Study of Acclimatisation using Virtual Reality

by

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Abstract

When people first visit an unfamiliar city they vary in their ability to construct a mental map. The skills they need in order to construct an effective mental map are known generally as acclimatisation, and specifically as orientation and way-finding. Orientation is having an image of where one is in a city, and way-finding is the skill of being able to find a location. Some people's orientation and way-finding skills are so poorly developed that they suffer anxiety when visiting unfamiliar places.

The purpose of this thesis is to determine whether or not immersion influences acclimatisation. In this study virtual environments are applied in order to test acclimatisation. It addresses whether or not virtual environments may be used to enable people to familiarise themselves with a place before ever visiting it. The subjects were then taken to Cambridge and their orientation and way-finding skills were tested, measured and analysed. They also completed a questionnaire relating to subjective acclimatisation.

The computer model captured a part of Cambridge City centre and contained many features which added realism. However, although state of the art computer hardware and software were used it was possible to model only a part of the city. Even then much detail could not be included, neither could sound nor moving figures. In order to determine which features are most important in becoming acclimatised, and therefore should not be omitted from the model, four preliminary studies were carried out modelling smaller environments. Additionally, there was a pilot study using the Cambridge model to debug the methodology of the study and test the logistics of observing task performance.

The main experiment included four display types which compared new technology, such as desktop and virtual reality with traditional technology, such as video and pictures. Forty subjects, who had never visited Cambridge before, were organised into groups of ten, to use each of the above mentioned display types.

The results suggest a significantly higher degree of spatial learning amongst those who experienced immersive virtual environments, specifically in their orientation results. However, there was no significant difference in the performance in way-finding tasks between the types of display.

In memory of my father
Who taught me how to fly

To Abdelkrim, Luisa and Yosef

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There are moments we remember all our life, and the time of this research is one of those moments...

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Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Overview

This thesis addresses the possibility of using *Virtual Reality* as a method for teaching people about unfamiliar environments as an alternative to traditional methods. The objective is to help people learn about complex spatial environments such as a city without visiting them. Therefore, the common problem of disorientation experienced in unfamiliar places would be minimised.

1.2 General Problem

Acclimatisation is the process of becoming accustomed to an unfamiliar environment. It can be expressed as how people are able to find their way to a particular place without anxiety and how they become familiar with new surroundings.

In visiting or exploring unfamiliar cities some problems can be experienced. For instance, disorientation which can lead to stress and frustration [Passini, 1992] may be accompanied by feelings of anxiety which can be a very strong emotion with disastrous consequences according to Downs (1977). Lynch (1960) emphasised that the simple word "lost" means more than geographical uncertainty.

In order to teach people their way around environments various methods of acclimatisation have been used, and are still used. These include: maps, pictures, verbal or written descriptions, films and architectural models of the environment. Each method by itself is an abstract and incomplete representation. Usually these methods used alone are poor in giving cues for orientation. People using these methods learn about objects and their related characteristics, such as social and cultural factors, and often they express a particular point of view; the information is presented through someone else's eyes which was filtered before being transmitted.

People differ in the way they perceive their environment; everyone creates and develops their own perception by experiencing it. They create different degrees of familiarisation with the environment through different ways.

Personal experience is an efficient way to become familiar with an environment; it is a rich, exploratory and interactive experience. People move, make decisions and interact with objects in the environment, and have the ability to select, organise and compile information in their own way. This personal discovery of the unfamiliar environment contributes to a full spatial experience [Passini, 1992]. Allen (1978) pointed out that people acquire knowledge about landmarks and routes as they move through their environment. Consequently, it is hypothesised that, in order to become acclimatised, the individual must be trained in the environment itself.

When a person is becoming acclimatised to an environment there are three main factors to take into account: their perception of the unfamiliar environment linked to past experiences, the physical environment as the symbol of a complex society based on social and cultural factors and finally, the person inside the environment, exploring and interacting with it.

This interactivity between a person and an unfamiliar environment makes the memory of it more vivid.

Navigation through any complex environment requires an abstract understanding of the route. This ability of a person to find their way, without undue delay or anxiety, is called *way-finding*. It uses a person's cognitive abilities to reach a destination, and it presupposes planning, information processing and making decisions. Finding one's way depends on a person's spatio-cognitive abilities, the ability to understand space and manipulate it mentally. The spatial understanding is

assumed to take a form of a 'cognitive map' a mental representation of environmental knowledge. Although, cognitive maps expressed through drawings often do not correspond accurately to the real world.
The ability to structure and identify the environment is based on the use of cues, not only the visual cues of colour, shape, motion, size, contour, surface texture and quality but also smell, sound, touch and kinaesthesia.
As it was emphasised earlier, there is a strong need to develop a method which represents an environment in such a way as to provide true sense of 3D space. It is hypothesised that the relationship between a person and a physical place, is crucial in learning about an environment.

1.3 Proposed Solution

Visualising urban form through computer simulations of real environments may not completely identify and solve the acclimatisation problem. The key point might be the interaction between the person and the environment and vice versa. This interaction may be made more realistic by the illusion of being inside the environment, and this can be achieved by using Virtual Reality.
Virtual Reality has the ability to make people believe that they are inside a 3D environment generated by a computer, feeling part of it and interacting with it.
It is part of this study to determine which environmental features are relevant in the acclimatisation process in order to achieve an effective *Virtual Environment*. Possible features include geometry, colour, texture, scale, size, sound, animation, representation of the participant's body, interaction and help tools.

1.4 Motivation

The motivation for this research comes from the need to develop a method capable of acclimatising people without visiting a locality, which minimises disorientation. The problem is common all over the world and it is of even more significance if communication between people is not possible because of language differences or other factors.

1.5 Scope and objectives

The objective of this thesis is to find out if Virtual Reality is an effective method to learn about unfamiliar environments. It is part of the scope of this study to compare the behaviour of a person inside the Virtual Environment and their performance in the real city. The investigation of the degree to which a person can orient and way-find in the real environment after gaining knowledge in the Virtual Environment was carried out.

The option to implement Cambridge city centre was chosen because it is a tourist attraction, one of the cities more visited in Europe, the city and its old and rich tradition have a special place in world cultural heritage.
The subjects responded to a request for volunteers, and were all drawn from two colleges in London. Some of the subjects were motivated by going to visit Cambridge, others were motivated by the state of the art technology, these being largely students studying computer science.

1.6 Approach

The basis for developing an application capable of identifying and solving the problem of being 'lost' in an unfamiliar environment is to find answers to questions such as: How do people mentally structure a city? What do people remember specifically about cities? How do people develop a knowledge about space? How do people relate to different parts of a city? How do people form *cognitive representations* of spatial environments? And what are the particular physical environmental features which influence the learning process?
Some of the answers to the questions above were encountered in a multidisciplinary field called Environmental Cognition which draws upon work in

other areas, such as: urban studies, psychology, geography, and sociology [Firey, 1945]. It refers to the entire range of physical, social and cultural aspects of the environment [Moore *et al.*, 1976], and to the awareness, impressions, images and ideas that people have about the environment; Strauss (1961) argued that it is unlikely to be able to understand an individual's behaviour in cities without understanding also their own way of thinking about cities.

The city as a space itself has an important role in this study and it appears in three distinct forms: virtual, psychological and physical space. Virtual space refers to the simulation of the real one, the environmental model created and generated by a computer, with some essential features, like geometry, colour, texture, movement, interactivity. The psychological space focuses on the individual's internal knowledge of the environment, it involves the complexity of an individual's mind, as it is an abstraction, it may not correspond with the real environment. This mental image of the environment is used to interpret and to guide action, the core issue is the memory of the space in the individual's mind. Finally, physical space is concerned with the real environment and how the individual interacts with it.

This research encompasses three main aspects; the design, the implementation and evaluation of an application with the objective of acclimatising a person to a new spatial environment.

The design is concerned with modelling a part of a city. The model involved architectural design, walk-through, identification information, interaction, and spatial relationship by the use of navigational aid tools.

The implementation was related to the learning process through two sessions using virtual reality; a free exploration and a training session.

The effectiveness of the application was evaluated through measuring subjects' task performance in the real city of Cambridge. Four methods of acclimatisation were compared; pictures, video, desktop and virtual reality.

It is noted that in this research the designation 'Virtual Reality' stands for a complete immersion experience, more specifically the use of a head-mounted display (H.M.D.), since it was the technology adopted for immersion.

1.7 Contributions

One of the interesting things in science is to realise that there are no boundaries between disciplines. This thesis brings together the computer science field of virtual reality with Environmental Cognition, which is itself a union of different fields: urban planning, geography, psychology and sociology. All these fields have a common theme: research interest in people, environmental space and their relationship with each other.

Specific contributions cover the following aspects:

- Case studies of how people look at the outside of buildings and also interior layout were carried out to assist in the methodology of creating a computer model.
- A set of navigation aid tools were created, based on traditional methods of presenting the spatial environment to help the individual within the Virtual Environment.
- An examination of traditional ways of measuring environmental learning contributed to an alternative method of quantifying the individual's internal spatial knowledge, i.e. the measurement of cognitive maps.
- An application using Virtual Reality was developed and evaluated in order to solve the common problems of orientation and difficulties in way-finding in an unfamiliar environment
- An investigation was carried out into the performance of acclimatisation using *passive* and *active* displays. The results indicate that active displays are crucial for the learning process, where interactivity is implicit. Immersive display type gives overall acclimatisation benefits over non-immersive one.

1.8 Organisation of the thesis

The remainder of this thesis is organised into the following chapters:
Chapter 2 centres on the theoretical basis, illustrated by a literature survey of the Environmental Cognition and traditional methods used in the acclimatisation process. Virtual reality technology is highlighted and is the method proposed to solve the specific problem of acclimatisation.
Chapter 3 focuses on four studies designed to refine the application under development. These studies were designed to learn the logistics necessary for a person to become acclimatised. They included two case studies in buildings environment and two others in the city context.
Chapter 4 covers a range of new methodologies for the construction and exploration of an application capable of acclimatising an individual to an unfamiliar environment. It describes and explains the reasons for each decision taken in planning different stages of the acclimatisation application. The methodology used in building a virtual city is described in this chapter. The implementation and evaluation of the application is then discussed.
Chapter 5 deals with the pilot experiment which evaluated the design process, while Chapter 6 concentrates on implementation of the main study and describes the experiment.
Chapter 7 presents the descriptive and statistical analysis, with the results and discussion, and finally Chapter 8 is dedicated to the conclusions and further work.

1.9 Thesis diagram

The diagram illustrated in Figure 1.1 summarises the Virtual Reality acclimatisation application.
In order to build an application able to solve the problem of acclimatisation, knowledge of two main areas was crucial: Environmental Cognition and Virtual Reality.

The study of Environmental Cognition underpinned the design process, by providing an understanding of the complex concepts of a city and the individual's behaviour in the city. The relevant issues in this area were the study of cognitive maps, orientation and way-finding. In order to create a set of tools capable of helping with orientation within virtual environments traditional methods were carefully analysed.

The evaluation of the entire application was accomplished by the performance of orientation and way-finding tasks in the real city. Subjects' task competence was analysed and compared to evaluate the effectiveness of the four different methods of acclimatisation (picture, video, desktop and Virtual Reality).

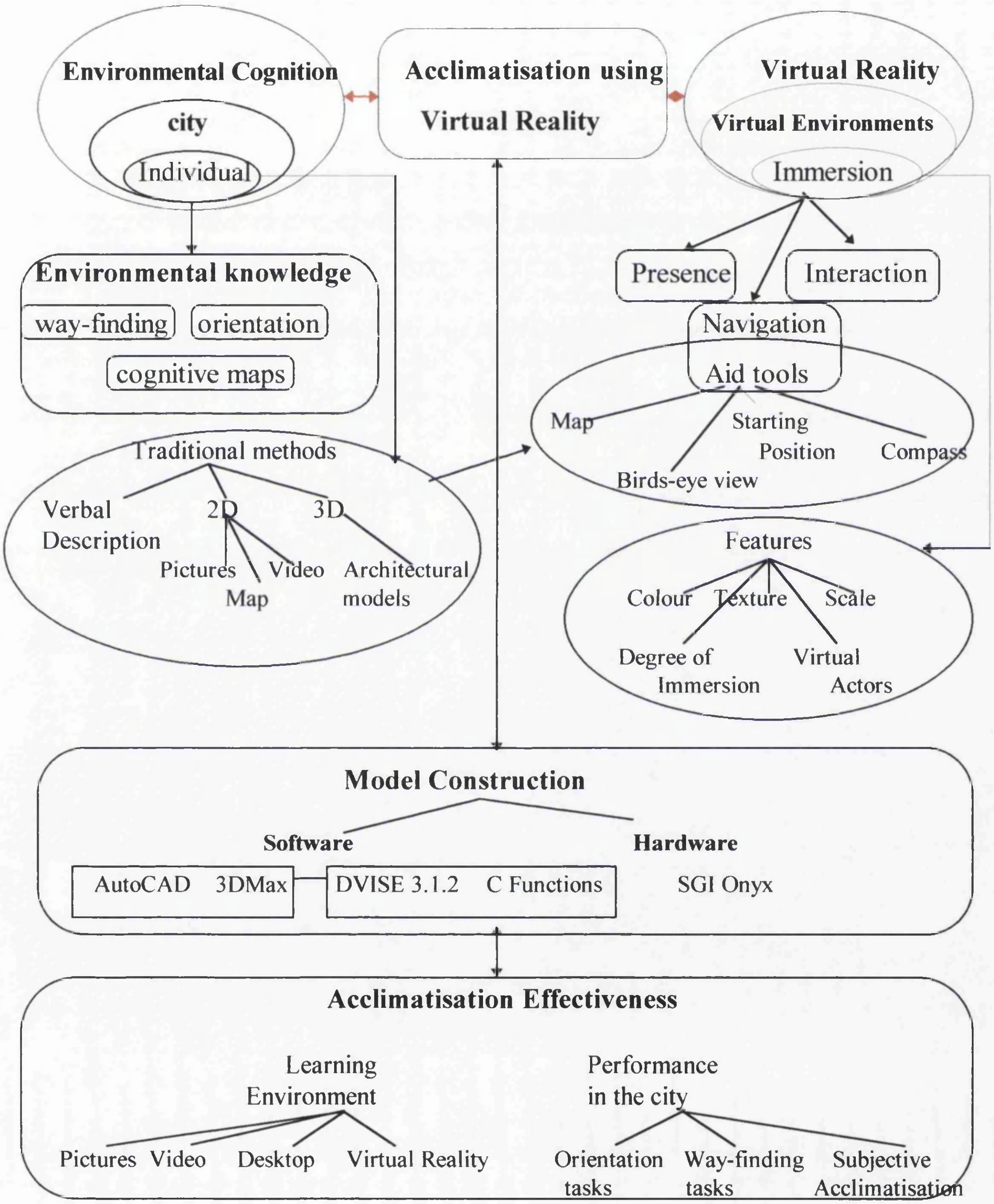


Figure 1.1 Diagram of the thesis

Chapter 2 Foundations

2.1 Overview of the Chapter

The focus of this chapter is to understand the concept of an environment, particularly a large scale one like a "city", in relation to a person who needs to become familiar with it. This is part of people's normal behaviour pattern in their everyday lives.

This chapter discusses some of the *acclimatisation* methods used so far and presents their limitations. A review of current knowledge in the field of spatial cognition is also presented in order to explain how people find themselves in large scale environments. In a brief introduction to Virtual Reality the types of technologies and parameters of visual displays are highlighted.

Studies of navigation in Virtual Environment are referred to here as this is the primary topic of training transfer.

2.2 Environmental cognition

Environmental Cognition is the study of images, thoughts, impressions and beliefs that a person may have about their environment [Moore, 1976]. It arises from direct environmental experience, not only at a specific moment but as a collection of all life experience. The images of the city have a personal meaning for each individual, very much influenced by the way they have been taught in a specific culture and social beliefs.

Therefore, environmental cognition is not linked to the physical aspects of the layout but to the spatial environment in the individual's mind. The city is what people think it is [Carr, 1967], everybody has a particular image of the city. This internal representation may be clear or vague, it may arise from real world experience or from a media representation, but no one image is more correct that any other, they are individual views and form a reconstruction of the environment through the beliefs and life experiences of an individual.

2.3 The City environment

Cities can be defined in different ways and from various perspectives. The physical form of a city is the result of social and cultural factors, and each city develops as a unique symbol of its particular inhabitants. The spatial complexity of a city environment is described by its geometry. In relation to the city of pure geometry, Batty *et al.* (1994) presented an interesting review particularly emphasising the distinctions between regular and irregular cities. The social aspect of a city is also very complex, and both aspects (the physical and social) are not easy to relate.

A city is defined in this thesis not only in terms of geometry, but also its life and events and the interaction between the city and people who are unfamiliar with it.

In order to consider a city in its all its complexity, it is necessary to understand human behaviour within the city. The main interest is in the individual's spatial comprehension and their spatial behaviour.

2.4 The individual within the environment

The environment is perceived by people through a 'filter', a highly developed interpretative process that Piaget (1952) calls a 'scheme'. What people understand in their mental representation of an environment is not completely everything they looked at, but only selected and compiled images.

People experience their environment and react to it in different ways, and that is the result of different factors such as life experiences, life style and socio-cultural circumstances. The environment has different symbolic meanings for different people; for some people the market place is a cultural centre, for others it is an area they would rather avoid. People differ greatly in their conceptions of space and the meanings they attach to the environment and consequently, their images of the same "objective" physical reality are different.

In order to study what people know about the environment the issue of how people perceive that environment must first be considered.

2.5 Perception and cognition

The difference between passive reception and active perception is noticeable even in an elementary visual experience. Passive reception takes place while an individual is surrounded by a given world in which each object has a location in space but the individual does nothing about it. Active perception occurs when the individual's eyes are directed somewhere by attention; this active performance is called visual perception.

Mental images of the world differ from what the eyes receive as mentioned above. This is due to manipulations which occur after the sense of vision has done its work.

Perception is related to information gathered through the senses, which then is subjected to a process of thinking, memorising and learning, called cognition; it is greatly influenced by higher cognitive processes. During a trip to a city a person may have expectations related to the kind of things they are likely to see, and this particular state of perceptual readiness influences what they see and ultimately what they remember [Bruner, 1957].

Messages reaching us about the environment are shared between visual and auditory perception and the other senses. Visual perception includes perception of depth, motion, symmetry, colour, shape, visual illusions and internal visualisation. The visual, tactile, olfactory, and kinaesthetic senses are complementary modalities combined in an integrated representation of any spatial environment. There are places forever registered in people's memories by their typical sounds, smells, or visual appearance. Sound and sight interact and can support each other; the visual experience of a city is closely related to the sounds that accompany it. Sound can direct attention to related visual elements and adds contrast, awareness and information when accompanying related visual displays. Mulligan (1987) hypothesised that, given a familiar array of visual information in an outdoor site, listeners expect the background noise level that usually would be heard there. Anderson (1983) concluded from his experiments that sounds have a constant effect regardless of site ("singing birds enhance any location where they are heard"). He also concluded that sounds are rated as more enhancing when presented with descriptive cues such as "wind in trees".

In order to explain how people oriented themselves in a spatial environment and find their way through it, it was mentioned by Tolman (1948) that the individual creates and organises a mental representation of the specific environment which he called *cognitive maps*.

2.6 Cognitive maps

The human brain has an enormous capacity to simultaneously process huge amounts of information. However, the information from the environment has to be filtered and compiled from what each individual notices in order to form a comprehensive representation of the environment. Cognitive maps are an essential component in the adaptive process of spatial decision making, within an environment. The personal schematic knowledge about an environment is embodied in cognitive maps. An extensive of the literature on cognitive maps is provided by Kitchin (1994).

The process of information acquisition and the product of this learning process at the specific time are referred to as cognitive mapping and cognitive map, respectively.

Cognitive mapping involves more than just spatial perception, it also collects earlier spatial learning from memories of places experienced. It is an activity that encompasses cognitive processes which enable people to store and manipulate information about the nature of the environment.

When people experience an environment they build an array of information updated as they become more familiar with the environment.

Downs (1973) presumed the cognitive map as the basis for deciding upon and carrying out any strategy of spatial behaviour. A cognitive map is therefore an internal "store" of knowledge of the environment, a kind of internal reconstruction. This information is not a cartographic map as the name cognitive map suggests, nor an internal model either, at least not in the sense of an accurate environmental representation.

Cognitive maps are mental representations of the space. In a conscious process they can have the form of network maps, route maps or cartographic maps. In an unconscious process they are simple abstractions by nature in two, three or four dimensions.

The study of cognitive maps would seem to be the most promising approach to understand how people organise the information gathered from their environment. However, an attempt for people to express their environmental knowledge through a drawing, such as a map, is far from an accurate approach. A drawing is a means of communication, and there are other ways in which people may feel more confident in expressing their knowledge. Commonly, in similar studies to this one, subjects are asked to draw their own cognitive maps, but some people's maps are very inaccurate, disconnected or distorted [Downs *et al.*, 1973]. This cannot suggest a defective mental image, but rather unfamiliarity with the task [Lynch, 1976].

Lynch (1960) divided representation of the urban environment into five types of point-references: i) paths, the channels along which the individual observes the city while they move through it, ii) edges, boundaries between two areas, iii) districts, a large part of the city with some common characteristics, iv) nodes, strategic points which force the individual to make a decision and v) landmarks, external physical objects noticeable by the individual. Landmarks can be anything which a person relies upon as a cue in *way-finding* or *orientation* performance. For example, an object may be selected for attention because it corresponds to the needs of the observer or perhaps it stands out against the rest of the visual world such as an unusual red building in a white block, or a small building among skyscrapers. Appleyard (1969) explored what makes buildings memorable landmarks and found that buildings are remembered because of two general aspects: social cultural factors such as land use and physical characteristics such as relative height difference and visibility from roadways. Of these two aspects the physical qualities were relatively less important than the social-cultural qualities. Therefore, the social and cultural significance of landmarks cannot be ignored [Moore, 1979].

Appleyard (1970) mentioned that individuals apparently use the attributes of form, visibility, use and significance patterns to structure their city knowledge. He noted also that the cognitive map representations of his subjects predominantly used sequential elements, such as streets, or spatial elements, such as landmarks. Within each of these two map types, four subtypes were identified. In the sequential type there were a gradation from the map which contained fragments of sequences, through chain, branch and loop maps to more complex and accurate network maps. The same gradation was identified for spatial maps, from clustered and scattered points, mosaic in form, others linked, to a more accurately patterned map; Figures 2.1 illustrates the diagram of the two dominant types.

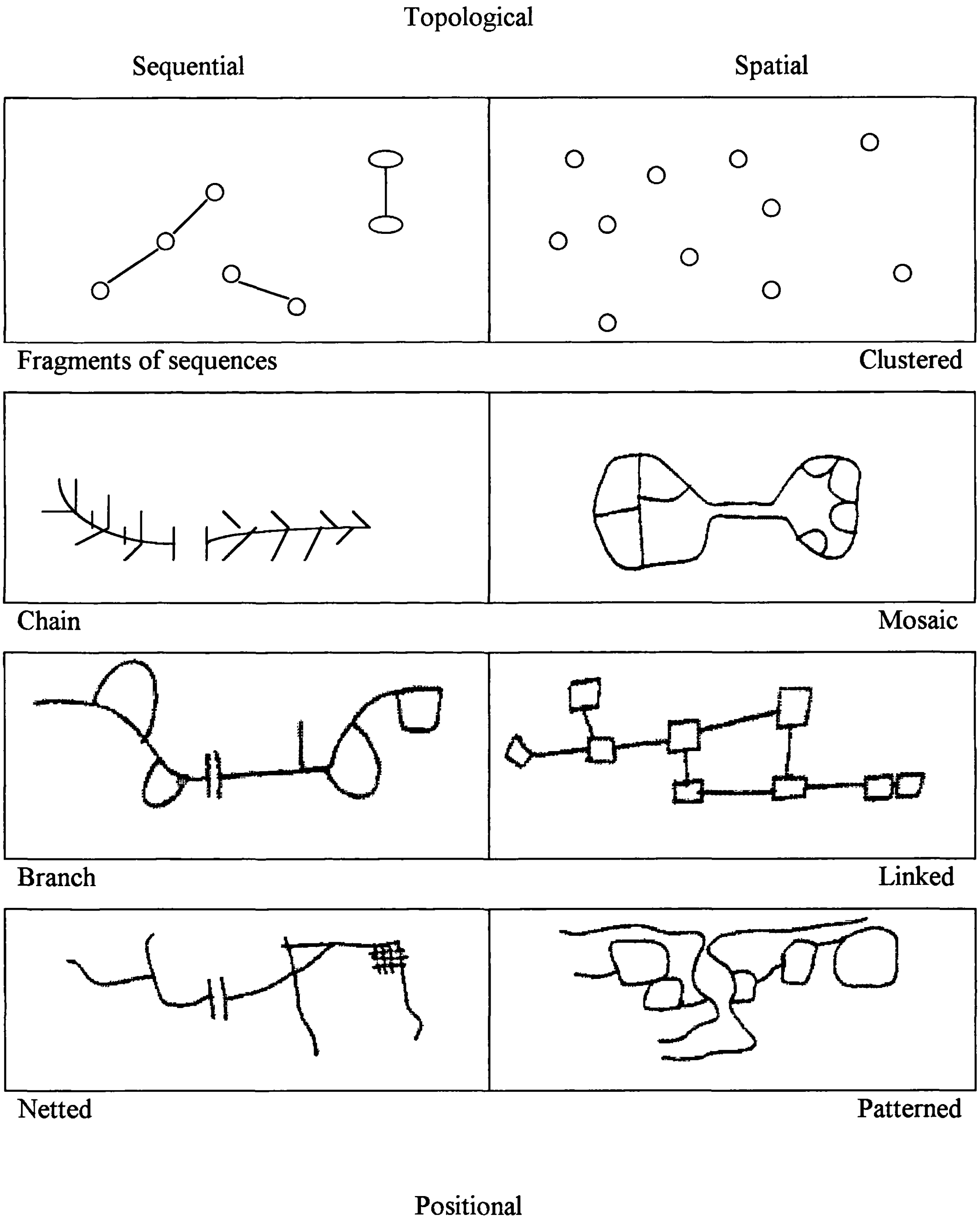


Figure 2.1 Dominant types of cognitive map representations

[Appleyard, 1970]

Hart *et al.* (1973) following Piaget's (1960) studies, conducted experiments with children from which he deduced that the development of cognitive maps may continue through three progressive stages, egocentric, fixed, and co-ordinate references where a person has full power over co-ordination of space. In egocentric representations the environment is represented in a sequential way by a route. The environment is placed in respect to the viewer; it is common in children and people unfamiliar with an environment. In fixed representations the objects and viewers are related to a specific point, such as the starting position. For example, tourists usually relate their position in the environment to the hotel or the train station. In co-ordinate representations people are able to present it in a spatial organisation, where objects are abstract representations, this occurs with familiarity with the environment.

It has been found that there are two separate subsystems within the visual system, one for recognising objects and one for discerning the spatial locations of objects [Otto, 1992]. One system identifies objects and the other determines where things are in space. This requires object recognition to identify the landmarks, and knowing where those landmarks exist in space in relation to each other and the observer [Chown, 1995].

A cognitive map develops in an evolutionary context. Its conscious representations increase in level of detail from topological to topographic by the contact or training within the environment. The first stage of development may be called the locations level, then it grows to a stage where places become landmarks in a complex structure. The next phase is called the landmarks location phase, where landmarks become related to other landmarks, at this stage people can orient themselves in the environment. The following stage is called the route map stage. The routes begin to take shape in topological detail. This is an egocentric stage. The final stage tends to be a cartographic map. However, the precision in size, proportion, distance and direction estimate are far from being precise. People visualise the environment in space and manipulate it mentally as the mind navigates through at high speed, flying above, able to visualise and rotate freely in space. People are prepared to perform way-finding tasks and are able to make decisions on how to reach or return from a place anywhere in the environment.

The "what" system relies upon the identification of objects, the "where" system relies upon location of objects in an orientation context and the "how" relies upon the route to reach a specific location, in a way-finding context.

The vector map is an example of a route map in topographic detail and a network map is a representation of nodes and paths in a topological detail. Figure 2.2 presents a network map.

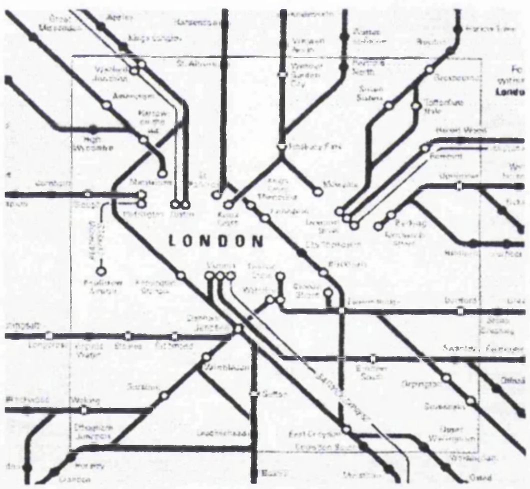


Figure 2.2 Example of a network map

[London rail-way, 1997]

Cognitive representations of the city implies a general spatial knowledge and *navigation* abilities. Way-finding and orientation are relevant skills for a person within a city. Golledge (1987) refers to cognitive maps as specialised structures which people relay in performing way-finding tasks.

2.7 Orientation and Way-finding

Orientation is the ability to relate one's location to other features in the environment, i.e. to know where you are in relation to cardinal direction, to a recognised landmark or even to a starting position. Passini (1992) characterised orientation, or the sense of direction, as the ability to maintain or point in a direction while moving independently from the individual's location in space.

The supposed internal ability of orientation may be confused with different levels of keeping the information of the environment in memory. Passini *et al.* (1990) used the example of how complex the first driving lesson is; once experienced it seems so natural that people almost forget the learning process. Actually, people do not normally remember the learning process in finding a location. Passini (1992) presented an excellent literature survey on this matter. Some psychologists have attempted to prove the idea of an instinctive sense of orientation; if this theory was true, people could maintain a direction without relying on cues from the environment, and they should be able to walk straight ahead when blindfolded. Shemyakin (1962) showed the impossibility of this task in his experiments with 100 blind-folded pilots asked to walk forward, some moved to the right others to the left, and gradually they began to walk in circles.

People vary greatly in their ability to keep a sense of direction, which depends upon the rapid and accurate assimilation of new scenes. Like any type of learning, its perfection depends partly on practice and partly on motivation, attention and memory which has an important role in any learning process.

When orientation is lost it can lead to anxiety, panic, or even stress. One fundamental aspect of stress is to affect the formation of cognitive representations, people are less able to form an accurate cognitive map of the environment [Langer *et al.*, 1977].

Way-finding is defined as the capacity to find the right way without delay and anxiety, using a person's cognitive and behavioural abilities to reach a destination.

It implies the abilities to understand space and to manipulate it mentally, presupposes planning, decision making and information processing, which involves three kinds of parameters, city layouts, way-finding paths and navigation rules [Peponis,1990]. Studies of way-finding and spatial mobility have investigated the ability of people to represent space and their movement through space mentally [Passini, 1988]. Lynch (1962) stated that there is unlikely to exist a mystic way-finding "instinct". There is constant use and organisation of sensory cues from the external environment. In addition, several studies have suggested that environmental cues as aid navigation tools, such as signs, are helpful because they help organise the input of environmental information [Love *et al.*, 1978].

Any literature review of orientation and way-finding would be incomplete without looking at navigation in animals, including in birds migratory behaviour. Darken (1996) presented a literature review on this matter, generalised to different animals relying on perceptual system to guide navigation. Furthermore, Griffin (1955) pointed out that animals could find their way to a goal in several different ways: piloting, which is steering by familiar landmarks (guidance), compass steering, which is heading in a constant compass direction (orientation), and true navigation, which is heading towards a specific goal regardless of the original starting place and the direction necessary to achieve the goal (map following). If migratory birds are captured and transported in a direction perpendicular to that in which they were flying, naive birds will continue to fly in the same direction which they had been headed and miss their destination, while experienced ones achieve their goal. Naive birds follow a compass direction, while experienced birds fly toward a goal.

The study of navigational abilities of birds and other animals contribute to understanding that general innate abilities are made possible by experience within an environment. The research on birds orientation could be the basis to develop navigational aid tools to assist people in facilitating orientation and way-finding tasks while navigating in an unfamiliar environment.

2.8 Memory and attention

Memory is essentially perception which has been stored earlier and can then be recalled. The level of motivation of an individual affects their memory and consequently the quality of new learning [Parent *et al.*, 1991]. The constant interaction between an individual and their environment elicits memories, which can be retrieved in an exact or equivalent form. Memory requires experience of an environment, change within the central nervous system, maintenance of that change, and an output that relates to the input [Filskov, 1981].

In the first phase of an individual's information processing the individual selectively attends to the environment depending on their interest at the time. During this phase a person has the capability to process enormous amounts of information for brief duration [Parent *et al.*, 1991]. The second phase of the process is the working memory, where information is retained by mental repetition; it can deal with approximately seven pieces of information at a time, and is considered part of a control mechanism for higher intellectual processing [Gathsercole *et al.*, 1993]. From working memory, items are consolidated into long-term memory; encoding begins with selective attention and is the means by which information is transformed in working memory so that it can be stored efficiently in long-term memory. Consolidation is the integration of new memories within the individual's existing cognitive linguistic schema or framework [Sohlberg *et al.*, 1989]. The more deeply that working memory processes information the better it is remembered [Parent *et al.*, 1991]. The final phase of the memory process deal with the retrieval of stored information, which consists of two stages, the search for available information and the directing of an appropriate motor response. Working memory for purely visual tasks depends on the ability to sustain a visual image and scan it [Parent *et al.*, 1991].

Memory, problem solving and other higher intellectual functions all have an attentional component. By choosing what to pay attention to, an individual is deciding what information is transferred from sensory memory to meaningful images which can be stored. Attention needs to be directed to a sensory input before any interpretation can take place [Christiansen, 1991].

Concentration is a factor required for the processing of new information and implies the ability to do mental work while attending to the process of active encoding in the working memory.

Learning an environment as a part of the learning theory is, in effect, based on concepts of attention, concentration, memory and motivation.

2.9 Traditional media presentations

A variety of methods are commonly used to provide spatial knowledge for the process of acclimatisation, these methods are: verbal descriptions, pictures, maps, architectural miniatures (models) of the environment and video or films. These different methods of presenting an environment may be separated into two modes, passive and active. In the first mode, subjects experience the environment in a manner similar to a guided tour, their participation is restricted. While in the second, active mode, they not only interact with the environment but also take part in decision making, such as choosing the path which they will follow. In this case active experience includes exploratory and interactive stages.

McDonald (1993) and Presson (1984) referred active and passive experiences as primary and secondary respectively. McKechnie (1977) referred to conceptual versus perceptual, and static versus dynamic. Conceptual means abstract and perceptual means concrete, while static and dynamic refer to the animation of the simulation. Weisman (1987) suggested that video could either be considered as passive or active. In this study an active experience is referred to when a person is able to interact and have power of decision in the walkthrough.

Verbal descriptions are commonly used in way-finding strategy. Asking for directions is generally considered undesirable, as it is unlikely a person will get more than half way to their destination [Butler *et al.*, 1993] and [Vanetti *et al.*, 1988]; understanding and relating the unfamiliar various paths is quite difficult.

Figure 2.3 presents a humorous problem of communication related to verbal descriptions. The instructions are given from a person's view, who in most cases knows the environment well, and expects the other just to follow the directions. Generally, verbal descriptions in the location are accompanied by pointing gestures, which are helpful for taking the right direction from the starting position.
Information written in books, such as tourist descriptions or novels, can have an impact in the creation of cognitive maps by transmitting one or more aspects of the geographical or social environment. As with verbal descriptions, written descriptions are abstract and fail in being objective. They may lead people to create distorted cognitive maps deviating from reality. This might happen because people have different experiences of life, and as mentioned above they relate the information to their own past experiences.
Sequential pictures provide identification but still lack spatial forms or relating paths. This method is again abstract and depends entirely on the picture itself.

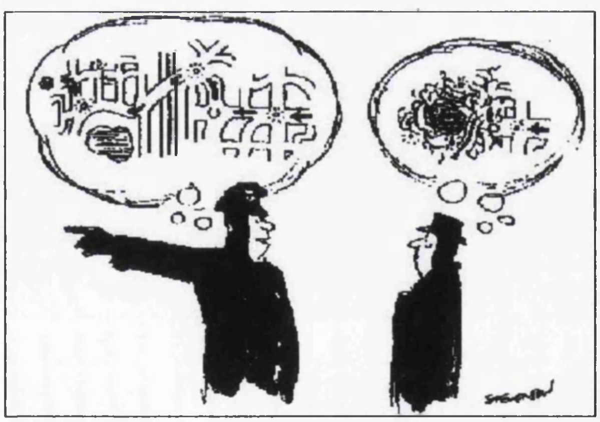


Figure 2.3 The complexity of verbal descriptions

[Stevenson 1976]

Maps are extremely useful for describing relations in space, they allow one to define the position of an object within the large scale environment. Because of its

2D nature, people have to make some mental effort to create a 3D image of the destination and to build a "solid" mental way-finding route. Consequently, from this point of view, maps also offer extremely abstract method and are poor in giving a sense of orientation [Kaplan, 1976b] and [Passini *et al.*, 1990]. Nevertheless, maps are very faithful representations of the area in the real world, being based on accurate survey.

Physical, 3D architectural miniature representations (scale models) of the environment provide an understanding of its full spatial form. Hunt (1984) used sequential slides to provide the identification of an object and a 3D miniature of the building to acclimatise people to their new accommodation. It was shown that people who were previously acclimatised were able to find their way around more easily when they moved to the new accommodation than those who had not experienced this.

When using videos or films the characteristics of the city are transmitted with accurate realism, since it captures the real images of the path taken. However, viewers follow a pre-defined path and a single angle of view. Consequently, the information is previous selected through someone else's preferences or decisions, which limits the ability to choose and decide what to see, listen or learn.

These existing methods of acclimatisation, described above, belong to the passive experience mode, i.e. interaction with the environment is missing.

Thorndyke (1982) who compared environmental learning through maps and navigation experience, demonstrated that subject's with navigation experience performed better on the orientation task than map-learning.

When visiting an unfamiliar city people are free to explore the environment, they take their time and identify the place in their own way. Obviously, there may be the anxiety associated with being in an unfamiliar place, and unfortunately the city environment does not offer all the possible cues of orientation and way-finding. City images are structured around a series of typical elements which are important to the observer because of their visual dominance.

The common factor in a new environment is the difficulty of an individual to fix the position of an object within the space. For example, that is the reason why it is so common to see tourists looking at a map in order to locate themselves in space and to understand the relationship between different paths.

To form a well-developed image it is important to identify the objects, to recognise the location and visualise the paths connecting them. As mentioned above, relying on one technique alone is abstract, partial and inefficient. There is therefore a need to employ more than one method to carry out environmental learning research. The unknown environment has to be presented in a way which simplifies its envisioning. Kaplan affirmed (1976a) in the 1970s, that there was no way of representing an unfamiliar environment which would fully meet the desired criteria. Any new way of presenting the new environment has to instil great confidence in a person by assuring them of sufficient contact with it. This confidence may be acquired with experience, and the passing of time is implicit. Kaplan (1977) argued that people without experience may not behave appropriately and may not know how to act. Generally the researchers in this area agree there is clear evidence that prior experience provides confidence [Kaplan, 1976b] and [Zanaras, 1976].

Consequently, if people want to learn the location of places and the paths that connect them it is important to personally experience the environment gradually.

2.10 Environmental representations

People have always had a desire to make representations of the things they see in the surrounding world. In doing so they have used many different channels of communication, predominantly visual and often enhancing realism. The drawings in the caves of France thirty thousand years ago were using perception cues to give a feeling of depth [Chauvet, *et al.* 1995]. Figure 2.4 presents one of those drawings.

Figure 2.4 Drawings in the caves

[French Ministry of Culture and Communication]

Two dimensional (2D) representations are the most common and oldest way to communicate and transmit information about the environment. Pictures, 2D drawings or paintings, stereoscopic pictures, panoramic paintings, films, computer graphics and virtual reality are examples of the different methods of communication through the power of vision.

The 3D effect is typically achieved by depth perception cues, such as interposition, shading, brightness, size, linear perspective and texture gradients.

Objects which are closer partially hide objects that are further away, this is part of a technique called interposition. Shadows associated with the object contribute to the depth of perception by contrasting the projection of the specific object in the environment. Darker objects seem smaller than light coloured objects, and this is why brighter objects seem closer to the viewer than the darker ones. Linear perspective is which involves an illusion using converging straight lines; the convergence is a stronger depth cue than the effect of size [Foley *et al.*, 1992] where a closer object has a larger image projected onto the retina, inversely a further object has a smaller image. In texture gradients techniques, the texture is well defined and densely compacted near the view point and less defined further away.

Light, size and form are always very strong cues in 2D representations, but some additional factors have also been used to increase the illusion of realism. Good illustrations of this are the "Panorama Paintings" from 1788, e.g. a single display (a 10 feet tall canvas) in a circular room 60 feet across. A great sense of realism was achieved by enormous dimensions and indirect light effect. Another example is the dome structure; Leonardo da Vinci, and other artists, utilised the natural human visual processing capabilities by painting the interiors of domes. When the eye points to the centre of the dome perspective is maintained by the properties of a sphere and the natural wide angle view.

Visual perception is attracted by movement and another form of great realism is the animation cue, closely linked to the notion of being alive. The illusion which suggests movement was first created in the late 1800s by making sequential drawings of a continual action and projecting them onto a screen at a constant rate. The illusion of depth can also be achieved by presenting images from two slightly different angles. Each image is directly presented to each eye, and the images processed and merged in the brain gives the illusion of a single 3D image. This binocular disparity is of particular interest, as it gives a form of depth perception known as stereopsis which, unlike monocular cues, affords the sense of 'real world' depth. An early device using such 'stereoscopic pairs' pictures, dates from 1833, as created by Weastone and is still commonly employed today, e.g. even as a toy known as the "View Master". As mentioned earlier, it enables an individual to view stereo images with a sense of depth and realism.

Applying stereoscopic techniques within computer graphics enables an individual to experience a powerful illusion of being inside the scene, sharing the same space with 3D objects generated by computer. A true notion of space in a natural scale environment, and the ability to interact with the objects, furnish this technique of Virtual Reality, with great potential and make it a capable, ultimate acclimatisation tool.

2.11 Virtual Reality

Virtual Reality is the technology that provides an illusion of being completely surrounded by 3D objects generated by computer displays, including interacting with them, as if they existed in physical 3D space. The illusion of being inside such a world can be achieved in part by wearing a head mounted display which is a component of being *immersive*.

The world generated by computer is called a Virtual Environment, and the person experiencing it is called a "participant", since they are actually part of it, rather than using equipment such as a computer screen or mouse [Slater *et al.*, 1992].

Sutherland (1968), who is widely accepted as the father of Virtual reality, characterised the goal of virtual interface research in the following way: "The screen is a window through which one sees a virtual world. The challenge is to make the world look real, act real, sound real, feel real".

There is an enormous variety of Virtual Reality displays, each one developed for a specific need. They differ greatly in a degree of immersion they can provide. There are different ways of experiencing the Virtual Environment, through non immersive to completely immersive, which is defined as being when the boundaries of the display disappear from the person's field of view [Pimentel *et al.*, 1992].

Experiencing a virtual environment using a head mounted display set is completely immersive, while a non-immersive environment is one in which a viewer is conceptually on the outside looking in.

The head mounted contains two tiny television screens, one for each eye, to provide the participant with a stereoscopic view of a virtual environment.

On the top of the helmet there is a sensor which tracks head movements, and as a participant moves their head, the computer generates the image related to that viewpoint.

In a head mounted display there are two important technical specifications to consider; resolution and field of view. In general, the better head mounted displays are those which provide high resolution and display a large field of view. Figure 2.5 presents a head mounted display.

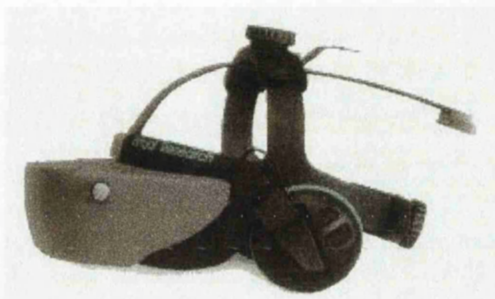


Figure 2.5 Head Mounted Display

Another example of the immersive display is the CAVE, originally developed at the University of Illinois. It is a projection-based virtual environment that surrounds the viewer with four screens, and allows physical and virtual objects to occupy the space. It usually consists of 10'x10'x9' room. Four projectors are used to project colour, computer generated images onto three walls and the floor. It is a multi-person high-resolution audio environment. To experience the stereo effect a person wears active stereo glasses [Cruz-Neira, 1992].

Another type of immersive display a wide-display across the wall, as presented to the public by SGI in Reading, England. It is a 8 metre diameter, partial dome screen providing 160-degree horizontal and 40 degree vertical field of view, and is many ways similar to the Panorama Painting and the dome structure described in section 2.10.

To be immersed in an environment means that the person is experiencing the illusion of being inside the environment, although not necessarily feeling part of it. Immersion is required in applications in which a need exists for participants to learn in a realistic simulation, were they can learn by experiencing and doing in a natural way, the way they are used to doing in everyday life.

Navigation through any complex environment does not depend wholly upon direct visual perception, but requires a more abstract understanding of the route.

In Virtual Reality, navigation is the ability to move freely around the virtual environment. A standard solution for navigation in immersive virtual environments is to make use of the hand-held pointing device, typically a 3D mouse. The user interface can rely on either of two metaphors: moving in the direction the hand is pointing to, or moving along line of the sight. In the second case the virtual hand is free to interact with the virtual environment.

Navigation has an impact on mental representations [Chance,1998], and walking is the more efficient method to learn the environment [Zannaras,1976]. In order to experience the world realistically it is necessary to obtain a sensory motor interaction with the environment. Slater (1994c) used a treadmill to simulate the walking interface. More important even than the individual being part of the environment it is crucial to have the power of control in the environment. A major feature of immersive virtual environments is the naturalistic form of human interaction; that is: participants carrying out activities in an everyday manner. From the technological point of view, interaction between the participant and virtual objects is made possible by using an input device such as a 3D mouse. The mouse has several buttons, and the picking and touching interactions are available.

For the interaction to be more realistic, the inclusion of the virtual body is essential. It represents the movements of real limbs with virtual limbs, and the participant knows when the virtual hand has touched the virtual objects. The tactile and visual feedback are received at the same time.

