTERACT 97, Sydney.

Kaur, K., Sutcliffe, A. G. and Maiden, N. (1998a). "*Improving Interaction with Virtual Environments*". The 3D Interface for the Information Worker, London.

Kaur, K., Sutcliffe, A. G. and Maiden, N. (1998b). "*Usability Requirements for Virtual Environments*". Proceedings: Human-Computer Interaction '98, Sheffield, UK.

Kaur, K., Sutcliffe, A. G. and Maiden, N. (1998c). "*Applying Interaction Modelling to Inform Usability Guidance for Virtual Environments*". First International Workshop on Usability Evaluation for Virtual Environments, De Montford University, Leicester, UK.

Kaur, K., Maiden, N. and Sutcliffe, A. G. (1999a). "*Interacting with Virtual Environments: An Evaluation of a Model of Interaction.*" Interacting With Computers 11: 403-426.

Kaur, K., Sutcliffe, A. G. and Maiden, N. (1999b). "*Modelling Interaction to Inform Information Requirements in Virtual Environments*". Workshop on Interactions in Virtual Worlds, Enschede, Netherlands.

Kaur, K., Sutcliffe, A. G. and Maiden, N. (1999c). "*A Design Advice Tool Presenting usability guidance for Virtual Environments*". Workshop on User Centred Design and Implementation of Virtual Environments, York, UK. http://www.cs.york.ac.uk/hci/kings_manor_workshops/UCDIVE/kaur.pdf

Kaur, K. (2002). "*Designing Usable Virtual Environments: Design of Environment Components, Interaction and Control*", City University, London http://www.soi.city.ac.uk/~dj524/demtool/frame.htm. 2002.

Kelkoo. (2004). "*Kelkoo Computing*", http://computing.kelkoo.co.uk/b/a/c_110001_computers_software.html. 2004.

Kennedy, R. S., Stanney, K. M. and Dunlap, W. P. (2000). "*Duration and Exposure to Virtual Environments: Sickness Curves During and Across Sessions.*" Presence: Teleoperators and Virtual Environments 9(5): 463-472.

Korves, B. and Loftus, M. (1999). "*The Application of Immersive Virtual Reality for Layout Planning of Manufacturing Cells.*" Proceedings of the Institution of Mechanical Engineers Part B – Journal of Engineering Manufacture 213(1): 87-91.

Lessiter, J., Freeman, J., Keogh, E. and Davidoff, J. D. (2001). "*A Cross-Media Presence Questionnaire: The ITC Sense of Presence Inventory.*" Presence: Teleoperators and Virtual Environments 10(3).

Lindgaard, G. (1994). "*Usability Testing and System Evaluation, A Guide for Designing Useful Computer Systems*". London, Chapman & Hall.

Logitech. (2004). "*Logitech*", http://www.logitech.com/index.cfm/products/home/FI/EN,CRID=17. 2004.

Mania, K. and Chalmers, A. (1999). "*Between Real and Unreal: Investigating Presence and Task Performance*". Proceedings of the Second International Workshop on Presence, Colchester, UK.

Mantovani, F., Castelnuovo, G., Gaggiolo, A. and Riva, G. (2003). "*Virtual Reality Training for Health-Care Professionals.*" CyberPsychology & Behaviour 6(4): 389-395.

Marsh, T. and Wright, P. (1999). "*Co-operative Evaluation of a Desktop Virtual Reality System*". User Centred Design and Implementation of Virtual Environments, King's Manor, University of York.

Marsh, T. and Wright, P. (2000). "*Maintaining the Illusion of Interacting within a 3D Workspace*". 3rd International Workshop on Presence, Delft, The Netherlands.

Marshall, E., Nichols, S. and Wilson, J. R. (2003). "*Interactivity, Control of Movement and Realism: Establishing the Factors Influencing Virtual Reality Training*". Proceedings, HCI International 2003, Crete, Greece, Lawrence Erlbaum Associates.

Marshall, E., Nichols, S. (2004). "*Interaction with a Desktop Virtual Environment: a 2D View into a 3D World*". Virtual Reality 8: 17-25.

Mazuryk, T. and Gervautz, M. (1996). "*Virtual Reality History, Applications, Technology and Future*". Austria, Institute of Computer Graphics and Algorithms, Vienna University of Technology.

Murta, A. (1995). "*Vertical Axis Awareness in 3D Environments*". In Framework for Immersive Virtual Environments '95, London.

NASA (2002). "*Astronaut Tests 'Virtual Glove box' for Space Experiments*", http://amesnews.arc.nasa.gov/releases/2002/02_95AR.html. 2004.

NASA (2004). "*Life Sciences Division – Research Labs*", http://lifesci.arc.nasa.gov/research_labs.html. 2004.

Nash, E. B., Edwards, G. W., Thompson, J. A. and Barfield, W. (2000). "*A Review of Presence and Performance in Virtual Environments.*" International Journal of Human-Computer Interaction 12(1): 1-41.

Neale, H. (2001). "*Virtual Environments in Special Needs Education: Considering Users in Design*". Virtual Reality Applications Research Team, Ph.D. Thesis. University of Nottingham.

Neale, H. and Nichols, S. (2001). "*Theme-Based Content Analysis: A Flexible Method for Virtual Environment Evaluation.*" International Journal of Human-Computer Studies 55: 167-190.

Nichols, S., Cobb, S. and Wilson, J. R. (1997). "*Health and Safety Implications of Virtual Environments: Measurement Issues.*" Presence: Teleoperators and Virtual Environments 6(6): 667-675.

Nichols, S., (1999). "Virtual Reality Induced Symptoms and Effects (VRISE): Methodological and Theoretical Issues." Virtual Reality Applications Research Team, Ph.D. Thesis. University of Nottingham.

Nichols, S., Haldane, C. and Wilson, J. R. (2000). "*Measurement of Presence and its Consequences in Virtual Environments.*" International Journal of Human-Computer Studies 52: 471-491.

Nichols, S., Ramsey, A. D., Cobb, S., Neale, H., D'Cruz, M. and Wilson, J. R. (2000). "*Incidence of Virtual Reality Induced Symptoms and Effects (VRISE) in Desktop and Projection Screen Display Systems*", Report: Health and Safety Executive (HSE), 274/2000.

NICVE. (2004). "*State of the Art in Virtual Reality Technology*", www.nicve.salford.ac.uk/CIBTG24/vr.html. 2004.

Nielson, J. (1993). "*Usability Engineering*". Boston, Massachusetts, Academic Press.

Norman, D. A. (1988). "*The Psychology of Everyday Things*". New York, Basic Books inc. Publishers.

North, M. M., North, S. M. and Coble, J. R. (1996). "*Effectiveness of Virtual Environment Desensitisation in the Treatment of Agoraphobia.*" Presence: Teleoperators and Virtual Environments 5(3): 346-352.

NVIDIA (2004). "*nVIDIA GeForce 6800 graphics processing units*", http://www.nvidia.co.uk/page/geforce_6800.html. 2004.

Oppenheim, A. N. (1992). "*Questionnaire design, interviewing and attitude measurement*", London and New York, Pinter Publishers.

Orr, T. J., Filigenzi, M. T. and Ruff, T. M. (2002). "*Desktop Virtual Reality Miner Training Simulator*", http://www.cdc.gov/niosh/mining/pubs/pdfs/dvrmt.pdf 2004.

Patel, H., Stedmon, A. Nichols, S., D'Cruz, M, D., Mager, R., Stoermer, R., Schaerli, H., Estoppey, K, H. and Bullinger, A., (2001) *"Usability Test-battery Manual"*, Report: VIEW of the future project IST-2000-26089, D3.2 www.view.iao.fraunhofer.de/workpackages.html

Patel, H., Nichols, S., Stedmon, A. W., Tromp, J., Griffiths, G. D., Bayon, V. Marshall, E., Johansson, E., Mourouzis, A., Karampelas, P., Stefani, O., Hoffmann, H., Karaseitanidis, G., Tzoumpas, A., Letourneur, S., Bullinger, A., and Mager, R., (2003). "*Pilot Outline and Results*", Report: VIEW of the future project: IST-2000-26089, D6.2, www.view.iao.fraunhofer.de/workpackages.html

Poupyrev, I.., Weghorst, S., Billinghurst, M. and Ichikawa, T. (1997). "*A Framework and Testbed for Studying Manipulation Techniques for Immersive VR*". In Proceedings of ACM Symposium on Virtual Reality Software and Technology 1997 (VRST), pp. 21-28.

Poupyrev, I., Weghorst, S., Billinghurst, M. and Ichikawa, T. (1998). "*A Study of Techniques for Selecting and Positioning Objects in Immersive VEs: Effects of Distance, Size, and Visual Feedback*". Presented at ACM CHI '98, 18-23 April 1998, Los Angeles, CA.

Poupyrev, I., Weghorst, S., Billinghurst, M. and Ichikawa, T. (1998). "*Egocentric Object Manipulation in Virtual Environments: Empirical Evaluation of Interaction Techniques*". Computer Graphics Forum [Eurographics Conference Issue], 17(3), C-41-C-52.

Preece, J., Rogers, S., Sharp, H., Benyon, D., Holland, S. and Carey, T. (1994). "*Human-Computer Interaction*". Harlow, England: Addison Wesley.

Prothero, J., Hoffman, H. G., Parker, Wells, M. and Furness, T. A. (1995). "*Foreground/Background Manipulations Affect Presence*". Human Factors and Ergonomics Society.

Reason, J. T., and Brand, J. J. (1975). *"Motion sickness"*. London: Academic Press.

Regian, J.W., Shebilske, W.L. & Monk, J.M. (1992). "*Virtual Reality: An Instructional Medium for Visual-Spatial Tasks*". Journal of Communication, 4, 136-149.

Romano, D. M., Brna, P. and Self, J. A. (1998). "*Collaborative decision-making and presence in shared dynamic virtual environments*". Proceedings of the Presence in Shared Virtual Environments Workshop, First International Workshop on Presence, Ipswich, Suffolk, UK.

Rose, D. F., M, A. B., Brooks, D. M., Parslow, D. M., Penn, P. R. and Ambihaipahan, N. (2000). "*Training in Virtual Environments: Transfer to Real World Tasks and Equivalence to Real Task Training.*" Ergonomics 43(4): 494-511.

Rose, D. F., Attree, E. A., Brooks, B. M. and Andrews, T. K. (2001). "*Learning and Memory in Virtual Environments: A Role in Neurorehabilitation? Questions (and occasional answers) from the University of East London.*" Presence: Teleoperators and Virtual Environments 10(4): 345-358.

Rowe, R. and Cohen, R. (2000). "*Virtual Reality Bronchoscopy Simulator*". American Society of Anaesthesiologists Annual Meeting – Poster, http://www.immersion.com/medical/docs/asaposter.pdf.

Satava, R., M (1995). "*VR for the Physician of the 21st Century*". Virtual Reality Applications. R. Earnshaw, A, J. Vince, A and H. Jones. London, Academic Press Limited: 19-26.

Schubert, T., Friedmann, F. and Regenbrecht, H. (1999). "*Embodied Presence in Virtual Environments*". London, Springer-Verlag.

SensAble (2004). "*SensAble Technologies*", http://www.sensable.com/products/index.asp. 2004.

SGI. (2004). "*Crashworthiness and Safety at BMW*", http://www.sgi.com/industries/manufacturing/automotive/#safety. 2004.

Shackel (1986). "*Ergonomics in Design for Usability*". People and Computers: Designing for Usability". Proc. 2nd Conf. Human-Computer Interaction Specialist Group British Computer Society, Cambridge University Press, Cambridge.

Sharma, A., Nakano, A., Kalia, R. K., Vashishta, P., Kodiyalam, S., Miller, P., Zhao, W., Liu, X., Campbell, T. J. and Haas, A. (2003). "*Immersive and Interactive Exploration of Billion-Atom Systems.*" Presence: Teleoperators and Virtual Environments 12(1): 85-95.

Sheridan, T. B. (1992a). "*Musings on Telepresence and Virtual Presence.*" Presence: Teleoperators and Virtual Environments 1(1): 120-126.

Sheridan, T., B (1992b). "*Defining Our Terms.*" Presence: Teleoperators and Virtual Environments 1(2): 272-274.

Sheridan, T., B (1996). "*Further Musings on the Psychophysics of Presence.*" Presence: Teleoperators and Virtual Environments 5(2): 241-246.

Sik Lányi, C., Bacsa, E., Matrai, R., Kosztyan, Z and Pataky, I., (2004). '*Interactive rehabilitation software for treating patients with aphasia*', Proceedings: 5th ICDVRAT 2004, 20-22nd September, Oxford, UK, University of Reading.

Sinai, M.J., Krebs, W.K., Darken, R.P., Rowland, J. H., and McCarley, J.S. (1999). "*Egocentric Distance Perception in a Virtual Environment Using a Perceptual Matching Task*". Proceedings: 43rd Annual Meeting Human Factors and Ergonomics Society, Houston, TX, 43, pp. 1256-1260.

Singer, M. J. and Witmer, B. G. (1999). "*On Selecting the Right Yardstick.*" Presence: Teleoperators and Virtual Environments 8(5): 566-573.

Slater, M. and Usoh, M. (1993). "*Representations Systems, Perceptual Position, and Presence in Immersive Virtual Environments.*" Presence: Teleoperators and Virtual Environments 2(3): 221-233.

Slater, M., Usoh, M. and Steed, A. (1994). "*Depth of Presence in Virtual Environments.*" Presence: Teleoperators and Virtual Environments 3(2): 130-144.

Slater, M. and Wilbur, S. (1997). "*A Framework for Immersive Virtual Environment (FIVE): Speculations on the Role of Presence in Virtual Environments*". Presence: Teleoperators and Virtual Environments 6(6): 603-616.

Slater, M., Linakis, V., Usoh, M. and Kooper, R. (1996). "*Immersion, Presence, and Performance in Virtual Environments: An Experiment using Tri-Dimensional Chess*". ACM Virtual Reality Software and Technology (VRST).

Slater, M. (1999). "*Measuring Presence: A Response to the Witmer and Singer Presence Questionnaire.*" Presence: Teleoperators and Virtual Environments 8(5): 560-565.

Stanney, K. M., Mourant, R. R. and Kennedy, R. S. (1998). "*Human Factors Issues in Virtual Environments: A Review of the Literature.*" Presence: Teleoperators and Virtual Environments 7(4): 327-351.

Stanney, K. M. (2002). "*Handbook of Virtual Environments Design, Implementation and Applications*". Mahwah, New Jersey, Lawrence Erlbaum Associates Inc.

Stedmon, A. W. (2003) *"Developing Virtual Environments Using Speech as an Input Device."* Proceedings, HCI International 2003, Crete, Greece, Lawrence Erlbaum Associates. Theory and Practice (part I) p.1248-1252.

Stone, R. J. (2003) *"Methodologies and Evidence in Support of a Human Centred Approach to Virtual Environment Systems Design."* Proceedings, HCI International 2003, Crete, Greece, Lawrence Erlbaum Associates. Theory and Practice (part I) p.1253-1257.

Sturm, R. and Wells, K. B. (1995). "*How Can Care for Depression Become More Cost-Effective.*" Journal of the American Medical Association 74(1).

Tan, H. S. (2000). "*Virtual Training Environments*". Asia Pacific Advanced Network Conference, Beijing.

Tromp, J., Eastgate, R., Nichols, S., Patel, H. and D'Cruz, M. (2003). "*VIEW: Development of Guidelines and Interactive Design Support Tool*". University of Nottingham. Report: IST-2000-26089, D8.1

VIEW, PI-casso (2004) *'PI-casso: Concept of an integrated VR and Desktop Workplace'* http://www.view.iao.fraunhofer.de/products. 2004.

