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METHODOLOGY FOR ASSESSMENT OF COGNITIVE SKILLS IN VIRTUAL ENVIRONMENTS

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ABSTRACT

The client briefing of the proposed building design is usually in the form of drawings and artistic impressions being presented to the client. However, very few clients are able to read a technical drawing and the artist impressions are limited and do not aid the client to visualise all aspects of the proposed building. During the client briefing process the client needs to have the experiential quality described, to be able to fully understand the design of the proposed building. Generally, humans perceive and directly experience architectural space by building qualities like texture, form, colour, light, scale, movement. A full-scale model of the proposed building would fully afford the experimental qualities. In reality it would be impractical and not cost effective. However, VR technology allows the creation of an inclusion of space in user's mind, through a minimum of means, but achieves a maximum impact, and affords all the experiential qualities offered by a physical model.

A virtual model with a high degree of detail which can be explored by the designer and his clients will therefore be of significant help. However, to give clients the best possible impression of the proposed design it is important to understand how dimensions of those designed spaces are perceived. Therefore, a study was carried out focusing on fundamental investigations into the perception of basic architectural dimensions in order to assess the potential usefulness of VR technology in architecture and the client briefing process.

In two experiments, subjects were required to estimate egocentric and exocentric dimensions in Virtual Environments and Real World Setting (RWS). The influence of stimuli orientation was also investigated. In estimating all dimensions a magnitude estimation procedure was employed using a modified free-modulus technique. All participants were pre-tested. Psychometric and visual tests were used for choosing an experimental group with a fair degree of homogenity. Two independent subject groups were used. In addition to dimension estimations recall of simple layout and feeling of space were investigated when evaluating the virtual interface.

The general null hypothesis assumed that people perceive space in VE as well as in the real world. It has been shown that the results are statistically significant and therefore one was able to reject the general hypothesis. Overall participants underestimated the dimensions in both experiments by approximately 20%. Results and limitations of the study are discussed. The results of the experiments would indicate that VR technology can be used for simulations of architectural spaces because despite underestimations of dimensions it still performed relatively well if one compares it with results of experiments in the Real World Settings.

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1. INTRODUCTION.

1.1 Motivation.

1.1.1 Industry Drivers.

In 1998 the Egan (1998) report described the UK construction industry as 'at its best excellent'. However, the report also expressed deep concern that the industry was under-achieving, with many clients' dissatisfied with the overall performance. Two earlier surveys, by The British Property Federation (1983) and Latham (1994), referenced by the report, indicated that more than a third of major clients were dissatisfied with the performance of both contractors and consultants involved in projects. These surveys also highlighted several key points in the client/construction interface that clients' suggested could be improved. The report surmised that improving the Client Briefing of a project would significantly improve the client's satisfaction with the completed construction, as the design team could more closely address the needs of the client. This concern over the 'Client Briefing' process is not new, it is mentioned as an issue in the Branwell (1964) report, a precursor to the Egan report, from 1964 and has been a subject of research in several publications over the last 40 years. Clearly, the interaction between client and construction industry is an area for concern, and has been for some time.

1.1.2 Current Practice.

For centuries Architects communicated their design ideas or proposals to their clients by using drawings and mock-up models. Drawings were only used as an explanatory device rather than an exploratory tool. Models were predominantly used as a design tool. At the beginning of the twentieth century, with the advancement of printing technologies and the popularisation of formal publications, drawings became the predominant tool for expressing architectural design. (Porter, 1979)

Drawings with a single linear perspective can convey information about a building, its texture, form, colour and scale. At their basic level, drawings are a 'flat substrate with colors placed onto it in a geometric/mathematical manner' (Zobel, 1995,pp. 260). Despite their limitation, drawings are the most popular tool for representing architectural designs. Some even say that many designers are so attached to traditional drawings technologies that they have spurned the growing influence of the computer in the design process. (Kaplan *et al.*, 1995)

Scaled architectural models are perhaps the closest media for actually experiencing a full-size constructed building. These models can carry texture and intended colours on the surfaces. Most of the time they are three-dimensional (3D). They can be built to any scale required including an exact full size replica of the building. However, this is not financially feasible, nor are the facilities usually available to allow a model to be mocked-up full scale (Zobel, *op cit*). Furthermore, observers typically view the model from a bird's eye point of view. For most humans it is not the most typical view. If the model is high quality it is sometimes possible to view the interior of the building by looking through the scaled windows. This can provide observers with some ideas of the layout of the building. Moreover, the exterior walk around gives the feeling of being in a *Lilliputian City*. These ways of experiencing architecture are not typical for humans.

Some Architects have used computers for drafting and visualisation techniques for over twenty years (Kaplan *et al.*, 1995). Firstly, computer programmes were used to draw up simple plans and produce printouts, and then computer programmes were developed to produce two-dimensional (2D) drawings. Some of these programmes allowed users to zoom in on a particular spot for a detail or zoom out to look at the drawing as a whole.

Most recent computer packages include programmes allowing designers to produce highly sophisticated, almost 3D images that can be rotated, changed or combined by a user via computer commands. However, even the most sophisticated of these programmes does not allow direct interaction with or immersion in the environment. Moreover, an introduction of any changes in the model is costly, time-consuming, requiring the regeneration of sequences of fixed frames to create the new image.

Drawings, described earlier, will always be used in some form or another. Most people find it difficult to thoroughly read flat drawings of volumetric spaces. To help those people, Architects include *elevations* in sets of blue prints. Elevations are used for the presentation of planned design representations. However, they fall short of providing a comprehensive view. Clients are often not able to judge the quality of architectural proposal based only on these types of drawings. They are even less able to evaluate the relationships between form, function or cost of a proposed design.

VR is a technology which can help to communicate an Architect's ideas to his/her clients. The goal of Virtual Reality (VR) is to interface humans more closely with computers. The VR experience should be imperceptible from reality. By displaying at appropriate update rates and in real-time, users no longer see a stream of flickering pictures in front of their eyes, but instead believe themselves to be in a new, computer-generated and believable world. The implications of this new set of perceptions - this new state of consciousness - will continue to be explored far into the future.

1.1.3 Potential of Virtual Reality.

Virtual Reality is an interface which allows humans to interact with virtual worlds. What makes *immersive* virtual environments distinct from other human-computer interfaces is that the human being has the illusion of being completely surrounded by spatial information. Humans become participants in this computer-generated world. The illusion is sufficiently compelling for the participants to develop a sense of presence within the synthesised space. This makes interpretation of spatial information intuitively similar to the real world. This intrinsic characteristic of VR makes it a particularly excellent tool for the simulation of spaces in architectural applications. It is a tool which can convey spatial information from designers to their clients. Thanks to VR, even before a building is built, an Architect and client can view and modify plans by walking, room to room, floor to floor, through a computer-generated 3D model of a building. By being completely surrounded by the model of the created building and able to walk through and manipulate the design, Architects and their clients will react differently than they would if they were relying solely on drawings or a scaled mock-up model.

VR models permit the detection of mistakes in design. Any mistakes can be corrected quickly. By walking inside and outside of the model it is possible to see all of its details, to react and collaborate on making any modifications on the spot in real-time. Mervyn Richards of Laing Technology (1999) wrote that thanks to the use of 3D models he and his team were able to discover design clashes in KLM's office plant room, which were not obvious on the 2D drawings, but that had become apparent in the 3D model. Prior to this, on First Point at Gatwick, there was a substantial overspend, a large proportion of which could be attributed to the lack of spatial co-ordination. This led to design clashes, which became construction clashes, that the team had to rectify on site because they were not picked up at design stage from 2D drawings. The difference of just 130mm on different contractors' drawings turned into a significant and costly problem.

By being able to experience designs before construction, Architects or clients can request adjustments. Architects and clients can view and modify virtual models of buildings and regenerate updated versions of it until they are satisfied. Revisions are far less time consuming than the original designs. By keeping information up to date in the system it is possible to retrieve from them plans which are accurate and current. All subplan drawing details from the master plan are automatically updated as well. VR models may be used to view final designs. They are extremely cost-effective in troubleshooting before expensive physical construction has begun. Using VR models not only saves time and money compared with the production costs of real 3D models, but also extends the creative resources of the people working on the project.

Architects and clients will be able to connect, separately and by long distance, to one VR model and walk through it together in virtual reality.

Karboulonis and Padmore (2000) endorse the view that the architectural community is one of the last trying to catch up with VE. The intrinsic characteristics of VE suggest that Architects would benefit enormously from the implementation of VE into their practice. The simulation of architectural spaces would improve communication between designers, who rely on architectural representation, and the client whose best understanding of the design occurs only when physically present within the space (Kaplan, and Back, 1995; Mitchell, 1995; Schmitt *et al.*, 1995; Nimeroff *et al.*, 1995; Feiner *et al.*, 1995; Henry, and Furness, 1993; Henry, 1992).

The previous methods of representing architectural spaces offered only limited views. Models were three-dimensional but could not be entered. Computer animations were dynamic but offered only pre-defined paths and restricted views. One of the characteristics which makes VE distinct from other human-computer interfaces is that the participants, human beings, have the illusion of being completely surrounded by spatial information. The illusion is sufficiently compelling for participants to develop a sense of actually being present within the synthesised space. This makes the interpretation of the information and interaction with the environment particularly easy because it requires similar spatial perceptual skills as the interpretation of real environments.

While it is clear that virtual interfaces can create the illusion of being present in a computer model, very little is known about the representativness of virtual spaces compared to real ones. The reality is, however, that a considerable amount of systematic research must be carried out in order for VR to fulfil its potential. Designing usable and effective interactive virtual environments for architecture is a new challenge for system developers and human-factors specialists (Stanney *et al.*, 1998). The technological components are all designed to simulate virtual spaces so that they are perceived in the same way as real spaces. However, it is not known whether or not similar spaces would actually be perceived to be the same in both virtual and real environments.

1.2 Research Focus.

The potential for using virtual interfaces as representations of all manner of spaces is clear. However, the risk of leading VE to misperceptions must not be overlooked. Indeed, if Architects and their clients use VE with the conviction that their perception of the virtual space is the same as it would be of the real space, when it is actually quite different, it could lead to errors of judgement. If distances were misperceived, spaces might be judged too big when in fact, in real life, they would be just the right size.

As discussed above, ideally the spatial representation should allow people to make accurate judgements about: (i) size of the individual spaces; (ii) the relative configuration of the spaces to each other; and (iii) the qualities and attributes of the individual spaces.

The main aim of the thesis is to investigate how accurately people perceive space in virtual environments as compared to their perception of space in real environments. However, any errors occurring during the communication between Architect and client could have catastrophic consequences. Therefore, the key objectives of this thesis are to:

- carry out a literature review to summarise current knowledge of space, perception of aesthetics in built environments and spatial perception in virtual environments with a focus on distance estimation,
- to compare the perception of egocentric[1] lengths in virtual and real environments,
- to investigate the perception of exocentric[2] dimensions in virtual and real environments,
- to investigate the perception of exocentric dimensions in virtual and built open space environments,
- to explore the difference in the perception of feeling of space in virtual and real environments.

The experience in virtual space is certainly not identical to the experience in actual space. Humans are spatial beings and in the real world one relies on an abundance of multiple modalities for everyday task performance. However, in virtual reality, technology may limit the quantity and quality of these essential stimuli. Therefore, researchers should actively seek the necessary understanding of human performance in virtual environments in order to create robust design guidelines that will make use of the technology in its current state of maturity.

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[1] Perception of egocentric lengths refers to the perception of the distance between the observer and any point, object in the three dimensional space.

[2] Perception of exocentric widths and heights refers to the perception of the distance between any given point, objects in the three dimensional space observed by an observer.

In order to evaluate the usefulness of VR for architecture two experiments were designed. The first experiment is concerned with the perception of the egocentric and exocentric dimensions in enclosed spaces. In addition, the "feeling" of space was investigated in this experiment. The second experiment is concerned with the perception of exocentric length and heights in open space conditions.

Furthermore, the results of this investigation will help to avoid a backlash from the false hopes and questionable offerings of the "technology pushers". Of course, it is understood that there are long-standing technical difficulties in developing bespoke VR systems, and the instability of small firms supporting this technology should be not undermined. However, one should be very wary when "playing with someone's head". The Squadron Leader for the crack aerobatic Red Arrows team on BBC's TV Programme *How Do They Do That?* screened on Tuesday 22 February 1994 said "**Never put your body where your mind's not been before!**". Therefore any applications should be extensively tested by human factors researchers before a variety of small businesses market their applications to an eager public or industrial user base.

1.2.1 Virtual Environments.

There are many definitions of Virtual Reality or Virtual Environments. The term Virtual Environment (VE) is particularly popular within the academic community. Virtual Environment implies a computer-synthesised, three-dimensional environment in which a plurality of human participants, appropriately interfaced, may engage and manipulate simulated physical elements in the environment, and interact with representations of other humans, past, present or fictional, or with invented creatures (Nugnet, 1991).

It is difficult to categorise VE Systems because they cross borders between different types of technologies. Some of them have sub-categories. Generally however VE Systems can be categorised as:

1. Non-Immersive Virtual Environment Systems (e.g. PC based systems. The VE world is displayed on the standard computer monitor).
2. Partially Immersive Virtual Environment Systems (e.g. BOOM, Projection VE Systems, Vehicle-based Simulator Systems).
3. Fully Immersion Virtual Environment Systems (e.g. Head-Mounted Displays (HMDs) or CAVE, Fully Immersive Spherical Projection System (The Cybersphere)).

The focus of this thesis is on HMDs Systems.

1.2.2 Research Hypothesis.

In the light of all of the potential problems, it is imperative that one must explore and determine the accuracy of the virtual interface in simulating the basic characteristics of real environments before VE is implemented by Architects for client briefing. In addition, it is crucial to evaluate to what extent people's perception of virtual and real environments coincide. Hopefully, this research will help to explain the nature of differences, if any, in the perception of real and virtual environments. In order to carry out this research in accordance with well established psychological methodology, one has to declare a hypothesis. In this case, we are using the *null hypothesis* [3]. The hypothesis of interest is as follows:

" People perceive space in VE as well as they do in the real world."

The hypothesis of interest will be tested by the following null hypotheses:

1. **There is no difference in the perception of egocentric lengths in enclosed space conditions,**
2. **There is no difference in the perception of exocentric widths in enclosed space conditions,**
3. **There is no difference in perception of exocentric heights in enclosed space conditions,**
4. **There is no difference in the perception of feeling of spaces in enclosed space conditions,**
5. **There is no difference in the perception of exocentric lengths in open space conditions.**

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[3] Null hypothesis - is a statement or set of statements, which claims that one does not expect there to be a significant interaction between the variables investigated in the experiment. It has a bearing on the statistical tests to be used once the experimental trials have been completed. What one is in effect saying is that the experimental results could be obtained by chance alone. It is the null hypothesis, therefore, that is under test, and the statistical analysis will yield results which define the significance of the interactions.

6. **There is no difference in the perception of exocentric heights in open space conditions.**

7. **The orientation of stimuli does not influence the accuracy of the perception of length and height estimations.**

Furthermore, the author will address such questions as; do humans estimate distances in virtual environments in a similar manner to the real world, and, are there any differences in the perception of quality of spaces between the real and virtual environments?

What follows is an investigation into these research hypotheses.

1.3 Organisation of this thesis.

This thesis is organised into seven chapters:

- Chapter 2 consists of reviews of up-to-date studies of spatial perception in virtual environments. Studies are reviewed in the fields of space perception, egocentric distance estimation, "feeling" of spaces and some aspects of cognitive maps. Not only are they important components of human spatial cognition, but they are also significant building blocks to the general theory of cognition. Current definitions are explored for Virtual Reality/Virtual Environments. In any research it is imperative to define terminology in order to avoid any confusion. It should be noted here that it is not the purpose of this chapter to debate issues of terminology. The chapter closes with the categorisation and reviews of currently available Virtual Reality Systems (VES).

- Chapter 3 is concerned with the experimental design of the first experiment. All the elements of experiment design process are described in detail: the experimental conditions and set-up, experimental tasks, subject group and processes involved in creating its homogeneity. The computer model and technology limitations are also reviewed.

- Chapter 4 contains the methodology and results of the first experiment. It is concerned with the perception of the egocentric and exocentric distance in enclosed spaces. In addition to these estimations cognitive maps and estimation tasks are investigated when evaluating the virtual interface. The results of statistical tests of significance are also included in order to accept or reject the null hypothesis. The results of the "feeling" of space experiment are also presented. The results of the above-mentioned statistical tests and an evaluation of presentational method are also included.

- Chapter 5 is concerned with the design of the second experiment. This includes the description of details of all elements of the experiment design process: the experimental conditions and set-up, experimental tasks, subject group and processes involved in creating its homogeneity. The computer model and technology limitations are also reviewed. The methodology and results of the second experiment are presented. It is concerned with the perception of exocentric lengths and heights in open space conditions. In addition to these estimations the orientation of stimuli influences on the perception of length and height estimations is discussed. The results of statistical tests of significance are also included in order to accept or reject the null hypothesis. The results of the above-mentioned statistical tests and an evaluation of presentational method are also included.

- Chapter 6 comprises an evaluation of the hypothesis, a general discussion of the experimental results and recommendations. It also includes proposals for subjects for future research.

The Appendices include questionnaires, experimental protocols used, raw data and all statistical data calculations.

2. SPATIAL PERCEPTION IN VIRTUAL ENVIRONMENTS- LITERATURE REVIEW.

In design environments, there is a unique opportunity to integrate the "viewer" into landscape through paths that beckon one onward through field, marsh, and woodlands, etc. Highways that caress the contours of the land rather than pushed blindly through them; gardens that lead the stroller through a succession of perceptions and discovery; buildings that welcome and co-operate with the user. In order to make that user feel comfortable in those built environments it is necessary to understand the psychological dimension underlining these processes of perception. Designers, Architects and developers of VEs should be aware of them. Therefore, in the first part of this section, some aspects of this psychological dimension are reviewed.

There is a substantial effort in the area of visual assessment to incorporate the aesthetic dimension into planning, design and management of built environments. The aesthetic has become more and more important for users. For instance, in the UK one could say that the aesthetics of built environment have become very important to the general public because of the exceptional popularity of DIY programs or due to the rocketing turn over of many DIY shops. Therefore, if one wants to use VEs to represent these environments it seems necessary to review some research into perception of aesthetics in built environments. These research fields are reviewed in the second section of this chapter.

In the last section of this chapter, research into the perception of space in VEs is reviewed. The main focus of this section is to review research into the perception of distance in Virtual Environments.

2.1 The Psychological Dimension of Perception of Space.

From the beginning of human existence man has not only acted in space[4], perceived space, existed in space and thought about space, but he has also created space to express the structure of his world.

The behaviour of individual usually suggests that they have some knowledge about their spatial environments. They are surrounded by it and no-one or nothing can be isolated from it. The environment is made up of places and objects. Places are units of environment. Objects subsist within an environment. Spatial knowledge of environments is necessary for living within them. The problem of human space has been studied by many philosophers and psychologists. It has been proved that space perception is a complex process and not fully understood. By perception, experimental psychologists understand the process of becoming aware of the stimuli in our surroundings. Giedion (1964) states that perceiving can mean both 'becoming aware through the senses' and 'getting knowledge by the mind'. We perceive different worlds which are products of our motivation and past experiences. Norberg-Schultz (1971) stated that, in general, perception applies to valid assumptions about the nature of environment, and these assumptions vary according to the simulations in which we are taking part.

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[4] Space: by space is understood the sum of successive perception of spaces

According to him we can differentiate between five space concepts: the pragmatic space of physical actions, the perceptual space of immediate orientation, the existential space which forms man's stable image of his environment, the cognitive space of the physical world and the abstract space of pure logical relation. By pragmatic space he understands a space which unites man with his natural, 'organic' environment. Man needs his perceptual space for his identity as a person, existential space makes him belong to a social and cultural totality. The cognitive space suggests that he is able to think about space, and logical space offers the tool to describe space to others. In essence, Norberg-Shulz's model is related to Telcott Person's 'System of Actions'. Person's system distinguishes four sub-systems which construct 'environments' to each other: the behavioural organism, the personality system, the social system and the cultural system.

Many philosophers have published extensive studies on space. To mention but a few: Gastan Bachelard (1964), Fridrich Bollnow (1963), Merleau-Ponty (1962), Martin Heidegger (1962), Eugene Minkowski (1932).

Merleau-Ponty was very critical of certain theories of perception psychology. He believed that 'cues' can convey the idea of space only if they are already involved in it, and if space is already known. He also discussed the existential meaning of place and direction. He thinks that depth is the most existential dimension. According to him place precedes perception and he concludes that our body and our perception always draw us to the centre of the world in the environment with which they present us. However, this environment is not necessarily that of our own life. One can be somewhere else while present in real current space (e.g. a

Virtual Environment). Therefore, space is the product of an interaction between the organism and the environment.

Space is envisaged to be a free element of nature. It is thought to be transcendental, abstract, continuous, vast and with no form. It is a repetition of the Platonic ideal concept of space as

"the mother and receptacle of all created and visible and in any way sensible thing ... the universal nature which receives all bodies ... for which receiving all things she never departs at all form her own nature and never in any way or at any time assumes a form like that of any of the things which enter into her" (Arnheim, R. (1977), p. 9)

This concept of universal space is hypothesised by psychologists as a basic condition of perception. According to Rudolf Arnheim space is experienced as the given which precedes the object in it. In the absence of such objects, he believes, space would still exist, as an empty boundless container. In other words, space is exclusively perceived as the background for the figure of form, as an *a priori* natural condition. Neither space nor nature should be overly affected by man's presence. It is important to leave Nature and its coincident image of space in balance so that space is conceived to be untouchable and must be unaffected by wilful human intervention. Furthermore, he suggests that Modern Space is a natural phenomena. It has properties similar to the field theories of light and energy, it is even present, untouchable, and abstract. Being indefinite, it cannot carry meaning and must remain the background condition to form. It cannot longer to be imagined as a medium of design. The restriction of this special framework forces designers to revise the situation and to establish volumetric space as a medium of architectural design. Space can be man-made, not found. It can be wilfully created. Its form can be made, either from a figure or from the ground. He concludes that space is not a natural phenomenon. Space seems to exist and have characteristics that are physical: scale, proportion, and size. Its shape can be measured and its limits defined.

Developments of mental images of space are essential to the development of the child and adult if he is to find his way through the complexity of environments. Jean Piaget (1955) conducted several experiments concerned with the development of spatial understanding in children. As Piaget saw it, a child learns first to recognise or to "construct" the world as a system of similarities. Secondly, he connects the things recognised with particular places, situating them in a more comprehensive totality, a space. Therefore, he concluded that space is the product of interaction between the organism and the environment in which it is impossible to separate the organisation of the universe perceived from that of the activity itself.

A concept central to Piaget's understanding of development is that of adaptation. According to him the process of adaptation consists of two complementary processes: assimilation and accommodation. Either the person assimilates aspects of environment into sets of cognitive structures he already has, or he accommodates those structures in order to incorporate some novel aspect of his surrounding. The type and balance of these aspects of adaptation give rise to distinctive features of any particular stage of development. (Canter, 1974)

However, the question of relative importance of innate factors and learning in perceptual development has not yet been resolved. It is probable that innate factors and learning are both essential to normal perceptual development. It is also very likely that some perceptual processes are much more affected than others by experience and by learning. Some research suggests that certain aspects of the basic elements of perception (e.g. perception of movement; certain aspects of depth perception) seem to be either innate or else acquired very quickly. In contrast, fine perceptual discriminations among objects (e.g. ability to distinguish visually between similar letters such as 'b' and 'd') may require much learning (Slater, 1990; Adams, Maurer, and Davis, 1986; Fantz, 1966; Gibson and Walk, 1960).

For many years psychologists have explored the process by which individuals come to know about and represent their spatial environment. This branch of psychology is called environmental cognition, developed out of early attempts to identify specific features within the urban environment, which make it memorable, or which contribute to the overall image of that environment (Jackson, 1994). These days environmental cognition takes into account not only some specific features of the environment, but also events and happenings within that environment, the meaning attached to these events, the emotions aroused by them and the significance they have to people as individuals and groups (Jackson, *op cit.*, Moore and Colledge, 1976). One of the tools for the study of spatial knowledge is a cognitive map, the term coined by Tolman (1948) during his research on rats' ability to learn correct routes. Cognitive maps can represent the processes of perception. They allow people to construct a mental representation of the environment which cannot be seen from one vantage point alone, and so they enable us to build a meaningful whole from various parts which have been previously perceived (Arthur and Passini, 1992). The cognitive map is constructed not just from the perception of environmental features, but from those features which are shaped by the individual's purposes, goals, past experience and future objectives regarding that environment. Consequently, cognitive maps are likely to contain features which make the maps meaningful to that individual (Jackson, 1994). A psychologically significant aspect of maps is that they provide an overview, a summary of potential action sequences, which enable humans to appreciate the internalised spatial structure within which a person is operating.

According to Kaplan (1973, 1976) people's ability to perceive the environment and to construct cognitive maps was developed thanks to the process of evolution. Early man had to develop it in order to survive in hostile environments. He suggests that these early maps were oriented towards processing and making sense of enormous amounts of available spatial information. This system could be divided into: anticipation, abstraction, generalisation, and responsible innovation. The ability of anticipation is needed for making quick intelligent decisions. This is important for functioning in the environment. The organism would be faced with a huge amount of possibilities. This amount of information can be processed only by the system allowing for information overlapping. It would ensure the best way of sorting experiences. A cognitive map would be built up from many different sources and it would enable access to the representation from a large number of experiences. Abstraction allows for the reduction of information which we are faced with. People are abstracting from previous situations to enable the transfer of prior experience to the present. This in turn requires the ability to generalise from situation to situation. Abstraction is aided by the capacity to shift scale. We are capable of making the cognitive leap from a representation of a room in a house, to a representation of a whole town, all with little effort. Although one takes this process for granted, it is more important in reducing detail and enabling abstraction (Jackobs, 1994). The success of the species was dependent upon the ability to derive appropriate solutions to problems never before encountered, i.e.: "responsive innovation". It seems that Kaplan supports Gibson's theory.

Cognitive maps develop not only in terms of the quality of information they contain, but more importantly in terms of the quality of detail contained. The development of spatial knowledge results from a discrepancy between what is observed in an environment and what has been stored in the individual's cognitive map of the environment (Moar and Carletan, 1982; Thorndyke and Hayes-Roth, 1982; Hart and Moore, 1979; Sigel and White, 1975). However, there is a problem which needs to be solved. Do people really hold 'maps' in their heads? The answer depends on what people produce as a representation of space and what is actually occurring in their minds (unfortunately, it is still not known). Even if researchers eventually demonstrate that the map is an inappropriate form for spatial representations it will not remove the value of mapping as a research tool. Precisely because of the efficiency, variety and summarising qualities of sketch maps they present a valuable means of exploring spatial representation systems.

Errors appearing in sketch maps provide researchers with evidence that there is a structuring process imposed upon experience, or at least upon sketches abstracted from experience. Using sketch maps alone, it is difficult to say whether these distortions arise in the process of sketching brought about by the use of a set of simple stereotype patterns to convey spatial information, or whether they are an aspect of the cognitive system developed as a means of storing spatial information. To resolve these possibilities one needs to deal with data which does not employ or invoke the sketching procedures. The estimation of distances is particularly useful in this respect.

The second problem faced by researchers using maps is that only a proportion of the population will ever be able to sketch a map. The type and quality of sketch maps produced often depends in part on the respondent's general spatial abilities. Furthermore, if we accept that a sketch is somehow extracted by a person from memory, it seems highly probable that some respondents will be more able to perform this action than others. Canter stated, after his research into perception of space by blind people, that this has distinct implications for the use of maps, because it suggests that it is the spatial arrangement of places and not their visual organisation which is crucial (Canter, 1977).

Our knowledge of distances, wayfinding or route navigation is primarily based upon direct environmental experience (Gale, Golledge, Pellegrino, Doherty, 1990). This experience comes from actively moving through environments. Downs and Stea (1973) state that spatial checking is continuous and errors about location and attributes are corrected by feedback from spatial behaviour. Indirect techniques involve usage of certain media: maps, and graphical representations, through to linguistic communication.

Over the years psychologists used the concept of 'cues' in association with space perception. People use a variety of perception cues in order to answer questions related to the shape and distance of objects within 3D environments. They use them to understand any given 3D environment. There were some attempts to replace this concept. It is still within the academic world because it has validity which is to be found in its implicit recognition of the symbolic nature of the perceptual process as it functions in any concrete transaction (Ittelson, 1960). The Penguin Dictionary of Psychology (1985) defines 'cue' as an aspect of a stimulus pattern that may be used in making a discrimination between that stimulus and any other; an identification mark, a clue. The relationship of cues to space perception is intuitively obvious to most people. However, it is not obvious that a cue is something that can be pointed to; rather it represents a complex interrelationship between a number of aspects that must be taken into account. Ittelson (1960), quoted after Graham (1951), categorised cues as:

1. *Size.* "Our discrimination of distances is dependent on the size of the retinal image provided by an object".

2. *Overlay, interposition or superposition.* "The cue of interposition occurs when an overlapping object is said to be nearer than an overlapped object."

3. *Linear perspective.* "A constant distance between points subtends a smaller and smaller angle at the eye as the points recede from the subject."

4. *Aerial perspective.* "When surface details of an object do not provide conditions for requisitive visual contrasts, a subject reports that the object seems far off."

5. *Movement parallax.* "When subject's eyes move with respect to the environment, or when the environment moves with respect to a subject's eyes, a differential angular velocity exists between the line of sight to a fixated object and the line of sight to any other object in the visual field."

6. *Light and shade.* "Various combinations of shadow and highlight are reported as objects having various dimensions and lying at different distances."

7. *Accommodation.* "Differential aspects of 'blur circles' in a retinal image may elicit spatial discrimination."

8. *Convergence.* "When an object is at a great distance, lines of fixation to the object are parallel. When the object is near at hand, the subject's eyes are turned in a co-ordinated manner so that the lines of fixation converge on the object. Convergence may serve as a cue for depth responses."

9. *Stereoscopic vision.* "When a subject regards an object in space, the retinal image in the left eye is different from the retinal image in the right eye. The difference in retinal images serves as the basis for many spatial discriminations."

To this list we have to add at least the following: *shape, colour, brightness,* and *position in the field. Colour* has been proven to be a cue to depth perception, however, the cue can lead to ambiguous results. Egusa (1983) has examined the effect of *brightness,* hue and saturation on perceived depth. He presented subjects with two achromatic stimuli. He found that the perceived depth between them increased with increasing brightness differences. However, the side that was judged nearer, either the darker or the brighter side, differed across the subjects. Results that are more consistent were obtained, however, when testing achromatic-chromatic and chromatic-chromatic combinations of stimuli using the colours red, green and blue with equal saturation. It was found that red appeared to be "nearer' than green or blue, and that green was "nearer" than blue. This effect is often referred to as "chromostereopsis". Even taking into account limitations of current VEs these results have to be taken into consideration during the process of designing VEs in order to omit unwanted effects due to these colour phenomena.

An object's *position in the field* can also convey information about distances. There is a general pattern of depth assignments assumed in visual processing. One assumption is that objects in the lower parts of pictures are closer to the observer than objects in the higher parts (Berbaum, Tharp and Mroczek, 1983).

The above listed cues have a very important role to play in the process of space perception. These cues help people to perceive space. One could classify their functions as: *differentiation, identification and location.* They are interrelated. Ittelson (*ibid.*) describes them as follows:

Differentiation is a function of indicating "togetherness and apartness" (Ames, 1955). Before there can be a visual space experience at all, there must be visual indications of certain partial togethernesses apart from other partial togethernesses. The visual cues most importantly involved in this function are colour, brightness, light and shadow, relative movement, contour characteristics (sharpness of edge, coincidence of edge, overlay), double images, accommodation, and convergence.

Identification: each differentiated partial togetherness is experienced as having its own particular object's characteristics. Any particular experience is partly composed of meanings conveyed by subtle visual characteristics, partly consisting of shape and solidity conveyed by visual cues such as light and shadow, stereopsis, shape, size, and perspective.

Location characterises an object's position in terms of distance and orientation. The more important cues involved here are size, overlay, position, stereopsis, perspective and parallax.

Distance can be perceived via both monocular and binocular depth cues. Monocular depth cues provide equivalent percept to both eyes; cues are equally effective whether using one or both eyes. Examples of monocular cues include linear perspective, texture, shadows and lighting, motion, and size. Binocular cues, on the other hand, take advantage of both eyes by allowing each eye to receive slightly offset views of the same visual scene. Binocular disparity is a binocular cue which creates the phenomenon of stereopsis.

It has been shown that humans do not need all cues in order to perceive depth. Julesz (1971) in his experiment proved that people can see depth without having to see surface properties such as lines or shapes. However, it also has been shown that our ability to correctly perceive shapes by stereopsis alone varies with the distance that the observer is located from the object. Our ability to perceive shapes from stereopsis is best when we are at intermediate viewing distance close to one metre (Johnston, Cumming and Parker, 1991; Crvarich, 1995).

Cues are a very important part of our process of perception. Cue conflict can cause motion sickness or as it is referred to in the research of VEs 'simulator sickness'. Casali (1986) has implicated a cue conflict as a source of motion sickness. Cue conflict occurs when there is a disparity between senses or within a sense. For motion sickness in VEs, two senses are held responsible - the visual and vestibular senses. In a fixed-base simulator, the visual system senses motion while vestibular system senses no motion. Thus, according to the cue conflict theory, a conflict results (Kolasinski, 1995).

McCauley and Sharkey (1992), and Kolasinski (1995) analysed potential sources of cue conflict which could occur in VEs. They suggested that ambiguities among visual, vestibular, and proprioceptive cues may be created in a VE in the representation of motion because these systems provide visual cues consistent with self-motion, but not corresponding vestibular cues. Such cues are necessary for supporting postural control and locomotion, with vestibular cues and peripheral vision appearing especially important for spatial orientation and self-motion detection.