Being immersed in a virtual environment, looking around, exploring it and interacting with it, can increase concentration, which is the result of the ability to focus attention [Pimentel *et al.*, 1992], it also leads to *presence*.

Presence is related to the degree of realistic feeling inside the environment [Slater *et al.*, 1993a]. The participants do not feel immersed, they feel present (or not) while they are immersed. While immersion is defined as being involved in the physical environment, presence refers to the sense of being completely involved in a particular point of interest. The sense of being there [Wells, 1992], can be achieved by reading a book, watching a film or simply thinking of something else in another time or space. It is in fact a complex and subjective sensation of being part of an environment. "It is concerned with locality, and is the extent to which a person is able to believe that they are in one particular place rather than another" [Slater *et al.*, 1994b].

It is possible to have a high level of presence in a Virtual Environment without having to stimulate all the senses. The mind compensates for the lack of information, the important factor is to discover how to capture the participant's attention and interest. However, in a simulation, the sense of presence contributes to the involvement of the participant in that simulation. The result of experiments by some researchers have found that there are several important factors in increasing the extent of presence [Heeter, 1992], [Held *et al.*, 1992], [Loomis, 1992], [Sheridan, 1992] and [Slater *et al.*, 1992]. These factors are: interaction, high resolution information, wide field of view, inclusion of a virtual body and spatial sound.

Nevertheless, virtual environments may not need to be immersive for an individual to achieve a high degree of presence. It all depends on the requisites of the application in which a Virtual Environment is used.

2.12 Spatial knowledge transfer

The appropriation of Virtual Reality proposed solution for acclimatisation is the central topic of study in this thesis. It has the characteristics of presenting an illusion of being inside the environment, exploring it and interacting with it in a realistic and natural way and it therefore has a potential for learning unfamiliar environments.

The purpose of the study of acclimatisation is to investigate the levels of difficulty experienced by a person while performing way-finding and orientation tasks after having gained sufficient knowledge from the virtual environment experience.

The aim of this study is also to investigate the degree to which information transfers between each learning mode and the real world, the degree to which spatial information acquired from exploring both worlds (the real and the virtual) are similar and if so to what extent.

At an intuitive level, active modes of display might have significant advantages when compared with passive modes of display. In an immersive environment, a participant explores, interacts and looks at the virtual environment as in the real world. The experience of exploring a virtual environment might be indistinguishable from exploring a real environment.

According to Regian (1992), Ruddle (1996) and Wilson (1996), people can be effective in training knowledge about the route through a large and complex office layout. Witmer (1996) stated that exposure to virtual environments can be effective in training knowledge about the route through a large and complex office layout. Bliss (1997) showed the possibility of training transfer.

Waller (1998) concluded that training in a virtual environment allows people to develop functional representations of large scale environments. Relatively to short exposures, virtual environments training may be no more effective than training with map and the same may happen between virtual reality and desktop training and be indistinguishable from training in the real world.

Wilson (1996) supported the belief that extensive training in simulated environment may enhance spatial learning in the real world and Tlauka (1996) concluded that navigation in computer-simulated space and real space lead to similar kinds of spatial knowledge. Wilson (1997) provided good evidence that spatial information acquired from a desktop computer simulation can transfer to an equivalent real environment.

Tlauka (1996) concluded that the results of internal representations are like those constructed from primary experiences derived from navigational learning in the real world. Tlauka also suggested that real world and simulated navigation both result in similar cognitive maps.

Furthermore, it has been demonstrated that people can orient themselves in simulated environments [Regian, 1992] and [Wilson, 1996].

2.13 Summary

The literature review was concentrated in two main aspects, the study of an individual's internal image of the environment and the development of an application capable to teach unfamiliar environments. Consequently, the behavioural study of an individual inside a city and its subsequent aspects (perception, cognition, cognitive maps, orientation and way-finding) were carefully considered. Virtual Reality is particularly well suited to spatial learning, since incorporates immersion by the very nature of the technology. In this study the focus was navigation and interaction.

Each method of acclimatisation used so far was also surveyed.

Figure 2.6 shows a visual summary of this chapter.

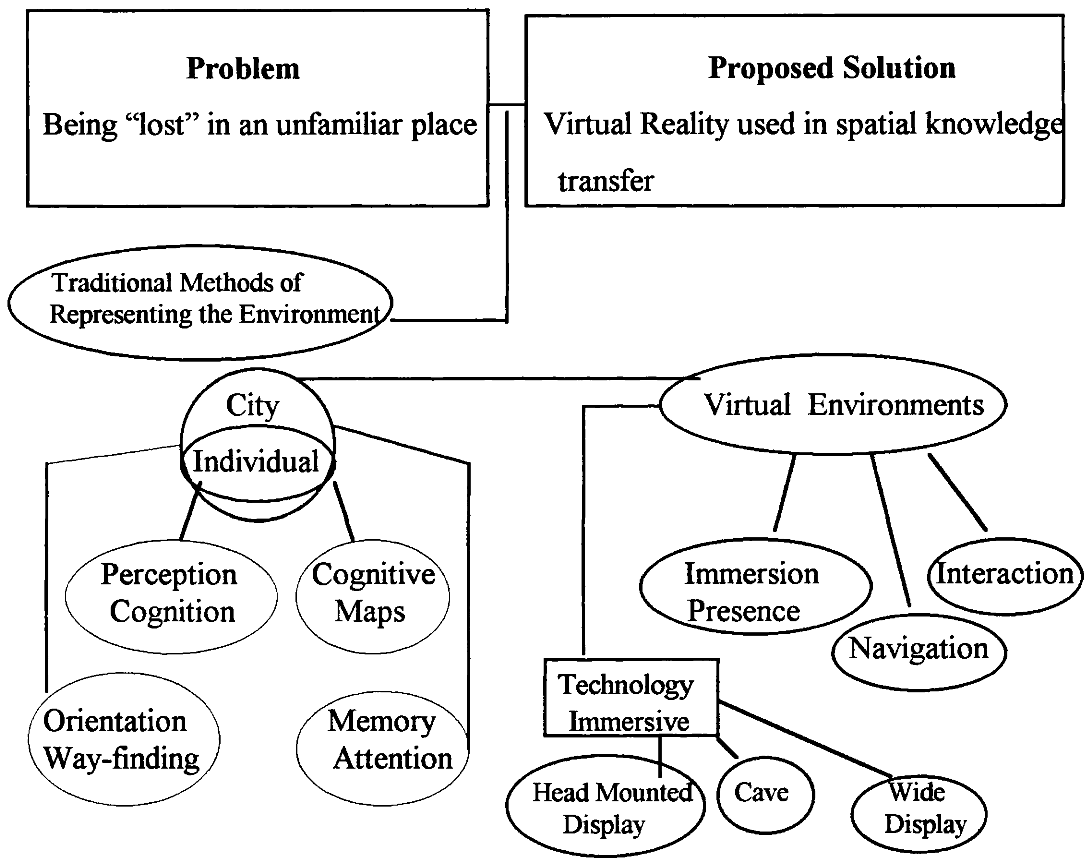


Figure 2.6Visual Summary of the Foundations

CHAPTER 3 Preliminary Studies

3.1 Overview of the Chapter

Four studies were carried out to understand the effectiveness of virtual environments in learning about unfamiliar places, to assist in the methodology of creating a computer model of Cambridge (England) city centre and to quantify subjects' spatial knowledge.

The first study (A) was an experiment to examine the effects of immersion on task performance in an interactive walk through. The experiment focused on three indicators of spatial awareness: a recognition task, a location task, and a navigation problem. Mental reconstruction of the geometry of the virtual environment and the relationship of this to the sense of presence was also considered.

The aim of the second experiment (B) was to study the behavioural differences between subjects in a control group and an experimental group. The factors included in this experiment were texture, monochrome versus colour and two dimensional (2D) virtual actors.

The third study (C) was designed with the goal of identifying the types of information needed, and to test the logistics necessary, for a person to become acclimatised to an unfamiliar environment, and to debug experimental procedures.

The fourth experiment (D) was designed to understand how much attention generally people pay to the layout of the buildings while navigating in the environment, apart from material of the buildings such as texture and colour.

It is worthwhile to summarise the following preliminary studies presented. This summary is presented in Table 3.1.

Table 3.1 Summary of the preliminary studies

Virtual Environment	Aim Research	Factors
Part of a university building 24 Subjects (A)	Examined the effects of immersion on task performance in an interactive walk through	immersion / non immersion memory colour
Computer laboratory 16 Subjects (B)	Studied the behavioural differences between subjects in a control group and an experimental group	texture colour virtual 2D actors
Part of Cambridge city centre 4 Subjects (C)	Identify the information needed for a person to become acclimatised to an unfamiliar environment	
Building facade in a middle of a square floor 50 Subjects (D)	To understand how much attention generally people pay to the layout of the buildings	shop structure colour windows roof

The computer system used in the first four experiments mentioned in this chapter, was a *DIVISION ProVision* 100, with a Virtual Research flight helmet and a *DIVISION* 3D mouse. *Polhemus* fasTtrack sensors were used for position tracking of the head and mouse. The displays were colour LCDs with a 360x240 pixel resolution and provided a horizontal field of view of about 75 degrees.

In the first experiment an arrow cursor was slaved to the 3D mouse and there was no virtual body representation other than a virtual arm. In the following three experiments there was a virtual body representation.

3.2 Experiment in a building floor environment (A)

The aim of this experiment was to compare immersive and non-immersive walk-through systems, with respect to the effect on the participant's task performance. The main objective was to examine the effects of immersion on whether the subjects could successfully complete a recognition task when later taken to the actual place that had been depicted in the virtual environment.

Two models differing in colour were presented to two groups of subjects. Half the subjects experienced a virtual environment which had (as much as possible) similar coloured walls as the real location, and the other half experienced a virtual building which had walls coloured similarly to another location. The purpose was to discover whether the subjects would use spatial and layout information in the recognition task (recognising the correct location) or whether they would rely on colour cues.

The assessment of the effect of short-term/long term memory on the recognition task was achieved by taking half the number of subjects to attempt to identify the real location immediately after experiencing the virtual environment, while the others made the visit 24 hours later.

This case study also examined the effect of immersion on task performance in an interactive walk-through indoor environment. It focused on three indicators of spatial awareness: a recognition task, a location task, and a navigation problem. Mental reconstruction of the geometry of the target area and the relationship of this to the sense of presence was also considered, as a continuation of an earlier work on this issue (Slater *et al.*, 1994b).

3.2.1 Experimental design (A)

Twenty four subjects were chosen arbitrarily throughout the Queen Mary and Westfield College campus. The only requirement was that they were fluent English speakers. There were 11 students, 7 administrators and 6 members of staff, none from the Computer Science department. The sample was equally split between gender: 12 female and 12 male, and the average age was 32 years. Two of the subjects had previously experienced virtual reality.

3.2.2 Model and scenario (A)

The scenario comprised two parts: one exploring the virtual building and the other a real building performance.

The virtual model represented a part of the floor of one building within the campus. The model comprised ten rooms, including a large room at the end of a corridor as shown in Figures 3.1 and 3.2. The starting position and the location of the plant are pointed in Figure 3.1

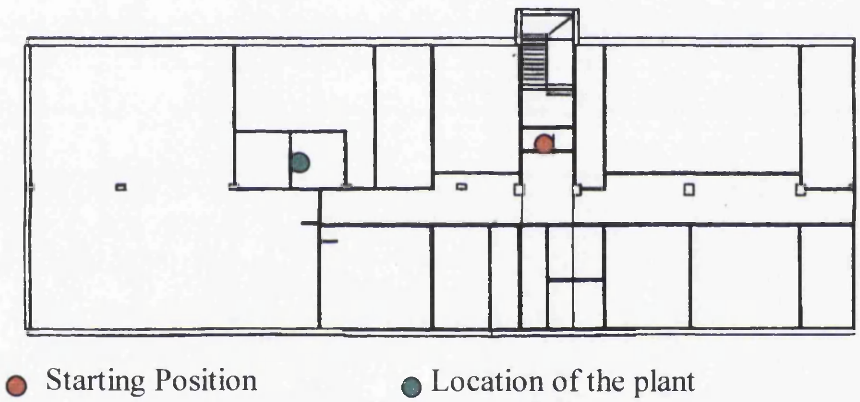


Figure 3.1 Plan of the virtual model

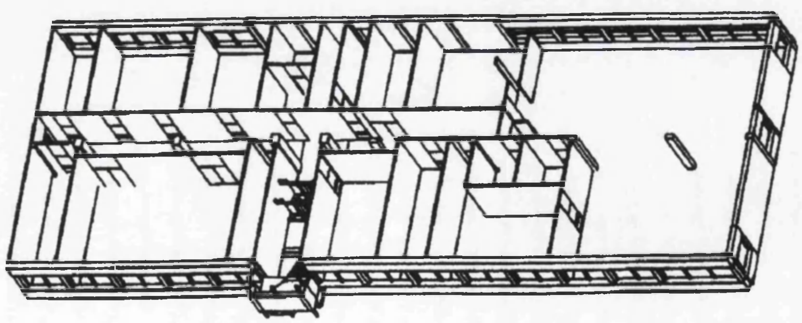


Figure 3.2 Birds-eye view of the virtual model

After a limited amount of background instructions and system familiarisation, each subject navigated the virtual environment, half of the subjects in an immersive system, the others half in a non-immersive system. Subjects in the immersive system had the facility to navigate through the environment at different speeds, by pressing buttons on a 3D mouse. The non-immersive system was viewed through a monitor. The conditions for immersive and non-immersive systems were kept as similar as possible. The only difference was that the view point was controlled by the movement of a swivel chair, since the head mounted display was placed there, and the navigation was exactly as the navigation in the immersive system by pressing a button in the 3D mouse, the user's left hand was controlling the swivel chair and the right hand was controlling the navigation.

There was no collision detection built into the model and the subjects were advised not go through walls or closed doors, and not to attempt climbing stairs. Apart from this they were allowed to explore the environment freely.

The task presented was to find a rubber plant which had been concealed in one room.

Later, each subject was taken to two different floors in the building, one was the location which had been modelled in the virtual environment. Although these two floors looked superficially similar in many aspects there were differences of decoration and layout. These visits took place immediately after the virtual reality experience for some subjects and 24 hours later for the others.

Subjects were allowed restricted movement through the two floors before making their choices as to which was the one they had experienced previously in virtual reality. Whichever floor the subjects 'recognised' they were taken to the floor depicted in the model and, with their eyes closed, taken to a particular room. Once in that room they could open their eyes and were then asked to find a real rubber plant which had been placed in the same location as it had been in the virtual environment. The time taken to find the plant was measured and recorded. Finally, they completed a questionnaire.

The factorial design is presented in Table 3.2.

Table 3.2 Number of people assigned to each experimental variable..

	Incorrect colour		Correct colour	
	same day	next day	same day	next day
Non-immersive	3	3	3	3
Immersive	3	3	3	3

3.2.3 Variables measured (A)

The measurements taken directly from the experiment were: time taken to find the plant in the virtual environment, and whether the correct real location was recognised and the time to find the plant in the real location.

The questionnaire given at the completion of the experiment was mainly concerned with assessing the sense of presence of the participants. It was taken into account that half of the participants had not had an immersive experience. There were three aspects of presence considered: the sense of "being there", the extent to which there were times that the virtual world seemed more real than the laboratory were the experiment took place, and the sense of having visited a place rather than having seen images.

These three aspects were elaborated into six questions with answers on a 1 to 7 scale, in which 1 indicated least and 7 indicated the most presence. There was an additional question asking the extent to which the subject had a sense of having "been there before" when visiting the real location.

People differ in the extent to which they require and use visual, auditory and tactile information in order to construct their world models. Each person may rely more on one type of representation (say visual) over another (say auditory). Slater (1994f), found that in experiments in which the virtual reality system presented an almost exclusively visual environment and the greater the degree of visual dominance the higher the sense of presence, conversely the greater the degree of auditory dominance the lower the sense of presence.

3.2.4 Results (A)

Figure 3.3 presents the time in minutes to complete a finding task. The values are clustered by display type. The duration that subjects took in finding the task in the real environment, clustered by display type is presented in Figure 3.4.

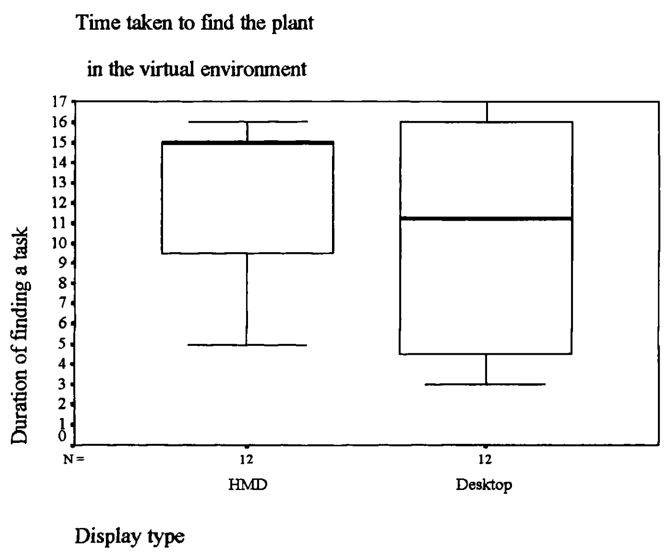


Figure 3.3 Time to accomplish a finding task in the virtual environment

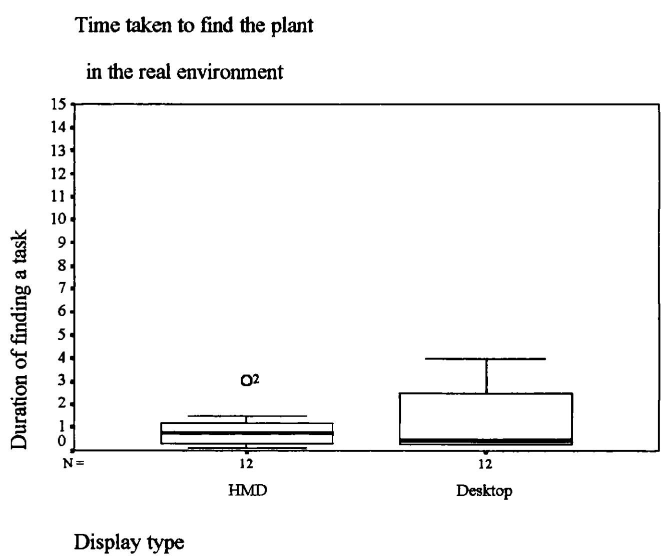


Figure 3.4 Time to accomplish a finding task in the real environment

The number of subjects who were or were not able to find the starting position and those who were or were not able to accomplish the recognition task is presented in Figure 3.5 and 3.6. The respective data is presented in Table 3.3. The difference between subjects who experienced an immersive and non-immersive environment was not significant. The starting position was a task inside the virtual environment whereas the floor choice was a task inside the real environment.

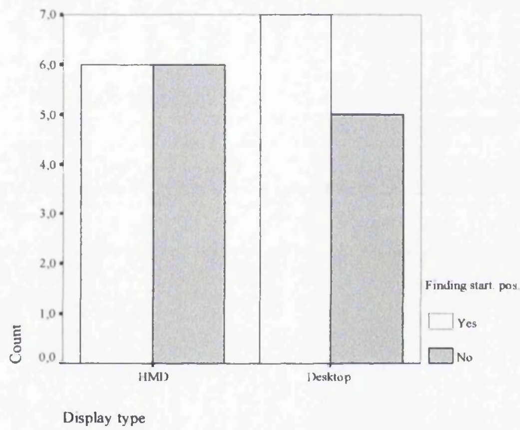


Figure 3.5 Recognition task in the virtual environment

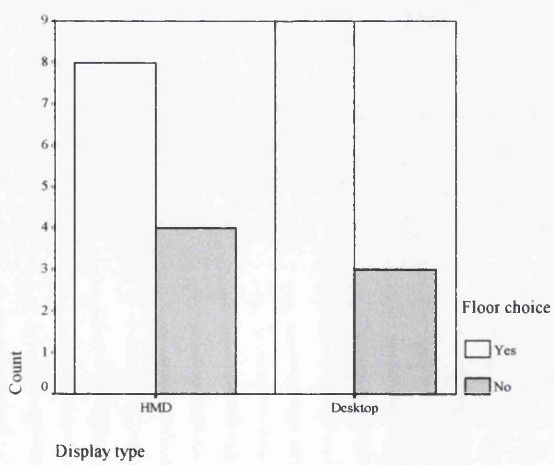


Figure 3.6 Recognition task in the real environment

Table 3.3 Recognition tasks

	HMD		Floor choice		
	No	Yes	No	Yes	#Subjects
Starting Position	6	6	5	7	24
Floor choice	4	8	3	9	24

The answers to the presence questionnaire are presented by the box plots through Figure 3.7, Figure 3.8, Figure 3.9, Figure 3.10 and Figure 3.11.

Subjects who experienced an immersive virtual environment reported a high degree of feeling sick or nauseous during the experience. The mean is 5 in a 0-7 range. Figure 3.12 presents the subject's report of sickness.

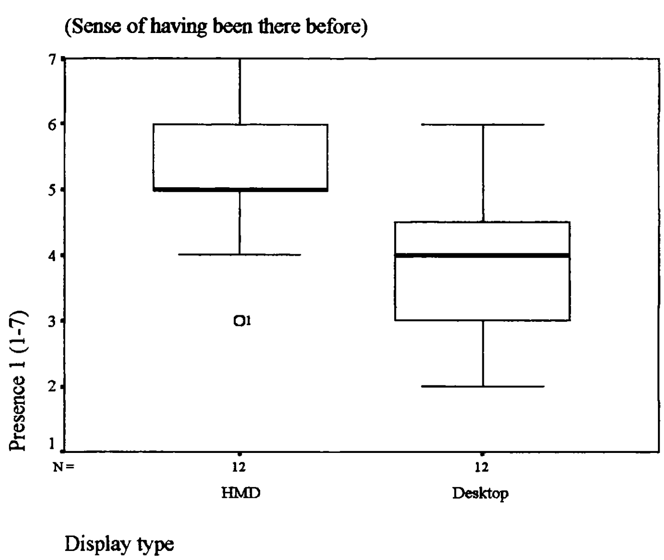


Figure 3.7 Sense of *dejá vu*

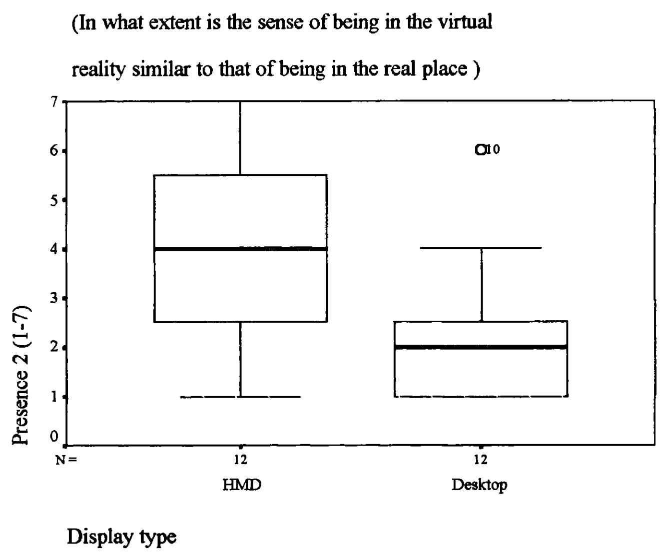


Figure 3.8 Sense of feeling in a real place

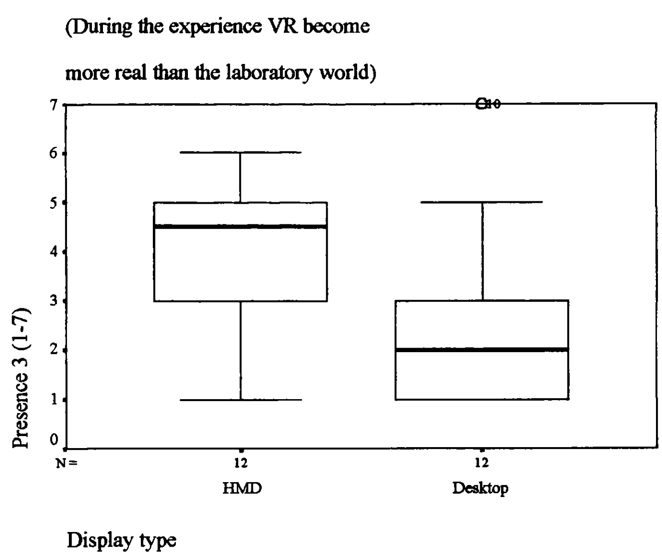


Figure 3.9 Sense of the virtual being real

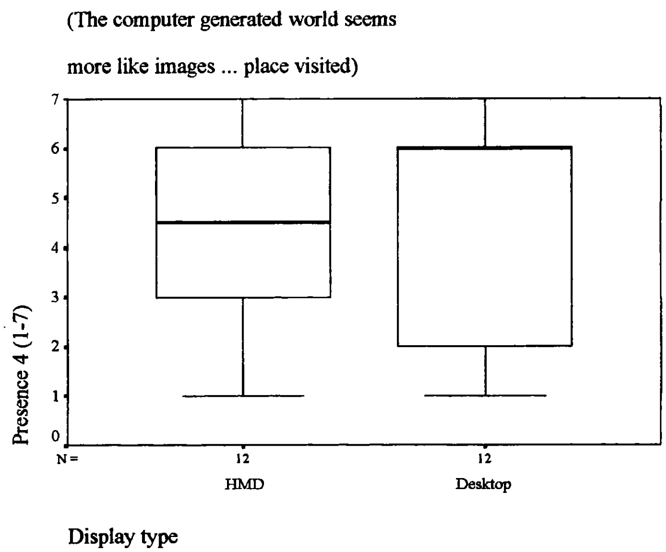


Figure 3.10 Sense of The virtual was a real placed visited

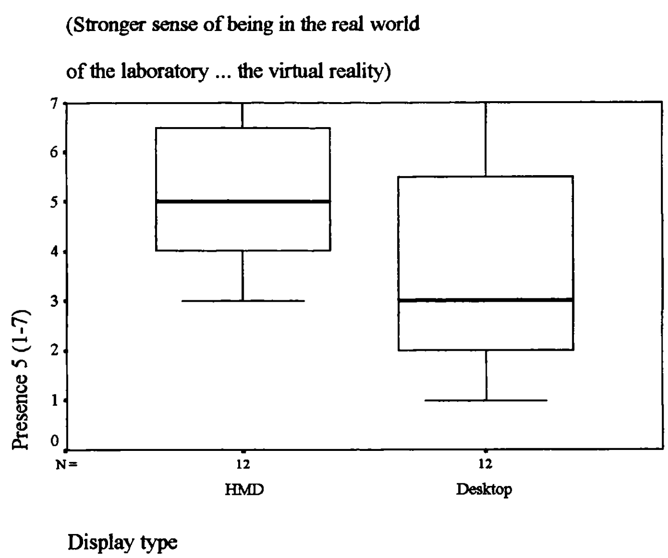


Figure 3.11 Degree of experience between two worlds (virtual and the laboratory)

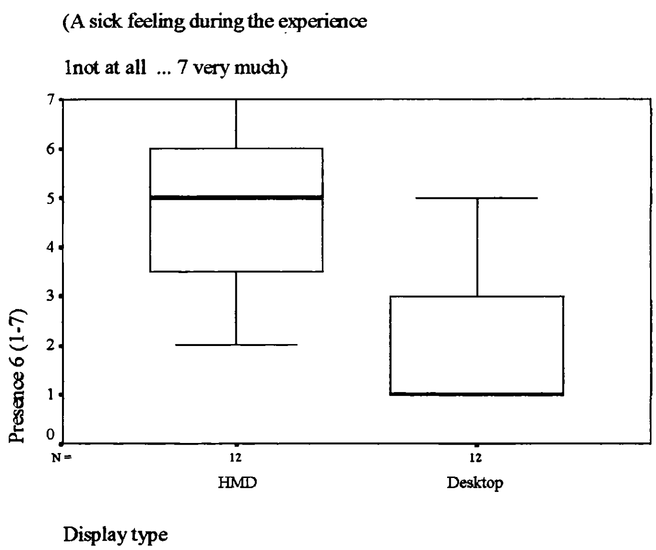


Figure 3.12 Sickness degree

After statistical analysis being used it was concluded that there was no significant difference measured of subjects' task performance in the immersive and non-immersive environments. None of the factors - immersion, colour and day of visit to the real building appeared to make any difference at all to the observed performance of the subjects.

There was, however, one strong and interesting result. Let y be the elapsed time taken to find the plant in the real location divided by the elapsed time taken to find the plant in the virtual location (for standardisation). This could be thought of as measuring the extent to which the two experiences were similar - a relatively large value of y would indicate that the subject may not have carried over memory from the virtual location to the real location. It was interesting to see how this varied with presence, and the representation system score. For example, would people who are more visually oriented have lower values of y than those who relied more on the auditory system?

It was found that using log (y) produced linear relationships with the presence and representation system variables. Scatter diagrams are shown in Figures 3.33, 3.14

and 3.5, each showing a linear trend. A regression analysis of log (*y*) on the presence score (*P*) and the representation system scored suggests strongly that: i) log (*y*) was negatively correlated with ***P*** - hence the higher the presence score the smaller the ratio ii) ***y*** was negatively correlated with ***V*** (visual dominance score) - hence the greater the visual dominance the smaller the ratio and iii) ***y*** was positively correlated with ***A*** (auditory dominance score) - hence the greater the auditory dominance the greater the ratio.

These results are shown in Tables 3.4 and 3.5. In the Table 3.4, ***V*** is not quite significant at the 5 % level. The ***A*** term was significant.

Table 3.4 Regression of log (*y*) on *P* and *V*

Multiple Correlation Coefficient $R^2 = 0.29$

Parameter estimate	Standard Error	Parameter
-1.0	0.70	1
-0.3	0.16	*P*
-0.3	0.16	*V*

Table 3.5 Regression of log (*y*) on *P* and *A*

Multiple Correlation Coefficient $R^2 = 0.38$

Parameter estimate	Standard Error	Parameter
-3.4	0.49	1
-0.4	0.15	*P*
0.4	0.14	*A*

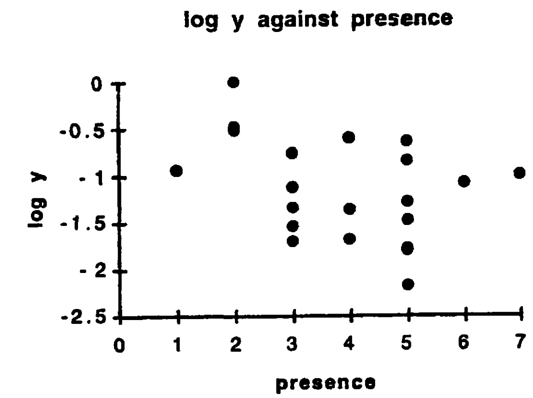


Figure 3.13 log (real_task/virtual_task) versus presence

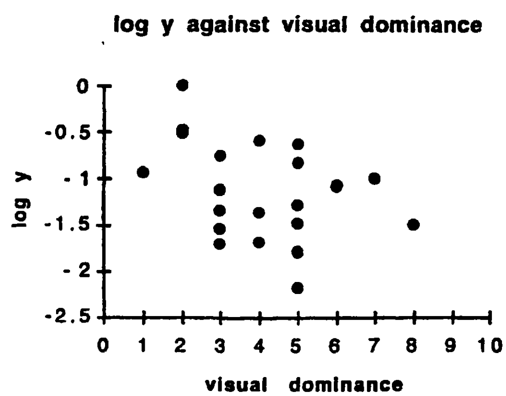


Figure 3.14 log (real_task/virtual_task) versus visual dominance

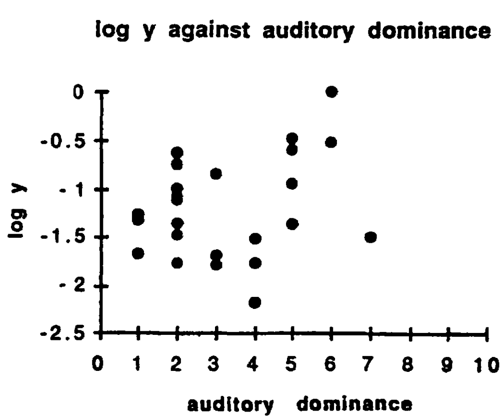


Figure 3.15 log (real_task/virtual_task) versus auditory dominance

3.2.5 Discussion (A)

The results suggest that for the walk-through and recognition tasks which were explored, and with the particular machine in use, that immersion does not make any difference to observed task performance. However, an interesting result was found; the subjects who were able to achieve a sense of presence, whether in an immersive or non-immersive system, were better at carrying out the tasks. Those for whom auditory rather than visual information was the more important in constructing their world models might be at a disadvantage in a model with little or no auditory information.

It is important to note that the tasks included in this experiment did not involve any interaction with the virtual environment, other than moving through it and looking around. It could be argued that this is the least favourable situation for immersion to have a noticeable effect, since the fact of being enclosed in the environment is not specifically needed in order to carry out these kinds of tasks.

The extent of presence increases with the richness of the virtual environment: for example, provision of a virtual body increases the sense of presence (Slater, 1993b, 1994a, 1994e), and the existence of dynamic shadows also increases the sense of presence for visually dominant individuals (Slater, 1995). However, these results were in highly interactive experiences, in which immersion was crucial to carrying out the task. It is also important to note that participants in this experiment did not have a virtual body, which is also a crucial component in a definition of immersion.

Wilson (1993) considered a similar problem comparing observations from subjects in non-immersive virtual and the corresponding real environments. The results showed that "The overall picture is one of little difference between spatial information gained from exploring the computer simulation of the building and real exploration." If this was the case for virtual non-immersive and real environments, then after all it is hardly surprising that it may the case for non-immersive and virtual immersive environments.

Subjects were advised not to go through closed doors and walls; however, they were not able to avoid this. The incorporation of collision detection seems an important factor in helping subjects to keep inside a virtual environment [Jacobson, 1997].

3.3 Experiments in an office environment (B)

It was noticed from previous experiments (Slater, 1996) that the greater the degree of presence for a person immersed in a virtual environment the higher the probability that their behaviour in a virtual environment would be similar to their behaviour in the real world under similar conditions. It was also noticed that the greater the level of immersion, the greater the chances of a person experiencing presence in the virtual environment. However, since immersion relates to the degree of information obtained from visual displays, then greater immersion can also lead to a higher level of acclimatisation. This raises interesting questions: will people who are familiar with a location in the real world behave differently from strangers when they encounter it in virtual reality? And is it possible for people who are not familiar with a locality to learn something about it from their virtual visit?

Regarding the first question, it is important to clarify how 'behave differently' could be measured in terms of observable behaviours.

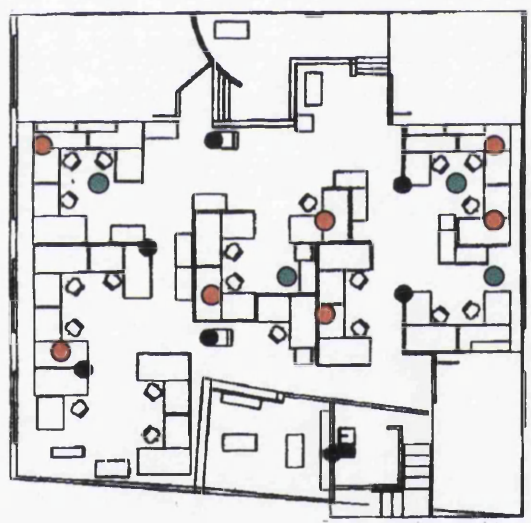
3.3.1 Experimental Design (B)

Sixteen subjects were chosen and divided into two groups: the experimental group and the control group. The experimental group consisted of eight PhD students and research workers who worked in the laboratory which would be depicted in virtual reality. The control group consisted of university staff and students who were not familiar with the room.

The average age was 26 years and the gender distribution was 12 male and 4 female. Four of the subjects had experienced virtual reality before.

3.3.2 Model and scenario (B)

A representation of a 400 m^2 university computer science laboratory was modelled in virtual reality (Figure 3.16). The model contained 20 desks, separated by low panels, in an open plan office and five adjoining rooms. Two of the rooms were separate offices, one was a meeting room, another a kitchen and the last a tea room (Figure 3.17).



Location of the virtual People Location of the computers

Figure 3.16 Plan view of the model

Figure 3.17 Three dimensional view of the model

The model was an accurate representation of reality, not only in terms of arrangement of the furniture and equipment but also in it's representation of details: the lamps, the plants, the doors and their glass, and the windows. The laboratory was chosen not only because it was spacious but also because it was the day-to-day working environment.

Each desk in the laboratory had been assigned a number. Since the control group did not have their desks in the laboratory they had randomly been assigned desks as theirs for the purpose of this study. The factorial design is shown in Table 3.6, with 4 subjects per cell.

Table 3.6 Factorial Design with number of subjects

	Monochrome Environment	Realistic Environment
Experimental Group	Inhabited:4	Uninhabited:4
Control Group	Uninhabited:4	Inhabited:4

The realistic environment was a model of the laboratory containing objects with the correct colour and texturing information, the monochrome environment did not have this information. An inhabited environment was an environment in which half the desks had a virtual person standing next to them, and these were not present in the uninhabited environment. They were given written instructions and a scenario which placed them in the context of the experiment and were observed throughout by the investigators. After entering the virtual laboratory, the subjects were given an opportunity to become familiar with the environment by moving through it - navigation was performed with a 3D mouse. They were asked to indicate when they felt ready to start the experiment. At this point they would automatically be moved to the starting position and the investigators would cease to talk to them until the experiment had finished.

During the familiarisation phase, before the experiment began, subjects were told to observe the location of the virtual computers. In order that the wording of the scenario should not influence their behaviour, they were simply instructed to move through the virtual laboratory and switch on six computers. They could switch on each computer by touching it with their virtual hand and a picture would appear on the monitor. At this point they would be automatically moved back to the starting position again. This made the successive selections of computers statistically independent. The procedure was performed six times and then they were asked to go back and touch the same six computers they originally selected. This time, after touching the computers, they were not transported back to the starting position in order to test their spatial awareness. Had they acclimatised to the room or did they have to go back to the starting position each time?

After the virtual experience each subject was taken to the real room and those in the control group were asked whether they recognised where they were. They were all asked to indicate on a plan of the room the location of the six computers they had selected during the virtual experience.

If a subject had experienced a high degree of presence an indication might be that they would not venture into an area occupied by a virtual actor or a private office. For the experimental group an indicator would be that they may tend to switch on the computers with which they were familiar. It would be expected these to include the computer they usually worked on and possibly those around them. For the control group the virtual room was completely unfamiliar and their pattern of behaviour should tend to be more random and not be significantly concentrated around the desk that had been assigned to them for the study.

3.3.3 Variables measured (B)

The independent variables included personal variables, comprising the age, gender, subjects' occupation, the extent to which they had experienced virtual reality before and the extent to which they used a computer, the sensory input responses, obtained from the questionnaire, were the same as those used in the previous study.

There were two main factors apart from the control/experimental one: monochrome/colour, uninhabited /inhabited environment.

The dependent variable was directly taken from the experiment, the number of correct matches of computers touched in the virtual world compared to the number of computers correctly identified in the real world.

As this study was involved in observing presence, the variable presence was also treated as a dependent variable. The questionnaire is presented in Appendix A.3.1.

3.3.4 Results and discussion (B)

There were six questions ranged from 0 to 7 to measure subjective presence. Presence was considered by the number of 6 and 7 scores, and then using a binomial logistic regression, it was found that there was no significant difference between the control and experimental group. It was also noticed that there was a higher degree of presence for those in the control group.

In the experiment, there was an attempt to determine differences in behaviour between the experimental group and the control group and the effects of different conditions on presence. Subjects' movements were monitored in the environment with the hypothesis that those who had experienced a higher sense of presence would exhibit socially conditioned behaviours.

The results showed no significant difference between the monochrome and colour environments, nor between inhabited and uninhabited virtual offices. When comparing the monochrome and colour environments it would appear that correct geometry is more important than colour or texturing when achieving presence. For this environment no significant difference was found between the number of correct matches of computers selected in the virtual room and the real room. There was also no immediate behavioural difference between the two groups. Activity within the virtual room seemed to be equally dispersed and not concentrated around a subject's desk. In fact all activity tended to be around the areas within a line of sight from the starting position. One experimental subject commented afterwards that he knew where his computer was but did not select it because it was a long way from the starting position. Subjects' comments are presented in Appendix A.3.2.

As expected, the experimental group recognised the virtual laboratory upon entering it. The control group did not know the room, however, they reported a higher subjective sense of presence. This could be explained by the experimental group realising what the experiment was about and making comparisons with the real room, therefore, not allowing themselves to accept the illusion. Statistical analysis did however reveal a relationship between group and auditory representation channel with associated presence. For the control group the level of presence decreased the more reliant on auditory cues the subject. For the experimental group there was no observable correlation. Nevertheless, the number of correct matches between the computers selected in the virtual room and the number correctly identified in the real laboratory increased the more auditory the subject was, and decreased the more kinaesthetic, independent of group.

A small pilot study, running before this one to test and debug possible inconsistencies and report any unexpected situations, showed that subjects reacted to the 2D actors as real people: they did not touch those computers where people were sitting.

The number of correct matches that subjects made in the virtual environment are presented in Figure 3.18. The values are clustered by group type; experimental and control group.

The number of correct matches that subjects were able to recognise in the real environment, clustered by group type are presented in Figure 3.19. The medians of the two groups are almost identical.

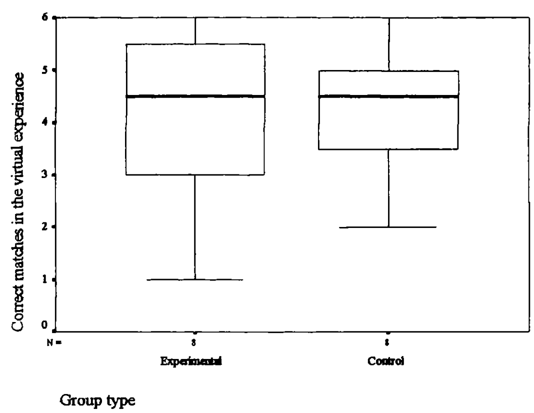


Figure 3.18 Number of correct matches in the virtual environment

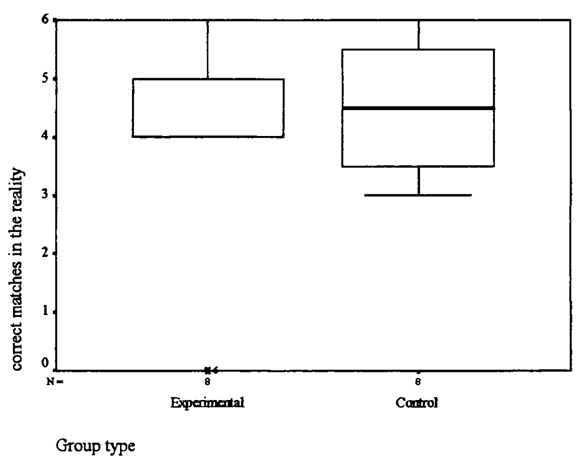


Figure 3.19 Number of correct matches in the real environment

In conclusion it is important to emphasise that this experiment (B) and experiment A took place in closed environments. The lessons learned in a closed environment might not be applied in an open space environment. These two experiments can be seen that accurate geometry was more important than colour or texture. Consequently, an object could be recognised by its geometric form or even by it's location or an associated sound. It is a fact that not all objects carry the same degree of simplicity. Examples of objects with an easily recognisable form would be a chair, a desk, a fountain in the middle of a market or a pillar box. In contrast an example of an object not easily recognised is large square box in a virtual scene, which with difficulty could be recognised as a phone box. Texture increases realism without increasing the complexity of the geometry.

3.4 Lessons learned from a preliminary study in a virtual city (C)

An experiment was designed to make a preliminary exploration of a virtual city. The main goals were to identify the types of information necessary for a person to become acclimatised to an unfamiliar environment, to test the logistics of acclimatisation of people to an unfamiliar city, and to debug experimental procedures.

3.4.1 Experimental design (C)

This small pilot study involved four subjects. Each subject learned the virtual environment through one of four media presentations; pictures, video, desktop or head mounted display. The subjects were of 23 to 33 years of age. All of them except the subject experiencing the desktop presentation knew the aim of the study.

3.4.2 Model (C)

The model was a realistic reproduction of the real environment (within the hardware limitations) in terms of geometry and it represented six streets in the centre of Cambridge. A map of the city centre with the area modelled is presented in Figure 3.20.

The streets contained a wide range of shops with flats above. These building were similar in height shape and pattern.

The model also included Kings College, some university buildings, a square of grass with a large sculpture, a church, five trees of varying design and a market place with stalls with colourful awnings several phone boxes and a fountain.

The buildings were rectangular and texture mapped in order to increase realism and to avoid the complexity of the geometry. Only five of the buildings facades had texture mapping, a restriction caused by the equipment used. The other buildings had the front facade in a single colour similar to the building. Both, the shape and the scale of the buildings were accurate.

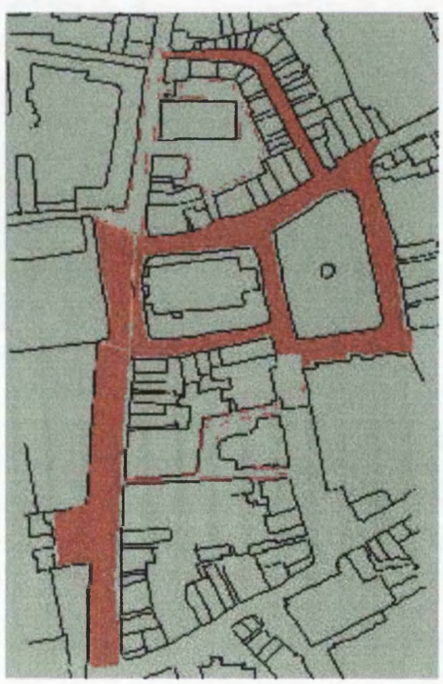


Figure 3.20 Map of the model: Cambridge city centre
(The dark red is the area created in VR)

3.4.3 Scenario (C)

It was an important requirement that the subjects had never visited Cambridge before. The experiment was conducted in three stages:

The first stage was a preliminary experiment, carried out on a university campus which aimed to measure subjects' navigational abilities. Each person was asked to examine a map of the campus for one minute, and then go and find, a place marked on the map and collect an envelope that was waiting for them. The time that it took to find the envelope was recorded and used as a measurement of navigational ability.