Virtalis (2004). "*RAF Tornado F3 Avionics Training Facility*", http://www.virtalis.com/index.php?cPath=28_1226_36. 2004.

VREfresh. (2004). "*Caterpillar*", http://www.vrefresh.com/Users.htm#Caterpillar. 2004.

Waller, D., Hunt, E. and Knapp, D. (1998). "*The Transfer of Spatial Knowledge in Virtual Environment Training.*" Presence: Teleoperators and Virtual Environments 7(2): 129-143.

Wallergård, M. (2003). *"Designing virtual environments for brain injury rehabilitation"*. Licentiate Thesis, Division of Ergonomics and Aerosol Technology. Lund University, Sweden.

Wann, J. and Mon-Williams, M. (1996). "*What Does Virtual reality NEED? Human Factors Issues in the Design of Three-Dimensional Computer Environments.*" International Journal of Human-Computer Studies 44: 829-847.

Welch, R. B. (1996). "*The Effects of Pictorial Realism, Delay of Visual Feedback, and Observer Interactivity on the Subjective Sense of Presence.*" Presence: Teleoperators and Virtual Environments 5(3): 263-273.

Welch, R. B. (1999). "*How Can We Determine if the Sense of Presence Affects Task Performance?*" Presence: Teleoperators and Virtual Environments 8(5): 574-577.

Welch, R. B. (2002). "*Handbook of Virtual Environments*". New Jersey, Lawrence Erlbaum Associates Inc.

Wickens, C. D., Gordon, S. E. and Liu, Y. (1998). "*An Introduction to Human Factors Engineering*", Addison-Wesley Educational Publishers Inc.

Wiehagen, G. B. (1997). "*Simulators and Simulation: Possibilities and Limits. Simulation: A Challenge or a Benefit?*" Seminar: Oberammergau, Germany, CCMS Report No. 217 (Brussels, NATO-CCMS).

Wilson, J. R., D'Cruz, M., Cobb, S. and Eastgate, R. (1996). "*Virtual Reality for Industrial Applications Opportunities and Limitations.*" Nottingham, Nottingham University Press.

Witmer, B. G. and Kline, P. B. (1998). "*Judging Perceived and Transversed Distance in Virtual Environments.*" Presence: Teleoperators and Virtual Environments 7(2): 144-167.

Witmer, B. G. and Singer, M. J. (1998). "*Measuring Presence in Virtual Environments: A Presence Questionnaire.*" Presence: Teleoperators and Virtual Environments 7(3): 225-240.

Zeltzer, D. (1992). "*Autonomy, Interaction and Presence.*" Presence: Teleoperators and Virtual Environments 1: 127 - 132.

Appendix

1. *All Experiments - Consent Form*

Virtual Reality Applications research Team

UNIVERSITY OF NOTTINGHAM

Study of the effectiveness of virtual reality training

My name is Eleanor Marshall and as part of my research within the Virtual Reality Applications Research Team (VIRART) I am carrying out a study into the effectiveness of virtual reality as a training tool. Virtual environments have been developed in which you may be required to explore and perform specific tasks. You will attend two sessions and in the first you will use or view a virtual environment or display screen for approximately 30 minutes. The total time of both parts of the experiment will not exceed 1hr 30 minutes. You will be paid £5 for your time.

Before the experiment I will ask you about your state of health. If you are not in your normal state of health another experimental session can be arranged for another time.

You will also be required to fill in a number of questionnaires and the experimental session will be recorded on video for analysis by the experimenter.

Your name will not be used in conjunction with the study, and all information you provide will be kept strictly confidential. If you have any questions please do not hesitate to ask.

Participation in the study is entirely voluntary and you may stop at any point if you do not wish to continue.

You should inform the experimenter if you suffer from any of the following:
Migraine
Recurring headache
Pregnancy
Back pain or back problems
Neck or shoulder strain
Heart condition
Asthmatic or respiratory disorder
Epilepsy (photosensitive or other)
Problems with depth perception
Other serious injury or illness

Subject consent form

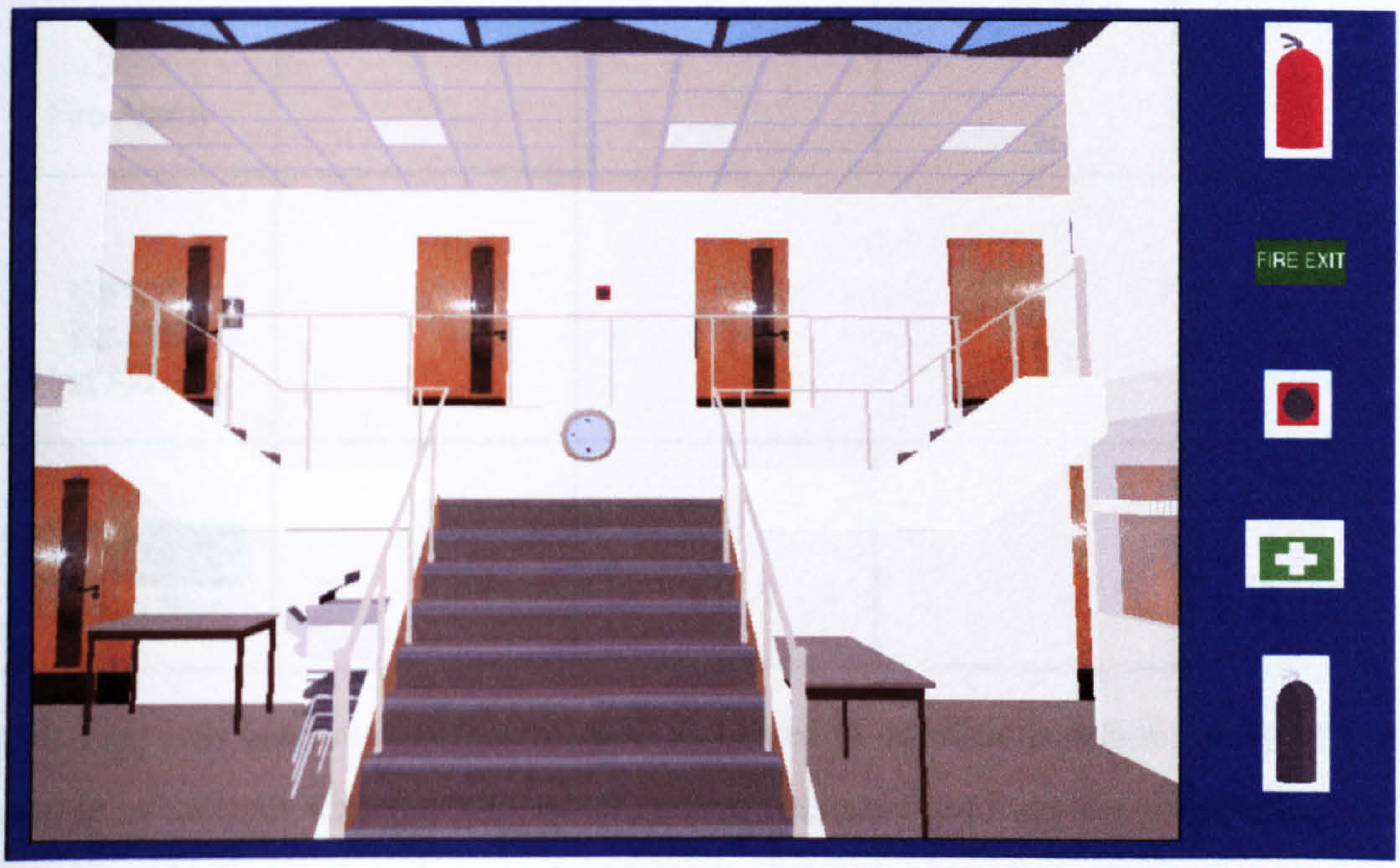
I confirm that I have read and understood the above description of the study and I agree to take part

Signed.. Date.......................

2. *All Experiments - Participant Instructions*

You will initially see a view similar to that on the picture below. In the task you have to perform you will take the guise of a health and safety officer who has arrived at the building to do a spot check on safety equipment existence and location.
You do not know the building and will have to explore all the possible rooms to search for the equipment indicated by the icons to the right of the screen (see the picture below: red fire extinguishers (h_20), fire exit signs, fire alarms, first aid box and black (co^2) fire extinguishers). When you find the equipment in the environment select it with the mouse and a green tick below the corresponding icon will indicate you have noted it down. Some rooms you can not enter as, as a safety officer you would not have suitable safety training or clothing.

You will move around the environment using the joystick and select items by clicking on them with the mouse. Please feel free to move around at your own speed, explore <u>everywhere</u> you can and interact with <u>whatever</u> you choose.



Thank you for your time.

NB: These instructions were adapted from this fundamental format according to the experiment the participant performed with respect to the level of interaction the participant experienced (experiments one and three) and if a task was not performed (experiments two, three, four). Where possible the same instructions were used.

3. Experiments One & Three - Participant Tick List

Please tick in the following boxes when you see the corresponding item in the environment you are about to see:

 Red Fire H2O Extinguisher				
 Black CO2 Fire Extinguisher				
 Fire Alarm				
 First Aid Box				
FIRE EXIT Fire Exit Sign				

NB: This was used in experiments one and three in conditions when the participant was unable to interact with the VE and therefore was unable to use the on screen tick list to monitor which search task items had been found and which had not.

4. All Experiments - General Questionnaire

Name________________________________

Gender M / F

Age__________

Occupation________________________________

Have you had any previous experience with VE or VR? Y / N

If so please describe here and indicate how often,

____

____

____

____

____

Are you familiar with the manufacturing engineering laboratories? Y / N

5. All Experiments - Presence Questionnaire

All answers were marked by the participant on the following 5 point scale:

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Please read the following questions or statements carefully. Please indicate how much you agree with each one by circling the appropriate point on the scale.

1. **I easily become deeply involved when watching films**
2. **I sometimes become so involved in a television programme or book that I am not aware of things happening around me**
3. **I often become so involved in a daydream that I am not aware of things happening around me**
4. **I sometimes become so involved in doing something that I lose all track of time**

The following questions or statement refer to the virtual environment you have just used. Your responses should be based on the equipment and environment you have just used.

5. **I had a strong sense of really 'being there' within the virtual environment.**
6. **I felt completely involved in the virtual environment.**
7. **I enjoyed being in the virtual environment.**
8. **I was able to control events in the virtual environment.**
9. **I felt more involved with the virtual environment towards the end of the experiment compared to the beginning of the experiment.**
10. **The environment reacted to my actions in a way that I expected.**
11. **I found that the input device distracted me from the virtual environment.**
12. **The visual display quality did not interfere or distract me from performing tasks in the virtual environment.**
13. **The visual display quality of the virtual environment increased my sense of feeling that I was actually in the virtual world.**
14. **At no point did I feel like I was actually 'in' the virtual environment.**
15. **I thought of the virtual environment as something that I saw.**

NB: The presence questionnaire was adapted slightly for conditions 'animation' and 'video' in experiment one as some questions referring to interaction within the VE were not applicable (throughout the words 'virtual environment' were replaced with 'display' and wording adjusted accordingly to make it generally applicable, questions 8, 10-12 and 15 were removed).

6. *All Experiments - Usability Questionnaire*

All answers were marked by the participant on the following 5 point scale (apart from Q 31 that required a written response from the participant):

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

1. **The objects within the virtual environment were very realistic**
2. **I did not experience any problems in getting used to the display**
3. **The virtual environment was too cluttered with objects**
4. **There were no distortions in the virtual environment images**
5. **I was happy with the way the display system showed the virtual environment**
6. **I found it difficult to learn how to use the virtual reality system**
7. **I found it easy to use the virtual reality system**
8. **I could effectively move around and manipulate objects in the virtual environment**
9. **Objects in the virtual environment did not move in a natural way**
10. **I would have preferred more control over the virtual environment**
11. **I think that I would feel uncomfortable using the system for long periods of time**
12. **The virtual environment did not respond to my actions immediately**
13. **The overall time it took for the virtual environment to respond to my actions did not affect my performance**
14. **It was not clear how I could perform different actions**
15. **I thought that the visual quality of the environment was good**
16. **The visual quality of the environment had a negative effect on my performance**
17. **I think that audio (sound) feedback (when used) improved my performance on the task**
18. **I did not notice any disturbing lag or delay between my movements of the controls and the response in the virtual environment to my actions**
19. **I interacted with the environment in a natural way**
20. **My general sense of presence (feeling of 'being there') in the virtual environment was high.**
21. **I could move easily through the virtual environment**
22. **I easily became lost or disorientated in the virtual environment**
23. **I was able to recognise all the objects in the virtual environment**
24. **The actions I could perform in the virtual environment were not obvious**
25. **After performing an action it was easy to see that the action was carried out**
26. **It was difficult to interact with objects in the virtual environment**
27. **When necessary I was unable to make precise movements in the virtual environment**
28. **I kept making mistakes whilst using the virtual environment**
29. **I found it difficult to correct any mistakes that I made**
30. **I felt that I performed the task well**
31. **What did you like/dislike about the virtual environment?**

NB: For the 'animation' condition in experiment one the usability questionnaire was adapted as it also referred to interaction (questions 6-8, 12-14, 16-19, 21, 24-30 were removed).

7. *Experiments Three, Four & Five – Enjoyment Questionnaire*

All answers were marked by the participant on the following 5 point scale:

Never Rarely Sometimes Often

Always

For each of the following adjectives, circle the word that indicates how much you felt that feeling whilst you were in the Virtual Environment

1. **Panicked**
2. **Exhilarated**
3. **Bored**
4. **Safe**
5. **Motivated**
6. **Scared**
7. **Happy**
8. **Trapped**
9. **Excited**
10. **Distressed**
11. **Lost**
12. **In control**

8. All Experiments - Short Symptom Checklist

Please read the following list of symptoms carefully and consider the scale provided.

If at <u>any</u> time during the experiment you feel you are experiencing any of the symptoms please tell the experimenter immediately.

Participation in this study is entirely voluntary and you may stop at any point if you do not wish to continue.

<u>Symptoms:</u>

- Headache
- Eyestrain
- Blurred vision
- Dizziness (eyes open)
- Dizziness (eyes closed)
- Sickness

0 5 10

None **Total**

Please tell the experimenter how you would rate your current feelings of each symptom.

9. *All Experiments - Subject Participation Record*

Virtual Reality Applications research Team

UNIVERSITY OF NOTTINGHAM

Study of the effectiveness of virtual reality training

I ______________________________ Have completed the experimental

session to study the effectiveness of virtual reality training and have received a payment of £5.