Cues and their functions always have to be taken into account during the process of designing real or virtual spaces in order to be perceived correctly by humans. Cognition is a complex process that is predicated by the interaction of individuals' sensori-motor and neurological systems. Spatial cognition is an important building block to general cognition, as it is the process by which we perceive, store, recall, create, edit, and communicate spatial images. The process of spatial cognition allows us to create meaning by manipulating images of the world in which we exist, and those which originate in our own minds. Research on distance and depth perception is ongoing. In sub-section 2.3.3 some of the research concerned with dimension estimates are reviewed.

At the end of this section one feels it necessary to include a short review of some studies concerned with individual differences which seem to be relevant to the field of Architecture and design. It is said that every one is different. It is said that even if there are some laws of average behaviour or tastes one could find that there would still be too much individual variation, and that these laws could be of little practical value in trying to predict people's experiences of buildings, cityscapes or landscapes. However, an empirical answer is that consistencies in behaviour have been observed between both identifiable groups and individual variations which has stimulated much psychological research. Furthermore, the occurrence of individual variations stimulated much psychological research, and these research projects are ongoing. One could list some of the individual differences as follows:

Age, sex and class.

According to Hutt (1973) men perform differently from women in a great number of psychological situations. Males are physically stronger but less resilient, they are more independent, adventurous and aggressive. They have greater spatial, numerical and mathematical ability. However, females possess sensory capabilities that facilitate inter-personal communication. They mature more rapidly, and their verbal skills are precocious and fluent. However, Hutt and other psychologists admit that there is a great overlap between sexes. Additionally, the existence of such differences in a large number and wide range of human population does imply it is necessary to take them into account while dealing with perception of spaces and constructing any architectural entities.

Bromley (1966), Witkin (1950, 1952) showed that age differences are as broad in their influence as those of sex. Older people have different psychological reactions to young people. They have different job experiences. They have been brought up in a different culture with different attitudes, tastes, etc.

There is also disparity between people in different classes. The experience and attitudes of people in different classes is demonstrably diverse and because the variable of age and sex also inter-relate with those of social class.

Cognitive complexity.

It is possible to distinguish individuals in terms of the number of dimensions they themselves have for constructing people and things and the relationships between these dimensions (Canter, 1974). For instance, one Architect may think about buildings almost entirely in terms of proportions of their façades whereas another Architect may think of them in terms only of their cost per square metre. They are both similar in that they look at buildings from a single viewpoint. These differences relate to their cognition and underlying patterns or structure. This distinction draws on analogies between different types of communication channel and the quantity and type of information they carry and support. According to Bieri (1966), Johnson (1955) the more complex person is more likely to be consistent in the view he holds and is more able to deal with conflicting information.

Creativity and intelligence.

For years psychologists have been using tests of intellectual abilities. These tests, somehow controversial, deal with verbal, spatial and numerical aspects of human cognitive abilities. They measure the degree to which a person is able to cope with intellectual problems. However, they only deal with a person's ability to solve problems which have a specific solution, which leads to convergent answers. They are important to Architecture because the users of buildings have different intellectual abilities and thus would be able to cope or deal with the building in different ways. This is especially the case for buildings normally housing groups from different ranges of population. For instance, public buildings may well be used by people drawn from the lowest as well the highest range of intellectual level.

Interpersonal distance.

Altman (1971), Porter, *et al.* (1970), and Sommer (1969) stated that the use of space may be considered both as determined by people and as a determiner of human behaviour. People use space as yet another medium of communication. They use it to indicate their feelings of, or attitudes towards, the type of activity in which they engage. However, Porter, *et al.* (1970) tested interpersonal proximity. The results of their experiment indicated that it was not possible to show that anything was communicated at all. It means that despite the fact that people may be able to interpret intentions of feelings from the use of space in some situations, this does not imply that people actively use space as a means of expression. Nevertheless, experiments by Festinger, *et al.* (1950) and Atkinson *et al.* (1993) concerned with a person's location influenced the information he received. The people he met and hence the friendships he made demonstrated that the location of person does influence his relationship to information. Their studies showed that the relationship between eye contact and distance indicates the amount of information they try to obtain by looking. The results of Sommer's (1969) experiments indicate that people arrange themselves in various positions in order to minimise or optimise the amount of information they receive from others. The implications for designers are that people are not passive but active users. They try to find a situation which optimises the balance between communications or information, which they want to receive or information they want to project. Designers have to think more carefully about people who will be using their buildings, why they have certain attributes and what they will be doing and how they will be doing it. People are able to talk to one another and to agree amongst themselves how they will use the space available to them. If this is a case then client briefing is an ideal arena for these types of discussion.

In this section, some aspects of the complex issues of human psychology were reviewed, specifically those which have to be remembered by designers during the process of constructing people-oriented environments. By remembering that humans are complex animals and by understanding their psychological processes and their requirements, designers can facilitate human needs for better living environments. In the next section some research in the perception of aesthetics of those built environments are reviewed.

2.2 Perception of Aesthetics in Built Environments.

The main concern in built environments aesthetics is understanding environmental influences and translating that understanding into environmental design that is judged favourably by the public. Aesthetics is only one among many considerations in environmental design, but it is an important one. The aesthetic quality of built environments influences immediate experience- a sense of well being- in these environments. It may also influence subsequent reactions to both the setting and its inhabitants. Furthermore, it may manipulate spatial perception and behaviour in that individuals are attracted to an appealing environment and are likely to avoid an unpleasant one. With the knowledge of the relationship between properties of visual environments and human affects, Architects and other design professionals can better plan, design, and manage settings to fit preferences and activities of the user. This, in turn, may contribute to enhancing the quality of life.

It is evident that the aesthetic quality of the environment is important to the public. Canter (1969) indicated that for both Architects and non-architects, the major factor in response to simulated environments was an aesthetic one-pleasantness. Most of the decisions about visual qualities of the environment are often made by design professionals. This is very true for large-scale facilities, such as offices, institutions, and commercial and recreational facilities. All of these facilities are perceived and experienced on regular basis by a large number of people. Canter *op cit.* (1969), Groat (1982), Hershberger and Cass (1974) indicated that professionals differ from the public in their environmental preferences. These differences can result in widespread effects. This only stresses the importance of client briefing and the use of VE technology.

As mentioned above, the aesthetic concerns seem to be central to many issues in architectural and environmental planning. However there is little scientific evidence concerning the manner in which beautiful and ugly interior environments influence human behaviour. One of the earliest experiments were conducted by Maslow and Mintz (1956). They examined the effects of "beautiful" and "ugly" rooms on participant's judgements of the amount of "energy" and "well-being" reflected in photographs of human faces. The experiment's results indicated that participants in the beautiful room gave significantly higher ratings on these two dimensions than participants who were tested in the ugly room. They hypothesised that the environmental aesthetics impact is indeed important and that attractive and unattractive rooms will exert, respectively, a positive and negative influence on human behaviour.

Richard Locasso (1988) based his experiment on those of Maslow and Mintz (1956). His experiment examined task-oriented behaviour. The main focus of his study was on the initial exposure to a space, as did Maslow and Mintz, as opposed to long-term effects that could appear over time via repeated visits to a space. He also used two rooms- beautiful and ugly. Each participant was exposed only to one room. The participants were asked to fill a questionnaire containing eighteen bipolar environment description adjectives. Every participant was presented with 32 photographs taken in the shopping centre. They were asked to rate photos on seven rating scales. The results of Locasso's experiment did not replicate the findings reported by Maslow and Mintz experiment. Photos of human faces were rated no differently when done in a beautiful or an ugly room. His research found no effect of surrounding on perception of photographs of human faces. On the other hand, the aesthetic impact of the physical surrounding is important. People go to great lengths and expense to surround themselves with that which appeals.

It has been said that people attach some meaning to architecture by way of convention, use purpose or value. This can vary from a feeling of warmth to some profound feelings of beauty. Meaning is considered very important in perception (Creelman, 1966). Hershberger and Cass (1974), Hershberger (1988) conducted a study concerned with the influence of form, colour and space on the

Architects' communication to the users of their buildings. They were concerned with the correlation between Architects' intended meaning for their building and the perception of the layman. They asked if the Architects and laymen share the same representations when they experience architecture. They designed an experiment in which Architects' and laymen's' attributions of meaning to building were directly compared. Each group of Participants were asked to rate the connotative meanings of twenty-five building aspects represented by colour slides. The buildings were chosen from the university campus. The semantic differential scales were used in order to measure connotative meanings. The results indicated that Architects were more concerned with the aesthetic nature of the building. The laymen were more concerned with the pleasantness of the building, their spaciousness, comfort, cheerfulness, and the like. Furthermore, the results confirmed that the Architects group was more homogenous in their judgments than the other group. The difference in results between Architects and laymen was accredited to the Architects' professional education and the exceptional diversity among the laymen group. It seems to be an important finding because there is a need for Architects to be taught how laymen perceive architecture. Architects must be taught how forms, spaces, scale are interpreted by laymen, so they can consciously manipulate them in such a way as to successfully communicate it with them.

Of course, if one hopes to communicate one's intentions to those whom use a designed building it is necessary to know the meanings that they attribute to the form, space, colour, light, and so on. In order to do so Architects must learn how to predict user responses to the building. As has already been mentioned in the introduction to this thesis, a client briefing or client-user group is one of these methods. Commissions are obtained by Architects not only in their own community but also throughout the country or from different continents. They are not only obtained from clients from the same socio-economic class or the ruling elite, but also from client groups having widely diverse socio-economic and ethnic backgrounds (Appleyard, 1969). It is quite possible for Architects to predict how clients or users will respond to their design if they come from the same socio-economic zone or share environmental and architectural believes. If the opposite is the case, then the problem of prediction becomes acute. If the Architects attribute to those groups' values, needs or interests that in fact they do not have, they are likely to make erroneous predictions of how such groups will comprehend and use the building they design. Hershberger and Cass (1974) developed an interesting experiment aiming to address this problem. As mentioned above, Architects differed from laymen in their perception of building attributes. In order to conduct this study they developed 30 semantic differential scales. Photographs were used as presentation media. They hypothesised that pictures could be useful during the initial stages of design. In their experiment, a view of 12 prototype house examples were judged on semantic scales. The subject group was divided into five groups which were assigned to five experimental conditions: single colour slides, colour slides, colour film, black and white film and black and white video tape. The study results indicated that there was a significant difference between judgements of the buildings across all conditions. Judgments in the real world indicated a greater degree of organisation than those based on the media. The buildings viewed in person were judged significantly more beautiful, pleasing, friendly and unique than buildings judged on the basis of colour slides or colour film. In addition, the buildings were judged as more quiet and safe during a real visit, whereas the media seemed to enhance the size and publicness of the building. Media were not able to express and represent lighting or temperature scales. Furthermore, the results of the experiment revealed that media such as colour film and colour slides could not be used to simulate actual design environment. These results further support the usage of VE technology for representing design spaces as it does not have the same limitations as the slides or colour films.

Light and colour must be taken into account in the architectural design. It is known that the appearance of any object depends to a great extent on the light in which it is seen. The quality of natural light varies with the time of day or night. The apparent colour of a building, as seen under natural light, changes not only with the hour of the day, but also from day to day and with the time of the year. The same building or object will look different in colour on a sunny day than on the dull one. Their aspect will change when seen against a blue sky as compared with a dark sky of winter. Not only does the apparent colour of a building or objects change during the day, but also their apparent form because of the constantly changing shadows, which define their form. Under artificial light one finds a different set of conditions. Artificial light usually stays constant. However, the appearance of a building or object under artificial light will depend on the quality of the light, its distribution, and its direction. The apparent colour of the building or object will depend not only on the colour of the light source but also on its spectral energy distribution. This applies both to the exterior of the building and to interior space.

Faulkner (1972, pp 5-6) summarised the importance of colour and its aesthetical purpose as follows:

1. **Creation of atmosphere.** Bright colour schemes for buildings tend to express high spirits and enthusiasm. A quiet scheme may express dignity and relaxation.

2. **Suggestion of unity or diversity.** A uniform colour schema may suggest unity, while feeling of diversity can give variety colour scheme.

3. **Expression of the character of material.** By using, for instance a red tile for the roof, grey stone for the walls and pine for the trims, the essential character of the materials is clearly stated.

4. **Definition of form.** A line, a two-dimensional surface, or a three dimensional volume is defined if its colour contrasts with its surroundings.

5. **Affect on proportion.** By using materials with contrasting colours vertically one may promote the sense of height. By positioning these materials horizontally one could achieve the feeling of breadth.

6. **It brings out scale.** By using elements of uniform colour, buildings would look monolithic. Their scale would be difficult to judge at a distance. If one uses elements of contrasting colours then the scale of the building is more easily conveyed.

7. **Sense of weight.** Elements in dark colours look heavy, however, those in light colours look light in weight. For this reason the colour of tall structures is sometimes graduated from dark at the bottom to light at the top.

It has been hypothesised that some lighting designs communicate impressions of meaning to the user of the space (Faulkner, (1972); Martyniuk, Flynn, Spencer and Hendrick (1973)). This perception of buildings and objects under light could also be referred to the theory of systemic visual cues, that tend to be recognized and interpreted in somehow consistent ways by the users who share cultural values and background. They also state that some psychological aspects of lit spaces can be recognized as an exercise in visual communication. By changing the character of patterns of light and colour designers change the composition and relative strength of visual signals and cues. By this action designers alert some shared meaning for the user. It has been observed that some light patterns seem to affect personal orientation and user understanding of the room or environment and their artefacts. For example, it is known that user's consciousness and attention can be affected by spot-lighting or shelf-lighting. Furthermore, the user's understanding of the room size and shape can be influenced by wall-lighting or corner-lighting. Considered as a system, these elements establish a sense of visual limits or enclosure (Martyniuk, *et. al.* (1973). Also, lighting can help designers to set moods, e.g. soberness, playfulness, pleasantness, etc. Equally, lighting can be use to affect such psychological states as intimacy, privacy or warmth. It can be used to produce atmosphere or festivity or sombre place for meditation. By using lighting, a designer can enforce often fundamental impressions or moods in satisfying some requirements of the constructed environment. Martyniuk, *et al.* (1973) conducted an experiment consisting of three independent conditions (three rooms with different type of lighting were tested simultaneously, with independent subject groups). The three rooms varied in size and shape, although the functions were similar because all were arranged as conference rooms. In each room similar lighting models were utilised: 1) overhead fluorescent light, 2) only illuminated from the wall, combined setting 1 and 2. The results of their experiment suggested that lighting could influence impressions of perceptual clarity, impressions of spaciousness and relaxation and impressions of spatial complexity. Furthermore, they also hypothesised that it is possible to identify instances in which lighting design may present cues that influence some categories of behaviour, such as attention, selection of path and selection of sitting and sitting position, e.g. in order to achieve the impression of relaxation a designer should use peripheral lighting.

Another problem that faces Architects and designers is the problem of personal preferences or taste. Kaplan (1979a) has hypothesised that preference judgments are neither uninformed nor idiosyncratic, but reveal common patterns of aesthetics values. On the other hand, Urlich (1983) stated with reference to the natural environment, that there is absolutely nothing in this substantial body of research to suggest that aesthetic preferences for natural environments are random and idiosyncratic. Oostendrop and Berlyne (1978c) stated that individual differences in taste for architectural styles may not be as large as some art theorists want us to believe. Some Architects and critics have suggested that in order to achieve contextual design one should leave the creative designer unconstrained by guild lines or the legislative barriers. However, Brolin (1980), and many others agreed that there should be certain design principles. There are established regulatory procedures and normative standards for evaluating contextual design and these are applied to a variety of feasibility studies. However, it is still difficult to write design guideline documents which would be not written in a purposefully open-ended fashion. It means that it is impossible to identify the specific types of contextual-design strategies. Many guidelines specify certain number of design relationships (e.g. scale, height or volume) (Groat, 1984; Lu, 1980).

Wohlwill and Harris (1980) based on the results of their experiment concluded that there was a high degree of concusses among small groups of respondents in their rank-order judgments of "fittingness". The results also suggested that there was virtually no difference in response patterns to the judgment of degree of "appropriateness" and the degree of liking. Based on these results, it could be suggested that preference judgments of contextual relationships may actually be highly consistent among various groups of respondents. It is clear that their research results brought to light two distinct aspects of the issue: 1) the consistency among various groups of respondents, and 2) the consistency with particular types of contextual-design strategies preferred over others. The former is concerned with differences among people; the latter, with differences among physical forms. Groat (1984) in her investigation studied the impact of only exterior design attributes. She has chosen urban and campus scenes, which were analysed in terms of three components of design strategy:

1) *Site organisation* was concerned with spatial patterns that buildings imposed on the site. It included setback distances, landscaping patterns, and circulation pathways.

2) *Massing.* Its building volumetric composition (shape, height, and complexity of overall form).

3) *Façade design.* The surface treatment of planes that defined the external envelope of the building.

She used a set of colour photographs consisting of a range of twenty-five urban scenes. Two independent sample groups were used. The first group consisted of seventy three nonexperts and the second group consisted of twenty four experts in the field. Each respondent was interviewed separately in either his or her home or office. The results obtained by her pointed out that there is a much higher level of consistency in preference judgments of contextual capability than is customarily suggested in much of architectural literature. The data has also suggested that design strategies that embody a relatively high degree of replication, especially in aspect of façade design, are consistently preferred over other types of design strategy. It would support Brolin's argument (1980) that small-scale façade details and ornaments may be critical elements in contextual design. On the other hand, Carlhian (1980) augured that buildings can achieve compatibility with their surroundings primarily through replication of site organization and massing. However, the results of the investigation here would suggest that such design strategies are unlikely to be appreciated by the public.

It has been suggested by Talbot (1988), Talbot and Kaplan (1984), Kaplan (1979a), Newman (1972) that planners of urban settings should be aware of the richness of personal affordance no matter what size the settings are. Talbot (1980) conducted an extensive study focused on the examination of the importance that an individual place has on size as well on other physical qualities of real places in the city. Both residential neighbourhoods and urban open areas were examined in her studies, and various questions about the design and arrangement of these spaces were considered. It has been noted that people are good at quickly recognizing what they like, but not as good at verbalizing the reason underlining their preferences (Kaplan, 1979a). The results of Talbot's studies support this point. For instance, people in her study say that they like a large place, and they point out similar characteristics when describing places they like and places that are physically large. The results of the rating task indicate that physical sizes are not related to people's preferences for different places. Having access to a large place has a limited impact on people's feelings of satisfaction with their surroundings. People in their studies strongly responded to smaller and more natural areas. A strong impact on neighbourhood satisfaction appears to arise from the presence of trees, gardens and other natural settings. However, people prefer natural areas that they perceive as being "spacious" and these preferred areas share certain physical attributes. These attributes relate to the coherence of a space: the sense of substance or meaning that setting reflects: the sense that the individual elements within the space are complementary to one another and essential to the place itself (Kaplan and Talbot, 1984; Kaplan, 1978a). Talbot (1988) suggested a set of guidelines for Architects and designers. They are as follows:

1) Encourage a moderate degree of variety in the treatment of adjacent land parcels, encompassing complementary sizes and shapes of lots as well as interesting mixtures of building placements and styles.
2) Since research indicates that natural elements strongly influence the perception of large regions, manage the landform, trees[5], and other plantings in such a way that a strong image of the urban natural landscape is promoted. Patterns of foliage soften harsh edges of buildings and contribute visual continuity to large scale urban settings, which are often sorely lacking in coherence.

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[5] For the importance of trees to those who do not live near parks see Nasar, J.L., 'Adult viewers' preferences in residential scenes: A study of the relationship of environmental attributes to preference', *Environment and Behaviour*, Vol.15, pp.589-614.

3) Create and maintain the unique qualities of each setting. Protect the physical elements that are most unique and valued at each site- an old, distinctive tree, a sharp incline, or winding pathways, perhaps- and add elements that enhance the character of the existing space.

4) Within the individual setting, create distinct, well-defined regions with clearly differentiated characteristics and functions. Carefully lay out the pathways and other connections among the different interior regions, since they will suggest similar linkages between the entire setting and the larger surroundings.

5) Capture the sense of mystery within the setting, maximising the potential for partially screened views that are quickly resolved as an individual moves through the area. This gives multiple definitions to setting and adds to its perceived size, since the individual experiences different facets of the space while continuing to move within it.

6) Providing multiple entrances into settings. Again, this enriches rather than limits the connections between the immediate setting and the larger environment. It also enhances the perceived substances or meaning of the setting, since it increases the opportunities available to the individual.

7) Imagine the individual within the setting and create a number of partial enclosures within each space. Each setting should offer a number of small, comfortable, somewhat sheltered spots. Each should be a distinct area within which the individual can appreciate a meaningful bit of nature, such as a group of plantings or a low tree. (Talbot, 1988, pp.298-299)

These are very interesting and important suggestions for designers with regards to individual preferences of spaces. The author believes that they should be also applied to VE in order to present the technological ability of representing designed spaces. By using these guidelines it is possible to take advantage of these findings and present VE in the best possible way by making clients comfortable in VEs. Furthermore, the results suggest that the belief of many designers and Architects that it is always necessary to have more land in order to design open spaces is not true. The feeling of spaciousness is important to many people but natural settings that are physically large are not necessarily preferred. It is possible to achieve the perception of spaciousness in relatively small places by manipulating physical elements within the setting to increase its coherence and to maximize the perceived opportunities for individual involvement.

2.3 Spatial Perception in VE- Distance Estimations.

One of the most systematic experiments was conducted by Lampton, Knerr, Golberg, Bliss, Moshell, and Blau at the U.S. Army Research Institute (1994). They developed a set of tasks known as the Virtual Environment Performance Assessment Battery (VEPAB). It is a set of tasks developed in order to measure human performance on vision, locomotion, tracking, object manipulation, and reaction time performed in 3D, interactive VEs. As the scope of the present report is the perception of space, the author centres his review on a small part of VEPAB: vision. Their experiments included the recognition of a familiar object (a human figure) and the estimation of the size of, and the distance to, the object. Acuity was measured using a standard Snellen eye chart placed at the end of a 20-ft corridor. All participants were asked to describe the visual scene and were not told about the eye chart. The controller of the experiment moved the subjects' eye point forward, towards the chart at one foot intervals and recorded the distance at which subjects could read the top line of the chart. Colour vision was tested using digitised Ishihara plates. The plates were covered with colour dots. Dot patterns within the plates formed numerals that subjects had to read aloud. All subjects were visually tested before immersion. A digitised picture of a human figure was placed at the end of a 40 ft corridor. The subjects were asked to identify the object and asked to estimate its height. Then they were told the correct height, 6 ft, and asked to estimate the distance to the figure. The experimenter then informed the subjects that the figure was 40 ft away and the figure started to move forward. The subjects were asked to call out when the figure was 30, 20, 10, 5, and 2.5 ft away. Twenty-four research subjects took part in the experiment. All of them had normal vision. The mean distance at which participants could first recognise the eye chart and read the top line of the chart was 4.65 ft, for about 20/860 acuity. The first 16 subjects had maximum scores on the VE colour vision test. The rest of the subjects did not recognise all numerals but that was attributed to the weakening of the HMD colour display. All of the subjects recognised the figure as a human. The mean height estimate was 62.83 in. (SD = 8.2). They found that the VE distance estimation was less accurate at shorter distances. The weak points in their experiment included that they failed to adjust the subjects' eye-level. Some of their taller participants reported that their estimation of the height of the object was distorted because of the difference between their real-life eye level and the VE one. The second problem which was not addressed was that subjects could memorise the Snellen eye chart and that could contribute to falsification of their experiment results.

Daniel Henry (1992) carried out an experiment into distance estimation at the Human Interface Technology Laboratory (HITL) in Washington. He conducted his experiment at the Henry Art Gallery and in the laboratory. He compared estimated distances in real life, to those in fixed and tracked conditions. His findings suggest that distances perceived are smaller in simulated environments.

The results also indicated that perceived distances are underestimated by more people in the virtual environment than both the monoscopic and stereoscopic walkthrough representation types. The subjects reported that they were often lost in the VE. However, Henry's results cannot be considered conclusive. His subject group was made of Architects. However, during the conducting of the experiment, because of the low number of Architects, he added some students in order to make up numbers. This broke the homogenity of subject group. However, he states that "This does imply that the results of this study can, strictly speaking, only be applied to this group of people". He did not check subjects' vision. Thus, it cannot be concluded that all of the subjects perceived correct visual cues. This also contributed to the lack of validity of the results. Prior to his experiment some of the participants had already been to the museum several times, so they were familiar with the spaces. This excluded the novelty factor and influenced their judgement. At the same time he did not follow the rule that an experiment's conditions should always be the same for all subjects.

In London, Slater, Alberto and Usoh (1995) conducted an experiment into spatial awareness. They centred their research on three indicators of spatial awareness: a recognition task, a location task, and a navigation problem. This consisted of mental reconstruction of the geometry of the target area and the relationship of this to the sense of presence.

Their subject group was made up of 12 people. Their only pre-experiment requirement was that all subjects should be fluent in English in order to complete a questionnaire. No other tests were administered. Part of the group was immersed into the VE, but others were not. All of the subjects had to search for a plant placed somewhere in the location. After leaving VE they were taken to the real location, the real counterpart of the virtual location, or another part of the building that was not the correct location (though it looked similar in many respects). The examiner informed them that they would be taken to two locations, one correct and the other incorrect. After having visited both locations they had to make a choice as to which was the correct one. After making their decision they were taken to the correct location, but with their eyes closed. Once in that room they could open their eyes, and they were asked to find a plant placed in the real room as it has been in the virtual location. The time taken to find the plant was recorded.

During the experiment all conditions were kept as similar as possible, apart from immersion/non-immersion. The non-immersed subjects used exactly the same system, except that they viewed their images on a TV screen.

In the immersive VE they were presented with one of two rendered scenes. The first had colour cues as similar as possible to the real location. The other room had colour cues similar to the incorrect room. The purpose here was to see whether subjects would use spatial and layout cues in the recognition task (recognising a correct location), or whether the colour cues would be used. After their experiment all the subjects were asked to complete a questionnaire.

The results were surprising. Slater *et al.* wrote "... we could find no relation between immersed and non-immersed subjects! That is, in the case of the recognition task, and in the time to find the plant in the real location, and even in the case of the presence score, there was no difference between the immersed and non-immersed subjects!". This is very important to the topic of the present research as it suggests that people utilised their cognitive skills in the same way in the real and virtual environments. They also found that the characteristics of a participant's way of perceiving space was somehow more important than the computer platform. They also noticed that people who were able to achieve a sense of presence in immersive or non-immersive types of VE were better equipped to carry out the tasks. Furthermore, the people for whom visual cues are more important were also better at carrying out the tasks.

In their previous work Slater and Usoh (1993b, 1994) classified factors influencing presence into two categories. The first category includes external factors that contribute to presence. These factors include technological characteristics of Immersive Virtual Systems (IVS): the extent of the field of view, outside-the-head sensations, degree of interactivity, the behaviour of objects in VE, and others. They reviewed work of other researchers and summarised these factors as follows:

1. High-quality, high-resolution information should be presented to the participant's sensory organs, in a manner that does not indicate the existence of the device or displays.

2. The environment that is being presented to the participant should be consistent across all displays.

3. The environment should be one with which the participant can interact, including objects and autonomous actors across that spontaneously react to the subject.

4. The self-representations of the participant, that is the participant's 'virtual body', should be similar in appearance to the participant's own body, respond correctly, and be seen to correlate with the movements of the participant.

5. The connection between the participant's actions and effects should be simple enough for participants to model over time. (Slater, Usoh, and Steed, 1994, pp. 131)

The second type of factors influencing presence are called internal factors. These factors determine the responses of different people to the same externally produced stimuli. They include the mental models and representation systems that structure a participant's subjective experience.

Slater *et al.* (1994) conducted an experiment with the aim of assessing the level of presence in immersive virtual environments. They used the idea of 'stacking depth', that is, where participants can simulate the process of entering the virtual environment whilst already in such an environment, which can be repeated to several levels of depth. The subject group was made up of twenty four people randomly assigned to experimental conditions; stacking environments and going through environments via doors. The experiment was run on Division Pro Vision200 system with a Division 3D mouse and a Virtual research Flight Helmet. All subjects saw a VB as a self-representation. Presence was assessed by subjects as "being there", the extent to which they experienced the virtual environments as being a representation of the real world and the extent to which the subject experienced the virtual environments as places visited rather than images seen. The findings indicated that subjective reporting of presence was significantly positively associated with visual and kinaesthetic representation systems, and negatively with the auditory systems. They noticed that it was not surprising because the VES used were primarily visual.

The very important components of presence are spatial orientation, distance, and dimension estimations. Lackner, and DiZio (1998), Colle, and Reid (1998), Waller, Hunt, and Knapp (1998), Ruddle, Payne, and Jones (1998), Hancock, Hendrix, and Arthur (1997), Arthur, Hancock, and Chrysler (1993), to mention a few, investigated spatial awareness in virtual environments.

One of the most interesting characteristics of VE is its flexibility in terms of possible modes of "entering" it. Users can take many positions within virtual environments. Lackner and DiZio (1998) carried out research into different ways of entering virtual environments and the influence of entering points upon people's perception. They believed that if there were big differences between virtual environments and real ones in this respect, it would reduce the speed of the user's abilities to develop spatial orientation and a sense of presence within it. Experimenters studied an environment that they called 'microgravity'. This environment characterised the ability of users to freely float within it. This gave users a unique visual perspective and patterns of touch and pressure cues on the body surface. Experimenters were able systematically to change subject's experience of body orientation by manipulating pressure cues, e.g. while isolated touch and pressure can give the subject a sense of up and down. Body position in relationship to the spatial surroundings is of paramount importance (Lackner and DiZio, 1993a,b; Lackner, 1990,1992).

These results are also very important to VE because it is possible to create visual perspectives on spatial environments that are impossible in the real world. They also remark that human spatial behaviour is much more dependent on how humans got there and where they started from than has been recognised. Lackner *et al* (1998) suggest that all developers of VEs should be aware of unwanted and unexpected side effects, e.g. changes in positions of floor and ceiling to the user, which may create false illusionary changes in self-orientation and visual orientation. If VEs are going to be used for training and familiarising people with environments, it is very important to remember that there is still a need for studies into the forms of spatial learning and how these forms relate to the exposure conditions being used. It is of great importance because VEs allow flexibility and versatility not possible in real environments. VEs can transgress normal real environment conditions and one still does not know what aspects of the real environment are influencing user performance for a particular task. The author agrees with them that VEs are a wonderful research tool for understanding spatial cognition, orientation or adaptation in the real world.

Colle and Reid (1998) investigated how people rapidly acquire survey knowledge of environments. In their experiments they compared spatial knowledge of objects in one room to knowledge of objects in different rooms. The first experiment examined whether a *room effect*[6] took place in standard rooms and hallways. Additional experiments explored the influence of wall elimination and hallways on spatial knowledge of their subjects. The VE model contained three rooms. The rooms were connected by 240mm wide hallways, and each room had a simple doorway that could only be entered from the hallway. All rooms were populated with office furniture. After every exposure to the model each

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[6] Room effect- objects within each room are spatially related to one another in the building and rooms are spatially related to one another.

participant received nine within-room questions (pointing task) and nine between-rooms questions in random order. After answering the pointing questions all participants either performed a free recall task (all objects named) or were asked to draw a map of the rooms and objects in the rooms. In the second experiment Colle and Reid *op cit.* explored the importance of physical walls by removing them and having participants still use the walkways defined by the hallway. The dimensions of the room were indicated by yellow tape placed on the floor. In the third experiment they explored the importance of movement patterns by removing the walls and not indicating room dimensions, and allowing participants to visit objects on their itinerary by navigating towards them via movement in any direction.

The results of the experiments suggest that there was pointing accuracy improvement between rooms when the walls were removed. The first experiment map drawing produced proportionally fewer errors than expected from pointing error data. A strong room effect was found in all three experiments. The data also supported the hierarchical characteristic of spatial knowledge. Participant's spatial judgements have been found to depend on their subjective hierarchies for objects. Furthermore, the results pointed to the concept that VEs should be built so as to capitalise on the use of local metric information, because rooms are local regions in which people quickly demonstrate survey knowledge. This also applies to different types of environments, e.g. driving cars.

Ruddle, Payne, Jones (1998) studied the components of spatial knowledge when people navigate large-scale Virtual Buildings (VB). In their first experiment they investigated the problem of how disorientated participants became when they travelled along simple paths in VB. The virtual model comprised of paths leading from one room to another and contained either one, two or three 90 degree turns. In each room subjects were asked to estimate the direction of the room they had come from. The results show that people will have difficulty remembering the direction they have come from if they follow complex paths in VEs, even if their paths contain no places at which they must decide in which direction to travel.

In the second experiment Ruddle *et al.* 1998 investigated the effect of a compass when participants repeatedly navigated two large-scale virtual buildings (VBs). They also explored whether people's spatial knowledge improved as a result of becoming more familiar with navigating VEs in general. The same VE model was used. Half of the participants were asked to navigate through the model with a compass, and the other half without a compass. Results of this experiment indicated that participants found a compass very useful for navigation. However, the displaying of a compass alone was not sufficient to help people quickly develop spatial knowledge. Participants also quickly developed a general feeling for a building's structure and size. This led participants to develop their spatial knowledge more quickly.