In the second stage, each subject used one of the four different methods of acclimatisation. Subject A was acclimatised using pictures and maps. He was given some tourist guides, pictures in 2D and 3D, and maps to look at over a period of 20 minutes. Subject B was acclimatised using video; he watched a silent film of Cambridge on a colour television for 20 minutes. There was no sound in order to make all the methods comparable and the virtual model did not provide sound. Finally, subjects C and D used non-immersive and immersive virtual reality systems respectively. They were introduced to the equipment, and shown how to navigate through the virtual city.

The third stage took place after 20 minutes of using the above methods. Subjects were asked to draw a sketch map of the city. The purpose of this task was to obtain some measurement of familiarity with the city before the real visit. Subjects also answered a questionnaire.

A visit to Cambridge one afternoon was part of the fourth session. The subjects waited at an agreed location for their turn to accomplish the task of finding three pre-defined locations: a particular pillar box, King's College and a McDonalds hamburger restaurant. At the last location all subjects were asked to complete a questionnaire.

3.4.4 Variables Measured (C)

The independent variables consisted of the personal variables: age, background and internal spatial ability which had been quantified by measuring the time taken in finding a location.

The dependent variables included the degree of accuracy of each individual's map, this was subjectively scored from 1 (not accurate at all) to 10 (very accurate); also the time taken to find each location and whether or not the correct real locations were recognised, both measurements were taken from the experiments in the real city.

There was also a subjective presence variable and a subjective acclimatisation variable. The questionnaire asked about the sense of presence and degree of acclimatisation given to the subjects after the virtual visit. The questions of presence were: "To what extent were there times while studying the representation of Cambridge when the subject almost forgot the about the room where the experiences were proceeding" , "To what extent did the subject have a sense of being in Cambridge" and "To what extent could the virtual Cambridge be recognised as somewhere that the subject visited".

The measurements of the sense of "having been in Cambridge before", "ease of finding the way" and "how helpful was the learning exercise in finding the way around" were from the acclimatisation questionnaire.

These two questionnaires mentioned above consisted of three questions each with answers on a 1-7 scale where 1 indicated the least and 7 indicated the most value. The questions are reproduced in Appendix B.5.

3.4.5 Results (C)

Results between different types of media presentation were compared and analysed. The scores allocated to the subjects' sketch maps are presented in Figure 3.21. They were obtained from a subjective view. The drawings were compared and given a score in previous already information mentioned.

Figures 3.22 presents the subjective presence clustered by the three questions.

The duration of subjects accomplishing the tasks, in the real city, is shown in Figure 3.23.

The subjective acclimatisation is presented in Figure 3.24.

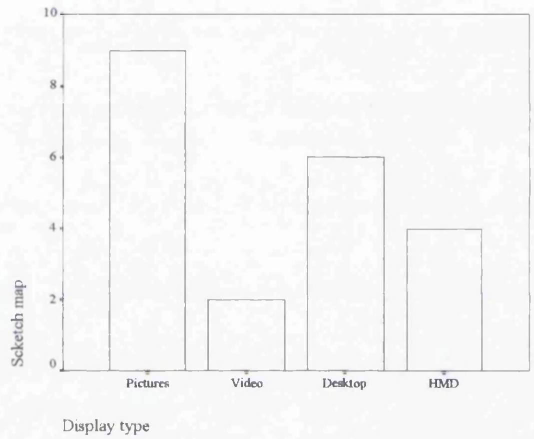


Figure 3.21 Cognitive drawings

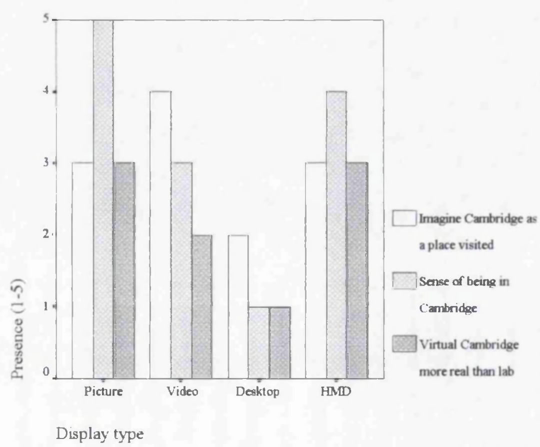


Figure 3.22 Subjective presence

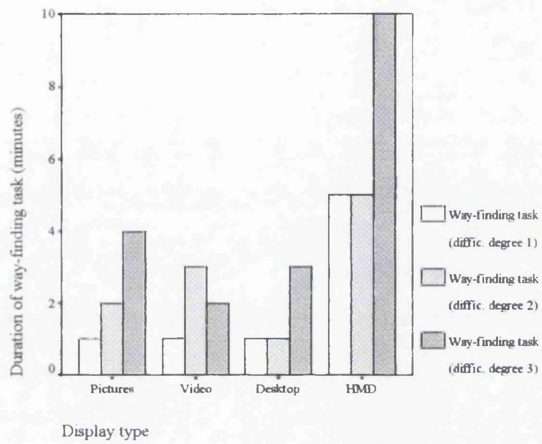


Figure 3.23 Way-finding task

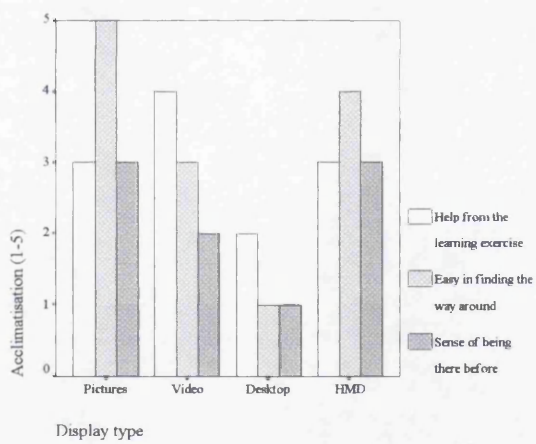


Figure 3.24 Subjective acclimatisation

3.4.5.1 Subjects comments (C)

Subject A, who was acclimatised by pictures, claimed that he had constructed a quite vivid and detailed visual mental model of the city on the basis of the photographs and maps. When he arrived in the city he remarked that it appeared to him to be smaller than he had imagined, but the topology was firmly in his mind. Consequently, the importance of the images and the importance of having the birds-eye view to connect the paths in forming a cognitive map seem to be important factors in achieving presence.

Subject B, who had been acclimatised by video, expressed a vague idea of where the targets of the task should be. For the pillar box, one of the tasks, he mentioned that he rather saw it than remembered it. For Kings College and McDonald's he knew they were at two different locations. He remembered that McDonald's was in a narrow lane. He mentioned that the video scenes recorded from the top of the church tower allowed him to have a better understanding of the routes connecting the market and King's College.

Once again the birds-eye view is referred to as an important factor in learning the space. The subject remarked that the absence of sound on the video detracted from his sense of presence.

Subject C, who was acclimatised using a non-immersive desktop system, had difficulty in relating the paths, and was disoriented in the real city.

Subject D, who had experienced the immersive virtual environment described the difficulty in starting since the starting point in virtual reality didn't match the starting point in the real city. Once the subject found the pillar box, it was easy for them to find King's College. In the virtual environment few objects were represented with texture. The pillar box was obviously recognisable by its distinctive shape and colour, and the subject took it as a landmark.

3.4.6 Discussion and Conclusions (C)

The time taken to complete the location task was not necessarily the most effective method of evaluating acclimatisation performance in the real city. The tasks tended to turn into a race, and subjects reported stress in performing the tasks as quickly as possible. However, the subjects' behaviour when confronted with the city should be taken into account and the researcher should follow the subjects and should record their behaviour in the unfamiliar environment.

All subjects, except the one acclimatised by the desktop display, were aware that the study involved spatial learning. So while in the laboratory they concentrated in learning about Cambridge.

It was not possible to identify the possible learning differences between the desktop media presentation and the head mounted display. The size of the sample was too small to yield concrete results. There was only a single subject for each category of acclimatisation used, giving little scope for comparison.

The visual appearance of the modelled city has to increase in richness by texturing as much of the virtual city as possible in order to improve the overall realism, since people should be free to choose their own landmarks [Lynch, 1976]. The difficulty of being in an environment where all the buildings are flat coloured was reported by the subjects who had learnt the environment through an active mode. This was due to the restrictions of the technology, which allowed only five textures in the entire model. The general image of the buildings is very important for a recognition task. It was observed than the subject acclimatised by pictures reported a high score in acclimatisation, this was due in part to the fact of the realism of the pictures.

The model should also provide a large view of the space to be able to connect the paths. One way of doing this, is to add the possibility of having a birds-eye view in the virtual environment in order to learn the space by connecting the paths. Another help tool could be a map which would appear at the participant's request with their position marked.

The virtual environment has to be more like a mirror image or closer to the reality and the participant needs to interact more with the environment. People experience the environment through action and the model has to permit that action.

It is clear that at least some subjects were familiar with the university campus and this might had some effect on quantifying the individuals' spatial ability. This might have affected the measurement and therefore should not be considered in the main study.

Another conclusion refers to the measurement of the subjects' cognitive maps drawings. It was difficult to understand people's internal models of the environment through their attempts to represent their cognitive maps in drawings. The drawings failed to give an idea of the subjects' personal internalised environmental information. People's cognitive representations are often far from accurate [Downs *et al.*, 1973]. A disconnected or distorted map does not indicate a defective mental image, but the unfamiliarity of the task [Lynch, 1976]. A cognitive map cannot be observed directly, it is described and limited by the person's ability to communicate. Probably too much importance was given into trying to understand people's internal model of the environment rather than seeing it in the global context of acclimatisation.

The spatial layout was not complex enough to permit a difficult task and to analyse the subjects' acclimatisation. The model has to increase in size relevant to a complex structure.

3.5 Preliminary study in Building Recognition (D)

The main target of this study was to obtain general knowledge in the area of buildings layout in virtual reality. As the hardware allowed only a small amount of texturing the solution may be that textures might be a windows pattern applied to almost all the houses. However, in finding out how to make buildings in the model more realistic, it was necessary to know what people remember about buildings from a glance. Buildings must be carefully examined to determine which features should be presented to maximise the recognition features and which features are secondary or even irrelevant.

The major concern of this study was to understand the impact of representation of physical aspects of the buildings on the acclimatisation process.

3.5.1 Experimental design (D)

Fifty subjects took part on this study, the gender distribution was 11 female and 39 male, all students at University College London.

3.5.2 Model (D)

The model consisted of a building with a textured facade, placed on a textured square floor, outside a city or street context. The building was subdivided into three horizontal layers, namely the shop, the central part, and the roof, as shown in Figure 3.25. Each of these principal units had further, secondary subdivision: a group of three arcs at the ground level, two rows of three windows at the second floor, and three windows in the roof.

There were five different versions of the building. Figure 3.26 presents the building layout:

i) The first was accurate in terms of colour, number of windows, structure and roof; a true representation of the building. Figure 3.26 a) illustrates this building.

ii) The second was correct in terms of colour, number of windows and structure, but without the roof as shown in Figure 3.26 b).

iii) The third differed from an accurate representation in terms of the number of windows as shown in Figure 3.26 c).

iv)The fourth was a different colour but every other feature was accurately depicted as shown in Figure 3.26 d).

v) The fifth version had the shape of the windows in the roof were replaced by the windows of the central part, as shown in Figure 3.26 e).

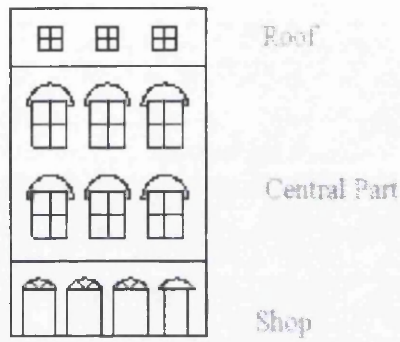


Figure 3.25 Structure of Building's facade

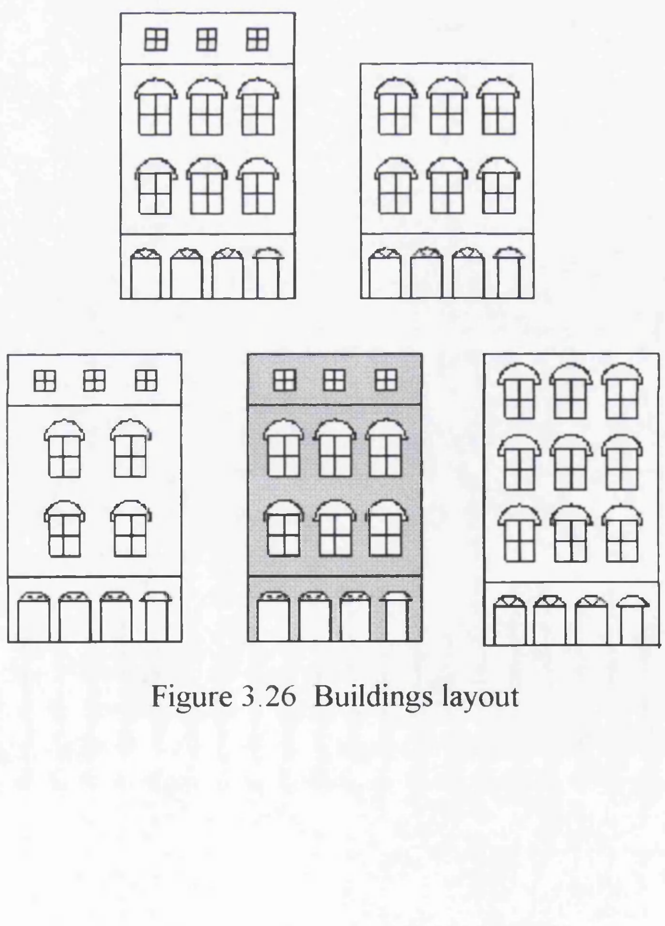


Figure 3.26 Buildings layout

3.5.3 Scenario (D)

The experiment consisted of two phases: learning and recognition. In the first part of the experiment, the building was presented in an immersive virtual environment for 10 seconds. It is assumed by Janssens [1984] that the first glance is the most important for the overall experience of the whole facade. Even if a facade is presented for only a very short period of time, the observer can give a good description of the building, because the eye has an enormous faculty for fast recognition of the most important centres of attention.

The subjects first experienced an immersive virtual environment and were asked to look at the building. They could look in any direction by moving their head. Using an immersive system the participants experienced the 3D illusion of looking at the building in space. The proportions of the building were accurately reproduced and the distance between the person and the building was realistic. There were no tasks while subjects were looking at the virtual building.

The second part was concentrated on a recognition task performance and had time limit of one minute. A set of ten pictures of buildings were placed on a table and the subjects were asked to select one picture which they thought could be the virtual building they had seen earlier. The layout of the buildings presented on the pictures can be found in Appendix C.

The participants, while looking at the building in virtual reality, did not know about the the recognition task.

The factorial design is shown in Table 3.7 and consisted of 5 different building exteriors; each building was presented to 10 subjects.

Table 3.7 Factorial design

Features	**Subjects**
True building	10
Without roof	10
Wrong number of windows	10
Wrong colour	10
Wrong structure	10

The material used in this experiment was exactly the same that it was used in the previous studies mentioned in Chapter 3, sections 3.2.3 and 3.4.4.

3.5.4 Variables measured (D)

This particular study case included two analyses: the performance task, looking at the match of features according to the picture chosen, and a subjective study, the match of the features that subjects believed had influenced their choice of picture.
The dependent variable was the task performance: picking one building from the pictures presented as "Pick the desired building" was a qualitative variable, 0 represented picking an incorrect building and 1 the correct one.
The independent variables were the features; colour, number of windows, structure, shop, roof and number of floors. These variables were also qualitative, each correct feature scored 1 and incorrect features scored 0.
The picture chosen by the subjects was analysed in terms of the corresponding features that subjects mentioned in believing influenced their decision, such as colour, number of windows, structure of the building, shop, roof and number of floors.

3.5.5 Results and Discussion (D)

As all the variables were qualitative, the method used to explore the data was cross tabulation using Chi squared analysis, which is used for determining the relationship between the two variables, each feature and "Pick the desired building".
Fifty subjects were asked to select a picture from a set of ten. The hypothesis was that the subjects who experienced the correct building would not having difficulty in selecting the correct building.
Thirty percent of the subjects who experienced a true representation of the building were able to pick the entire building, as shown in Figure 3.27. This means that subjects were not able to retain in mind all the features of the building as they

glanced at the building rather than absorb the building in its entirety. In this way, free from memory and attention factors, people notice only some features, they are not able to assimilate the entire building. The fact that subjects were not able to pick the desired building. Simply suggests that they could not form a coherent image of the totality. The fact that a person is looking at a four storey building from ground level, without knowing the purpose of the study would perhaps explain why this result is not surprising.

The same values are registered for those who experienced the building with a different tone.

When the building with wrong number of windows was presented to the subjects, half picked the desired building.

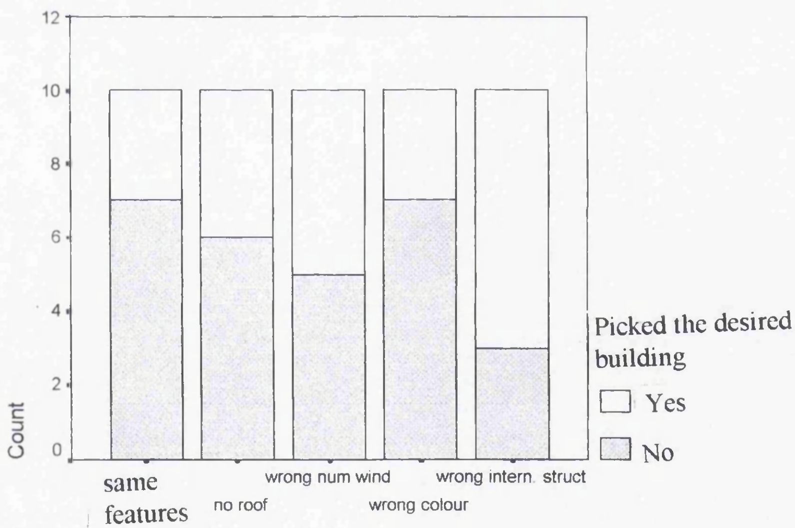


Figure 3.27 Frequency of each building type clustered by selection

From the cross-tabulation between the types (colour, number of windows, structure, shop, roof and number of floors) with the correct building picked by the subject, presented in Table 3.8, it was noted that the shop was highly significant, p=0.002, as 83% of the subjects matched the shop and were able to pick the desired building, and 32% picked the desired building but did not match the shop.

This might be related to the functionality and activity of the building in accordance with Moore (1979).

Janssen (1984) concluded that roofs are not an important factor, since they are very seldom at eye level. However, roof was significant, p=0.025; as 71% of the subjects were able to pick the desired building and matched the roof, and 33% were able to select the desired building without matching the roof.

Table 3.8 Contingency table for Type versus Choice

	Select desired building	No match feature	Match feature	Subjects	p
Colour	No	(16) 68%	(10) 32%	26	0.56
	Yes	(12) 50%	(12) 50%	24	
Number of windows	No	(14) 67%	(7) 33%	21	0.25
	Yes	(14) 48%	(15) 52%	29	
Structure	No	(5) 45%	(6) 55%	11	0.50
	Yes	(23) 59%	(16) 41%	39	
Shop	No	(26) 68%	(12) 32%	38	0.002
	Yes	(2) 17%	(10) 83%	12	
Roof	No	(24) 67%	(12) 33%	36	0.025
	Yes	(4) 29%	(10) 71%	14	
Number of Floors	No	(25) 64%	(14) 36%	39	0.042
	Yes	(3) 27%	(8) 73%	11	

The same study was carried out with the features measured by subjective values. Table 3.9 presents the percentages of the subjective features in correctly picking the building. Subjects believed that shop and roof were the most significant factors in their choice of picking the correct building.

Table 3.9 Contingency table for Subjective features versus Choice

	Select desired building	Match Feature	Subjects	p
Subjective colour	No	(3) 23%	13	0.11
	Yes	(19) 51%	37	
subjective number of windows	No	(16) 47%	34	0.56
	Yes	(6) 37%	16	
Subjective structure	No	(4) 21%	19	0.02
	Yes	(18) 58%	31	
Subjective shop	No	(0) 0%	28	0
	Yes	(100) 22%	22	
Subjective roof	No	(0) 0%	12	0
	Yes	(22) 22%	38	
Subjective number of floors	No	(4) 25 %	16	0.08
	Yes	(18) 53 %	34	

The statistic analysis was done using a logistic regression, which allows someone to predict a discrete outcome from a set of variables. The dependent variable was "choice" and the independent variables were shop, roof and number of floors, structure colour and number of windows. The results suggest that the variable shop was the only one statistically significant. Table 3.10 presents the results of the logistic regression analysis for the building recognition, while Table 3.11 presents the model if term removed. Table 3.12 shows the variables not in the equation.

If the term "shop" was removed the Log-Likelihood would change by -34.400, and 2Log-LR would increase 10.589. With the variable "shop" in the model, the -2Log-Likelihood was 58.211. The initial -2Log-Likelihood was 68.59298, only with the constant.

Table 3.10 presents the results of the logistic regression analysis for the building recognition.

Table 3.10 Variables in the Equation

Chi Square was 10.832 with a significance of 0.0013, and df = 1

	B	S.E.	Wald test	df	Sig	R
Shop	2.38	0.85	7.86	1	0.005	0.29
Constant	-0.78	0.35	4.91	1	0.026	

Table 3.11 Model if term removed

Term removed	Log Likelihood	-2 Log LR	df	Sig
Shop	-34.4	10.589	1	0.001

Table 3.12 Variables not in the equation

Variable	Score	df	Sig	R
Colour	0.26	1	0.61	0
Number of windows	1.20	1	0.27	0
Structure	1.29	1	0.25	0
Roof	3.43	1	0.63	0.15
Number of floors	2.51	1	0.11	0.86

3.5.6 Conclusions (D)

It was noticed that subjects were distracted by looking at the realism of the pavement which was texture mapped with a tile pattern, nevertheless, in this experiment the pavement was not at all important. However, the short time imposed on the subjects to look at the building facade did not permit distractions. There were also other distractions, such as the virtual reality technology itself. A comment made by a subject who experienced a building with a different pattern roof, mentioned: "Actually I didn't concentrate enough on the building because I was too amazed about virtual reality". Other subjects' comments are presented in Appendix C3.

People create a mental representation of the building when seeing it for the first time. The recognition task could be done in another way, such as asking for a description of the virtual building; verbal or drawing, after the learning phase. This would give more flexibility in analysing the features separately. The problem encountered by the process used was that when subjects were asked to mention the relevant features they identified pictures that were inconsistent with their beliefs.

It was expected that people would not retain a complete detailed image of buildings they had been shown. It could be also hypothesised that architectural training would affect how people would look at and evaluate buildings. [Craik, 1975], [Janssens, 1984].

The results suggested that the shop is the most obvious feature involved in remembering buildings, rather than the number of windows or the colour.

It is believed from the experimental results that subjects tried to match the building feature by feature. The complete layout of a building is most relevant since the information is gathered by the angles of the building. It is therefore important to preserve the structure of the building in the modelling process.

Colour was not expected to be a significant feature in building recognition [Slater *et al.*, 1994d]. Nevertheless Buswell (1935) demonstrated the importance of colour for the individuals' tendency to fixate certain details. Red and orange appealed more to visual attention than for instance blue or green. Generally, the eye is attracted by complex, colourful and bright textures, rather than by empty and simple surfaces. However, detailed information is detected more easily in a simple environment than in a complex textured environment.

3.6 Summary

It is worthwhile to summarise all the conclusions, presented so far, along the four preliminary studies, which may assist in understanding the methodology of creating a virtual city. This is presented in Table 3.13.

Table 3.13 Summary of the conclusions

Experiment A	B	C	D
Personal characteristics important in determining their behaviour	Possibility of knowledge transfer	Increase Visual Richness	Shop the most important feature
Tasks better accomplished by subjects more present	Colour, texture and 2D Virtual actors not relevant features	Navigation aid tools (birds-eye view, map)	
Richness of immersion implies more presence		Increase size of model	
Colour not relevant		Interactivity Necessary	

In these case studies some hypotheses were introduced as the base of the development of the design principles of the experiment. It was hypothesised that the mode of learning would enable subjects to experience a deeper sense of acclimatisation. It was also hypothesised that navigation aid tools would enable subjects to gain a better understanding of the spatial environment. Consequently, this research will investigate the effect of navigation aid tools on participants' knowledge development. Thorndyke (1982) suggested that with the aid of maps in an active exploration, people learn more quickly the environment. Darken (1996) showed that participants were able to return to their start position quicker when they had a map than when no navigational aid tools were provided. Ruddle (1997) stated that subjects learned the objects position in space quicker when they had a map than without any navigation aid tools.

The navigation aid tools could include a map, a compass [Ruddle, 1998] and a bird eye view (Chapter 3, section 3.4.6).

Chapter 4 Methodology for Acclimatisation Using a Virtual City

4.1 Overview of the Chapter

This chapter describes a methodology for the design principles for constructing the model of Cambridge city centre, and the experimental procedures to be followed. The technology is evaluated and its limitation with respect to the degree of realism which can be included in the virtual environment is also discussed.

The earlier objective of this study was to find out the relevant features to build an effective model which would increase presence and acclimatisation.

After outlining the different features the aim then turned to defining the design principles in order to examine the effect of immersion in a spatial learning context.

4.2 The model design

Exploration is the most common way to obtain spatial knowledge of an environment, walking has an effect on mental representation, people learn the environment faster than if they are driven in a vehicle [Zannaras, 1976]. A person inside the environment repeats certain experiences and via a trial and error process learns by doing, active participation demands attention and facilitates learning.

The most important aspect of acclimatising a person to an unfamiliar environment is developing their spatial understanding of a complex structure. For this purpose a model containing a part of a virtual city was created. This simulation had to permit the same natural activities and interaction which the real environment offers, plus a set of navigation aid tools to maximise spatial understanding.

The desire for great realism, with a large amount of detail, conflicts with the requirement of using abstractions and simplification to make computation possible using current technology.

Itelson (1975) believed that the environmental experience does not need to represent a realistic image of the environment; it is sufficient to offer a view of the environment which will enable the participant complete their tasks. However, the aim of a virtual environment is to convey information [Foley *et al.*, 1992], the degree of realism required depends on the application, which is in this study is acclimatisation in an unfamiliar city.

The main goal of constructing a 3D model of part of Cambridge was to present a good functional model, capable of supporting learning about environments, by providing the participant with sufficient spatial information to create an useful cognitive map.

The size of a model could be determined by the time a participant might typically take to experience the virtual environment and to become accustomed to it. This should not take more than 30 minutes to avoid long periods of exposure to the virtual reality system and not tiring the subjects, besides, symptoms of motion sickness have been increasingly reported in Virtual Reality systems [Durlach *et al.*, 1995] and [Howarth, 1996]. The model also needed to be big enough to enable location tasks to be carried out with a suitable degree of difficulty. Implicitly, the model had to have some complexity in its structure, such as including at least several streets, as concluded in the preliminary study, described in Chapter 3, section 3.4. To increase complexity, the model included a further four streets as shown in Figure 4.1. The environment had to be reconstructed from small views [Passini *et al.*, 1990], the conclusions taken in this experiment can be addressed in a larger environment.

Figure 4.1 Map of the new modelled area

4.2.1 Geometry

Functional meanings of buildings and other parts of the urban environment are often expressed directly by visible forms, or at least have learned associations with forms. Sizes, shapes of buildings, spaces and location patterns may be immediately revealing to anyone familiar with the culture.

Carr (1969), a city planner, suggested that a real environment should respect some basic principles, which apply equally to virtual environments, increasing the perceptual accessibility of the city. Environmental elements can be made easier to recognise, identify and remember by ensuring that the attributes which are most critical to recognition are most visible, as well as simplifying and clarifying visual shape. Further, by decreasing ambiguity in city form conventionality is increased and complexity is decreased. A delicate balance needs to be used in the design process.

Some scheme must be derived to determine which features are necessary for the effective perception of the city. A confusing environment, which needs total concentration to avoid getting lost, is not a supportive environment for studying acclimatisation.

An appropriate representation in virtual reality has to leave a mark on perception, it should demonstrate simplicity and unity and it has to give a sense of reality. It is not an arbitrary collection of features but a substitute for what it stands for. To increase the level of realism, some objects, apart from buildings, which should be included in the model must be considered. Therefore, it seems desirable that features which enhance the environment such as trees, grass and pavement, should be represented in the virtual environment.

In any environment, virtual or real, there are small details which might be crucial in the familiarisation process. The aesthetics of an environment may lead to a high degree of attention which is likely to increase motivation.

As the model was too large to be rendered as a whole it had to be divided in parts. The model was divided into groups of streets, small enough to be rendered, each group divided from the next by an invisible door. When a participant touched an invisible door the next group of streets was rendered without them noticing. The way in which the model was divided into manageable pieces is shown in Figure 4.2. The backs of the buildings were removed since they were not seen from any viewpoint. The model provided collision detection to force the participants to keep on the roads and pavements.

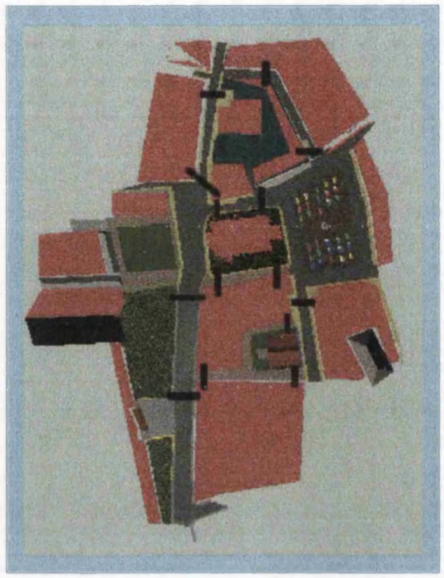


Figure 4.2 Invisible doors in the model

4.2.2 Texture

The texture capability of a location provides vital spatial information. Gibson (1979) emphasised the critical role of texture, by which gradients provide information about depth through systematic variation in the perceived size of repeating elements further from the participant.

There was a need to reduce the number of textured objects to the minimum possible due to the limitations of the technology used. The implication of this on acclimatisation is particularly important.

The priority of texture in the virtual city was the facades of the buildings, with particular attention to the resolution of the shops, which were found to be an important feature as described in chapter 3, section 3.5. Objects, such as trees, pavements and cars, would not include texture, as it was concluded (in chapter 3, section 3.3) that texturing detail in small objects was not relevant due to their obvious form, colour and size. Consequently, completely realistic reproduction of all the detail would not be necessary since the participant would compensate for the gaps and complete the illusion.

Some buildings were not textured but presented in a grey dark colour; this was intended to represent the boundaries of the model to give the subjects an illusion of the model continuing. The boundaries were also expressed by traffic cones placed in the end of each street, indicating the limit of the virtual environment. This is illustrated in Figure 4.3.

Figure 4.3 The model's boundary

4.2.3 Navigation aid tools

There is a significant need to use navigational aid tools to efficiently learn about an unfamiliar environment. These tools give people knowledge of where they are in a particular place and provide information of the sequence of features. Consequently, a set of navigational aid tools was analysed and implemented, based on traditional methods used in the physical environment as described in chapter 2, section 2.2.6.

In order to learn the environment it is essential to learn the location of places and the paths connecting them [Kaplan *et al.*, 1976b], [Golledge *et al.*, 1973]. A birds-eye view may support subjects in forming a good mental picture of the environment. This aid tool would provide a general view of the environment and permit the participants to understand the connection between paths and landmarks at a glance. This navigation aid tool, moved the participant 50 meters vertically above their position; the system allowed subjects to look around but not to fly nor move, this was to keep subjects in their position and orientation once they came down.

A map is an alternative navigation aid tool which supports the orientation process as a person is able to relate the paths and to see a representation of the whole area. It is a method used frequently by people who are generally unfamiliar with a city. The use of a map in a virtual environment requires two principles to be addressed: the navigator's position should be constantly updated, and the orientation of the map should correspond to the navigator's orientation in the environment in order to provide a consistent spatial representation. Furthermore, Levine (1984) concluded the importance of a principle of map use: the alignment principle, which means people tend to assume that maps are aligned. These principles need to be taken into account when producing a helpful aid tool for navigation in virtual environments. The map was a two dimensional plan of the geometric data used in the model, it appeared when requested in a horizontal position at about shoulder level. There were a total of five landmarks shown on the map. The number of landmarks which can be active at one time is limited to five, in accordance with Mandler (1975) who identified that the number of units people can accurately hold in working memory is limited to five.

People try to orient themselves by judging the direction of a known point; this orientation is rather easier when streets form grids or regular patterns, difficulty arises when streets are curved or irregular. It is a common situation to lose one's sense of direction and encounter difficulty in returning to the starting point. The virtual environment should afford sufficient navigational aid to provide the information needed for the participant to return to the starting position from anywhere in the model. An alternative for this concern was the possibility to visualise a red arrow constantly pointing to the starting position, called a compass.

Lynch (1960) noted the importance of frequent directional cues to orientation maintenance. Passini *et al.* (1990) also gave particular importance to direction signs as important help tools in an unfamiliar city. Direction signs were not implemented as an additional aid tool in the model to permit people to explore the environment in a free and adventurous way.

The inclusion of these navigation aid tools in the design principles has to be taken into account; furthermore, these aid tools should be optional, easy to access and available to the subjects on request. They support orientation and way-finding skills while navigating in the environment.

Figure 4.4 presents the compass showing the starting position, the map, and a birds-eye view.

Figure 4.4 Navigation aid tools

4.2.4 Interaction with the environment

Increasing people's exposure to a variety of environmental settings and potential interactions stimulates and facilitates exploration of the environment.

Each person is unique in the way in which they interact with an unfamiliar environment according to their own particular agenda, their prior knowledge and their previous experiences. These interactions, whether 'successful' or not, have adaptive value, by increasing individuals' adaptation to the environment and vice versa. By such adaptive interaction people gain competence and their understanding of the environment is improved.

Exploration can satisfy what may be a basic human need for new experience. Increasing individuals' interaction with unfamiliar complex environments leads to an increased sense of competence and capacity to formulate and execute new plans.

A gesture is a motion of the body that conveys information, it is an extremely effective form of communication as it increases the level of information conveyed by its expressiveness which also has a value in itself. It is an intuitive interface technique and the participant has more functionality, and can get more physically involved, in the environment thereby establishing a sense of presence [Kurtenbach *et al.*, 1990].

The use of gesture in virtual reality too may be an extremely efficient way of communication. The design criteria for gestures as a means of interaction in virtual environments have to be natural and easy to remember.

When the actions are subjectively "too many", the gesture becomes inefficient. It also requires an excessive amount of time for the learning process, and carries the risk of the participant forgetting or confusing gestures, this could also cause distraction from the environment. The functions have to be spontaneous, not memorised with the risk of hesitation or even being forgotten.

The use of a menu system is undesirable in an immersive environment since it could be a negative factor reducing the sense of presence. A menu with an icon representing each action may be more efficient for the purpose of communication within a non-immersive environment. A small case study using a technique of menu interaction in the form of a "help-bag" was analysed. This help system consisted of a bag attached to the virtual body with the characteristics of an everyday bag a visitor to a city may use to carry a map or compass. The purpose was to permit the participant to feel in a real situation, look inside the bag, take out the map, and look at it. The top of the bag had a number of buttons with icons representing actions available. However, this technique had two undesirable features; firstly, the help bag was associated with a number of actions, secondly, the participant had to stop and look at the bag buttons to press one of them and they were unable to continue viewing the environment. In conclusion, the crucial factor is not only representing reality, or finding real life solutions for virtual environments. Virtual Reality goes beyond the boundaries of reality.

The proposed solution is to make the most of gestures to interact with the environment. In an immersive environment simple meaningful gestures would be preferable; these actions need to be easy to learn and to memorise. The actions initiated by gesture in the model were consulting a map, asking for a birds-eye view, requesting the direction of the starting position, and returning to the starting position.

The gesture to initiate the action of consulting a map was performed by the participant touching the top of their head; the idea was related to the map kept in the mind, with the head as the symbolic meaning. By touching it they could make the map appear.

Going up in the environment to obtain a birds-eye view was possible by raising an arm; the meaning related to this particular action was to indicate to go up.

Asking for the direction to the starting position, was triggered by stretching an arm forward, indicating order to move.

Returning to the starting position was performed when the participant touched the floor. It was intended that this gesture should be interpreted as an order to the earth to take the participant to the starting position. Figure 4.5 shows the call for the compass.

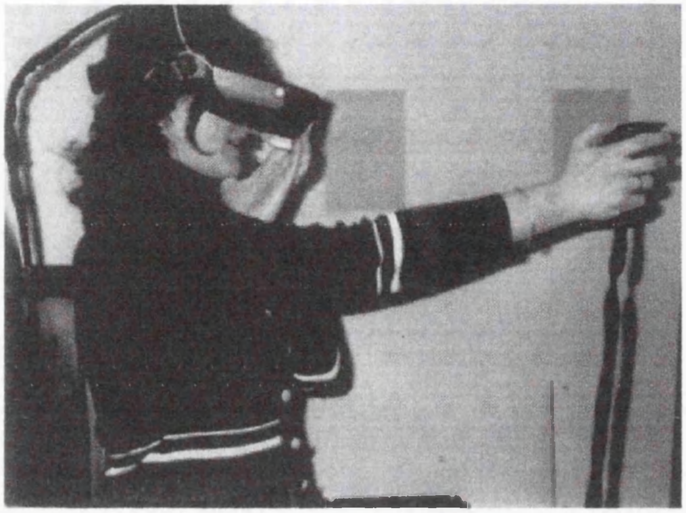


Figure 4.5 Call for the compass

These interactions by gestures have to be accompanied by the representation of an arm which calls the respective activities; consequently, the arm representation has to be inserted in a body context. Every activity in life is in the presence of one's own body, it is part of people's mental representation. Slater (1993b) noted that the degree of presence is higher when participants see their visual representation.

An ideal virtual body would be a complete body representation. When subjects looked down they would see their arms, and all the way down their feet on the ground. In this study the only body parts which had the ability to move directly were the right hand and the head. However, the system was able to rotate the virtual body when the participant moves their head around by an angle greater than 60 degrees.

Furthermore, this body representation might be important for the acclimatisation process; it has been observed that people pass through three distinct modes in organising their spatial knowledge: the egocentric, the fixed and the co-ordinate [Passini, 1992] and [Moore, 1975]. This observation justifies the importance of a self-representation of the viewer by a virtual body, especially for people unfamiliar with the environment.

4.2.5 City Activity

The model has to be flexible, and to have strength without rigidity. The virtual environment is experienced only by the visual sense and it has to appeal to the participant who navigates through it.

It is noted by Janssen (1984) that the presence of people in the visual field strongly affected the eye tracking pattern, this remained true even when the subjects were asked not to do so. The city life naturally involves people who interact with the environment.

The aim is to populate the urban environment with human agents who can perform typical actions; the model should include a simulation of appropriate human movements and interactions with objects as might be observed in the real place.

The human body has to be a shape that is a living form and in balance ready to move to perform an action not just a lifeless static form. The human animated characters should be realistic, imitate typical human movement, and be dressed in realistic clothes. Their positions in the model need to be considered to give a notion of life.

To animate virtual actors requires a combination of geometry and behaviour. It is not important to portray in detail the virtual actor's face, although the animated actor needs to move convincingly. The animation of moving objects is defined by their positions and orientations in a sequence. A sequence of frames which are scheduled at specified intervals animates an object. In order to provide a realistic illusion of motion a rate of 24 frames per second is usually used. Sixteen frames per second is the lowest acceptable speed for motion to be perceived as realistic.

Other objects included in the model were the bicycles which are a well known feature of Cambridge, an ice cream seller, young people looking around the college, people standing near the landmarks and others sitting on walls and benches just as in the city.

The model did not necessary need to represent a crowded city, Cambridge also has its calm periods too. The city may be represented at a certain time of the day when it is less active such as early morning with fewer people, bicycles and cars.

4.2.6 Sound

Southworth (1969) mentioned that the experience of the city is a mixture of sense impressions, each of which contributes to the total picture. He carried out an exploratory study to find how sound influences perception of the visible city. It is important to consider the factor of auditory perception and its relation to vision.
Studies of people with visual impairment contribute to the understanding of auditory perception; some studies suggest the effects sound may have on visual perception [Southworth, 1969], [Knapp, 1948]. By taking away the sounds of activity life would have few contrasts. A city without sound would be different from the same city with sound: everything outside the visual field would be unknown. Auditory perception improves when accompanied by related visual displays; similarly, sounds can direct attention to related visual elements [Broadbent, 1958]. Sounds which can be localised and identified are less annoying than background noise [Broadbent, 1958], and when associated with events we can see appear to provide an important link to reality and have a protective and enriching function. With sound, visual perception is full of contrasts, information and demands attention. The contrast between silent films and those with sound is an illustration of this point.
Sound and sight interact, and they can support each other. Southworth (1969) performed a field study testing people's perceptions of sounds and sights in a city and the correlation between visual and auditory perception. He concluded that the typical sounds of cars or of people walking and talking conveyed little information. Sounds vary much depending upon the time of the day and the day of the week, the city centre on Sundays is typically a complete contrast with the other days. He described that evaluative judgements of the sonic environment depend upon the

information in the sound, the site where the sound occurred and the sound level. Subjects mentioned that the noise of nearby traffic was disorienting, but the sound of people gave a feeling of involvement.

Ballas *et al.* (1987) pointed out in his study that when the subjects were asked to describe an environmental sound, they described the event that was thought to have caused the sound and did not describe the sound in terms of acoustic properties. Environmental sound is usefully thought of as a form of language. Anderson *et al.* (1983) mentioned that appreciation of urban sites was little influenced by the types of the sound, even natural sounds had a neutral effect on the appreciation of these sites. The pattern might sound like chaotic noise if it were perceived as a unitary phenomenon, but the listener is able to hear a set of events which is important in the perception of the environment [Vicario, 1982].

Environmental sound refers to events by virtue of the laws of acoustics; if the environmental sounds were to be taken out of context they would vary in recognisability [Balas *et al.*, 1987], the audition of environment effects can complicate the perception of location in other ways. Blauert (1983) pointed out that the spatial image of a sound source grows larger and increasingly diffuse with increasing distance in a reverberate environment, a phenomenon that may tend to interfere with the ability to judge the direction of the source, in which people have difficulty in judging its absolute distance [Coleman, 1963].

4.3 Acclimatisation Process

It is also part of the scope of this thesis to compare the virtual reality with some other traditional methods; passive and active as described in chapter 2, section 2.9. Moreover, the analysis of the spatial cognitive representations through different types of learning is part of the interest of this study in order to learn how the mode of spatial learning affects people.

The approach presented throughout this chapter has the main goal of building a proper model to be experienced in immersive mode. However, for the evaluation of the application, it is indispensable to compare this approach with other forms of acclimatisation used so far.

The features of the alternative methods to teach spatial environments such as free navigation, true scale, realistic surrounding, interaction and sequential pictures, were compared. Methods with different features were chosen to be used in the main experiments. Table 4.1 presents these methods with their features.

Virtual Reality is the only method available which allows the study of the effect of the variable 'true scale' in the acclimatisation process, which can be achieved only by being in immersive environment and looking at the environment in a realistic manner.

In the desktop media presentation, the 3D model could be freely explored using a 21inches display, the navigation is achieved by the use of an ordinary mouse. The navigation aid tools were available by pressing the correspondent keys.

There was no interaction or any kind of active participation in the video method.

Table 4.1 Acclimatisation methods with the respective features

Features **Media Presentation**	Free Navigation	True Scale	Realistic Surrounding	Interaction with the environment	Sequential Pictures
VR	Yes	Yes	Yes	Yes	Yes
Desktop	Yes	No	Yes	Yes	Yes
Pictures	No	No	Yes	No	Yes
Video from city	No	No	Yes	No	Yes
Desktop & Video	Yes	No	Yes	Yes	Yes
Desktop & Pictures	Yes	No	Yes	Yes	Yes
Pictures & Video	No	No	Yes	No	Yes

____ Implemented ------ Not implemented

Each method alone is abstract and incomplete as referred to in Chapter 2, section 2.10; there is a possibility to present some combined methods which shared together some features; desktop and video, desktop and pictures and pictures and video.

It was noted that sharing methods would not bring any original combination of features that was not presented by any other method presented alone.

Desktop combined with pictures, or desktop with video have the same features, and both combinations are not different from video alone. The same was noted with video and photographs, these two methods were not worth combining since the resulting features coincided with the video.

As the Internet and web pages become more common, it is becoming an useful way to present a series of visual methods of acclimatisation to an unfamiliar environment. Such pages often contain photos, videos, audio or even interacting and navigating through a dynamic model using Virtual Reality Modelling Language (*VRML*).

4.3.1 Learning process

The number of subjects who took part in the main experiment was ten for each of the four methods presented: a total of forty subjects, as shown in Table 4.2.

Table 4.2 Factorial design

Media Presentation	Pictures	Video	Desktop	Head Mounted Display
Population	10	10	10	10

The learning process was intended to permit subjects to gain spatial knowledge and familiarisation with the environment, so people could perform in a confident way once in the real city.

The Virtual Reality methods used for the learning process were presented using a head mounted display for the immersive system, while the other methods (pictures, video and desktop) were presented through a computer screen, using a web browser. The learning period, for all the acclimatisation methods was define to 30 minutes.

The main page had a typical tourist map of Cambridge, with a choice of pictures (presented in Appendix D) or video. The acclimatisation through pictures offered a further choice of 6 pages, one for each street in the study. Each page was selected by clicking on one of six streets on the map. The pictures were taken from a variety of angles to completely cover each street, which had an average number of 15 pictures.

The video also covered the modelled area, and although it showed all the streets it concentrated on landmarks and important buildings.

4.3.2 Measurement of Acclimatisation

Acclimatisation effectiveness was assessed by subject's competence in graded tasks, orientation and way-finding tasks. The accuracy of mental maps they produced, their reported sense of presence and their reported sense of acclimatisation were included in the study to understand the whole process of acclimatisation.

Familiarity within the environment is achieved when people recognise their surroundings and are confident in pointing directions. This process involves orientation as well as identification of the place where a person is at a particular moment.