I confirm that any symptoms or effects I have reported during this experiment

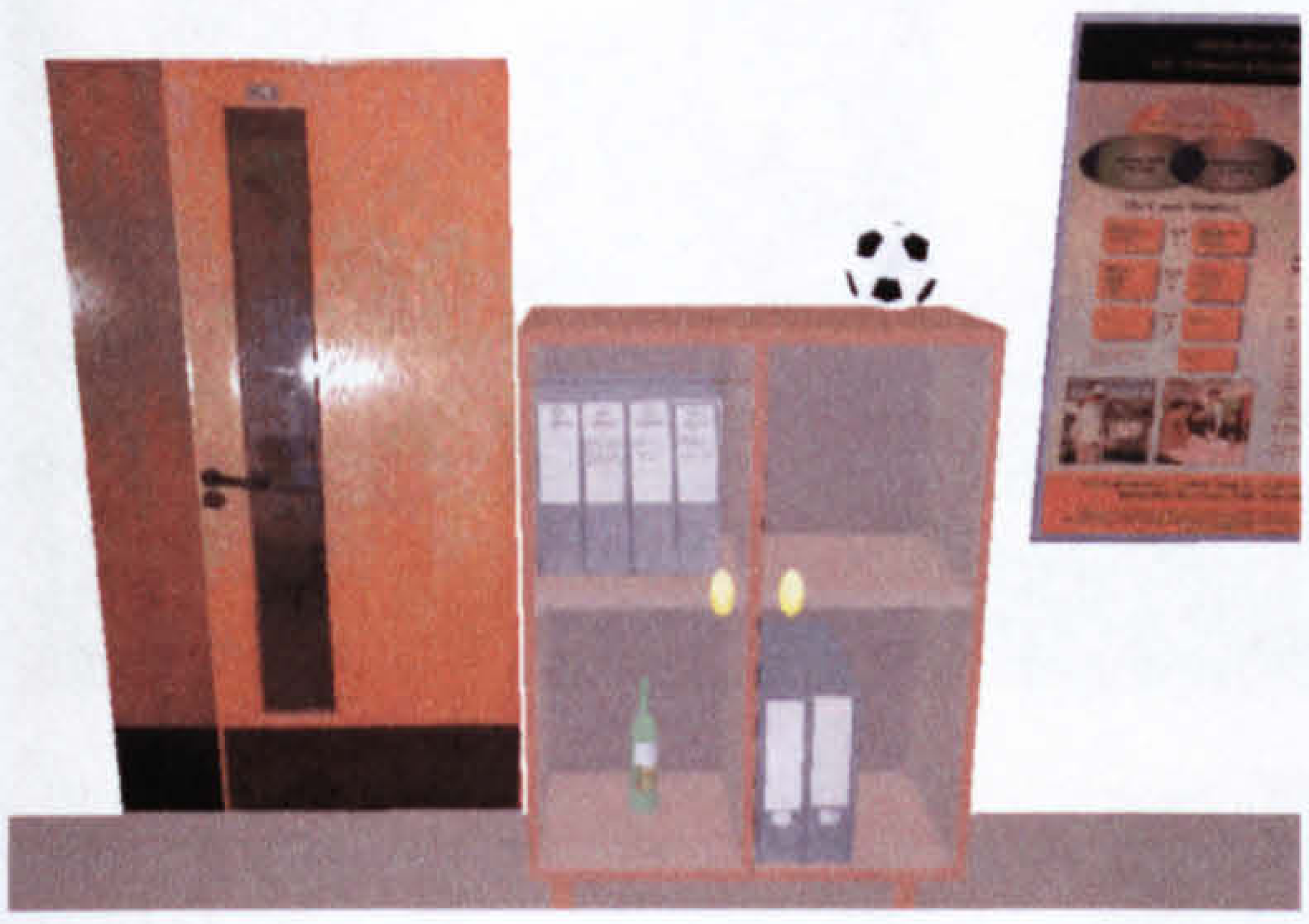
have subsided and I feel fit and able to leave the laboratory.

Signed___________________________________ date_____________

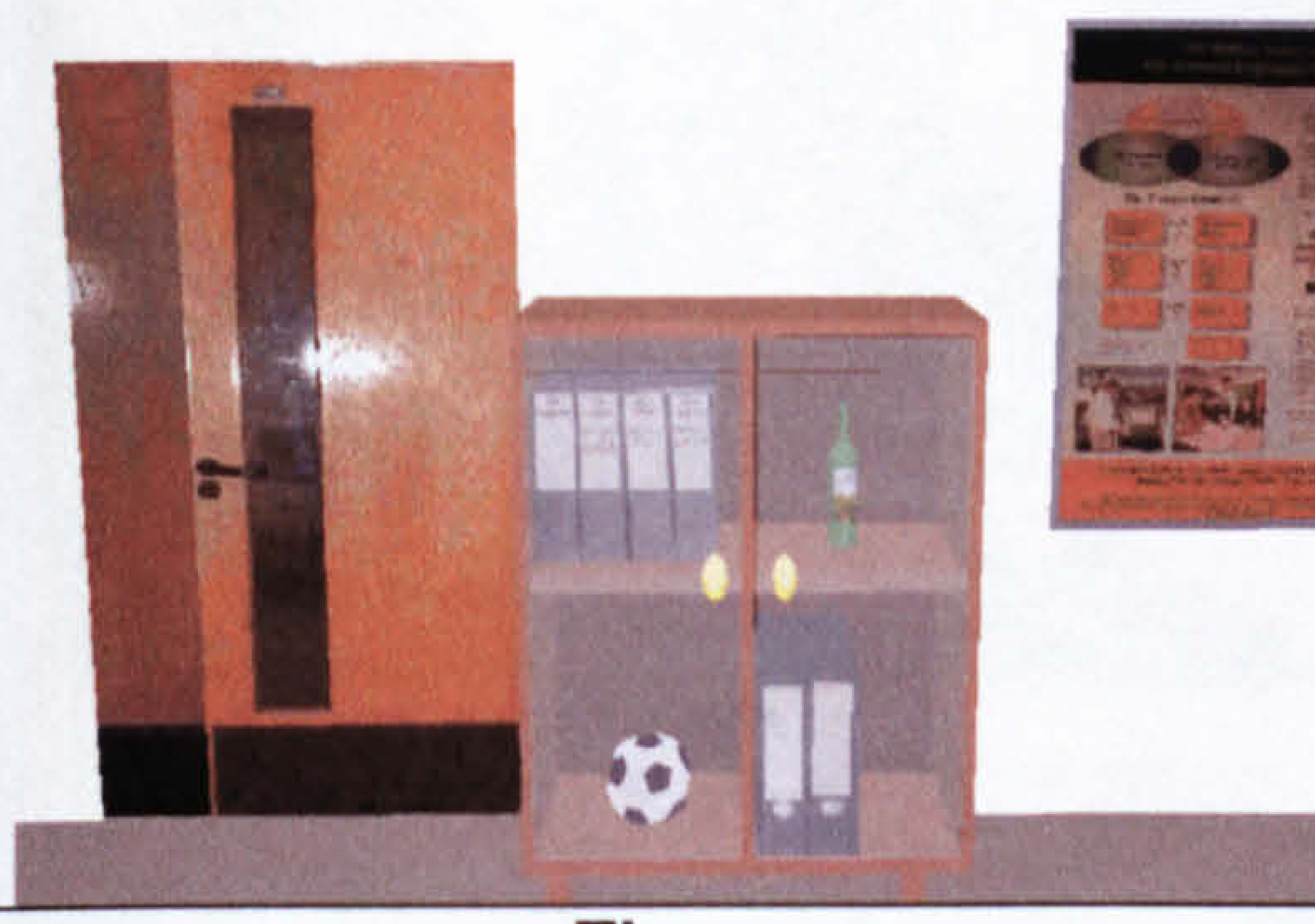
10. Experiment Three - Post Experiment Recall Questionnaire