Waller, Hunt, and Knapp (1998) studied the transfer of spatial knowledge acquired in VEs to real-world situations. They used the concept of *fidelity*. By fidelity they understood the extent to which the VE and interactions with it were indistinguishable from the participant's observations of and interaction with a real environment. Caird (1996) pointed out that when one is able to hold all factors constant, increasing the overall fidelity of a simulator will lead to an increase in knowledge transfer. However, the reality of today's VR technology is that even a minimal increase in fidelity may be very expensive. By using lower-fidelity equipment, experimenters studied the cost-effectiveness of VE in training. As stated above, the aim of their experiment was to study the ways in which exposure to a computer-replica of an environment can substitute for the actual exploration of the real world. The real world model was a 14-foot x 18-foot maze with a 7-foot tall black curtain. Numerals were used to indicate the correct route. A VE model of a real-world maze was modelled. The arrows indicated the correct route to take through the maze. All participants were psychometrically tested (Guilford Zimmermann standardised test of spatial orientation). Twenty participants were randomly assigned to each of the following conditions; *blind, real, map, VR-desk, VR-immersive, and VR-long immersive.* In the blind condition, participants were given no exposure to the maze. In the *real* condition participants were allowed to wander freely in the maze for one minute. In the *map* condition participants were shown a map of the maze and were asked to study it for one minute. The experimenter allowed participants two minutes exposure to a visited replica of the maze at each trial in the *VR-desk* and *VR-immersive* conditions. In the *VR-long immersive* condition participants were allowed to immerse for five minutes in the virtual maze. Apart from the blind condition, participants were advised which route to take from location one to location three. The time was measured whilst performing this task. Overall, results suggest that even low-fidelity allows people to develop useful representations of large-scale navigable spaces. This finding supports results of studies by Hancock *et al.* (1997), and Arthur *et al.* (1993). However, it is also shown that if participants are not allowed to be exposed for enough time to VE that VE training is not more effective than using desk-top VE. Of course, if people spent enough time in immersive VE then they would perform better in tasks requiring route knowledge than people using maps. On the other hand, there was no additional help in the VE model, e.g. grids on the floor.

In 1995 Crvarich carried out research into the estimation of relative distances within an exocentric display. The overall goal of her research, as she stated herself, was to address a question: " How can computer graphics features such as image rotation, stereoscopic viewing and head-motion tracking contribute to one's ability to make rapid and accurate relative distance judgements, within an exocentric view of a computer- generated 3D perspective display?" She hypothesised that stereoscopic viewing and head-motion tracking could be beneficial for making accurate relative distance judgements. The tasks for her research were based on the research previously conducted by Bemis, Leeds and Winer (1988), in which subjects first detected threats and then selected the closest interceptor within a command-and-control display. The world model was made of four coloured cubes hovering over a terrain. As we stressed earlier in this chapter, colour as a cue is a very important one and should always be taken into account not only during the process of designing VEs but also real environments as it can greatly influence our perception. The subjects were asked to judge relative distances between a white cube and another coloured one. Subjects were also told to assume that all the cubes were the same size. The VE model was static, in so far as the cubes' positions did not change relative to each other. The results of her first experiment showed that image rotation improved relative distance judgements made within an exocentric view, but it also increased the length of time taken to make that judgement. This concurs with the generally accepted principle that image rotation is a computer feature which is beneficial for the spatial understanding of a 3D environment. A benefit of rotation is the ability to view a scene along a variety of different axes. This ability becomes more important with the projection of a 3D space onto a 2D screen, as our 2D retinae inherently remove stereoscopic information regarding one of the three axes of space. Rotation provides access to the missing axis of a perspective display.

In the second experiment Crvarich explored the influence of subject-and-computer rotation techniques upon relative distance judgements. She explored the problem concerning whether or not people need to control the manipulation of 3D environments in order to accurately judge relative distances. She asked a question " When making distance judgements within a 3D spatial display, do people need only missing axis information regardless of control over rotation?"

During her experiment she used four rotation techniques: *Manual Rotation*, *Discrete Views*, *Discrete Views + Manual Rotation*, and *Animated Views*. *Manual Rotation* allows the viewer to rotate the world to obtain any desired view. The *Discrete View* technique allows subjects to view the world from one of four pre-determined views by pressing a single keyboard key, for instance. *Discrete View + Manual Rotation* combined, is a technique providing very specific discrete views with the flexibility of altering those views if desired. The fourth technique- *Animated Views*- is where the rotation of worlds is controlled entirely by the computer allowing a smooth rotation of the world to each of four pre-determined positions. The same coloured cubes were used as before and the same experimental conditions were applied. In her third experiment all conditions were the same but the responses were timed.

The findings of Crvarich's research suggested that, within the range of conditions tested, providing stereoscopic viewing head tracking in order to appropriately change the world view does not increase performance in a relative judgement task within an exocentric display. It has also been shown that users should have the ability to control changes in world view. The most useful technique, as expected, consists of *Discrete Views* combined with *Manual Rotation.* This was more effective for the subjects using motion parallax as a cue. Discrete Views were used more extensively by those subjects who used 2D distances in various views to make their relative distance determination. It was also shown that Discrete Views greatly reduce the time taken to make relatively accurate distance judgements.

However, there were some limitations within her study. The five cubes and the world plane were in positions ten feet from the observer's eyepoint in order for the whole scene to be seen within the display views at all times. This influenced the features of head-motion tracking and stereo viewing, as close images would have afforded a great perspective change. It has been proven that stereopsis is most useful when objects of interests are within approximately one metre from view (Johnston, Cumming and Parker, 1991).

Wanger, Ferwerda, and Greenberg (1992) conducted a study concerned with the influence of cues on people's performance of chosen tasks. The first experiment investigated the ability to determine an object's 3D position using images containing a different combination of pictorial cues. The VE model shows three balls hovering over the terrain. Two balls were fixed in position and the third one could be moved by adjusting three knobs. In each trial of the experiment, participants were asked to move the adjustable ball to lie at the midpoint of the imaginary line segment pointing to the two other balls. In the second experiment participants were asked to adjust the movable cube until its orientation matched the orientation of the fixed cube (rotation task). In the third experiment participants were asked to scale the adjustable ball until its size matched the size of the fixed ball. The results of the experiment suggest that shadow cues had a dominant effect in positional accuracy, followed by a perspective cue. The motion cue, object texture, and ground texture did not significantly influence positional accuracy. The shadow cue provided a ground-plane-relative reference for height and distance, and the perspective cue provided a size/distance gradient.

Orientational accuracy perspective had a dominant effect, followed by the motion cue, and the shadows cue. However, in this case, the presence of perspective projections reduced performance by preventing participants from performing the task. Motion was an effective cue, revealing transformational equality when the objects were in the same orientation.

In size scaling accuracy, shadows had a predominant effect, followed by motion and perspective. The shadow cue defined spatial location in perspective trials and intensified projected size matching. They also found that a relation between cues was the most important factor influencing participants' performance seen in the task. The results of these experiments imply that cues play very important roles in interface design because information provided in the displays changes in harmony with the tasks in hand.

Research on distance and depth clues is ongoing. However, some previously conducted scientific investigations into depth clues will be reviewed here. Unfortunately, it is difficult to compare the results of these experiments because there were differences in dependent measures, stimuli, and viewing distances applied.

Cole, Merritt, Fore, and Lester, 1990; Reinhart, Beaton, and Snyder, 1990; Drascic, 1991; Yeh, and Silverstein, 1992; Barfield and Rosenberg, 1995; and Surdick, Davis, King, and Hodges (1997) conducted research on some aspects of depth cues.

Cole *et al.*, (1990) investigated stereoscopic and monoscopic displays. They asked their subjects to guide a rod through a wire maze. They reported that the very small performance improvement for monoscopic display resulted from trial/error. However, they discovered that this type of task was virtually impossible without stereopsis.

Drascic (1991) also compared stereoscopic and monoscopic displays. In his experiment subjects were asked to teleoperate a Remote Mobile Investigation Unit (RMIU). They drove RMIU for 3 m, and were asked to lower mock X-Ray photographic plates between two "bombs". Drascic concluded that stereoscopic display helps in the initial learning of a task. Additionally, he reported that for some subjects, performance advantage existed even after large amounts of practice.

Reinhart *et al.,* (1990), investigated stereopsis, relative size interposition, and relative brightness cues. They designed an experiment in which it was possible to manipulate the presence of depth cues in three geometric shapes. Subjects were asked to indicate the depth ordering of the three. Experimenters found that stereopsis did not significantly decrease reaction time. Interestingly, subjects did not react quicker when stereopsis was the only cue presented.

Stereopsis, relative size, relative brightness, occlusion, and linear perspective cues were topics of investigation by Yeh and Silverstein (1992). In their experiment subjects were asked to perform tasks of depth or altitude judgements. Stimuli comprised of simulated geometric shapes in 15°, 45°, and 90° viewing orientations, with or without stereopsis. Their experimental data indicates that orientation had an effect on performance. It was particularly evident in conditions where other visual cues were less effective.

Barfield and Rosenberg (1995) reported the advantage of stereopsis for elevation location in their experiment of determining azimuth and the elevation location of targets. However, no advantage of stereopsis over perspective information for azimuth location was reported.

Surdick, Davis, King, and Hodges (1997) carried out one of the more comprehensive studies of depth cues in VE. The aim of their experiments, was to investigate which cue provides the most relevant distance information in VE. Their eight experimental conditions comprised of seven '*carefully selected depth cues*' (Surdick *et al.* (1997), pp. 515). Namely, they were: relative size, relative height, relative brightness, foreshortening, linear perspective, texture, stereopsis. The eighth condition was the complete cues condition. The subject group was made up of ten college-aged subjects who participated in six to seven sessions of approximately two hours each. Stimuli were presented on a high-resolution grayscale Apple monitor. The simulated scene comprised of walls and floor on which the cues for linear perspective, foreshortening and texture gradient were presented. In conditions where these perspective cues were manipulated, the square stimulus was anchored to the floor by a single vertical line that extended from the centre of the square to the floor. For foreshortening, the lines on the floor of the model were drawn at simulated intervals of 30cm. For linear perspective, the lines were drawn at simulated intervals of 2 cm. The viewing distance was at 1 and 2 metres. In each depth-cue condition (except the all-cues condition) only one cue was manipulated and signalled relevant distance information in the simulated display.

The aim of the second experiment was to determine whether it was possible to train a female stereo-anomalous subject to perceive stereo-depth. The set up and procedure of the experiment were like that in the first experiment. The results show that it is possible to train stereo-anomalous subjects to perceive stereopsis in this type of display.

Based on the data obtained from their first experiment (JND, and Weber fractions[7]) Surdick *et al.,* (1997) concluded that investigated perspective cues (linear perspective, foreshortening and texture gradient with ground intercept) are the most effective for egocentric distance and depth perception for the stimuli and viewing distances tested by them. It seems that these findings support previous results of experiments by Barfield and Rosenberg, *op cit.* Bruce and Green, 1995, and Gibson, 1979. This has implications in designing VE, because it indicates that the foreshortening cue and the ground intercept may be enough for adequate distance perception of geometric objects. They also reported that the all-cue condition does not enhance distance perception for these stimuli and viewing

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[7] For Explanation of Just Noticeable Difference and Weber fractions see Appendix B.

distances. Furthermore, relative brightness, relative height, and relative size cues all significantly decreased in effectiveness with increases in viewing distance.

In 1998 Winter and Kline published results of their two experiments into judging perceived and traversed distance in Virtual Environments. By *perceived distance* judgement they understood a task in which stationary observers judged the distance between themselves and a stationary or moving object immediately perceivable to them. *Traversed distance* judgement refers to a task in which an observer is asked to judge the length of a route, or a portion thereof, usually following a traversal of space. The first experiment's aim was to investigate the accuracy of distance estimation to an object in a simple virtual environment with relative size, linear perspective, and texture cues presented. In a VE and a real life setting an object (black cylinder) was placed between 10 and 110 feet. The real-world setting utilised a 150 feet long corridor. Experimenters compared estimates of distance by stationary observers in a simple VE with estimates made in a similar real-world environment. The VE model consisted of a 130-foot-long corridor, terminated by a wall at the far end. The subject group was made up of 24 students with 20/20 vision uncorrected or corrected with contact lenses. VE setting participants viewed a virtual model in BOOM2C display. The results of the first experiment showed that distance estimation performance in VE was degraded relative to the real world distance estimation. They believed that it was caused by a limited amount of depth cues. Therefore, in the second experiment an additional motion cue was introduced. They hypothesised that the presence of the motion (walking) cue would improve the accuracy of distance judgement. The participants group was made up of 72 students with 20/20 vision or corrected to normal. The experiment was conducted on a Virtual Environment Test Bed.

Experimenters used the same software and hardware described in the first experiment. The VE model consisted of four test routes, each consisting of a series of eight connected hallway segments. The hallways were 10 feet wide and 10 feet high, and 20, 50, 90, 130, 170, 210, 250, and 290 feet in length. Witmer and Kline also examined the effect of different methods of movement (a joystick, a treadmill, or being passively teleported by the experimenter) within a VE on participants' estimates of traversed distances. The second goal of this research was to determine the effect of different textural densities on subjects' estimates of traversed distance in a VE. A third goal was to investigate the effect of different speeds of movement on subjects' estimates of a traversed distance in a VE. The last aim was to study the value of providing compensatory cues and their influence on estimates of traversed distances. All participants experienced only one method of movement and traversed only one out of four routes.

The results of both experiments suggest that distance estimation is less accurate in virtual environments than in the real world. In both conditions distances were underestimated. Furthermore, the results suggested that adding additional texture cues did not improve subjects' performance. They have shown that the introduction of compensatory cues (a tone every 10 feet travelled) improved performance dramatically, even on non-cued trials. They believe that using these types of cues may be the best available way of improving distance estimates in VE. An interesting finding was that the method of movement does not improve subject performance. However, movement cues improved participants' performance. Travel time appeared not to be an important factor in subjects' performance. They concluded that knowledge of distance in some form, either metric or nonmetric, affected perceived layout and that inaccuracies in judging distance could reduce the accuracy of judging perceived layout.

Over the years, some periphery degraded display systems have been proposed (Slater and Usoh, 1993b; Maciel, and Shirley, 1995). There are many rendering techniques that can be used to reduce the complexity of depth cues. However, their work was centred on the reduction of a frame rate. Watson *et al.* (1997) hypothesised that their LOD degradation techniques would result in minimal perceptual loss and dramatically improve frame rate. They designed an experiment in order to prove their hypothesis. In their study ten college students with correct vision were used. Subjects wore Virtual Research Flight Helmets with a vertical field of view (FOV) of 58.4 degrees, and horizontal FOV of 75.3 degrees. The motion of subjects during immersion was tracked with a Polhemous Isotrack II 3D. The stimuli consisted of a floor, indicated by a grid of white lines on a black background. The background above the floor was also black. The tasks performed by subjects were search, location and identification of a simple target object. Seven different size and peripheral details were used by all subjects. The experimenters controlled frame rate, target location, subject-input method, and order of display. The results of their experiments supported their hypothesis that peripheral LOD degradation can be a very useful technique for improving frame rate. The search task was divided by them into two parts: motion into an area of interest, followed by examination. The results indicated that all peripheral resolution (fine, medium, and coarse) applied was adequate for the first part of the search task. Furthermore, since even the smallest inset could control most of the target object, peripheral resolution proved irrelevant in the second part.

Additionally, they showed that a normal resolution display offered no significant performance advantage over a display with high-resolution periphery.

In their second paper Reddy *et al.* 1997 proposed a method for measuring subjects' visual acuity through the use of a pattern known as a *contrast grating.* They wrote that "this is simply a pattern where contrast is varied sinusoidally across the display, producing a series of alternating light and dark vertical bars. The spacing between bars is measured by a quantity called *spatial frequency.*" (Reddy *et al,* 1997, pp. 661). Spatial frequency is a measure of detail that is presented to the visual system, e.g. in HMD it is a measure of detail presented on the display device. The most important advantage of using this measurement method is that one finds it impossible to accurately predict what will be displayed by simply looking at the geometry of the scene, because geometry can be displayed differently depending upon the level of lighting, shading of the model being applied, etc.

They also suggested that "the calculation of the spatial frequency of the objects must be done from several points of view around the object in the model in order to capture all of the object's features. One can then interpolate these values during the simulation in order to predict the spatial frequency content of any atributory position object in real-time and subsequently select the most suitable LOD to utilize." (Reddy *et al,* 1997, pp. 662)

Research into various aspects of perception of space has been presented in this chapter. Most of this research was centred around issues of spatial knowledge transfer, the influence of various cues on the perception of distances, wayfinding, cognitive maps, components of presence and locomotion. All of these investigations are very important steps in evaluating Virtual Environment Systems. However, there is still the need for many more experiments into perception of space dimensions in virtual environments taking into account the perception process *per se* and different Virtual Environment Systems and settings. In the following chapters, two experiments are presented investigating the perception of egocentric and exocentric dimension estimations in real and virtual buildings by utilising some elements of psychophysics. With the results of these experiments and through their innate characteristics, one hopes not only to contribute to the domain of the knowledge of human factors, but also to assess the potential usefulness of the technology for architectural planning with its stress on error free communication between architects and clients. It seems that human factors are still not deemed important by many branches of academic and industrial researchers. In 1992 Bishop (quoted in Slater, Alberto and Usoh, *op cit.*) pointed out to the scientific community in his report on 'Research Direction in Virtual Environments' that "Research in VE should look towards applications which promote measurement. The NSF[8] should encourage applications which provide discriminatory power to evaluate VE technology". Furthermore, Stanley et al. (1998) repeated this same appeal for more research into human factors in VR. What follows is, one hopes, a contribution towards research into human factors and the promotion of these measurements.

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[8] NFS: National Science Foundation.

3. EXPERIMENTAL DESIGN.

This chapter contains introductions to experiment one (part one and two) and relevant information for experiment two. All elements of experimental design model, conditions, and participants for experiment one are discussed. Sections on methodology and variable, psychometric testing, questionnaire design, and elements of scale also relate to experiment two.

3.1 Methodology and Variables.

In any experiment, the ideal is to control all relevant variables whilst manipulating only Independent Variables[9] (IV). It must be a very careful process to exclude random variables and to eliminate constant errors. The reason for this is that, if all other variables are controlled, only the IV can be responsible for changes in the Dependent Variables[10] (DV). Complete control of the IV is the hallmark of experiments (Coolican, 1994). In essence, any experiment is an arrangement of conditions or procedures for the purpose of testing some hypothesis.

This study consists of evaluating one simulation condition against the control condition - *Real World Setting (RWS).* There are many methods of running psychological experiments. However, most of them have too many disadvantages, and in our case, they would produce too much bias in the data. One of these methods is called *Related Design Method (RDM).* As the name suggests it is a method which, when results are presented, a value in one condition

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[9] *Independent Variable-* Any variable whose values are, in principle, independent of the changes in the values of other variables. In experiments, any variable that is specifically manipulated so that its effect upon the *dependent variable(s)* may be observed (Reber, 1985).

[10] *Dependent Variables-* Any variable whose values are, in principle, the result of changes in the values of one or more *independent variable(s).*(Reber, 1985)

is directly related to a value in another condition. A disadvantage of this method is that any difference found could be caused by differences between the people in our two groups. To eliminate this one can use the same people in both conditions. In effect, the experimenter seeks to eliminate the source of differences between the people and what he/she says is that difference between conditions must be because the same people differed in the two circumstances. However, one has to take into account the order effect. People might improve on the second condition because they have had some practice or may perform worse on the condition because they are disheartened by failure, through boredom or fatigue (Coolican, 1994). One can improve this method by randomising conditions or leaving long time gaps between conditions. However, one has to remember that not every participant will be naïve for the second condition and may try to guess the aims. Additionally, one could lose participants between conditions.

An alternative method of doing psychological experiments is called *Independent Sample Design (ISD).* This is a method which limits the disadvantages of RDM. During the experiment entirely different groups of people are subjected to each condition. The scores from one group of participants, who undergo just one condition of IV, are quite unrelated to the scores from another group who participate in the other condition of IV. The advantages of this method are: no order effect, participants cannot guess the aim of an experiment. In addition, it can use exactly the same stimulus list and there is no need to wait for participants to 'forget' the first condition. However, the major flaw of this method is that there could be variations among people, which may be unevenly spread across groups of participants. In ISD it would always be difficult to rule out participant variables as a possible source of variations in our results. Furthermore, a lack of homogeneity of variance may prevent us from using parametric tests. One can limit the possibility of error by random allocation of participants to conditions or by pre-testing them.

There is a third method which can be used for running psychological experiments. It is called the *Matched Pairs Method (MPM)*. In MPM, each participant in one group or condition is paired on specific variable(s) with a participant in another group or condition. The advantages of this method are that there is no order effect and one can partly control participants' variables. One does not have to wait for them to forget conditions and the same stimuli list can be used. However, there are still some participant variables and one can find that it is difficult to select perfect matches. It is also a really time consuming method. Furthermore, loss of one member of a pair entails the loss of a whole pair.

Takings into account all of the advantages and disadvantages of the above-mentioned methods, a modified version of Independent Sample Design was selected. It is called *Random Blocked Design (RBD)*. In this study, each participant group only experiences one of the two conditions. This design is easy to administrate. The disadvantage of this method, however, is that the variation due to subjects has to be eliminated. It makes it much more difficult to find significant differences.

To solve this problem one can create a homogenous subject group. By homogenity, broadly speaking, is understood similarity, sameness. Applied in various settings it is referred to groups, subjects, data, variables, etc. when the items under consideration are not appreciably or meaningfully different from each other. It can be, for instance, subjects' profession, age, social background, IQ, blood group, etc. (Reber, 1985). Firstly, to secure some homogenity, a large number of initial participants was used. Every participant was psychometrically tested. Only subjects scoring above average were chosen. In addition, several vision tests were performed. Participants were assigned randomly to two groups. The name of every participant was written on a separate slip of paper and all 40 pieces of paper were placed in a hat. The first name drawn would be assigned to the first group, the second to the second group, etc. In this manner, the experimenter ended up with two groups, each with twenty subjects. A simple flip of a coin did then told the experimenter who is to be in the Real -World Setting (RWS) group, and who is to be in the Virtual Setting (VS).

In order to participate in this experiment all participants have to have a normal vision and their scores in the parametric tests have to be above average. All of these precautions are necessary to facilitate a basic and important presupposition made in any type design that the means of the groups should not differ significantly at the start of the experiment. If the t test indicates that the two groups are significantly different (on the dependent variable scores), it may be concluded that this difference is due to the variation of the independent variable, it also may be concluded that the two values of the independent variable in these experiments are effective in producing the differences in the independent variable. For details on psychometric and vision tests see Chapter 4 (Sections 4.6.1 and 4.6.2).

These two equal groups had equivalent gender ratios. None of the participants had ever visited the experimental site before taking part in the study, so they possessed no recognition of features of the building.

3.2 Components of the Immersive VR System.

All of the components of the immersive system used to conduct Experiment one are discussed below.

3.2.1 Head-Mounted Display.

In order to comply with our project's characteristics of cost and accessibility, an *i-Glasses* headset was used in the experiment produced by Virtual I-O Inc. (Figure 1). The i-Glasses are inexpensive and work with most Personal Computers (PCs). The i-Glasses are capable of presenting images in 3D and of head tracking. They are stereoscopic; which means they have two screens, one for each eye. Each eye can view a different perspective at the same time. This enables users to experience the illusion of seeing the depth and comparative distance of objects.

Figure 1 Virtual I-o *i-Glasses.*

The technical characteristics of the i-Glasses are as follows:

1.Optics:
  - Heads-up see-through distortion-free display
  - Field of view: 30 degrees in each eye
  - Fixed focus to minimise eye strain
  - 100% stereo overlap
  - Can be worn with eyeglasses

2. Display:
  - 2 full colour 0.7" LCDs
  - Input: 1 NTSC channel, fixed sequential
  - Resolution: 1880,000 pixels per LCD panel
  - VideoMute™

3. Audio:
  - Stereo RCA
  - Frequency response 20Hz-20kHZ
  - 3D audio spatialization

4. Mechanical:
  - Ergonomically designed for comfort
  - Weight: 8 ounces
  - Clip-on immersion visor

5. 3D Capable:
  - True stereoscopic imaging
  - Field sequential- flicker free

6. PC Head Tracker
  - 3 degrees freedom: pitch, roll and yaw

7. PC Interface module:
  - Video: Single channel RCA input
  - Audio: Stereo- input and pass-trough output
  - VGA interface- input and pass-trough output
  - 60 or 70Hz operations
  - Both field and line sequential 3D formats

8. Electrical:
  - Power supply: 110 VAC input/6VDC output

3.2.2 Interaction Devices.

The head-tracking device is supplied together with the i-Glasses. The head tracker senses the movement of the user's head and relays the information to the visualisation program. It provides three degrees of tracking- pitch, roll, and yaw. 'Pitch' is an up and down motion; 'roll' is a movement to the right or left as if to see one ear on your shoulder, and 'yaw' is a head movement similar to shaking your head to represent 'no'.

After head-tracking, movement is probably the form of interaction most important for conveying a sense of presence in virtual environments. Ideally, it is preferred that participants physically walk through the modelled environment. This technique enhances the perception of space because, in addition to the visual cues, users also benefit from kinaesthetic feedback so essential for making estimates of distances. However, these types of system (e.g. treadmills) are still very expensive and far from perfect. In our case, apart from a head-tracking device, we have to use a computer keyboard as a movement control device. The arrow keys were assigned to enable subjects to control their movement in the modelled environment.

3.2.3 Computer Platform.

The experiment was run on a PC 486DX2 with the clock speed 66Hz. The computer was equipped with 632K conventional memory and 19456K extended memory. The Video Adapter was type VGA together with VESA support version 1.02. A joystick and a mouse were attached to the computer as well.

3.2.4 Software: Modelling and Run Time.

There are many computer modelling software packages available on the market today; some CAD packages, Superscape Virtual Reality Toolkit (VRT) Shape Editor, Sense8 WorldUp, MultiGen, MEDIT, and many more. In our study the model was developed in the Superscape VRT software.

The VR computer programmes continually interpret both the position tracking data and model data base in order to render and display the appropriate view of the model to the HMD. There are several commercially available packages (i.e. Sense8 WorldToolKit, Division dVS, Superscape VRT Visualiser, Silicon Graphics Performer), as well as many locally fabricated software programmes in various research or university laboratories.

Superscape VRT Visualiser ver. 4.00 was used. During the time of these experiments, it has been available free of charge.

3.3 How it All Works.

Figure 2 shows the computer equipment set-up for use during our experiment. When participants put on i-Glasses then they find themselves "surrounded" by the interior of the computer model. The i-Glasses are equipped with a head-tracker which allows the computer to up-date the view according to the position of the participant's head. For every movement of the head, there is an equal change in the viewpoint of the computer model. This leads the participants towards a feeling of immersion within the virtual environment.

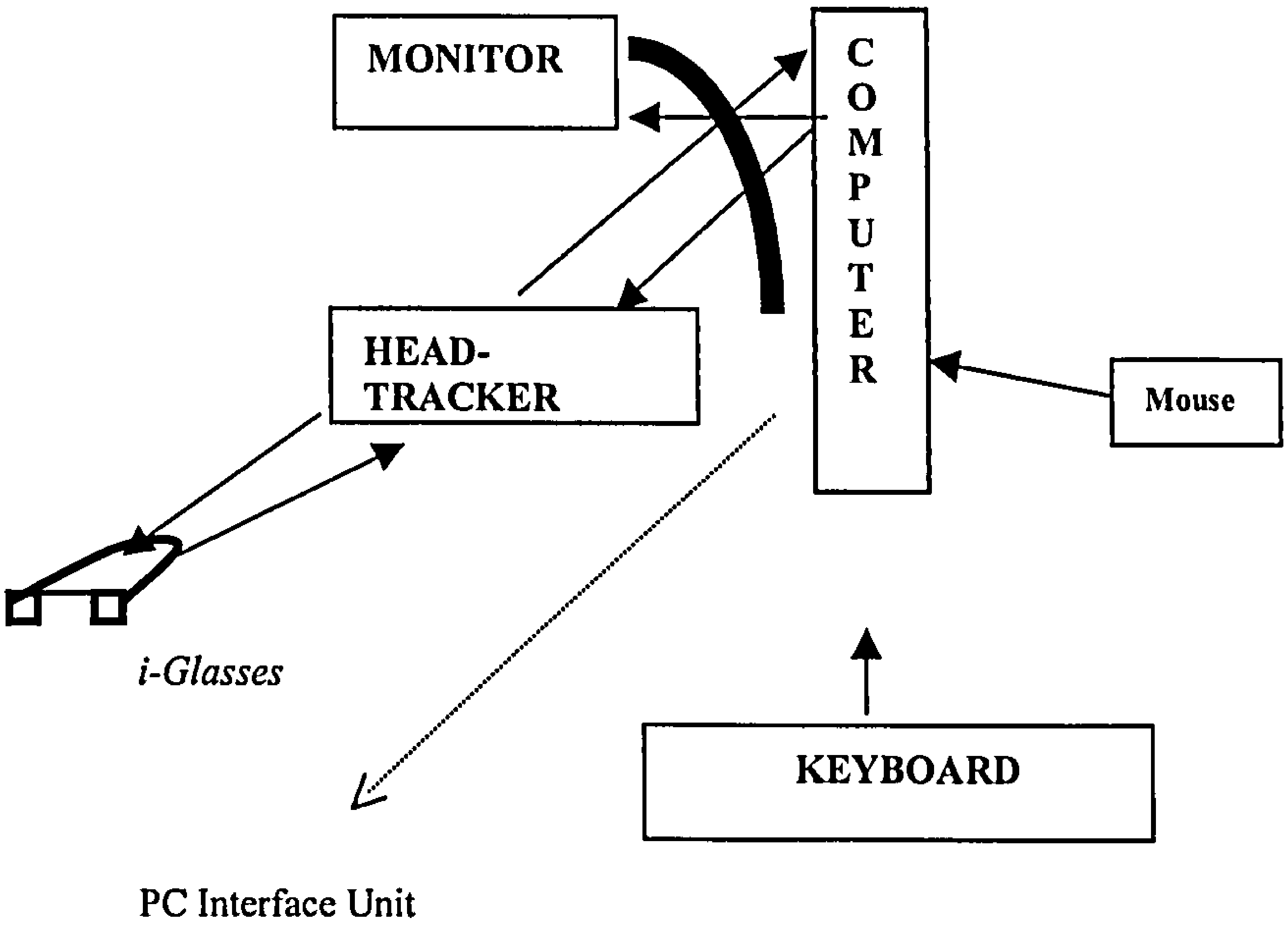

Figure 2 Experiment's Computer Equipment Set-up.

3.4 Experimental Conditions.

In order to measure the extent to which virtual interfaces succeed in providing accurate perception of the basic characteristics of space, two experimental conditions were used: a virtual model and a Real World Setting. By comparing the results of measurement we will be able approve or reject our null-hypothesis (see Chapter 1).

For the RWS we used the ground floor of the Business House Building at the University of Salford (see Figure 3), colours indicate rooms used for our experiment). During the period of execution of Experiment one VR Solutions Ltd. occupied this building. However, the ground floor was not occupied apart from the reception area. The reception area was only a starting point for our walkthrough. (for details see Chapter 4). The ground floor was ideal for running the study. It provided participants with many basic cues - perspective (grid on the ceiling, poles placed in equal intervals), scale (familiar objects, human figure), and texture cues (texture of surfaces, layout texture).

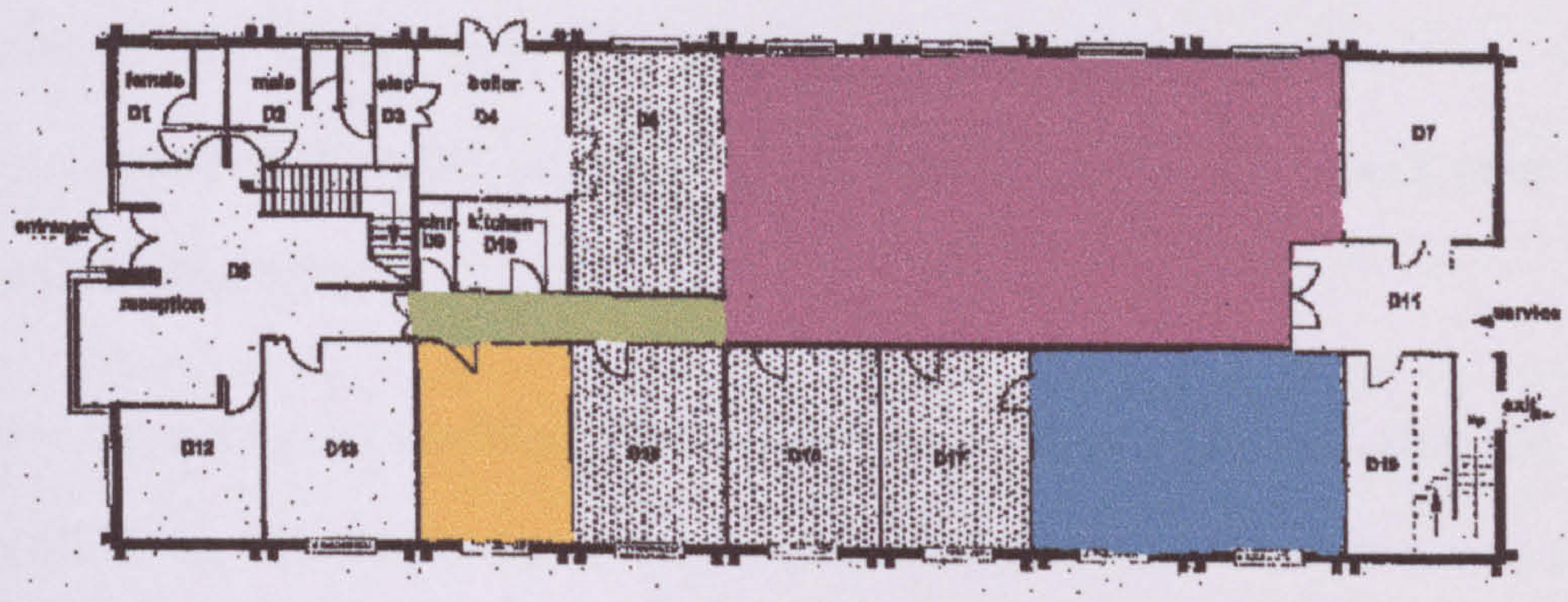

Figure 3 Ground Floor Plan.

For the immersed condition a virtual representation of the ground floor was modelled. The viewers could move their viewpoint in the model by using the interactive devices. The participants were viewing a virtual environment via the i-Glasses. None of the participants had seen the virtual model before taking part in our experiment.