Following the learning session, the testing phase was identical for the four groups which consisted of several tasks. In order to measure subjects' spatial knowledge the tasks used were a map-drawing task, the completion of a network map and a questionnaire. Other tasks were performed in the real environment and these were three pointing direction tasks and three way-finding tasks. They had to be performed within 30 minutes.

It is possible to measure the individual's orientation in relation to the objects by pointing to other specific landmarks. These measurements take place in the scene while the person looks around and relates objects and paths. It is meant to be purely qualitative in nature. Subjects were either able to point successfully in the general direction or not. Errors of up 45 degree (approximate) were accepted. The study is concerned with whether or not subjects had a notion of landmarks and their relationship to each other. Thorndyke (1982) showed that people make reasonably accurate direction estimates once they have developed accurate spatial knowledge.

Darken (1996) classifies way-finding tasks into 3 categories: naive research which he defines as finding a location unknown by the subject implying an exhaustive search, the primed search in which the subject has some previous knowledge of the environment; the target could be known before, or not, and the exploration; which is a way-finding task in which there is no target.

It is important to present tasks in different degrees of difficulty, to be able to realise how far someone succeeded in learning the environment. An easy task, a medium task and a difficult task have to take place at a primed research level. A task with degree of difficulty of 1 is when a place is almost visible from the participant's starting position. A degree 2 task is defined as finding a location easily recognised by its characteristics in the middle of a street. The difficult task (degree 3) is defined as finding an object placed in a street which would make it difficult to find in the physical environment.

There are two factors involved in finding a location: the path chosen and the duration taken in accomplishing the task. The route chosen to reach a location is not always related to the shortest way, but can be the fastest way or the most pleasant way for example. To measure only the time that subjects took in accomplishing the tasks could lead to misleading results because subjects can rush to achieve the location tasks. Speed is related to ability in navigating in the environment and not necessarily to the degree of familiarisation.

The way-finding is meant to be purely qualitative in nature; the task accomplished or not.

When they are familiar with an environment people tend to find their way without any impression of using some mental effort. However, it is difficult to measure familiarisation with an environment; one possible method is to measure the knowledge of an individual of urban geography; the spatial layout.

Cognitive map drawings are personal mental structures representing the environment.

An attempt to quantify cognitive maps is crucial for the analysis of this study. Blades (1990) demonstrated that sketch maps are a reliable method of data collection. People tend to draw a geographical layout of the environment, which is usually far from the real one and also far from their internal representations. The technique of drawing a map is limited by the individual's drawing ability [Lynch,1976] and [Byrne,1979]. The drawing is likely to fail in giving an idea of the environmental information that people have. The analysis of cognitive map representations via drawing is very complex and ambiguous [Appleyard, 1970], [Passini, 1992] and [Moore, 1974]. The cognitive map drawings are addressed in this thesis as sketch maps and were assigned following Appleyard (1970) method, as described in Chapter 2, section 2.6 and Figure 2.2. The drawings were sorted into five groups. The fragmented (sequential) and accumulation of dots (spatial) were scored with value 1, the chain (sequential) with value 2, the branch and loop (sequential) were classified as 3, the linked (spatial) with value 4 and the patterned (spatial) with value 5. The written spatial knowledge were classified in accordance with the cognitive map drawings into 5 development levels.

Byrne (1979) went further in studying the consistent patterns of errors found in estimation of distances and angles along urban routes, even with people familiar with the environment. Routes with bends were estimated as being longer than straight routes, and routes in town centres were estimated as being longer than suburban ones. People do not use vector distances, the more locations which are remembered to be along the route, the longer it is perceived to be. In estimation of angles between urban roads, people also do not generally encode vector information, so junctions and turns are based on right angles in their minds. Sadalla (1980) agreed that subjects in map drawings tend to straighten curves and represent the angles as right angles. Even though cognitive maps do not include vector information they are still generally adequate for effective urban navigation.

Byrne (1979) also referred to the theory that people use a network map which is a mental representation that accurately preserves only topological connectedness, rather than a vector map, which preserves two dimensional vector distance information. The order of locations and the connection between them are represented by branches. If spatial knowledge is topological, then the notion of metric distance is irrelevant. However, this does not mean that the environment can be presented in a different scale for spatial acquisition.

In order to analyse spatial location one approach would be to ask subjects to draw a network map based on their knowledge of the environment.

In order to quantify the degree of success in showing the correct spatial relationship between objects, subjects could be given a map with only empty nodes. The names of landmarks could be listed separately and subjects could be asked to match each one with its position on the map. One of the landmarks would be defined to help co-ordinate the spatial relationship.

Network maps include nodes and paths, the concentration of this study is to observe the orientation between objects in space: the location of objects in relation to other objects. The paths which are related are not relevant for this study, since there are other methods to measure way-finding.

Some information about subjects' experiences with an environment is difficult to obtain by simply asking questions. For example, it is difficult to discover how someone is responding to the environment if the subject is not consciously aware of their own reactions. So it is necessary to observe the subjects and to follow their movements and record their reactions. If the environment is familiar to the individual then they move through it in a habitual manner; if it is unfamiliar they move in an exploratory manner looking in many directions, hesitating and retracing their steps. Exploratory activity usually occurs in unfamiliar environments and habitual activity usually occurs in familiar environments.

These methods of measuring individual spatial knowledge may be used to compare subjects' performances and the effectiveness of various training approaches in teaching environments.

Acclimatisation occurs when a person demonstrates good orientation and way-finding from any point in the environment. The confidence to move in an unfamiliar place is achieved when both orientation and way-finding are possible. Some authors [Passini, 1990] relate way-finding and orientation as one. Although, if someone keeps their sense of direction from the starting position it can lead to confidence in going back. They keep a sense of orientation but are not acclimatised as concluded from the preliminary study described in chapter 3, section 3.6.

The starting position in the real environment may be important to vary from the starting position in the virtual environment, to measure acclimatisation; the ability to be oriented and finding the way to defined locations.

As people are different, the subjective responses are crucial to know about the subjects' degree of presence and acclimatisation.

Following the tasks, the subjects were asked to answer two questionnaires, one to measure the sense of presence (subjective presence), after the virtual visit, the other to measure the sense of acclimatisation (subjective acclimatisation), after the real visit. While subjective acclimatisation will be analysed as a response variable, to find out the feature related to it, subjective presence will be analysed as an explanatory variable in the context to examine the effects of immersion in relation to acclimatisation.

It was appropriate to look carefully at the factor of presence, even when presence was not the main concern of this thesis. It was argued by Slater (1994b) that presence is the key to the science of immersive virtual environments. If an application does not require presence, there is little point in using a virtual reality system. The important factor, which distinguishes virtual reality from other forms of interaction, is the presence of the individual inside the virtual world. It is of great interest for this research to define what degree of presence is required to acclimatise people to an unfamiliar environment. Presence was measured by a questionnaire related to the subjects feelings while experiencing the virtual environment, there also the possibility of observing participants' behavioural responses to the virtual learning environment.

It was interesting to note a situation from a research group doing experiments for a presence study, reported in an informal way that a particular subject who had experienced a basic environment without interaction or any known factor to enhance presence, responded with the highest score for everything in the questionnaire. The subject was amazed by the technology. After the experiment was accomplished the research group showed the subject another virtual environment, but this one with more features. The subject asked to have the questionnaire back again, in order to change the answers. This illustrative story describes how complex it is to evaluate a variable through questionnaires. The answers are probably related to the individuals' expectations and life experience.

People differ in their knowledge and performance in a city, they also differ in their aptitudes, abilities, prior experiences, culture and strategies. Consequently, the categories which people develop spatial knowledge might be related to their personality, sensory input or other individual characteristics.

These personal inputs are gathered from the following questionnaires.

Personality Test

The personality test adopted in this study was concentrated on a personal sense of being and it was based on the work of Myers-Briggs [Myers, 1993].

The questionnaire scores on four different types: the extroversion/introversion, the intuitive/sensitive, the feeling/thinking and the judging/perceptive. The test was composed of 70 questions that all require an "A" or "B" answer. At this stage, it is uncertain how this personality test can be related to environmental learning, performance in a city, or acclimatisation, however, the tests were included to learn if the personality is in any way involved in the acclimatisation process.

Personal Sensory Dominance Test

The sensory dominance test was applied in some preliminary studies in Chapter 3, sections 3.2 and 3.3. Since the models were predominantly visual, the test could elucidate if the accomplishment of the tasks, or the learning process, was in more difficult for an auditory dominant person in relation to the other who had a visual sensory dominance.

This test is discussed by Slater (1993b) and (1994f), and it is based on a therapeutic model known as neuro-linguistic programming. The aim of the test is to identify which sense, visual, auditory and kinaesthetic, is predominant in an individual.

Steed (1996) presented the variation of presence with sensory input dominance: visual, auditory and kinaesthetic. Figure 4.6 shows the visual representation of the data relating the predominant sensory inputs with presence.

A high degree of acclimatisation might be achieved when people are able to demonstrate spatial representation of the model in their mind. The ability of orientation and way-finding varies between people, so, in this context it was found appropriate to quantify individuals' capacity of internal spatial ability.

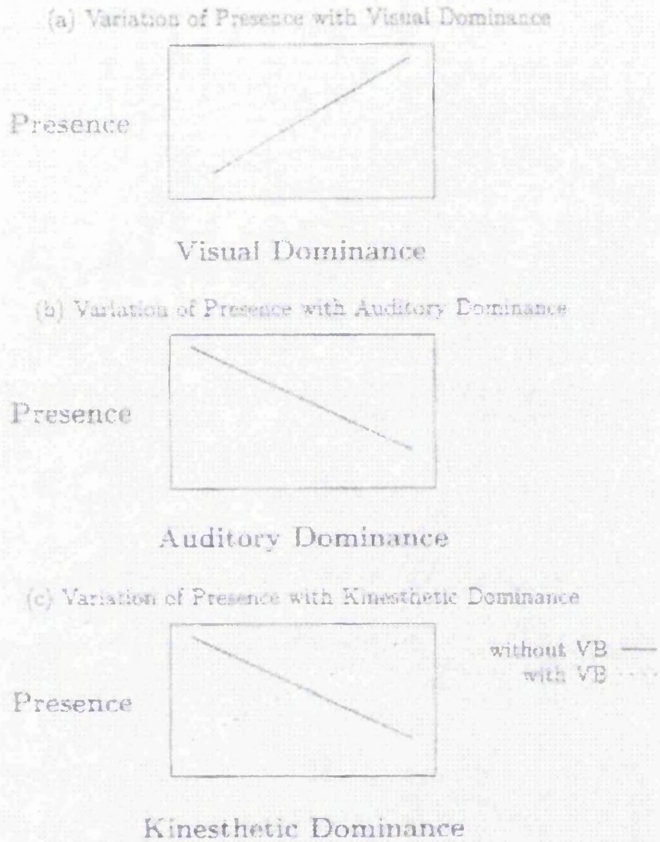


Figure 4.6 Presence related to the predominant sensory input

Spatial ability test

As orientation is the ability to visualise and to manipulate the environment in the space it might be necessary to conduct a spatial ability test on subjects, since the effect of natural human spatial abilities on way-finding might be a relevant issue.

In experiments of way-finding, Darken (1996) used a spatial ability test to measure the individuals' spatial orientation. The spatial ability test aims not only to measure subjects' orientation but also to measure subjects' navigation abilities. This navigation refers to travel in the context of orientation and way-finding in a cognitive 'construction'.

The spatial ability test used in this study consisted of two tests used in Darken's experiments which were designed by Witkin (1971) and are part of the "Embedded Figures Test", and one of Guilford's experiments [Guilford *et al.*, 1947] and

[Guilford *et al.*, 1948]. The tests used in this spatial ability test are concentrated on visualisation, by manipulating the object mentally in space. The test is presented in Appendix F, section F.3.

4.4 Summary

The Virtual Environment was designed following some principles with respect to size, geometry, texture, navigation aid tools, interaction, virtual body, city activity with particular attention to the virtual actors, sound and included various help tools to assist navigation.

Forty subjects experienced alternative representations of Cambridge: a desktop screen presentation of the model, pictures and video. Their performance in the various tasks was measured.

Later all the subjects, not only those who had taken part in the Virtual Reality experiment but also those who had experienced the alternative representations, were taken to Cambridge. In the real city the subjects were once again assessed in completing tasks equivalent to those they had completed in the laboratory and also asked how useful the prior learning experience had been.

The effectiveness in acclimatising subjects was assessed by measuring subjects' in orientation and way-finding tasks. Moreover, the accomplishment of tasks like representation of cognitive maps and network maps and the subjective responses of acclimatisation contributed for the general understanding of the impact that immersion has on acclimatisation.

It was hypothesised that the subjects' sketch maps representing their mental spatial image of the environment would be more accurate for subjects who experienced an immersive virtual environment than those who experienced a desktop display.

Figure 4.7 presents the visual summary of the chapter.

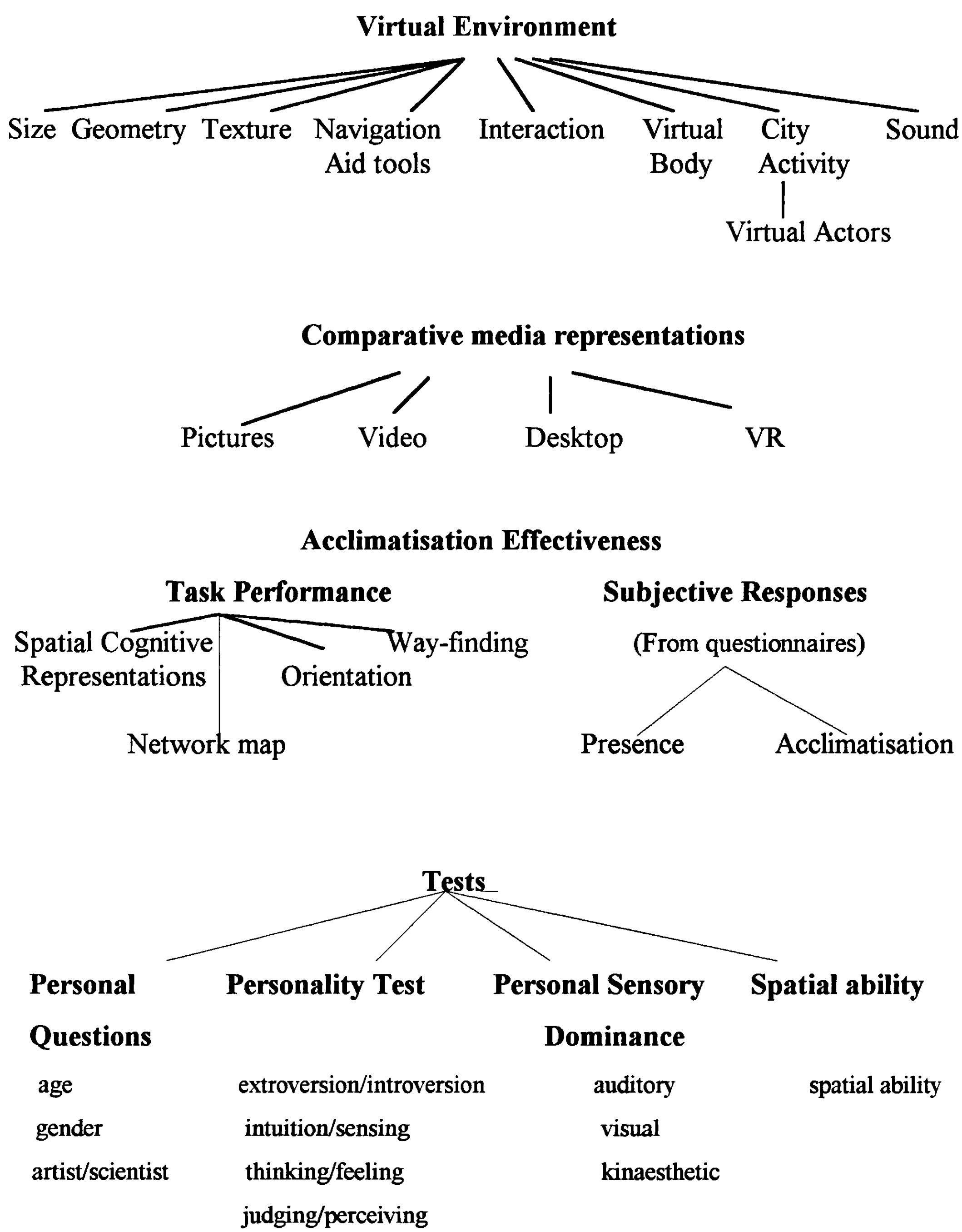


Figure 4.7 Summary

CHAPTER 5 Pilot Acclimatisation Experiment

5.1 Overview of the Chapter

The aim of this pilot experiment was to test the logistics of the experiment and to observe the performance of each subject in the real city after a familiarisation session in the laboratory. Subjects were acclimatised through one of the four different media presentations: pictures, video, non-immersive desktop virtual reality and immersive virtual reality using a head mounted display. Attention was paid to the methodology of the design principles and the difficulties subjects may experience in accomplishing the tasks.

The pilot experiment helped in identifying the potential risks inherent in the acclimatisation validation covered previously. The findings of this study were later used in the main experiment which enhanced the quality of the experimental design and scenario.

5.2 The Model

The anatomy of the model constructed to teach the environment through virtual reality and desktop is presented in Chapter 4, section 4.4.2. All the building facades were texture mapped. The highest resolution for textures available was 264 x 264 pixels. However, due to insufficient computer memory and disk storage the textures had to be kept at the lower resolution of 128 x 128 pixels.

The total scene consisted of 10,455 faces and 9,382 vertices used to model an area of approximate 90,000 m^2. There were 824 objects in the model including many shops, three churches and a chapel, private homes and university buildings. There were also 10,210 faces and 5,920 vertices used to model the 123 objects representing the virtual actors, the bicycle and the car. The model was exclusively visual.

5.3 Equipment

The hardware used for virtual reality was a *Silicon Graphics Onyx* computer with twin 196 MHz R10000 processors, with an Infinite Reality graphics card and 64 MB of main memory. The software used was *Division*'s *dVS* and *dVise* version 3.1.2.

The tracking system used two *Polhemus* Fastrak movement sensors: one for the helmet mounted display and the other for a 5 button 3D mouse. The helmet was a Virtual Research VR4 which has a resolution of 742 x 230 pixels for each eye and a field-of-view 67 degrees diagonal and 85 % overlap. The scene was presented in stereo.

The navigation was at a constant velocity and always in the direction of the participant's view.

5.4 Experiment and Scenario

Eight subjects were selected on an arbitrary basis to participate in the pilot experiment. There were six male and two female in a range of 25-46 years old. The only restriction was that they had never visited Cambridge before and no experience with computers was required. There were two subjects for each method of display: pictures, video, desktop and Virtual Reality. The experiment comprised two parts; the learning process of the spatial environment in the laboratory and tasks performance in the real city.

The pilot experiment was restricted to half an hour. The route taken by each subject and the times they passed through the invisible doors throughout the model were recorded in a file. This file logged the identity of the door and which direction, in or out, they passed through it. The log file also recorded elapsed time in the model and when and where the subject used the navigational aid tools.

After the familiarisation session, subjects were asked to describe in detail the sequences of objects and events they had noticed, their feelings, and what had made the greatest impression on them: buildings, features of buildings or shop windows. Subjects were asked if the part of the city they visited in the laboratory seemed to fit with the image of an ordinary city.

A questionnaire given at the completion of the learning session was mainly concerned with the participants' subjective feeling of presence.

To learn how many landmarks, and spatial relationship, subjects kept in their minds, a network map of the environment was presented to the subjects, after the learning session. The empty nodes (circles) were shown on the map together with a list of landmarks. Subjects were asked to match these empty nodes with the correct landmarks. The network map is presented in Appendix E.

Subjects were also asked to express their environmental knowledge through their own chosen channel of communication; this could be anything like written sentences, drawings representing a picture or map organisation. For those subjects who presented a cognitive map in a map structure these drawings were scored on a scale of 1 to 5.

The real visit to Cambridge took place on the day following the virtual visit. Each subject was taken to a different starting position than the one they had started from in the visual visit. The subjects were asked to complete three orientation tasks and three way-finding tasks with different degrees of difficulty. After the first group of tasks was accomplished, subjects performed the way-finding tasks, which consisted of finding the same locations as in the orientation tasks.

Subjects were instructed to keep inside the area corresponding to the virtual environment as far as possible. Each subject was followed by a researcher who was about two metres away and recorded the path of the subject.

After the visit, subjects filled in a questionnaire related to familiarisation with the city. The questions covered their ease in finding their way, the extent to which the learning exercise helped in finding their way around and their sense of having been there before. The answers were scored on a scale from 1 to 5.

Subjects were not allowed to share the experience about the study verbally among themselves while waiting for their turn near the starting position in an area which was not modelled.

5.5 Discussion: Implications for the Main Study

Much was learned about how subjects experienced the city, their usage of navigation aid tools, the way subjects carried out the tasks and their performance in the real city.

It has been hypothesised that immersion is essential for individuals to become acclimatised and to construct effective cognitive maps. Hence, the aim of this research was to attempt to elicit factors influencing acclimatisation and to evaluate the significance of the type of visual display.

In Chapter 4, section 4.3.1, it was postulated that for consistency in both environments, virtual and real, the period of time had to be limited and predefined. However, as people are different they take different time in the familiarisation process, so, the time should not be limited. The aim was to let subjects explore in a free way to gain individual knowledge.

Once in the city subjects were not trained to locate particular landmarks, so it is concluded that a training task would be included in the design principles of the main experiment. It was at this stage that it was decided that environmental learning could not be restricted to one phase. So, the familiarisation should be kept unrestricted with subjects being free to explore the virtual environment in their own time, followed by a second session one day later with a training purpose.

Besides, orientation is the ability to visualise the environment in space and to relate the paths, and this is hardly achieved after the first contact with the environment.

To acquire knowledge in a new environment people have to go through a construction dynamic process as described by Siegel (1975).

Navigational knowledge in an unfamiliar environment is gathered through two phases: procedural knowledge and survey knowledge. The first is gained by personal exploration, while the second comes later after few visits to the environment; the first can be considered a familiarisation phase and the second a consolidation one, in the first exploration people look around, while in the second one people are able to see, assimilating and improving spatial relationship.

In the first process dedicated to free exploration people take only principal routes, and this was observed in this pilot experiment.

Schmidt (1988) cited that repeated practice results in the information being transferred to more permanent storage. It leads to the development of stronger long-term memory, and that memory are often present after long time.

When people perform attention demanding tasks, they are expending mental effort, which will be kept in long term memory. A second virtual session could be dedicated to a training session, where subjects have to accomplish same tasks, like finding places or objects.

The starting position in both virtual visits should be different to allow people to enter the environment through a different door [Lackner, 1998]. This mental effort increases the spatial relationship which leads to an easy adaptation to the environment to avoid path integration, which is a restriction on route training.

The navigation aid tools, especially the birds-eye view, were intended to create deeper spatial understanding about the environment by seeing it as a whole and connecting the paths. Typically, subjects mentioned the thrilling sensation of being above the city seeing it from another viewpoint, they were not aware that it was an aid tool for the learning process. This might have occurred because the subjects had completed only their first contact with the environment and they were not yet at the stage of relating things. The aid tools might be, therefore, requested only during the survey knowledge stage.

5.5.1 Subjects' comments

One subject acclimatised by desktop display, commented after the real visit, that he felt as if he had been there before, he said: "The ice cream vendor, people in the same places, the phone box, the trees and the sky, I remember everything". His approach to the learning process was related to the objects in the environment, which is also part of the familiarisation process and the development of the cognitive map.

Two subjects commented how well they remembered the positions of the cake shop, Marks and Spencer's and Barclays bank. They read the names of all the shops while in Virtual Environment. They also mentioned that if they had been asked to go to these places when visiting Cambridge they would have been very confident going there. People have to have freedom to choose their own landmarks, which should not be pre-selected by the virtual environment.

Subjects who experienced the active mode of learning (desktop and Virtual Reality) noted the realism of the model, they said they could imagine themselves walking in the city centre. However, they referred to the difficulty they experienced in becoming familiar with the navigation process. The lack of motion typical of city life was also referred to, and that is one factor which could increase realism as noted earlier. In previous experiments with empty buildings (chapter 3, section 3.2, empty Cambridge (chapter 3, section 3.4), or even in the laboratory with 2D virtual actors (chapter 3, section 3.3) the lack of motion had not been referred to. Although the virtual actors were realistically rendered and were a contribution to a more pleasant and natural environment, their constant static positions were not pleasant at all.

The subject who saw the video of the city, mentioned that his personal best way to really know a place is to be there. Subjects acclimatised by photos said they found it disturbing not being able to gain sufficient knowledge from the pictures.

5.5.2 Observation of Subjects' Behaviour

From the observation of subjects in the real city it could be concluded that people who had been acclimatised by being in the virtual environment walked more confidently and had a better notion of the environment as a whole. The subjects acclimatised by photos or video were walking as they were looking for something and their lack of confidence was obvious.

Two subjects, one acclimatised by photos and the other by video, got lost and asked for directions. Subjects were not informed before the real visit that they could not ask questions of people in the city since the possibility of this happening have not been considered.

One of the location tasks, considered to be the most difficult, could not even be found by some Cambridge shop workers, in some cases they would be just in front of a narrow passage and they did not know about it. Some pointed in the wrong direction in complete 180 degrees error. It can be stated that the shop keepers who may be quite familiar with the environment did not know specific locations.

Anecdotally, there were subjects with very clear reactions of disorientation, but whose subjective assessment of finding their way easily in Cambridge was very high. This might have occurred because that they did not feel the anxiety when they were disoriented, or they might have enjoyed the experience so much that they gave high scores whatever the question.

In expressing subjects environmental knowledge, one subject wrote about the image of Cambridge he had before, compared with the one created after the video. Since the place is famous around the world for its university, people who have never been to Cambridge before often have a vivid idea about the place. Another subject drew a castle, a park and a church in order of importance for him. One subject acclimatised by pictures wrote the names of some streets and some objects in each street. Two other subjects, one who had experienced the head mounted display and the other the desktop display noted the names of an enormous amount of shops. Subjects' drawings are presented in Appendix E.

5.6 Discussion and Conclusion

It was observed from this pilot experiment that there was a route which subjects never took, its narrow entrance could be one of the reasons that subjects did not choose it. This was a problem because the third task was finding a church located exactly in that particular street. An additional training session forcing subjects to go there, might solve this problem.

The most difficult task for the subjects was completing the network map because the orientation of the network map did not match with the orientation that subjects had in their internal knowledge; they were visualising the environment from another viewpoint. Evidence has been observed that subjects acclimatised from desktop and virtual reality gained orientation-free, resulting from a free exploration through the virtual environment. This came in accordance with Thorndyke (1982); those subjects who learned the environment through walking in it, presented orientation-free representations. It can be stated that subjects have to be free to represent their spatial knowledge and to relate locations from their own viewpoint.

In the network map, the location tasks which were supposed to be landmarks did not coincide with the subjects' landmarks. Subjects did not learn the names of the landmarks by looking at the map. They created their landmarks which coincided with the name of the shops or even particular characteristics of virtual people. Some subjects did not complete the network map as they had not remembered the names of the streets and locations. A need to include signs is evident.

The important buildings in the environment have to be labelled to satisfy the individual's internal question "What is this building?" Some locations have to be presented with their respective names since the model is only visual.

The six most important locations would be labelled with their respective names, printed on a sign and held by a virtual actor. The presence of the virtual actors might help in the learning process, by calling attention to the written words. Moreover, Appleyard (1969) argued that people remember buildings more easily if they can pin a linguistic label on them.

Subjects were asked to express the internal image they had about Cambridge in either writing or drawing. The approach each subject took was personal and different. It was expected that subjects who were from an arts background would draw images while subjects from human and scientific backgrounds may use words to express their feeling. Only two subjects, one who used a desktop display and another who used a head mounted display, both from human scientific backgrounds were able to express their image as maps, referring not only the spatial layout of the environment but also the location of things noticed.

The four subjects acclimatised by passive learning environments (pictures and video) expressed their knowledge by drawings, typically a church or college, or by writing a few sentences. It was noted that subjects might have expressed their own environmental knowledge depending on the display type than according to their ability.

Subjects acclimatised from video and pictures visited the city on a Saturday morning, and at that time the city was very crowded with tourists. This might have had a slight negative influence on the experiments, since finding McDonalds which had been planned as a medium difficulty task was made rather easier by the litter of food wrappers leading back to the restaurant, the main experiment has to take part in a more quite period of time.

5.7 Summary

There were 8 subjects in the pilot experiments, the learning process was divided into passive mode including pictures and video and the active mode which included desktop and virtual reality. After the learning process, familiarisation was measured by the cognitive map drawing and network map drawing tasks, and the performance once in the city centre was measured by orientation and way-finding tasks. The visual summary of the chapter is presented in Figure 5.1.

The main conclusion was that the learning environment had to be divided in two sessions: a free exploration session and a training session. It was also clear that the free exploration should not be restricted by time, and the training session should last about fifteen minutes. The most important buildings should be labelled to be easily identified, instead of being mentioned only on the map navigation aid tools.

The network map presented to the subjects after the acclimatisation sessions, to measure spatial knowledge, should not have any empty nodes (circles) printed on it, to let the subjects to place them from their own view point since they present orientation-free abilities.

It is hypothesised that the second experiment subjects would have better knowledge of the environment and therefore produce more accurate maps.

It is also hypothesised that the second virtual learning session would enable subjects to perform better orientation and way-finding tasks in the real environment.

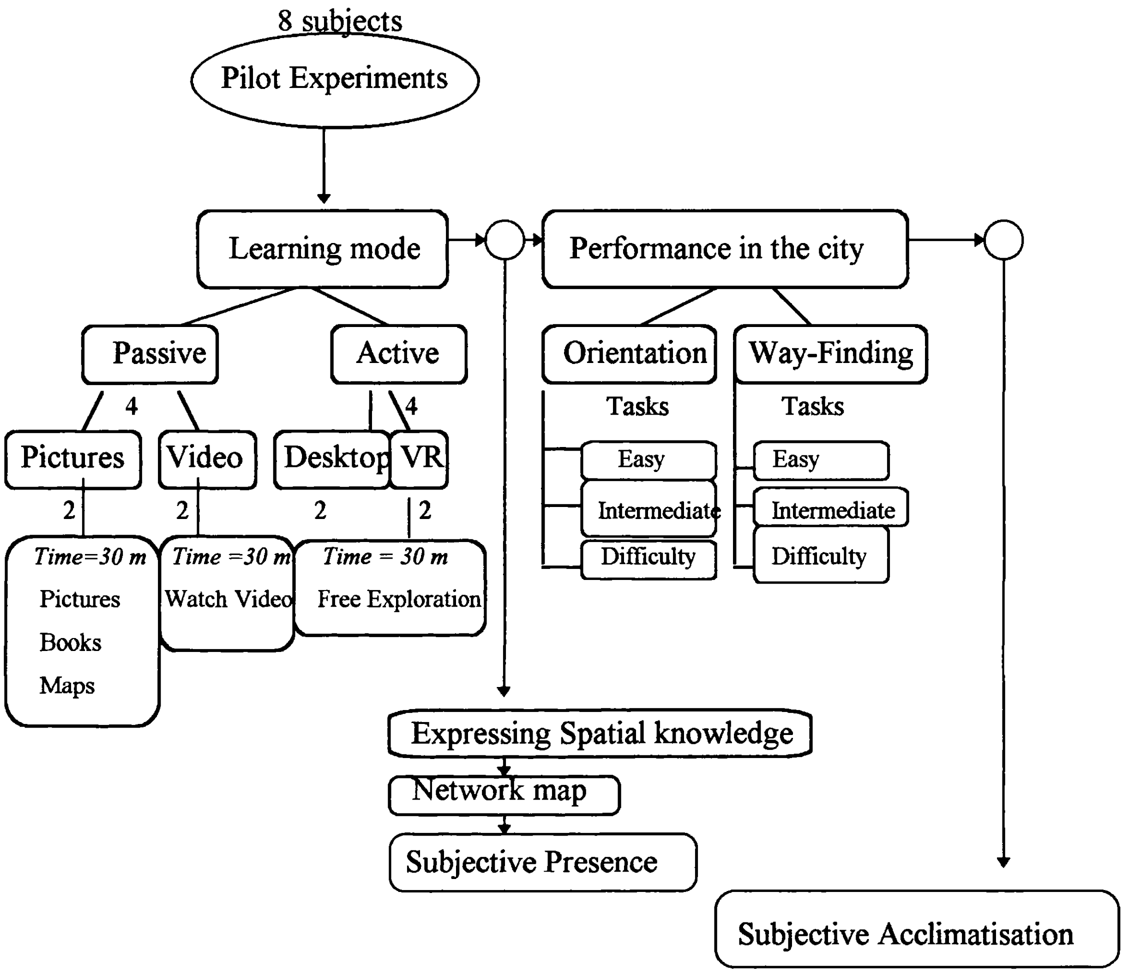


Figure 5.1 Visual Summary

CHAPTER 6 Virtual Cambridge Main Study

6.1 Overview of the Chapter

This chapter describes the design and implementation of the main experimental study of this research. The final design of a virtual reality version of a part of Cambridge city centre incorporating the lessons learned from the pilot experiment is described. The results are presented in chapter seven.

6.2 Experimental Design

Forty subjects were selected on an arbitrary basis to participate in the main experiment. The participants were from a wide variety of cultures. None had ever been to Cambridge before and all were living in England doing post graduation studies at University College London and Queen Mary and Westfield College London.

The subjects were given a rail ticket from London to Cambridge and a bus ticket from Cambridge railway station to the city centre. The participants were not paid for taking part in the experiment. Some subjects were motivated to participate in the experiments by the trip to Cambridge, others were motivated by participating in a virtual reality experience.

6.2.1 Model's incoherence with the design principles

The design principles incorporated sound; however, this feature could not be implemented because the *Onyx- SGI* workstation which was available did not have a sound card.

Human motion and its characteristics, in both running and walking, were studied in depth and were incorporated in the design principles. However, the hardware limitation of insufficient storage made it difficult to include as many virtual actors moving as required without the machine's performance being unreasonably degraded. The attempts to incorporate the planned number of moving figures took more time than had been planned. It was finally possible to include only one animated virtual person and a car following a set route, and this is not considered sufficient in a study of this dimension. The implications of a city life in the acclimatisation process, would not be capable of being addressed. However, it is an indispensable factor to be considered in further work.

6.3 Model and Scenario

The hardware used in the main experiments was the same as in the pilot experiment and is described in Chapter 5, section 5.3. Apart from small improvements such as improved texture maps, the model remained the same with its space layout complexity and geometry.

The learning process using passive experience modes (pictures and video) was the same as used in the pilot experiment. The experimental design about these two media presentations is described in Chapter 5, section 5.4. The active learning process, using immersive virtual reality and non-immersive desktop was divided into two sessions in the laboratory. Subjects knew they were going to visit the virtual Cambridge twice and the real Cambridge once on separate days. Subjects were aware that they choose not to continue to take part in the experiments at any time.

6.3.1 Learning environment

When subjects arrived for the familiarisation process, they were given two questionnaires and the spatial ability test which took three minutes. Subjects read the written instructions and hardware information before the first virtual visit. The main instructions are presented in Appendix F.

In the first virtual reality experiment, subjects were free to explore the environment with no time limit. They looked at the objects in the environment however they chose and each subject paid attention to what they found interesting.

The starting position had been set at the border of the model to allow the participant to go through it in a straight way and to get used to the equipment without missing the street layout. The starting position is presented in Figure 6.1.

The task set was to find virtual people wearing green trousers or a green skirt while they were exploring the virtual environment. These virtual people were positioned in front of the main buildings in the environment, and were holding signs showing the name of the building behind them. There were six virtual people: one in front of each of three churches, one in front of the Senate House, another at King's College and the last at the City Council buildings. Figure 6.2 presents the spatial location showing where each virtual person was. The aim of this task was mainly to encourage subjects to experience the entire model in the first virtual visit.

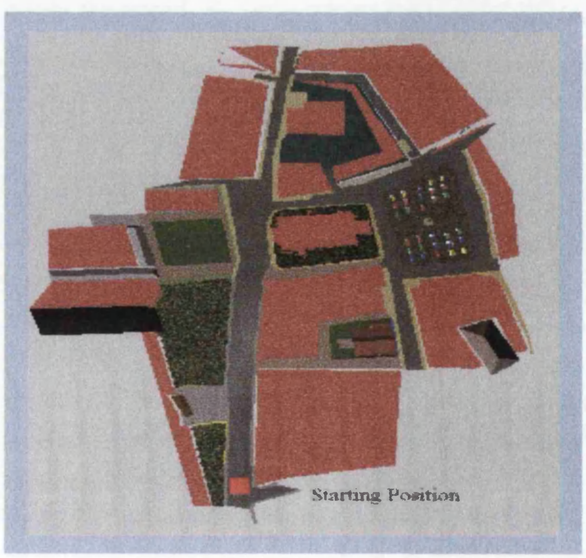


Figure 6.1 The Starting Position of the first visit

Figure 6.2 Spatial Location of the 6 virtual actors

The virtual people were holding signs not to impose landmarks but rather to identify the buildings. It was thought that this could facilitate the subjects' accomplishment of drawing a network map. All the shops had also their signs above the windows. These signs might be the key factors which distinguish a church from another church or a shop from a bank. From the pilot studies it was found that subjects were able to memorise names such as Marks & Spencer, Sony and so on. Figures 6.3 and 6.4 show the signs on buildings and shops respectively.

At the end of the first virtual experiment a questionnaire related to the sense of presence was given to the subjects. They were also asked to write which objects caused an impression on them and what were the salient characteristics of these most memorable objects.

A spatial relationship task was administered after the virtual experiment, in which the subjects were asked to place some given location names in spatial order completing a network map. Subjects were also asked to present their internal image of the environment by writing or drawing their internal spatial environmental organisation.

Two questionnaires were given to subjects to complete away from the laboratory and bring back in the following day when they returned for the next virtual learning session. The questionnaires were related to personal variables, from the personality test and the sensory input test. Both tests were described in Chapter 4, sections 4.3.4.

The second virtual experience took place 24 hours after the first experiment. Subjects returned their questionnaires and read the instructions for the second learning session. The main task was to find two named location tasks in a limited time (20 minutes).

The starting position was different from the first experience. The reason for selecting a different starting position was to give the subjects an opportunity to answer a common question "Where am I?" and also to relate their actual position with the environment. Figures 6.5 and 6.6 present the second starting position.

Figure 6.3 Sign outside Senate House

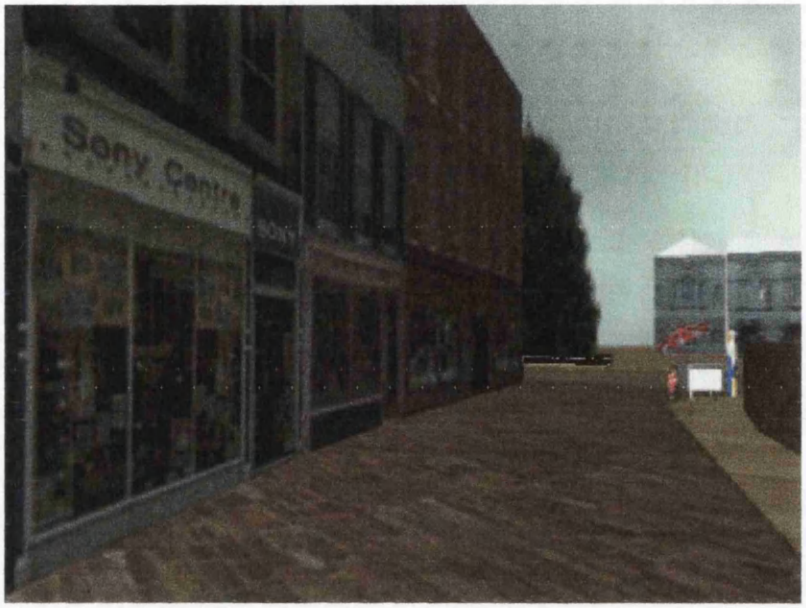


Figure 6.4 Signs on some of the shops in the High Street

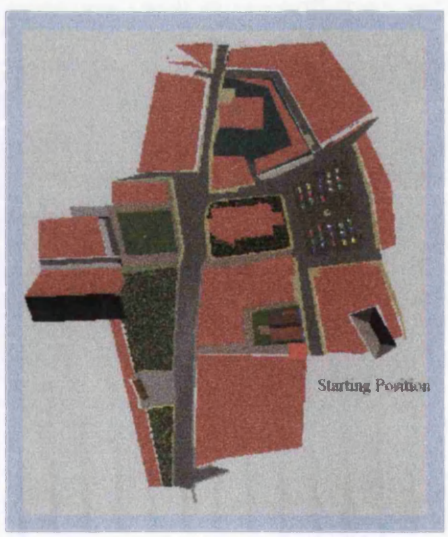


Figure 6.5 Spatial location of the second starting position for virtual experience

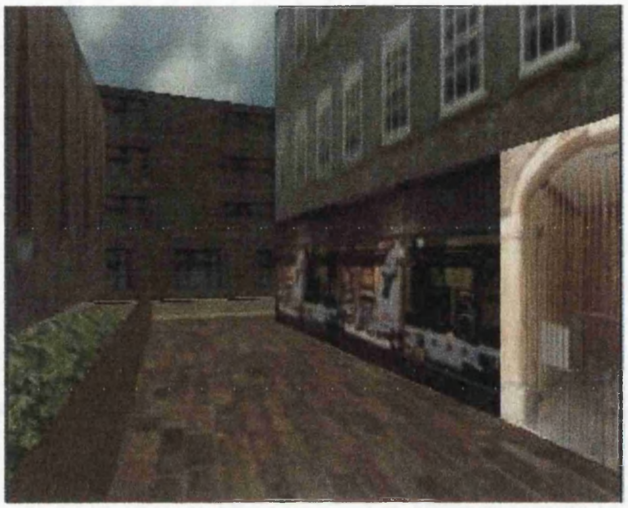


Figure 6.6 Location of the second starting position for virtual experiment

The training task was part of the second session. Subjects were asked to find a bicycle which had been left in a street. This statement was made in order to avoid subjects looking for the bicycle in the market behind stalls, the fountain, etc... The aim was once again to encourage the subjects to navigate through all the paths in the environment. The location chosen for the bicycle was a narrow path which many subjects had not noticed during their first virtual experience. Figure 6.7 shows the spatial location of the first training task while Figure 6.8 presents the bicycle placed in the middle of the street.

The second task was to find McDonalds. This location task allowed the subjects who did not pay attention to the shop signs to complete it. The spatial location of the second training task is presented in Figure 6.7, while Figure 6.9 shows its location.

Figure 6.7 Spatial location of the first and second training task

Figure 6.8 First training task

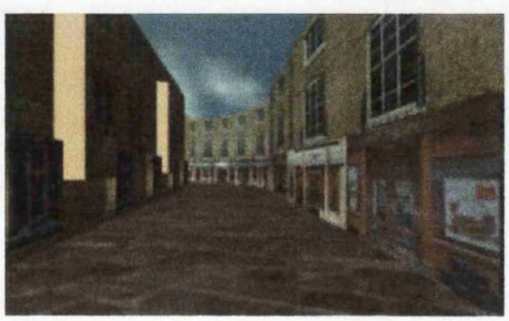


Figure 6.9 Second training task

At the end of the second virtual experiment the questionnaire given to the subjects related to their sense of presence was identical to the one given after first virtual experiment; this was not defined in the experimental design. However, it seemed useful to learn if subjects were maintaining the same level of presence or not.
The other pencil and paper tasks related to the relationship between nodes, filling in the network map, and the test of internal environmental knowledge were also completed by the subjects.

6.3.2 Real visit

Subjects were taken to Cambridge in groups of eight or fewer, since they were to complete the tasks individually while the others waited for their turns near the starting point. Each subject took on average 20 minutes to perform the tasks in the city, so the waiting time for the last participant was about 2 hours and 30 minutes. Subjects were asked not to move from the waiting position and they complied. They were also asked not to talk with each other about the experiments before or after attempting the tasks.
The market place was chosen as the new starting position in order to present a new view of the area. Figure 6.10 presents the view of the starting position and the waiting place.
The tasks to be completed in Cambridge consisted of pointing in the direction of three specified places and then finding these three places. At the starting position the subjects were asked to look around to situate themselves in space and were asked to point to McDonalds, King's College and St. Edward's church. If the subject could not remember which of the churches was St. Edward, a verbal cue was given by referring to where the bicycle was hidden in the virtual environment, these cues were recorded.

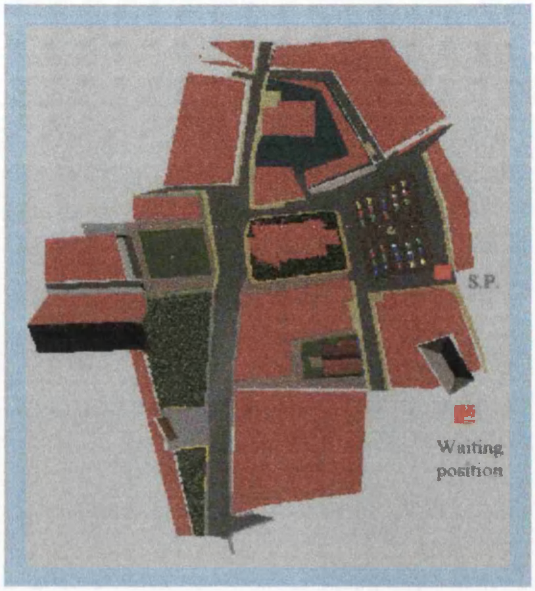


Figure 6.10 Spatial location of the starting position and waiting place

The answer to the pointing task was assessed on a scale of two responses: pointing the direction correctly or incorrectly. Since the three places were all around the starting position, and as they were not too far away, the acceptance of a larger amount of error could not be justified.

The pointing task quantified the spatial orientation of each individual, while the performance of the location finding tasks quantified their ability in way-finding.

The researcher accompanied each subject in the way-finding task in order to record subjects' impressions between Cambridge and the virtual reality model of Cambridge. No cues were given to subjects on any occasion to help them find their way. All subjects spoke about what they were feeling about the environment and their comments were recorded. By this communication it was possible to know the objects and routes that subjects were familiar with, and to hear expressions like "Completely lost", "No idea", "Oh! This is very funny! So similar" etc. Errors and hesitations when finding a location were registered. An error occurred when a place wasn't correctly found, while hesitation occurred when the subject stopped to look around and took time to consider. Although the errors and hesitation of the subjects were registered they were later discounted in this study since it was a subjective view of the person who was classifying.