One

A



B



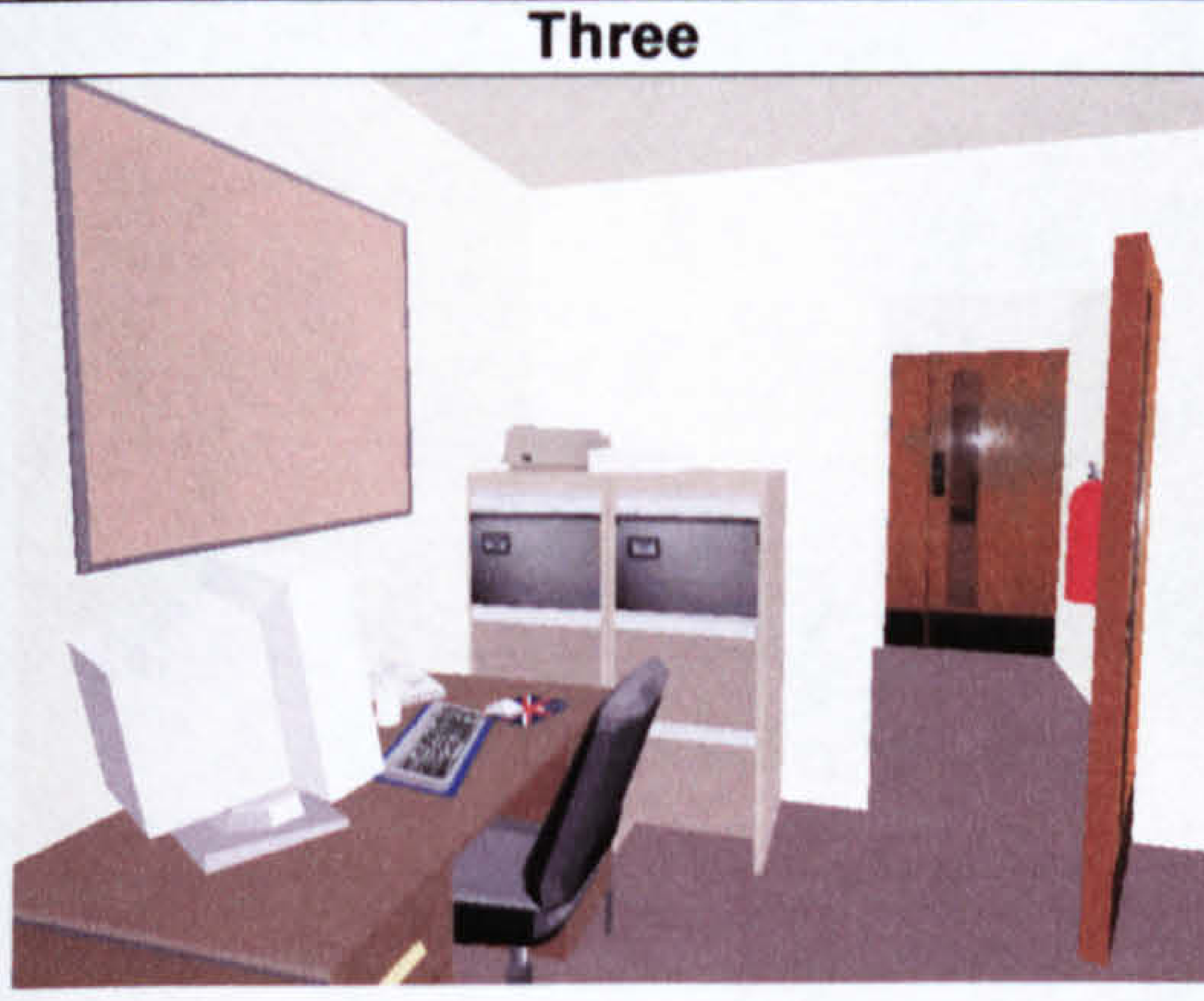
Two

A

B

Three

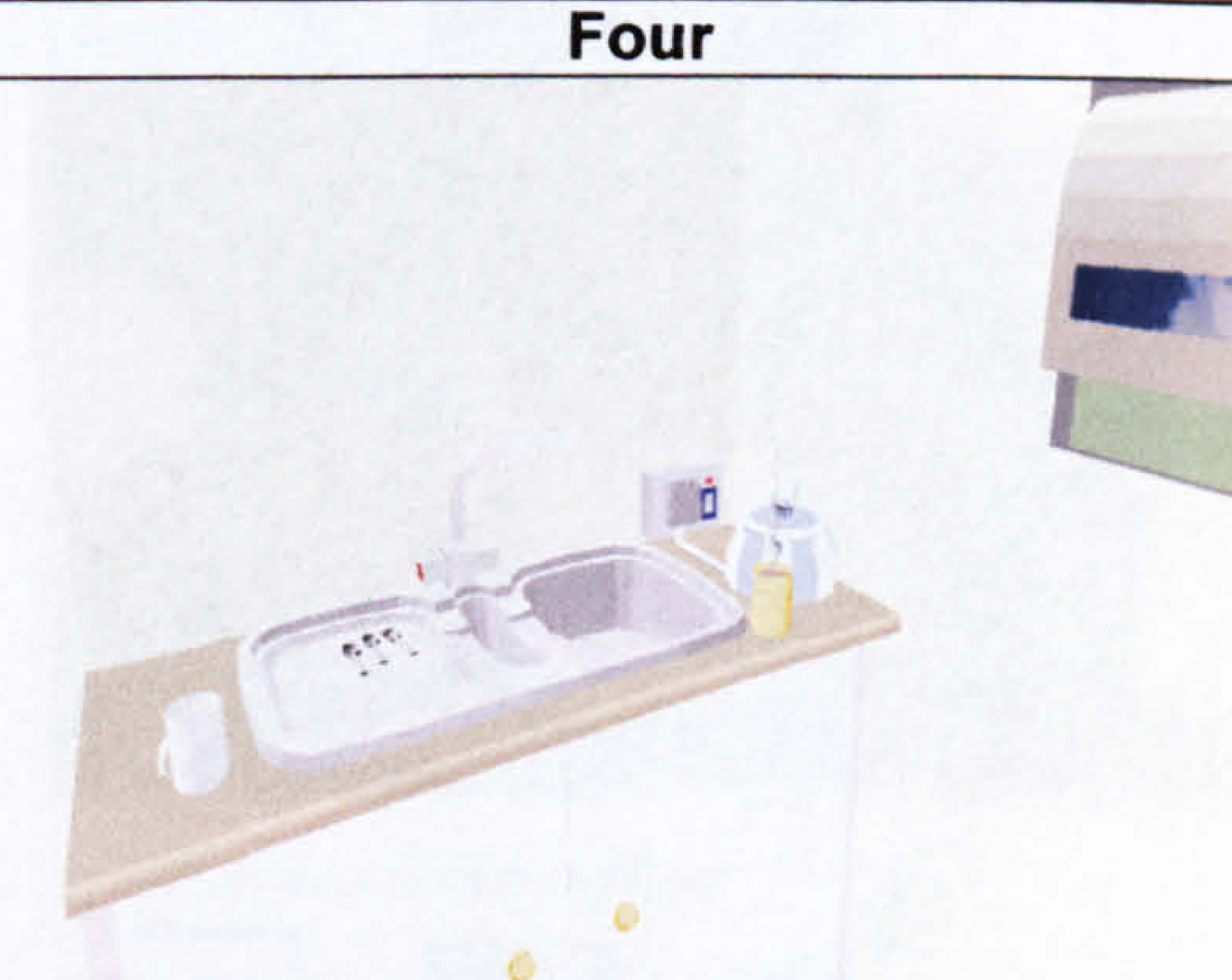
A



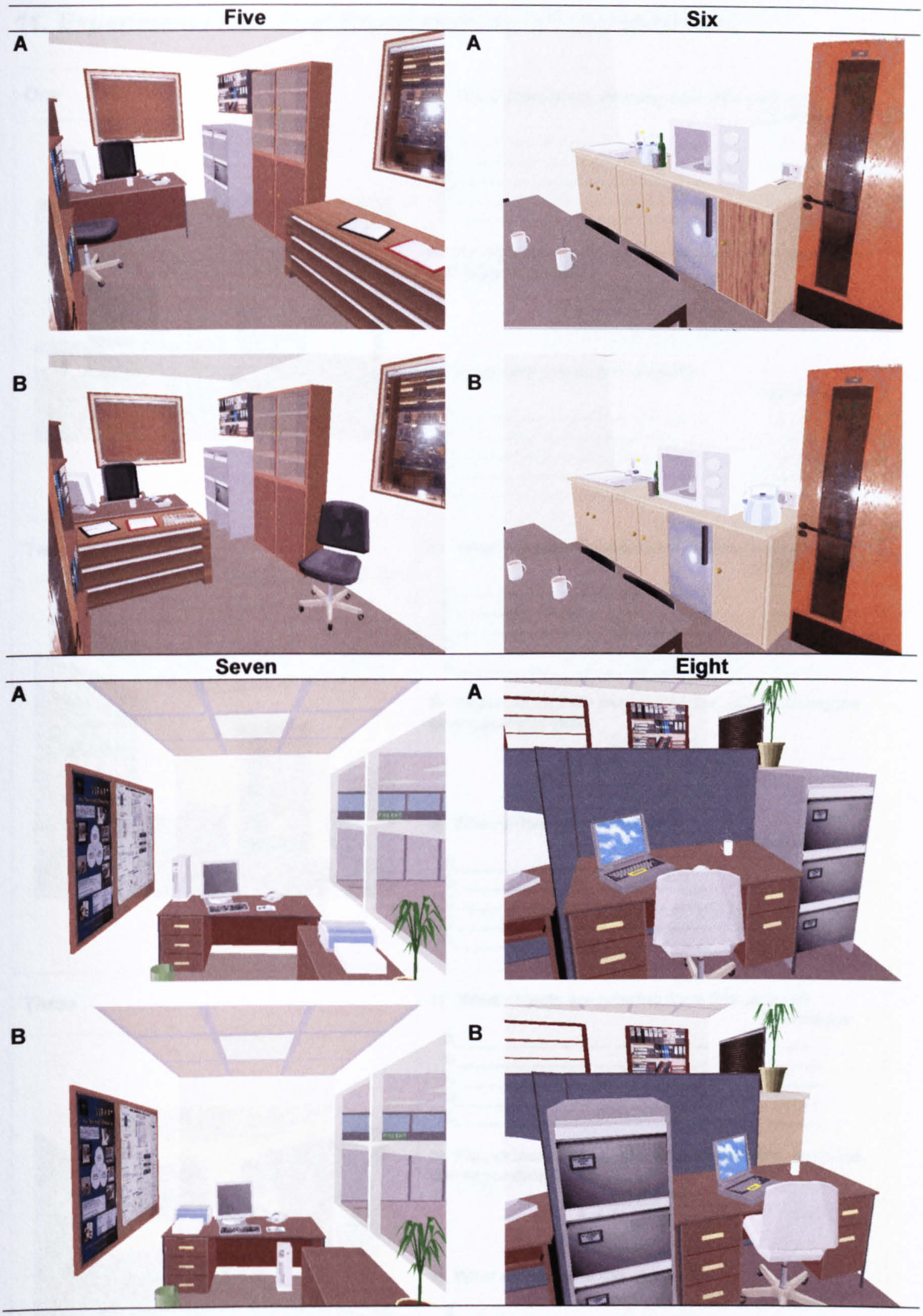
B

Four

A



B


Five
Six
A
A
B
B
Seven
Eight
A
A
B
B

11. Experiment Five - Post Experiment Recall Questionnaire

One

1) What objects are missing from this picture?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

2) Please mark their position on the picture using the corresponding letter.

Confidence

A	B	C	D	E

3) What colour were the objects?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

Two

1) What objects are missing from this picture?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

2) Please mark their position on the picture using the corresponding letter.

Confidence

A	B	C	D	E

3) What colour were the objects?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

Three

1) What objects are missing from this picture?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

2) Please mark their position on the picture using the corresponding letter.

Confidence

A	B	C	D	E

3) What colour were the objects?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

Four

1) What objects are missing from this picture?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

2) Please mark their position on the picture using the corresponding letter.

Confidence

A	B	C	D	E

3) What colour were the objects?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

Five

1) What objects are missing from this picture?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

2) Please mark their position on the picture using the corresponding letter.

Confidence

A	B	C	D	E

3) What colour were the objects?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

Six

1) What objects are missing from this picture?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

2) Please mark their position on the picture using the corresponding letter.

Confidence

A	B	C	D	E

3) What colour were the objects?

Confidence

A______________________ ____
B______________________ ____
C______________________ ____
D______________________ ____
E______________________ ____

Seven

1) **What objects are missing from this picture?**

	Confidence
A	
B	
C	
D	
E	

2) **Please mark their position on the picture using the corresponding letter.**

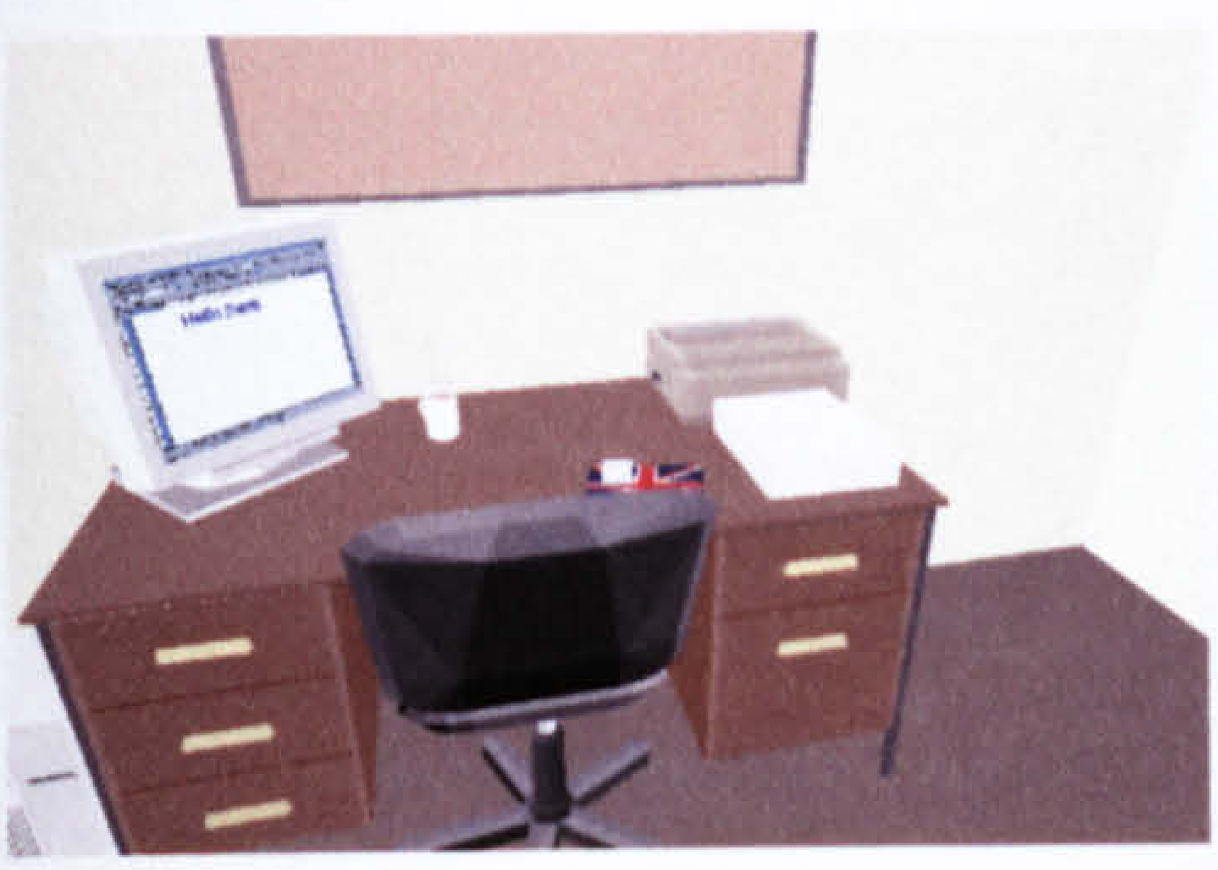
Confidence

A	B	C	D	E

3) **What colour were the objects?**

	Confidence
A	
B	
C	
D	
E	

Eight



1) **What objects are missing from this picture?**

	Confidence
A	
B	
C	
D	
E	

2) **Please mark their position on the picture using the corresponding letter.**

Confidence

A	B	C	D	E

3) **What colour were the objects?**

	Confidence
A	
B	
C	
D	
E	

Nine

1) **What objects are missing from this picture?**

	Confidence
A	
B	
C	
D	
E	

2) **Please mark their position on the picture using the corresponding letter.**

Confidence

A	B	C	D	E

3) **What colour were the objects?**

	Confidence
A	
B	
C	
D	
E	

Ten

1) **What objects are missing from this picture?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

2) **Please mark their position on the picture using the corresponding letter.**

Confidence

A	B	C	D	E

3) **What colour were the objects?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

Eleven

1) **What objects are missing from this picture?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

2) **Please mark their position on the picture using the corresponding letter.**

Confidence

A	B	C	D	E

3) **What colour were the objects?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

Twelve

1) **What objects are missing from this picture?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

2) **Please mark their position on the picture using the corresponding letter.**

Confidence

A	B	C	D	E

3) **What colour were the objects?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

Thirteen

1) **What objects are missing from this picture?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

2) **Please mark their position on the picture using the corresponding letter.**

Confidence

A	B	C	D	E

3) **What colour were the objects?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

Fourteen

1) **What objects are missing from this picture?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

2) **Please mark their position on the picture using the corresponding letter.**

Confidence

A	B	C	D	E

3) **What colour were the objects?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

Fifteen

1) **What objects are missing from this picture?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

2) **Please mark their position on the picture using the corresponding letter.**

Confidence

A	B	C	D	E

3) **What colour were the objects?**

Confidence

A____________________ _____
B____________________ _____
C____________________ _____
D____________________ _____
E____________________ _____

Appendix II

1. *Experiment One - Time Taken*

	Time taken (min:sec) SNC	NC
1	16.38	9.56
2	8.38	15.02
3	11.07	14.32
4	18.51	9.23
5	17.57	17.47
6	19.38	16.54
7	12.29	12.31
8	9.49	9.5

2. *Experiments One, Two Three, Four and Five - Presence Scores*

All answers were marked by the participant on the following 5 point scale:

Strongly Agree = 5	Agree = 4	Neutral = 3	Disagree = 2	Strongly Disagree = 1

*negatively worded questions have been accounted for.

Question:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SNC: exp one and two	**1**	3	2	2	3	4	4	5	5	4	4	4	4	4	5	4
	2	4	4	4	4	4	4	3	4	3	4	3	3	4	4	3
	3	4	4	4	4	4	3	4	3	4	4	2	4	4	2	4
	4	4	4	3	4	2	3	4	3	3	4	2	3	2	1	4
	5	4	2	2	4	4	3	3	4	3	4	4	4	2	2	3
	6	4	3	3	3	4	4	3	3	2	2	2	2	1	2	3
	7	4	4	3	5	2	3	4	2	5	3	1	5	2	1	4
	8	5	5	5	5	3	2	4	4	4	4	3	4	3	3	3
NC: exp one	**1**	4	5	3	5	3	3	4	5	3	5	2	4	4	2	5
	2	4	4	4	4	4	3	3	4	4	4	3	4	4	3	4
	3	4	5	3	2	4	4	4	4	2	3	4	2	4	4	4
	4	4	4	3	4	2	1	3	3	4	4	2	2	2	4	3
	5	3	3	3	4	2	2	4	3	4	3	2	2	3	2	3
	6	4	5	1	1	4	4	4	5	5	5	4	4	4	4	4
	7	4	4	4	3	4	4	4	4	3	4	4	4	5	4	4
	8	4	4	4	3	3	3	4	2	3	3	3	4	3	3	4
Animation: exp one	**1**	4	2	2	3	3	3	4	4	4	3	2				
	2	3	4	2	4	3	4	4	3	4	4	4				
	3	4	3	3	4	2	2	3	3	4	3	2				
	4	2	2	2	2	4	3	4	4	4	4	4				
	5	4	3	2	3	3	2	3	5	5	4	3				
	6	2	1	5	3	4	3	4	3	1	3	3				
	7	2	2	2	4	4	2	4	5	4	3	4				
	8	5	4	4	4	4	4	5	2	2	2	3				

Video: exp one	**1**	4	4	4	5	2	2	2	4	1	3	1				
	2	3	4	4	4	2	3	2	4	2	2	1				
	3	4	3	2	4	3	3	4	3	4	3	3				
	4	4	3	3	4	4	4	4	3	4	3	3				
	5	4	2	2	4	4	3	4	4	2	2	5				
	6	2	2	2	2	2	3	4	4	3	3	3				
	7	3	4	3	3	2	2	3	3	2	3	2				
	8	4	4	3	5	2	3	3	4	3	2	2				
FSNC: exp two	**1**	4	5	3	4	3	2	3	4	5	4	2	2	2	3	4
	2	5	4	2	4	3	3	4	5	5	4	2	4	4	3	4
	3	2	2	5	4	4	4	2	2	4	2	4	4	4	4	4
	4	2	1	2	4	3	4	4	4	4	4	5	4	4	3	2
	5	5	4	3	4	4	4	4	3	5	3	3	3	4	4	3
	6	5	4	3	4	5	5	5	4	3	4	4	2	4	4	4
	7	4	4	4	4	4	4	4	4	3	3	2	4	4	4	4
	8	3	3	2	4	4	4	3	4	2	4	4	4	4	2	4
SNC: exp three	**1**	4	4	2	3	5	4	5	5	5	4	4	4	4	4	5
	2	5	4	5	5	4	2	3	4	4	4	4	4	4	2	4
	3	3	4	2	4	3	4	4	2	4	4	3	3	4	3	4
	4	2	2	4	4	4	4	4	3	5	4	4	3	3	4	2
	5	4	4	4	3	4	2	3	2	4	4	2	4	4	4	4
	6	4	3	3	3	4	3	3	2	4	2	3	4	4	3	4
	7	4	5	4	4	4	4	4	4	2	5	5	4	4	4	4
	8	4	4	2	4	4	4	4	4	2	3	4	4	4	4	3
	9	4	4	3	4	3	4	4	5	4	4	2	5	4	2	5
	10	3	2	4	4	5	5	5	4	4	4	4	5	4	4	4
	11	3	4	2	4	4	4	4	4	5	5	4	4	3	4	4
	12	4	5	5	4	3	3	5	4	5	5	3	3	4	2	2
	13	4	4	2	5	4	4	4	5	4	4	2	5	5	4	5
	14	4	3	2	3	4	4	3	3	2	4	2	2	4	3	4
	15	1	2	5	4	2	2	3	2	4	4	4	2	3	1	2
NC: exp three	**1**	2	1	3	1	5	4	4	4	3	4	4	5	4	4	4
	2	4	3	4	3	4	4	4	3	4	4	3	3	2	3	4
	3	4	3	5	5	3	4	4	4	2	4	5	2	4	2	4
	4	4	3	3	3	3	4	4	3	4	3	3	4	4	2	4
	5	4	3	4	3	3	3	4	3	4	4	3	4	3	3	4
	6	3	4	2	3	4	4	4	3	4	4	3	3	4	2	4
	7	4	3	3	4	3	3	4	4	3	3	5	5	4	1	5
	8	4	4	3	3	3	3	2	2	4	3	3	2	4	3	5
	9	4	3	3	3	4	4	3	2	3	4	2	2	4	3	3
	10	5	5	5	5	4	4	4	3	4	2	2	4	2	2	3
	11	5	4	5	3	4	4	4	2	5	4	4	4	4	2	4
	12	5	4	3	4	4	4	5	4	5	4	3	4	4	2	4
	13	4	3	2	4	4	4	3	4	4	5	4	4	4	4	4
	14	2	2	2	3	3	3	4	3	4	4	5	1	3	3	4
	15	3	2	2	3	3	4	4	4	3	5	4	4	3	1	3