3.5 Experimental Set-up.

During the arrangement of first experiment the most important condition was a novelty factor. The experimenter had to make sure that none of the participants had visited the experiment site before and the experimental site had to be kept secret to all of the chosen participants. Unfortunately, one was forced to exclude many people from the experiment - all workers of VR Solution Ltd. as well as most of the staff from the Department of Surveying. One was trying to avoid the situation that some of them could be well acquainted with the building, and some of them could be tempted to visit the site before taking part in this study in order to score higher. All of these restrictions were necessary in order to create a homogenous subject group. To keep the novelty factor to a maximum, all participants in the RWS were met by the experimenter on the campus prior to walking into building.

For the simulation condition additional preparations were required. One had to exclude the influence of the virtual interface on the subjects. In order to keep the homogenity at a possible maximum, only those people who had never before had experience with virtual environments were chosen. However, this lead the experimenter to the problem of giving subjects a chance of getting used to the new interface. Proshansky (1970) wrote that human perception of space is greatly modified as humans adapt to an environment and as a result human perception of space can be stabilised. One had to allow the participants sufficient time to adapt to the medium. For these reasons, a simple model was used, consisting of a supermarket floor, in which participants could get acquainted with the virtual interface. They could open doors to the supermarket and move around the shelves

(Figure 4). With every participant's move the environment was becoming increasingly inclusive. They were allowed to stay immersed for 15 minutes. This was found to be a sufficient, for this subject group to start to feel comfortable using the interface.

During the RWS participants were asked to stand whilst making their judgements. In his study of a film simulation technique, Sasanoff (1967, quoted in Henry 1992), wrote that the posture can affect the behaviour of the participants. He argued that the comfort of viewing while seated in a chair can cause an increase in the propensity of the observer to seek a broader range of experiences than might be the case in real world experiences. Since participants were walking in RWS, then they at least had to be standing in the simulation condition. Their eye height was adjusted individually to suit their height. Also standing position was a scale cue. As mentioned before, in the tracked condition they viewed the model through the stereoscopic i-Glasses (Section 3.2.1). To move in the model, participants used the arrow keys on the keyboard, and moved in the direction they were looking. They controlled their direction of view by actually turning their heads, as in the RWS.

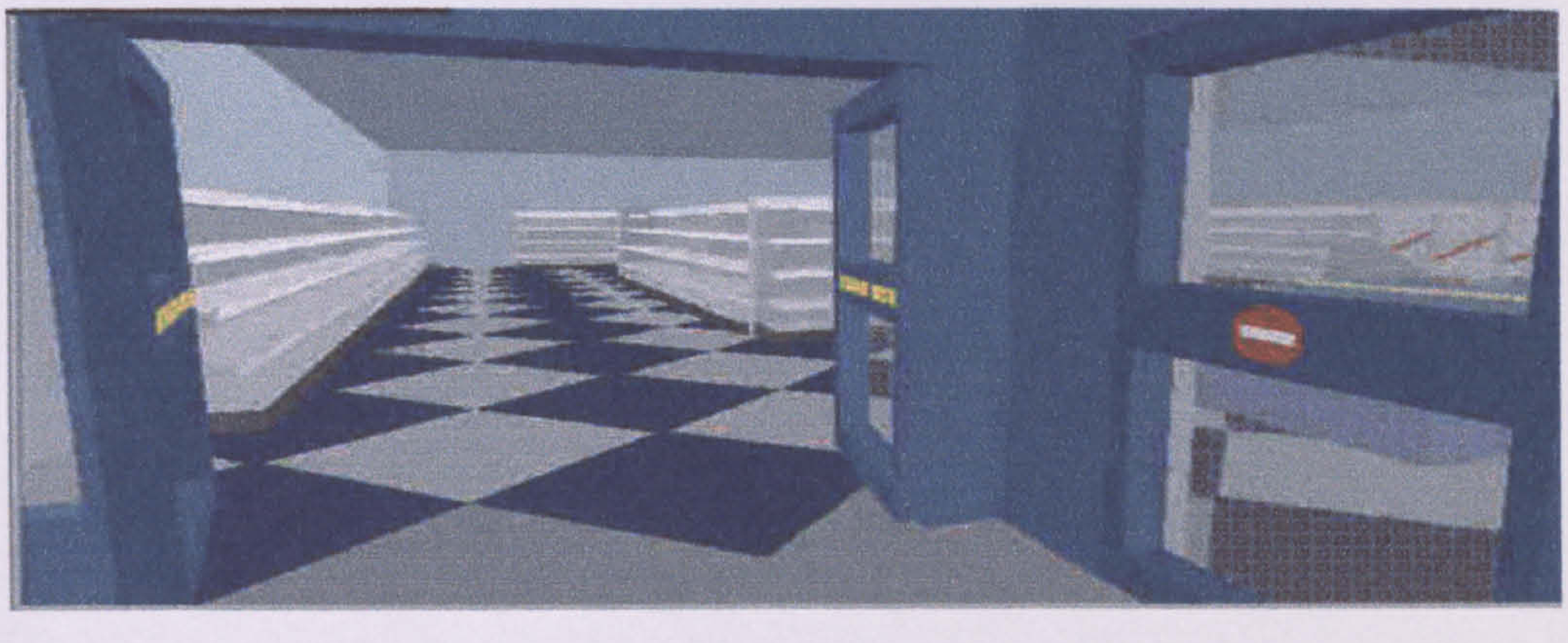

Figure 4 Supermarket model.

3.6 Designing the Tasks.

In order to validate the hypothesis of interest, the participants were asked to estimate the basic characteristics of four spaces in the building. All spaces differed in volume. Participants were asked to estimate the width, height, and length of the spaces. The estimates of the rooms vary as a function of the size and shapes of the volumes as well as from the effect of increased familiarity with the environment. Having participants estimate a number of different kinds of spaces for this task averages the variation.

For the feeling of space task the descriptive questionnaire was administrated after each visit. It included a list of bi-polar adjectives. Participants were asked to select the most appropriate adjectives which described the chosen room by circling one of the numbers on the semantic differential scale (see Appendix A).

For object recognition we used a 6ft tall manikin and a standard computer chair placed strategically in one of the rooms. At the chosen point the participants were asked to recognise a figure and then asked to estimate the height of it. A figure of the same height was placed at the same place in the virtual model. The chair was placed in the RWS and virtual model at the same place for scale purposes (Figure 5).

After each of these tasks, participants were asked to express ease or difficulty of making each specific estimate as well as their level of confidence in their estimates

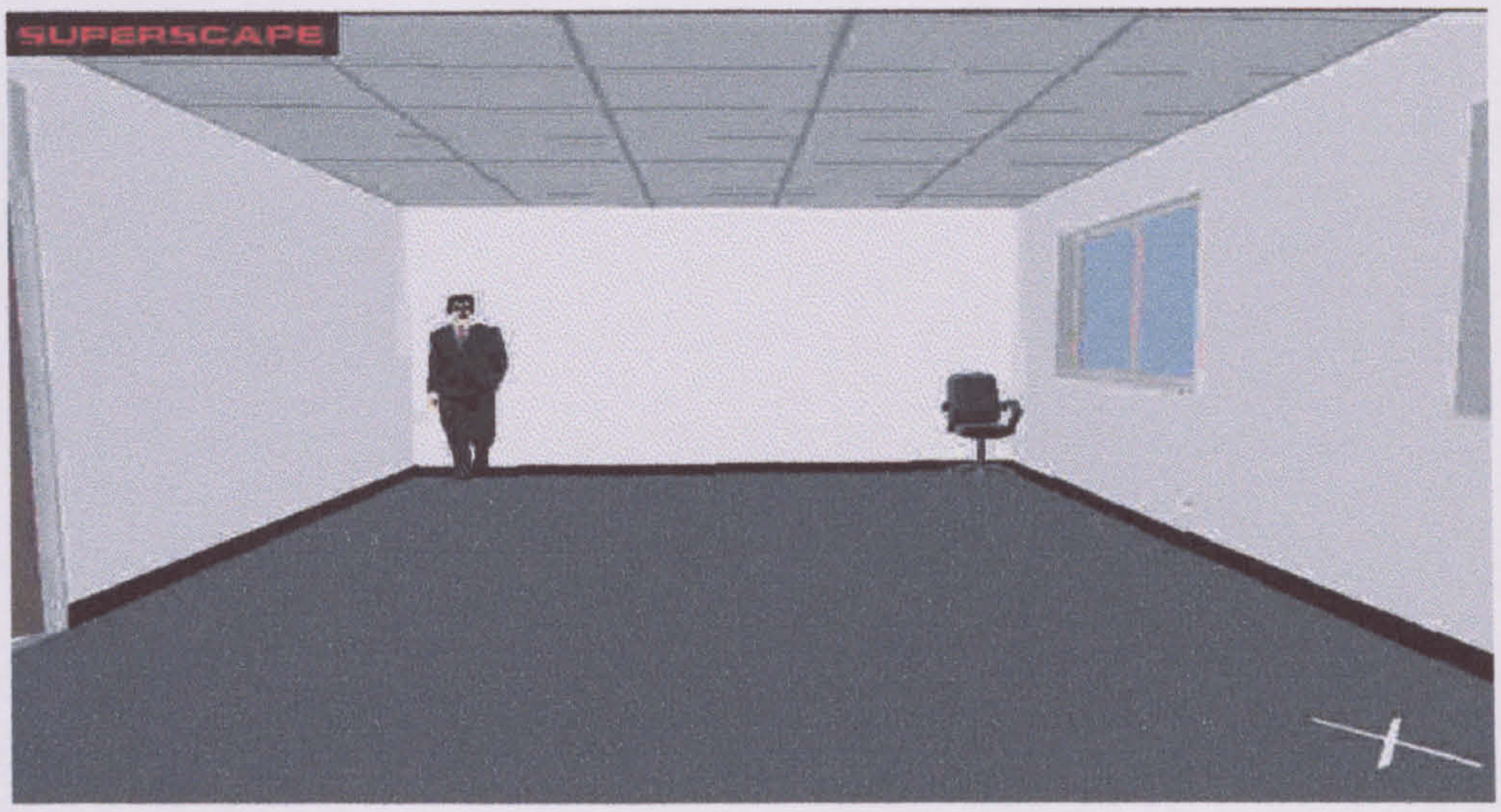

Figure 5 Room D with the figure.

After each visit, participants were also asked to draw the plan of the visited spaces. Their plans were rated as a function of their perception of:

1 the location of rooms relative to each other;

2 the path of the visit;

3 their ability to rank the spaces by size from the smallest to the largest.

These less formal tasks were designed to capture information which might not appear through the size task.

3.7 Recruiting Participants.

The experiment 1 and 2 were prepared and conducted according to guidelines set by the British Psychological Society. Firstly, participants were not at risk during testing and taking part in our experiment. All subjects entered the study voluntarily and were permitted to withdraw from it at any time without any penalty if they so desired. They were also briefed in advance about all aspects of the study that could be expected to influence their willingness to co-operate (psychometric test, vision tests, time required to complete study, etc.). However, they were not told about the aim of the study or about the hypotheses tested, in order to comply with the rules of carrying out psychological experiments (Coolican 1994; D'Amato, 1970; McGuigan, 1968). Subjects who asked about it, were told that the tested hypotheses would be revealed to them after the experiment.

The participants' *right to privacy* was observed by separating their names and all identifying information about them from the data once it had been collected. The data were then identified only by the numbers which were allocated to every participant at the beginning of the study. In that way, nobody other than the experimenter had access to the information concerning the responses of any individual subject.

All of the above guidelines were necessary in order to adhere to the psychological rules of experimenting. The experimenter was trained in first aid, and had a working experience of working with people effected by psychological/psychiatric disorders. All participants had to fulfil certain additional criteria in order to qualify to take part in the experiment. First of all, they had to be willing to participate in the experiment, as there were no funds available to pay them. The only reward was the chance to experience the virtual interface. All subjects had to be fluent in English. There was no limitation to the age, sex, professional status, etc. The intent was to invite as broad a range of people as possible so that as many participants as possible could get involved in the process of shaping this technology and it was assumed that clients of architectural businesses can be of different age, social and educational background, different IQ, etc. It could be argued that these characteristics of people form a bias. However, to qualify for the second part of our experiment all participants had to successfully pass psychometric tests and vision tests. Psychometric tests were utilised to create a homogenous subject group in order to find the above mentioned *sameness*.

To recruit a satisfactory number of participants, the experimenter started by asking colleagues and students from the Department of Surveying who had never visited the experiment site and had never experienced a virtual interface. Around 90 people took part in the pre-selection process. The participants' ages ranged from 21 to 47 years. The qualifying subject group was constructed of 40 people: 30 males and 10 females. The subjects' average age was 28.5.

3.7.1 Psychometric testing.

In order to secure the creation of a homogenous subject group, apart from the above-mentioned requirements, technical instruments of psychology were used. Psychologists have developed many tests, which were intended to be standardised instruments for the measurement of human psychological characteristics. These are known as *psychometric tests* and their use as *psychometry.* The tradition goes back to Galton who began the measurement of mental abilities in the 1890s by testing thousands of people on many sensory and cognitive tasks. Many of the people tested paid Galton a fee for the privilege! (Coolican, 1994). One group of these tests is called *mental ability tests.* The great majority of the tests provide a satisfactory measure of one kind of spatial ability or another although factorial data is not available for all of them and some are more thoroughly validated than others. During the selection process of appropriate tests for our study we answered the following questions, proposed by Maccoby and Jacklin (1974):

1. Does success in the test depend critically on perceiving configurations rather than details?

2. Has the type of test/material been shown to have a satisfactory loading in the factor identified as spatial by two or more researchers?

3. Has the type of test been shown to have significant sex differences in the mean score in favour of males?

4. Has the type of test been shown to be reliable by any of the standard formulae? Most of the standard spatial tests have been formed to have reasonably high reliability coefficients, usually in the region of .85 to .95.

5. Has the type of test been shown to be valid for the researcher's purpose?

6. Is the test likely to be boring or tedious because it contains items entirely of a single type? A composite test consisting of several different types of item is

most likely to be interesting, as well as producing a better measure of the major spatial group factor.

7. Has the test been adequately standardised and are there normative data? It is a mistake to assume that because a test has been available for a long time it is satisfactory. One must always study the manual to ensure that there are adequate data on reliability, validity, standardisation and mean sex differences.

Taking into account the scope of our study, the methodology and subject group, many tests were analysed (i.e. Cards, Gestalt Competition, Hidden Figures, Identical Blocks, Shapes, Shapes Analysis (Heim), Spatial Aptitude (GATAB), Spatial orientation (Guilford and Zimmermann), Spatial Relation (DAT), Spatial Visualisation (Guilford and Zimmermann), and many more). However, all of these tests have shown too much difference in scores between the genders. After very careful consideration, two tests were selected which were appropriate for the study. The first test is called the S&M Test and the second one the Group Embedded Figures Test (GEFT).

The S&M Test is a quick test of mental rotation ability based on the tasks devised by Roger N. Sheppart and Jacqueline Metzler in 1971. Their test consisted of 1600 pairs of objects. Each object consisted of ten solid cubes attached face-to-face to form a rigid armlike structure with exactly three right-angled "elbows". In the S&M version of their test the participants were presented with 20 pairs of objects. They had to decide if each pair of objects presented to them is "same" or "different". In order to find the answer to this problem they have to perform a mental rotation of objects because one of them is always rotated in some degree around an axis. This test was chosen because it is checking if the participant is able to see and manipulate three-dimensional objects in a two-dimensional plane. This ability is also important for perceiving depth cues in monoscopic displays.

The administration of the tests is quite simple, but it is important to control time. All participants had 2 minutes for completion of all of the tasks. The experimenter kept time with a stopwatch. After explaining the rules to the participants, they began by filling in the test when the experimenter said the word START. Everybody had to stop when 2 minutes had passed and the experimenter said STOP. All participants were presented with 20 pairs of objects in order from 1 to 20. If they found themselves stuck on a difficult pair they were told to leave it and go on to the next pair, but it was stressed that they had to try them in the numbered order. During 2 minutes they had to try to complete as many tasks as possible. The experimenter read these instructions to them before testing commenced. The scores were counted by subtracting the number of incorrect answers from the correct ones according to the test manual. For the results see Table1 below.

S&M	**Male**	**Female**
N	30	10
Mean	13.00	9.4
Std Dev	3.61	2.11
Minimum	8	7
Maximum	20.00	13.00

Table 1 S&M Test Results.

The Group Embedded Figures Test was designed to provide an adaptation of the original individually administrated Embedded Figures Test (EFT) developed by Herman A. Witkin. The decision was taken to use this version of the test because of the large number of subjects and because of the characteristics of the test, which complied with the scope of our study. The EFT was impractical to use (it is face-to-face consuming a lot of time). The GEFT is a perceptual test. The subject's task on each trial is to allocate a previously-seen simple figure within a larger complex figure which has been so organised as to obscure or embed the sought-after simple figure. Under strict interpretation, therefore, scores on the GEFT reflect the extent of competence at perceptual disembedding (Witkin, Oltman, Raskin, and Karp, 1971). Most of all, the test assesses an ability to break up an organised visual field in order to keep a part of it separate from that field. The GEFT test measures the extent to which subject perceptions are dependent on (or independent from) cues in the environment (the 'field'). A high score in this test means that the person is able to perceive objects independently form cues. These characteristics have implications for VR because it is still impossible to produce models with all of the cues that humans experience in the real world.

The test was validated over many years (Witkin, Oltman, Raskin, and Karp, 1971; Witkin, 1950; Witkin, 1952, Witkin, Lewis, Herzman, Machover, Meissner and Wapner, 1954).

The format and presentation of GEFT is as close as possible to the parent EFT. It contains 18 complex figures, 17 of which were taken directly from the EFT. The function of colours in the EFT, which was to emphasise large organised Gestalten serving (see Appendix B) to embed the simple forms, was achieved in the GEFT by light shading similar sections. The subjects are prevented from seeing simultaneously the simple form and the complex figure containing it. This was accomplished by printing the simple forms on the back cover of the GEFT booklet and the complex figure on the booklet pages, so that both simple forms and complex figures could not be exposed simultaneously. However, the subject could look back at the simple form as often as he wished.

The GEFT is divided into three sections: the First Section, containing 7 very simple forms, is primarily for practice, whereas the Second Section and the Third Section, each contains 9 more difficult items. Every participant was provided with one test booklet and a soft black pencil with an eraser. As the test is time-limited, the experimenter was controlling time on a stopwatch. Two minutes were allowed for completion of the first section, and the Second and Third Sections were both allocated 5 minutes each. At the beginning of the test administration all participants were asked to read the first three pages containing explanatory notes. The experimenter was circulating in the room making sure that all participants were doing two practice problems correctly and that they did not turn past page three. When all participants finished reading the instructions the experimenter read the statements from page 3, stressing the need for tracing all lines of the simple form, including the inner lines of a cube. After these, the experimenter gave a signal for the participants to start. When the participants finished doing the First, Second and Third Sections they were allowed to leave the room.

The score is the total number of simple forms correctly traced in the Second and Third Section combined. Omitted items were scored as incorrect. The items in the

First Section were excluded from the total score. All items were checked for correctness. The final scores were as follows:

GEFT	Male	Female
N	30	10
Mean	16.90	15.80
Std Dev	1.12	1.62
Minimum	14.00	13.00
Maximum	18.00	18.00

Table 2 GEFT Test Results.

3.7.2 Vision Test.

All participants were submitted to the vision test. The examiner used the Keystone View VS-II - Vision Screener with standard targets. None of the participants objected to taking part in this test. The test was conducted in the examiner's office on a one-to-one basis. The vision test consisted of checking: *visual acuity*, *phoria*, *fusion*, *stereopsis*, *colour vision*, and *horizontal field* tests. All of those tests were run for near and far vision.

The *visual acuity* test was divided into three parts. Firstly, right eye acuity was checked and then left eye acuity and at the end both eyes' acuity. The visual acuity is usually defined as a capacity to see fine details of objects in the visual field. In the clinical practice standard displays are used (e.g. Snellen Charts or Keystone VS apparatus). Acuity is given by a ratio D'/D, where D' is the standard or normal viewing or normal viewing distance and D is the distance at which the object viewed would subtend an angle of 1 minute of arc. For example, 20/200 means that when 20 feet away the person cannot distinguish an object subtended 1 minute of an arc while he or she is standing 200 feet away; this person is visually blind.

Visual acuity is measured in many ways. However, in this case the participants were asked to read lines of digits. They were allowed to miss only one digit per line. The acceptable standard ratio was vision acuity 20/30, 20/25, and the best 20/20. All participants had the allowed vision standard for this test.

Phoria is the orientation of the two eyeballs while focusing on an object. The Phoria Test checks for any abnormality in which there is a lack of co-ordination between two eyes. During this test participants were asked to decide at which point two lines are crossing. The red line was lateral and the green line was vertical. The acceptable margin was between 3.5 and 5.6 points on the scale.

The *Fusion* test indicates a potential imbalance in eye positioning muscles. It is a combination of the images presented to each eye into a single visual experience. Sometimes it is called a *binocular* (or *retinal*) *rivalry*. It is a perceptual phenomenon that occurs when the proximal stimuli to the two retinae cannot be resolved onto one single percept. The effect may be produced, for example, by presenting a field of blue to one eye and a field of yellow to the other eye. The resulting perception is an irregular alternation from the inputs of the two eyes so that the subject sees first blue then yellow then blue, etc. When the subject can resolve the two different inputs into a single percept (which, of course, is the normal state of affairs) the term *binocular* (or *retinal) fusion* is used. During the test administration all participants were presented with a set of four balls. Two balls were white, one was red and the other was blue. In the correct vision the participants could see only three balls because the two white balls were overlapping (fusing). Seeing three balls was the acceptable standard score.

Stereopsis is the displacement of two objects in the third dimension. The test administered used measured the minimum difference in depth (distance from the viewer) that can be perceived using both eyes. The participants were presented with five lines with five objects placed in every line (box, heart, cross, star, ring). The participants had to distinguish one object that was placed closer to them in every line. The accepted level was to distinguish all objects correctly.

A *Colour* test was conducted in order to eliminate from the trials all participants with colour defective vision. Colour blindness is any one of a complicated variety of congenital defects in vision that renders a person unable to distinguish two or more colours that normal individuals can distinguish easily. Although there are forms of total colour blindness (*achromatopisia*[11] and *monochromacy*[12]), these are quite rare and most individuals distinguish many colour wavelengths. There is a fascinating book about colour blindness written by Oliver Sacks (1996). He describes the population of an island where all inhabitants are colour blind. The most common is *dichromacy* whereby the colours experienced can be described by using only two hues. The vast majority of dichromats confuse reds and greens; blue-yellow dichromacy is rare. Colour blindness is a sex-linked genetic trait and is far more frequent in males than females with approximately 1 in 15 men showing some defects but only about 1 in 100 women (Reber, 1985).

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[11] Achromatopsia- a condition wherein all visual experiences are achromatic, lacking in both hue and saturation. Any person with this condition can only see shades of grey.

[12] Monochromacy- complete colour blindness. A monochromat can differentiate colours only on the basis of brightness.

The participants were presented with the two pairs of plates with embedded two digit figures. The first plate pair was a severe (red/green) plate with the digits 79 and 23. The second pair was mild (blue/violet) with digits 92 and 56. The participant task was to correctly distinguish all pairs of digits for both plates.

The *Horizontal Vision* test is a test of peripheral vision. This test checks vision using the periphery of the retina. The periphery of the retina is the outermost area of the retina, that farthest from the fovea. It is not sharply defined, but generally referred to as the area where the cones are effectively absent. It is relatively poor, low in acuity and strictly achromatic. In our test the participants were looking onto the Keystone's ocular and the examiner was pressing the LCD lights in an ad hoc manner. The participant had to say if he could see the flashing light. The test was conducted for both sides of the head starting from the nasal area up to the target at 85°. If the subject could not recognise the L.E.D. target at 70° on both sides, they were disqualified from our study.

All these tests had one main aim - to eliminate from the study all those people with vision problems. Only participants scoring in acceptable and above field were asked to take part in the experiment. Subjects who passed the vision test and psychometric tests were invited for further participation in the experiment. Also, the author wanted to ensure that the subject group was as homogenous as possible.

3.7.3 Questionnaire Design.

Questionnaires are instruments for gathering structured data from people. Special attention has to be placed on their validity and reliability. There are some general rules which apply to the process of building questionnaires: (i) ask for the minimum information required for the research purpose; (ii) make sure questions will be answered truthfully; (iii) make sure questions can be answered; (iv) make sure questions will be answered and not refused. All questions should be phrased clearly and unambiguously in order to prevent participants from having no doubt in answering them. One should omit technical terms or jargon which could not be understood by the participants.

During the process of constructing the questionnaire scales were used. They served as instruments for gathering quantitative data. The scales are similar to the questionnaires, however, they do not usually use questions (see Appendix A). The author utilised two types of scales in the questionnaire: *summated ratings* (Likert, 1932) and *semantic differential* (Osgood, Suci and Tannenbaum, 1957).

The first time the *summated ratings scale* was described by Likert in 1932. This is a technique for the measurement of attitudes. During the construction of this scale one has to produce an equal number of favourable and unfavourable statements about the attitude object. The respondent has to indicate their response to the statements. The values on the scale are used as scores for each respondent for each item. The participant's overall score is a sum of scores for each item. Next, one has to carry out an item analysis test in order to determine the most discriminatory item - those on which high overall scorers tend to score highly and vice versa. This is the Likert scale's greatest strength relative to other scales. It means that an item does not need to relate obviously to the attitude issue or object. It can be counted as diagnostic if responses to it correlate well with responses overall (Coolican, 1994). On the *semantic differential scale* (Osgood, Suci and Tannenbaum, 1957) the respondent is asked to mark a scale between bipolar adjectives according to the position they feel the object in question holds on the scale for them. This test produces good reliability value and correlates well with other attitude scales. However, there are some weak points. As Coolican (1994) states, the *semantic differential scale* may force the respondents towards a 'position response bias', where they habitually mark at the extreme end of the scale or will not use the extreme at all without considering possible weaker or stronger responses; and here, too, we have the problem of interpretation of the middle point on the scale.

The questionnaire utilises both scales. It was divided into seven parts: (i) length, width, and height estimation (ii) figure recognition; (iii) cognitive maps; (iv) feeling of space (v) description of experience; (vi) evaluation of virtual reality interface; (vii) personal data. A copy of the questionnaire is provided in Appendix A.

Parts 1 and 2 were partially completed by the experimenter. In Part 3 participants were asked to draw their path of the visit, and rate the size of spaces. Part 4 consisted of thirteen bipolar adjectives. The participants were asked to rate their perception of the biggest room indicated during the course of the experiment. In Part 5, they were asked to rate their experience. Part 6 was designed for the participants experimenting with the immersed computer simulation only. There were questions relating to the virtual interface. The last section, Part 7 was designed to gather some information about people taking part in the study. Before running the main study, the questionnaire was evaluated through pilot studies. It was necessary to change some of the vocabulary, and define more precisely some terminology. The questionnaire also was shortened in order to provide greater efficiency for the operation of the study. Some of the pilot study participants complained that it took too much of their time to fill in the questionnaire. Most of the personal questions were removed. In addition, thirty per cent of the scales regarding the feeling of space were removed. Following this exercise, completion of the entire questionnaire took approximately 30 minutes for each participant.

3.8 The Computer Model.

The computer representation of the ground floor of the building was modelled using Superscape's VRT package. The model was designed by VR Solutions Ltd. (now Virtual Presence Ltd.). The model was modified, by the experimenter, in order to suit the study. It was necessary to limit the file size by removing some textures in order run it on a 486 computer.

3.8.1 Level of Detail.

It was very important to achieve the highest possible level of realism in the model. This was dictated by the fact that one did not want to have a variable bias due to the different settings in RWS and computer simulations as one was comparing participants' perceptions of the basic spatial characteristics. The choice of the experiment site was perfect for the study, because the ground floor of the site was an empty, not furnished, space. Also, the site was completely void of any people. Therefore, it was a lot easier for the experimenter to achieve the closest possible level of detail in both RWS and the computer simulation (colour, texture depth cues, or surfaces). The chosen space contained few architectural details. It was easy for the experimenter to control the elements. All spaces used during the experiment consisted of the most basic spatial establishing elements. Included in the model were walls, doors, ceiling and floor. In the biggest room there were three poles placed at three metre intervals. At the back of this room, there was a shelf with a book (Figure 6). The rooms had artificial lighting. The same room was used for the description of space task.

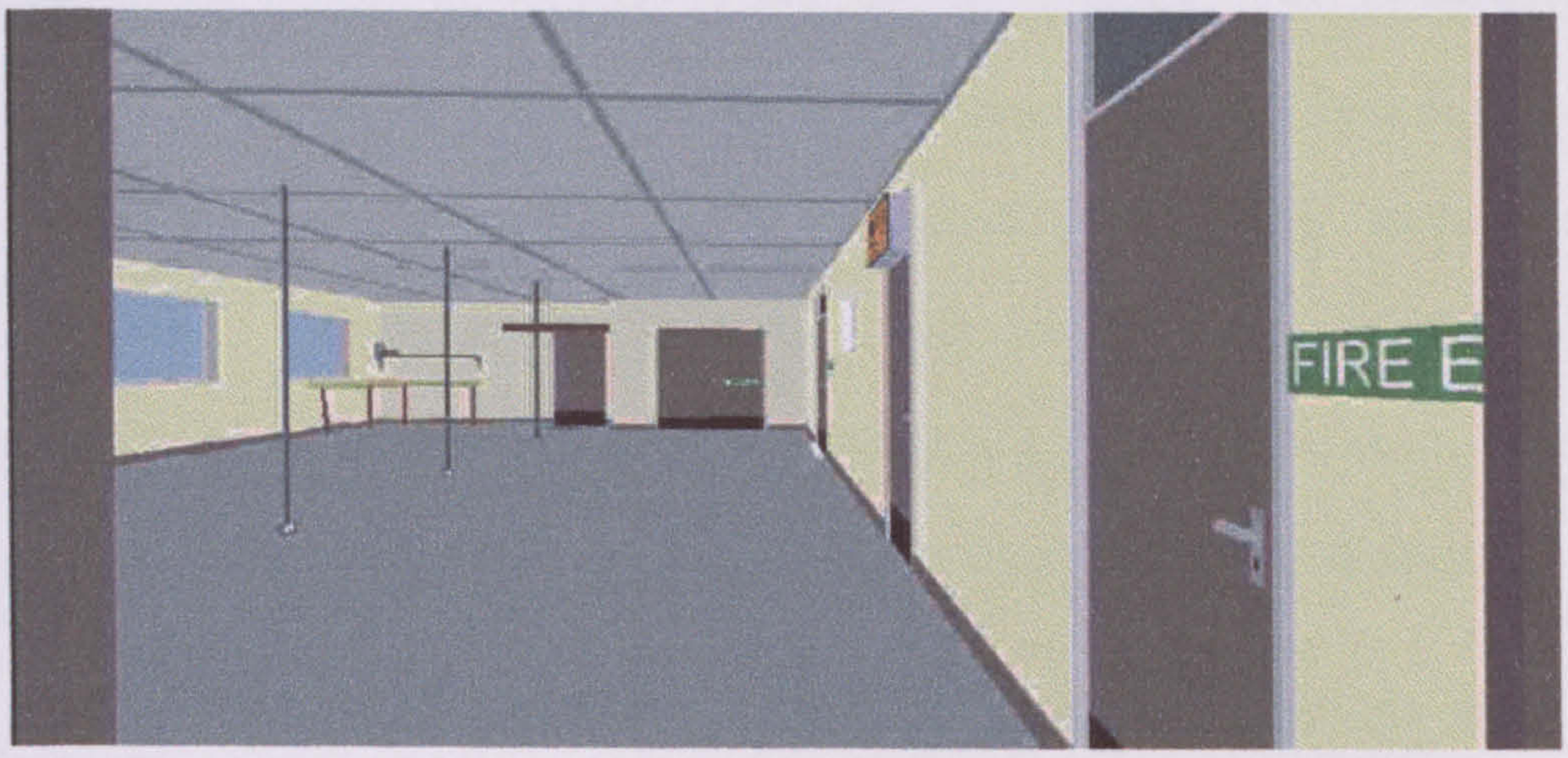

Figure 6 Room C.

3.8.2 Elements of Scale.

In every architectural mock up model, scale always plays an important role. The scale contributes to understanding of the experiential quality of architecture (Zobel, 1995). The scale can be classified as physical, proportional and human. Physical scale is defined as a direct size relationship of one form to another. The form is what physically makes up everything that can be touched or seen. The relationship of forms within a particular object or set of objects relates to such things as size and arrangement of doors and windows in the room. The human scale is believed to be the most important of these factors. It is a relationship between the size of a human being and the architectural elements, or the environment generally. People understand through continuous visual contact, the size and proportion of other people. The best use of human scale is to put your own body near the object so that one has a direct correspondence between one's own dimension and the dimension of the building, as well as getting a visual indication of distance and size from parallax and perspective as one approaches and moves through the building (Zobel, *op cit.*, Licklider, 1965, Rasmussenn, 1962). In the virtual environment, the lateral movement of one's head is a small but insufficient indication of scale, also standing or walking while being immersed. In order to help participants with the perception of scale in the author's experiment there were door, windows and some familiar objects in the rooms. In one of the rooms, there was a desk with a PC and one chair (Figure 11).