The questionnaire given at the end of the real visit included questions related to the extent to which the subject had a sense of having "been familiar with the city", the ease in finding their way around Cambridge and how helpful the learning experiences had been.

Subjects were encouraged to speak if they felt like something was missing while taking part in this study. There was an attempt made to discover their opinions of the relative strengths and weaknesses of the implementation of the experiment in the virtual and real environments.

6.4 Summary

Forty subjects took part in the main experiment, ten in each mode of learning (passive: pictures, video, and active: desktop and VR); the active mode included two sessions, a free exploration with the aim to find eight people with green trousers, and a training session restricted to fifteen minutes with the target to accomplish two tasks, the first one to find a bicycle and the second one to find the McDonalds.

There were two subjective responses by answering questionnaires (Presence and Acclimatisation), the first was made after the virtual visit and the second after the performance in the real visit.

Figure 6.11 presents the visual summary of the chapter.

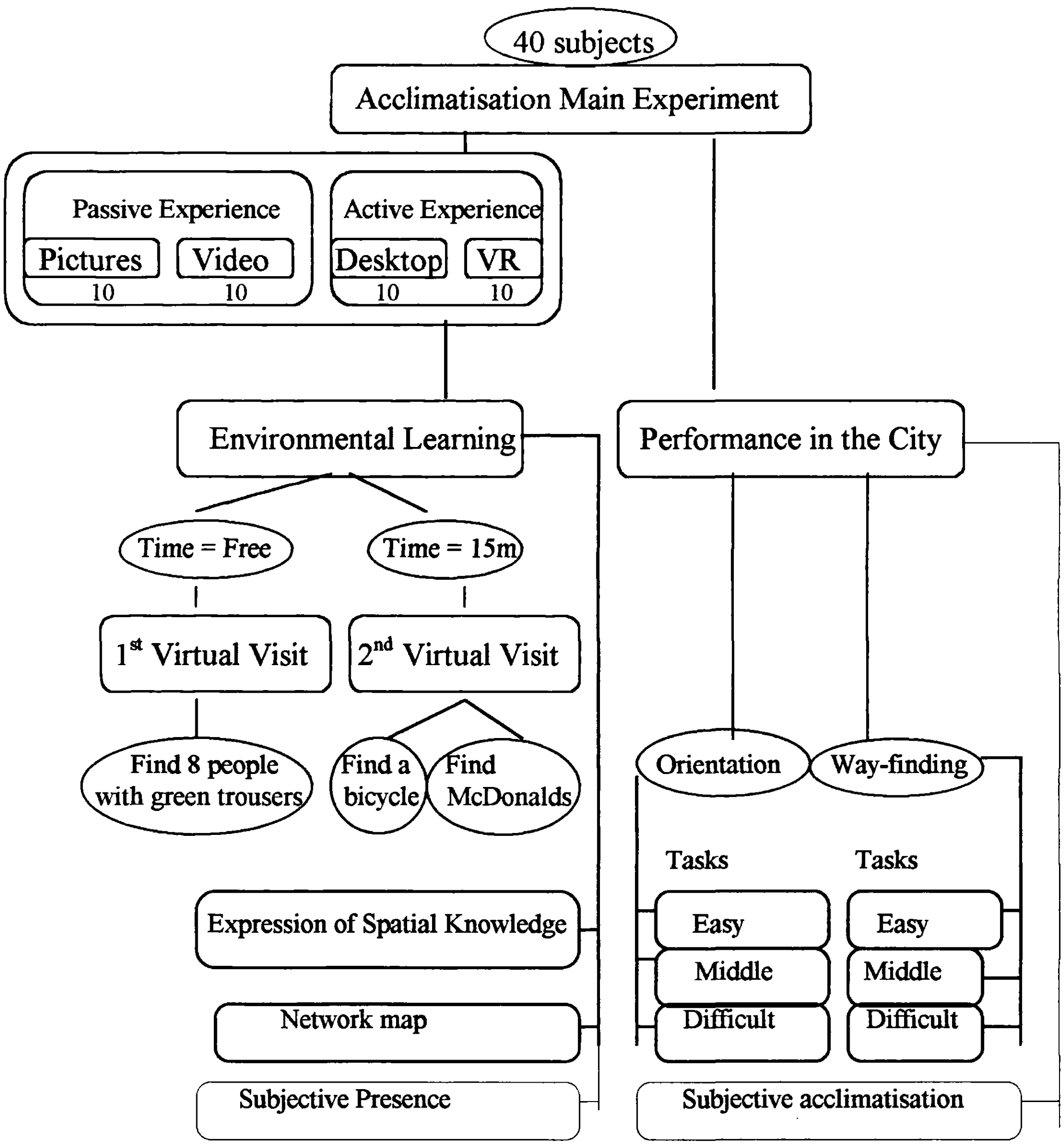


Figure 6.11 Visual Summary

CHAPTER 7 Results and Discussion

7.1 Overview of the Chapter

This chapter presents the analysis, results and discussion of the main experiment. It is the study that answers the main question about the extent of the impact of the display type on acclimatisation.

The main goal was to find out the role that different variables play in acclimatisation, and to examine the effects on acclimatisation when using different types of display. It is important to define whether immersion is influential in acclimatisation. The analysis used two methods of evaluation:

- exploration of the data from the response variables to learn the general differences in effectiveness between mode of learning (active and passive).
- a statistical study to examine the effects of immersion, using desktop and virtual reality displays, in an active mode of learning about unfamiliar environments.

7.2 Identification of the variables

7.2.1 Dependent variables

The main objective of this thesis was to study the dependent variable `acclimatisation` which was assessed by several response variables and to observe how this was related to the independent and explanatory variables.

A diagram identifying the response acclimatisation variables with the tasks accomplished is presented in Figure 7.1.

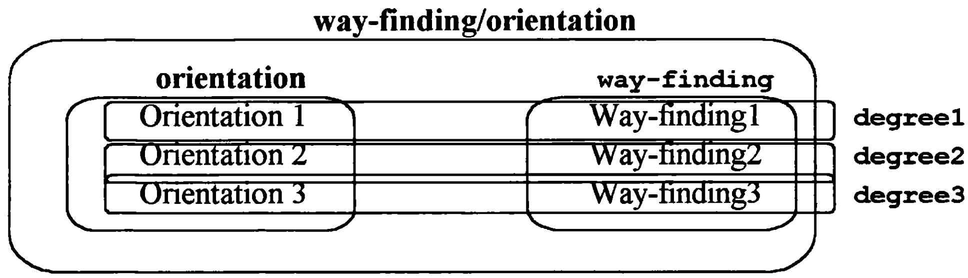


Figure 7.1 Diagram of the acclimatisation response variables

The response variables involved in the acclimatisation study were:

- `way-finding/orientation`

This variable includes the results of three orientation tasks and three way-finding tasks. Each task result is measured in a binary mode; task accomplished (1)or not (0). The result ranged from 0 (no task accomplished) to 6 (all the tasks accomplished).

- `degree1, degree2 and degree3`

These three variables are the orientation and way-finding variables grouped in degrees of difficulties. These variables refer to the degree 1, 2 and 3 of difficulty in orientation and way-finding tasks, respectively. Each of these variables were recording values from 0 to 2. Zero meant that neither of the two tasks were accomplished. The value 1 meant that only one task was accomplished and the value 2 meant that subjects were able to accomplish both tasks: the orientation and the way-finding task.

- `way-finding1, way-finding2, way-finding3`

These are three binary variables, each one had the value 0 for the way-finding task not accomplished and 1 for task accomplished.

- `orientation1, orientation2, orientation3`

These variables were measuring orientation. The measurements were binary as in the way-finding variables.

- `orientation`

A variable comprising three orientation tasks with different degrees of difficulty; an easy, a medium and a difficult task. Each task was classified in a binary way; the subjects who were able to perform a task and those who were not able to accomplish it. The values were ranged from 0 to 3.

- `way-finding`

This consists of three tasks with different degrees of difficulty. The measurement of these variables were identical to the measurement of the orientation variables.

- `Subjective acclimatisation1, subjective acclimatisation2` and `subjective acclimatisation3`

These variables were measured from the responses of an acclimatisation questionnaire. Each question was graded from 1 and 5. This was defined in chapter 4, section 4.3.2:

There were several other dependent variables which contributed to the general understanding of the influence that immersion has on several additional task performances. Almost all these dependent variables played a dual role, they were also explanatory variables for the other dependent variables. These dependent variables were:

- `way of expressing environmental knowledge`

This is a variable grouping the subjects who presented a cognitive map in a written mode (1), in a drawing (2) or in a map organisation (3). There was another variable grouping these values into two categories; those who presented their environmental knowledge in a map organisation, from those who did not. This variable is way of expressing environmental knowledge binary.

- sketch map after 1st virtual visit, sketch map after 2nd virtual visit

These two variables record the level of the response of a task performed after the first virtual visit and the second virtual visit. Both tasks were graded from 0 and 5.

- network map after 1st virtual visit and network map after 2nd virtual visit

These two variables recorded the level of performance in accomplishing a network task after each virtual visit. These tasks were graded from 0 and 8.

- navigation aid tools

This is a binary variable which separated the subjects into two groups: those who used navigation aid tools from those who did not. There were also three variables recording the time each subject spent with each navigation aid tools separately; birds-eye view, map and compass.

- duration of birds-eye view, duration of map, duration of compass

These variables recorded the duration of each navigation aid tools used by a subject in the virtual environment.

- duration of accomplishing 1st training task and duration of accomplishing 2nd training task

These variables recorded the duration of accomplishing the two training tasks in the virtual environment.

- `duration of 1st virtual visit, duration of 2nd virtual visit`

These variables measured the time a subject spent in each virtual visit. These variables were added together to give the total time: `duration of both visits`.

- `task accomplished in the virtual environment`

This is a binary variable separating the subjects who accomplished each task from those who did not.

- `duration of finding 1st task` and `duration of finding 2nd task`

These two variables were recording the time a subject took in finding each training task in the second virtual visit.

7.2.2 Independent and explanatory variables

The independent variables were the `mode of learning` which held the data relating to whether the subject experienced the passive or active mode. The variable `display` distinguished the subjects who were acclimatised through desktop or virtual reality, in an active mode of learning.

Some variables were not manipulated in advance; consequently, some of these variables were not evenly distributed between display type. These explanatory variables were:

responses to a personality test which was described in chapter 4, section 4.3.2:

- `extroversion/introversion, intuition/sensing, thinking/feeling, judging/perceiving`

The four variables which were the responses of a personality test had values from 0 to 100.

Other personal data collected from the subjects and held in the following variables were :

- age, familiarity with VR technology

The familiarity with VR technology variable separates subjects who had previous experience of the virtual reality technology from those who did not.

- sensory input dominance

This is a variable with the values 1 for the subjects with visual dominance and 2 for subjects with auditory dominance.

The three related variables were sensory visual dominance, sensory auditory dominance and kinaesthetic which were measured from a sensory input questionnaire (see chapter 4, section 4.3.2).

- spatial ability

This is a variable made by the three scores of spatial problems. The values ranged from 1 to 11. This was described in chapter 4, section 4.3.2.

- artist/scientist

This is a binary variable with the values 1 for subjects who consider themselves artists and 2 for subjects who consider themselves scientists.

- presence1,presence2 and presence3

The three variables were taken from the presence questionnaire. Presence was a variable created to record presence in general. This was described in chapter 4, section 4.3.2:

7.3 Descriptive Statistics for the Response Variables

In this section the results are shown descriptively and the formal statistic analysis is done in section 7.4. The description of the explanatory variables related to the person involved in the study can be examined in Appendix G.3.

7.3.1 Way-finding/Orientation

The values clustered by display type are presented in a bar chart in Figure 7.2. From the graph, it is evident that the active modes of learning positively support subjects in acclimatisation.

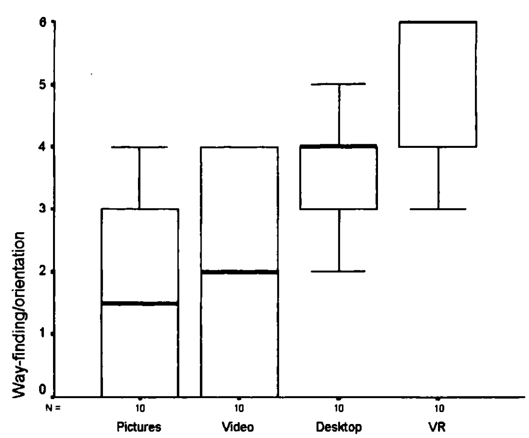


Figure 7.2 Way-finding/orientation among display type

7.3.2 Degree1

The subject's performance in accomplishing degree1 of difficulty in orientation and way-finding tasks is presented in Table 7.1, while Figure 7.3 presents the respective bar chart.

Table 7.1 `Degree1` in difficulty of way-finding and orientation

	no task accomplished	one task accomplished	two tasks accomplished	#Subjects
Pictures	4	2	4	10
Video	6	1	3	10
Desktop	3	3	4	10
Virtual Reality	-	-	10	10

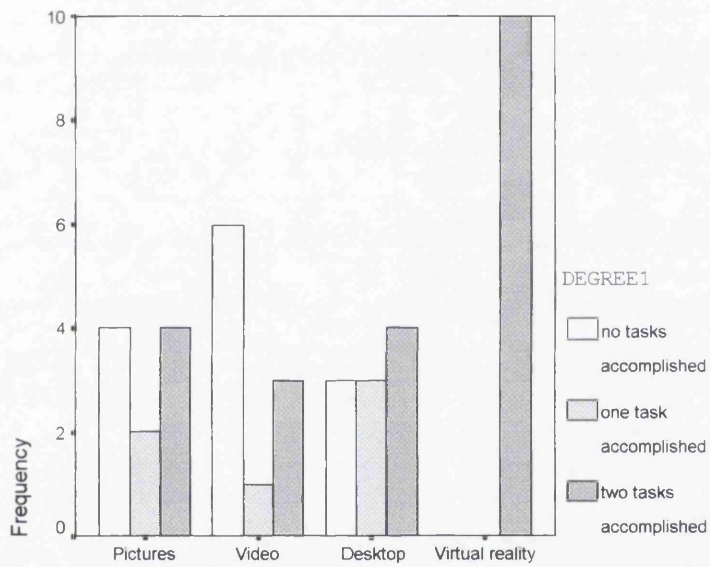


Figure 7.3 `Degree1` in difficulty of way-finding and orientation

From the graph, it was noted that all subjects using virtual reality accomplished the `degree1` tasks.

7.3.3 Degree2

The data from the accomplishment of the orientation and way-finding tasks, related to `degree2` of difficulty is presented in Table 7.2 and the respective graph in Figure 7.4.

Table 7.2 `Degree2` in difficulty of way-finding and orientation

	no task accomplished	one task accomplished	two tasks accomplished	#Subjects
Pictures	4	4	2	10
Video	3	3	4	10
Desktop	1	5	4	10
Virtual Reality	-	1	9	10

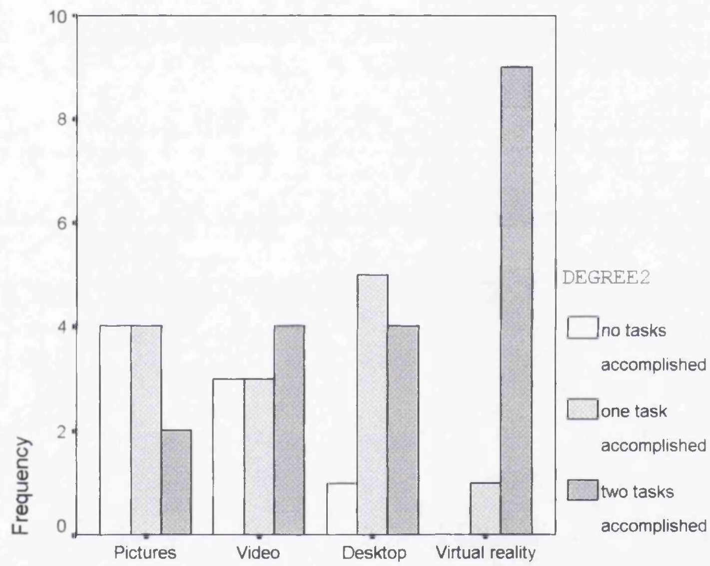


Figure 7.4 `Degree2` in difficulty of way-finding and orientation

It was noted that almost all subjects who experienced an immersive display type were accomplished the tasks with success.

7.3.4 Degree3

The performance of orientation and way-finding tasks of `degree3` is presented in Table 7.3 and the respective bar-chart in Figure 7.5.

Table 7.3 Degree3 in difficulty of way-finding and orientation

	no task accomplished	one task accomplished	two tasks accomplished	#Subjects
Pictures	10	-	-	10
Video	8	2	-	10
Desktop	1	5	4	10
Virtual Reality	3	-	7	10

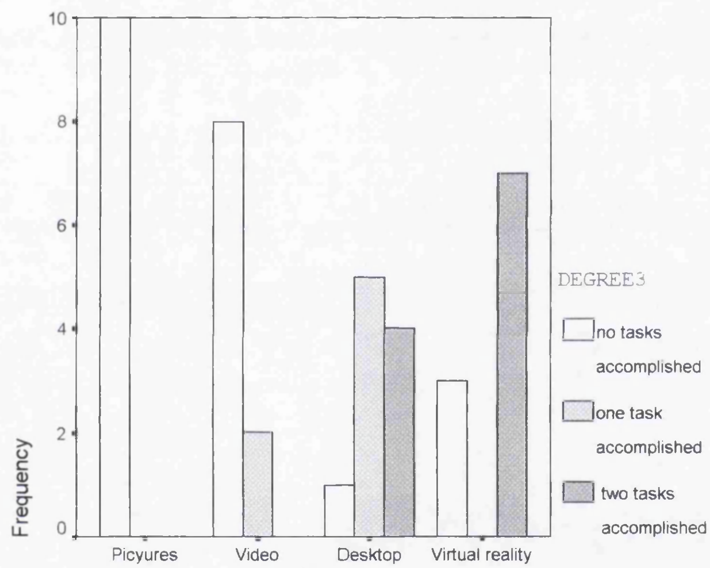


Figure 7.5 Degree3 divided by display type

From the graph, it was observed that subjects from virtual reality display were significantly better than those who used other display type. Also no one who experienced the passive mode of learning the environment accomplished the tasks.

7.3.5 Orientation

The comparison between display type according to the three orientation tasks is presented in a box-plot in Figure 7.6.

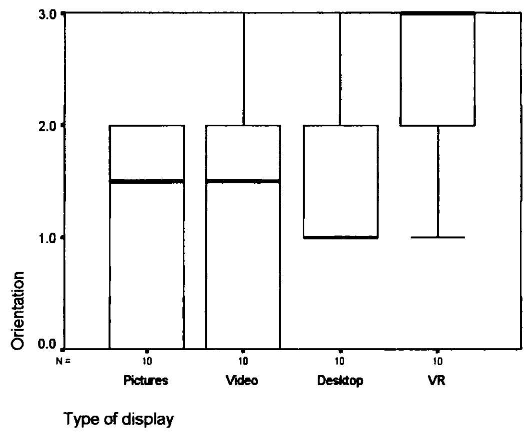


Figure 7.6 `Orientation` clustered by `Display Type`

The graph shows that subjects who experienced virtual reality were successful in all three orientation tasks. So those using desktop displays were relatively successful as they accomplished two of the three tasks. It is particularly interesting to note that subjects using the passive mode of learning were significantly less successful than those using the active mode.

7.3.6 Way-Finding

The box-plot of `way-finding` grouped by type of display is presented in Figure 7.7 and the differences between passive and active learning mode are striking.
Once again, subjects experiencing virtual reality out-performed those using desktop display.

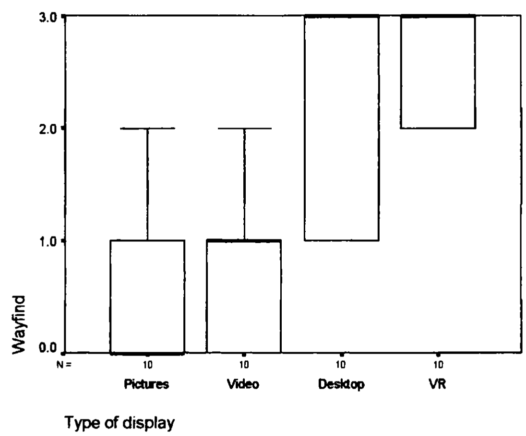


Figure 7.7 Way-Finding clustered by Display Type

7.3.7 Subjective Acclimatisation

Subjective acclimatisation clustered by display type is presented in Figure 7.8. Those subjects who experienced virtual reality reported the highest degree of subjective acclimatisation. This suggests that immersion is an important factor in subjective acclimatisation.

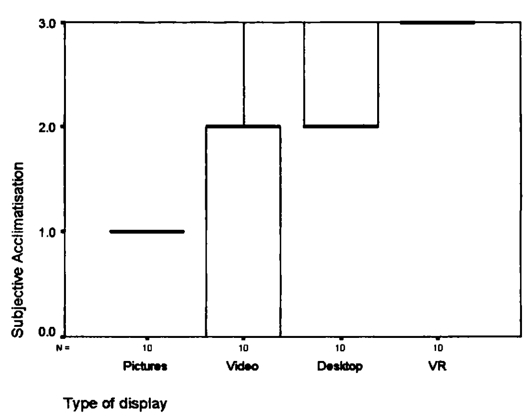


Figure 7.8 Subjective acclimatisation grouped by display type

Figure 7.9 presents the results relating to the sensation of being familiar with the place. Almost all subjects reported a degree of familiarity in the real environment. Subjects who experienced the active mode of learning reported a greater degree of familiarity than those in the passive mode. Subjects who experienced virtual reality reported the highest degree of familiarity.

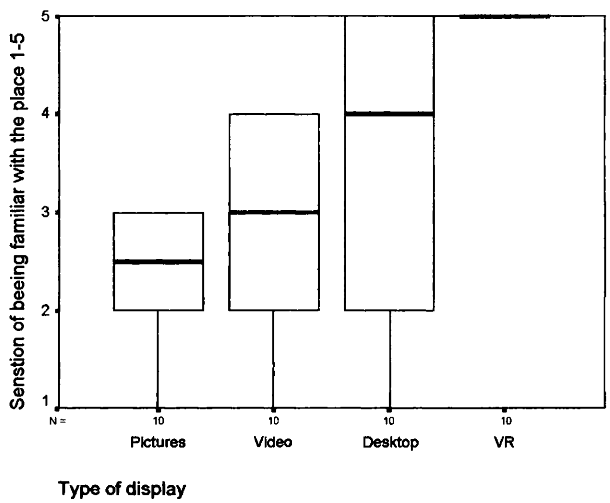


Figure 7.9 Sense of being familiar with the place

Figure 7.10 presents the results of the question 'training helped in the acclimatisation process', almost all subjects reported that training had been useful. Subjects who experienced the active mode of learning reported a greater appreciation for the training, while a few subjects who experienced the passive mode of learning reported that the training was not particularly supportive.

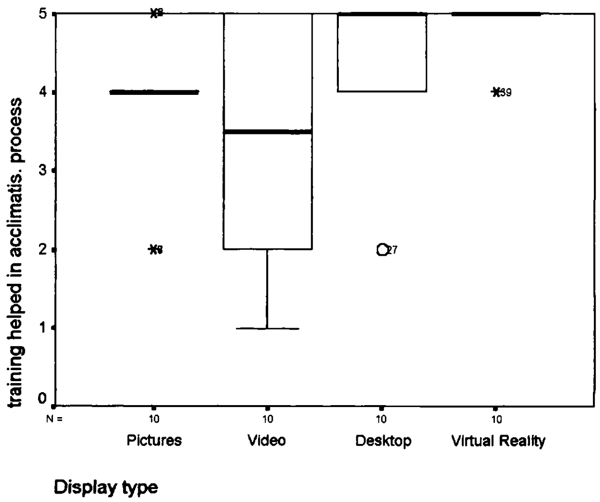


Figure 7.10 Training helped in the acclimatisation

Figure 7.11 presents the results referring to the extent of finding their way around. All the subjects reported a degree of ease in the real environment; subjects who experienced the active mode of learning reported a greater degree of ease while those who experienced virtual reality reported the greatest degree of ease in Cambridge.

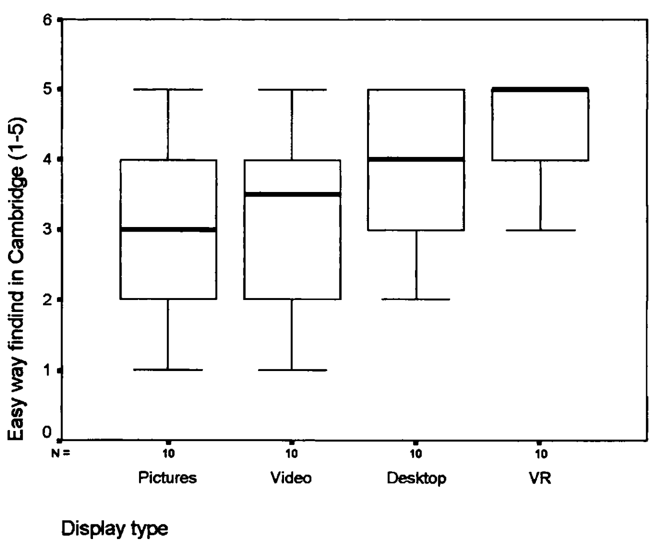


Figure 7.11 Easy way in Cambridge grouped by `display type`

The above suggests that immersion might be an important factor in subjective acclimatisation.

7.3.8 Sketch Maps

This study was based on two sketch maps, one produced after the first virtual visit, the other after the second virtual visit. The aim was to test the hypothesis that subjects with sensory visual dominance may draw more accurate maps than those who have sensory aural dominance.

First Sketch Map

The first attempt of this study was to observe the difference in grades between subjects who had used the different types of display (see chapter 4, section 4.2.2). A comparison was made between the sketch maps for levels of accuracy for each type of display and this is presented in Figure 7.12. The graph presents only the values between desktop and virtual reality, since there were only one and three subjects who expressed their environmental spatial knowledge in a map structure, by pictures and video, respectively. The respective values are detailed in Table 7.4.

From the graph it was noted that those subjects who were acclimatised using virtual reality display presented their spatial knowledge in a sketch map of significant improvement.

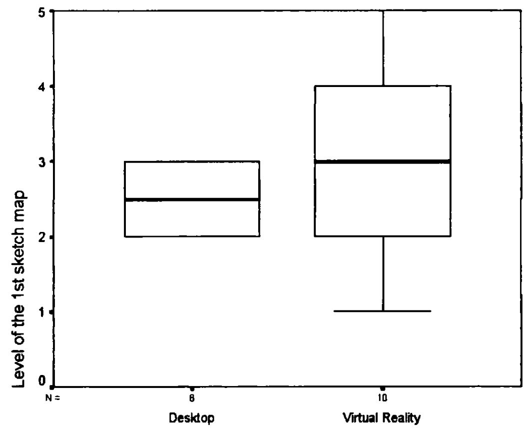


Figure 7.12 Sketch map after the first virtual visit

Table 7.4 Sketch map after the first virtual visit

	Written	grade 1	grade 2	grade 3	grade 4	grade 5	#Subjects
Pictures	9	-	-	1	-	-	10
Video	7	-	1	1	1	-	10
Desktop	4	-	3	3	-	-	10
Virtual Reality	-	1	2	3	2	2	10

It was observed that the high scoring grades were only achieved by subjects who had experienced virtual reality. However, subjects from a virtual reality display, produced maps which scored throughout the range, while subjects using desktop display were concentrated in grades 2 and 3.

The experience of immersive virtual reality might appear to be the important factor in enabling subjects to produce sketch maps of quality and accuracy. It can be seen that subjects who experienced immersive virtual reality were more likely to produce sketch maps of greater accuracy.

Second Sketch Map

The grades obtained from the second sketch maps (after the second training session) clustered by display type in the active mode of learning is presented in Figure 7.13, and the respective data is presented in Table 7.5.

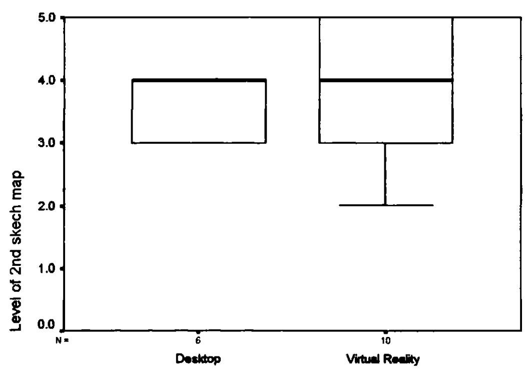


Figure 7.13 Sketch map after the 2nd virtual visit

Table 7.5 Sketch map after the 2nd virtual visit

	Written	grade 1	grade 2	grade 3	grade 4	grade 5	#Subjects
Desktop	4	-	-	2	4	-	10
Virtual Reality	-.	-	1	3	2	4	10

It was observed that the subjects who experienced immersive virtual reality achieved the highest grade, which means that subjects presented more accurate sketch maps.

This shows that the first sketch map task was significant in influencing subjects when involved in the second sketch map task. For example, subjects improved their accuracy through familiarity with the tasks and contact with the virtual environment. The reason for this may be that subjects paid greater attention in the second virtual visit which permitted a conscious process of gathering relevant information.

7.3.9 Network Map

This was based on two sketch maps produced: one after the first virtual visit the other after the second virtual visit. The network map task was expected to learn whether subjects would be able to identify and record specific landmarks in the correct spatial order, and to discover whether there were significant factors which influenced the level of accuracy.

First network map

The main comparison between display type is presented through a box-plot in Figure 7.14 and the respective data in Table 7.6. There was a difference between passive and active modes of learning the environment. However, the difference between the accuracy of network maps is evident in terms of the degree of immersion.

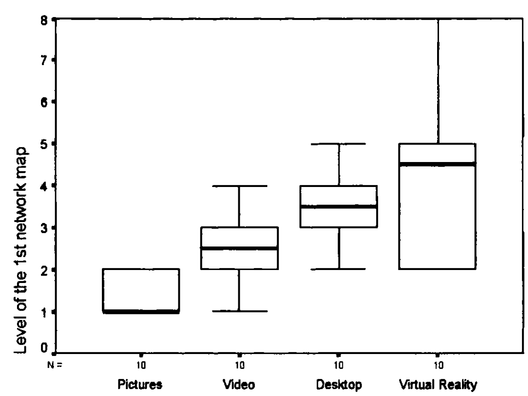


Figure 7.14 Network Map after the 1st virtual visit

Table 7.6 Network Map after the 1st virtual visit

	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	#Subjects
Pictures	6	4	-	-	-	-	-	-	10
Video	3	3	2	2	-	-	-	-	10
Desktop	-	2	3	3	2	-	-	-	10
Virtual Reality	-	3	1	1	2	1	-	1	10

Second network map

Figure 7.15 presents the grades (0-8) attributed to the task. The data is presented in Table 7.7. As in the previous sketch map study, all subjects achieved better results in the second task and subjects acclimatised through virtual reality made the most gains.

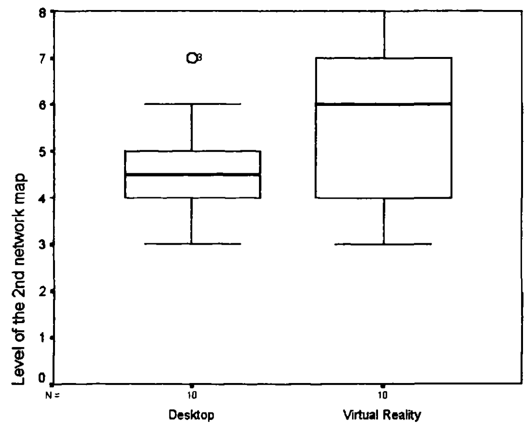


Figure 7.15 Network map after the 2nd virtual visit

Table 7.7 Network map after the 2nd virtual visit

	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	#Subjects
Desktop	-	-	2	3	3	1	1	-	10
Virtual Reality	-	-	2	1	2	-	3	2	10

There was no significant difference between the response of the task performance between display type

7.3.10 Training Tasks

This study was designed to observe subjects' behaviour to determine whether display type had significant influence on subjects accomplishing the tasks.

Training Task One

The objective of the training task was to find a particular bicycle in a specific location. Figure 7.16 presents the time in seconds to complete training task one clustered by display type.

There was a difference between display types.

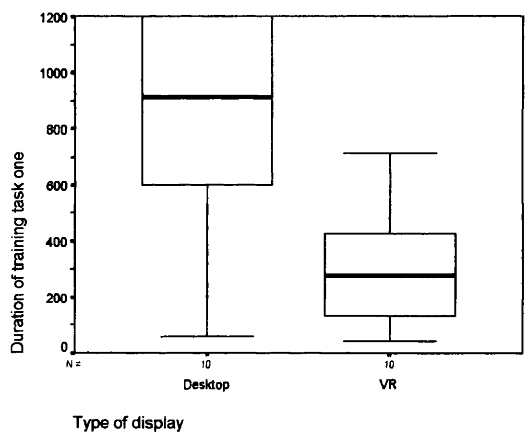


Figure 7.16 Time to Complete Training Task One Clustered by Display Type

Training Task Two

The objective of task two was to find a specific location. The time in seconds a subject took in accomplishing the second training task is presented in Figure 7.17.

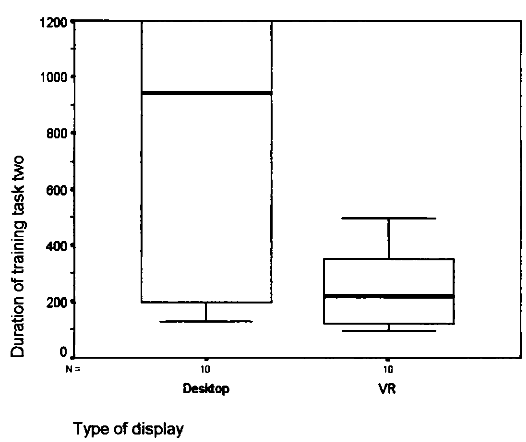


Figure 7.17 Time to Complete Training Task Two

It can be seen that subjects experiencing virtual reality accomplished this task more quickly than subjects using desktop displays. This would suggest that the degree of immersion is an important factor in task performance.

It was noted that only half of the subjects using desktop displays were successful in completing the training tasks in the second virtual environment, and for that they needed almost all the time allowed (see Figures G.14 and G.15)

Paush (1997) also found that subjects experiencing virtual reality completed search tasks faster than those using desktop displays. This would suggest that subjects experiencing virtual reality have absorbed their environment in a more natural way as in everyday life and can apply their learning more successfully in the virtual environment.

7.3.11 Use of Navigation Aid-Tools

In this study it was important to find out whether the navigation aid tools contributed towards the acclimatisation process.

Initially a look at the Figures 7.18, 7.19 and 7.20 shows that the navigation aid tools were more frequently used among subjects who experienced an immersive virtual environment.

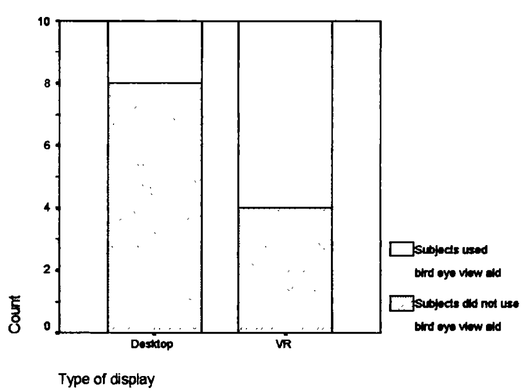


Figure 7.18 Birds-Eye View Clustered by Display Type

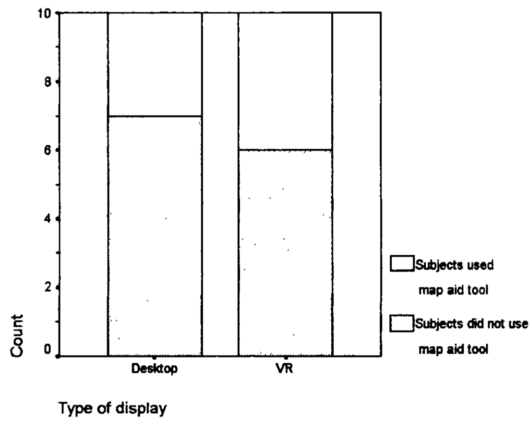


Figure 7.19 Map Aid tools Clustered by `Display Type`

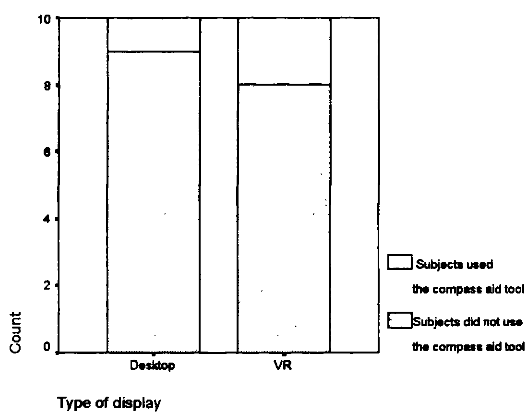


Figure 7.20 Compass Clustered by `Display Type`

From the graphs above, it was noted that although three of the four navigation aid tools were more frequently accessed by virtual reality subjects the information they obtained from this experience had almost no effect on the way in which they performed the tasks.

It appears that the navigation aid tools were used only minimally. See Figures G.17, G.18 and G.19.

Subjects did not use the navigation aid tools in the free exploration, as it was observed in the pilot experiment described in chapter 5, section 5.5. Subjects did use the navigation aid tools in the second training session, as it was expected in chapter 5, section 5.5.

It was hypothesised that the navigation aid tools would be helpful to the subjects in performing the training tasks in the virtual environment. However, from the examining of the data, it did not have an impact on subjects' task performance; the data is presented in Table 7.8.

Table 7.8 Navigation aid tools against training tasks

	Training Task 1		Training Task 2	
	Not accomplished	Accomplished	Not accomplished	Accomplished
Navigation aid tools not used	3	7	2	8
Navigation aid tools used	2	8	3	7

7.4 Statistical Analysis

A statistic study was carried out using the Genstat statistical system except for the Fisher's exact test that used the NAG Excel Add-Ins.

The data was input to Genstat with some variables being defined as factors (classification variables); the computations were performed interactively. A summary of the commands used are in the Appendix G.4 and the output from this file is in the Appendix G.5.

7.4.1 Multiple-variable logistic regression

The analysis relies on the assumption that the dependent variable is binomially distributed. Logistic regression is used to fit a model to binary response (η) data, such as whether a subject is acclimatised (event) or not (non-event). These events are often described as success versus failure. For each possible set of values for the independent (X) variables, there is a probability p that a success occurs. The linear logistic model fitted by maximum likelihood is:

$$\eta_i = \beta_0 + \sum_{j=1}^{k} \beta_j X_{ij} \quad (i=1,2,\ldots,N)$$

where N $(=20)$ is the number of observations, since the study carries in analysing immersion and desktop displays, in an active mode of learning the environment, and η is the logit transformation of p:

$$\eta = \ln (p/(1-p))$$

The logistic regression model links the expected value $E(p_i) = n/(1+exp(-\eta_i))$ where n is the number of binomal trials per observation. Maximum likelihood estimation is used to obtain estimates of β coefficients.

Logistic regression is an example of a generalised linear model which has the following three components:

1. An error distribution for the response variable y.
2. A link function relating the mean, μ, of the distribution to a linear predictor, η, $\eta = g(\eta)$.
3. A linear predictor, $\Sigma \beta_i x_i$

For the logistic regression these are:

1. A binomial distribution with mean μ,
2. A logistic link function $\log(\mu/(n-\mu)) = \eta = \Sigma \beta_i x_i$

The significance of terms in a logistic regression can be tested by comparing the differences in the deviance with a χ^2 distribution [McCullagh, 1989].

7.5 Results of the Regression Analysis

The analysis of the data focuses on the relationship between `Display` and the response variables, in particular the acclimatisation variables. Further analysis could be carried out to investigate further relationships between the explanatory variables and the response variables.

The explanatory variables were divided into two groups. This helped in the understanding and also overcame some computational problems for large models. However, the groups were not critical and the results could easily be adapted to different groups or no groups.

A preliminary test for the effect of `Display` on the outcome variables `way-finding1`, `way-finding2`, `way-finding3`, `orientation1`, `orientation2` and `orientation3` gave the following results using Fisher's exact test. The results are presented in Table 7.9.

Table 7.9 Results from the Fisher's exact test

Variables	Results
way-finding1	not significant
way-finding2	no information, values constant
way-finding3	not significant
orientation1	significant (p=0.032)
orientation2	significant (p=0.011)
orientation3	not significant

From these results `Display` appears to have an effect in orientation but not in way-finding.

The second step was to construct the variables `Y` (`way-finding/acclimatisation`), `degree1`, `degree2`, `degree3`, `way-finding` and `orientation`. The description of these variables are presented in Table 7.10.

Table 7.10 Outcome variables for Acclimatisation

Y = wayfinding1 + way-finding2 + way-finding3 + orientation1 + orientation2 + orientation3	
degree1	= wayfinding1 + orientation1
degree2	= wayfinding2 + orientation2
degree3	= wayfinding3 + orientation3
way-finding	= way-finding1 + way-finding2 + way-finding3
orientation	= orientation1 + orientation2 + orientation3

These variables could be considered as binomial variates with denominators 6, 2, 2, 2, 3 and 3 respectively.

For this specific study the explanatory variables considered are listed below in Table 7.11.

Table 7.11 Explanatory variables included in the Acclimatisation study

1.Extroversion/introversion	***p***	13. Presence1	***p***	25.first training task	***o***
2. Intuition/sensing	***p***	14. Presence2	***p***	26.duration of accomplishing 2nd training task	***o***
3. Thinking/feeling	***p***	15. Presence 3	***p***	27. birds-eye view	***r***
4. Judging/perceiving	***p***	16. Presence	***r***	28.duration of birds-eye view	***o***
5.Gender	***p***	17. Way of expressing environmental knowledge	***p***	29.map aid tools	***r***
6.artist/scientist	***p***	18. way of expressing environmental knowledge binary	***r***	30.duration of map	***o***
7. Familiarity with virtual reality	***p***	19.duration of the 1st virtual visit	***r***	31.the use of map navigation aid tools	***r***
8.Visual	***p***	20.duration of the first virtual visit	***o***	32.compass navigation aid tools used	***r***
9.Auditory	***p***	21.duration of the second virtual visit	***o***	33.duration of compass	***o***
10.Kinaesthetic	***p***	22.time spend in both virtual environments	***o***	34.compass	***r***
11.Sensory input dominance	***p***	23. duration accomplishing first training task	***o***	35.navigation aid tools	***o***
12.Spatial ability	***p***	24.second training task	***o***		

Those in class ***r*** repeat information and were not included in an initial test of all variables. The explanatory variables were divided into two groups: group ***p*** indicates that the variables relate to the person involved in the test, group ***o*** indicates that the variables relate to an outcome of an aspect of the experiment, e.g., the length of time to complete a task. The relationship between the four groups of variables is shown in Figure 7.21.

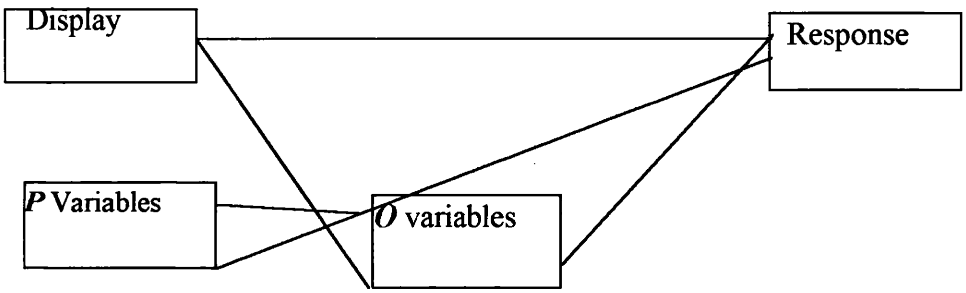


Figure 7.21 Relationship between variables

For each of the six derived response variables (`y (acclimatisation/way-finding)`, `degree1`, `degee2`, `degree3`, `way-finding` and `orientation`) the logistic regression on each of the explanatory variables (and the independent variable `Display`) was carried out. The results are summarised in the Table 7.12 (° Significant only at 10%, * 5%, ** 1%, *** 0.1%).

The significant results for `Display` confirmed the initial finding on the relationship between display with orientation.

The next step was to see if the effect of `display` is still significant when other explanatory variables are taken into account.

Of the variables that were significant at least 10% were used in the next stage. The variables were then jointly fitted to the response variables using a logistic regression and the non-significant terms were removed. This leads to the following models for each group.

Table 7.12 Results of logistic regression on each of the explanatory variables

Variables	Y	degree1	degree2	degree3	way-finding	orientation
Display	***	***	**			***
extroversion/introversion			o			
intuition/sensing	*	o	*			o
thinking/feeling				*		
Judging/perceiving				*		
Gender			*			
artist/scientist	**	**	*		o	*
Visual			o			
Auditory		*	*			o
Kinesthetic						
Sensory input dominance			o			
Spatial ability			o			o
presence1	*	o				*
presence2		o				
presence3	*	**				*
way of expressing environmental knowledge	*		o	o		*
duration of the 1st virtual visit						
duration of the 2nd virtual visit						
duration of accomplishing 1st training task	**	***				**
second training task	***	***	*		**	**
first training task	**	***				**
duration of accomplishing 2nd training task	**	***	*		**	*
duration of birds-eye view	*	o	o			*
duration of map	*			*	*	o
duration of compass	*	o		*	o	
navigation aid tools						

7.5.1 Analysis of way-finding/orientation

The output of the logistic regression analysis of way-finding and orientation is presented in G.3.1.

Variable **Y** (acclimatisation/orientation)
Group *p*: ARTIST/SCIENTIST, WAY OF EXPRESSING ENVIRONMENTAL KNOWLEDGE
Group *o*: 2nd TRAINING TASK

This means the model for group ***p*** is η = ARTIST/SCIENTIST + WAY OF EXPRESSING ENVIRONMENTAL KNOWLEDGE, where η is the linear predictor.
When Display was fitted after group ***p*** it was not significant, but was the most significant term. When fitted after group ***o*** it was not significant. Comparing 2nd TRAINING TASK and Display, the following Table 7.13 is obtained:

Table 7.13 Comparison between 2nd training task with display

	Desktop	Virtual Reality
2nd TRAINING TASK not accomplished	5	0
2nd TRAINING TASK Accomplished	5	10

Indicating a close relationship between 2nd TRAINING TASK and Display.