FSNC: exp three	**1**	4	4	4	3	4	4	4	4	3	3	4	4	4	4	3
	2	3	2	4	4	2	2	4	2	4	2	4	4	2	4	4
	3	4	4	4	5	4	4	4	4	4	4	4	3	3	4	3
	4	4	3	5	2	4	4	4	4	5	3	3	4	3	4	3
	5	5	3	5	5	3	2	4	4	4	4	2	4	4	4	3
	6	4	4	3	3	3	4	4	3	4	4	4	4	4	2	3
	7	4	4	2	4	4	3	4	2	2	4	4	4	4	4	4
	8	4	4	3	4	3	3	4	4	3	4	4	3	2	2	2
	9	4	5	4	5	4	5	5	3	3	4	4	3	4	3	4
	10	4	4	3	4	2	2	3	4	3	4	2	4	2	2	4
	11	5	4	3	4	4	3	4	4	2	4	4	4	2	4	2
	12	4	4	4	4	4	4	4	4	2	4	4	2	4	4	4
	13	4	4	3	5	4	3	4	4	4	4	3	3	3	4	2
	14	4	3	3	4	5	5	4	2	3	3	3	2	4	1	4
	15	4	4	3	4	3	3	2	3	4	4	3	3	4	2	3
SNC – Abs: exp four	**1**	4	4	2	4	3	4	4	3	4	2	3	2	4	4	4
	2	3	3	4	5	2	3	3	2	4	2	4	2	4	1	2
	3	4	4	2	3	2	2	3	4	3	4	4	1	4	1	5
	4	4	5	4	5	3	2	4	4	5	3	2	4	2	4	3
	5	4	4	2	2	5	4	4	4	3	2	2	5	4	3	4
	6	4	4	2	2	3	3	4	4	4	3	3	4	2	4	3
	7	4	3	4	4	4	4	4	5	4	4	4	4	4	4	2
	8	4	4	2	3	1	2	3	2	4	1	4	4	2	2	4
	9	4	4	4	3	3	3	4	4	5	3	3	5	4	2	4
	10	3	4	3	4	3	3	4	4	4	3	4	4	2	2	3
FSNC – Abs: exp four	**1**	3	4	3	4	2	2	3	4	4	2	2	4	3	1	4
	2	4	4	3	5	2	2	4	5	4	5	2	5	2	2	3
	3	4	2	3	4	4	3	4	5	5	3	4	5	4	4	4
	4	4	4	3	4	2	1	3	3	4	3	2	4	2	1	4
	5	2	3	2	4	4	4	4	4	5	4	4	3	4	3	4
	6	4	4	4	4	3	3	4	4	4	4	4	4	3	2	4
	7	4	4	3	4	5	5	4	4	5	4	4	4	3	3	4
	8	4	3	5	2	4	3	4	4	4	2	3	4	3	4	4
	9	5	5	3	5	2	4	4	4	4	4	2	1	1	1	4
	10	4	4	2	4	2	3	4	2	4	2	2	5	3	2	4

SNC – cued: exp five	1	3	3	2	2	3	2	2	2	4	4	2	2	4	3	4
	2	4	2	2	2	3	2	4	4	4	3	4	4	4	4	4
	3	4	4	4	3	4	4	4	3	4	4	4	4	4	4	4
	4	4	4	2	4	4	4	3	4	4	4	4	5	3	3	4
	5	3	2	2	4	4	4	4	4	5	4	3	4	4	3	4
	6	4	4	3	5	5	5	5	4	5	4	4	4	4	4	4
	7	4	4	4	4	2	4	4	4	5	4	2	4	2	2	4
	8	3	3	4	4	4	3	5	4	4	3	4	5	2	2	4
	9	4	4	3	4	3	3	4	4	4	3	3	4	4	4	4
	10	2	5	4	2	2	4	4	5	4	4	2	2	5	2	4
	11	4	4	4	5	2	2	4	2	3	2	1	4	2	1	3
	12	3	2	2	4	4	3	5	4	3	4	4	4	4	4	4
SNC – not cued: exp five	1	4	3	4	3	3	3	4	4	4	4	2	2	3	3	4
	2	4	4	4	5	4	4	4	4	4	3	2	5	5	3	4
	3	4	4	4	4	2	2	4	4	3	4	2	5	3	2	2
	4	4	3	4	4	2	2	3	5	2	5	3	4	3	2	4
	5	3	2	2	4	1	2	2	3	2	3	2	1	1	1	4
	6	4	3	2	4	4	4	4	4	4	4	4	4	4	3	4
	7	5	5	3	5	5	4	5	4	2	3	3	5	4	4	4
	8	4	4	4	4	4	3	4	4	4	5	3	3	3	4	4
	9	4	5	5	5	4	3	4	4	5	4	1	2	3	4	2
	10	5	4	2	4	4	3	5	4	4	4	4	4	4	2	4
	11	5	5	4	5	5	4	5	4	3	3	4	3	4	4	5
	12	3	4	3	5	4	3	5	5	5	4	2	3	4	2	5
	13	4	4	4	4	3	3	2	4	3	4	4	4	4	4	5
	14	3	4	4	3	4	3	4	4	2	4	5	4	3	3	2
	15	5	5	4	4	3	4	3	4	3	4	2	4	3	2	4
	16	4	4	3	4	3	3	4	4	2	4	2	3	3	3	2
	17	4	2	4	3	4	4	4	3	4	3	4	4	4	4	3
	18	4	4	3	4	4	4	4	4	3	4	3	3	3	3	2

3. *Experiments One, Two Three, Four and Five - Usability Scores*

All answers were marked by the participant on the following 5 point scale:

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
= 5	= 4	= 3	= 2	= 1

*negatively worded questions have been accounted for.

	Question:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
SNC: exp one and two	1	4	4	4	4	4	5	5	4	5	3	5	4	4	5	4	5	3	4	4	4	4	4	5	4	5	5	4	4	4	4
	2	4	4	4	3	4	4	4	4	4	2	2	4	3	4	4	3	2	4	3	3	4	3	4	4	4	3	4	4	4	5
	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	3	5	4	4	4	2	4	4	4
	4	2	5	4	2	3	5	4	3	4	1	3	5	4	5	3	4	2	3	4	2	3	4	5	5	4	4	2	4	4	4
	5	4	4	3	4	4	5	4	4	4	2	1	4	5	3	4	5	2	4	3	4	4	3	5	4	4	3	4	4	2	3
	6	3	3	3	2	2	3	2	2	3	2	2	2	4	3	3	2	2	2	2	2	2	2	3	3	3	3	4	3	2	3
	7	4	4	4	3	4	3	2	1	3	2	1	3	3	4	4	4	3	4	2	2	3	3	4	3	4	4	3	2	3	2
	8	2	4	4	4	4	4	4	4	3	3	4	4	4	4	3	3	3	4	3	3	4	4	5	2	5	4	3	5	4	4
NC: exp one	1	5	5	4	4	5	5	5	5	4	3	4	3	4	3	5	4	4	4	4	3	5	4	4	3	5	3	4	4	3	4
	2	4	4	3	4	3	4	3	3	3	3	3	4	4	4	4	3	4	4	3	4	4	4	4	4	4	3	4	3	3	4
	3	5	4	5	5	4	4	4	4	4	3	4	3	3	3	5	4	3	3	4	4	4	3	4	4	4	3	2	4	3	4
	4	3	2	5	2	2	4	4	4	1	3	2	1	2	3	3	4	5	2	3	4	2	2	4	4	3	4	2	3	2	4
	5	2	3	2	2	2	3	3	3	3	2	1	2	3	3	2	3	5	2	3	2	2	2	2	3	3	2	3	2	2	3
	6	4	5	4	5	5	4	4	5	3	4	4	4	3	5	5	4	4	4	4	5	5	3	5	4	5	5	1	5	5	5
	7	5	4	4	4	5	5	4	5	5	4	2	4	2	4	5	5	3	4	4	4	4	4	5	4	4	4	2	3	4	3
	8	3	4	4	4	4	4	4	3	3	3	3	4	4	4	4	4	3	4	3	3	3	3	4	3	3	2	4	3	3	4
Animation: exp one	1	4	4	3	3	4	3	3	3	3	4	4	3																		
	2	3	4	4	4	4	4	4	3	4	3	3	4																		
	3	3	4	3	2	3	3	3	4	4	3	3	4																		
	4	4	2	4	2	4	4	4	4	4	4	4	5																		
	5	5	4	5	5	5	4	1	2	5	4	2	5																		
	6	4	4	4	2	4	4	2	4	4	4	4	4																		
	7	4	4	4	3	4	4	2	2	5	4	4	2																		
	8	4	5	5	4	4	4	2	2	4	4	4	4																		

FSNC: exp two	1	4	4	3	2	3	4	4	3	4	2	4	4	4	4	3	3	3	4	2	3	2	4	4	4	4	4	1	4	4	4
	2	4	5	4	4	4	5	5	5	4	2	4	4	4	4	4	4	3	4	4	3	4	4	4	2	4	4	2	4	4	4
	3	3	3	4	2	4	2	2	3	2	3	2	2	2	2	4	3	3	4	2	4	2	2	4	3	4	4	4	2	3	2
	4	4	5	2	2	4	5	5	4	2	1	4	3	2	3	4	4	4	4	3	4	4	5	4	3	5	4	5	4	5	4
	5	4	3	3	5	5	2	3	4	4	2	2	3	3	3	5	4	3	1	2	4	2	2	5	2	4	3	5	2	4	3
	6	5	5	1	2	4	5	5	5	4	3	4	4	4	5	4	5	4	2	4	5	4	4	5	4	4	4	4	4	5	5
	7	4	4	4	3	4	4	4	4	4	2	3	4	4	4	4	4	4	4	4	4	3	3	4	4	4	4	4	4	4	4
	8	3	4	4	4	3	4	4	2	3	1	2	4	2	4	5	5	2	4	4	3	2	4	5	4	4	5	2	5	4	4
SNC: exp three	1	4	5	3	4	5	4	5	5	4	2	5	3	4	4	4	4	1	3	4	5	5	4	5	3	5	4	2	2	5	5
	2	4	4	4	4	4	4	4	4	4	4	2	2	4	4	4	4	3	2	4	3	4	4	4	4	4	2	4	4	4	4
	3	4	2	4	4	4	4	4	4	4	2	4	2	2	2	4	4	4	3	2	3	2	2	5	2	2	3	2	3	2	3
	4	3	4	4	1	4	4	4	3	4	4	4	4	2	5	3	4	3	4	4	3	4	3	4	4	4	4	2	3	2	3
	5	4	2	3	4	4	3	3	2	3	2	3	4	4	3	4	4	4	4	4	4	3	4	4	2	4	3	2	2	3	3
	6	2	4	3	4	4	3	4	2	3	2	2	2	4	3	4	3	3	2	4	3	2	3	4	2	3	2	2	2	2	3
	7	4	5	4	4	4	5	5	5	4	4	4	5	5	4	5	4	3	5	4	4	5	5	4	4	5	4	4	4	4	5
	8	4	4	4	2	3	4	4	2	3	4	4	4	4	4	3	4	3	4	2	4	2	4	4	4	4	4	2	3	4	4
	9	4	3	3	4	5	4	4	4	4	2	4	4	4	4	4	3	4	4	4	4	4	4	2	3	4	4	2	2	4	3
	10	5	5	4	2	5	5	5	5	3	3	5	4	4	4	4	4	1	4	4	4	5	4	4	4	5	4	2	4	4	4
	11	4	5	4	4	4	5	5	4	4	4	4	4	4	5	4	5	3	4	4	4	3	5	4	4	4	4	3	2	4	3
	12	3	5	4	4	3	5	4	4	3	3	5	4	4	4	4	4	3	3	4	4	4	5	5	4	5	5	5	5	5	3
	13	5	5	2	4	5	5	4	5	5	4	3	5	5	4	5	5	4	5	5	5	4	4	5	4	5	4	4	2	4	3
	14	4	4	3	2	3	4	4	4	4	2	1	3	3	4	3	2	4	4	4	3	3	3	4	2	4	4	2	3	2	4
	15	3	5	4	3	3	5	5	5	3	2	3	3	3	4	3	4	3	3	2	2	4	4	5	4	4	4	4	4	3	4
NC: exp three	1	5	4	5	4	5	4	4	4	4	4	4	4	4	4	5	4	3	4	4	5	5	4	5	3	5	4	4	4	4	4
	2	4	4	3	4	3	4	4	4	3	2	3	4	3	3	4	4	4	4	4	4	4	2	3	4	3	2	2	2	2	2
	3	5	5	4	2	4	5	5	4	4	3	2	5	4	5	3	4	3	5	3	2	3	5	5	4	5	4	4	4	4	3
	4	4	2	3	3	4	4	3	4	3	3	3	3	4	3	4	4	3	3	4	3	4	3	4	3	4	4	2	4	3	3
	5	5	4	2	4	4	3	4	3	4	3	4	3	2	4	4	3	4	5	4	3	4	3	3	4	2	4	3	2	4	3
	6	3	5	3	3	4	3	2	3	3	2	4	4	3	4	4	4	3	2	4	4	3	3	4	3	3	4	3	3	4	3
	7	4	4	5	2	4	4	4	4	2	4	4	4	4	4	5	5	3	4	1	2	4	4	4	4	5	4	1	4	4	4
	8	4	2	3	3	3	2	2	3	3	2	2	2	3	3	3	4	4	2	4	3	2	2	4	4	3	3	2	2	3	2
	9	4	4	3	4	3	4	4	3	2	2	2	3	4	2	2	3	3	4	4	3	3	3	4	4	4	3	3	3	2	4
	10	2	4	2	4	3	3	3	2	1	2	2	1	5	1	3	3	3	4	1	1	2	1	2	1	2	4	1	2	2	3
	11	2	5	4	2	4	4	5	5	4	4	1	5	2	4	4	5	3	5	5	4	4	4	5	5	5	4	5	1	4	3
	12	4	4	4	2	4	4	5	4	3	2	4	4	4	3	4	4	3	4	4	4	4	4	5	3	4	4	3	4	4	4
	13	4	3	4	4	4	5	5	4	4	3	1	5	4	5	4	4	2	5	4	4	5	4	5	5	5	5	4	4	5	4
	14	4	4	4	4	4	4	4	4	4	2	4	4	3	4	3	4	3	2	3	3	3	2	4	4	3	3	3	3	2	3
	15	4	4	5	4	4	5	5	5	4	4	4	5	4	5	4	4	3	4	4	4	4	5	4	5	4	4	4	4	4	4