In the room used for the recognition of objects, a figure and a chair were placed in order to assist this task (Figure 7). The whole computer model and all objects were scaled

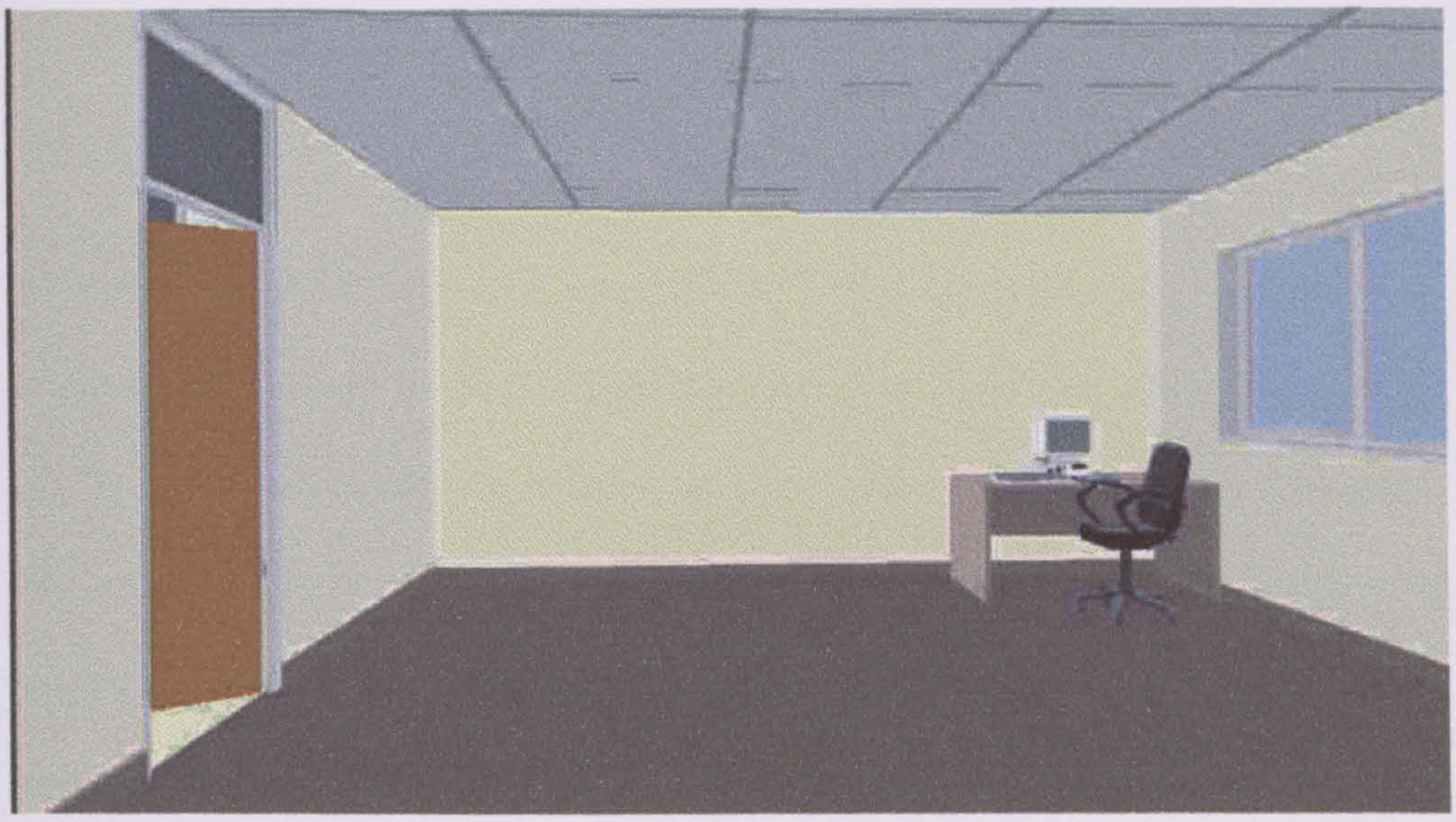

Figure 7 Room B.

3.9 Technological Limitation.

During the process of modifying the model, one had to take into consideration the speed of the computer used for the experiment. The first version of the model had to be stripped of some number of polygons in order to facilitate the computer's speed. The colours used for the all of the elements of the space in the virtual model were as similar as possible to RWS. Another important element limiting this study was the *Field Of View* (FOV) of the i-Glasses headset. Human natural binocular FOV of 180° horizontally by roughly 120° vertically remains virtually unchanged as a constant frame of reference from birth to death. Head Mounted Displays substantially reduce the FOV of the user, obscuring the perception of cues in peripheral vision. This discrepancy between an observer's natural visual field and an HMD field of view can mislead an observer in to believing that a reduced displayed field of view represents their full visual field, resulting in perceived minification of the virtual environment and distortion of viewed distances.

Another factor which can contribute to the limitation of perceived depth cues is *low resolution.* Low-resolution displays can also degrade the general appearance of VE. *Movement method* also plays the important role in perception of distances. Movement methods are control devices and styles of movement (e.g. 2D and 3D joysticks, Spacemouse, Or Spaceball). These movement methods differ in the amount of visual flow information being afforded to the user. However, using these devices is rather artificial. Walking with a treadmill seems to provide a more natural way of moving within VE (Witmer *et al,* 1998, Kline *et al.,* 1996, Witmer *et al.,* 1996). It also has been observed that HMD may produce deformed imaged nonlineary. This can provide a misleading perception of object size in the centre of the field. Furthermore, this deformation of object size may reduce the accuracy of distance estimates to those objects (Stanley *et al.,*1998; Psotka *et al.,* 1998) *Accomodation-vergence conflict* also can lead to visual fatigue and blurred vision, which may distort VE distance perception, particularly more than 10 feet away from the observer (Wann and Mon-Williams, 1996; Rushton and Wann, 1993).

In 1989, Venturino and Kunze ran the study concerned with the human ability to acquire and memorise patterns of spatial locations using HMD. They based their study on the hypothesis that human spatial cognition can be measured by the ability to locate, memorise, and replace patterns of spatial locations in an area 240 degrees azimuth by 90 degrees elevation. All subjects had to spatialise object locations existing around them rather than only within the display directly in front of them (Draper, 1995). Their work was a continuation of previous research conducted by Wells, Venturino, and Osgood (1988). They manipulated FOV, number of targets, and availability of context in the replacement task.

Their findings indicate that FOV affects acquisition of spatial information about one's surroundings, as indicated by increase of "time to memorise" with decreasing FOVs. Small FOVs require more head movements, more sampling time, and more integration effort to build a mental representation of the spatial environments. These results indicate that a large FOV helps in the development of spatial awareness. A large view allows for easier integration of environmental elements and their associated relationships (Draper, 1995; Venturino and Kunze, 1989; Boff and Lincoln, 1988).

In the next chapter is described an experiment designed and run after taking into account all of these intrinsic limitations of virtual environments.

4. EXPERIMENT 1: ESTIMATION OF EGOCENTRIC AND EXOCENTRIC DISTANCES, FEEL OF INDIVIDUAL SPACES.

This chapter presents the methodology and results of the first experiment. This experiment was concerned with estimation of exocentric and egocentric room dimensions, and "feel" of individual spaces.

4.1 Overview.

The perception of visual space has been a focus of study for many decades. However, it is still not properly understood in functional terms or in terms of underlining mechanisms. The diversity of theoretical approaches and empirical findings exist without any serious attempt at integration. Most of the work regarding distance estimation was centred on subjects viewing from a more or less fixed point. Loomis (1992) and Gibson (1979) argued that a fixed position is not typical of ordinary viewing. According to them, the observer should be free to assume different vantage points in order to have motion parallax information. Furthermore, there are also systematic distortions of visual space accompanying such viewing that provide important cues about the visual process that ultimately must be part of the understanding of both stationary and dynamic viewing (Loomis, *et al.*, 1992). The tasks in this experiment were conducted from a fixed position with head movement encouraged during the estimation of tasks in order to limit the bias in participants' FOV in the real and virtual settings.

The task of viewing from a fixed location can be divided into two types of research. The first type is concerned with the perception of egocentric (absolute -

i.e., distance from the observer to an object) distances and the second one is concerned with the perception of exocentric (relative - i.e., distance between two objects or other people) distances or depth, and size. The studies by Darken, *et al.* (1998), Lackner and DiZio (1998), Waller *et al.* (1998), Witmer and Kline (1998), Norman *et al.* (1996), Foley (1980, 1991), Johnston (1991), Ellis (1991) Gogel (1960), Baird (1970), and many more, contributed to the author's understanding of the functional description of visual space. There are many methods for distance estimation used by researchers over the years. Glinsky (1951) used scales of perceived egocentric distances using the method of *equally appearing intervals*. He marked stripes of 0.3m in length on a field of grass, extending away from the observer. However, more distant physical intervals had to be made larger in order to appear of constant apparent length. Other methods are called the *direct scaling method of verbal report*, *magnitude estimation*, and *ratio production yield scales*. Unfortunately, these scales also have major flaws, because adult observers are generally cognisant of perceptual foreshortening of far distance intervals and have been hypothesised to correct their judgements (Loomis, 1992; Ellis, 1989; Gogel and Da Silva, 1987; Gogel, 1974; Baird, 1970).

Gogel (1990, 1982,) has shown that the apparent motion concomitant with lateral head movement can be used to provide uncontaminated measures of perceived distances for relatively short physical distances. However, Loomis (*et al.*, 1992) argued that he has yet to show the efficacy of the method for measuring the perceived distances of distant targets in full-cue environments.

Under natural, unrestricted viewing conditions, the perception of distance is remarkably consistent (Baum and Jonides, 1979; Boff and Lincoln, 1998). Baird and Biersdorf (1967) as well as others have shown that the relationship of perceived distance and actual distance, on average, can be described by the power function:

$$J = kD^n$$

Where **k** and **n** are constants for that location/orientation, **J** is the judged distance, and **D** is the actual distance. The exponent '*n*' approximates 1.0 overall; it is generally slightly greater then 1.0 with indoor observation and generally less than 1.0 with outdoor observation (Da Silva and Fukusima, 1986).

Research shows that large individual differences exist in the judgement of apparent distance (Cook, 1978; Da Silva and Fukusima, 1986). However, Da Silva and Fukusima (1986) found that these individual differences, manifest in individual exponents of each fitted power function for magnitude estimation of apparent distance, remain stable regardless of environment (natural indoor or natural outdoor), range of distance estimated, and length of the inter-session interval, for up to 9 months. It is reasonable, then, to use the experiment design described in Chapter 3. This design style would negate effects of large individual differences observed in distance estimation while maintaining the observed temporal stability found within each individual's judgements.

4.1.2. Methodology.

In first experiment RWS and virtual model, participants were asked to follow a pre-determined path. It was necessary to do so in order to have control over the variation due to differences in the way people explore new spaces. All of the spaces were visited only once. On the floor were placed red lines in strategic places. On these lines, participants were asked to perform estimation tasks. The start of entry point of the visit was in the reception area. Other than this, the reception area did not play any role in this experiment. Figure 8 shows the plan of the experiment's site, visit path and labelled spaces. The rooms were chosen in a way that they could represent different distances. Room A was the smallest one and the room C the largest in volume. Room D was very interesting for the experiment because its shape was the closest to a square. It was chosen because of this characteristic. It was hypothesised that it would be the most difficult to estimate because of its shape. The locations where subjects were asked to estimate the size of the rooms are also shown on the plan of the rooms. The red lines indicate places where participants were asked to perform estimation.

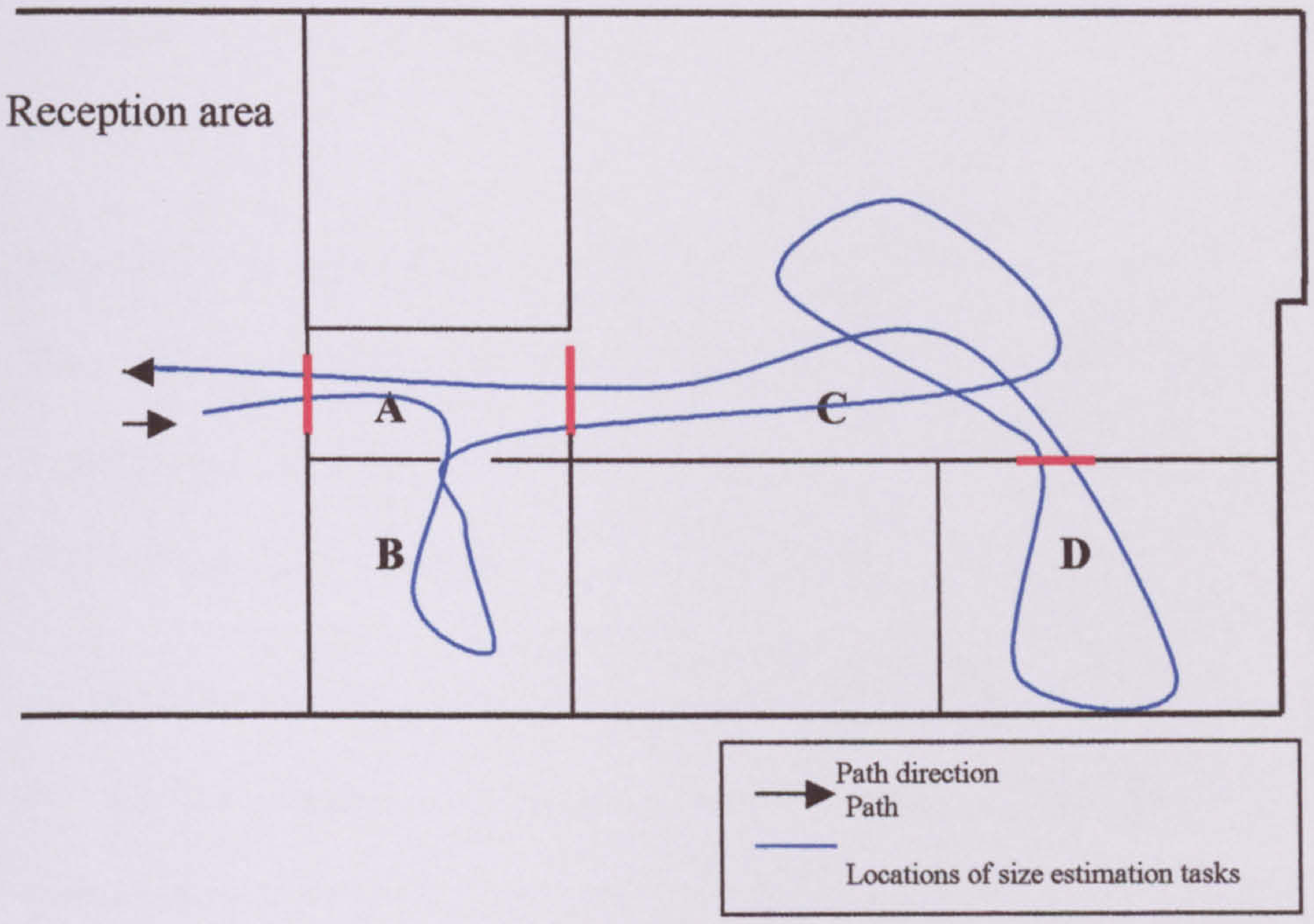

Figure 8 Plan of the experiment site.

As previously mentioned, the subjects started participation in the experiment in the reception area. In the simulation condition, the viewpoint was automatically positioned there. In RWS they were accompanied by the experimenter to the starting point. Each subject was asked to stand on the first red line which was placed at the entry to room A (Figure 8). It was the smallest place in the site. They were asked to estimate the dimensions of the room without moving from that line. They were free to describe the dimensions of height, width and length in any order they chose. They were told that all their answers would be written into their questionnaire as well as taped on the Microcassette Recorder. Then they were taken to room B where the desk with a computer and a chair were placed. Later in the questionnaire participants were asked to indicate where these objects were located. They were then led to the second line, which was positioned at the entry to Room C (Figure 8). There, as in Room A, participants were instructed to estimate the dimensions of the space. After this task, they were encouraged to have a look around the room for a while (2 minutes). Participants were asked to remember this space because they would be asked to describe it in the questionnaire.

Then they were led to the next red line placed at the entry to Room D (Figure 8). Then again, participants were instructed to estimate the dimensions of the space. After this task, they were taken through rooms C and A back to the reception area. That concluded the experiment. It took approximately 45 minutes.

All participants were asked to fill out a post-experimental questionnaire. To fill out the questionnaire took approximately 30 minutes (For details about the questionnaire see: Chapter 3, Section 3.7.3, and Appendix A).

4.1.3 Estimation method.

The experiment method of magnitude estimation[13] was utilised (Loomis, 1992; Ellis, 1989; Gogel and Da Silva, 1987; Stevens, 1975; Gogel, 1974; Baird, 1970) It has been popularised by S. S. Stevens. In this method the participant is required to assign a number that reflects the estimated dimension to a standard stimulus. For first and second experiment this method has been altered slightly. In order to make tasks easier, participants were asked to estimate dimensions in a familiar unit of length (metres or feet). However, one is aware that the notion of metres or feet could vary among participants. It was foreseen that each individual possesses some concept of metres/feet. Thus, it should be more established than the participant's notion of an unnamed discretionary unit of distance.

4.1.4 Power Law.

Stevens *ibid.* demonstrated that the judgements of unidimensional stimuli almost universally fit a power function. For distance estimation Baird *ibid.* showed that the power function describes estimates of the stimuli in both the frontal plane and in depth.

The method of least squares was used to determine a linear regression function relating log actual dimensions to log estimated dimensions. The slope of the function is the exponent of Stevens power function:

$$J = kD^n$$

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[13] For Psychophysical Theory see Appendix B.

Where k is a proportional constant, J is the judged distance, and D is the actual distance. The exponent 'n' of this function determines if the relationship between the actual and estimated dimension is linear or nonlinear. In general, the exponent for any one continuum is quite stable. Myers (1982) stated that, as long as the experimental situation is kept reasonably standard, and the same measure of physical stimulus intensity is used, the average exponents produced by different groups of observers for the same continuum are quite similar, e.g. for line some are close to 1. An exponent of n=1.0 indicates, in this experiment, that dimensions judgements are exactly proportional to true distance. It means that there is veridical discrimination among the dimensions being judged. A dimension twice that of the modulus (metre, foot) is judged twice the true modulus distance. Exponents less than or greater than 1.0 indicate that the estimated dimensions are proportional to the *n*th power of the true dimension. However, it has to be noted that the exponent of 1.00 does not mean that the estimates are accurate, because k can vary greatly, indicating large underestimates or overestimates (Witmer, and Kline, *op cit.*).

4.1.5 Statistical tests- *t-test.*

In order to reject or accept the null hypothesis, appropriate statistical tests were utilised. There are many statistical tests used in psychological research. Some of them are more robust than others. They are generally divided into two groups: parametric and non-parametric tests. The parametric tests are characterised by higher power and efficiency compared with non-parametric tests. They are more sensitive to features of data collected. On the other hand, the non-parametric tests are often not far from their parametric equivalent. However, they may need a higher number of cases. In addition, they are simpler and quicker to calculate, and they do not put as high a demand on meeting data requirements as parametric tests do. Unfortunately, there are no precise rules available to apply to test choice, neither can anyone guarantee a 100% correct choice of test. Howell (1982), Coolican (1994), Ferguson and Takane (1989), Brzezinski (1996) suggest that not all principles for choosing correct tests are set in concrete. One can conduct a parametric test on data which do not fit the assumptions exactly. The parametric tests will still give accurate probability estimates under the imperfect conditions because they are very robust. They do not break down, or produce many errors significant to the decision.

The experiment's design was unrelated, because the two groups that were used experimented under only one condition each. This required that the author had to consider two tests. The first test is called *t*-test. It is a parametric test which is extensively used in psychology. The *t*-test indicates sample differences by using means and the distribution of sample scores around the mean. In order to fulfil the condition for using *t*-test we have to have the level of measurement at least to an interval status. The sample data have to be drawn from a normally distributed population, and the variance of the two samples should not be significantly different. Most of the samples are too small to look anything like a normal distribution, which only gets its characteristic bell-like shape from the accumulation of very many scores. In practice, for small samples, one has to assume that the population they were drawn form a normal distribution on grounds of past experience (Coolican, 1994).

The homogeneity of variance between two samples can be made by checking the two ranges. One can use the *F-test* which tests for the difference between two sample variances in much the same way as the *t-test* checks for a significant difference between the two means. There is not one answer to the question regarding the size of the sample. It has been suggested that a sample larger than 20 elements can be sometimes considered as a large one depending on the aim of research (Brzezinski, 1996, Ferguson and Takane, 1989).

After analysing these requirements it was decided that *t-test*s would be run. The First Experiment's sample was made up of two groups: N_A= 20 and N_B= 20. It is assumed that estimation tasks would form a near normal distribution. The sample numbers are the same and therefore the homogeneity of variance requirement is not so important. However, if *F*-test of sample's homogeneity of variance will exceeds the table values than the results *t-test* for independent samples with an equal variance not assumed will be presented.

Experiment 1 was run with two groups. One had to calculate two means- $\bar{x}_A$ and $\bar{x}_B$ - which are an estimation of the means drawn from population μ_A and μ_B. Therefore, null hypothesis for the *t-test* is as follows:

$$H_0 : \mu_A - \mu_B = 0$$

The *t-test* is a test of significance of the null hypothesis. One wants to make a decision of rejecting or accepting the null hypothesis.

Another decision, which one has to make, is the significance level. Psychologists reject a null hypothesis at several levels. They calculate the probability of the difference in their results, which could have occurred by chance alone. If the probability is less than the set level they reject the null hypothesis and conclude that the results occurred by chance alone. Thus, they claim support for their research hypothesis. They say that the results are significant and the significance level is a measure of how confident they are that the results are not a fluke (Coolican, *op cit.*). The *golden standard* is the level of $p \leq 0.05$. Through all our statistical tests we use it as our level of significance. It means that if we find the result significant ($p \leq 0.05$) the null hypothesis will be rejected and subsequently we will retain the null hypothesis if a result will not be significant ($p \geq 0.05$).

4.1.6 Relative Error.

In order to check the accuracy of dimension estimations a *Relative Error* measure was calculated. It is likely that the size of error will increase with increasing dimensions. Witmer and Kline (1998) stated that, the best measure of accuracy might be the amount of error relative to the dimension judged (relative error). Relative error was calculated as follows:

$$\text{Relative Error} = \frac{(\text{Dimension Estimation - True Dimension})}{\text{True Dimention}}$$

This represents the percentage error in an estimate relative to the true distance. The sign indicates direction of error. Negative relative errors indicate underestimates and positive relative errors reflect overestimates.

4.1.7 The Results.

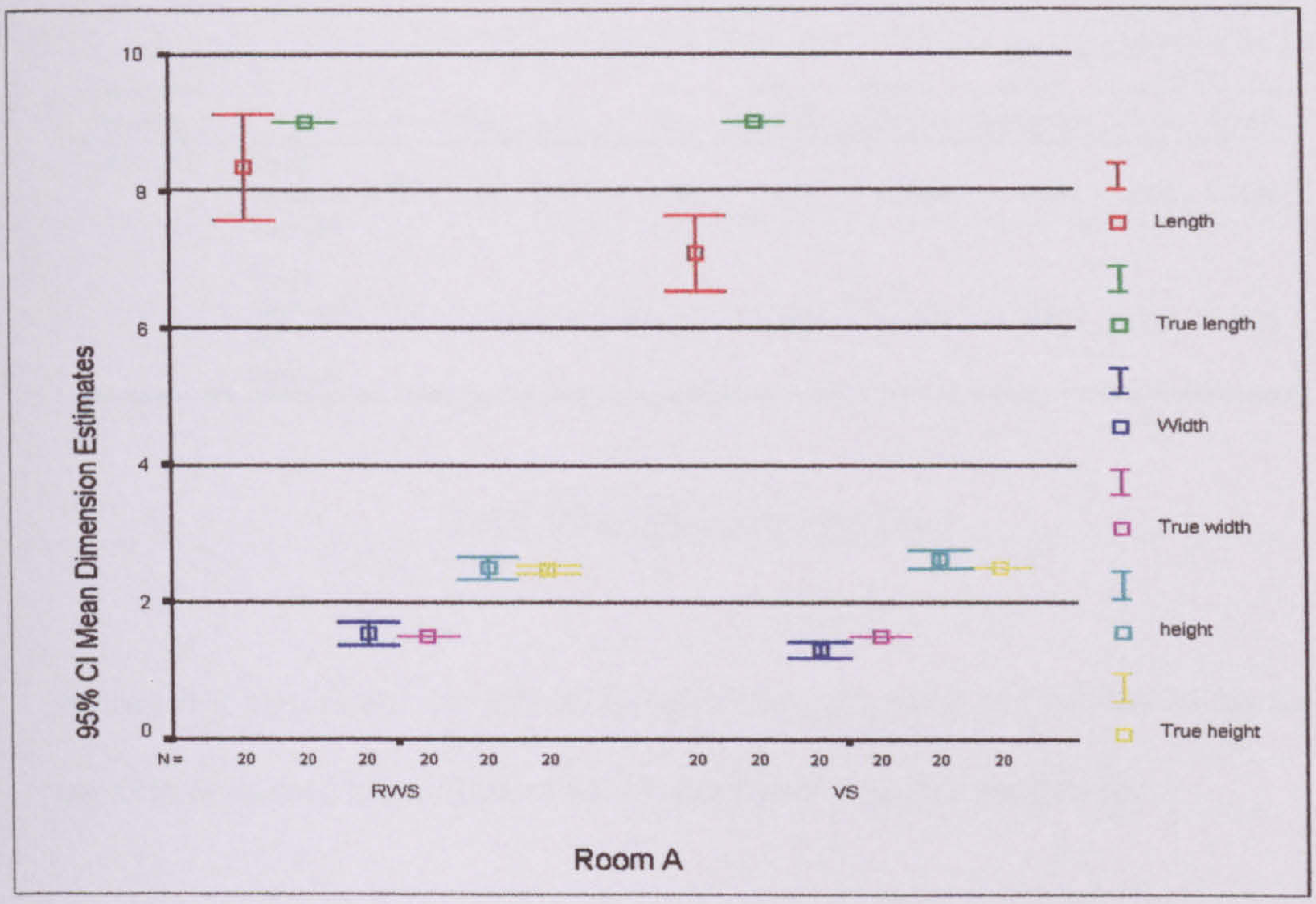
During Experiment 1 the basic dimensions of spaces were measured. The modified method of magnitude estimation was used. The subjects were asked to estimate the dimensions of three chosen rooms in order to facilitate the requirements of the experiment. The representativness of VEs was measured in the form of self-reported evaluations from the participants. The statistical tests were used in order to accept or reject the null hypothesis. All statistical data were computed using SPSS v. 7.5 statistical software.

None of the participants taking part in the experiment reported any difficulties with distinctions between length, width or height of the spaces. It was reported that in order to estimate horizontal dimensions, subjects generally tried to imagine the number of steps it would take them from standing point to the point in question. All estimations were exocentric in nature apart from length. Most participants found the estimation task difficult. On the other hand, estimation of the vertical dimensions they found relatively easy. It was due to the fact that all of them were standing during the tasks so their own height gave them some sense of scale. What follows is an analysis of the gathered data.

4.1.7.1 Room A.

Room A was the smallest of all the rooms used during Experiment 1. It was a narrow corridor leading from the reception area to room B and room C (Figure 8). It had been chosen for our experiment because of its dimensions. Its actual dimensions were as follows: length 9 metres, width 1.50 metres and height 2.50

metres. The participants performed a total number of 120 perceptual tasks (60 in the RWS and 60 in the simulated environment. Of the 120 estimates (40 participants x immersions), 36 were perfect (30%). Figure 9 shows the results of the estimation tasks in room A.



RWS- Real World Setting **VR-** Virtual Setting

Fig 9 Mean perceived dimensions estimates in VE and in real world.

4.1.7.1.1 *t-test.*

As mentioned previously, parametric *t*-tests were performed for every dimension in every room. Based on the results of this test, the null hypothesis will be accepted or rejected. Three *t-tests* for the independent sample were performed separately for each dimension. In Table 3 the *t*-test results for length of Room A are shown. For the two-tail test for length, with equal variance not assumed, and *df=38* the critical value of *t*[14] is 2.031 for significance with $p<0.05$. By comparing t from the above table with the critical value of t one can state that

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
Dependent variables		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LENGHT	Equal variances assumed	1.936	.172	2.753	38	.009	1.2500	.4541	.3308	2.1692
	Equal variances not assumed			2.753	34.033	.009	1.2500	.4541	.3272	2.1728

Table 3 Length - *t*-test results.

the result is significant. In order to be significant the value of t calculated must be equal to or exceed the critical value for significance at the required level.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
WIDTH	Equal variances assumed	.922	.343	2.097	38	.043	.1250	5.961E-02	4.335E-03	.2457
	Equal variances not assumed			2.097	34.422	.043	.1250	5.961E-02	3.922E-03	.2461

Table 4 Width - *t*-test results.

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[14] Source: Powell, F.C. (1970), *Cambridge Mathematical and Statistical Tables*, Cambridge University Press.

In Table 4 *t-test* results for the length of Room A are shown. For the two-tail test for length, with equal variance not assumed, and *df=38* the critical value of *t* is 2.031 for significance with p<0.05. By comparing t from the above table with the critical value of t one can state that the result is statistically significant.

Table 5 shows *t-test* results for the length dimension in Room A. For the two-tail test for height, with equal variance not assumed, and *df=38* the critical value of *t* is 2.031 for significance with p<0.05. By comparing t from the above table with the critical value of t one can state that the result is not significant.

Independent Samples Test

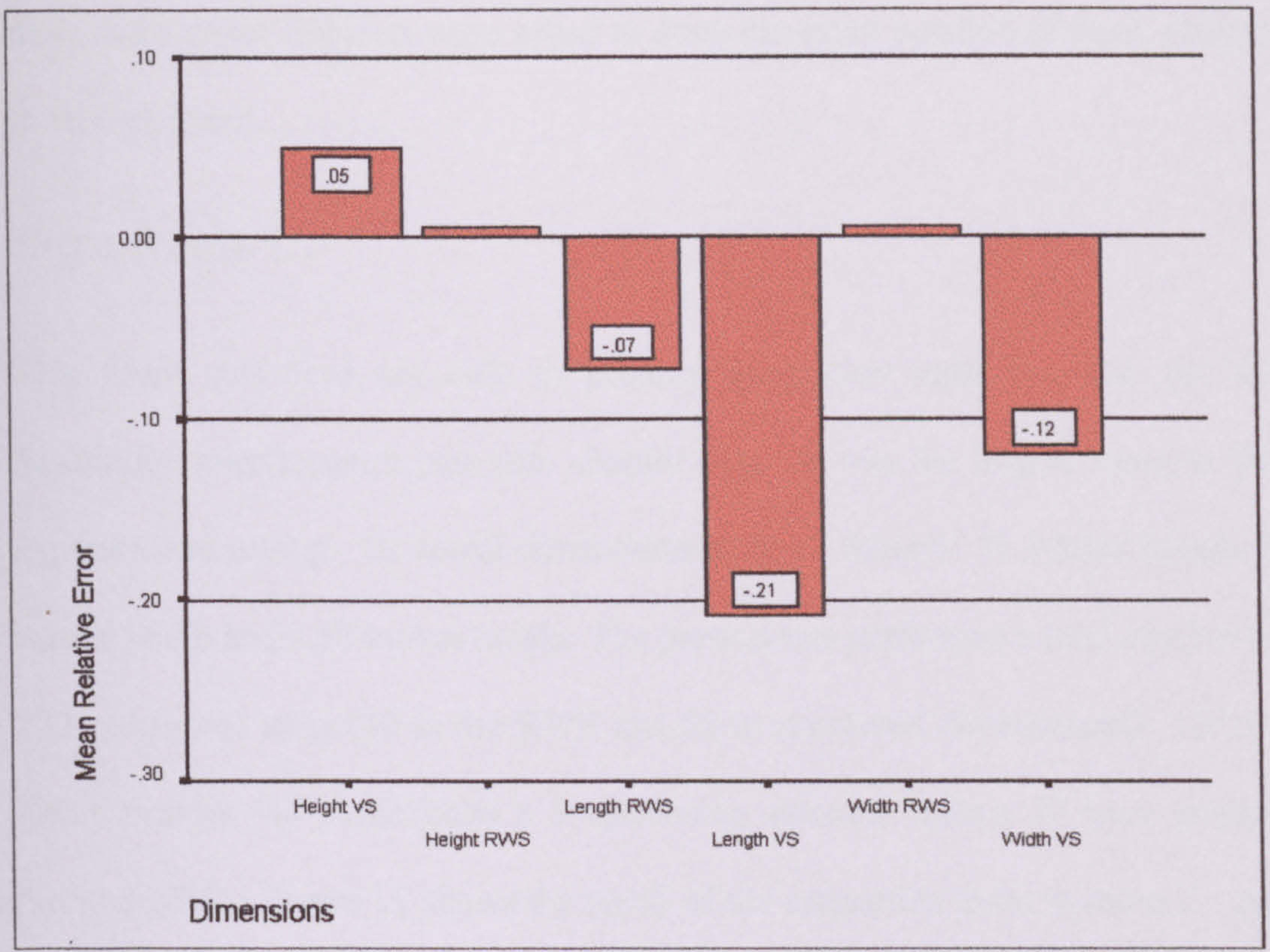
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
HEIGHT	Equal variances assumed	.194	.662	-1.313	38	.197	-.1280	9.745E-02	-.3253	6.928E-02
	Equal variances not assumed			-1.313	37.507	.197	-.1280	9.745E-02	-.3254	6.937E-02

Table 5 Height- *t*–test results.

4.1.7.1.2 Relative Error.

Figure 10 shows the relative error for the Room A dimensions. A direct comparison between the estimates made in the virtual environment and the true height reveals that participants were the most accurate when estimating this dimension. Participants' length and width estimation were less accurate in VE.

Taking into account results of the relative error data presented in Figure 10,



RWS- Real World Setting **VR-** Virtual Setting

Figure 10 Room A- Relative Errors.

one can conclude that participants underestimated the length by approximately 8%, and their estimates of width and height were nearly error free in real world. However, participants typically underestimated by an averaged of 21% in length, and 12% in width in VE. However, height was overestimated by 5% in the VE. For data and calculation see Appendix C.

4.1.7.2 Room B.

Room B was used only as a part of the layout for the cognitive map task. There was a task in the post experimental questionnaire regarding the location of the PC, desk and a chair. Subjects were asked to draw the exact position of these objects in their sketches.