7.5.2 Analysis of degree1

The output of the logistic regression analysis of degree1 is presented in G.3.2.

Variable **Degree1**
Group *p*: ARTIST/SCIENTIST
Group *o*: TIME SPENT IN ACCOMPLISHING 1ST TRAINING TASK, 2ND TRAINING TASK

In both cases Display type is not significant when the other terms are present in the model.

The comparison ARTIST/SCIENTIST with Display type can be observed in Table 7.14

Table 7.14 Comparing Artist/Scientist with Display

	Desktop	Virtual Reality
ARTIST	5	1
SCIENTIST	5	9

Shows the association between Desktop category and the SCIENTIST category.

7.5.3 Analysis of degree2

The output of the logistic regression analysis of way-finding and orientation is presented in G.3.3.

Variable **Degree2**
Group *p*: GENDER, ARTIST/SCIENTIST
Group *o*: 2nd TRAINING TASK

In this study it was salient that both cases Display is not significant when the other terms are present in the model.

7.5.4 Analysis of degree3

The output of the logistic regression analysis of way-finding and orientation is presented in G.3.4.

Variable **Degree3**
Group *p*: THINKING/FEELING,
WAY OF EXPRESSING ENVIRONMENTAL KNOWLEDGE
Group *o*: DURATION OF MAP

In both cases Display is not significant when the other terms are present in the model.

7.5.5 Analysis of way-finding

The output of the logistic regression analysis of way-finding and orientation is presented in G.3.5.

Variable `Way-finding`
Group ***p***: `no model`
Group ***o***: `2nd TRAINING TASK`

`Display` is not significant when the other terms are present in the model.

7.5.6 Analysis of orientation

The output of the logistic regression analysis of way-finding and orientation is presented in G.3.6.

Variable `Orientation`
Group ***p***: `INTUITION/SENSING, PRESENCE 1`
Group ***o***: `DURATION OF ACCOMPLISHING FIRST TRAINING TASK, DURATION OF BIRDS-EYE VIEW`

`Display` is significant (<0.01) after group ***p*** are included in the model but not significant after group ***o*** terms have been included.

There is evidence that the immersive display improves performance in orientation tasks even when variables from the ***p*** group are taken into account.

Research undertaken by Regian (1992) and Wilson (1996) illustrated that people orient themselves in a real environment after a previous learning session. This, together with the study of orientation would seem to suggest that a previous experiment in the virtual environments enables subjects to improve their performance to a greater extent.

When variables from the ***0*** group are taken into account, in particular `2nd TRAINING TASK`, there is no evidence of an improvement. There is also no evidence of an improvement in `way-finding tasks`.

7.6 Analysis of other Responses

If more data were available a more sophisticated analysis may be possible for the three subjective responses and the variables NETWORK MAP AFTER 2ND VIRTUAL VISIT and SKETCH MAP AFTER 2ND VIRTUAL VISIT. However, a simple regression and correlation analysis indicates the basic results. The response was treated as a quantitative variable rather than a categorical variable. The correlation between Display and the response variables (this is equivalent to a t-test) is presented in Table 7.15.

Table 7.15 Correlation between the response variables

Variable	Correlation coefficient
Subjective acclimatisation1	0.59
Subjective acclimatisation2	-0.22
Subjective acclimatisation3	0.34
Network map after 2nd virtual visit	0.33
Sketch map after 2nd virtual visit	0.13

Hence, Display is only significant for SUBJECTIVE ACCLIMATISATION1 when ignoring all other variables. This was confirmed by means of a likelihood ratio χ^2 test computed using logistic regression with Display as the response. Looking at the other explanatory variables, the following significant correlations are found and presented in Table 7.16. (All correlation were positive.)

Table 7.16 Significant Correlation

Subjective acclimatisation1	Subjective acclimatisation 2	Subjective acclimatisation 3	Network map after 2nd virtual visit	Sketch map after 2nd virtual visit
ARTIST/SCIENTIST	PRESENCE1	ARTIST/SCIENTIST	ARTIST/SCIENTIST	DURATION 1ST VIRTUAL VISIT
AUDIT	PRESENCE2	SPATIAL ABILITY	FAMILIARITY WITH VIRTUAL REALITY	
PRESENCE3		2ND TRAINING TASK	PRESENCE1	
WAY OF EXPRESSING ENVIRONMENT. KNOWLEDGE			DURATION 1ST VIRTUAL VISIT	
2ND TRAINING TASK			2ND TRAINING TASK	
1ST TRAINING TASK				

Examining the variable `Subjective acclimatisation1` further, taking into account the other variables by means of multiple regression, the following was obtained.

The output of the logistic regression analysis of way-finding and orientation is presented in G.3.7.

Variable **SUBJECTIVE ACCLIMATISATION1**

Group ***p***: ARTIST/SCIENTIST, AUDITORY, WAY OF EXPRESSING ENVIRONMENTAL KNOWLEDGE

Group ***o***: 2^{nd} TRAINING TASK

Display was found not significant when added after group ***p*** or group ***o***.

There is some evidence of a relationship between Display and SUBJECTIVE ACCLIMATISATION1 but this can not be substantiated in the presence of combinations of other variables, in particular ARTIST/SCIENTIST and AUDITORY, but is still significant if only one other variable is taken into account.

7.7 Subjects' Comments

Subjects ´ comments after the virtual visits, in general, were that the models in the active modes of learning were realistic particularly in terms of detail. However they reported that they missed aspects of city life such as people moving. This was especially true of the subjects who had experienced virtual reality in the study.

Other factors which detracted from the experience were the background noise from the laboratory and the cables around the virtual reality machine: "The problem is that with all the cables and the noise in the laboratory brings you back to the real world", and, "I felt something uncomfortable with the wires".

Subjects commented that the second virtual visit was crucial in becoming familiar with the environment.

After the real visit, subjects reported the similarity between both virtual and real environments and consequently familiarisation with the real environment was greater than they would have expected. One of many subjects said: "The experiments were unbelievably similar. I never expected to have the impression that I had been in Cambridge before, but I did", and "I was astonished how similar the virtual and real Cambridge were. I think it was very helpful and exciting to experience the virtual Cambridge first".

Some subjects expressed their familiarity with the environment and the ease in finding their way around in Cambridge: "I couldn't have felt better prepared to find my way around", and "All the references were so similar that finding the way in Cambridge was very easy. All the places were very familiar to me... The experiments indeed helped me to feel like I've been there before... I was very confident and very sure in finding my way around", and "I Found my way in Cambridge was very easy. I think that the virtual Cambridge was very real, mainly the market, the fountain, the market's floor. "It was very easy to find my way around. All the places were very familiar... A great experience!". "While I was in the real city I recognised everything. The two places were just the same, very similar. It was like I've been in the real city before."

There was one subject who mentioned that the experiment helped in orientation in the real city: "I was very well oriented in the city".
A subject expressed the lack of motivation in the virtual experience "Pity I did not pay more attention in the virtual visit". Motivation is clearly very important. It is a fact that attention controls and limits what people perceive, what they decide to do, and how they decide to do it [Schmidt, 1988]. This study suggests that performance is based on attention which is influenced by motivation.
The subjects comments after each visit; virtual and real one, are presented in Appendix F.3, F.4 and F.5, respectively.

7.8 Discussion

From the results of the logistic regression of each of the explanatory variables, it was noted that the mode of display was relevant for the three orientation and the three way-finding tasks when measured together. Display was relevant, as well, for `degree2`, which includes medium degree of difficulty in orientation and way-finding tasks.
It was noticed that the first and the second training task and the duration of accomplishing the second training task were relevant to the variable `degree1`, which included easy orientation and way-finding tasks.
There was evidence that immersive display improves performance in orientation tasks, but when the training tasks were taken into account, there was no evidence of an improvement in orientation, nor in way-finding.

It was illustrated in this experiment that subjects experiencing immersive virtual reality presented more accurate sketch maps. Examining the accuracy of the sketch maps as a function of increased environmental experience, it was noted that the spatial development between the first and the second environmental learning sessions lead to an improvement as the general experience of exploring the environment increased.

The first virtual visit was free exploration while the second virtual visit was designed to accomplish two location tasks, these tasks enabled many of the subjects to go into areas not visited in their free exploration where they had tended to experience only large open spaces such as wide streets, the market and the park. This could be due to a lack of confidence in entering narrow alleys and other streets of the principal routes in an unfamiliar city. Subjects using desktop displays had a tendency to move forward rather than turning left or right. Whereas subjects immersed in virtual reality tended to move more slowly absorbing their surroundings.

In the second visit subjects had to enter narrow streets to complete the tasks. Those subjects immersed in virtual reality were successful in entering a narrow street in order to complete the task and were able to produce a sketch map to a high degree of accuracy.

Other factors which may have influenced subjects' response to the second task are their improved response, their level of co-operation, motivation and desire to apply their learning.

It was observed that the performance in the second network map task was related to performance in the first network map task as subjects benefited from their earlier learning experiences. This supports Moore's (1979) statement "People seem to differ in terms of what and how much they know but also they differ in terms of the way they organise what they know and they change over time in clear developmental stages", and Ruddle's (1998) statement: "Participants did develop significantly more accurate spatial knowledge as they became more familiar with navigating virtual environments in general".

As navigation aid tools were hypothesised to be a indispensable orientation and way-finding tool, attention was paid to it. It was detected that subjects did not use the navigation aid tools in the first virtual visit. However, they did use them in the second training session, although only minimally.

7.9 Conclusions

From the examination of the data it was clear that there was a difference between modes of learning. It is a fact that the active mode of learning (desktop and virtual reality) was more effective in acclimatisation in general than the passive mode of learning (picture and video).

For almost every variable considered in the descriptive studies section, subjects who experienced virtual reality showed greater degree of acclimatisation than those who experienced the desktop. This is an important evidence in itself independently of formal significant tests.

The majority of subjects who experienced the environment through an active mode of learning reported a sense of being acclimatised, and performed well in orientation and in expressing their environmental knowledge through sketch maps and network maps. Those who experienced virtual reality performed at a higher level in all respects than those who used a desktop display.

It was found that immersive display improves performance tasks in orientation. this come in accordance with Regian (1992) and Wilson (1996) who illustrated that people oriented themselves in a real environment after a previous learning session.

It was noted that navigation aid tools did not have an impact in acclimatisation, this is in accordance with Ruddle (1998) who noted that the compass made no difference in the development of subjects spatial knowledge.

It can be determined that Virtual Environments can be used to acquire spatial knowledge of specific real places. The virtual reality was in fact the most effective method of training to orient a subject to a new spatial environment when compared with other methods of training.

Immersive virtual environments can be effective training media for the acclimatisation process.

Chapter 8 Conclusions and Further Work

8.1 Overview of the Chapter

This chapter presents the main conclusions, specifies the potential sources of error and suggests possible further studies in the acclimatisation process.

8.2 General discussion

The focus of interest of this research is on cities, which are symbols of a complex society based on social and cultural factors. On the basis of previous studies in the environmental cognition field, a model of part of Cambridge city centre was digitised in *AutoCAD* and the pictures of the buildings were used as texture maps. Some features were added to the model derived from case studies and pilot experiments, such as: the vividness of virtual presentation, the visual textures, the addition of a virtual body, the inclusion of virtual actors and interaction within the virtual environment. Navigation aid tools (direction arrow, map and birds-eye view), which were not intrusive, were provided, based on the hypothetical and intuitive factors of navigating in the environment in the familiarisation process.
The model of part of Cambridge city centre was used in the main acclimatisation study, where subjects could perceive, navigate and interact within it.
This study had its foundations in a literature review carried out in two main areas; Environmental Cognition and Virtual Reality. This review was supplemented by presenting the traditional methods of acclimatisation commonly used, underlying their strengths and weaknesses. The city environment associated to the individual's behaviour in that environment shows the strong relationship between

the individual and the city. The individuals' perception of the city linked to life experience leads to their mental constructions of the environment; cognitive maps. This cognitive representation of the city implies a general spatial knowledge of the environment and navigation abilities which are far beyond physical movement through space. It involves way-finding and orientation skills. These foundations were presented in Chapter 2.

Four case studies were presented in Chapter 3 in an attempt to learn more about acclimatisation in general. Subjects reactions towards adapting to and learning about these environments were carefully studied and analysed. However, as the main research is in the city environments some lessons learned from closed environments, did not easily transfer to a city context.

Chapter 4 presented the methodology for the design principles of the construction of the model, looking at each feature in particular. Sound could not be incorporated in the study since the Onyx-SGI workstation did not have a sound card, nor could animation of virtual actors be incorporated due to hardware limitations. The procedure of the experiments was presented and discussed in the context of comparing Virtual Reality with three other existing methods of acclimatisation; pictures, video and desktop.

The pilot experiment, presented in Chapter 5, was conducted to debug possible errors in the design principles. At this stage, the need was found to incorporate a second virtual experience in the environment learning process to permit subjects to have an additional training session.

The main experiment was fully described in Chapter 6. The values collected from sketch and network maps, orientation and way-finding tasks, and the answers from the questionnaires, were analysed and presented in Chapter 7.

8.3 Conclusions

The study of this thesis showed that immersive virtual environments are an effective media technique to teach environments. Moreover, Virtual Reality can be an alternative method to the traditional ones. Certainly, disorientation would be minimised in the real place, after learning the Virtual Environment.

The relevant issue of this study was to understand the city through the individuals' behaviour, by studying the cognitive maps, orientation and way-finding.

This research showed that people structure in their mind the city as a result of their life memories and experience, briefly, the subjects' images of the city were virtual actors, shops, pleasant or no pleasant objects, which in a certain way made an impact on subjects' perception. The physical environment feature which influenced the learning process was certainly the vividness of the model, Appendix F, section F6, F7 e F8.

It was also a point of interest in this study to compare the behaviour of a person inside the virtual environment and their performance in the real city. There was no contrast observed by the experimenter between subjects' behaviour in the two different worlds. However, there was some evidence mentioned by the subjects according to the differences between both environments; these were related to the vividness and motion factors. Subjects could read the shop names from the other side of Cambridge market while in the virtual environment they had to be much closer to the shops to read their names, in consequence, they had to travel more in the virtual environment.

From the investigation of the degree to which a person can orient and way-finding in the real environment after gaining knowledge in the virtual environment, it was noticed that subjects who experienced the immersive virtual environment presented improved spatial orientation skills, compared to those who experienced a desktop display. Relatively to the way-finding tasks, there was no significant difference noted. This could suggest that subjects should go through another virtual experiment, to consolidate the relationship between objects in space and their position while navigating through the environment.

It was concluded in Chapter 3, in experiment B, that subjects were able to understand the meaning of the objects simply by their geometry. However, the conclusions could not be generalised to the outdoor environment because the urban area required more than the geometry which has to be accompanied by the realism of texture, as shown in experiment C. Moreover, as the was to have the model similar to the real environment, it was necessary to understand what were the relevant features a person notices in a building facade. The building recognition experiments showed that people, in general, do pay attention to shops. This was reinforced by subjects' comments, who mentioned that they recognised specific shops, such as the cake shop, Marks and Spencers, Barclays bank, as described in the pilot experiment in chapter 5, section 5.5.1 and in the main experiment, Appendix F, section F.7.

From the preliminary study of acclimatisation in Cambridge, experiment C, which was mainly an investigation of environmental features and their role in navigation and way-finding, it was hypothesised that a set of navigation aid tools such as a birds-eye view, a map and a compass, would be crucial to help subjects keeping a sense of orientation and enhance way-finding skills while learning the virtual environment. However, these navigation aid tools were not often used by the subjects in the experiments. In relation to the birds-eye view some subjects mentioned the fear of being so high without their virtual feet on solid ground.

While navigating in the immersive environment, subjects had greater opportunity to notice features in a more natural way, compared to subjects who experienced non-

immersive environments. This was noticed in the second virtual visit of the main experiment, where subjects accomplished tasks more successfully than those using other display types. Those using the immersive display were much more successful in the training tasks than those using the desktop display. This would then appear to lead to greater success in the orientation tasks, once in the real environment.
The second virtual visit enabled all subjects to apply their knowledge of the environment previously gained, and to increase their understanding of it. This is in accordance with Evans (1981), "Individuals initially comprehend the relative positions of items in space, but fine tune the exact location of items in space with increasing experience" .

It was interesting to observe that the large 'Cambridge city map' placed on a wall of a building next to the real environment starting position was framed up side down. Four subjects acclimatised by pictures and video who were searching for clues in the environment looked at the map and were more disoriented afterwards. They did not realise that the map was upside down and made a 180 degrees error in their route. This shows that people assume that maps are aligned with the spatial layout [Levine, 1982, 1984].

8.4 Potential Sources of error

Apart from display type, the variables were not controlled. Subjects who experienced Virtual Reality were scientists and all but one were male. This presented an unequal distribution in terms of all the personal variables in general. Subjects volunteered and the study took insufficient account of their hidden agendas, such as, the majority were keen to visit Cambridge but not overly keen to take part in preparation and experiment, while others were looking forward to experience Virtual Reality.

Hence, Appleyard's (1969) study on the differences in environmental behaviour in unfamiliar places between subjects due to gender. Andrews' (1973) study with age related differences in quantifying environmental knowledge, whereas Gittins (1969) brought the differences between artists and scientists to light. Differences in education were mentioned by Appleyard (1970) in influencing the drawings of an unfamiliar city. He suggested that the more educated group were expected to draw the city more objectively, fitting their maps together more coherently, even from limited experience [Bruner, 1957].

Altogether, the distribution by gender, scientist/artist background, age and education should be well-distributed between the different modes of learning.

Subjects nationalities were English, Japanese and Korean, throughout all the media display groups. The non-English subjects had only been in the country for a few months whereas the English subjects, although they had never been to Cambridge were, nonetheless, comfortable in the new surroundings. Clearly the challenge is to know to what extent culture, tradition and lifestyle have on anxiety or confidence when making a visit to an unfamiliar place.

The measurement of subjects' pointing direction was not measured in angles, the variable should have been quantitative rather than qualitative. The data could be collected from the subjects' actual errors in degrees and used in statistical analyses.

8.5 Further work

Further work could be done to clarify how many explorations a person might need to be acclimatised in a new environment, to perform way-finding tasks.

It is essential that there is further study of acclimatisation and behaviour in similar experiments so that each subject could try each of the two active methods of learning about an environment.

It is fundamental to find out the reason why subjects did not commonly use the navigation aid tools in the virtual environments.

It is essential to make a city in a computer model "alive", to compare between static and dynamic virtual environments, and to measure these implications on the acclimatisation process, since the lack of motion was referred by a great number of subjects.

An important feature to include in any future study is sound, and its effects in the acclimatisation process. Agreeable sounds (such as birds) would need to be contrasted with sounds such as traffic. Sensory integration, through environmental interaction contributes to the development of perception and orientation in space [Cabay *et al.*, 1989]. Visual sensation has to be related to sound for effectiveness.

It would also be interesting to study the effects of experiencing the virtual city in a multi-participant experiment. Would the participants enjoy themselves more, in terms of motivation, in visiting an unfamiliar city in a group? What would be the consequences in the acclimatisation process? Naturally, each person could explore the city on a personal basis and call the others' attention to their relevant features. Consequently, such studies would need to look at personal differences and human behaviour in groups, including from a sociology perspective.

Acclimatisation through Virtual Reality has the potential to be appropriated as a treatment for visual spatial agnosia; topographagnosia and environmental agnosia. In these cases the virtual environment would need to be adapted to access people suffering from these conditions. An important change to this model would be to identify which areas act as landmarks, and then to find out how to call the subjects' attention to those landmarks. What type of marks could be effective. One possibility is to use high visibility effects or even flamboyant objects that can only be possible in an unlimited virtual world, such as animated street-lamps. For this proposed work, it is necessary to prove the effectiveness in a specific treatment of one of the above spatial awareness conditions.

At the hardware level, the mode of travelling through the environment should improve to give a sense of freedom from the cables and to leave the hands of the participant free for interaction with the environment. The travelling should be as intuitive as walking.

Appendix A Preliminary study in "indoors" environments

A.1 Overview of the Appendix

This appendix is concerned with two study-cases which took place in two different environments: A building's floor and an office. The questionnaires and subject's comments are presented.

A.2 Experiment with a Building's Floor

A.2.1 Instructions for building walk-through

3D Graphics for City Walk-through

The Virtual Reality (VR) machine uses a head-mounted display (HMD) to show a 3D scene filling your view which will change as you move your head.
The HMD comprises a helmet containing two small television screens, one for each eye. The helmet is connected to the VR machine by a cable. On the back of the helmet there is a nut which tightens or loosens a headband and a switch.
Place the helmet on your head and tighten the nut.
To move through the building use one of the two buttons.

Left buttons	right button
Move forwards	move backwards

You can explore the virtual building as you like for 15 minutes.
You have to stay inside the building.
You can go through open doors.
Do not climb stairs.
You can turn your head and body around normally, but move slowly.

There is a plant placed in one of the rooms. FIND IT. It is on the floor, but could be anywhere, even behind a door.
When told that the time is up, please return to your starting point, in the virtual city, before taking off the helmet.
Some people do experience a degree of nausea while using the virtual reality system. If at any

time you do not want to continue please say so.

A.2.2 Instructions to perform in the real building

This virtual building which you have been is a model of a real building.
You are going to the real building now.
There was no furniture in the virtual building but you will find furniture in the real one.

You are going to two different places in order to make a choice about which one is the correct.
You can have a look around, but you are not allowed to explore the building.
Please tell us your decision only after you have seen both places.
You will have 3 minutes to examine each place.

1. Which floor was the correct one?
First ___ Second ___

2. Go to look for the plant that has been placed in the building.
It is in the same place as you saw in the virtual building.

3. There is now a short questionnaire for you to complete.

Thank you for your collaboration with us in this study.
Please do not speak with anyone about this for 48 hours, in case you happen to speak to someone else who will be taking part.

A.2.3 Questionnaire

The following questions relate to your experiences.

1 When you walked through the real building corridors and rooms, to what extent did you have the sensation of having been there before? Please circle your answer on the following 1 to 7 scale.

I had the sense of having been there before...	Please tick against your answer
1. not at all...	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5

6. ...	6
7. very much so...	7

2. To what extent was your sense of being in the virtual reality similar to that of being in the real place?

In the virtual reality I had a sense of being in the real place...	Please tick against your answer
1. not at all...	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. very much so...	7

3. To what extent were there times during the experience when the virtual reality became the "reality" for you, and you almost forgot about the "real world" of the laboratory in which the whole experience was really taking place?

There were times during the experience when the virtual reality became more real for me compared to the "real world"...	Please tick against your answer
1. at no time	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. almost all of the time	7

4. When you think back about your experience, do you think of the virtual reality more as images that you saw, or more as somewhere that you visited? Please answer on the following 1 to 7 scale.

The computer generated world seems to me to be more like...	Please tick against your answer
1. Images that I saw	1

2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. somewhere that I visited	7

5. During the time of the experience, which was strongest on the whole, your sense of being in the virtual reality, or of being in the real world of the laboratory?

I had a stronger sense of being in...	Please tick against your answer
1. the real world of the laboratory	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. the virtual reality	7

6. How dizzy, sick or nauseous did you feel resulting from the virtual reality experience, if at all? Please answer on the following 1 to 7 scale.

I felt sick or dizzy or nauseous during or as a result of the experience:	Please tick against your answer
1. not at all	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. very much so	7

7. When you think about the virtual reality, to what extent is the way that you are thinking about this similar way that you are thinking about your visit to the real place?

I think of the virtual reality in a similar way that I'm thinking about my visit to the real place...	Please tick against your answer
1. not at all	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. very much so	7

8. During the course of the virtual reality experience, did you often think to yourself that you were actually just standing in a laboratory with a helmet, or did the virtual reality overwhelm you?

During the virtual reality experience I often thought that I was really standing in the lab with a helmet...	Please tick against your answer
1. most of the time I realised I was in the lab	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. never because the virtual reality overwhelmed me	7

9. What is your job, if any?____________________
   If student, what is your subject of study? ____________________

10. When you were in the real building you had to choose between two alternative sites as being the one corresponding to the virtual reality. List the reasons for your choice. (Continue overleaf if necessary)____________________

Reminder - all answers will be treated entirely confidentially.
Thank you once again for participating in this study, and helping with our research. Please do not discuss this with anyone for 48 hours. This is because the study is continuing, and you may happen to speak to someone who may be taking part.

A.3 Experiment with an office

A.3.1 Questionnaire

The following questions relate to your experiences of the virtual reality

1.How dizzy, sick or nauseous did you feel resulting from the experience, if at all?

Please answer on the following 1 to 7 scale.

I felt sick or dizzy or nauseous during or as a result of the experience...	Please tick against your answer
1. not at all	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. very much so	7

2. Please rate your sense of being there in the place depicted by the virtual reality on the following scale from 1 to 7, where 7 represents your normal experience of being in a place.

In the virtual reality I had the sense of "being there"	Please tick against your answer
1. not at all...	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. very much...	7

3. Did you recognise the place depicted in the virtual reality as corresponding to anywhere real that you know?

1. I did not recognise the place	1
2. I did recognise the place	2

4. The total time that I spent in the virtual reality was about ____ minutes.

5. Gender:

1. Male	1
2. Female	2

6. To what extent were there times during the experience when the virtual reality became the "reality" for you, and you almost forgot about the "real world" of the laboratory in which the whole experience was really taking place?

There were times during the experience when the virtual reality became more real for me compared to the "real world"...	Please tick against your answer
1. at no time	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. almost all of the time	7

7.

My status is as follows:	Please tick against your answer
1. Undergraduate student	1
2. Master student	2
3. PhD student	3
4. Research Assistant / Research Fellow	4
5. Staff member - systems/technical staff	5
6. Academic staff	6
7. Administrative staff	7
8. Other	8

8. When you think back about your experience, do you think of the virtual reality more as images that you saw, or more as somewhere that you visited? Please answer on the following 1 to 7 scale.

The computer generated world seems to me to be more like...	Please tick against your answer
1. Images that I saw	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. somewhere that I visited	7

9. Have you experienced "virtual reality" before? __________Yes/No

10. During the time of the experience, which was strongest on the whole, your sense of being in the virtual reality, or of being in the real world of the laboratory?

I had a stronger sense of being in ...	Please tick against your answer
1. The real world of the laboratory	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. The virtual reality	7

11. To what extent did you experience the virtual hand as "your hand"?

The virtual hand become "my hand"...	Please tick against your answer
1. not at all	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6

7. very much so	7

12. when you think about the virtual reality, to what extent is the way that you are thinking about this in a similar way that you are thinking about the various places that you've been today?

I think of the virtual reality as a place in just the same way as other places that I've been today...	Please tick against your answer
1. not at all	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. very much so	7

13. Are you a regular computer user? ___________Yes/No

14. During the course of the virtual reality experience, did you often think to yourself that you were actually just standing in an office wearing a helmet, or did the virtual reality overwhelm you?

During the virtual reality experience I often thought that I was really standing in the lab wearing a helmet...	Please tick against your answer
1. Most of the time I realised I was in the lab	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. never because the virtual reality overwhelmed me	7

15. Further Comments

Please write down any further comments that you wish to make about your experience.

Reminder - all answers will be treated entirely confidentially. Thank you once again for participating in this study, and helping with our research. Please do not discuss this with anyone for 48 hours. This is because the study is continuing, and you may happen to speak to someone who may be taking part.

A.3.2 Subjects comments

From experimental group:

1. I hit the hall with my head and the cable of the headset kept interfering. Otherwise, I was pretty impressed!

2. I felt sick when I had to turn around to relocate myself.

3. I felt taller than I feel in real life. Once or twice I walked into a real wall and touched it with my hand, this seemed strange, but reminded me that I really was in the physical laboratory, not in the VR one.

4. I realised fairly quickly that I could go through things. The 3D mouse occasionally touched the laboratory wall which remind me of reality.

From control group:

1. I went out the virtual room and when I knew where I was; going in the room I was completely absorbed in the virtual reality. When I was lost, I got frustrated and remembered what all the situation was not real.

2. Really I enjoyed it - graphics a lit bit crap.

3. It was a great experience!

4. I felt very sick and nausea at first but my condition improved greatly when I got used to the VR equipment.

5. Some times I found very difficulty to control the hand. Also it was quite disorienting when I was close to walls.

Appendix B Preliminary Experiment in Cambridge

B.1 Overview of the Appendix

This appendix is a collection of instuction sheets, questionnaires and subjects' drawings of their environmental "cognitive representations". It is also presented the detailed map of the area.

B.2 Detailed map of Cambridge

B.3 Invitation

Virtual Reality Research

Please help

We offer you a chance to experience Virtual Reality in the computer science department at QMW and visit Cambridge.

Your help is really appreciate.

The whole experience will be divided into two sessions; the first will take about 45 minutes.

Hour:________________ Date:________________

The real visit will take place in Cambridge.

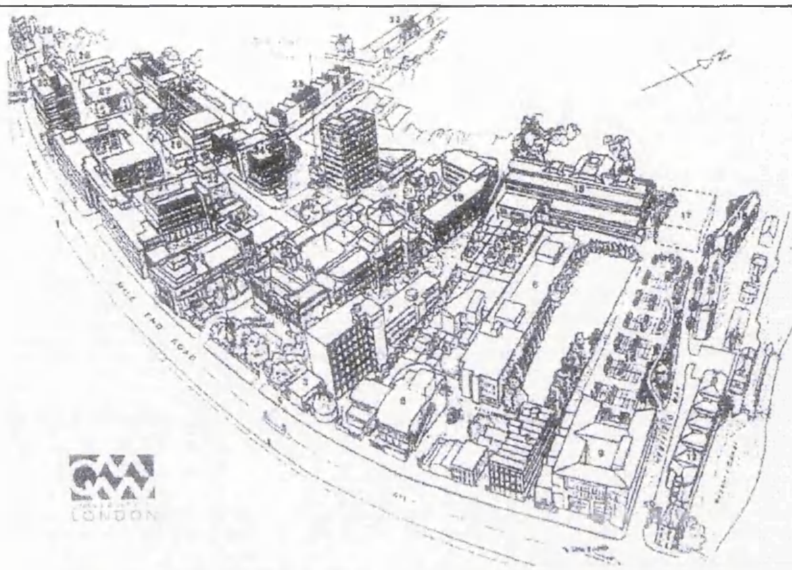
Departure Hour:________________ Date:________________

B.4 Instructions

B.4.1 Measuring way-finding skills

Look carefully to the map of QMW campus, for one minute.

Collect a letter addressed to you, from the place marked 21, and then return to this point. The task is timed, however, there is no need to run, walk normally.



B.4.2 Acclimatisation by pictures

There are about 100 pictures, maps and books.

The purpose of this task is to find 3 places:

1. Post Box
2. King's College
3. McDonalds

You have 20 minutes to look at them.

B.4.3 Acclimatisation by video

You are going to watch a film of Cambridge city centre.

The purpose of this task is to find 3 places:

1. Post Box
2. King's College
3. McDonalds

The video takes approximately 15 minutes.

B.4.4 Acclimatisation by desktop

3D Graphics for City Walk-through

The Virtual Reality machine uses a head-mounted display to show a 3D scene filling your view which will change as you move your head.

To look around in the VR city you can turn the helmet. For comfort the helmet will be placed on a swivel chair. You can also tilt or lift up the helmet to look up and down around or around.

You are going to hold a hand-device in your right hand.

To move you use one of the two buttons of the device.

Left buttons	right button
Move forwards	move backwards

You can explore the virtual city as you like for 20 minutes.

Move slowly.

There is a letter on the King's College porter's hand. Try to find the letter, and try to post it in the post box, also find McDonalds.

When told that the time is up, please return to your starting point, in the virtual city, before taking off the helmet.

If at any time you do not want to continue please say so.

B.4.5 Acclimatisation by VR

3D Graphics for City Walk-through

The Virtual Reality (VR) machine uses a head-mounted display (HMD) to show a 3D scene filling your view which will change as you move your head.

The HMD comprises a helmet containing two small television screens, one for each eye. The helmet is connected to the VR machine by a cable. On the back of the helmet there is a nut which tightens or loosens a headband and a switch.

Place the helmet on your head and tighten the nut.

To look around in the VR city you can turn your head and body as usual. You can move through the building by use one of the two buttons.

Left buttons	right button
Move forwards	move backwards

You can explore the virtual city as you like for 20 minutes.
You can turn your head and body around normally, but move slowly.
There is a letter on the King's College porter's hand. Try to find the letter, and try to post it in the post box, also find McDonalds.
When told that the time is up, please return to your starting point, in the virtual city, before taking off the helmet.
Some people do experience a degree of nausea while using the virtual reality system. If at any time you do not want to continue please say so.

B.4.6 Representations of Environmental Knowledge

Do a sketch map of Cambridge.
Annotate the map as best you can.

B.5 Questionnaires

B.5.1 Questionnaire after the virtual visit

1 To what extent were there times while studying the representation of Cambridge when you almost forgot about the "real world" of the room in which you were doing this?

There were times during the experience when the virtual reality became more real for me compared with the "real world"...	Please tick against your answer
1. at no time	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5

6. ...	6
7. almost all of the time	7

2. To what extent did you have a sense of "being" in Cambridge?

I had a sense of being in Cambridge ...	Please tick against your answer
1. not at all	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. very much so	7

3. To what extent can you now imagine Cambridge as somewhere that you visited? Please answer on the following 1 to 7 scale.

I can imagine Cambridge as somewhere that I've visited...	Please tick against your answer
1. not at all	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. very much so	7

Reminder - all answers will be treated entirely confidentially. Thank you once again for participating in this study, and helping with our research. Please do not discuss this with anyone for 48 hours. This is because the study is continuing, and you may happen to speak to someone who may be taking part.

B.5.2 Questionnaire After the real visit

The following questionnaire relate to your experiences

1. When you walked through Cambridge, to what extent did you have the sensation of having been there before? Please circle your answer on the following 1 to 7 scale.

I had the sense of having been there before...	Please tick against your answer
1. not at all	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. very much so	7

2. Estimate the degree of ease in finding your way around Cambridge

To find my way around Cambridge was...	Please tick against your answer
1. very difficult	1
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. very easy	7

3. To what extent did the learning exercise (the virtual visit) help you in this real visit to find your way around?

The virtual visit	Please tick against your answer
1. did not help at all	1

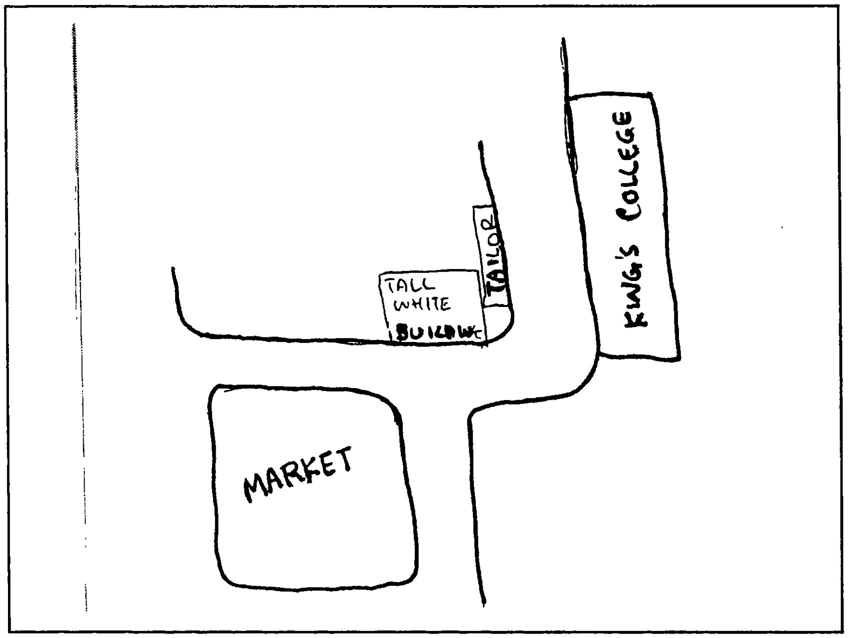
2. ...	2
3. ...	3
4. ...	4
5. ...	5
6. ...	6
7. helped very much	7

Reminder - all answers will be treated entirely confidentially. Thank you once again for participating in this study, and helping with our research. Please do not discuss this with anyone for 48 hours. This is because the study is continuing, and you may happen to speak to someone who may be taking part.

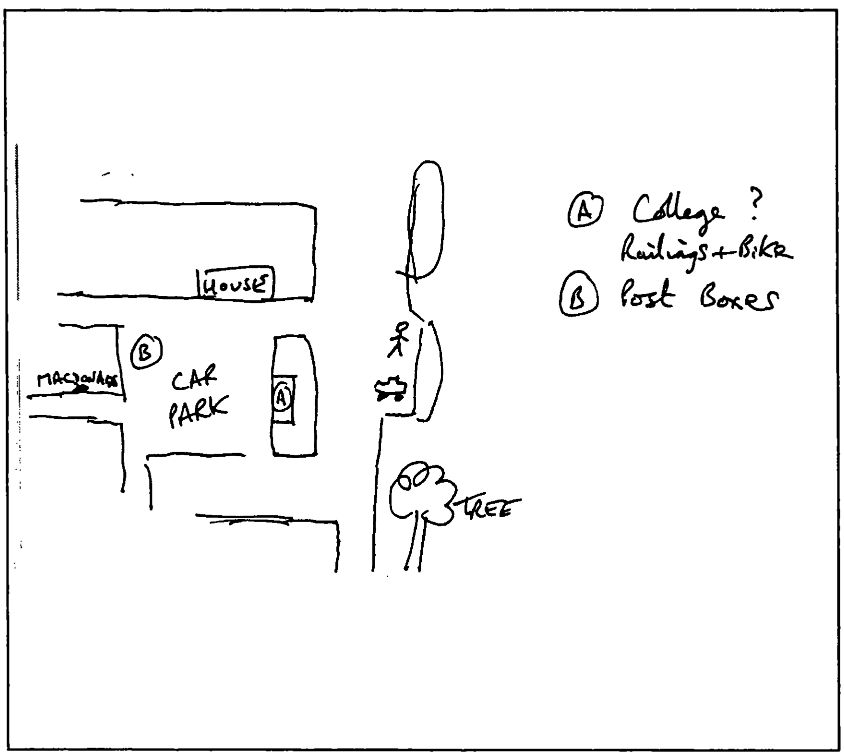
B.6 Subjects' drawings

Pictures

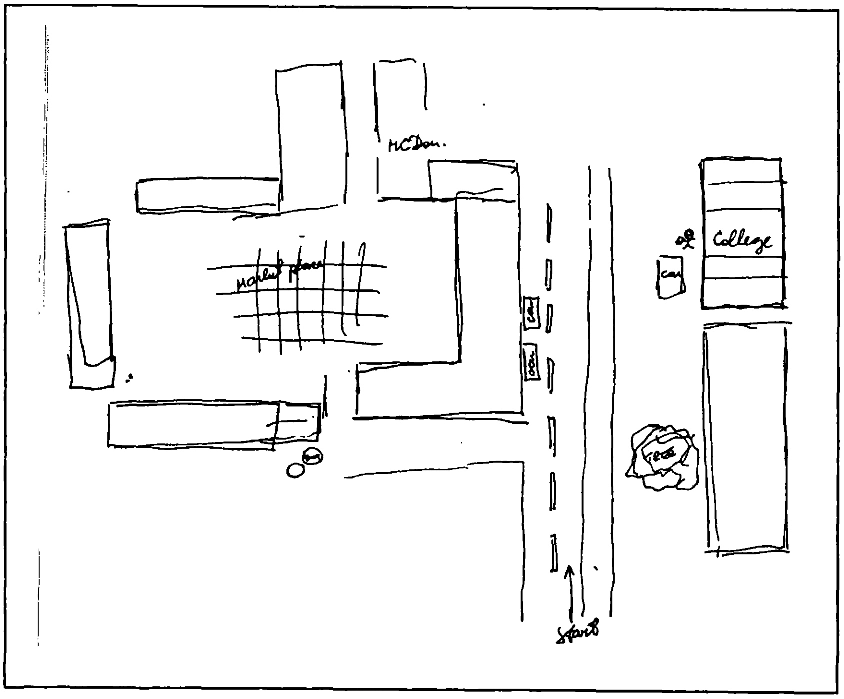
Video



Desktop



VR



Appendix C Preliminary Study in Recognition of Building's facade

C.1 Overview of the Appendix

This appendix is related to the experiments of building's facade recognition. The representation of the pictures presented to the subjects, the questionnaires and their comment are included.

C.2 Questionnaire

Thank you for taking the time to participate in this study. Your help is greatly appreciated.

1. There are 10 pictures. On the back of each one there is a number.
   You have one minute to look at the pictures.
   Please indicate below the number(s) of the picture(s) you think was the building you saw before. ______________________

2. What were the factors which influenced your choice?
   Colour ______________________
   Number of windows ______________________
   Structure of the building ______________________
   Details of the whole building ______________________
   Details of parts (please state which parts) ______________
   Others, please state ______________________

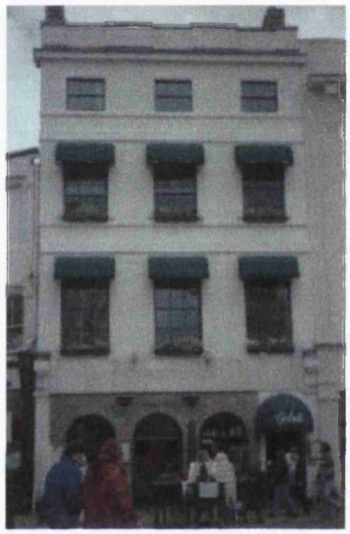
3. Please include any comments you would like to make about the experiment.
   ____
   ____

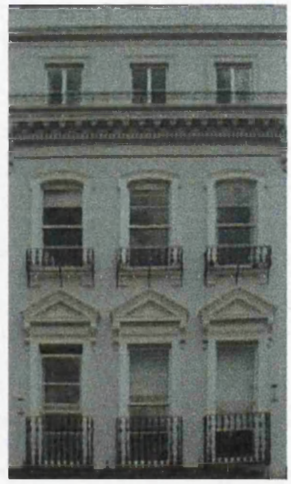
C.3 Subject's comments

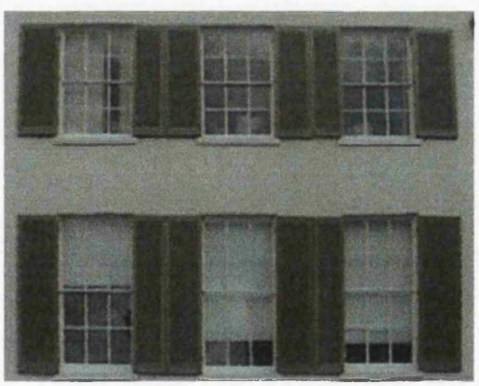
1. Resolution was unclear, I saw only the windows and not too much of the building.
2. I realised it was a shop front, but not which one.
3. I remember very well the building's shape.
4. The building I saw is not in the photographs.
5. When I had the headset on I was not making a conscious effort to memorise the building in advance because I was not told to do so.
6. Actually I did not concentrate enough in the building, too amazed by VR system.
7. Difficult to match up with the real photos because there was no context i.e. surrounding buildings.
8. The detailed part of the building I paid more attention was the bottom.
9. I remember a pink building. I have no memory of the roof.
10. I looked all the time to the floor texture!
11. I just remember that I saw a common building, but honestly I didn't pay attention to it.
12. If I was told in advanced I could count the windows.
13. I didn't look up.
14. I really felt I was there, I didn't realised that I should memorise the building.
15. I had an idea of the building in general, shape, windows, shop, but I can not tell how many windows or floors.
16. The building seemed so real.
17. The texture mapping was blur.

C.4 Pictures

The following pictures were presented in the experiment of building recognition.







Appendix D Environmental Learning by Pictures

D.1 Overview of the Appendix

This appendix presents the map and the pictures used in the passive mode of learning the environment, in particular to the pictures display type.

D.2 Map links

A map was first presented to the subjects, who by clicking the button of the mouse on one of the streets could visualise the respective pictures.

Figure D.1 presents the map of Cambridge city centre with the respective links.

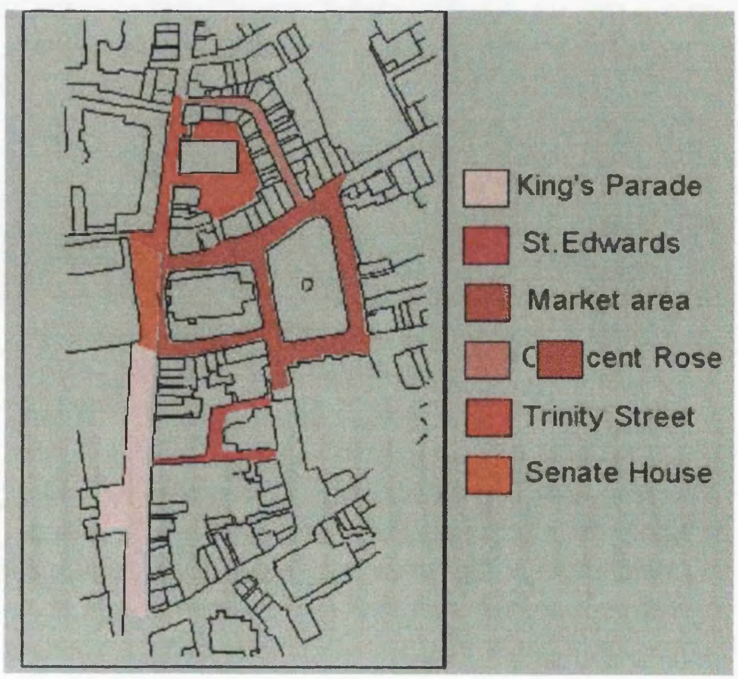


Figure D.1 Map of Cambridge city centre and the respective links

D.3 Pictures of King's Parade

Figure D.2 presents the pictures of King's Parade.