FSNC: exp three	1	4	4	4	4	4	4	4	4	4	3	3	4	4	2	4	4	4	4	3	3	4	2	3	2	4	3	2	2	3	4
	2	2	2	4	4	2	3	3	2	2	2	4	4	2	4	2	3	4	4	4	2	2	2	4	4	4	2	2	2	2	2
	3	4	4	4	2	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	3	5	4	4	4	3	2	4	4
	4	4	3	4	3	4	4	4	4	3	2	4	4	5	5	4	4	4	4	3	4	4	5	4	4	4	4	3	3	3	3
	5	4	4	4	2	4	4	4	4	4	2	4	4	4	2	4	4	3	4	4	3	4	5	4	3	4	4	4	4	4	4
	6	3	3	3	4	4	3	3	4	3	2	3	4	3	4	4	3	4	3	4	3	3	3	4	2	4	2	3	3	2	3
	7	5	4	4	2	4	5	5	5	4	1	4	3	4	4	4	4	4	4	4	4	4	4	5	3	4	4	2	4	4	4
	8	4	4	4	2	4	4	4	3	3	2	4	3	4	2	4	4	4	4	4	4	4	4	5	4	4	4	3	4	4	5
	9	3	4	4	4	4	5	4	4	2	2	4	3	4	3	3	4	2	2	4	4	4	5	4	2	4	3	2	3	4	4
	10	2	4	3	1	3	5	5	4	2	1	2	3	2	4	3	4	4	1	3	2	4	4	4	4	4	4	2	4	3	4
	11	3	4	4	1	4	5	4	4	4	3	2	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	2	4	4	4
	12	4	4	4	2	4	4	4	4	4	2	2	4	4	2	4	4	3	4	4	4	4	4	4	2	4	4	2	4	4	4
	13	4	2	4	2	3	5	5	4	2	2	4	2	2	4	4	4	2	3	3	4	4	4	2	4	4	4	4	4	4	3
	14	3	4	2	4	3	3	4	4	3	2	1	2	2	2	3	2	2	4	3	4	4	3	4	2	4	3	3	2	4	3
	15	3	3	4	2	3	3	3	2	2	2	3	3	4	2	4	3	4	3	2	2	3	3	3	2	3	3	2	3	2	3
SNC – Abs; exp four	1	4	3	3	2	4	4	3	2	4	2	4	2	2	3	4	4	4	3	2	3	3	4	4	3	4	4	2	2	4	3
	2	2	4	4	2	2	4	4	2	2	1	2	4	3	2	3	3	4	4	4	2	3	2	3	1	4	2	2	3	3	2
	3	4	5	5	4	5	5	5	4	4	2	4	5	5	3	4	4	4	5	4	3	4	5	5	2	3	4	4	5	5	4
	4	2	4	4	2	4	3	2	2	3	2	2	2	4	1	2	4	5	4	1	2	2	2	5	4	4	4	1	2	2	4
	5	4	4	4	4	5	2	2	3	4	4	2	4	4	2	4	4	4	4	4	3	4	4	4	2	4	2	2	2	4	3
	6	2	3	4	4	4	3	2	3	2	2	4	4	4	2	3	4	4	4	2	3	3	4	3	2	4	2	2	2	2	2
	7	2	5	4	4	4	5	4	4	4	2	3	2	4	4	4	4	3	3	2	4	4	4	4	4	3	3	2	4	4	4
	8	1	4	3	3	4	5	5	1	2	2	2	1	3	1	4	4	4	4	2	2	4	5	2	2	2	1	2	4	4	4
	9	2	5	4	5	4	4	4	4	2	2	2	4	4	4	4	4	4	4	3	3	4	4	3	4	5	4	2	3	3	3
	10	2	2	4	3	4	3	2	2	4	4	4	4	4	4	4	4	4	4	4	2	3	2	3	3	3	4	2	1	4	3
FSNC – Abs: exp four	1	2	4	4	3	4	3	4	4	2	2	4	3	4	2	2	4	4	4	4	3	3	4	2	2	4	3	2	2	4	3
	2	3	5	4	4	5	5	4	4	4	4	4	4	5	4	4	5	4	5	4	3	4	5	4	3	4	4	4	4	4	4
	3	4	5	4	3	4	4	4	4	4	4	3	4	4	4	5	4	4	4	4	4	4	4	4	4	3	4	4	3	4	4
	4	3	2	3	4	4	2	2	2	4	2	3	4	3	2	4	4	4	4	2	2	3	2	3	2	2	3	1	1	2	2
	5	4	5	4	4	4	4	5	4	1	4	1	4	4	4	4	4	5	5	4	3	4	4	4	4	5	4	5	5	4	4
	6	2	3	4	2	4	4	3	2	3	4	2	4	3	3	4	4	4	5	4	2	4	2	4	2	3	2	3	2	4	3
	7	3	4	3	4	4	4	4	4	2	2	1	4	4	4	4	4	2	5	4	4	4	4	4	3	4	4	4	4	4	4
	8	1	4	3	4	4	4	4	4	5	2	3	4	3	4	3	4	3	4	4	3	4	4	4	2	4	4	2	2	4	3
	9	1	4	3	2	1	4	4	4	4	2	4	4	4	2	1	2	3	4	3	2	4	4	4	1	4	2	3	3	3	4
	10	1	5	4	4	4	4	3	4	3	2	3	4	4	4	4	4	3	5	2	2	3	2	4	4	5	4	4	1	2	2

SNC – cued: exp five	1	4	4	4	3	3	4	4	2	4	2	4	4	4	4	3	3	4	3	4	2	3	2	3	2	4	2	2	3	3	4
	2	5	5	3	4	5	5	5	5	5	4	4	4	4	4	5	4	3	4	4	4	5	3	5	4	4	4	4	3	4	4
	3	4	4	4	2	4	4	4	3	3	2	2	4	4	3	4	4	2	2	2	4	4	4	4	2	3	4	2	3	4	4
	4	4	3	5	5	4	4	4	4	4	4	1	4	4	5	5	5	3	2	3	2	3	4	4	4	5	4	3	4	4	4
	5										3	2	4	4	3	4	4	3	2	3	3	4	4	5	4	4	3	3	3	2	3
	6	4	4	4	3	4	4	4	4	4	3	4	4	4	4	4	4	3	3	4	4	4	4	4	3	4	4	4	4	4	4
	7	4	4	4	2	4	4	4	4	4	3	2	4	4	4	4	4	4	4	2	2	4	2	4	4	4	4	4	4	4	4
	8	4	5	4	3	4	4	4	4	4	4	4	4	4	4	4	4	3	3	4	3	4	4	5	3	4	4	2	4	4	4
	9	3	4	4	2	4	4	4	3	4	2	2	2	4	4	4	4	3	2	2	4	4	4	4	4	4	4	2	2	4	3
	10	4	2	5	4	4	2	2	4	4	4	1	4	5	5	4	4	4	4	4	2	2	4	4	4	5	4	2	2	4	3
	11	2	4	4	1	3	4	5	2	2	2	2	4	4	3	3	4	2	4	2	2	4	5	4	2	4	3	2	4	4	4
	12	4	4	4	3	4	4	4	4	4	1	3	2	4	3	4	4	4	4	4	4	4	5	5	4	5	4	4	4	5	5
SNC – not cued: exp five	1	3	4	3	4	4	4	4	3	3	3	2	3	2	3	3	4	4	2	3	3	3	3	4	2	3	2	3	3	4	3
	2	4	5	5	3	4	4	3	3	4	2	5	2	1	4	4	5	3	2	2	4	2	5	5	4	4	3	1	2	2	2
	3	4	5	4	2	4	5	5	4	4	3	4	4	3	4	3	4	3	4	4	2	4	4	4	4	4	4	3	4	4	5
	4	3	5	5	4	3	5	5	5	3	3	4	2	2	4	3	4	2	2	4	3	3	4	4	4	4	4	4	4	4	4
	5	4	4	3	2	1	4	3	2	3	2	2	2	1	3	2	2		1	2	2	2	3	4	2	4	3	2	4	3	4
	6	5	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4		4	4	4	4	4	4	3	4	4	3	4	3	4
	7	4	4	4	4	4	4	4	3	3	3	2	3	4	3	5	4	3	3	4	4	4	4	4	4	3	4	3	4	3	4
	8	4	4	4	4	3	4	4	5	4	3	4	3	3	4	4	4	4	3	4	4	4	4	4	3	5	4	4	4	4	4
	9	3	4	4	2	3	3	2	3	3	2	2	3	4	4	4	3	2	4	3	3	2	4	4	4	4	4	4	2	4	4
	10	4	3	4	2	4	4	4	4	4	2	4	3	4	3	4	4	2	4	3	4	4	4	4	2	4	3	4	4	4	4
	11	3	2	4	2	4	3	2	4	4	3	4	3	4	2	4	4	2	4	4	4	3	2	4	3	4	4	1	2	2	4
	12	5	4	3	3	5	4	4	4	4	3	4	4	4	4	4	4	3	4	4	3	4	5	5	4	5	4	3	4	3	4
	13	4	4	4	3	4	4	3	3	3	2	3	4	4	4	4	4	4	3	3	3	2	2	5	2	5	3	3	2	4	2
	14	2	5	4	4	3	4	4	4	3	3	2	5	5	2	3	5	3	5	2	4	4	4	5	2	4	3	3	2	4	4
	15	3	4	2	2	4	4	4	4	4	3	2	3	4	4	3	4	2	4	4	4	4	4	4	4	4	4	2	4	4	4
	16	4	4	4	2	4	3	4	4	3	2	1	2	3	2	3	3	4	2	4	3	3	3	4	1	4	3	1	3	4	4
	17	4	4	3	2	3	4	4	4	3	2	4	3	4	3	4	4	4	3	4	4	2	4	4	3	4	3	4	3	4	3
	18	3	3	4	3	4	5	5	4	1	2	1	1	1	5	4	4		1	4	3	3	4	4	4	3	3	1	2	4	4

4. *Experiments One, Two Three, Four and Five - Usability Written Responses*

Question 31: What did you like/dislike about the virtual environment?

Group	No.	Response
SNC: exp one and two	1	The quality of the images was great. The environment was interesting with loads of features. No dislikes.
	2	Visual quality generally good might help if there is sound feedback.
	3	Like; That ticks don't appear again if the objects have been selected before, the VE itself. Dislike; some of the rooms were too close together and when you go into some of the rooms there is not much space to turn around.
	4	Disliked; couldn't sidestep, could only turn left and right not just move that way sometimes difficult to move round objects. Liked; being able to open cupboards, use keyboards etc. which were not related to the task.
	5	Movement seemed easy (to get around) though the field of view was narrow so it felt I was looking through a gap or tunnel etc.
	6	It is not easy to manipulate the device.
	7	
	8	Too many blank white areas without depth. Not realistic enough light shadow needs a lot more sound effects.
NC: exp one	1	Excellent detail, clear visuals.
	2	A bit plastic i.e. 'characterises'
	3	I liked the backdrop. It was very interesting to move through.
	4	Disliked how slowly the person walked.
	5	Disliked distortion and delay in reaction.
	6	It would be nice if there was a sound effect like the fire alarm at the beginning of the experiment so that one felt like a fire officer on an inspection task.
	7	Getting stuck behind objects I could not see.
	8	When you get lost its difficult to figure out where you are - you have to keep turning round - a bit disorientating.
Animation: exp one	1	It's interesting. I did not expect to find this and pay attention to these objects.
	2	I disliked the lack of sound and that it was empty of people/activity.
	3	likes; close resemblance of objects/environment to realistic analogues. Dislikes; unorthodox moving patterns, ability to discern whether viewing an area for the first time or not.
	4	I liked the feeling of being there and my experience of movement.
	5	I found it difficult to clearly identify which scenes were which. Many rooms were very similar (more so than I would have imagined them to be in reality).
	6	The environment was well modelled and structured and objects were easily identified. Would like more interaction with the environment like moving objects and performing such like tasks to make all activities closer to reality.
	7	Was disorientated at first and lost track of where I had seen and where I hadn't. This improved as the simulation proceeded. I liked the swimming fish.
	8	Intermittent poor quality of environment tape. Some blurring, difficult to see FIRE EXIT.

FSNC: exp two	1	Movement difficult and too slow. Hand to manoeuvre through doors at times. The objects were clear and realistic, with obvious flashing colours to indicate an action could be performed.
	2	I liked the less obvious actions like the remote control and TV upstairs, and the moving mice. The laptop was good to, in that a series of actions were needed (I.e. open the top, use the mouse)
	3	Bumping into things and not being able to move out of a room.
	4	Not all identical items reacted in the same way e.g. telephones. Some items did not appear to work - button on the joystick, chess pieces can not float. It was amusing to move all the monitors.
	5	I am not very good at make movements in the precise part, I mean I find it difficult to keep proportionality when enter a room for example. I feel a bit sick.
	6	I liked the feeling of being there but the only thing that confused me was I never understood if while walking I would clash some object. Maybe the focus was too close. Probably a broader view might help or changing the actual scale might help.
	7	I dislike that I stare at a computer screen -not a real 3D environment. All the other aspects - the details - the visual quality - are good.
	8	Was very similar to real life (upstairs and GF offices). I would like to have access to all areas and make use of the fire extinguisher. In the computer lab it would be more realistic if there are people using the equipment so I would easily know which PC to use. Like being able to access the filing cabinet and the clock on the stairs was very good. In some areas it was a bit different to what I expected it. Was a bit slow in climbing the stairs. When I pushed the joystick backwards to look up, I could easily make a circle (which makes it look unrealistic). I couldn't get access to the upstairs space. The graphics display was very good, I felt involved in discovering all the spots in the building which I did not know before.
SNC: exp three	1	Very interactive and good background provided by the experimenter. Thanks.
	2	Sometimes difficult to move in and out of rooms. No people.
	3	The sign of the fire extinguisher, don't like some furniture.
	4	The graphics went wrong a few times and I got stuck a couple of times.
	5	Difficulty of knowing where I am relative to doors.
	6	The picture is nice and something looks like the real one.
	7	Like the sense of depth and easy loose interaction system.
	8	
	9	Easy to control but sometimes graphic is not smooth.
	10	Precise detail and ease of use.
	11	Liked the level of realism in the environment and thought controls fairly straightforward (but I did find it difficult to navigate through doors sometimes!)
	12	I wish I could move faster. Objects could have more realistic look. Ok otherwise.
	13	Some of the spaces felt slightly too small for me to fit through. Liked you could manipulate everything that you wanted to.

	14	
	15	Things happen as you expect (e.g. no fire extinguishers in the offices…)
NC: exp three	1	Liked going up the stairs and the differing objects in each of the rooms to minimise confusion.
	2	Virtual environment is really like the real environment but sometimes it's hard to turn around and look at everything.
	3	bit too slow, very clear re: building layout etc.
	4	I like about it can easily find when emergency event have.
	5	Like, it's very good and easy to find it.
	6	
	7	It looked realistic, I liked the fish. Distortion is a problem.
	8	
	9	I don't like the light source, I feel headache after experiment and feel nausea and vomiting.
	10	I think the joystick is hard to use. Moreover the screen makes me feel dizzy and a little bit head ache.
	11	Flickering frame was odd.
	12	It was very realistic, the detail was amazing. The interaction was limited, but overall was very impressive.
	13	The interaction with the environment is very promising.
	14	If one loses the track/sense of direction, difficult to find it back.
	15	Realistic and easy to move around.
FSNC: exp three	1	Easy to get lost but very realistic!
	2	As I do not have a good sense of direction in the 'real' world, I felt a little disorientated. More signs/landmarks or room numbers would be useful.
	3	The objects that were aimed to be touched/opened were clear. I sometimes got stuck behind a desk or door.
	4	Liked the way the on screen mouse moved when mine did! Disappointed the goldfish didn't do anything!
	5	Not being able to sidestep (dislike).
	6	
	7	I'd only been in a few rooms in the building and it gave me a good idea of what else is in there.
	8	Liked the football, disliked not being able to fit around some objects.
	9	It was fun!
	10	Parts of it looked quite realistic. Some problems navigating, only simple repetitive one-step tasks.
	11	You needed to be at the correct angle to enter rooms. It also felt like my head was trapped by a stair well although this was not obvious at the time (ground floor on the left facing the stairs).