4.1.7.3 Room C.

This room was used not only to perform estimation tasks but also for the descriptive questionnaire (see sub- chapter 4.2). It was the largest room in the experimental setting. Its actual dimensions were as follows: 16 metres length, 8 metres width and 2.50 metres height. The participants performed a total number of 120 perceptual tasks (60 in the RWS and 60 in simulated environment). Of the 120 estimates (40 participants x 3 dimension estimate tasks), 32 were perfect (around 26%). Figure 11 shows the result of the estimation tasks in room C. All participants were asked to spend some time here as there would be specific questions regarding Room C in the questionnaire. For the data regarding this room see Appendix C.

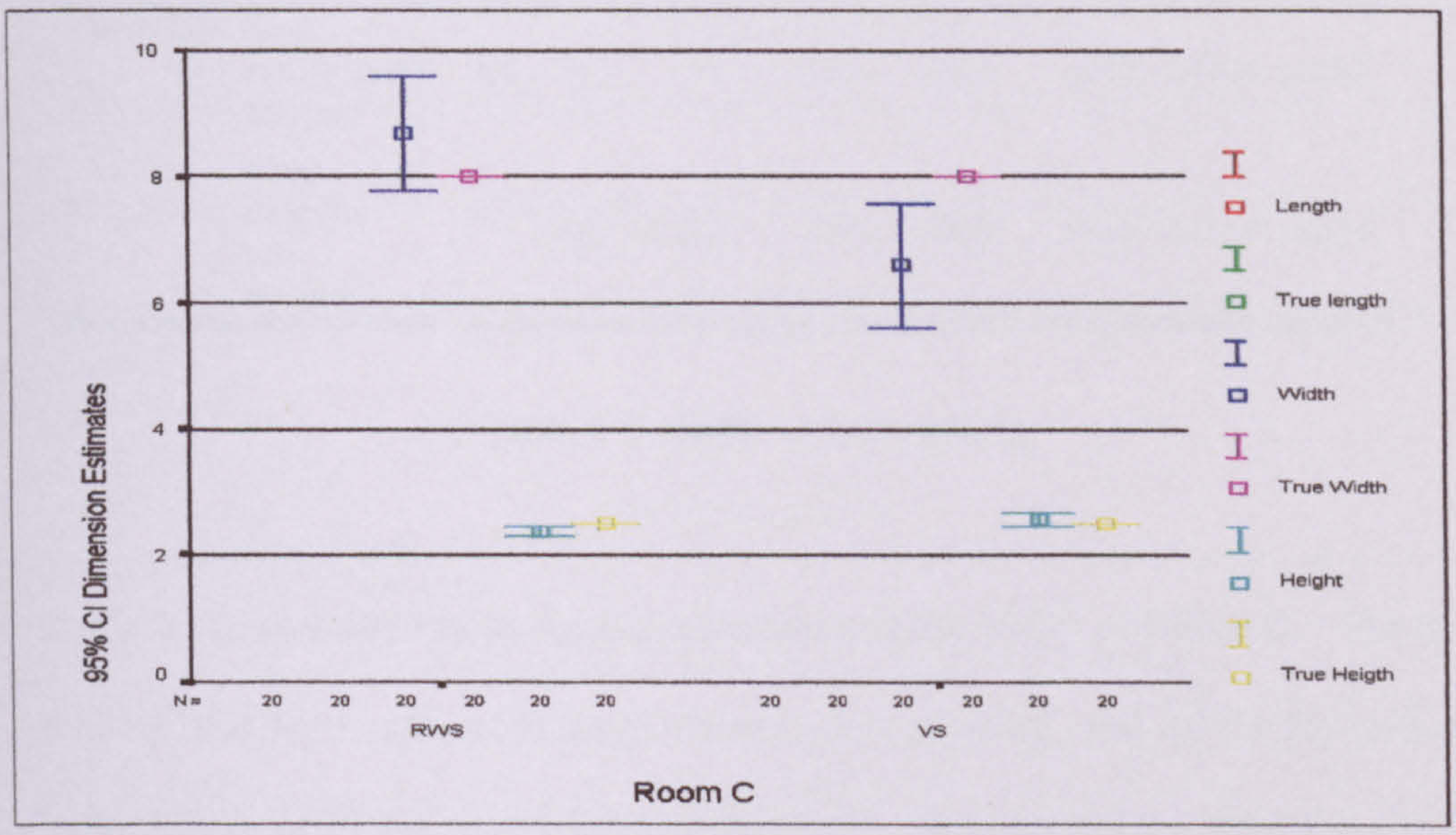


Figure 11 Mean perceived dimension estimates in VE and in real world

4.1.7.3.1 *t-test.*

Table 6 shows *t*-test results for the perception of the length of Room C. For the two-tail test for length, with equal variance not assumed, and *df=38* the critical value of *t* is 2.031 for significance with p<0.05. By comparing t from the above table with the critical value of t one can state that the result is not significant. In order to be significant the value of t calculated must be equal or exceed the critical value for significance at the required level (p<0.05).

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence ıterval of the Mea	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LENGTH	Equal variance assumed	3.509	.069	-.363	38	.719	-.3500	.9646	-2.3027	1.6027
	Equal variance not assumed			-.363	32.718	.719	-.3500	.9646	-2.3131	1.6131

Table 6 Length - *t*-test results.

Table 7 shows *t-test* results for the perception of the width of Room C. For the two-tail test for length, with equal variance not assumed, and *df=38* the critical value of *t* is 2.031 for significance with p<0.05. By comparing t from the above table with the critical value of t one can state that the result is statistically significant.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
WIDTH	Equal variances assumed	.032	.859	3.267	38	.002	2.1000	.6428	.7988	3.4012
	Equal variances not assumed			3.267	37.757	.002	2.1000	.6428	.7985	3.4015

Table 7 Width - *t*-test results.

In order to be significant the value of t calculated must be equal to or exceed the critical value for significance at the required level. Our result is statistically significant by a narrow margin.

Table 8 shows *t*-test results for the perception of the height of Room C. For the two-tail test for height, with equal variance not assumed, and *df=38* the critical value of *t* is 2.031 for significance with $p<0.05$. By comparing t from the above table with the critical value of t one can state that the result is statistically significant.

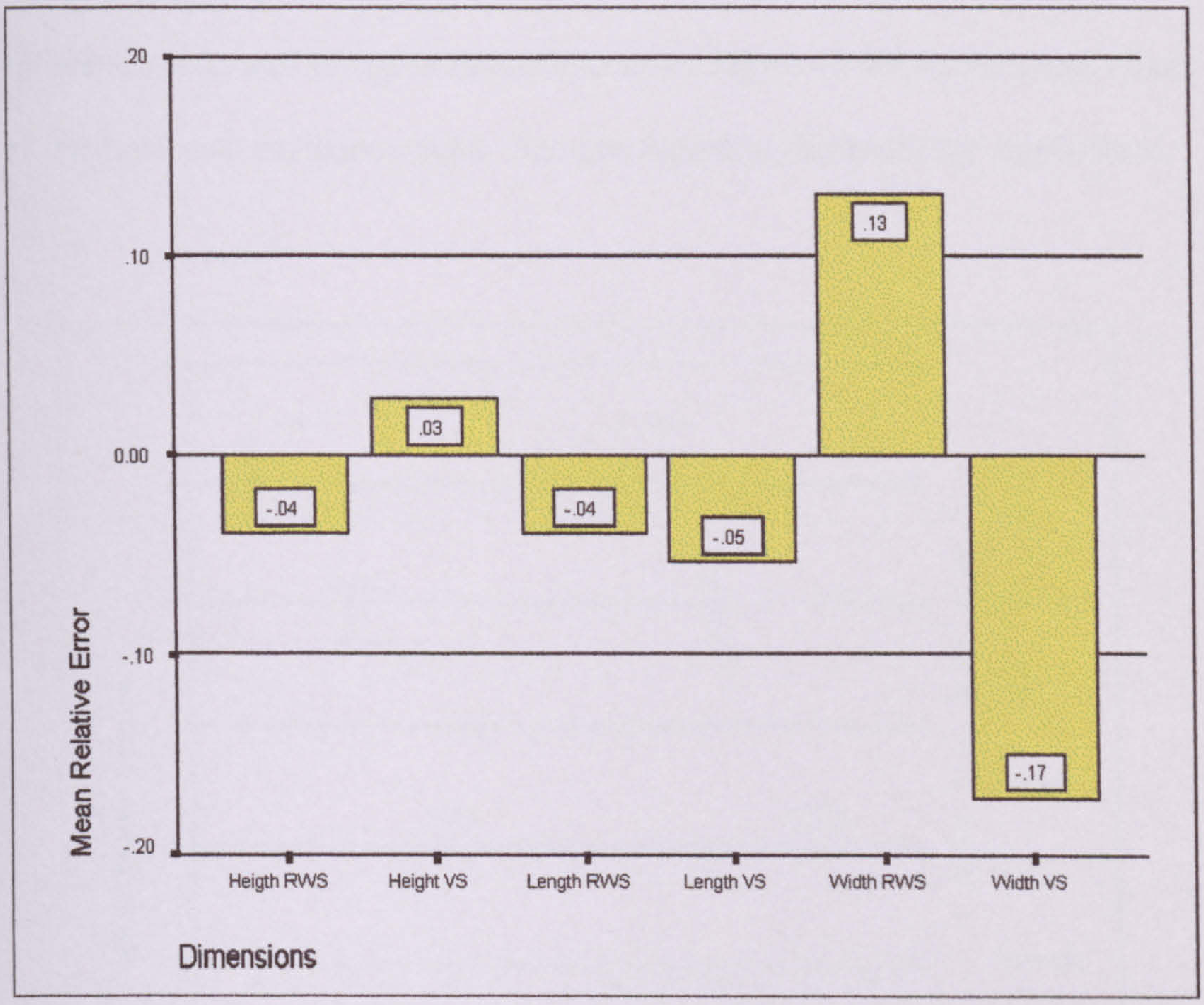
Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
HEIGTH	Equal variances assumed	.891	.351	-2.969	38	.005	-.1950	6.568E-02	-.3280	-6.2028E-02
	Equal variances not assumed			-2.969	33.452	.005	-.1950	6.568E-02	-.3286	-6.1432E-02

Table 8 Height - *t*-test results.

4.1.7.3.2 Relative Error.

Figure 12 shows the relative error for the judgement of dimensions in Room C. Data analysis reveals that participants generally underestimated length both in the real and virtual words. However, estimates in the VE were less accurate. The width was the least accurate estimation in both conditions.



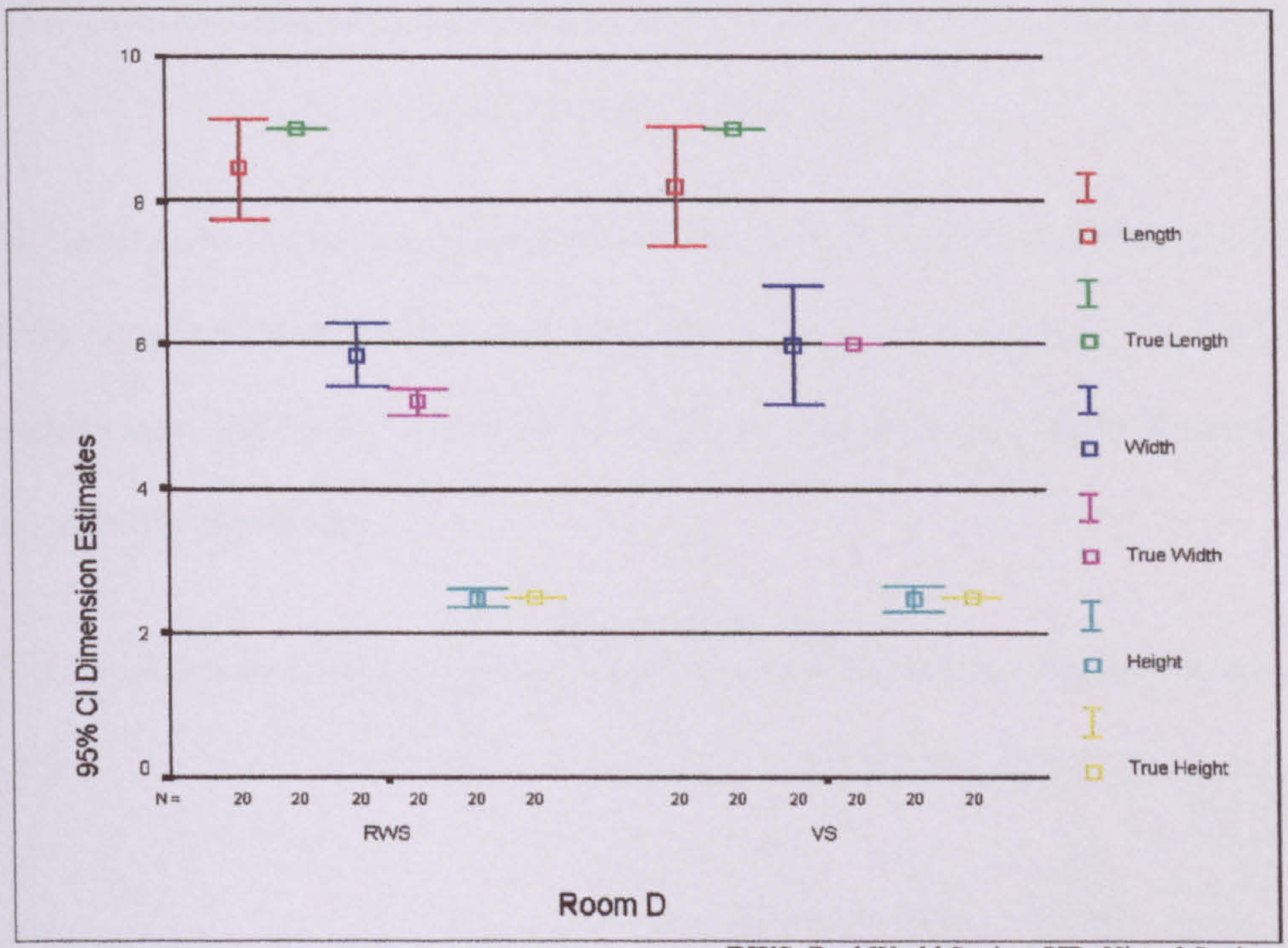
RWS- Real World Setting **VS**- Virtual Setting

Figure 12 Room C- Relative Error.

The most underestimated dimension in this condition was width in the VS (17%), followed by length at 5%. Generally, participants in this room performed better in RWS with width being underestimated by 13% and both length and height by 4%.

4.1.7.4 Room D.

Room D was the last space visited in this experiment (Figure 8). The actual room dimensions were as follows: 9 metres length; 6 metres width, and 2.50 metres height. In this room participants performed three dimension estimation tasks as well as figure recognition and height estimation task. The participants performed a total number of 160 estimation tasks for both conditions; 120 dimensions estimation tasks and 40 figure estimations tasks. Figure 13 shows the mean values of the dimension estimation tasks. For data regarding this room see Appendix C.



RWS- Real World Setting VR- Virtual Setting

Figure 13 Mean perceived dimensions estimates in VE and in the real world.

4.1.7.4.1. *t*-test

Table 9 shows *t-test* results for the length of Room D. For the two-tail test for height, with equal variance not assumed, and *df=38* the critical value of *t* is 2.031 for significance with p<0.05. By comparing t from the above table with the critical value of t one can state that the result is not significant.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LENGTH	Equal variances assumed	.995	.325	.487	38	.629	.2500	.5134	-.7893	1.2893
	Equal variances not assumed			.487	36.779	.629	.2500	.5134	-.7904	1.2904

Table 9 Length - *t*-test results.

Table 10 shows *t*-test results for width of Room D. For the two-tail test for width, with equal variance not assumed, and *df=38* the critical value of *t* is 2.031 for significance with p<0.05. The results from the length dimension in Room D are statistically significant.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
WIDTH	Equal variances assumed	.032	.859	3.267	38	.002	2.1000	.6428	.7988	3.4012
	Equal variances not assumed			3.267	37.757	.002	2.1000	.6428	.7985	3.4015

Table 10 Width - *t*-test results.

Table 11 shows *t*-test results for the height of Room D. For the two-tail test for height, with equal variance not assumed, and *df=38* the critical value of *t* is 2.031 for significance with p<0.05. By comparing t from the above table with the critical value of t one can state that the result is not significant.

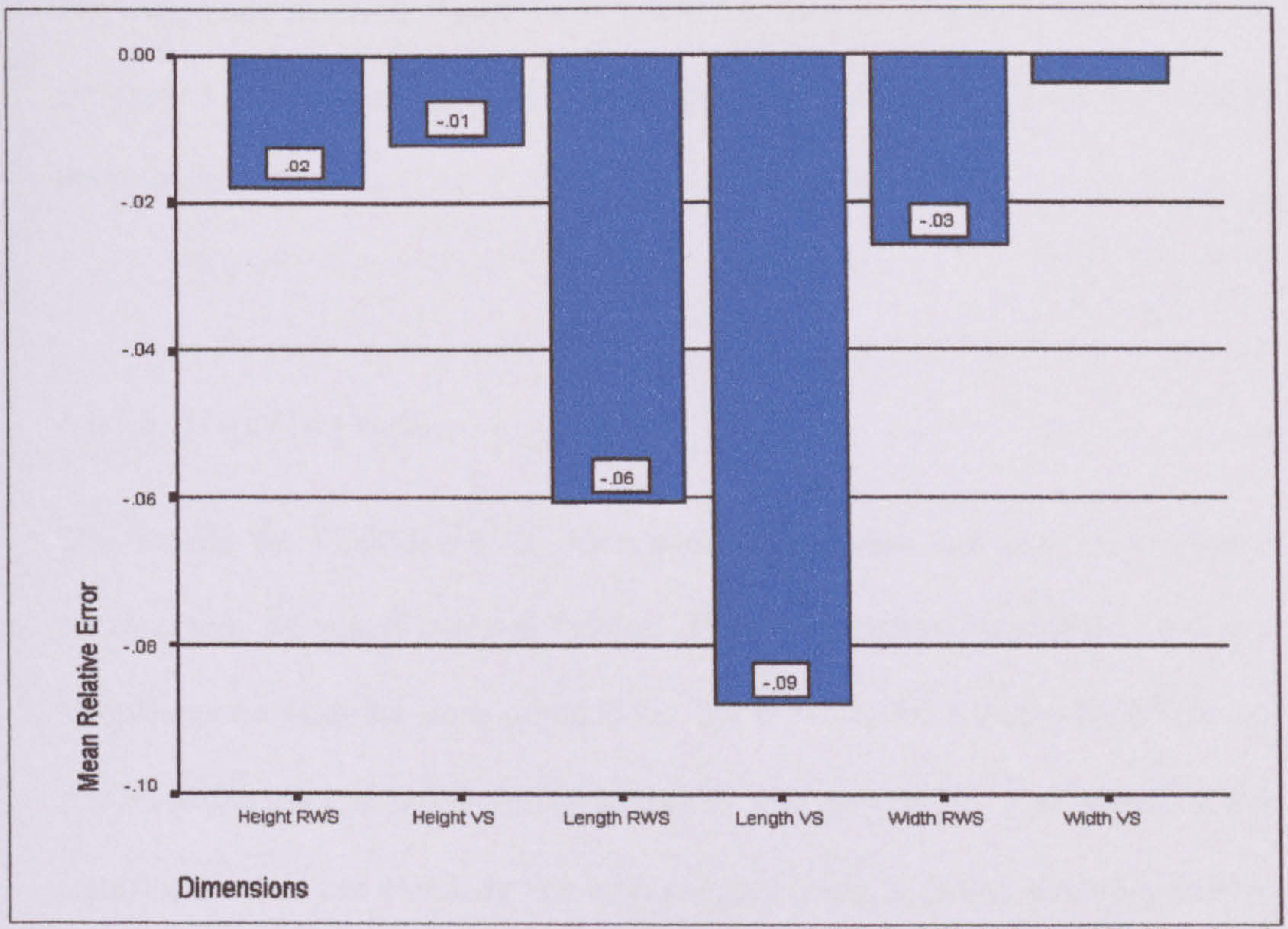
Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
HEIGHT	Equal variances assumed	3.802	.059	.150	38	.882	1.500E-02	.1001	-.1876	.2176
	Equal variances not assumed			.150	35.744	.882	1.500E-02	.1001	-.1881	.2181

Table 11 Height - *t*-test results.

4.1.7.4.2 Relative Error.

Figure 14 displays the mean relative errors for dimensions in Room D. An analysis of data between the estimates made in the virtual environment and the true length reveals that participants generally were not accurate in their estimations of this room's dimensions. Estimates of the length dimension in the VE typically average 9% of the true dimension and the height dimension was underestimated by 2% of the true distance.



RWS- Real World Setting **VR**- Virtual Setting

Figure 14 Room D- Relative Error.

Participants also underestimated all dimensions in the real world (2%). For details see Appendix C.

4.1.7.5 Power function.

A Table 12 shows Steven's Power Law exponents for Mean Dimensions Judgement in VS and RWS.

Dimension	**RWS**	**VS**
Length	1.00	0.95
Width	1.04	0.98
Height	0.99	1.00

Table 12 Steven's Power Law Exponents for Experiment 1.

The exponents shown in Table 12 vary from a low 0.95 to a high 1.04 where an exponent 1.0 indicates that the dimension judgements were exactly proportional to the true dimensions.

4.1.7.6 Confidence.

The results for Confidence of dimensions judgements are not very reliable because they were self-reported values. They nonetheless suggest that our two samples came from the same population. For a two-tailed *t-test*, with df=38, the critical value of t is 2.030 for significance with $p < 0.05$. Our result is not significant so we can conclude that both samples come from this same population. The non-parametric Wilcoxon rank sum test supports our findings as well. The *z*-score is -.781, therefore it falls into the area ±1.96. For details see Appendix D. It was reported that people found the estimation task more difficult in the RWS. It is very interesting because it would support the purpose of this representation. Being free from distractions and unnecessary details, simulated representations make it easier for people to judge and evaluate specific spatial attributes, in this case, the dimensions of the space.

4.1.7.7 Cognitive Maps: Sketches Task.

The sketch task was performed as a part of the post-experiment questionnaire. The cognitive maps were not a part of the main hypothesis - they should be studied as separate research subject. However, they are part of people's space perception.

After their visit, each participant was asked to draw a plan of the experiment site. Their cognitive maps were rated as a function of their perception of the location of rooms relative to each other, the path of their visit and, their ability to rank their spaces by size from smallest to largest. The experimenter's intention was to capture information which might not have been apparent through the dimension judgement tasks. The maps were analysed by looking at them and the number of errors in their sketches were checked, e.g. if the size of rooms were wrong or missing, or if they were able to indicate where a computer was placed with a desk and chair. The findings indicate that all cognitive maps were correct to 100%. It could be due to the fact that the experiment site was a simple one. All participants in both conditions had a perfect recollection of their visit path. None of the participants had a problem with distinguishing the size of the rooms (Figure 12 and Figure 13).

As many as 70% of participants found Room D the most difficult to estimate because of its shape. They found it generally less well 'proportioned'. Overall, they found Room C the easiest for estimation of differences of distances/size dimensions between length, width and height. The task of choosing which space was the most pleasant and the least pleasant exhibited tremendous variability in answers. The variability in answers can be explained by the way each individual person decides what makes a space pleasant or unpleasant for them. Everybody experienced sharing a flat or house with somebody during their life and all of them said that it takes a lot of compromise, for instance to agree on the colour of the living-room. However, 57% of participants reported that they found Room C the most pleasant and the Room A the least pleasant. Room C was chosen because it was the most spacious room in the experiment site. As one of the participants put it, "It invited you to wander around".

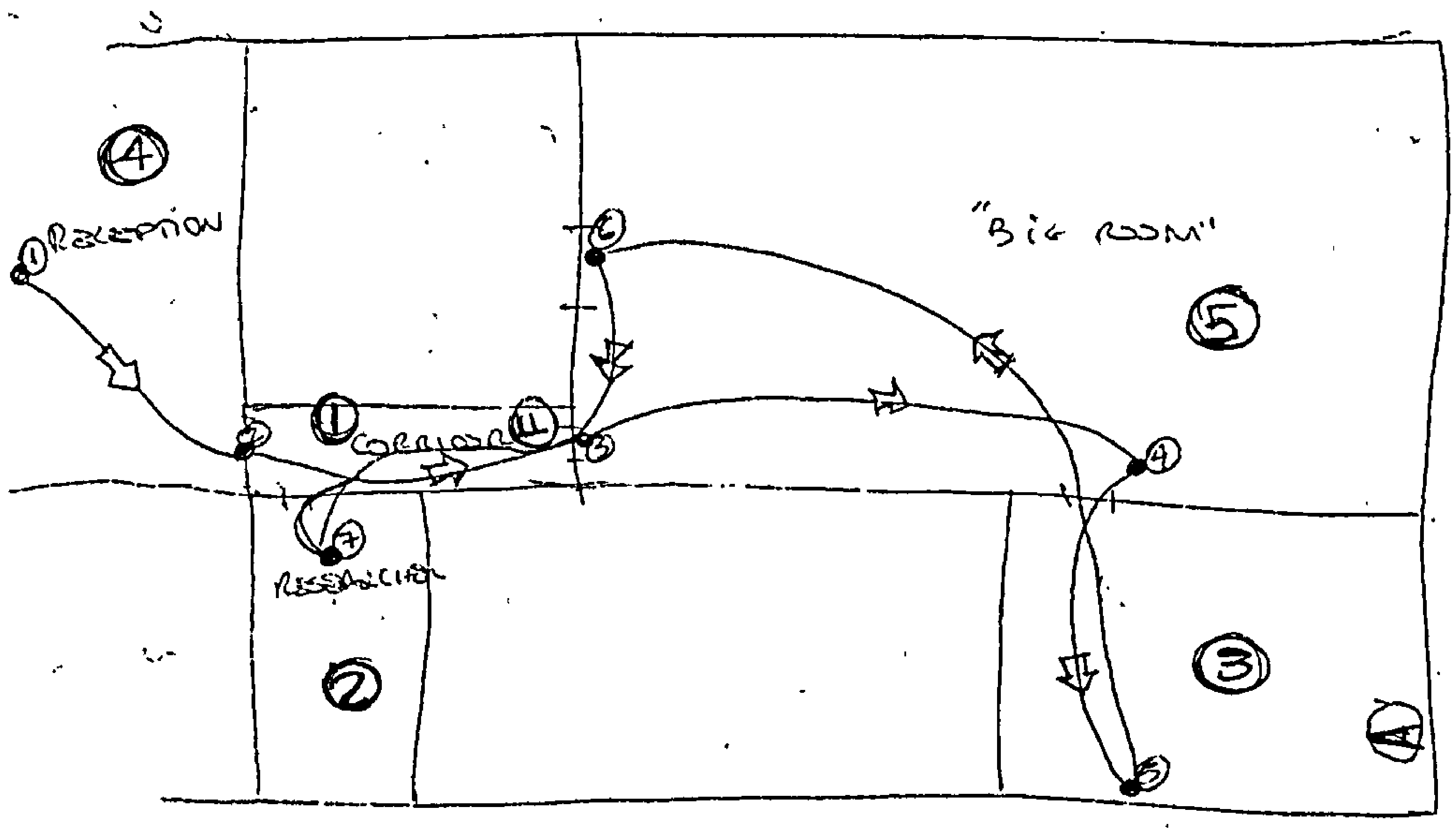


Figure 15 An example of a participant's sketched map.

Overall, results suggest that participants had accurate recall of a simple layout. It is a very important result because it would support the hypothesis of the usefulness of using virtual reality as a tool for modelling architectural spaces. Even, if they are simple ones.

4.1.7.8 Discussion.

Participants in this experiment generally underestimated dimensions in VE and the real world. The errors in dimension estimations were found to be greater in VE than in the real world. The performance in the real world is usually better because of the presence of depth cues (see Chapter 2, Section 2.3). However, the results of estimation tasks were very good as compared to the results of previous research (Witmer, and Kline, 1998; Wright, 1995; and Lampton *et al.*, 1995; Lampton *et al.,* 1994; Coren *et al.,* 1993). It could be due to the characteristic of the participants group. All participants scored above average on the psychometric tests. The S&M test investigates people's ability to manipulate 3D objects. It is an ability very important in VEs because if there is lack of stereopsis or depth cues are missing the participant is still able to see an object three dimensionally. Furthermore, the GEFT test measures the extent to which subject perceptions are dependent upon (or independent from) cues in the environment (the "field"). Subsequently, participants who scored highly on this test are able to perceive objects without presence of many visual cues. These would explain the high accuracy of estimates particularly in VE where environment was not cue reach. Another clue to the high accuracy of estimates is that all participants were students or lecturers of building surveying. Even if one assumes that there is a variety of abilities in judging dimensions within this profession one cannot ignore the fact that they are dealing in measurements of building sites and buildings quite frequently, and their concept of metres, or feet must be quite stable. Also, there is one cognitive factor which may influence their estimates- namely learning process. Surveyors learn how to measure objects, space, and the speed of learning is rather dependent on the person's individual cognitive characteristics. Moreover, participants in the group had different level of experience in estimating dimensions. One should also consider the age of participants. However, it still has to be investigated how influential age is in determining how much difficulty a user will experience in learning a system (Stanley, *et al.*, 1998). One also should remember about participants' attitudes, attention, memory, sex, personality, and physical and sensory characteristics. These factors influence human performance in real and virtual environments.

Another factor which did not seem to play such an important role was the field of view in real world, as compared to the limited field of view in VE. The VS group still performed very adequately with high mean accuracy scores. However, other researchers suggest that it is a very important factor limiting humans' ability to estimate dimensions of space in the real and virtual worlds (see Chapter 3, Section 3.8 for more details).

The data also suggests that participants were able to recall a simple layout of the building without being lost in the model. Furthermore, the power function exponent shows that participants were not confused by dimensions of rooms and were able to discriminate between them without any problem.

Even if all the limitations are taken into account it seems that VE is an attractive alternative for modelling virtual space where visual perception is a very important factor. In the second experiment six different dimensions would be investigated in two orientations in an open space environment. An important question is also raised in respect of human ability to accurately estimate dimensions where there is not an enclosure or building present.

4.2 Feel of individual spaces.

4.2.1 Overview.

As discussed in Chapter 2, Section 2.3 and Chapter 3, Section 3.9, people are sensitive and respond to cues embedded within environments. Thanks to these cues, we are able to distinguish among different environments and architectural spaces. An environment can be described in many ways. One can call them cold or warm, open or closed, and so on. Much research has been conducted on these issues (Osmond, 1959; Baker, Davies, Sivadon, 1959; Berger and Good, 1963; Kling, 1959; Smith, 1959; Springbett, 1960; Write and Rainwater, 1962; Canter, 1969; Appleyard, Craick, 1970; Hagen, Jones, Edwards, 1978; Ittelson, Proshansky, Rivilin, 1970; Pedersen, 1978; Dolezal, 1982; Henry, 1990; Bruce, Green, 1995, and many others). Yet, they did not come up with a simple answer how to measure the perception of feeling of space.

For this experiment the approach was taken of using bipolar adjectives as they seem to be an appropriate tool for the description of spaces. When humans are asked to describe any space they usually tend to use adjectives. Joyce Kasmar (1970) ran a very interesting study on descriptive adjectives used for describing architectural spaces. Initially she drew up a list of 500 adjectives taken from the architectural and interior design magazines, as well as from previous research on aspects of music, colour, lines, art and theatre. From this list she chose 197 adjectives which she used for her descriptive questionnaire. She ran her study in three stages. She used three rooms at the University of Washington for her experiment. After running her study she came up with a list of 66 pairs of bio-polar adjectives, a vocabulary which included terms which are relevant and appropriate to describe architectural spaces and which are understandable for the layperson (Kasmar, *ibid.*).

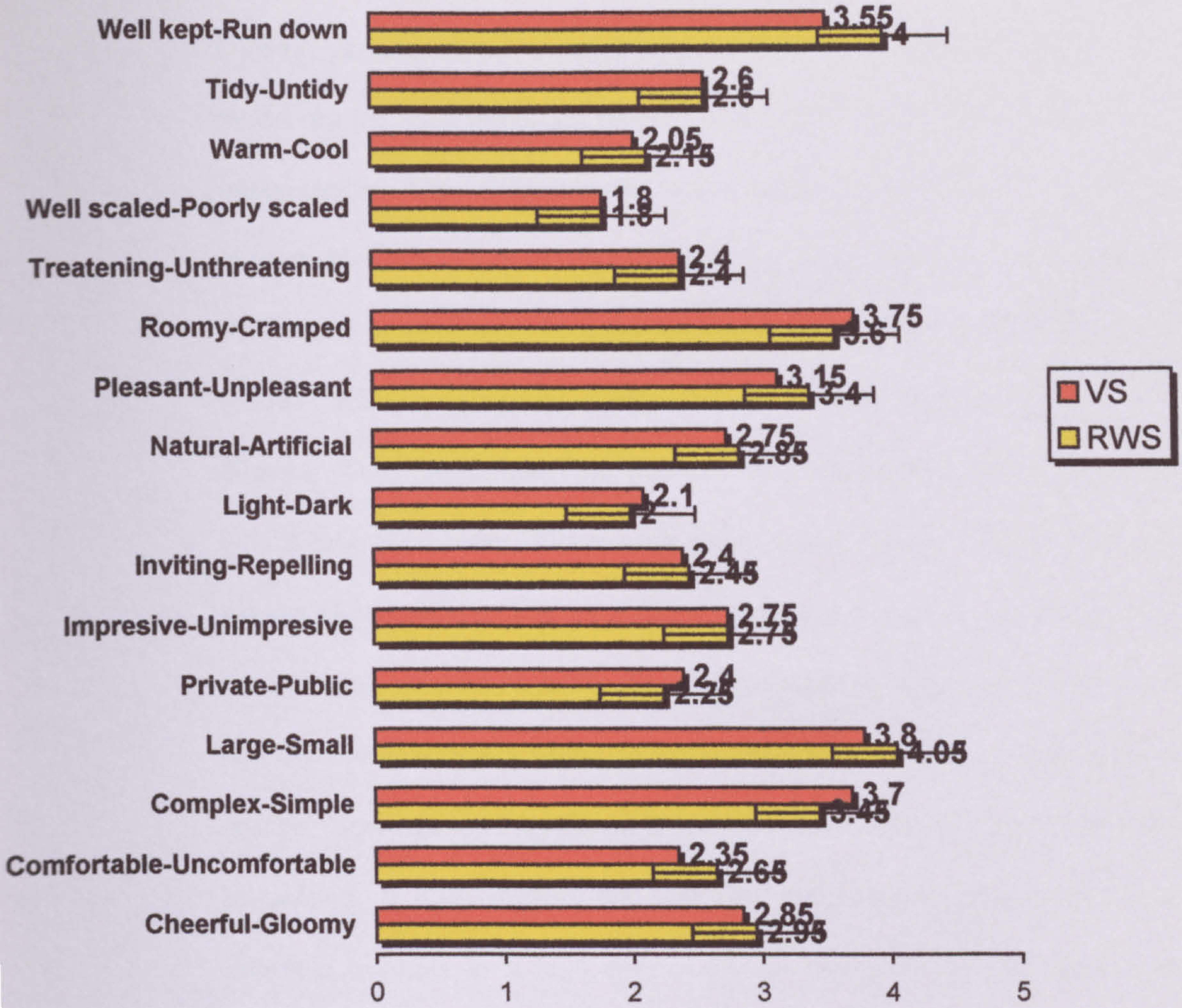
This author selected a list of 16 pairs of bipolar adjectives as the most appropriate for a description of the experimental site. The amount of bi-polar adjectives being used had to be limited because of the constraints of time offered by the participants. The criterion for choosing adjectives was simplicity. The list of bi-polar adjectives used is in Appendix A.