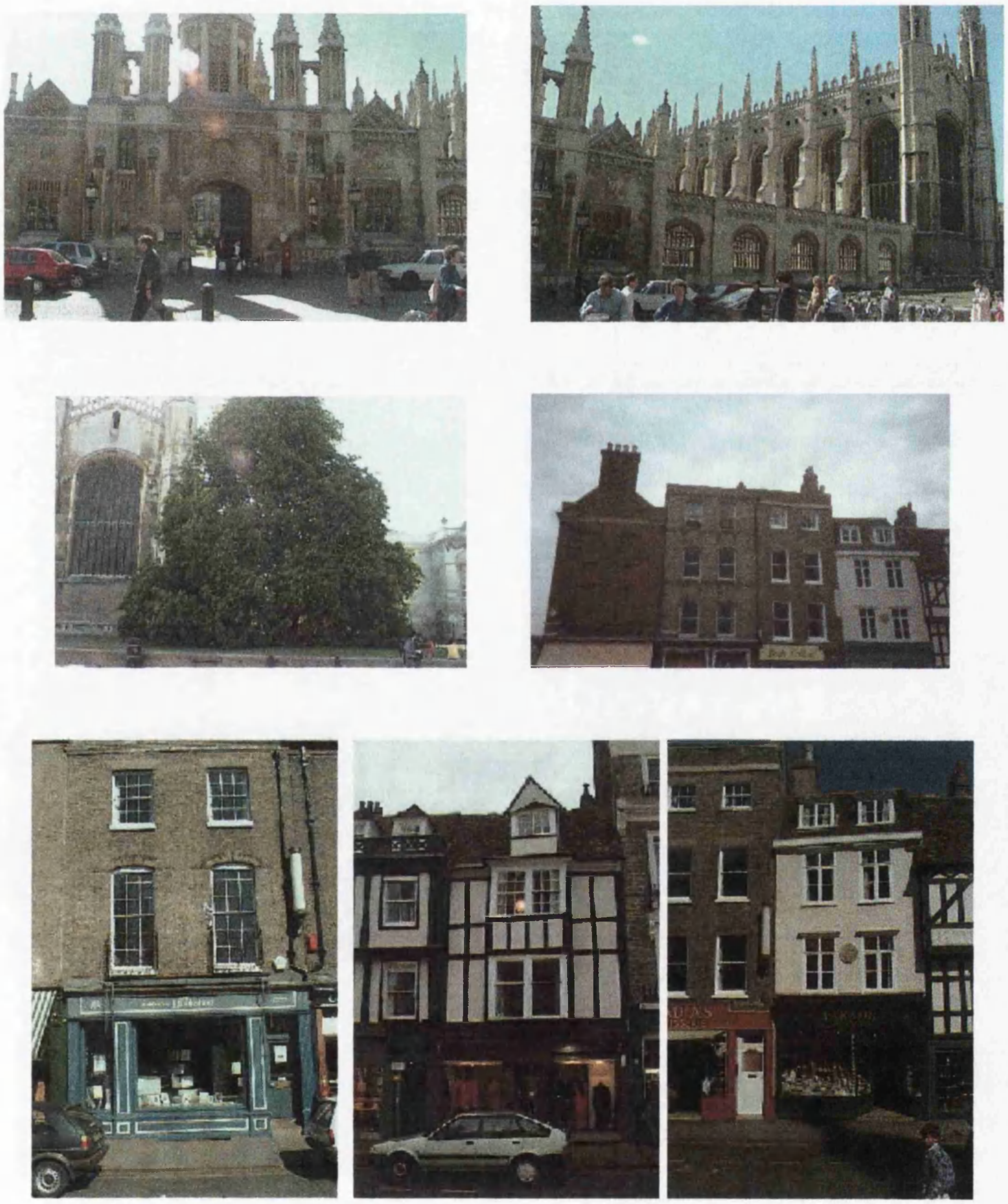


Figure D.2 Pictures of King's Parade

D.4 Pictures of St. Edward passage

Figures D.3 presents the pictures of St. Edward's passage

Figure D.3 Pictures of St. Edward's passage

D.5 Pictures of the Market area

Figure D.6 presents the pictures of the market area.


AUNTIES TEA SHOP

Figure D.4 Pictures of the Market Area

D.6 Pictures of Crescent Rose

Figure D.5 Pictures of Crescent Rose

D.7 Pictures of Trinity street

Figure D.6 presents the pictures of Trinity street.

Figure D.6 Pictures of Trinity

D.8 Pictures of Senate House

Pictures D.7 presents the Senate House.

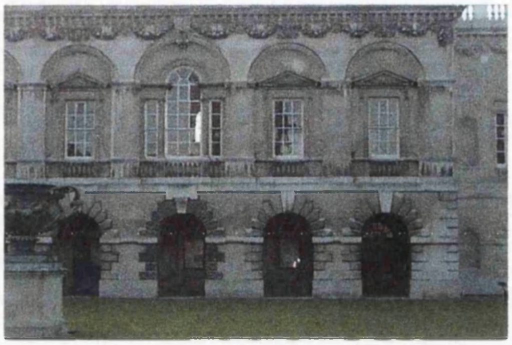


Figure D.7 Pictures of the Senate House

Appendix E Pilot Experiment

E.1 Overview of the Appendix

This appendix is related to the pilot experiment. Instruction sheets, questionnaires, subject's cognitive representations, network maps and comments are presented.

E.2 Instructions

3D GRAPHICS FOR CITY WALKTHROUGH

INSTRUCTIONS

Thank you for taking the time to participate in this study. Your help is greatly appreciated.

The Virtual Reality (VR) machine uses a head-mounted display (HMD) to show a three-dimensional scene which will change as you move the head.
The HMD comprises a helmet containing two small television screens, one for each eye. The helmet is connected to the VR machine by a cable. On the back of the helmet there is a nut which tightens or loosens a headband and a switch.

Place the helmet on your head and tighten the nut.

You are going to hold a hand-held device in your right hand.

To look around in the Virtual Environment(VE), you can turn your whole body around, bend down or reach up. You can move through the VE by using one of two buttons.

Left button: Move Forwards

Right button: Move Backwards

If at any time you do not want to continue, please say so immediately.

Since this study is running throughout this week, in the interest of not prejudicing the research, please do not discuss this with others until the end of the week.

Virtual Cambridge Instructions

There are some help tools to help you with the tasks:

1. If you touch the top of your head, a map will appear. To make the map disappear touch the same place.

2. If you extend your arm straight above your head, you can have a bird-eye view. To return to the level position, perform in the same way.

3. If you extend your arm straight in front of your head, an arrow indicating the starting position will appear. To make the arrow to disappear perform in the same way.

3D GRAPHICS FOR CITY WALKTHROUGH

INSTRUCTIONS

Thank you for taking the time to participate in this study. Your help is greatly appreciated.

There are some help tools to help you with the tasks:

1. If you press key "4", a map will appear. To make the map disappear press the same key.

2. If you press key "2" , you can have a birds-eye view. To return to the level position, perform in the same way.

3 If you press key "3", an arrow indicating the starting position will appear. To make the arrow to disappear perform in the same way.

Since this study is running throughout this week, in the interest of not prejudicing the research, please do not discuss this with others until the end of the week.

E.3 Questionnaire

The answers to all questionnaires are treated in the strictest confidence

1 Please circle your answer on the following 1 to 2 scale.

Gender	Please tick against your answer
1. male	1
2. female	2

2. How old are you ? ______________

3. Please circle your answer on the following 1 to 5 scale

Educational background	Please tick against your answer
1. Ph.D.	1
2. Master degree	2
3. B. Sc.	3
4. A levels	4
5.Other______________	5

4. Would you consider your background and training to human scientific or in the arts and humanities? ________________________

5. Please circle your answer on the following 1 to 5 scale.

Times experienced Virtual Reality before	Please tick against your answer
1. not at all	1
2. once	2
3. twice	3
4. 3 - 5	4
5. more than 5	5

6. Please circle your answer on the following 1 to 5 scale

Do you feel lost or disoriented when you go to an unfamiliar environment (for example, travelling to a city for the first time).	Please tick against your answer
1. not at all	1
2. only occasionally	2
3. sometime	3
4. almost always	4
5. all the time	5

E.4 Questionnaire after the virtual visit

1 To what extent while you were in the 'virtual' Cambridge were there times you almost forgot about the "real world" of the room in which you were doing this?

There were times virtual reality became more real for me compared with the "real world"	Please tick against your answer
1. at no time	1
2. only briefly	2
3. ...	3
4. most of the time	4
5. all of the time	5

2. To what extent did you have a sense of "being" in Cambridge?

I had a sense of being in Cambridge ...	Please tick against your answer
1. at no time	1
2. only briefly	2
3. ...	3
4. most of the time	4
5. all of the time	5

3. To what extent can you now imagine Cambridge as somewhere that you visited?

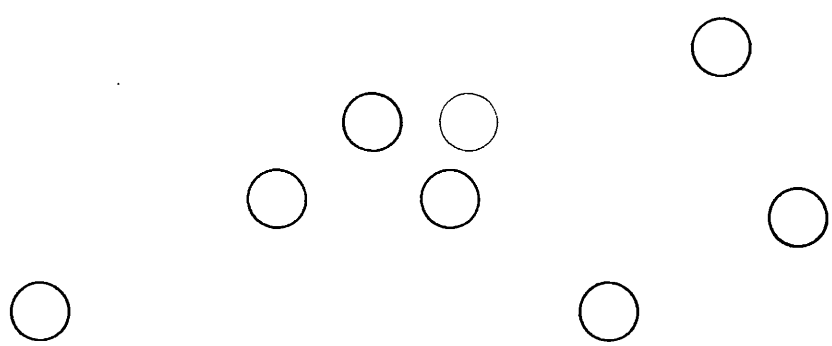
I can imagine Cambridge as somewhere that I've visited...	Please tick against your answer
1. not at all	1
2. only vaguely	2
3. ...	3
4. most frequently	4
5. very much so	5

Comments:

Describe briefly in words how 'realistic' the virtual Cambridge seemed to you and how difficult the tasks were.

E.5 Network Map

Please place the numbers correspondent to the locations written above inside the nodes.



1. Market Place
2. Church of St. Michael
3. McDonalds
4. Church of St. Edward
5. King's College
6. Senate House
7. Church of St. Mary
8. Starting Position

E.6 Questionnaire after the real visit

1. When you walked through Cambridge, to what extent did you have the sensation of being familiar with the environment? Please circle your answer on the following 1 to 5 scale.

I had the sense of being familiar with the environment	Please tick against your answer
1. not at all	1
2. only on a few occasions	2
3. …	3
4. on many occasions	4
5. very much so	5

2. Estimate the degree of ease in finding your way around Cambridge

To find my way around Cambridge was...	Please tick against your answer
1. very difficult	1
2. easy	2
3. neither easy nor difficult	3
4. difficult	4
5. very easy	5

3. To what extent did the learning exercise (the virtual visit) help you in this real visit to find your way around?

The virtual visit	Please tick against your answer
1. did not help at all	1
2. helped a little bit	2
3. neither helped nor didn't help	3
4. helped sometimes	4
5. helped very much	5

Comments:

Please state briefly how you would compare your visit to the virtual Cambridge with the visit to the real Cambridge.____

____

E.7 Subject's cognitive expressions about Cambridge

Subjects acclimatised by pictures:

1. **Market Place:**

The stalls in the market + Flower's stall
Main street
Midland Bank
Old houses

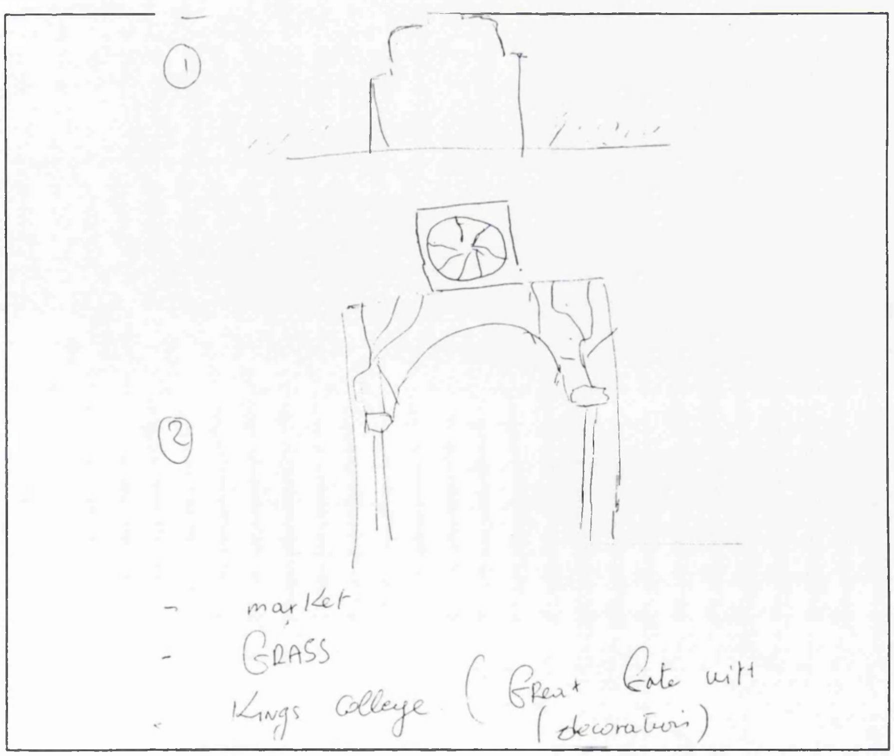
Kings Parade

Main Castle
People cycling
Small monument

Trinity street

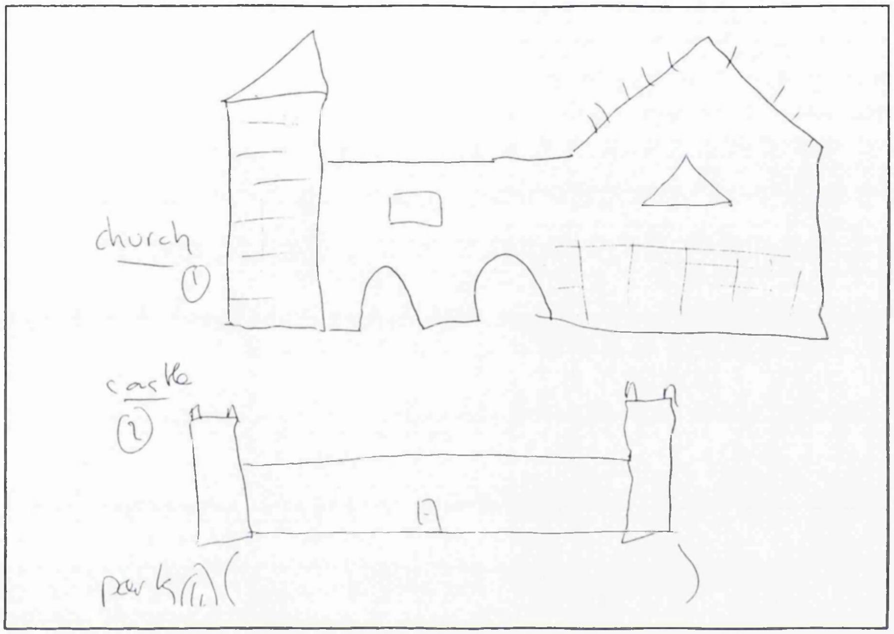
The church
Building Society

2.



Subjects acclimatised by video:

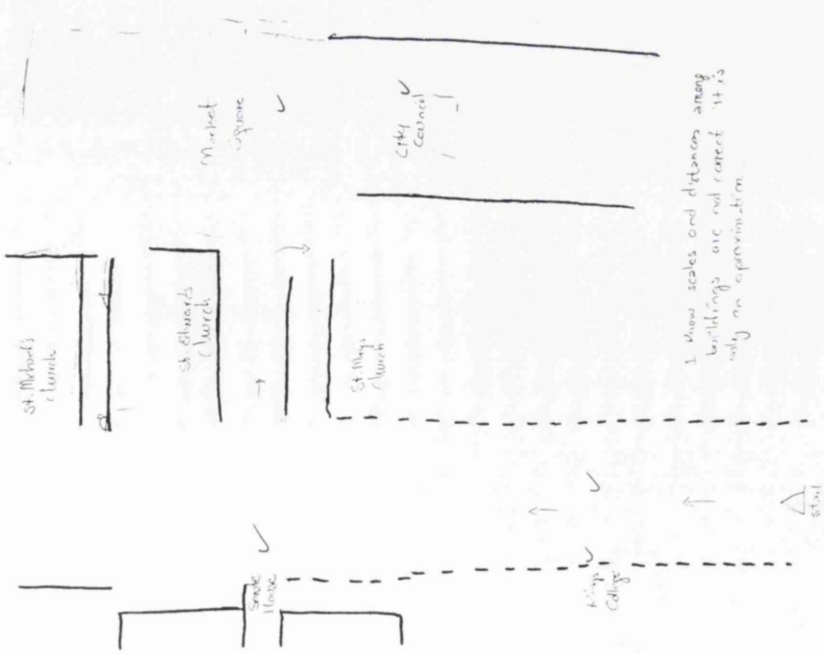
1.



2. Before watching the video I thought that the Colleges, were far from the market area, now I realised they actually are in the city centre.

Subjects acclimatised by desktop:

2.



Subjects acclimatised by VR:

1.

2. I am not good with locations and maps. So, for this reason it would take several "virtual" visits before I would be able to fairly find my way around. Because of this, I wish to describe my impressions about the place.

Cambridge is an old city, with a number of shops. It has a really old church with 2 park benches. Somewhere I saw: Hamburger van - Jewellery store - Marks & Spencer shop - Patisserie, McDonalds - Empty market stalls - Sports shop - Barclays bank - Bradford & Bingley Society.

E.8 Subject's comments

E.8.1 Virtual visit

Subjects acclimatised by desktop:

1. I found it realistic in that I could imagine walking in the city centre.

2. Because of very good graphics and texture mapping the virtual world was very much realistic. I have an image of the city in my mind.

Subjects acclimatised by virtual reality:

1. Everything seems so realistic; the buildings, the people, the shops...

2. Virtual Cambridge was visually realistic. It gave me an overall view of what to expect if I were to visit the city.

E.8.2 Real visit

Subjects acclimatised by pictures:

1. Something live is always different from static pictures. In the real city you are free to explore it.
2. Apart than recognising some pictures, real Cambridge was different.

Subjects acclimatised by video:

1. No comparison, the best way to be acclimatised with a city is to be there.

Subjects acclimatised by desktop:

1. The virtual visit prepared me in a general way, i.e. I would know how to make my way around.
2. I was familiar with the city. Unfortunately, I didn't virtual visited the location 3. Those places which had high saturation colours like roof stalls, phone boxes, post-boxes and ice-cream vendor were easy to remember and found.

Subjects acclimatised by virtual reality:

1. Both cities were the same, but of course Virtual Cambridge missed the traffic.
2. It made the place seem familiar. I did not realised that the virtual visit was for finding one's way around. However, when I arrived at some points I recognised the place. Overall I found the model very useful.

Appendix F Main Experiment

F.1 Overview of the Appendix

This appendix is related to the main experiment. The majority of the questionnaires used in the main study were presented in the previous appendix E; the pilot experiments. However, some of new instructions and questions were introduced in this appendix. This appendix contains also some comments made by the subjects, network maps and cognitive representations after the first and the second virtual visit, as after the real visit.

F.2 Invitation

Invitation to participate

You are invited to experience virtual reality in the Computer Science department at UCL and a free trip to Cambridge, provided that you have never been to Cambridge before.
The whole experience will be divided into three sessions; the first will take about 45 minutes at UCL in London, the second will take about 30 minutes and the third will take place in Cambridge, in the following day.

1st day: **Virtual experience**
Location: Computer Science department- room 127-1st floor
Pearson building - UCL
Date: __/__/1997 Hour: ______

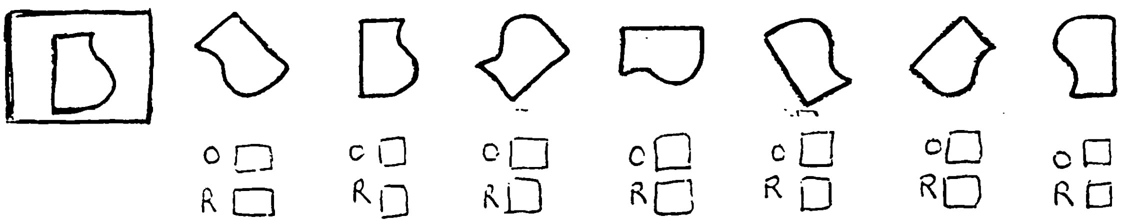
2nd day: **Virtual experience**
Location: Computer Science department- room 127-1st floor
Pearson building - UCL
Date: __/__/1997 Hour: ______

3rd day: Virtual experience Date: __/__/1997

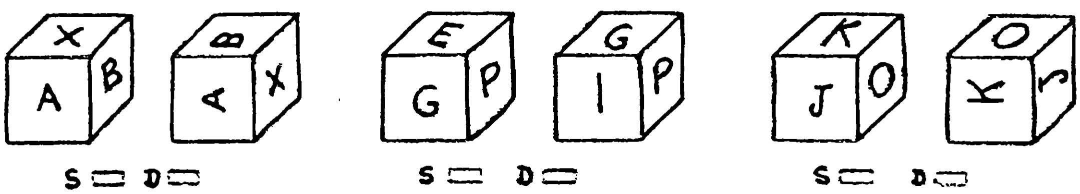
Location:	**Time**
UCL -main entrance	9:30
Train station -King X- Platform 9	10:00
Train Departure	10:15

F.3 Spatial Ability test

1. Please indicate whether the card has been returned over or rotated



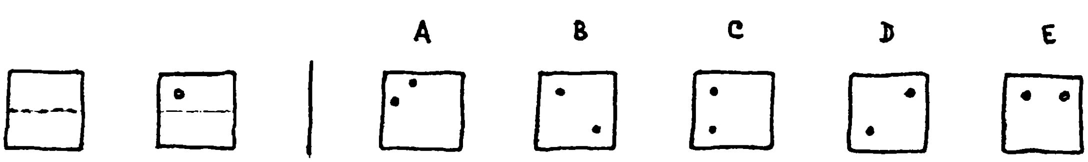
2. Each item presents two drawings of a cube. Assuming no cube can have two faces alike, please indicate which items present drawings that can be of the same cube and which present drawings that cannot be of the same cube.



3. For each item successive drawings illustrate two or three folds made in a square sheet of paper.

The final drawing of the folded paper shows were a hole is punched in it.

Please select one of five drawings to show how the punched sheet would appear when fully reopened.



F.4 Instructions

Second experiment
You have 20 minutes to accomplish two fiddling tasks.
1. Please find a bicycle which was left in the middle of a street.
2. Go to the starting position.
3. From the starting position go to McDonalds.

F.5 Salient objects in virtual Cambridge

These are the responses to 'State the objects which you paid more attention, and describe the characteristics which made them important".

Subjects acclimatised by desktop:

1. The virtual people, their bright colours made them stand out. The ice-cream man in particular stroke my attention, in both experiments I wished to have a real ice cream. The Barclays bank stood out for several reasons, I'm not too sure if it was it's location (corner) or something related to their visual appearance. The market place because of its colours. Mark & Spencer.

2. I paid attention to the shops, the phone boxes and post-boxes were just great. The cafes were very attractive and real, as the shops. I remember shops familiar to me like Mark & Spencer, McDonalds, Barclays bank (my bank), Sony, Kodak, Gap.

3. The people and their clothes, the sun shades in the outside café, the ice-cream man.

4. The door in the trinity street was extremely real, the shops around the market were giving the illusion that everything was just real, the Sony shop, the phone boxes.

5. St Michael church, St. Mary church - chairs and sun shades in the street café - Telephone boxes - jewellery - green vase monument in front of Senate house - hot potatoes van- bicycle - ice-cream man - Barclays bank - Midland bank - Sony shop - people.

6. Market place - Mark & Spencer - McDonalds - bicycle - people with green trousers - King's College - city council - Senate House - grass and footpaths.

7. The market stalls stood out because it was a really pleasant contrast. All the churches because I'm Christian. A lot of shops and banks, I looked to every shop window, they were really clear once you were near.

8. The Sony shop because I have a Sony Walkman. The food shops because I was hungry. In the second visit I really paid more attention to all sort of details.

9. The bicycle and McDonalds because I was looking for them. I have a personal general interest in churches, I paid great attention to the 4 of them.

10. I always read everything while I'm walking in a city, I found plenty things to read in these virtual visits, shops and street names, I found particular interesting the people standing out with the names of the main buildings.

Subjects acclimatised by virtual reality:

1. The car, people, bicycles, shop fronts. The bright colour objects in the streets. The shops fronts stand out because all of the shops are well textured.

2. The large buildings. The texture made them seen like old buildings, which kept my attention. A statue in front of the senate house, because of its shape. Some shop windows, the people especially the ones with green trousers.

3. Barclays bank, I really don't know why but what I can really remember are the Barclays building I saw.- a man selling ice-cream - The travel agency because it looks real- the market place because it's big and it is in the middle of everything - Marks & Spencer because it's very well emulated.

4. The shops' appearance was very realistic - the market with very attractive and colourful stalls - In general most of the outside look of the buildings were very realistic and attracted me looking at. - The texture of the pavement had a nice appearance.- People in the street because the realism of the cloths, very distinctive.

5. The car because it was just one that I had, the trees, the people, the market stall's, all objects with pure attractive graphics, nice colours, textures and detail, i.e. the lady's bag, the man's hat, the ice cream vendor. However, the buildings' fronts give a more realistic impression.

6. The street names and shop labels I read all, I found very important the task to look for people with green trousers and found the Buildings names. I paid attention to all the churches. One door looked quite inviting, especially the one left at the start of Trinity street.

7. As a computer interested I paid great attention to graphics part of the environment. The details of the bicycle, the post-box, the ice-cream man, all were so realistic that I was expecting the people start moving at any time.

8. The Senate House because it looked beautiful, the green car, the market place, it was very much interesting walking under the market stalls. - Midland bank, Kings College very beautiful. I also remember an enormous amount of shops, specially the well known ones like Mark Spencer, McDonalds...The shop fronts were so realistic, they were looking very inviting.

9. The market, very beautiful, streets and shops fronts.

10. I saw a wooded open door which impressed me because of its elegance, but I can not remember were it was. In the second visit After the first visit I didn't even paid attention to the market, I was surprised how I didn't realise it, the second visit is like a consolidation of vague ideas, I found two more streets and I paid attention to the texture of the floor, the shops names, because I was looking for McDonalds.

F.6 Subject's internal image about Cambridge

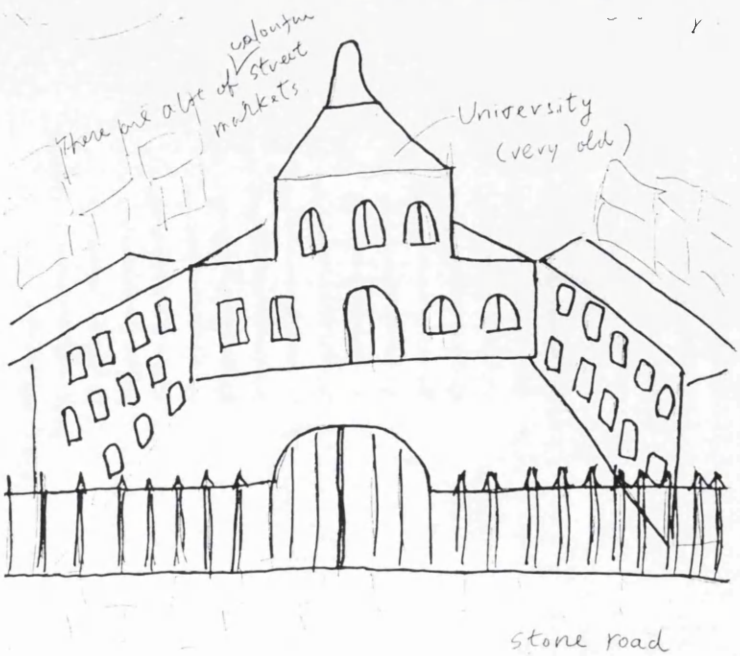
Subjects acclimatised by pictures:

1. Cambridge is a very famous university place, because of it's beauty.

Subjects acclimatised by video:

1. A small town - many splendid churches - beautiful coloured areas - few people not cloudy - not hot or humid -classical architectures - beautiful - grass and trees.

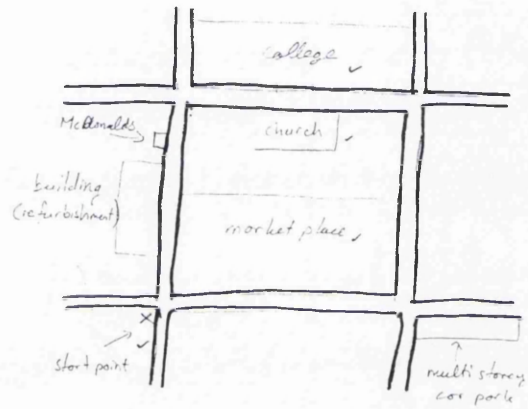
2.



3. It is very traditional and beautiful city especially the decoration of building is very sensitive, the market in the middle is disturbing that harmony. Most of the buildings are very high. It is very ironic to have McDonalds in a traditional building.

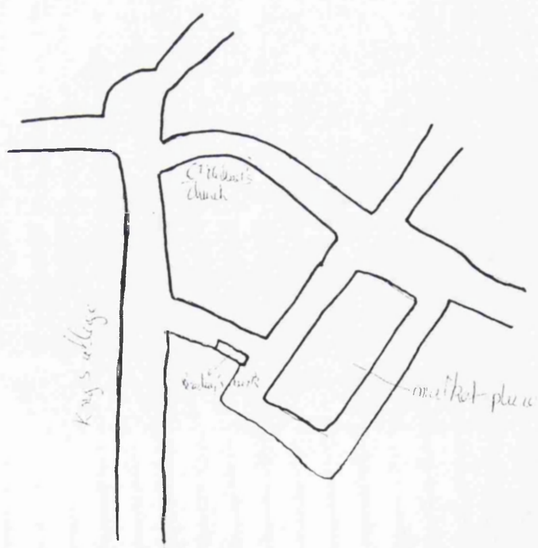
4. Lots of bicycles - Big church - old buildings with new buildings - market street and McDonalds.

5.



Subjects acclimatised by desktop:

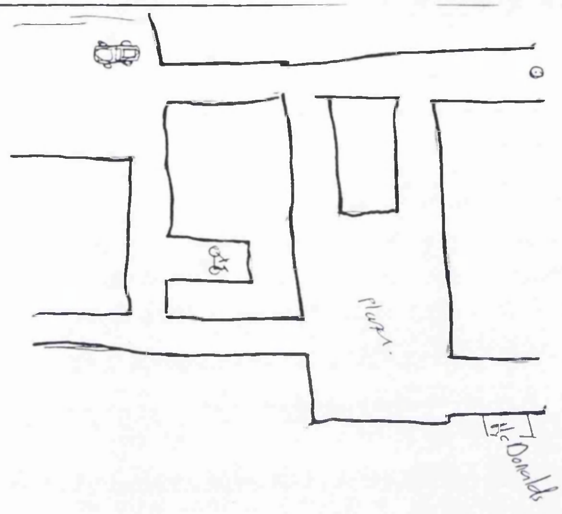
1.



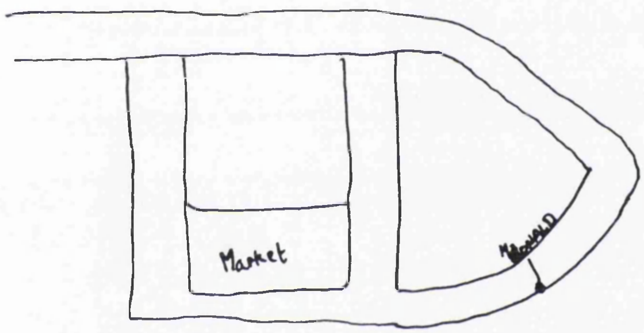
2. (1st experiment) Cambridge has a big College: Kings College, Senate House and several churches, shops, Barclays. It is an old city with green places.

(2nd experiment) There is a open market and 3 churches.

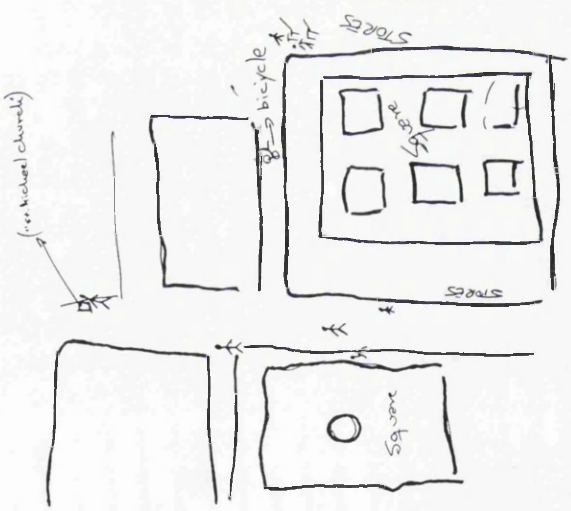
3.



4.



5.

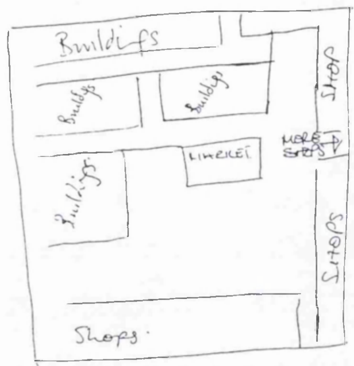


6. (1st experiment) It is an old city with old buildings, churches and colleges, a warm place.

(2nd experiment) My internal image turned to a more commercial one, since I look at the shops labels to find McDonalds.

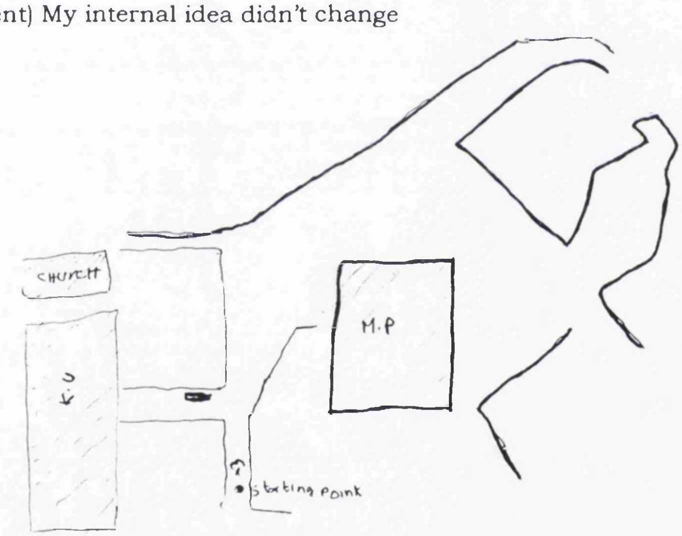
7. (1st experiment) Banks, post office, church, banks, Mark Spencer, Threes, people, jewellery, market place, Colleges

(2nd experiment)



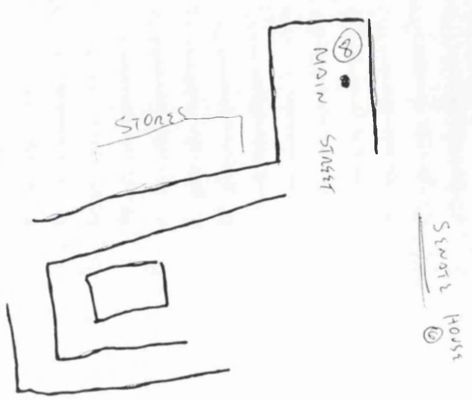
8. (1st experiment) It's a nice city with Churches, Senate House, King's College, market.

(2nd experiment) My internal idea didn't change



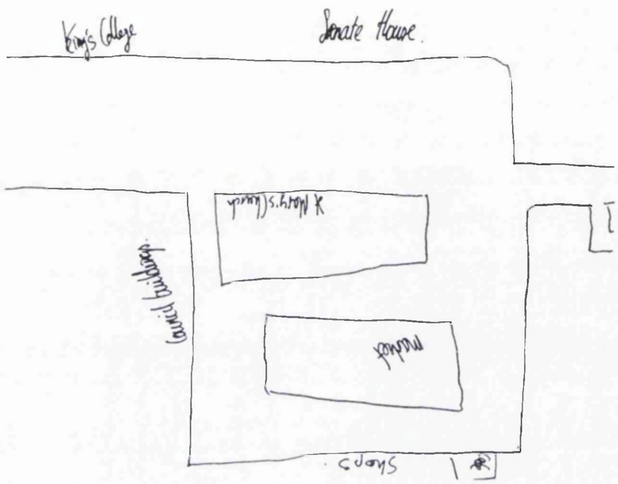
9. (1st experiment) Many shops.

(2nd experiment) It is a very interesting place because of the old new contrast.



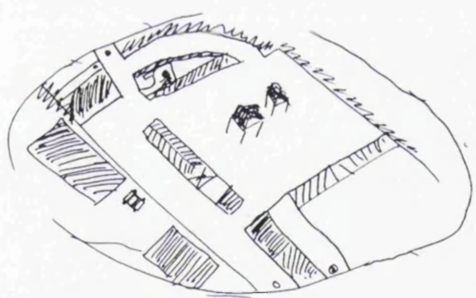
10. (1st experiment) small and traditional place.

(2nd experiment)

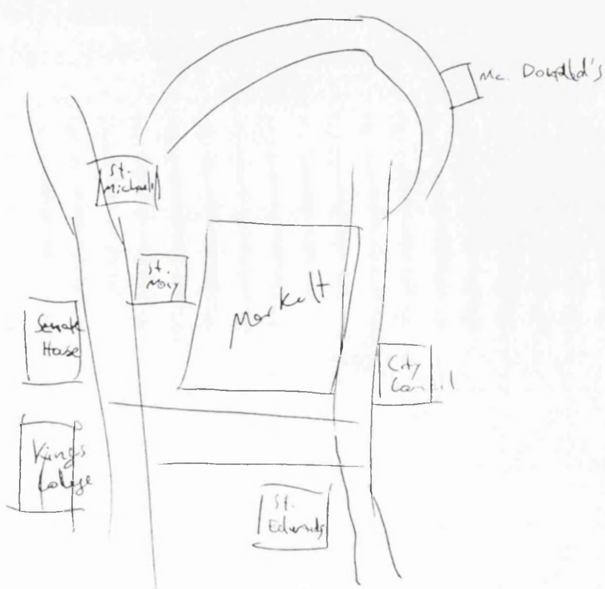


Subjects acclimatised by Virtual Reality:

1.



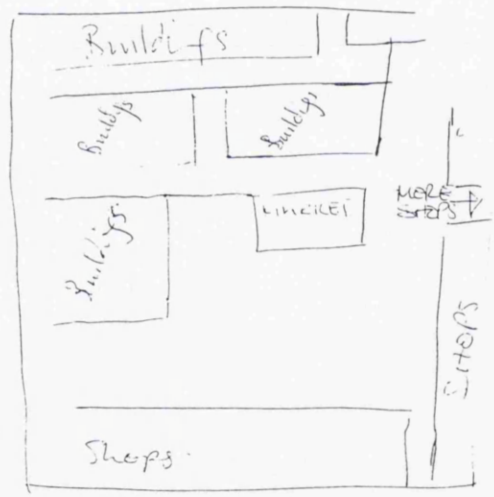
2.



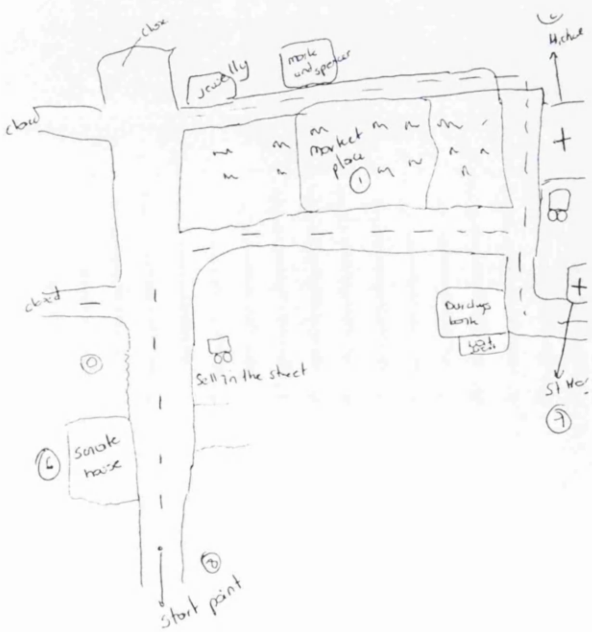
3.


CHURCH
MARKET
Δ CHURCH
Δ COLLEGE

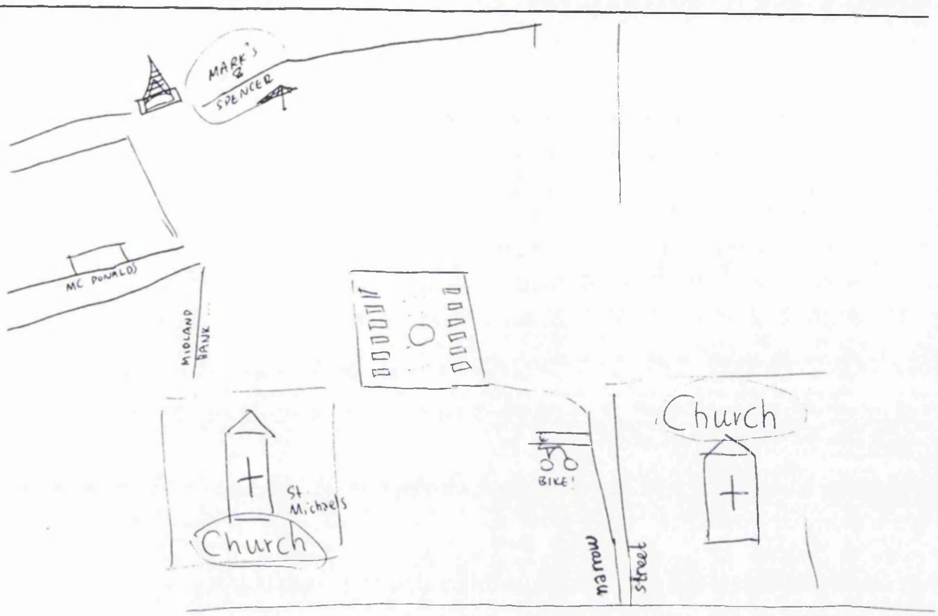
4.


Shops
SHOPS

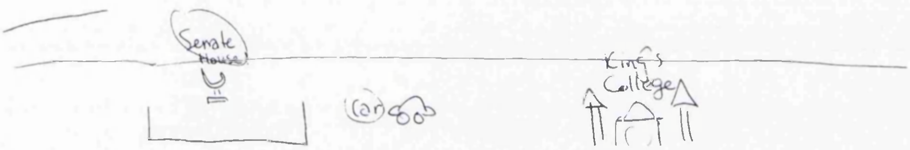
5.

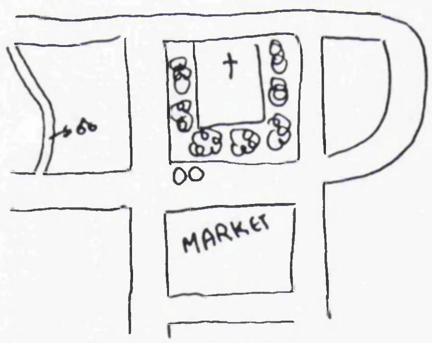

market place
Sell in the street
Start point

6.

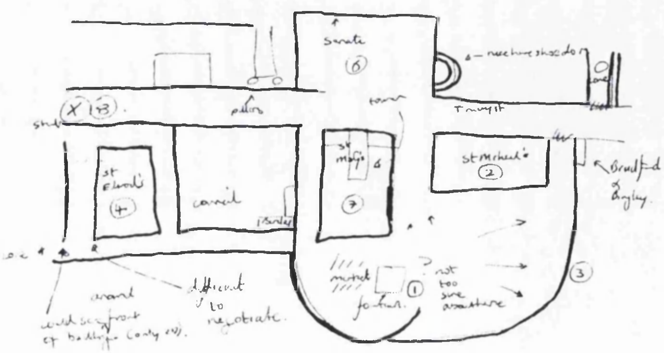

MARK'S & SPENCER
MC DONALD
MIDLAND BANK
Church
St. Michaels
Church
BIKE!
narrow street

7.


Senate House
car
King's College


MARKET

8.

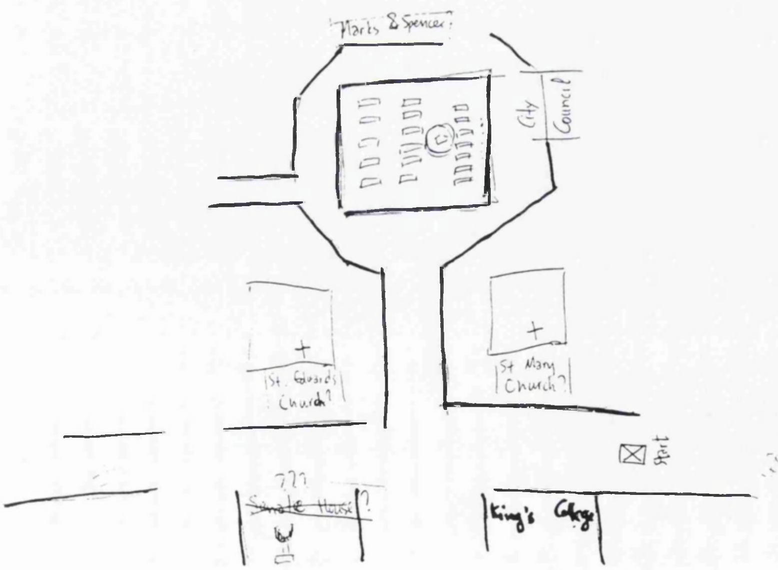

Senate
St Michael's

9. (1st experiment) I have the idea of a small, sweet old town. The College contributed to the dignified atmosphere. There are new buildings out of the city centre contrast.

(2nd experiment) I can imagine Cambridge now better, I have a realistic idea about the market. I'm looking forward to see how the real city.

10. (experiment 1) There is a market, surrounded by some stores, churches, College. Very quite place.

(experiment 2) Small town



F.7 Subject's comments after virtual visit

Subjects acclimatised by pictures:

4. I could make an idea about Cambridge in general but I did not imagine Cambridge around me.

Subjects acclimatised by video:

1. It can not be very real to me through the video, because I can not feel the wind on my face. Through video is very difficult to be acclimatised. However it is better than reading books or looking at pictures.

2. Seemed to small. It was no realistic at all.

4. It was difficult to follow the video's sequence. However, I the video gave me the sense of being in Cambridge.

Subjects acclimatised by desktop:

1. I felt a great realistic experience apart than when in front a very realistic open door, and you can go through. The shops look very realistic, the people miss their movement to give a better impression of reality.
The birds-eye view was great!