	12	Very realistic - a good representation of the actual building. Occasional problems with parts of the environment disappearing and manoeuvring through small gaps. On the whole very good.
	13	Liked the photo textures of doors, posters etc.
	14	Dislike - feel dizzy if use for long time.
	15	Liked - quite realistic, not bad imitation of real life and real life motion. Disliked - relatively easy to become disorientated.
SNC – Abs: exp four	1	
	2	I found the speed of movement a little slow also I was slightly frustrated I could not change my trajectory while I was moving. Thou mouse also provided little opportunity to meaningfully interact with the environment.
	3	Liked - simplicity, clarity Disliked - limited interactions
	4	I found the control system difficult to master.
	5	A little difficult to move up and down smoothly. Liked the bright colours of the environment.
	6	I liked the fact it's just like playing a game, but I don't like the fact it doesn't feel quite real even though it's close.
	7	Easy to use, interesting.
	8	Interaction with objects wasn't clear
	9	Colourful, interesting but a bit basic
	10	using the joystick to move around
FSNC – Abs: exp four	1	Quite slow moving - reacting
	2	
	3	I liked the variety of shapes and objects in the environment
	4	I found it difficult to use the joystick effectively
	5	I liked the numbered dart boards you could follow. I disliked very close contact with the flashing blue object.
	6	Disliked that there wasn't anything to do - with practise would be easy to use.
	7	Dislike - feel dizzy after using for a long time. Like - looks like a real 3d space I am in.
	8	
	9	Left/right control is reversed when upside down. I felt like there was a task that I wasn't doing. I also wanted to start following the numbered targets, but ran out of time.
	10	Feeling rather disorientated at times, Having not used a joystick for many years it took quite a while to get used to it again, As a consequence of the above my movements were very jerky, which meant I never really had a sense of 'being there'
SNC – cued: exp five	1	
	2	
	3	
	4	Because I knew the building slightly it helped me not to feel as disorientated as I know I would have if this were not the case.
	5	

	6	Enjoyed the experience, felt as though I was in the building.
	7	Quite real so was good, joystick control quite heavy, could have been easier to use somehow.
	8	Very realistic - easy to get around.
	9	I quite liked the feeling of being there without actually being there - as though you are watching other people! I didn't like the way it felt slightly unnatural.
	10	Moving around was often quite jerky - kept having to think weather I was turning to the side or moving to the side. Realistic display and object movements.
	11	Didn't like having to use the mouse and the joystick at the same time.
	12	Attention to detail - posters, wood grain effect on the doors etc. was very good.
SNC – not cued: exp five	1	It takes a long time to respond, I am not used to the input device.
	2	The details were very nice, fish swimming, clock ticking, posters etc. The controls were too slow to respond, move analogue control of turning was missing.
	3	Rotation too slow, easy to do what I needed to do.
	4	The frame rate was a bit slow, takes a long time to turn around.
	5	Way too slow, movement was not natural - it looked like I was gliding and not walking.
	6	Very realistic, like the inside of the labs.
	7	It takes too long to turn round. Good quality visuals e.g. doors and posters - made me feel more part of the environment.
	8	Turning or looking round would be better if it was done a bit quicker.
	9	I found the controls difficult to master.
	10	Because I am nosey I would have liked to be able to interact with more objects (e.g. doors, doors etc). I thought it was very user friendly over all.
	11	I liked: Good graphics (especially the doors), environment not too cluttered nor too bare, interesting way of exploring a place/doing a task, smooth movement. I disliked: Difficulty in manoeuvring around using the joystick, the sounds from the virtual environment were distracting.
	12	Little items like toasters in cupboards/hot cups of tea made the environment more real, and added humour. Not many dislikes - the noise of moving up the stairs was somewhat off-putting.
	13	I liked the simplicity of the rendering, but felt it was a little clinical.
	14	Difficult to walk through one of the doors. The floor became transparent at one point.
	15	Having a task to perform.
	16	The screen was a bit juddery. Sometimes it was hard to walk through doors as I was not perfectly aligned. There was inconsistency in what I could interact with i.e. some computers but not others.
	17	I liked the sense of reality. Felt like I was actually in the building. I disliked the inability to move in a very natural manner.
	18	Pros: Proper layout of items, good feel of environment. Con's: Bad frame rate, imprecise input mechanism (leading to frustration); probably a larger viewing area screen might help more with the virtual immersion.

5. Experiments Three, Four and Five - Enjoyment Scores

All answers were marked by the participant on the following 5 point scale:

Never	Rarely	Sometimes	Often	Always
= 1	= 2	= 3	= 4	= 5

*negatively worded questions have been accounted for.

Question:		1	2	3	4	5	6	7	8	9	10	11	12
SNC: exp three	1	5	4	3	5	5	4	4	3	4	4	5	5
	2	5	1	4	5	5	5	4	5	3	5	5	5
	3	5	3	3	5	3	5	3	4	3	5	3	4
	4	5	2	3	5	4	4	3	2	3	4	3	4
	5	3	4	4	4	4	4	3	4	4	3	4	4
	6	3	2	4	3	3	5	4	4	3	4	2	4
	7	5	3	4	5	4	3	2	4	3	5	4	5
	8	5	2	4	5	3	5	3	4	3	5	4	3
	9	3	2	5	3	4	5	4	3	3	4	4	4
	10	5	5	5	5	5	5	5	5	5	5	5	4
	11	5	2	4	5	4	5	4	5	3	5	4	5
	12	5	2	5	5	5	5	5	5	3	4	4	5
	13	5	2	5	4	4	5	5	3	3	5	4	4
	14	3	3	2	4	3	4	2	2	2	3	3	4
	15	5	3	3	5	4	5	3	3	2	5	5	5
NC: exp three	1	5	1	5	4	4	5	4	4	3	5	3	4
	2	2	3	4	2	4	2	2	2	4	3	2	3
	3	5	1	4	5	4	5	4	4	1	5	5	5
	4	4	1	2	5	2	3	5	3	4	3	1	4
	5	4	3	3	4	4	4	5	5	3	3	4	4
	6	3	3	5	4	3	3	4	2	3	4	2	3
	7	5	1	5	5	5	5	5	5	2	5	4	5
	8	3	3	4	2	4	2	3	3	4	3	1	5
	9	3	3	2	4	4	3	4	3	4	2	3	2
	10	3	3	4	5	3	5	2	4	1	5	2	3
	11	5	3	4	5	4	5	5	3	2	5	3	4
	12	5	2	3	5	3	5	3	4	2	5	4	4
	13	3	2	5	5	4	5	4	3	4	3	4	3
	14	4	3	5	5	3	5	3	2	3	4	3	4
	15	5	1	5	5	3	5	3	5	2	5	5	4
FSNC: exp three	1	5	3	4	4	4	5	3	4	3	5	3	4
	2	3	4	4	4	4	5	4	3	4	4	2	4
	3	5	1	4	5	4	5	3	3	3	5	4	4
	4	5	2	5	5	4	5	4	4	2	5	5	4
	5	5	2	3	5	3	5	1	4	3	5	5	5
	6	3	3	4	4	4	5	5	2	5	4	3	4
	7	5	2	4	5	3	5	3	4	2	5	5	4
	8	5	3	4	5	5	5	4	5	3	5	3	4
	9	5	2	4	5	4	5	4	5	3	5	5	5
	10	5	2	3	5	3	5	1	5	2	5	5	5
	11	5	1	5	2	2	5	3	5	2	5	5	5
	12	4	3	5	5	5	5	3	3	4	4	4	5
	13	4	3	4	5	4	5	4	4	2	4	4	4
	14	4	2	3	4	2	4	1	5	1	2	3	3
	15	4	1	3	4	3	5	1	3	1	5	3	3

SNC – Abs: exp four	**1**	4	3	4	4	3	5	3	4	3	4	5	3
	2	4	2	3	4	2	5	3	3	2	4	3	4
	3	5	1	3	5	3	5	2	5	2	5	5	5
	4	4	1	4	5	4	5	2	3	1	5	3	2
	5	5	4	5	5	4	5	5	5	3	5	5	4
	6	3	1	4	4	3	5	3	4	2	5	4	3
	7	5	1	5	5	4	5	4	5	3	5	4	4
	8	5	2	3	5	3	5	3	4	3	5	4	5
	9	5	1	5	5	4	5	3	4	3	5	4	4
	10	4	1	5	1	4	5	2	5	3	5	3	3
RSNC – Abs: exp four	**1**	4	1	3	4	3	5	3	5	1	5	5	4
	2	5	2	5	4	5	5	3	5	3	5	5	5
	3	5	2	4	3	4	5	3	4	2	5	4	4
	4	4	1	2	4	2	5	2	3	2	5	2	2
	5	5	3	4	4	3	5	4	5	4	4	4	5
	6	5	1	4	5	4	5	3	5	1	5	4	3
	7	4	2	3	4	4	4	3	5	3	4	5	4
	8	5	2	4	5	3	5	3	5	2	5	5	5
	9	5	1	5	5	4	5	4	5	4	5	5	5
	10	4	2	5	5	3	5	3	5	2	5	2	3
SNC – cued: exp five	**1**	4	3	2	4	3	4	2	2	3	3	2	3
	2	5	2	5	5	5	5	5	2	5	4	4	5
	3	5	1	3	5	3	5	4	5	1	5	5	4
	4	5	2	5	1	4	5	1	4	1	5	4	4
	5	5	2	4	4	4	5	3	3	2	5	4	5
	6	5	3	5	5	4	5	4	5	3	5	3	4
	7	5	3	4	4	4	5	3	4	4	5	2	5
	8	5	1	5	5	5	5	4	5	3	5	4	4
	9	3	3	3	4	4	3	4	4	4	4	4	4
	10	5	3	5	5	4	5	4	5	2	5	4	4
	11	5	1	5	5	3	5	3	5	1	5	5	5
	12	5	3	5	3	2	5	4	5	4	5	5	5
SNC – not cued: exp five	**1**	4	2	2	5	3	5	3	3	4	4	3	4
	2	5	2	4	5	2	5	4	5	3	4	4	3
	3	1	4	2	1	2	1	2	1	4	1	1	1
	4	5	1	3	4	2	5	3	5	2	5	5	4
	5	5	1	2	5	3	5	3	3	1	5	4	5
	6	5	2	5	5	3	5	3	5	2	5	5	4
	7	4	2	4	5	4	5	3	3	2	5	5	4
	8	5	2	4	4	4	5	3	4	3	5	3	4
	9	5	2	5	4	4	5	3	5	3	5	5	4
	10	5	3	5	4	4	5	4	5	4	5	3	5
	11	5	1	5	5	5	5	3	2	4	5	2	4
	12	5	2	5	5	5	5	4	5	3	5	5	5
	13	5	2	4	5	4	5	3	3	2	5	2	3
	14	5	2	4	5	4	5	2	3	2	5	4	4
	15	5	1	5	4	4	5	3	3	2	5	5	5
	16	5	1	4	5	3	5	2	4	1	5	3	4
	17	4	3	4	4	3	5	3	3	3	3	3	4
	18	4	2	3	5	3	5	2	3	2	4	5	5

6. Experiments One and Two - Recall Values

	Correct recall (maximum = 14)				
	SNC	NC	Animation	Video	FSNC
1	13	13	11	7	8
2	12	10	10	9	3
3	7	9	6	8	1
4	13	11	7	8	4
5	5	12	9	8	5
6	10	9	8	5	2
7	10	14	9	7	5
8	4	11	13	9	4

*participants 1 to 4 performed recall one day after training, participants 5 to 8 performed recall one week after training.

	Participant - SNC								Participant - NC							
Recall object	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Red front foyer	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Red Top corridor			1	1	1		1	1	1	1	1	1	1	1	1	1
Red B6 corridor	1	1	1		1		1		1	1			1		1	1
Black Front Foyer	1	1	1	1	1	1		1	1	1	1		1		1	1
Black B11	1	1	1					1		1		1		1	1	
Black B12	1	1	1		1				1				1	1	1	
Aid Top corridor	1	1	1		1		1	1	1	1	1	1	1		1	1
Alarm Front foyer L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Alarm Front foyer R	1	1	1	1	1		1	1	1	1		1	1		1	1
Alarm Top corridor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Alarm B11	1	1			1	1		1	1	1	1	1		1	1	1
Exit Main doors	1	1	1	1	1		1	1	1		1	1	1	1	1	1
Exit Lab door	1	1			1		1		1		1	1	1	1	1	1
Exit B6 corridor	1	1	1		1		1		1			1	1		1	1

	Participant - Animation								Participant - Video							
Recall object	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Red front foyer	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1
Red Top corridor	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1
Red B6 corridor	1		1		1			1	1	1	1	1				1
Black Front Foyer		1					1	1								
Black B11	1	1	1		1			1		1	1	1			1	
Black B12										1						
Aid Top corridor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Alarm Front foyer L		1		1	1	1	1	1			1	1	1			1
Alarm Front foyer R	1			1	1	1		1	1	1						
Alarm Top corridor	1	1		1	1	1	1	1	1		1	1	1		1	
Alarm B11	1	1		1	1		1	1					1	1	1	1
Exit Main doors	1	1					1	1	1	1			1			1
Exit Lab door	1	1				1	1	1					1	1		1
Exit B6 corridor	1		1		1	1		1	1	1	1	1			1	1

Recall object	Participant - FSNC 1	2	3	4	5	6	7	8
Red front foyer	1	1						
Red Top corridor	1			1	1		1	1
Red B6 corridor								
Black Front Foyer								
Black B11								
Black B12								
Aid Top corridor	1	1		1			1	1
Alarm Front foyer L	1			1	1		1	
Alarm Front foyer R	1			1	1		1	
Alarm Top corridor	1				1			1
Alarm B11		1						
Exit Main doors	1					1		
Exit Lab door	1		1		1	1	1	1
Exit B6 corridor								

* 1 = correctly recalled in the real world

7. Experiment Three - Recall Values

	Correct recall (maximum = 8)			Incorrect recall (maximum = 8)			No answer recall (maximum = 8)		
	SNC	NC	FSNC	SNC	NC	FSNC	SNC	NC	FSNC
1	1	2	2	3	2	2	4	4	4
2	2	2	2	2	3	3	4	3	3
3	1	1	2	2	3	3	5	4	3
4	1	2	2	2	2	4	5	4	2
5	2	2	2	1	6	3	5	0	3
6	1	3	1	4	3	3	3	2	4
7	2	3	1	4	1	6	2	4	1
8	3	0	1	3	2	6	2	6	1
9	2	4	2	2	4	5	4	0	1
10	2	4	1	2	2	5	4	2	2
11	1	3	1	2	1	7	5	4	0
12	0	2	2	1	3	6	7	3	0
13	4	0	1	2	4	3	2	4	4
14	0	0	2	2	1	2	6	7	4
15	1	2	2	3	2	5	4	4	1

	Participant - SNC 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Picture 1	2	2	0	2	2	2	2	2	2	2	2	0	2	0	2
Picture 2	1	1	2	0	2	0	1	0	1	0	1	0	0	1	1
Picture 3	0	0	0	0	0	1	2	2	0	0	0	0	2	0	1
Picture 4	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1
Picture 5	1	0	0	0	0	1	0	1	0	0	1	0	0	0	0
Picture 6	0	0	1	0	0	0	1	0	0	1	0	0	2	1	0
Picture 7	0	2	0	1	0	1	1	2	2	0	0	0	1	0	0
Picture 8	0	0	0	0	0	0	0	1	0	2	0	0	2	0	0

	Participant - NC														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Picture 1	2	2	2	2	2	2	2	0	2	2	2	2	0	0	2
Picture 2	1	1	1	2	1	1	0	0	1	2	0	0	1	0	0
Picture 3	0	0	0	0	1	2	2	0	1	2	0	0	0	0	0
Picture 4	1	1	1	1	1	1	0	1	2	1	2	0	1	1	2
Picture 5	0	1	0	0	1	1	1	0	2	0	1	1	0	0	1
Picture 6	2	0	1	0	1	0	2	0	1	1	2	2	1	0	1
Picture 7	0	0	0	1	2	0	0	1	2	2	0	1	1	0	0
Picture 8	0	2	0	0	1	2	0	0	1	0	0	1	0	0	0

	Participant - FSNC														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Picture 1	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2
Picture 2	2	0	1	0	0	1	1	1	1	1	1	1	1	0	1
Picture 3	0	1	2	2	0	0	1	1	0	1	1	1	1	2	2
Picture 4	1	1	1	1	0	1	1	1	1	1	1	1	0	1	0
Picture 5	0	0	1	0	1	2	1	1	1	1	1	1	0	0	1
Picture 6	1	2	0	1	2	0	1	1	2	1	1	1	1	1	1
Picture 7	0	0	0	1	1	0	1	1	1	0	1	1	0	0	1
Picture 8	0	1	0	1	1	0	0	0	1	0	1	2	0	0	1