4.2.2 Methodology and results.

The questionnaire was administered after each visit by participants to the experiment sites. The participants were asked to rate the qualities of Room C using an adjective checklist. The idea of this task was to look for the similarities in the overall description of Room C.

Because adjectives are non-parametric we ran 16 Wilcoxon rank sum tests. The results suggested that our sample came from the same population. Appendix H contains the results of the statistical calculations.

Figure 16 shows the descriptive task averages by question number. There appears to be a remarkable similarity in the results between our two groups. It could be suggested that because the experiment conditions were stripped of the more elaborate visual cues (shadows, texture) therefore the results exhibited such high level of similarity. However, this part of the hypothesis deals with the basic attributes of spaces, therefore one can say that, in this experiment, data suggests



RWS- Real World Setting **VR-** Virtual Setting

Figure 16 Descriptive task averages by question.

that virtual reality tools are appropriate for conveying information about the feeling of space.

4.2.3 Evaluation Of the Presentation Method: Virtual Interface.

There were open-ended questions regarding the virtual interface. The purpose of these questions was to capture information about the characteristics of the virtual interface used which needed improvement in order to be used for professional application.

Overall, participants felt that the input devices and the speed of rendering of the model are the most important aspects of the virtual interface needing much more improvement. They suggested that they would prefer it if there were more objects in the model, which would help them with the scaling process. Of course, one did not include more of them because one was researching the basic characteristics of spaces. Many participants complained about the navigation device and the i-Glasses. They did not like their limited field of view. They also suggested that it would have been better if there were some outside views. The hardware was the subject of complaints. The computer was too slow. Only one person reported that the i-Glasses gave him a headache. All participants in the experiment confirmed that the virtual interface would be a perfect tool for the simulation of architectural spaces. However, the experiment's computer set-up did not provide the feeling of immersion. It does support the idea that wide implementation of the virtual interface depends to a high degree on the prices of software and hardware. However, this assumption had to be scientifically proven.

It was also found that 99% of participants in the Virtual Simulation did enjoy the interface. Probably it was due to their curiosity of experiencing something they had heard about on TV or read about in the newspapers. In any event, the appeal of the interface and its ease of use are its own very important distinctions. They confirm the significance of this technology and endorse continued research.

5. EXPERIMENT 2- PERCEPTION OF EXOCENTRIC LENGTH AND HEIGHT ESTIMATIONS IN AN OPEN SPACE ENVIRONMENT.

The design and the results of the second experiment are presented in this chapter. Details of all elements of the experiment design process, experimental conditions, set-up, participants and their tasks are discussed. This experiment was concerned with the perception of exocentric length and heights in open space environments.

5.1 Experiment Aims.

The purpose of the previous experiment was to determine how accurate people were in estimating dimensions of rooms in virtual and real world settings. Participants were asked to walk through a building and perform dimension estimation tasks at the points suggested by the experimenter. The tasks were performed stationary with only head movement allowed. The rooms were of different dimensions. The aim of this experiment was to investigate the perception of exocentric length and height estimations in a full-clue environment. Moreover, the influence of orientation of stimuli on performing perceptual tasks was investigated.

5.2 Participants.

A total of 40 people (34 men and 6 women) participated in the experiment. They were either researchers or post-graduates, who volunteered for the experiment and were not paid an honorarium for their participation. Their ages ranged from 22 to 36 years (M=27.4). All participants had 20/20 vision uncorrected or corrected with contact lenses and had no other vision problems. All participants were psychometrically tested. The S&M, and GEFT tests were administrated. The results of the test are shown in Table 13.

	S&M	GEFT
N	40	40
Mean	11.80	13.52
Standard Deviation	3.18	3.57
Minimum	11	12
Maximum	18	18

Table 13 Results of psychometric tests.

For detailed description of tests and test protocols used see Chapter 3, Sections 3.7.1 and Section 3.7.2.

5.3 Experiment Design.

In Experiment 2, as in Experiment 1, a Random Blocked Design (RBD) was implemented. Each participant was randomly assigned to one out of two independent experimental groups. Participants in Group 1 experienced only Virtual Setting (VS) and participants in Group 2 experienced only Real World Setting (RWS). For description of methodology and variables see Chapter 3, Section 3.1.

5.3.1 Experimental Condition.

In order to study the perception of exocentric length and height estimations in a full-clue environment two experimental conditions were used:

1. **Real World Setting.**

   For this condition a part of the University of Salford campus was used. The place for conducting the experiment was chosen because it was an open space with a line of horizon visible, but at the same time there were visible buildings and bushes. The pavement was covered with grey coloured flagstones. On the pavement there was a bush. The idea was that the bush should have given some additional indication of scale for participants. In this condition the experiment was conducted during the weekend in order not to have any human figures in view. As was indicated earlier, humans are the most common scale cue used for day-to-day estimation tasks.

2. **Virtual Setting.**

   A model of the University campus (Figure 17) was used for this condition. The model was produced by Virtual Presence. MEDIT software was used for the modelling. However, the model was updated and modified by adding bushes and some texture in the ground in order to have a model as similar as possible to the real world. Furthermore, the scale of the model was checked with the blueprints of the campus and necessary corrections were implemented. The VE model had most of the possible visual depth cues, e.g. perspective, texture, light, scale cues.

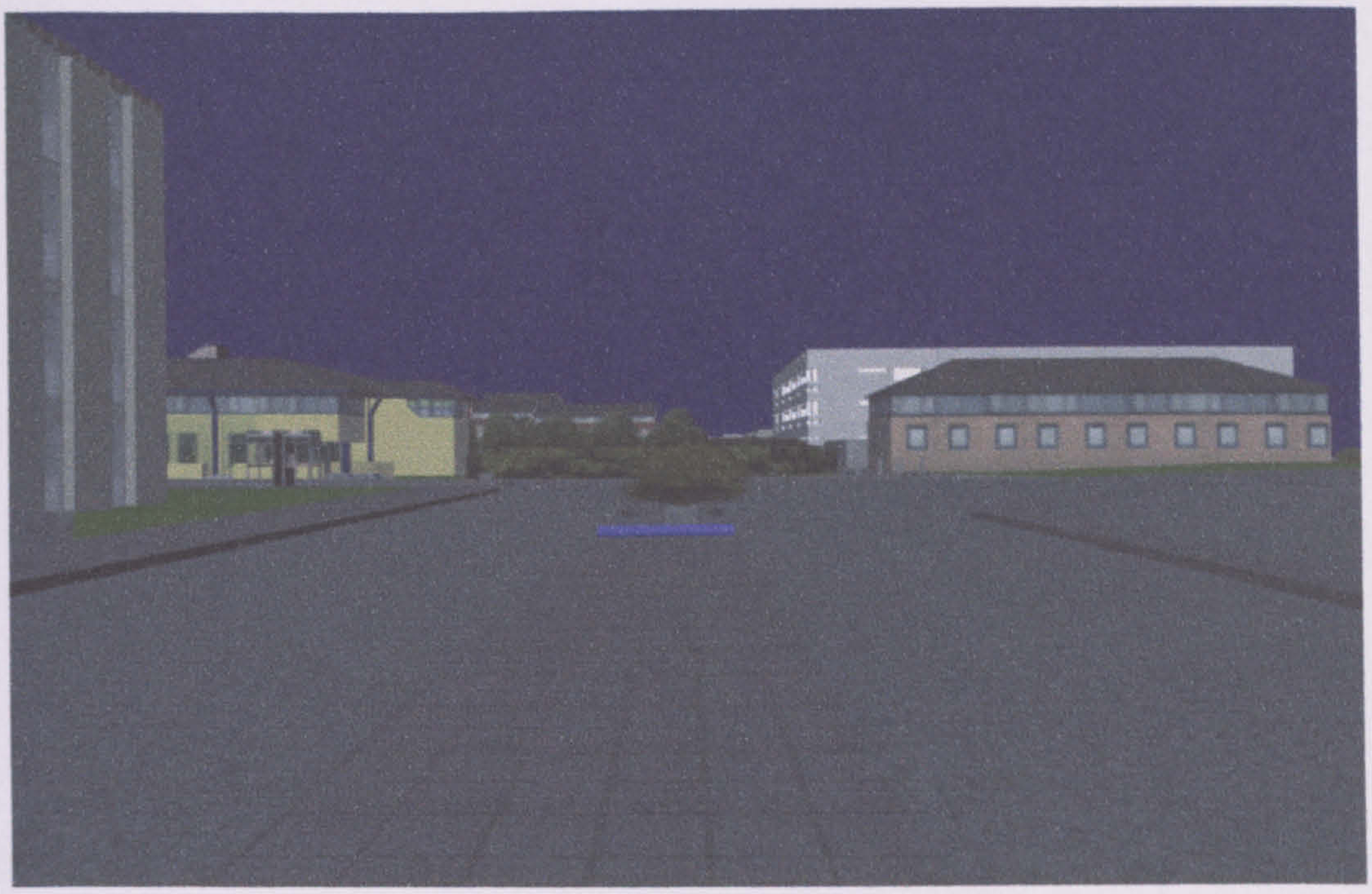


Figure 17 The University of Salford campus model with a horizontal stimulus.

5.3.2 Components of Immersive VR used.

5.3.2.1 HMD and Computer Platform.

Stimuli were presented on a V8 Head Mounted Display produced by Virtual Research Systems[15] (Figure 18). V8 is a new, high performance HMD with active matrix LCDs with true VGA with ((640x3)x480) resolution. The FVO is 60 degrees diagonal. The head was tracked by a Flock of Birds tracker. The model was run on an Infinite RealityEngine Onyx2 Silicon Graphics computer[16] with Relax Visualiser and IRIX operating system.

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[15] More details are available at the Virtual Research website at http://www. virtualresearch.com/ product/v8.htm.

[16] More details are available at SGI website at http://www.sgi.com/products/remanufactured/onyx/

Figure 18 V8 HMD.

5.3.2.2 Stimuli.

Six poles of different dimensions were presented to the participants. Three of them were placed horizontally and the other three vertically. Participants were able to see only one pole a time. The poles were shown to participants in random manner. The height/length of the poles were: 2.5m, 2.00m, 1.50m. The poles were placed directly on the ground.

5.3.3 Participants' tasks.

The participant tasks were to estimate dimensions of the presented stimuli. The magnitude method from Experiment 1 was used (see Chapter 4 for details). In Experiment 2 participants also used metre/feet as their moduli. Every participant performed six dimension estimation tasks.

5.3.4 Questionnaire.

The Experiment 2 questionnaire differed from the questionnaire in Experiment 1 (Appendix E). The Experiment 2 questionnaire was a one page short questionnaire designed for capturing basic statistical data about participants' profession, age, gender, rating of difficulty of performing the estimation tasks, and the confidence with which they were doing it. Furthermore, there were two questions regarding presentational method. Every participant was asked to fill a questionnaire after finishing his or her trial. During construction of this questionnaire were used general rules reviewed in Chapter 3, Section 3.7.3.

5.4 Methodology.

Prior to performing tasks every participant was told the purpose of the research, briefed on the experimental tasks, and given specific instructions regarding the length and height estimation tasks. In both conditions participants were standing during performing tasks. The VE condition was performed in the Centre for Virtual Environments at the University of Salford. In the VE and RWS setting every participant was standing at the cross placed on the floor/pavement in order to control distance between the participant and stimuli. A standing position gave participants scale cues (see Chapter 3, Section 3.7.2). Participants also were informed about the distance between them and the stimuli being 16 metres or 50 feet. After putting on the HMD participants were told to "have a look around" in the model for five minutes. The idea behind this was that the experimenter wanted participants to get some idea of the scale in the model, and to allow their vision to stabilise. After five minutes the experimenter asked participants to centre their vision on the bush on the pavement, because one did not want participants to perform detection or identification tasks (see Appendix B Section 1 for definitions). Then, every participant was asked to estimate the height and length of the stimuli. For each trial the dimension estimates were recorded manually. After finishing their estimates they were asked to complete a short questionnaire (Appendix E). Whilst conducting the experiment, participants were encouraged to comment on the performed task. All their comments were recorded on the Sony minidisk recorder. The experiment took approximately 30 minutes per participant to perform. The only procedural difference was that, in the real world, participants were asked to stand with their back to the bush until asked to turn and face the stimuli. Upon reporting their estimate, participants again turned their back to the bush. This procedure ensured that participant did not see changes of the stimulus to the next one, and it thus limited their viewing time and comparing stimuli to human changing stimuli. Participants were allowed to see only one pole a time.

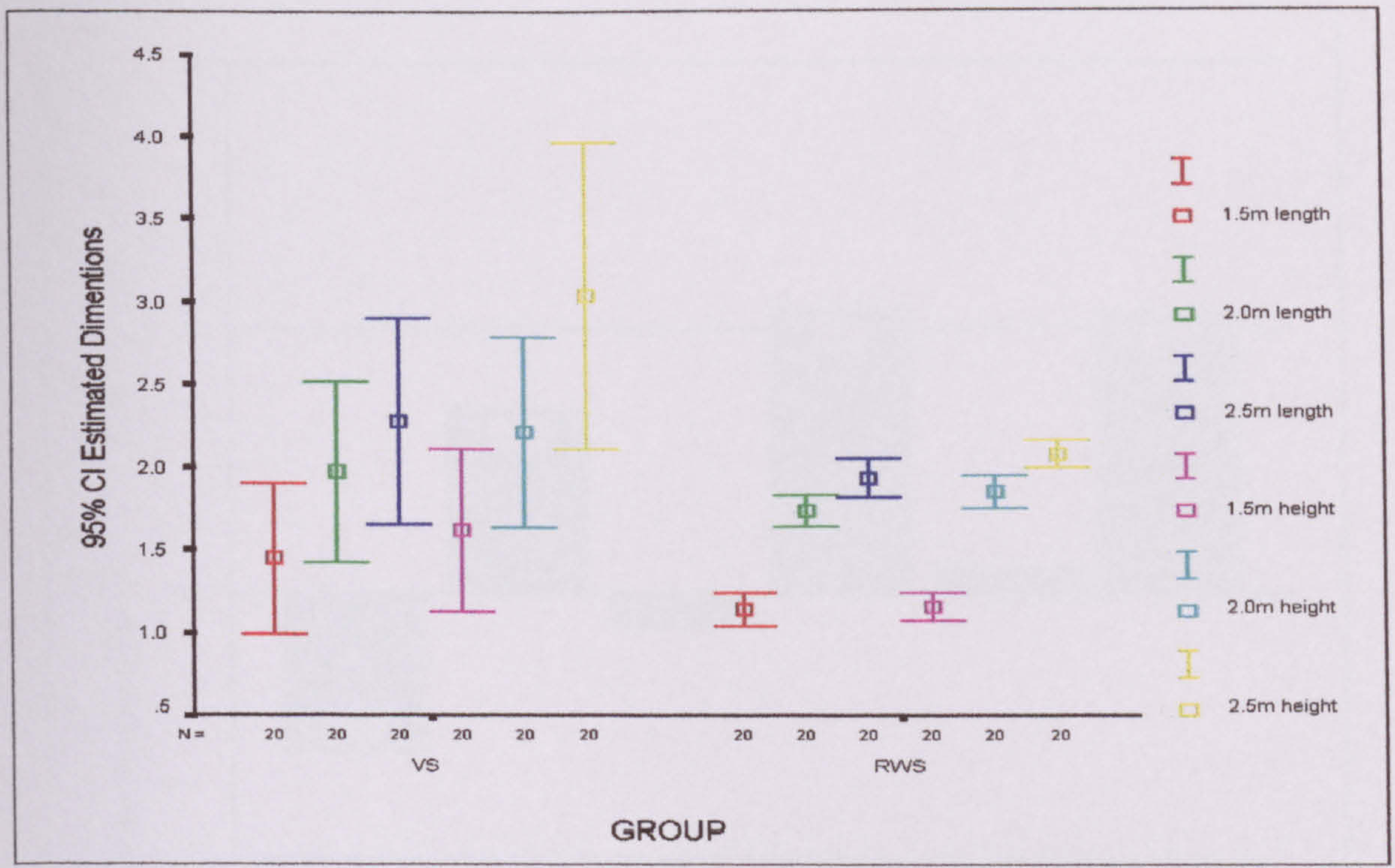
5.5 Results.

The results of Experiment 2 are analysed below.

5.5.1 Estimation tasks.

All participants performed six estimation tasks per trial. For every condition there were 120 estimations. Figure 19 shows mean perceived length estimates in both experimental conditions.

Data in Figure 19 suggests that participants' range of scores spread more widely in VS than in RWS.



RWS- Real World Setting **VS**- Virtual Setting

Figure 19 Mean exocentric length estimates in VE and in the real world.

5.5.2 Relative Error.

Relative errors were calculated for every dimension and every condition (Appendix F). Figure 20 shows the results of mean relative error in the VE stimuli orientation.

The data analysis of mean relative errors suggests that participants overestimated horizontal dimensions by 4% and vertical dimensions by 10% as compared to real dimensions in VE. Furthermore, it seems that the orientation of stimuli had influenced their judgements with estimations of vertical stimuli being less accurate than horizontal one. It could be concluded that the estimation of vertical dimensions were less accurate because the body scale clue was not sufficiently prominent for participants in the model. It is particularly prominent in estimation of 1.5m stimuli.

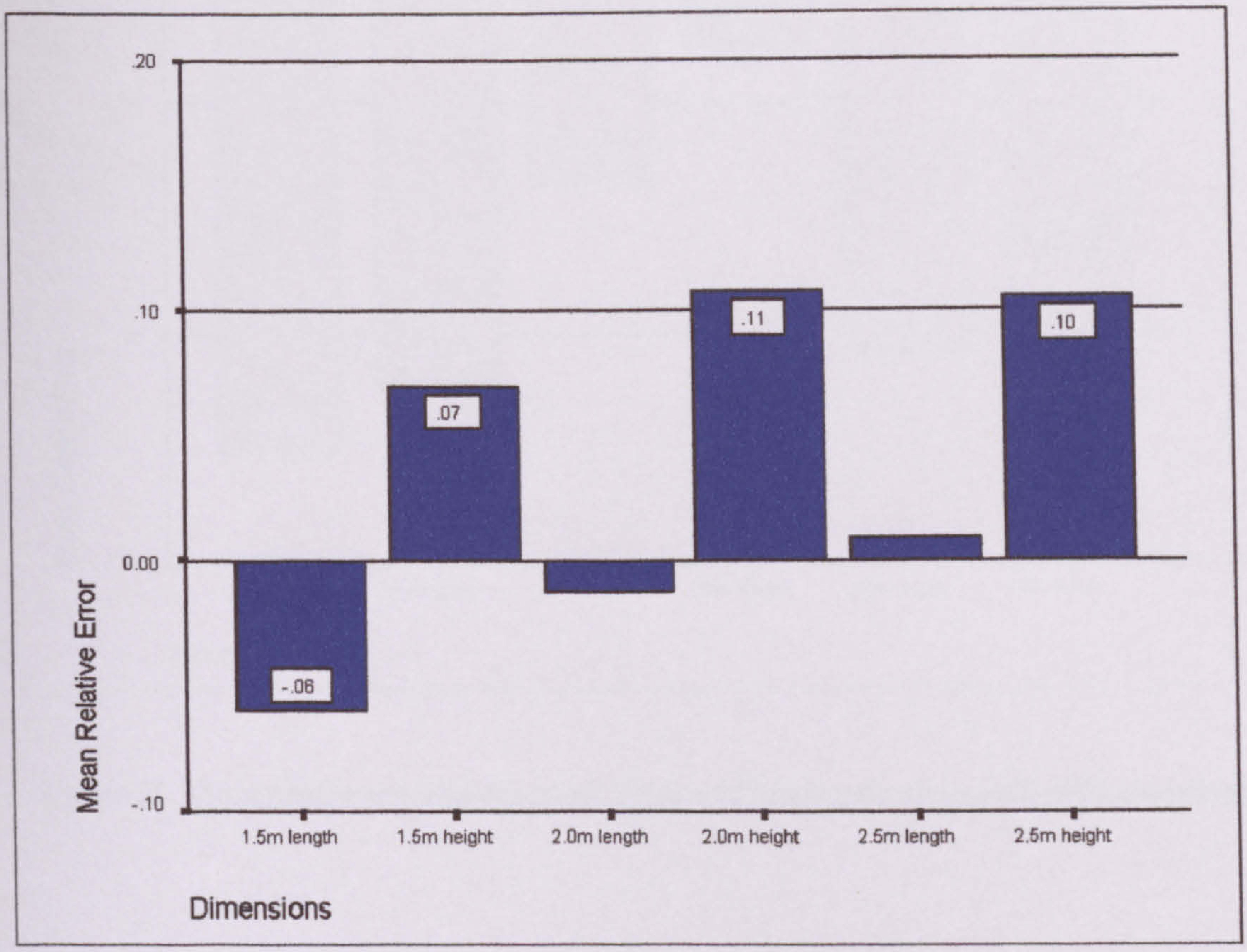


Figure 20 Mean relative error in exocentric length and height estimations in VE.

Figure 21 shows mean relative errors in exocentric length and height estimations in the Real World Setting. The data suggests that participants underestimated horizontal dimensions to a greater than the vertical one in real world. Their estimations of the vertical dimensions were underestimated by 15% and horizontal dimensions by 21%. Thus, one could conclude that the orientation of the stimuli whist performing estimation tasks did influence the accuracy of participants' estimations, with vertical stimuli being easier to perceive for them. It could be caused by the standing position of the participant and scale or other cues being more prominent in this condition

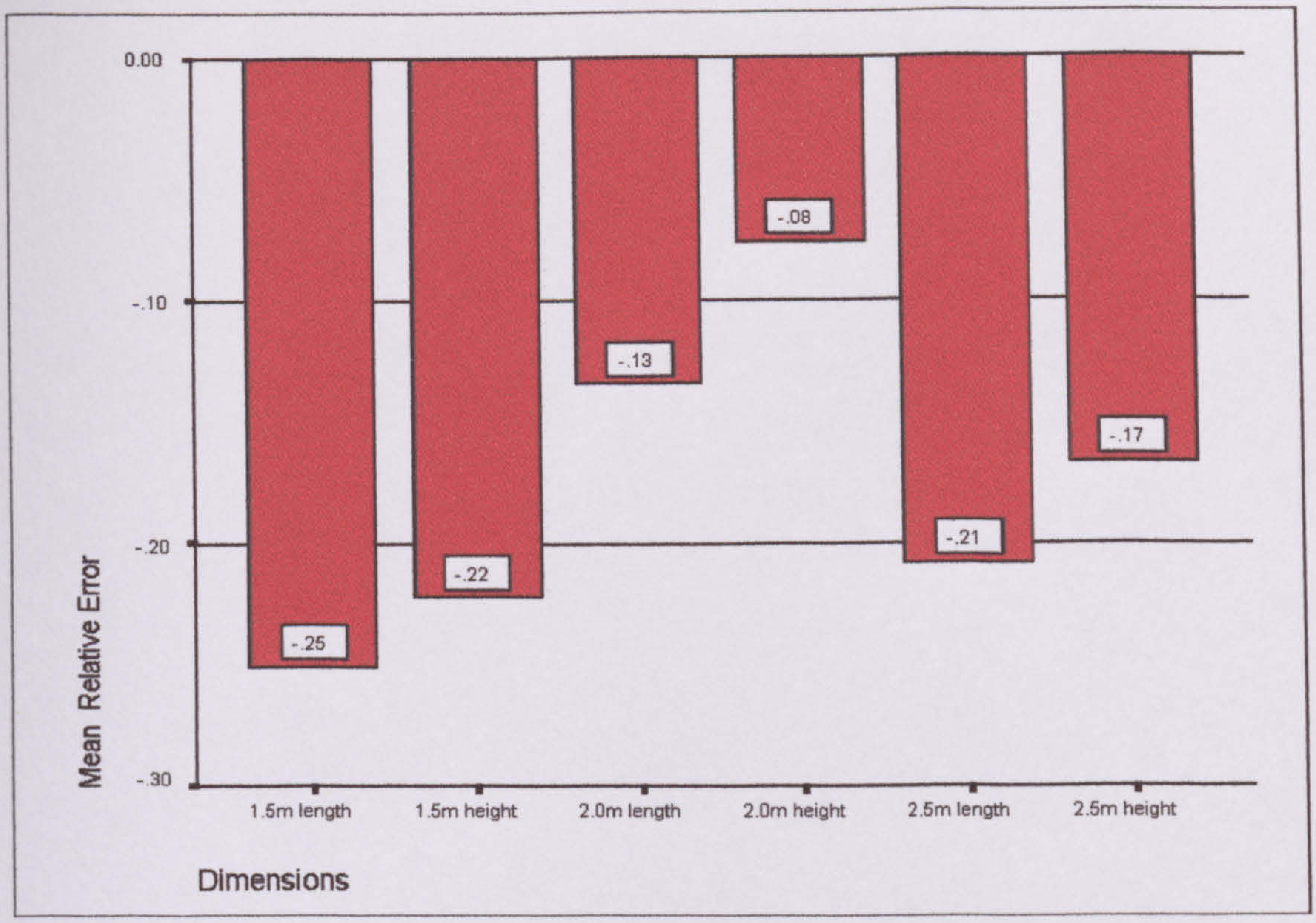


Figure 21 Mean relative errors in exocentric length and height estimations in Real World Setting.

5.5.3 *t*-tests results.

Six *t*-tests were performed for every dimension. Table 14 presents the results of *t*-tests for every dimension in this experiment, where *h* represents horizontal dimension of stimuli (height), and *v* represents vertical dimension of stimuli (length). Four two-tailed *t* tests with equal variance assumed, with $df = 38$, the critical value of *t* is 2.031 for significance with $p<0.05$ were performed.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
H1.5	Equal variances assumed	10.845	.002	.990	38	.328	.2060	.2080	-.2151	.6271
	Equal variances not assumed			.990	21.060	.333	.2060	.2080	-.2265	.6385
H2.00	Equal variances assumed	9.980	.003	.488	38	.628	.1185	.2428	-.3731	.6101
	Equal variances not assumed			.488	20 156	.631	.1185	.2428	- 3878	.6248
H2.5	Equal variances assumed	5.734	.022	.737	38	.466	.1990	.2701	-.3479	.7459
	Equal variances not assumed			.737	20 868	.470	.1990	.2701	-.3630	.7610
V1.5	Equal variances assumed	10.519	.002	1.523	38	.136	.3125	.2051	-.1028	.7278
	Equal variances not assumed			1.523	20.709	.143	.3125	.2051	-.1145	.7395
V2.00	Equal variances assumed	12.385	.001	.803	38	.427	.1940	.2415	-.2949	.6829
	Equal variances not assumed			.803	20.475	.431	.1940	.2415	-.3090	.6970
V2.5	Equal variances assumed	15.380	.000	1.819	38	.077	.6600	.3629	-7.4595E-02	1.3946
	Equal variances not assumed			1.819	19.533	.084	.6600	.3629	-9 8098E-02	1.4181

Table 14 Results of Independent Sample t-test.

By comparing the t value for all dimensions and stimuli orientations from Table 14 with the critical value of *t* one can state that these results are not statistically significant. In order to be significant the value of *t* calculated must be equal to or exceed the critical value for significance at the required level. Even with equal variance not assumed the results also are not significant. These results mean that that null hypothesis is retained.

5.5.4 Power Law Exponent.

Table 15 shows the power law exponent for dimensions estimated in both conditions. As it has been indicated in Chapter 4 Section 4.4 the power exponent n=1.0 indicates that the dimension estimates were exactly proportional to the true distance.

Condition	1.5 m horizontal	2.0m horizontal	2.5m horizontal	1.5m vertical	2.0m vertical	2.5m vertical
VS	0.94	0.96	0.87	1	0.96	1.12
RWS	1.05	1.06	0.97	0.82	0.96	1

Table 15 Power Law exponents for dimension estimations in VE and real world.

5.5.5 Confidence and Difficulty of Estimates.

Table 16 includes results of t test for confidence and difficulty of dimension estimates. The results for confidence and difficulty are not very reliable because they were self-reported values. However, they suggest that the experimental samples came from the same population. For the equal variance assumed two-tailed *t*-test, with *df*=38, the critical value of t is 2.031 for significance with $p<0.05$. The calculated *t* is smaller than the critical *t* so our results are not significant with $p<0.05$. For full data see Appendix J. Participants reported they found the task not too difficult, with more of the RWS participants reporting that they found the task easier than participants in VS condition.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CONFIDEN	Equal variances assumed	3.150	.084	-1.405	38	.168	-.4000	.2847	-.9763	.1763
	Equal variances not assumed			-1.405	33.839	.169	-.4000	.2847	-.9787	.1787

Table 16 The results of t-test for Confidence of dimension estimates.

5.6 Discussion.

The participants in Experiment 2 generally underestimated dimensions in the real world and overestimated dimensions in VE. In the real world, participants overestimated dimensions by an average of 15%, with horizontal dimensions being less accurate that vertical ones. In VE participants overestimated horizontal dimensions and underestimated vertical dimensions. These differences in results can be explained by a lack of all depth cues in VE. By large, most of the participants in the VS condition would prefer to have a human figure or have their own body model in VE. They would like to use these as scale cues. Body-scale information provides a direct indication of the distance of surfaces from the body (Wann, and Mon-Williams, 1996). Some participants wanted to be able to approach stimuli or would like to have known the bush dimentions. This would suggest that participants in VE and the real world use some scale cues as modulo to compare different dimensions of object. Unfortunately, results would also suggest that the concept of feet or metres was not very stable within the VS group because they found it rather difficult to transfer these concepts into VE. Before the experiment, every participant was told that all elements of the model were scaled, and there were also some elements of the building visible, e.g. doors, and a staircase to the building.

The analysis of the power exponent shows that all participants distinguished distances from each other.

It is seems necessary to point out that there are also factors other than the VE model or computer speed influencing VE - namely user characteristic. User differences have already been reported to influence the sense of presence and motion sickness in VE (e.g. Slater *et al*, 1995; Rushton, and Wann, 1993, many others). Furthermore, factors like age, personality, or cognitive aspects of the human psycho like sensory systems, individual abilities, attention, memory, learning, may also influence spatial perception or the perception of architectural spaces. These factors also influenced participants' performance in both conditions (Stanley, *et al.,* 1998).

Another contributing factor to these overestimates could be the HMD's field of view. It has been pointed out in Chapter 2, Section 2.3 that these individual differences play an important role. People perceive their environment primarily through their senses. It has been mentioned in the Introduction that the visual, tactile and auditory effects of built or natural environments make an impression on humans. Brawne *ibid.* stressed that vision is clearly dominant among senses. Furthermore, he wrote that the second dominant impression is through bodily movement: walking, reaching out, stopping. This sensory experience is directly combined with the visual and memory. Moving observer senses visual images in sequence. The combined effects of these elements allows people to understand the plan and the spatial organization of buildings. Therefore, any limitations in the human field of view or movement does influence perception of space. One of the limitations of the experiment was that people in VS had limited FOV and were not allowed to move their bodies apart from their heads. This also could contribute to the results of this experiment. Other research indicate that the field of view is a contributing factor in over or underestimates in the perception of space (Psotka, *et al,* 1998; Barfield *et al,* 1995; Barfield, and Kim, 1991, also see Chapter 3, Section 3.8 for more information regarding FOV).

All participants were psychometrically tested. The S&M test was chosen because it is checking if the participant is able to see and manipulate three-dimensional objects in a two-dimensional plane. This ability is also important for perceiving depth cues in monoscopic displays. Another test chosen was the perceptual GEFT test. The subject's task on each trial is to allocate a previously-seen simple figure within a larger complex figure which has been so organised as to obscure or embed the sought-after simple figure. Under strict interpretation, therefore, scores on the GEFT reflect the extent of competence at perceptual disembedding (Witkin, Oltman, Raskin, and Karp, 1971). Most of all, the test assesses an ability to break up an organised visual field in order to keep a part of it separate from that field. The GEFT test measures the extent to which subject perceptions are dependent on (or independent from) cues in the environment (the 'field'). A high score in this test means that the person is able to perceive objects independently cues. These characteristics had implications for VS because it is still impossible to produce models with all of the cues that humans experience in the real world. By using these tests the author wanted to give some homogeneity to the sample group. The results of the test and experiment suggest that the sample group did not require so many cues in order to perceive stimuli. However, further investigations are required with a subject group who do not score highly on those psychometric tests in order to further evaluate exocentric perception of chosen dimensions. The psychometric testes used did not show sex differences in the subject groups.