2. I don't think it was very realistic because of the movement with the mouse through all the visit, maybe is a personal problem I'm not very friendly with computers. I think it is a good and interesting simulation.

3. It did not seemed realistic at the beginning, because of navigation's difficulties, once I got it things were much better, and seemed real. It was surprising how real the shops and buildings seemed, I was about to stop and have a look around the shops windows! I had difficult to go through narrow streets. I'm sure I don't need a map when I'll be in Cambridge.

4. The shops looked very realistic.

5. The streets, the shops, the buildings were very real.

6. It is a good representation! Realistic but not enough, there was no sound, no life expected in a city.

7. The tasks are very difficult for me, since I had problems to find the bicycle.

8. It's difficult to control the mouse, it's rather real, but is always a computer screen.

9. I'm not able to go inside the shop!

10. Virtual reality is a realistic place, if I could go inside shops, It would be better.

11. It was realistic but I have the same sensation when I see a film or look at pictures.

Subjects acclimatised by virtual reality:

1. (experiment 1) The virtual Cambridge was realistic in the sense that the place seemed quite and the texture mapped buildings looked very real. The archway half covered by a door was misleading because it looked like it was possible to go through it, but if that was possible I did not manage it.

(experiment 2) The tasks were very easy, simply a question of navigating round the environment until popped up. I found the second task more difficulty because I had not noticed McDonalds the day before and I expected it to be more predominant i.e. I expected to see golden arches.

2. (experiment 1) The virtual Cambridge looked incredible realistic; the texture of the buildings, the spatial perspective all made it seems so real!

(experiment 2) Yesterday experiment was like visiting an unknown city for the first time. Today it was like walking in a city were I've been before but don't know well enough to remember the direction of the streets.

3. (experiment 1) With the helmet the idea of being in Cambridge is quite realistic. The problem is that with all the cables and the noise in the laboratory brings you back to the real world.

(experiment 2) It was very close to be in Cambridge some times. Specially when I got familiar with the place, I was actually walking with specific direction. Of course, again the cables and noise didn't let me part of it.

4. (experiment 1) In the beginning it was quite dizzy, but after a few minutes it was OK. The virtual city was realistic enough (Especially when I looked around).

5. (experiment 1) Virtual Cambridge seemed very realistic to me, especially the look of some shops and banks, I only found difficulty in using the handset devise but after it was OK, I enjoyed it ! I felt sometimes uncomfortable with the wires, and there was a feeling of loosing my balance. From the sky view some graphics were trembling and this was not too much realistic.

6. (experiment 1) I got difficulty to turn around corners.

(experiment 2) Quite realistic!

7. (experiment 1) I took time to learn the navigation, missing the action of people which I met.

(experiment 2) Missing the sound.

8. (experiment 1) It was missing the people's movement. I had problems in turning to small streets.

(experiment 2) The virtual visit seems more realistic now. My feeling of having been there increased.

9. (experiment 1) Too hot in the laboratory! I had difficulties in managing the button of the hand device. The town is very nice and it seems very realistic indeed.

(experiment 2) It's really amazing!

10. (experiment 1) It was the first time I used a VR equipment, the navigation was difficult, and I couldn't see the hand device buttons, I felt sick! This difficulties didn't let me to enjoy the virtual visit.

(experiment 2) It was more realistic now, that I got familiar with the place and with the system. I learn more about the physical place in this second virtual visit.

11. (experiment 1) It was really a great experience, even not feeling very well.

(experiment 2) Much better now, this time I really enjoyed! It's amazing!

F.8 Subject's comments after real visit

Subjects acclimatised by pictures:

1. It's hard to be acclimatised through maps and pictures.
2. The 3D map was really useful. I realised while in the city that I saw the pictures of the College and church.
3. The real Cambridge and the pictures, there is no comparison possible.
4. I realised that Cambridge is a complicated city.
5. Cambridge's pictures does not match with the real city.

Subjects acclimatised by video:

1. It seams that I have been in Cambridge in my dreams. The experience was very close to the real situation.

2. I recognised the market, Mc Donalds, Kings College, e.g. shape, colour. I did not get any idea about the objects' location.

3. I could not memorise everything and I had difficulty to find the places. I did not get enough information through the video.

Subjects acclimatised by desktop:

1. The places were very similar. The only difference between the two visits were the 'atmosphere' which is very powerful in the real Cambridge, having the people, the perfume, there is a particular flavour in the real one that the virtual does not have. Otherwise, everything was as expected from the virtual visit. Even the ice-cream man, the bicycle, the people were there!

2. I can not say that I had the impression to be in Cambridge, but I had the impression that I knew the place, the streets direction and the buildings.

3. It was very easy to find my way around. All the places were very familiar. I was not disoriented at any time. I knew exactly where the places were. A great experience!

4. Very funny! While I was in the real city I recognised everything. The two places were just the same, very similar. It was like I've been in the real city before. I had no problem in accomplishing the tasks.

5. It was a very interesting experiment, I had the feeling I was in the real city before, I was very well oriented in the city.

6. They were definitely the same place, only the sounds and weather. A lot of people and a crowed market in the real city.

7. I always have orientations problems, but I found this experiment very helpful, since I felt I've been in the real city before. I think that the virtual Cambridge need that virtual people.

8. Visiting the virtual Cambridge it was like discover the place, it's not exactly as the real experience, but it is better than look at pictures and maps.

9. Virtual Cambridge helped me in getting familiar with the real city.

10. They are very different places. However, the virtual visit was very useful, pity I did not pay more attention in the virtual visit, since I was not told to.

Subjects acclimatised by virtual reality:

1. The two visits were identical in terms of navigational ease, I couldn't felt better prepared to find my way around. Real Cambridge is busier but that seams the only difference.

2. The experiments are unbelievably similar. I never expected to have the impression that I had been in Cambridge before, but I did. All the references were so similar that finding the way in Cambridge was very easy.

3. All the places were very familiar to me. After the virtual visit I thought it was not going to be like that, but today I think in a different way. The experiments indeed helped me to feel like I've been there before. Actually they were some streets I did not remember, but in some way, I was very confident and very sure to find my way.

4. It helped a great deal! Actually, the virtual visit helped me to orient through the streets and market. In general I have the feeling that I've visited these places before.

5. Real Cambridge was very lively, contrasting the virtual one. However this movement of people usually distracts your attention. It would help increasing to high resolution pictures, otherwise, it is impossible to read the shops labels from the other side of the market.

6. The virtual Cambridge missed the sound, smells, lots of people. However, the virtual experience was a great help in finding my way around in the real city.

7. Found my way in real Cambridge very easy. I think that the virtual Cambridge was very real, mainly the market, the fountain, the market's floor. I got the feeling that the city was a quite place, which was not.

8. Of course the real city was much more fascinating, because you have all the senses working together experiencing the city. Still, I was astonished how similar the virtual and real Cambridge were. I think it was very helpful and exciting to experience the virtual Cambridge first.

9. There are differences between the two Cambridge; smell, sound, noise, people moving...

10. The visit to the virtual Cambridge was so close from the real one. The problem was that during the virtual visit I could not find everything. I felt really familiar with the entire real place; market, shops, streets.

Appendix G Data Analysis of the Main Experiments

G.1 Overview of the Appendix

The nature of the data in the statistical study and some aspects of it in the statistical analysis of the main experiments is presented in this appendix.

G.2 Description of the explanatory variables

There were 40 subjects. Their characteristics presented through personal explanatory variables are discussed below.

G.2.1 Gender

There were 24 male and 16 female subjects who selected from the display types which were available to them. Table G.1 presents a table with the number of subjects in each display type clustered by display type. Figure G.1 presents this gender distribution for each display type.

Table G.1 `Gender` versus `display`

	Male	Female	Total
Picture	7	3	10
Video	6	4	10
Desktop	5	6	11
VR	8	2	10
Total	26	15	41

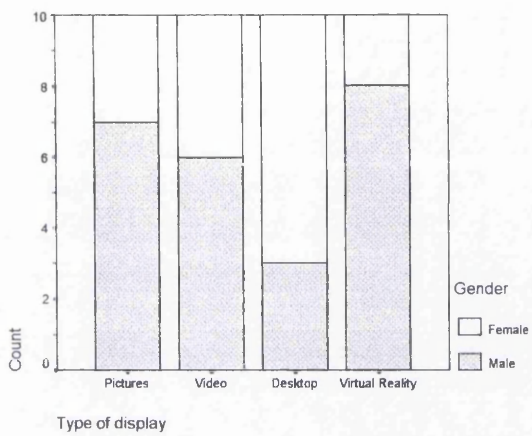


Figure G.1 Gender versus display

G.2.2 Subjects' Skills in Virtual Reality

Table G.2 presents the number of subjects who did not experience a virtual environment before and those who did, selected by the display type. Table G.2 presents the number of subjects who had familiarity with virtual reality technology clustered by display type and the graph is presented in Figure G.2.

Table G.2 Familiarity with virtual reality technology clustered by display type

	No Experience in immersive environments	Experience in immersive environments	Total
Picture	9	1	10
Video	9	1	10
Desktop	9	1	10
VR	8	2	10
Total	35	5	40

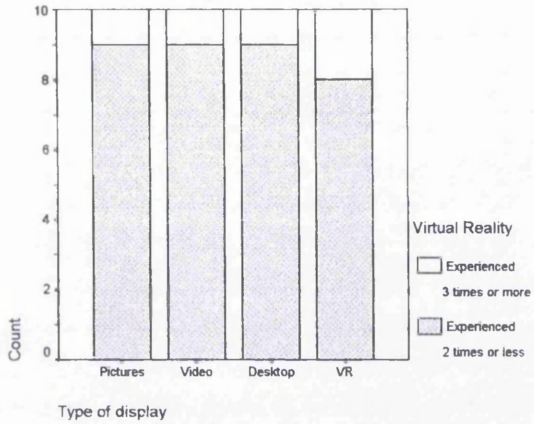


Figure G.2 Subjects' Skills in Virtual Reality

It could be observed that it was not frequent that subjects explore immersive environments before.

G.2.3 Personality Test

The four variables from the responses of a personality test are presented through histograms with the corresponding normal curve. This tested the following four areas:

- Extroversion/Introversion
- Intuition/Sensing,
- Thinking/Feeling
- Judgement/Perception.

Figure G.3 shows the values for Extroversion/Introversion while Figure G.4, Figure G.5 and Figure G.6 display the frequencies for Intuition/Sensing, Thinking/Feeling and Judgement/Perception, respectively.

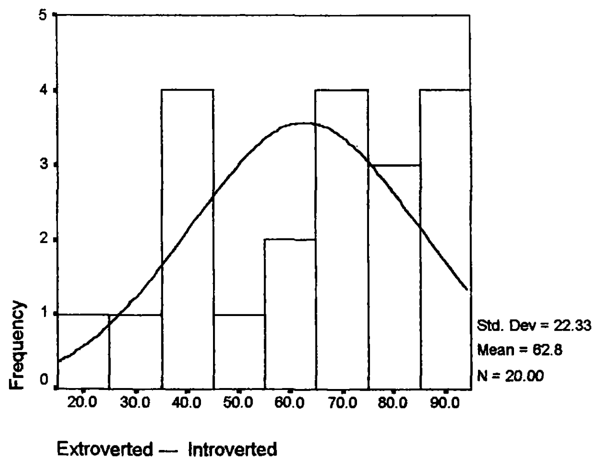


Figure G.3 Histogram for Extroversion /Introversion

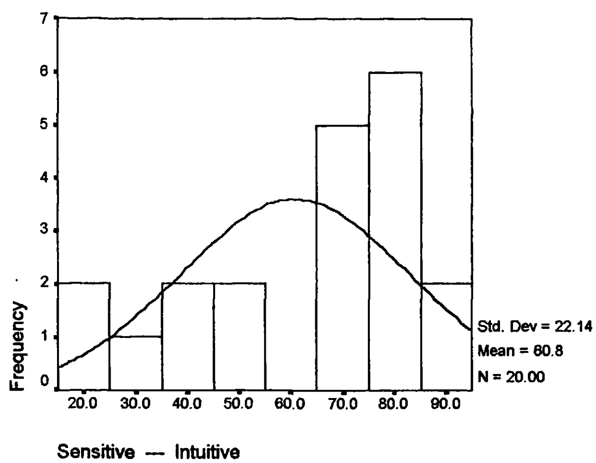


Figure G.4 Histogram for Intuition/Sensing

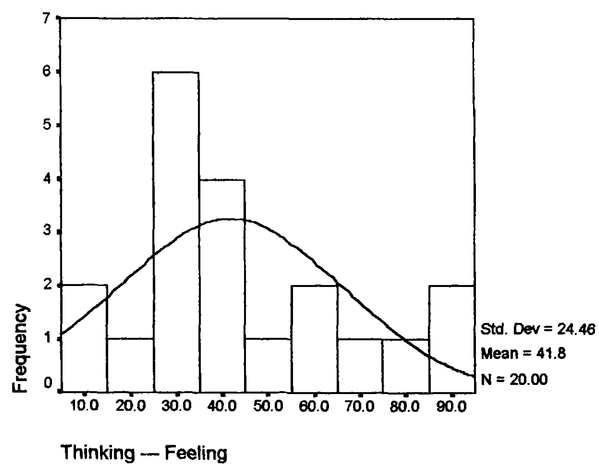


Figure G.5 Histogram for Thinking/Feeling

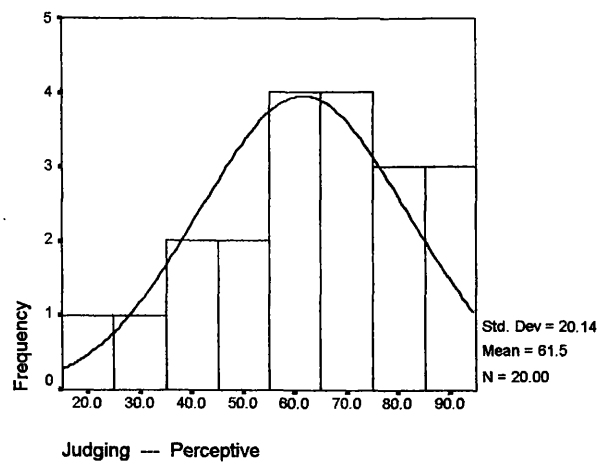


Figure G.6 Histogram for Judging/Perceptive

G.2.4 Age

The subjects' ages ranged 18 to 46 years, the average age was 25. This data is presented in Figure G.7

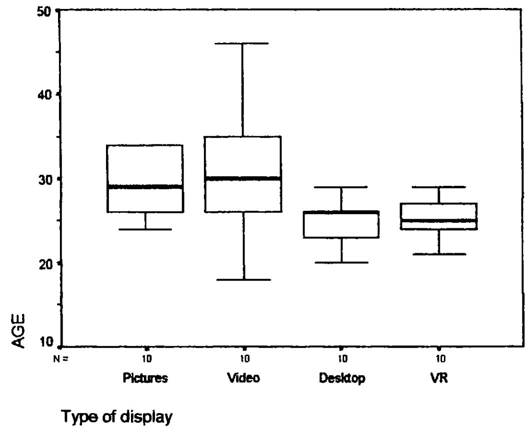


Figure G.7 Age

G.2.5 Artists and Scientists Subjects

The distribution of artists and scientists by each display type is presented in Table G.3 and also shown in Figure G.8.

Table G.3 `Artist/scientist` versus `display`

	Artists	Scientists	Total
Picture	6	4	10
Video	8	2	10
Desktop	5	5	10
VR	1	9	10
Total	20	20	40

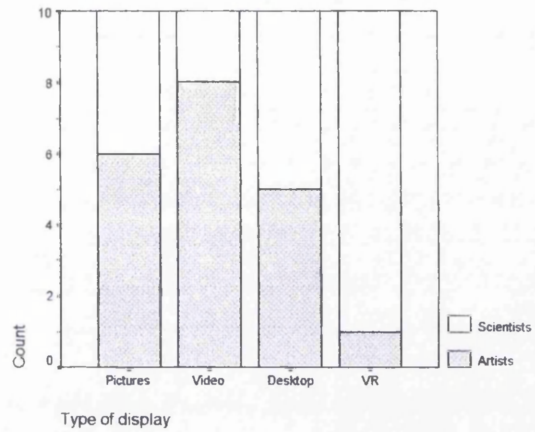


Figure G.8 Artists and Scientists

G.2.6 Spatial Ability Test

The spatial ability test was scored from 0 to 11, by adding the three spatial problems. Subjects' scores are grouped by the display type. Certainly, some more discerning questions should be included in the spatial ability questionnaire.

The values of the `spatial ability test` clustered by `display` is presented in Table G.4. A box-plot presenting these values separating the display type is presented in Figure G.9. It was observed that all the subjects who took part using virtual reality had got the maximum score in the spatial test.

Table G.4 `Spatial ability test` clustered by `display`

	5	6	7	8	9	10	11	Total
Picture	1	1	1	1	1	2	3	10
Video	1	-	-	1	2	2	4	10
Desktop	1	-	-	2	1	3	3	10
VR	-	-	-	-	-	2	8	10
Total	3	1	1	4	4	9	18	40

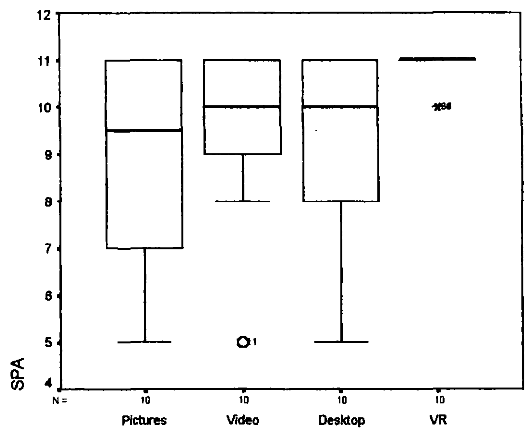


Figure G.9 Spatial Ability Clustered by Display Type

G.2.7 Sensory Input Test

The responses of the sensory input questionnaire were grouped into two distinguished categories; those who were visual dominant from those who were auditory dominant. These values are presented in the Table G.5. A bar chart of these values are presented below in Figure G.10, which shows the visual and auditory sensory input divided by the display type.

Table G.5 Visual and auditory versus display

	Visual dominance	Auditory dominance	Total
Picture	7	3	10
Video	8	2	10
Desktop	9	1	10
VR	6	4	10
Total	30	10	40

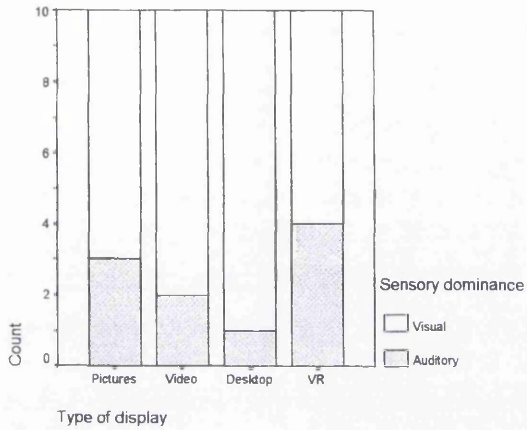


Figure G.10 Sensory Input Dominance

G.2.8 Presence

Figures G11, G12 and G13 present the data obtained from the questionnaire of Presence.

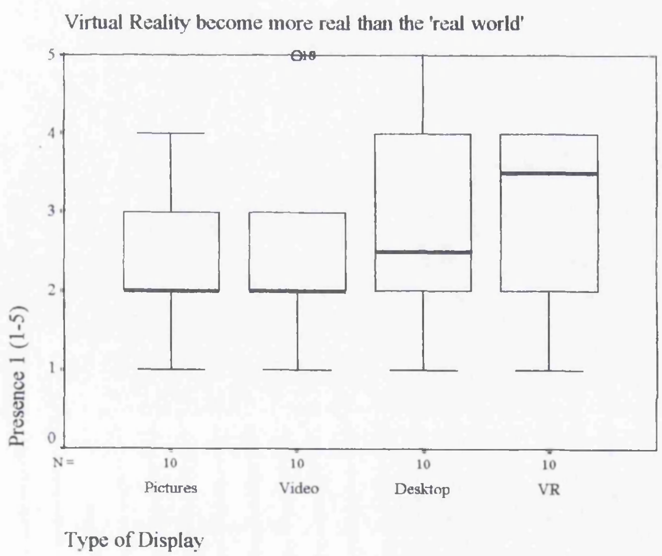


Figure G.11 Virtual Reality more real than the real world

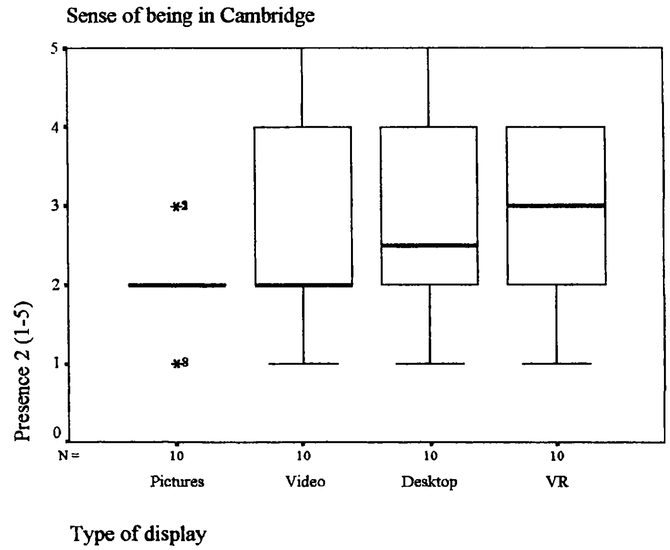


Figure G.12 Sense of being in Cambridge

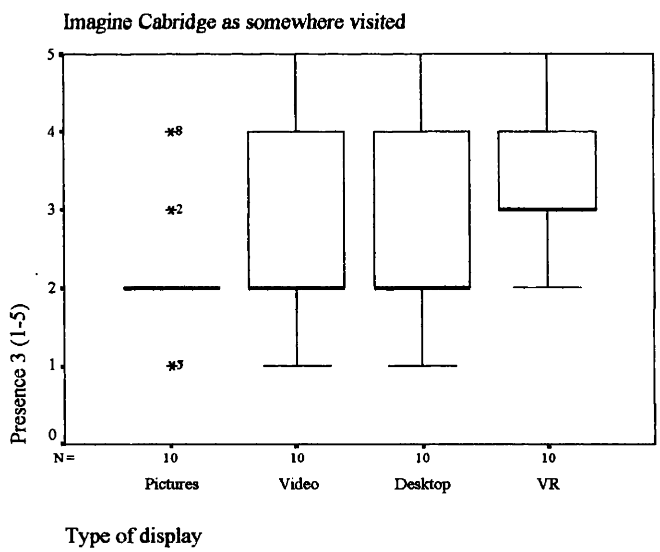


Figure G.13 Virtual Cambridge as somewhere visited

G.2.9 Data Related to Time

This is the duration of visits and tasks and the time spent using navigation aid tools.

The time variables in the virtual visits were:

- Duration of first visit
- Duration of second visit
- Total duration of both visits

The data is presented in Figures G.14, G.15 and G.16.

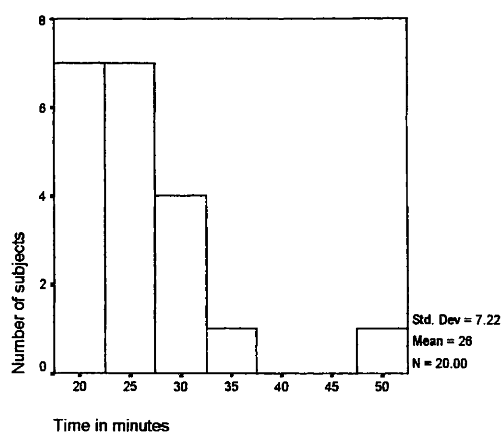


Figure G.14 Duration of First Visit

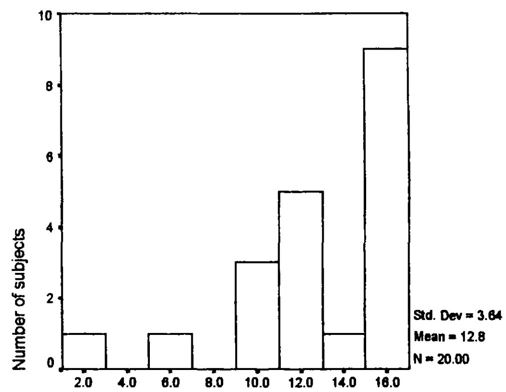


Figure G.15 Duration of Second Visit

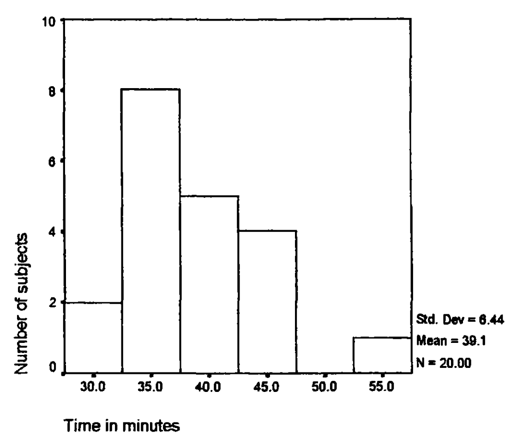


Figure G.16 Total Duration of Both Visits

Even though the subjects were allowed to take as long as they wished in the first visit the average time taken was about 30 minutes. Subjects were allowed a fixed time of 20 minutes in the second visit.

The time variables in the training tasks were:

- Duration of training task one

- Duration of training task two

The data is presented in Figures 7.17 and 7.18.

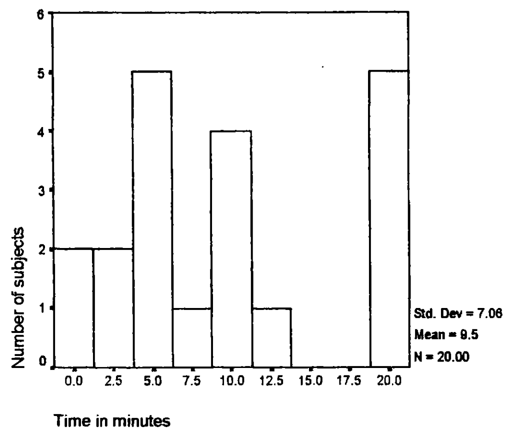


Figure G.17 Duration of Training Task One

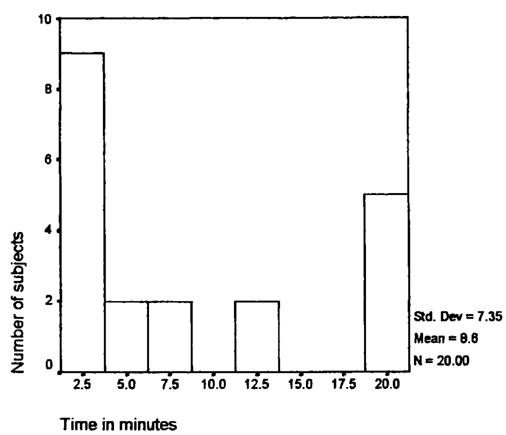


Figure G.18 Duration of Training Task Two

The time variables relating to navigation aid tools were:

- Time birds-eye view used
- Time compass used
- Time map used

The data is presented in Figures G.19, G.20 and G.21.

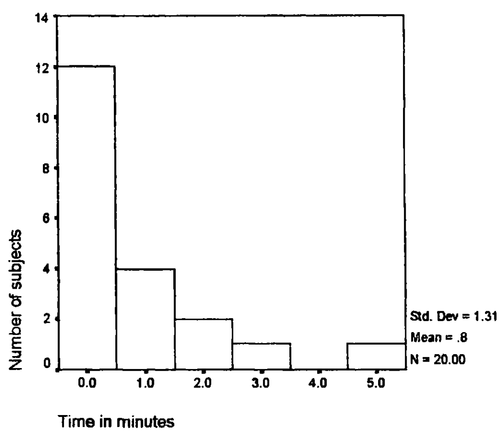


Figure G.19 Time Birds-Eye View Used

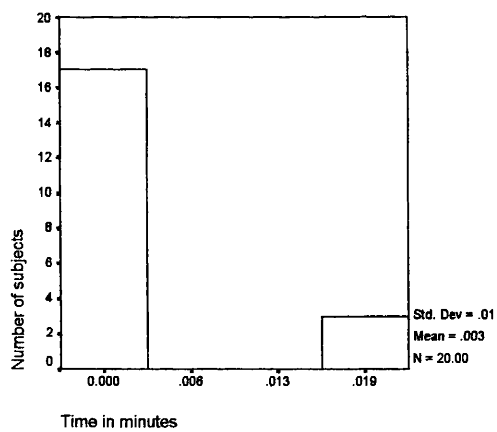


Figure G.20 Time Compass Used

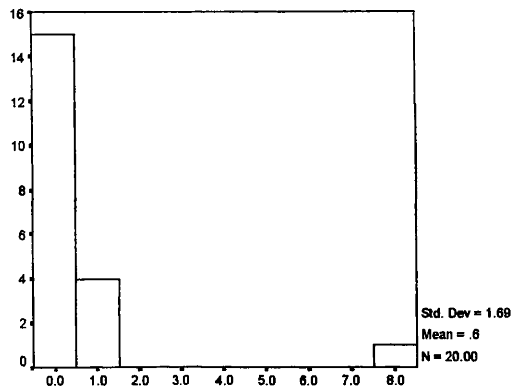


Figure G.21 Time Map Used

In the first visit subjects were allowed to use the navigation aid tools as many times as they wished for as long as they wished. The first visit was for as long as the subjects needed to complete the task, whereas the second visit was limited to 15 minutes.

G.3 Commands used in the logistic regression study

A summary of the commands used is described below.

"Derive variables"

calc y=L1+L2+L3+ORI1+ORI2+ORI3

calc d1=L1+ORI1

& d2=L2+ORI2

& d3=L3+ORI3

calc l = L1+L2+L3

& o = ORI1+ORI2+ORI3

"Perform initial tabulations (used in Fishers exact test)"

```
for yy=L1,L2,L3,ORI1,ORI2,ORI3
 getat [ident] yy;name
 print [ipr=*] #name
 tabu[t;DISPLAY] yy
endf
```

"Screen explanatory variables"

```
for yy=y,d1,d2,d3,l,o;nn=6,2,2,2,3,3
 model [b] yy;nn
 getat [ident] yy;name
 print [ipr=*] 'y variable ',#name
 fit [*]
 rkeep dev=dev0
 for
x=DISPLAY,EXT_INT,SEN_INT,THNK_FEE,JUD_PERC,GENDER,ART_SCI
, \
    VR_TIME,AUDIT,VISUAL,KINET,DOMINANC,SPATIAL,VC_LAB2, \
    SEN_BE2,PLA_VI2,EXPRESSI,MIN1,MIN2,MINBIC,MCTASK, \
    BICTASK,AID,MCDONMIN,COMPMIN,FLYMIN,MAPMIN
  fit [*] x
  rkeep dev=devm
  calc devt=dev0-devm
  getat [ident] x;name
  if devt > 2.5
   print [ipr=*] #name,' deviance = ',devt
  endif
```

```
 endf
endf

"Set up pointers to the two groups of variables"

point
[v=EXT_INT,SEN_INT,THNK_FEE,JUD_PERC,GENDER,ART_SCI,VR_TIM
E, \
    VISUAL,AUDIT,DOMINANC,SPATIAL,VC_LAB2,SEN_BE2,PLA_VI2, \
    EXPRESSI] xp
point [v=MINBIC,MCTASK,BICTASK,MCDONMIN,FLYMIN,MAPMIN, \
    COMPMIN] xo


"Below are the final models fitted"

model [b] y;6
fit xp[6,15]
fit xp[6,15]+DISPLAY

fit xo[2]
fit xo[2]+DISPLAY

model [b] d1;2
fit xp[6]
fit xp[6]+DISPLAY

fit xo[1,2]
fit xo[1,2]+DISPLAY
```

```
model [b] d2;2
fit xp[5,6]
fit xp[5,6]+DISPLAY

fit xo[2]
fit xo[2]+DISPLAY

model [b] d3;2
fit xp[3,15]
fit xp[3,15]+DISPLAY

fit xo[6]
fit xo[6]+DISPLAY

model [b] l;3

fit xo[2]
fit xo[2]+DISPLAY

model [b] o;3
fit xp[2,5,6,8,11,12,14,15]
fit xp[2,5,6,8,11,12,14,15]+DISPLAY
fit xp[2,12]
fit xp[2,12]+DISPLAY

fit xo[1,5]
fit xo[1,5]+DISPLAY
```

```
"Investigate further relationships by tabulation"

tabu [c;DISPLAY,MCTASK]
tabu [c;ART_SCI,DISPLAY]

"Scan for relationships with other responses"

for yy=BE_BEF, EASY_WAY,HELP_LAB, NODES2, MAP2
 getat [ident] yy;name
 calc corr=correlation(yy;DISPLAY)
 print [ipr=*] #name,' Corr ', corr
endf

"confirm relationship with BE_BEF"

group BE_BEF; SA1
tabu[c;SA1,DISPLAY]
calc yvar=DISPLAY
model [b] yvar;1
fit BE_BEF

"Scan for relationship of other explanatory variables with
other responses"

for yy=BE_BEF, EASY_WAY,HELP_LAB, NODES2, MAP2
 getat [ident] yy;name
 print [ipr=*] #name
```

```
 for
x=DISPLAY,EXT_INT,SEN_INT,THNK_FEE,JUD_PERC,GENDER,ART_SCI
, \
    VR_TIME,AUDIT,VISUAL,KINET,DOMINANC,SPATIAL,VC_LAB2, \
    SEN_BE2,PLA_VI2,EXPRESSI,MIN1,MIN2,MINBIC,MCTASK, \
    BICTASK,AID,MCDONMIN,COMPMIN,FLYMIN,MAPMIN
  calc corr=correlation(yy;x)
  getat [ident] x;name
  if corr > .35
   print [ipr=*] #name,' Corr ', corr
  endif
 endf
endf

"Fit models for BE_BEF"

model BE_BEF
fit DISPLAY
fit xp[6,9,15]
fit xp[6,9,15]+DISPLAY
fit xp[6,9]+DISPLAY
```

G.4 Output from the logistic regression study

The output from the above commands is following

```
Wayfinding1
      DISPLAY       Total
         0.00       6.000
         1.00      10.000

Wayfinding2
      DISPLAY       Total
         0.00       10.00
         1.00       10.00

Wayfinding3
      DISPLAY       Total
         0.00       8.000
         1.00       7.000

Orientation1
      DISPLAY       Total
         0.00       5.000
         1.00      10.000

Orientation2
      DISPLAY       Total
         0.00       4.000
         1.00      10.000

Orientation3
      DISPLAY       Total
         0.00       5.000
         1.00       7.000
```

```
           y variable          way-finding/orientation(y)

     DISPLAY  deviance =         12.52

     SEN_INT  deviance =         5.03

     ART_SCI  deviance =         9.09

     VR_TIME  deviance =         6.77

     VC_LAB2  deviance =         5.07

     PLA_VI2  deviance =         4.02

    EXPRESSI  deviance =         5.17

      MINBIC  deviance =         8.69
```

*** Summary of analysis ***

	d.f.	s.s.	m.s.	v.r.
Regression	3	19.56	6.52	8.03
Residual	16	12.99	0.81	
Total	19	32.55	1.71	

Percentage variance accounted for 52.6
Standard error of observations is estimated to be 0.901
* MESSAGE: The following units have large standardised residuals:

Unit	Response	Residual
6	1.000	-2.54

* MESSAGE: The following units have high leverage:

Unit	Response	Leverage
2	2.000	0.66
11	5.000	0.45

*** Estimates of parameters ***

	estimate	s.e.	t(16)
Constant	-3.22	1.81	-1.78
ART_SCI 2	1.21	0.44	2.72
AUDIT	0.24	0.10	2.44
EXPRESSI	0.93	0.38	2.44

******* Regression Analysis *******

Response variate: BE_BEF
Fitted terms: Constant + ART_SCI + AUDIT + EXPRESSI + DISPLAY

*** Summary of analysis ***

	d.f.	s.s.	m.s.	v.r.
Regression	4	19.87	4.97	5.88
Residual	15	12.68	0.85	
Total	19	32.55	1.71	

Percentage variance accounted for 50.7
Standard error of observations is estimated to be 0.919
* MESSAGE: The following units have large standardised residuals:

Unit	Response	Residual
6	1.000	-2.44

* MESSAGE: The following units have high leverage:

Unit	Response	Leverage
2	2.000	0.67

*** Estimates of parameters ***

	estimate	s.e.	t(15)
Constant	-2.58	2.12	-1.22
ART_SCI 2	1.069	0.505	2.12
AUDIT	0.221	0.109	2.03
EXPRESSI	0.810	0.437	1.85
DISPLAY 1	0.336	0.552	0.61

***** Regression Analysis *****

Response variate: BE_BEF
Fitted terms: Constant + ART_SCI + AUDIT + DISPLAY

*** Summary of analysis ***

	d.f.	s.s.	m.s.	v.r.
Regression	3	16.97	5.66	5.81
Residual	16	15.58	0.97	
Total	19	32.55	1.71	

Percentage variance accounted for 43.2
Standard error of observations is estimated to be 0.99
* MESSAGE: The following units have high leverage:

Unit	Response	Leverage
11	5.000	0.46

*** Estimates of parameters ***

	estimate	s.e.	t(16)
Constant	-0.37	1.88	-0.20
ART_SCI 2	0.947	0.54	1.76
AUDIT	0.213	0.12	1.83
DISPLAY 1	0.802	0.53	1.52

Appendix H Snap-shots of the Virtual Cambridge

H.1 Overview of the appendix

This appendix presents a collection of captured pictures of Cambridge's model.

H.2 Snap-shots

Figures from H1 to H16 are snap-shots of the virtual model.

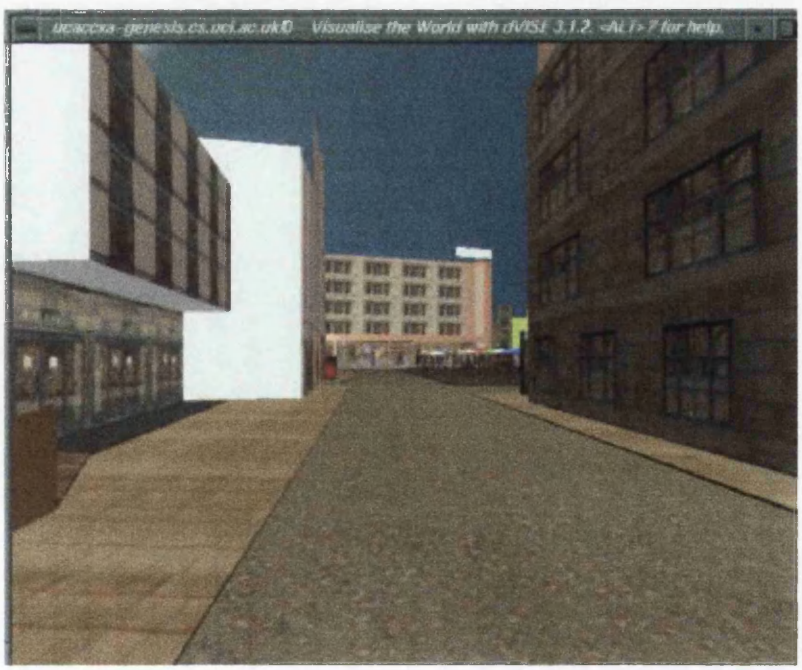


Figure H.1 Town-Hall building

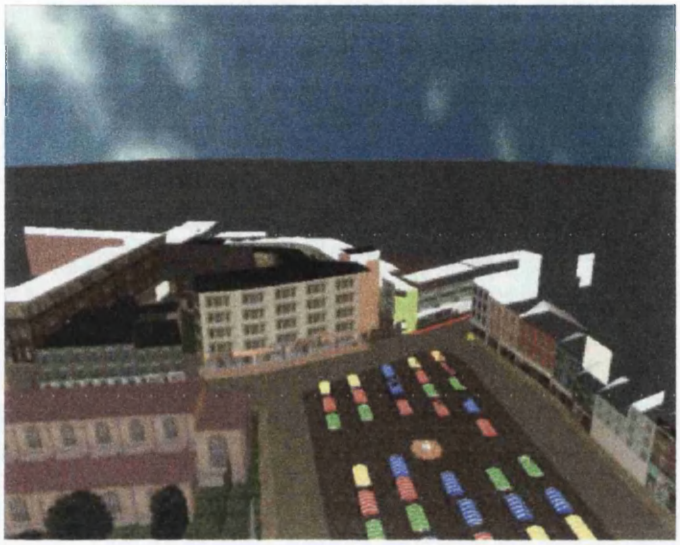


Figure H.2 Birds-eye view to the market (I)

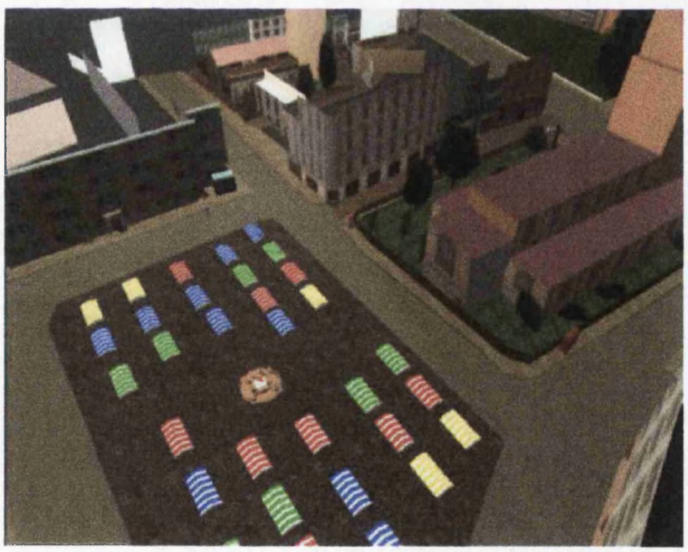


Figure H.3 Birds-eye view to the market (II)

Figure H.4 Birds-eye view to St. Mary church

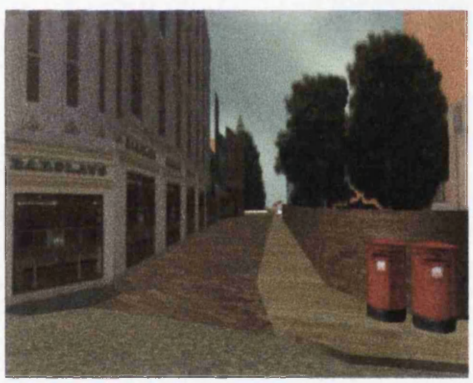


Figure H.5 St. Mary parade (I)

Figure H.6 Barclays and Midland buildings

Figure H.7 St. Mary street

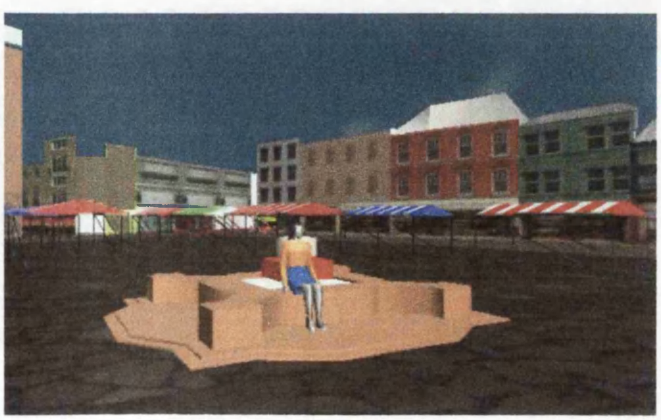


Figure H.8 Market street with a virtual actor

Figure H.9 Virtual actors sharing the virtual life

Figure H.10 Crescent rose street

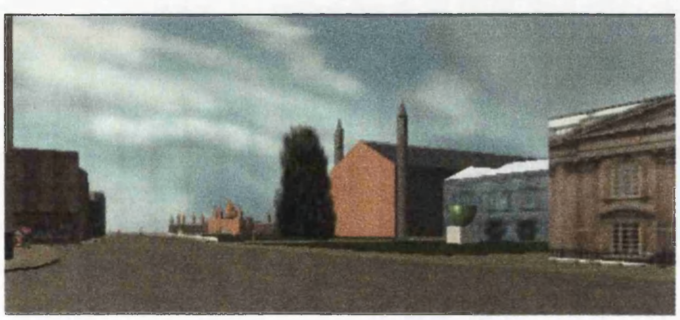


Figure H.11 King's parade (I)

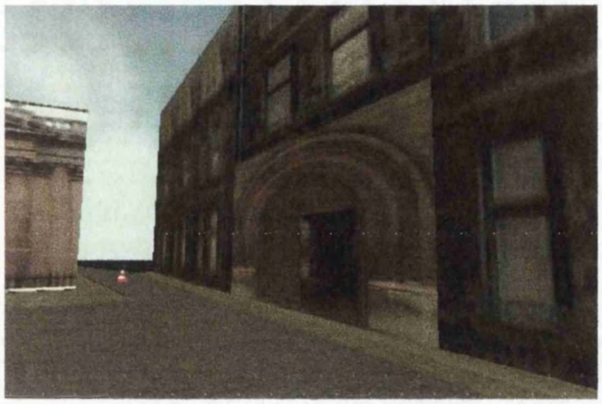


Figure H.12 Senate house

Figure H.13 St. Mary church corner

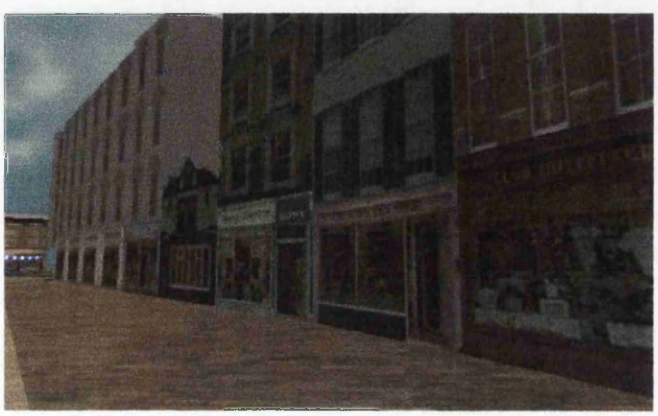


Figure H.14 St. Mary parade (II)

Figure H.15 Ice-cream vendor

Figure H.16 Kings; parade (II)

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