* 2 = correct, 1 = incorrect, 0 = no answer

8. Experiment Four - Recall Values

	Correct recall (maximum = 10)		Incorrect recall (maximum = 10)		No answer recall (maximum = 10)	
	SNC - Abs	FSNC - Abs	SNC - Abs	FSNC - Abs	SNC - Abs	FSNC - Abs
1	2	4	4	0	4	6
2	3	6	4	1	3	3
3	3	1	3	1	4	8
4	0	1	0	0	10	9
5	1	0	0	3	9	7
6	0	4	1	0	9	6
7	2	3	3	5	5	2
8	3	4	2	1	5	5
9	2	3	2	1	6	6
10	0	2	0	2	10	6

	Participant: SNC - Abs									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Green	1	0	1	0	0	0	0	0	1	0
Sphere	0	1	2	0	0	0	0	0	0	0
Pyramid	0	2	1	0	0	0	0	0	0	0
Red	1	0	0	0	0	0	2	1	2	0
Cone	1	1	0	0	0	1	1	1	0	0
Brown	0	2	0	0	0	0	1	2	1	0
Cylindrical	0	0	1	0	0	0	1	0	0	0
Sphere	2	2	0	0	0	0	0	0	0	0
white/grey	1	1	2	0	2	0	2	2	2	0
Yellow	2	1	2	0	0	0	0	2	0	0

	Participant: FSNC - Abs									
	1	2	3	4	5	6	7	8	9	10
Green	0	0	0	0	0	0	1	0	0	0
Sphere	0	2	0	0	1	2	1	0	0	2
Pyramid	0	2	0	0	0	0	0	0	1	0
Red	2	2	2	0	0	2	2	2	2	2
Cone	0	0	0	0	1	0	0	0	0	0
Brown	2	2	0	0	0	2	2	2	2	1
Cylindrical	0	2	0	0	0	0	1	2	0	0
Sphere	2	0	0	0	0	0	1	1	0	0
white/grey	2	2	0	2	0	2	2	2	2	1
Yellow	0	1	1	0	1	0	1	0	0	0

* 2 = correct, 1 = incorrect, 0 = no answer

9. *Experiments Five - Recall Values*

	Correct recall (maximum = 10)		Incorrect recall (maximum = 10)	
	SNC - cued	FSNC – not cued	SNC - cued	FSNC – not cued
1	3	0	0	2
2	1	2	4	2
3	8	5	1	5
4	5	1	1	5
5	7	3	1	0
6	0	2	1	2
7	6	3	4	0
8	1	4	4	2
9	7	0	0	1
10	3	6	1	4
11	5	1	3	0
12	19	2	4	12
13		5		3
14		5		0
15		12		4
16		7		5
17		5		3
18		3		1

10. *Experiment Two – Selection Data*

	Objects selected - SNC			Objects selected - FSNC		
	Cued	Not cued	Total	Cued	Not cued	Total
1	31	7	38	41	28	69
2	6	3	9	63	61	124
3	9	2	11	11	2	13
4	3	1	4	12	6	18
5	1	0	1	66	51	117
6	1	0	1	0	0	0
7	1	0	1	62	64	126
8	52	18	70	18	12	30

	Participant - SNC								
	1	2	3	4	5	6	7	8	Total
Red	7	0	2	1	0	0	0	8	18
Blue	10	0	0	0	0	0	0	11	21
grey	4	2	1	0	0	0	0	7	14
Yellow	7	2	2	2	0	1	0	8	22
Movement	1	0	0	0	0	0	0	4	5
Sound	0	0	0	0	0	0	0	2	2
Textured/photo realistic	2	2	4	0	1	0	1	12	22
Highlighted	12	3	1	1	0	0	0	16	33
Flashing	16	1	4	2	0	1	0	18	42
Total	31	6	9	3	1	1	1	52	

	Participant - FSNC								
	1	2	3	4	5	6	7	8	Total
Red	9	10	1	2	13	0	7	2	44
Blue	8	11	4	4	11	0	9	5	52
grey	5	9	2	0	12	0	9	3	40
Yellow	8	10	1	1	8	0	6	3	37
Movement	3	10	0	1	8	0	10	1	33
Sound	1	1	0	1	4	0	4	2	13
Textured/photo realistic	7	12	3	3	10	0	17	2	54
Highlighted	13	18	2	2	21	0	14	6	76
Flashing	17	22	6	5	23	0	17	7	97
Total	41	63	11	12	66	0	62	18	

	Coloured cue design - SNC		
	All Max = 18	Part Max = 23	Surround Max = 15
1	8	10	10
2	2	1	1
3	0	5	0
4	0	3	0
5	0	0	0
6	1	0	0
7	0	0	0
8	9	15	10
Total	20	34	21

	Coloured cue design - FSNC		
	All Max = 18	Part Max = 23	Surround Max = 15
1	8	13	9
2	11	16	13
3	2	4	2
4	2	4	1
5	15	17	12
6	0	0	0
7	9	14	8
8	3	5	5
Total	50	73	50

11. Experiment Three – Selection Data

	Cued recall objects selected	
	SNC	FSNC
1	0	7
2	0	6
3	0	6
4	2	8
5	2	6
6	1	5
7	1	7
8	0	8
9	0	8
10	3	7
11	0	8
12	0	8
13	6	7
14	0	1
15	3	5

	SNC – Seen only			SNC – Seen and selected		
	correct	incorrect	don't know	correct	incorrect	don't know
1	4	0	4	0	0	0
2	3	1	4	0	0	0
3	2	1	5	0	0	0
4	1	0	5	2	0	0
5	0	1	5	2	0	0
6	4	0	3	1	0	0
7	4	1	2	1	0	0
8	4	2	2	0	0	0
9	3	1	4	0	0	0
10	1	0	4	2	1	0
11	3	0	5	0	0	0
12	1	0	7	0	0	0
13	1	0	1	2	3	1
14	2	0	6	0	0	0
15	3	0	2	1	0	2

	FSNC – Seen only			FSNC – Seen and selected		
	correct	incorrect	don't know	correct	incorrect	don't know
1	0	0	1	3	1	3
2	1	0	1	3	1	2
3	0	0	2	4	1	1
4	0	0	0	5	1	2
5	1	0	1	3	1	2
6	0	1	2	2	1	2
7	0	0	1	7	0	0
8	0	0	0	7	0	1
9	0	0	0	6	1	1
10	0	0	1	6	0	1
11	0	0	0	8	0	0
12	0	0	0	7	1	0
13	0	0	1	5	0	2
14	2	1	4	1	0	0
15	3	0	0	3	1	1

12. Experiment Four – Selection Data

	Total Selections	
	SNC	FSNC
1	25	53
2	58	64
3	34	42
4	11	163
5	4	13
6	2	30
7	30	61
8	13	116
9	33	79
10	0	70

	# Objects selected: SNC - Abs			# Objects selected: FSNC - Abs		
	Cued	Not cued	Total	Cued	Not cued	Total
1	9	3	12	15	12	27
2	3	3	6	14	15	29
3	7	1	8	9	8	17
4	5	0	5	16	17	33
5	1	1	2	5	8	13
6	1	1	2	5	8	13
7	5	2	7	9	17	26
8	2	3	5	12	13	25
9	9	13	22	12	10	22
10	0	0	0	16	15	31

Participant: SNC - Abs											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**total**
Red	2	0	1	1	1	0	1	0	1	0	7
Blue	1	0	2	1	0	1	0	0	2	0	7
grey	1	1	0	0	0	0	0	0	2	0	4
Yellow	2	1	1	1	0	0	1	1	1	0	8
Movement	1	1	1	2	0	0	2	0	1	0	8
Sound	0	0	1	0	0	0	0	0	0	0	1
Textured/photo realistic	2	0	1	0	0	0	1	1	2	0	7
Highlighted	3	1	2	0	1	0	1	0	3	0	11
Flashing	3	1	2	3	0	1	1	1	3	0	15
Total	15	5	11	8	2	2	7	3	15	0	

Participant: FSNC - Abs											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**total**
Red	2	2	2	2	1	0	2	2	2	2	17
Blue	2	2	0	2	0	1	2	1	2	2	14
grey	2	2	1	2	0	1	0	1	0	2	11
Yellow	2	2	2	2	1	0	1	2	1	2	15
Movement	3	2	2	3	2	2	3	3	2	3	25
Sound	0	0	0	1	0	0	0	0	1	1	3
Textured/photo realistic	4	4	2	4	1	1	1	3	4	4	28
Highlighted	4	4	2	4	1	0	2	3	3	4	27
Flashing	4	4	3	4	1	2	3	3	2	4	30
Total	23	22	14	24	7	7	14	18	17	24	

		Correct			Incorrect			No answer		
		SSR	SS	Seen	SSR	SS	Seen	SSR	SS	Seen
SNC - Abs	1	1	1	0	2	0	2	1	2	1
	2	2	0	1	1	0	3	0	0	3
	3	1	2	0	0	1	2	1	0	3
	4	0	0	0	0	0	0	2	2	6
	5	0	0	1	0	0	0	1	0	8
	6	0	0	0	0	0	1	1	0	8
	7	1	0	1	1	0	2	0	1	4
	8	0	2	1	0	0	2	0	0	5
	9	1	1	0	0	1	1	2	1	3
	10	0	0	0	0	0	0	0	0	10
FSNC - Abs	1	3	1	0	0	0	0	2	3	1
	2	3	3	0	0	0	1	2	1	0
	3	1	0	0	0	1	0	4	2	2
	4	0	1	0	0	0	0	4	3	2
	5	0	0	0	0	0	3	1	1	5
	6	0	3	1	0	0	0	0	1	5
	7	2	0	1	1	2	2	0	0	2
	8	2	2	0	0	0	0	1	3	1
	9	1	2	0	0	1	0	3	1	2
	10	2	0	0	1	1	0	2	3	1

13. *Experiment Five – Selection Data*

	Total task objects selected - SNC	
	Cued	Not cued
1	1	1
2	3	4
3	15	14
4	11	5
5	8	2
6	1	1
7	20	1
8	0	2
9	24	1
10	7	2
11	23	0
12	35	2
13		9
14		4
15		23
16		14
17		6
18		4

	Correct recall: SNC - cued			Correct recall: SNC – not cued		
	SSR	SS	Seen	SSR	SS	Seen
1	0	0	3	0	0	0
2	0	0	0	0	1	1
3	4	0	2	2	0	2
4	4	0	1	0	0	0
5	2	1	4	0	0	1
6	0	0	0	0	0	2
7	5	0	1	0	0	3
8	0	0	0	1	0	2
9	5	2	0	0	0	0
10	2	0	1	0	0	5
11	5	0	0	0	0	1
12	17	1	1	0	0	2
13				3	0	2
14				2	0	3
15				7	2	3
16				4	1	2
17				1	1	3
18				0	0	3

14. Experiment Five – Verbal Responses to 'Why Recall Missing Objects?'

- *Do you recall anything specific about the missing objects?*

Blue font = Experimenter comment

Participant Number*	Comment
1	Cant recall clearly the position of items.
2	Sometimes couldn't control where I was so lots of time in a position.
3	C Computers, fire exits [task objects].
4	E Fish tank wasn't expected, D football was the first thing I saw.
5	F Played with them or E obviously shouldn't have been there.
6	Guess Context of items – made sense they would be there. E Towel was fun and football – more interesting!
7	A Flashing (but don't think all?).
8	One item flashed red so I recalled it [programme error].
10	A Red flashing, either obviously marked or F interacted with and did remember, E something looked out of place (like the football).
11	Guess Obviously missing. B Microwave in kitchen not sure about as picture is from a different angle than I saw.
12	E Fish floating, F remembered index box as it opened and B remembered the TV in the lecture room.
13	C Concentrating on the task.
14	B Recall the sound, E the ball was bright, F the microwave changed colour, F the OHP changed when selected, F the hand towel reacted and A I remember the red flashing.
15	Guess OHP I presumed, F the glass doors I opened and thought items should be there.
16	Guess What should be there.

17	F TV, because I switched it on. Noticed things as missing from the pictures, not the them themselves. E Remembered the fish tank!
18	F Reacted.
19	-
20	A Flashing (so opened the door) A mouse and keyboard were flashing.
21	E Electrical socket as not meant to be there near the sink! E TV because it was in a corner (door would be in the way and you would not be able to see it)
22	F Football – interacted with, uniform environment. A Red flashing.
23	E Strange it was there. Computer not sure?
24	F TV's you could turn them on. Guess There was obviously something missing. F Items missing that I interacted with (microwave, cupboards etc.).
25	Vague recollections.
26	F Recalled from interaction mainly.
27	E Keyboard next to union jack mouse mat, remember the mat. F Football as played with it and opened the cupboard to get at it. E Remember the room with the chess board and flashing cupboard, F clicked on and tried to interact with matches. B Remembered the microwave but not 100% where (near kettle?). D remember the OHP as first room I went in.
28	Red flashing cues [programme error]. Guess Projectors, stands were there they were not. B Laptop – just remembered!
29	D OHP – first thing that reacted I clicked on. F Recalled football – amusing and opened the door. F I tried to play with the spoons but not sure which sink. B Remember seeing the photocopier, laptop. F Played with lots. Guess Expected a lot of things as opposed to actually remembering.
30	Guess Intuition/expectation. C Some based on recall but focused on task items.
31	B Tissue box, thought it was a toilet but it wasn't there.

* Red number = cued condition
A = Red flashing objects
B = curiosity about objects
C = Task focused (didn't recall)
D = First thing see/selected/reacted
E = unexpected/out of place objects
F = Objects selected/reacted

15. Experiment Five – Verbal Responses to 'Why Select Certain Objects?'

- *What, if anything, prompted you to select certain objects?*

Blue font = Experimenter comment

Participant Number*	Comment
1	G Red indicator, D some doors/cupboards – wanted to see what was inside.
2	D Just to see what would happen.
3	Didn't notice any cues.
4	B Looking for first aid kit in cupboards – D just playing.
5	D To see if they do anything (flashy thing), F then same again so why bother?
6	E Looked like they would do things – draws/objects – F stopped trying if they did not react.
7	G Only went for flashing.

8	E Looked like they would do something like cupboards may open. F Once clicked item type once did not try again.
10	G Cued, but very few.
11	-
12	A Fish tank prompted first interaction.
13	B As above [concentrating on the task]
14	-
15	Red flashing [programme error], D didn't know what they were and wanted to see what the photocopier would do.
16	F Click on one, not much response no reason to try any more so didn't.
17	A Looked more interesting i.e. TV to work wanted to fish whereas a chair is not interesting.
18	G Red flashing, taps reacted and the phone made a noise.
19	-
20	C Doors to see if you could enter and G flashing objects as they seemed to react.
21	D To see if there was a reaction.
22	F Clicked on one, if same items didn't bother again – B didn't think search items would be there.
23	B Didn't think I would find anything that I was looking for [for the task].
24	G Red flashing and D playing.
25	One flashing red [programme error] and D out of interest.
26	E Selected because hopeful it would react.
27	E Interested if they would do anything (i.e. fish). D Tried a few things, mainly playing no particular reason!
28	D Trying most things – if saw something then clicked on it.
29	E Did expect everything to interact. C Had expectations from previous items that reacted and was surprised when others did not.
30	-
31	E See if they would open.

* Red number = cued condition
A = Unexpected out of place objects
B = Task focused (didn't recall)
C = Expectations from previous objects reacting
D = Curiosity about objects/playing
E = Objects looked like they did things
F = No reaction first time, did not select again
G = red flashing/cued objects