Age does influence perception of spaces. The participants' age could also contribute to the results because older people have different psychological reactions to young people, have different job experience, different attitudes. Age is also influential in determining how much difficulty a user will experience in learning a system. The more complex a system becomes, the more influential are the effects of age, particularly if information from different sensory channels is to be integrated. This is disturbing since it is predictable, with their multimodal interaction and complex visual scenes it would be beneficial to determine how to adopt VEs to the needs of older individuals. It has been suggested that deficits in perception and cognition, which often are experienced by the elderly, may lead to a reduction in the information perceived from VEs (Birren and Livingston, 1985; Fisk and Rogers, 1991; Hertzog, 1989, Stanney *et al.*, 1998).

Cognitive complexity also influences perception of space. Some people have a "simple" cognitive structure or other can be "cognitively complex". Person possessing a "complex structure" is more capable of dealing with complex or conflicting information. Also intellectual ability of participants could contribute to the results of experiment. All participants were students or lecturers at the university. Of course, it was assumed that they represent some level of intellectual abilities if they study at the university. Of course it is only an assumption because no formal testing were done before or after experiment. People with higher intellectual ability deal with the buildings or environments in a different ways, and therefore it is necessary to take these different patterns of behaviour into account. It is an important aspect of any research because VR can be used by people drawn from the lowest as well as the highest range of intellectual levels.

The results of Experiment one and two clearly show that there are different patterns of accuracy in the perception of horizontal and vertical dimensions. The dimensions in the real world were underestimated. In VE, dimensions were generally overestimated. These differences could be due to the experiment apparatus limitations or individual participant's differences discussed above.

6. CONCLUSION, DISCUSSION AND FUTURE RESEARCH.

What follows is a summary of the research. The hypotheses are evaluated, and findings discussed, along with some recommendations for future research.

6.1 Hypotheses Evaluation .

The purpose of this research was to examine the extent to which people's perception of dimensions in real and virtual environments differ from each other. The procedure of magnitude estimation was used for assessing participants' dimension estimations. Participants were asked to estimate dimensions in a building and full-cue open space environments. The hypothesis of interest assumed that people perceive space in VE as well as in the real world. It has been proved that the results are statistically significant and therefore one was able to reject the experimental hypothesis. But before this was possible, one had to statistically evaluate the components of the null hypothesis. Therefore, these sub-hypotheses (H) are summarised below.

H 1: There is no difference in perception of egocentric length in enclosed space conditions.

Chapter 4 incorporated the presentation of results of the estimations of length in the real and virtual Rooms (A, B and C). The results of statistical tests suggest that the results were significant for $p<0.05$ in two rooms. In Room C the results of the *t*-test were not significant because participants' estimates are very similar to each other meaning that there is not a big difference between the means of these groups. However, taking into account the average performance in all three rooms the results are significant. Therefore, one can conclude that based on Experiment

1 results, the null hypothesis can be rejected. Furthermore, one can state that there is a difference between human perception of egocentric lengths in enclosed space conditions. Participants perceived length dimension on average 5% shorter than the true length in the real world. They perceived length approximately 11% shorter than the true length dimension

H 2: There is no difference in perception of the exocentric width in enclosed space conditions.

The data presented in Chapter 4 also points out the fact that the results of two two–tail *t*-test for width in all three rooms are significant. Therefore, one is able to reject this null hypothesis. Participants underestimated width in both conditions, but they were more accurate in the real world (average. 5%.). In VE they underestimated width on average by 10%.

H 3: There is no difference in perception of exocentric height in enclosed space conditions.

Statistical tests were only significant in Room C. The average height estimations were statistically insignificant. It means that one cannot reject this null hypothesis. Of course, it does not mean that people are very accurate in height estimations. Participants underestimated height in the real world by approximately 26% and overestimated height on average by 25%.

H 4: There was no difference in perception of feeling of space in enclosed space conditions.

The sixteen pairs of bipolar adjectives were chosen in order to investigate participants' feeling of space. Taking into account the non-parametric characteristics of the 16 adjectives, from which Wilcoxon rank sum tests were calculated. These tests revealed that the results of this exercise were not significant, so that the null hypothesis concerning the feeling of space has to be retained. There appeared to be a remarkable similarity in the results between experimental groups in this experiment. Therefore, one can say that VR tools are appropriate for conveying information about feelings of space.

H 5: There is no difference in perception of exocentric heights in open space conditions.

Statistical tests show that the results in Experiment two attained for two-tailed t-tests with $p<0.05$ were not significant. Therefore, the null hypothesis is retained.

The estimations in the real world were on average 21% underestimated with only 2% underestimated in VE. It is an interesting finding because it seems that people were on average very accurate in VE. The most underestimated height was on average 1.5m in the real world and the least underestimated height was the 2.5m stimulus in VE (Figures 19 and 20).

H 6: There is no difference in perception of exocentric lengths in open space conditions.

In this null hypothesis, the perception of exocentric length was studied. The results of statistical t-tests revealed that the null hypothesis should be retained. Furthermore data suggests that participants on average overestimate horizontal dimension by 4% in VE and they underestimate length by 15% in the real world (Tables 14 and 15).

H 7: The orientation of the stimuli does not influence the accuracy of the perception of length and height estimations.

The results of the experiment concluded the fact that the orientation of stimuli had influenced participants' perception of dimensions, with vertical stimuli being less accurate than horizontal ones.

6.2 Discussion of Results.

The results of both experiments suggest that participants on average underestimated dimensions in enclosed and open spaces. When measured with three perceptual tasks, it became apparent that virtual environments did not fully satisfy the requirements for completely replacing other forms of spatial representations that are meant to convey the basic spatial characteristics of proposed spaces. The quality of the virtual interface used in this study is not sufficient for making *quantitative* judgements of spaces. The distances are on average underestimated. The errors in dimension estimates were found to be greater in VE than RWS. However, results of the experiments were more accurate than in previous research (Witmer, and Kline, 1998; Wright, 1995; and Lampton *et al.*, 1995; Lampton *et al.*, 1994; Coren *et al.*, 1993, Henry, 1992). The factors which could contribute to these results were the psychometric characteristics and the professions of the subject group. All participants scored above average on S&M and GEFT. The first test investigates people's ability to manipulate a 3D object. It suggests that if there is lack of stereopsis or depth cues people are still able to see objects three dimensionally. High scores achieved on the GEFT means that participants' perception does not depend upon cues in the environment.

6.2.1 Limitations of the Experiments.

There were some limitations in the design of these experiments which could limit the findings presented in the thesis. They can be divided into: 1) limitations of the virtual model, 2) limitations of the technology, 3) participants' characteristics.

1. Limitations of the virtual model.

It is generally accepted that texture, form, colour, light, scale and movement are qualities used by humans to perceive and directly experience architecture (Zobel, *op cit.*). In the case of the first experimental model only very basic characteristics of this experience were present. The model of the building had only limited amounts of texture cues with an ambient light and without a shadow cue. Texture and shadow cues are important depth cues, which influence perception of spaces (Lackner and DiZio, 1998; Crvarich, 1995; Kolasinski, 1995; Johnston *et al.*, 1991; Ittelson, 1960). Scale cues were provided by doors presented in the model and it was expected that a standing posture during the performance of tasks in both experiences would also provide important cues. However, it was reported by participants that they would have preferred to have had some human figures placed in the models. This supports suggestions that people are the most dependable element by which to judge the size of objects relative to ourselves in the environment.

Movement is an important cue in architectural experiences. However, participants performed dimension estimation tasks with only head movement allowed. Thus, the lack of movement could have distorted the perception of dimensions experienced by participants in both experiments. It has also been suggested that the horizontal and vertical dimensions of spaces in simulation conditions were on average perceived to be significantly smaller than in the real spaces. It was suggested that this misperception is due to the well documented size-constancy phenomenon, whereby sizes and distances appear to be smaller when seen through a truncated field of view (Dolezal, 1982; Alfano, Michael, 1990; Henry, 1992). This supports findings that perceived distances were on average underestimated in the virtual environments. However, the results attained are quite good. It could be due to having selected people with high mental manipulation and orientation abilities.

2. Limitations of the technology.

It has already been suggested that FOV plays a limiting part in the perception of dimensions. The limitation of FOV on the perception of space, could be solved by including many familiar elements of scale in the model. It has been mentioned earlier that many participants indicated that the task would have been easier had there been more elements of scale.

Another important aspect of technology limitation can be computer speed. It is assumed that computers with fast graphic performance would be more appropriate for rendering models in real time. However, the findings in this research show that even a PC with standard graphics was adequate for participants to assess dimensions with high accuracy. These results can be explained by limitations in experiment design, because participants were performing their tasks whilst stationary and only with head movement allowed. In the second experiment an Infinitive Reality Silicon Graphics computer was used. However, the average accuracy of dimension estimations between these two experimental set-ups is very similar.

3. Participants' characteristics.

Participants' characteristics are the elements of experiments that are the most difficult to control. As pointed out in Chapters 3, 4, and 5, the individual participants' attributes play an important role in any research dealing with humans. Participants in both experiments were psychometrically tested, with scores above average on tests. The results of tests point to the mental and perceptual qualities of these participants. Therefore, the high level of accuracy in estimation tasks could be explained by this factor. Another important factor was the profession of participants in the first experiment. The group was made up of students and academics in the field of surveying. It is assumed that their perception and concept of measurement units was higher than, for example, students of history. This could explain relatively high scores in the first experiment. Furthermore, the model was representing a building with standard scale cues, e.g. dimensions of the standard doors. This element alone could make the height estimation task easier for them. Some of the other characteristics were already discussed in Chapters 3, 4, and 5. They are namely: the level of experience, age, personality, attitudes to technology, eye acuity, etc.

6.3 Evaluation of VR on an Actual Building Construction Project.

Recently the author supervised an experiment which was part of the Masters' thesis in Virtual Environments at the University of Salford. The project was commissioned by the Templar Housing Association. Before Templar committed themselves to the project, they wanted to gauge the level of interest that potential tenants (clients) showed regarding long term occupancy of apartments. Traditionally the clients would be shown around an already completed house, apartment or Show-Home to obtain commitment from them to rent or purchase the property. However, this was not possible. Templar had to investigate an alternative to the traditional methods of presenting property to clients. Hence, they commissioned a Virtual Realty Model of the new Housing Development, which was constructed by 3D Web Technologies and the Centre of Virtual Environments (CVE). The 3D model would then be used for the client briefing process, for their proposed development. The Model allowed for changing the floor finish and the wall finish. There was also an option to change the wall configuration in the apartments within a combined kitchen and lounge. In addition, the model allowed the style of the kitchen units to be changed. Colour schemes could be changed throughout the apartment. To add realism to the model, doors were programmed to open at the click of a mouse, as the viewers were navigated around the apartment. The experiment was in two separate parts. The first part consisted of a questionnaire evaluating the presentation method. Participants were asked to fill in a short questionnaire after participating in the presentation of the model. The results of the questionnaire were very promising.

All respondents preferred the 3D presentation to the 2D one. Furthermore, all participants were able to recognize which room was the largest one. Also. 98% of participants were correct in pointing out which room had more than one window. The participants group was not psychometrically tested. It would be a fascinating study to create a guide book which would specify how to adjust the space dimension according to a client's psychometrical abilities in order to facilitate their cognitive abilities. Participants expressed their approval for the presentation method. They said that they could imagine themselves living in this apartment with their possessions populating its space.

The second part of the experiment was concerned with perception of dimensions in the CAVE and Reality Room. The virtual model of one apartment from the Templar Project was used. Participants were asked to estimate the dimensions of the kitchen units in the kitchen. In the Bathroom participants were asked to judge the dimensions of the bath. In the bedroom they were asked to estimate the dimensions of the chest of drawers. Two independent subject groups were tested, each group experiencing only one condition. On average participants underestimated all the dimensions in both conditions by 15%, which concurs with the results of most research into the judgement of dimensions. What was important in this project was the opportunity to question clients about their experience of VE. As Campion (2000) said, all clients of the project were impressed with the tool and expressed that it should be used for all client briefings in the future. According to them the biggest strength of VE is the ability to interact with the model and that it gives them the possibility of interaction. These experiments illustrate that VE could play an important part in the client briefing process.

6.4 Future Research.

Despite some limitations, VE technology can still be used as a supplement for existing techniques of spatial representation. Also, by manipulating certain cues it is possible to help people to perceive spaces more correctly in VE. The main aim of this research was to evaluate VE technology for the client briefing during the process of designing a building. What makes up a building is its space, light, proportions, colours, texture and all other components of the building form and act together, producing visual and kinaesthetic impressions. Most decisions about the visual qualities of environments are often made by design professionals. However, Architects' ideas are often misunderstood by laymen. The results of experiments by Hershberger and Cass (1974) suggest that Architects are more concerned with the aesthetic nature of the building. Laymen were more concerned with the pleasantness of the building, its spaciousness, comfort, cheerfulness, and the like. Client briefing with a virtual model of the proposed design could be of immense help in making a correct interpretation of a designer's ideas to laymen. Architects also ought to consider how forms, spaces and scales are perceived by laymen, so Architects can consciously manipulate them in order to make their ideas understood by their clients. Studies using photographs, colour slides, colour films for the representation of built environments indicate that these representations are not able to convey the intended information to perceivers. The studies by Hershberger and Cass (1974) show that there were significant differences among judgments of a building across the representation media utilised. Judgements in RWS indicated a higher degree of organisation that those based on the media listed above. The buildings viewed in person were perceived as being more beautiful, good, pleasing or unique than buildings judged on the basis of the slides or film. VE technology overcomes this limitation by enabling immersion into the model. It is a very important implication in support of using VE technology for those purposes.

6.4.1 Colour.

It is known that the appearance of objects depends to great extent on colour and the light in which they are seen. It has been mentioned in this thesis that by manipulation, for instance of colour, it is possible to create an atmosphere, suggest unity or diversity of the building. Colour can also express the character of material, define a form, affect proportion, bring out scale or give a sense of weight into a design. It is a very important characteristic of colour usage in architecture, but it also has serious implication for VE. It would suggest that by manipulating colour in the VE it would be possible to communicate a required design to client without having to use a powerful computer. Research was already done into perception of colour in VE. Some of it was discussed in the Chapter 2, Section 2.3 (Crvarich, 1995; Wagner *et al.*, 1992; Reinhart *et al.*, 1990; Bemis *et al.*, 1988). All of this research indicates the importance of colour as a cue in distance estimations and the influence of other cues on perception of depth. However, there is still a need for more complex experiments in colour manipulation for architectural designs. Despite current achievements there is still a need for more complex experiments in colour manipulation for architectural design, e.g. the manipulation of colour in different experimental settings with the use of different set of participants.

6.4.2 Light

Another cue which is helpful in dimension estimations and is used in architecture is lighting. By the manipulation of light it is possible to communicate and change the composition and relative strength of visual signals and clues. It has been observed that manipulation of light can affect personal orientation and users' understanding of the room or environment and artefacts. It can influence users' understanding of the room size and shapes, and establish a sense of visual limits or enclosure (Faulkner, 1972). Lighting can help Architects and VE designers to set moods in environments. It also can be implemented in order to affect psychological states such as intimacy, privacy or warmth. Martyniuk *et al.*, (1973) suggested that by using certain types of lighting it is possible to convey perceptual clarity, impressions of spaciousness and relaxation, and spatial complexity. It is also possible to influence some categories of people's behaviour, e.g. attention. Future research could look at the behaviour of people under different light settings in virtual environments in order to investigate the influence of these settings on people's psychological states.

6.4.3 Scale.

More cues were reviewed in Chapter 2. One of the cues, the importance of which was stressed by subjects throughout the research is the issue of scale of both the physical and the virtual realms in architecture. Scale issues were studied in terms of "human" scale, the detail of one's environment, and the development of connections.

The "human" scale is necessary in real and virtual environments, although they are accomplished throughout different means. In the real world, scale is established by the size of elements relative to the participant. In the VE, the participant does not have an inherent size, so scale is only indicated throughout velocity. That is, the scale of one's environment is indicated by the rate at which one moves through it. Both types of scale are affected by the size of openings. A participant gains a sense of scale when passing throughout a relatively small opening whether by virtue of one's tight fit or by having to reduce one's velocity to ensure passage through the opening.

Perception of scale is also influenced by the detail of one's environment. The richness or articulation of surface in the physical world can affect one's sense of scale in much the same way that the size of elements does. Similarly, the detail and number of polygons rendered within a participant's FOV affects one's virtual perception of scale. It has been observed that participants tend to move more slowly through complexly detailed environments than trough simpler one (DeLucia, 1991).

Connection can also affect one's sense of scale in architectural spaces. In the real world, the detailing of connection is accomplished by a hinge, a reveal, or any number of other ways to join elements. This joint introduces a smaller element at the connection. These smaller connections present in the real world add richness to scales. In VE, the traditionally understood connections are not necessary. Without the physical forces of nature, all elements exist inter connectedly as abstract geometry without the need for connecting elements. Therefore, connections do not serve to enrich the scale of virtual architecture. Some further investigation could take the form of experiments into how different scale cues influence human perceptions of architectural spaces. Through the manipulation of these cues researchers could become more aware of the importance of scale in the perception of the environment in a general sense not only the virtual one.

6.4.4 Communication.

It is important to remember that people use space as yet another medium of communication. For instance, Altman (1971), Porter *et al.* (1970) stated that people use space to indicate their feelings of, attitudes towards, the type of activity in which they engage. Sommer (1969) hypothesised that people arrange themselves in various positions in space in order to optimise the amount of information they receive from others. It is an important suggestion for designers because it implies that people are not passive but active users of space.

6.4.5 Preferences.

Kaplan (1979a) noted that people are good at recognising what they like, but not as good at verbalizing the reasons underlining their preferences. The results of Talbot's (1988) studies into perception of and preferences of large places support Kaplan's statement. Her subjects preferred smaller and more natural places. They liked places with trees, gardens and other natural settings. However, they had to perceive these natural areas as spacious places and they liked areas with certain attributes. She proposed some guidelines for designing spaces to fulfil people's satisfaction with the environment. These guidelines can be also implemented by VE designers to simulate space representations that satisfy humans. Among other things she proposed to encourage a moderate degree of variety in the treatment of land parcels. She suggests that natural elements influence the perception of large regions and therefore designers should use trees, plantings and patterns of foliage in order to promote visual continuity in large scale urban settings. One should create, protect and preserve unique qualities of spaces. Within individual spaces should be created distinct and well defined regions with clearly differentiated characteristics and functions. Every designed setting should have multiple entrances. Each space should be designed with its user in mind. They should be able to appreciate a meaningful bit of nature, e.g. groups of trees, bushes, etc. These suggestions when implemented in VE simulations should be able to help to convince users that VE technology is a powerful tool for the representation of spaces.

6.4.6 Navigation and cognitive maps.

The interface is adequate for making *qualitative* evaluation of spaces. People would accurately predict their perception of the feel of the real space. It seems that interpreting spatial information using the virtual interface is perhaps as simple and intuitive as it is to interpret real spaces. To interact with the virtual environment, participants used their body and head to look around, as they would have done in the real space.

The success of physical and virtual architecture depends not only on how easily one can orient oneself in the design, but also how well one can move, or navigate, through the environment. Successful navigation depends on one's ability to develop a cognitive map (Ellis, 1992). Orientation in simple virtual models did not provide any problems for participants in the experiment presented in this thesis. Their cognitive maps of the spaces were very accurate (Chapter 4, Section 4.6.6). All of this supports the idea that the virtual interface, despite its faults, is a very important tool for conveying spatial information about our environments. The results of these experiments are particularly encouraging for the developers of architectural spaces, because it seems that space dimensions were perceived accurately in VE, sometimes even more accurately than in the real world. Overall, the results support previous findings in experiments by Witmer, and Kline 1998, Barfield and Rosenberg 1995, Reinhart et al 1990, Cole et al. 1990).

Although cognitive maps were not the subject of the general hypothesis, one was still able to gain some interesting information. In the first experiment all participants built correct cognitive maps of the visited spaces. It is known, from previous research, that people are generally good at building them; even blind people are able to build quite accurate cognitive maps. One of the concerns was that participants in the simulation condition would have a problem with building their maps because previous research indicated that a limited field of view could obstruct people's ability to build correct cognitive maps (Alfano, Michael, 1990). The findings of the first experiment contradict this research. However, participants were accurate in recalling only simple spatial layout. It included only four simple spaces and the path of the visit was too informative. Of course, this was *de facto* restricted by the aim of the research (perception of basic dimensions of spaces) presented here. For research into cognitive maps it would be necessary to choose different experimental sites and to use more spaces in order to make the cognitive map building task more difficult. However, one felt that it would still be interesting to include the cognitive map task in our research. Until in-depth research into cognitive maps in virtual environments is conducted, professionals wishing to use this tool for representing building spaces should, for instance, provide the participants with additional layout information, such as a plan view of the space as was demonstrated in the research by Ruddle *et al.,* 1998; Waller *et al.,* 1998; Surdick *et al.,* 1997, Moar and Carletan, 1982, and many more.

One possible explanation for the lack of a greater distinction between virtual and real world environments can be accredited to experimental space simplicity in the first experiment and the high level of similarity between the model and the real environment in the second experiment. The second possible explanation is the adjective selection in the experiment of feeling of space. Only the adjectives which could appropriately define the space were chosen, thereby narrowing variability in choices. There is still a need for in-depth research in this area. However, the results demonstrate the advantage of using virtual simulation for representing, in architectural spaces, the quality of being able to accurately assess how a place would feel, and conversely, how one would feel in a place. This is the advantage of virtual simulations over drawing or physical scale models.

6.5. Future Use of VR in Building Construction.

The results of these two experiments suggest that even with its technological limitations architecture is a natural application domain for VE. VE in architecture can be implemented in all stages of building design and construction. It has been mentioned in Chapter 1 that the briefing, sketch drawing, and working drawing stages can be utilised by providing Architects with a tool allowing them to present visual ideas of designs to clients or to a team of designers. Every attempt to create an inclusion of space in a user's mind, through a minimum of means, achieves a maximum impact. A visually trained person is, in most cases, perfectly capable of understanding a hand sketched diagram of a few lines that communicates a proposed idea of a building or an urban space. This is the Architects' personal design language (Schmitt *et al.*, 1995). However, if the person is not visually trained or does not have some innate ability to perceive simple drawings, they will not be able to judge the quality of architectural ideas based only on 2D and 3D abstraction. They are even less able to evaluate the relations between the form, function, behaviour or costs of a proposed building.

A virtual model with a high degree of detail that covers all of these aspects of a proposed building or any architectural space in an integrated manner, and that Architects, the design team and clients can explore in many ways, will be therefore of significant help. By being able to experience designs before construction, everyone can request adjustments. Architects and clients can view and modify virtual models of buildings and regenerate updated versions of it until they are satisfied. Revisions are far less time consuming than the original designs. By keeping information up to date in the system it is possible to retrieve from them plans which are accurate and current. All subplan drawing details from the master plan are automatically updated, as well. VE models may be used to view proposed final designs. They are extremely cost-effective in troubleshooting before expensive physical construction has begun. Using VR models not only saves time and money compared with the production costs of real 3D models, but also extends the creative resources of the people working on the project. Architects and clients will be able to connect, separately and by long distance to one VR model and walk through it together in virtual reality. However, in order to prevent any misleading information being presented to clients or Architects, further studies are needed.

On the other hand, VE developers should also learn from architectural expertise. Architecture can provide answers to the problems of how to compose space in order to accommodate function and convey meaning. Such expertise may be selectively used when designing 3D spaces in VEs. For instance, if doors are in the model users immersed in the model should not be allowed to pass through the wall to another space, because this would negate the value of the door in that model.

As was indicated in the introduction to this thesis the goal of Virtual Reality is to connect humans more closely with computers. The experience should, ultimately, be imperceptible from reality. By displaying at an appropriate update rate and with systems latencies, users would no longer see a stream of flickering pictures in front of their eyes but instead believe themselves to be in a new, computer-generated world. The implications of this new set of perceptions- this new state of consciousness- will continue to be explored far into the future.

Designing valuable and interactive virtual worlds is a challenge for system developers and human-factors specialists. VE commands a close bond between the user and the system. Therefore, it is imperative that in order to achieve the potential of VE there has to be a clear communication and co-operation between designers, systems developers and human-factors specialist. It is the capabilities and limitations of the user that will often determine the effectiveness of the virtual world. By incorporating knowledge from the human factors domain the direction of future VE research can be determined in order to meet the needs of its users. These user limitations and capabilities are very important as far as perception of architectural spaces is concerned because the intrinsic characteristics of VE suggests that they make an excellent tool for simulation of spaces for architectural applications. It is a tool which can convey spatial information from architects to their clients during the briefing process. VE allows architects and their clients to view and modify plans of the building before it is built by being completely surrounded by the model of the created building and able to walk through and manipulate the design. One does not have be an oracle to predict that the lack of knowledge of how accurately people perceive length, width and height of the real and virtual rooms or buildings could have catastrophic consequences for the process of conveying spatial information. By conducting two experiments the author's aim was to provide additional information and help for developers to prevent the occurrence of errors in communication between designer and clients which could lead to customer dissatisfaction and disappointment with this astounding interface. Furthermore, the results of experiments proved that the evaluated subset of VE technology is very accurate in conveying spatial information.

There is one issue which one feels should be mentioned here despite the fact that it is no objective of this thesis, but a very important one nonetheless. This is the issue of Health and Safety concerns in VE. With the improvement of technology and increases in application which can be used with it, the user base will also grow. The increased diversity should users make greater demands on the human-system-task interface will strengthen concern over side effects in VE. Side effects can prevent the spread of technology not only in Architecture, but in many other domains where VE can be used. Among these side effects one can list motion sickness, ocular disturbance, visual performance changes, respiratory or biochemical changes, changes in cognitive psychomotor performance, disorientation, physical discomfort and many others. This list is not complete, but one should regard the side effects listed here as being serious.

The development of techniques for the measurement of VE effects is still ongoing but there are already some techniques which can be used for the assessment of physiological symptoms and signs, performance changes and users' experience. This can be achieved by the employment of self-reporting, performance measurement, and physiological monitoring. Techniques such as these have their flaws, but they are a first step in developing an assessment battery for VE effects. For instance, there are differences among individuals. Athletes will perform better than an average individual in many physical tasks. They can be more flexible, have better balance, speed, and posture.

Nichols *et al.* (1977) pointed out that all measurement methods should be able to identify if effects exist, measure the degree of the effect, and aid the understanding of causative factors related to effect. Also, measurement methods need to accommodate different user behaviours in virtual environments. Last but not least, measurement methods should able to assess the subsequent consequences of any effect on individuals' well-being and safe performance. Measuring any effects is a difficult task because of the complex elements involved in it: hardware, software, an individual's variations and characteristics, interaction between measure and interaction between effect between causative factors. There are also ethical issues involved which could restrict and influence experimental design, duration, conditions, and activities involved in immersion.

Even though these issues are of great importance to VR developers and users they should not stop the development of this exciting technology. What is important, as Wilson *et al.* (1996), Stone (1998) point out, is that research into Health and Safety issues should take a realistic application-centred approach with both subjective and objective reports of effects and their consequences taken into account. VR can be used extensively at work and home, Health and Safety issues can only assist in development and implementation.

The increasingly wide spread of VR, visualisation, simulation and 3D computer graphics highlights the need for a systematic approach to the understanding of the role of a range of human factors in virtual environments. In particular, there is a need for cross-disciplinary collaboration with researches from a wide variety of backgrounds, such as human factors, cognitive psychology, computer graphics, and virtual reality design. There should be stimulated inter-disciplinary interests in the role of human factors in the design, use, and evaluation of virtual environments, with emphasis on user-centred virtual world modelling and system design.

With computer power increasing at an unexpected speed, the author believes that the VE interface will become transparent as Sutherland (1965) predicted it should. Every day new techniques are developed for modelling worlds that are more complex, more realistic. The author believes that VE will become an integral part of the real world.

6.6 Contribution.

In the presented thesis the author explored the possibility of employing Virtual Reality technology in the client briefing process. It has been demonstrated that a VR model can be successfully applied in this process instead of drawings or artistic impressions of the proposed building. The VR model is able to provide the experiential qualities of the contracted building in order to aid clients in a full understanding of the offered design. This type of model is cost effective and can shorten considerably the process of client briefing.

However, to give clients the best possible impression of the proposed design it was important to understand how dimensions of those design spaces were perceived. While it is clear that virtual interfaces can create the illusion of being present in a virtual model, very little is known about representativness of virtual spaces compared to real ones. The reality is that considerable systematic research must be carried out in order for VR to fulfil its potential. The human experience in the virtual buildings is not identical to the experience in the real buildings. As mentioned in Chapter 2, humans are spatial beings, and in the real environment one relies on an abundance of multiply modalities when performing everyday tasks; in virtual environment, the technology may limit the quantity and quality of these essential stimuli. Therefore, researchers should actively seek the necessary understanding of human performance in order to create robust design guidelines that will make use of technology in its current state of maturity. The author hopes to contribute to this research by focusing the experiments presented here on the investigations into perception of exocentric and egocentric dimension of architectural spaces in open and enclosed experimental settings. The obtained results suggest that VR technology can fulfil its potential in the client briefing process by successfully creating architectural spaces which can be perceived in a similar manner to the real one. With the results of these experiments and through their inner characteristics, the author also hopes to contribute not only to the domain of the knowledge of human factors, but also to the assessment of the potential usefulness of the technology for architectural planning with its stress on error free communication between architects and clients in client briefing process.

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Appendix A. Questionnaire

Part 1. Length, width , and height estimation

Easy 1 2 3 4 5 6 7 8 9 10 Difficult

Total guess 1 2 3 4 5 6 7 8 9 10 Highly confident (within 1 meter)

1.1 Room: 'A' 'C' 'D'

Width: ....

Length:
....

Height: ....

Confidence (-5 to 5):..

Me: As you enter the site, you will be asked to formulate your 'first impressions' of the volumes. Your answer will be recorded with the aid of a small microphone. You may qualify your impressions and add them as you proceed, until you have visited the entire place. you may talk about any aspect you wish.

1.2 What are your first impression of the room?
....
....
....
....

1.3. What does it remind you of?
....
....
....
....

1.4. How does it feel; is it pleasant or unpleasant?
....
....

……………………………………………………………………………………
……………………………………………………………………………………

Comments:……………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

Part 2. Figure recognition.

2.1 Do you see a figure ahead of you?

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

2.2 Could you tell me how tall this person is?

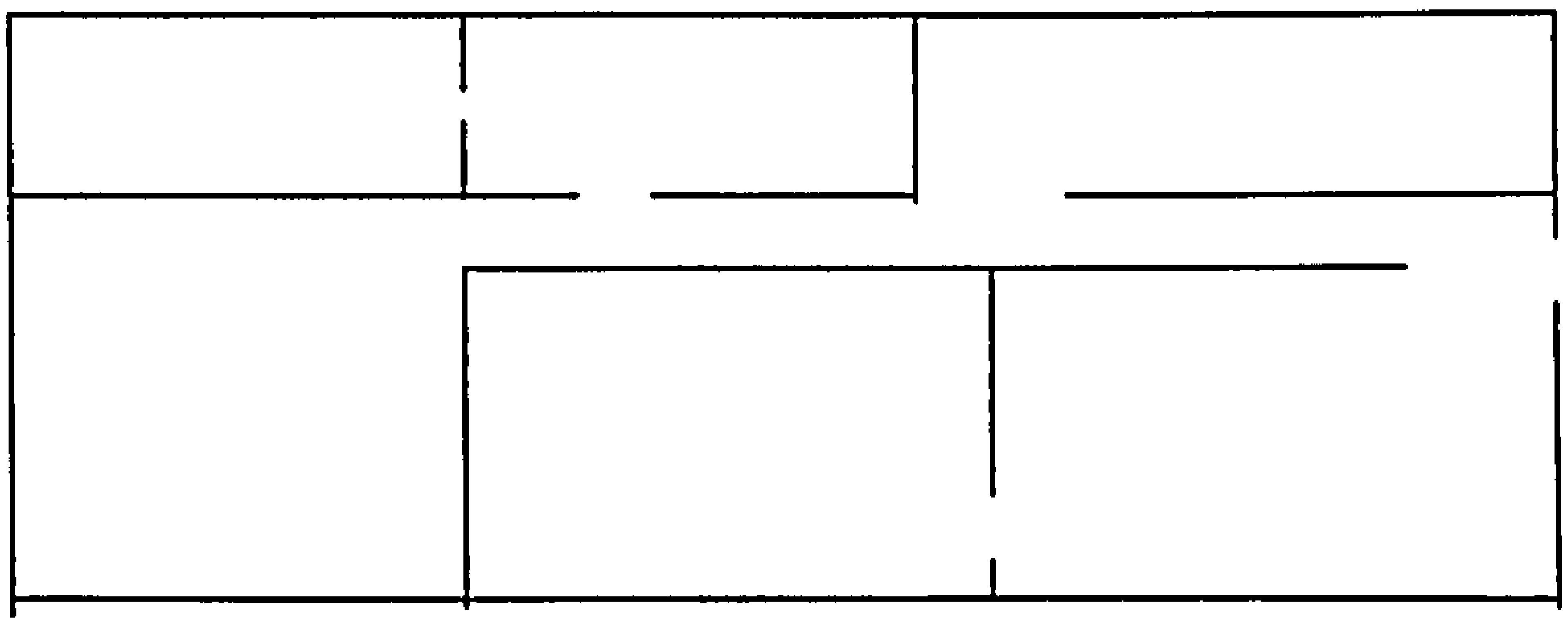
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

2.3 Do you think if this person could pass through the doors on the left of you ?

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

Part 3. Cognitive Maps.

After having completed your visit, you will be asked to draw a map of the space as you remember it. Follow the instructions below.



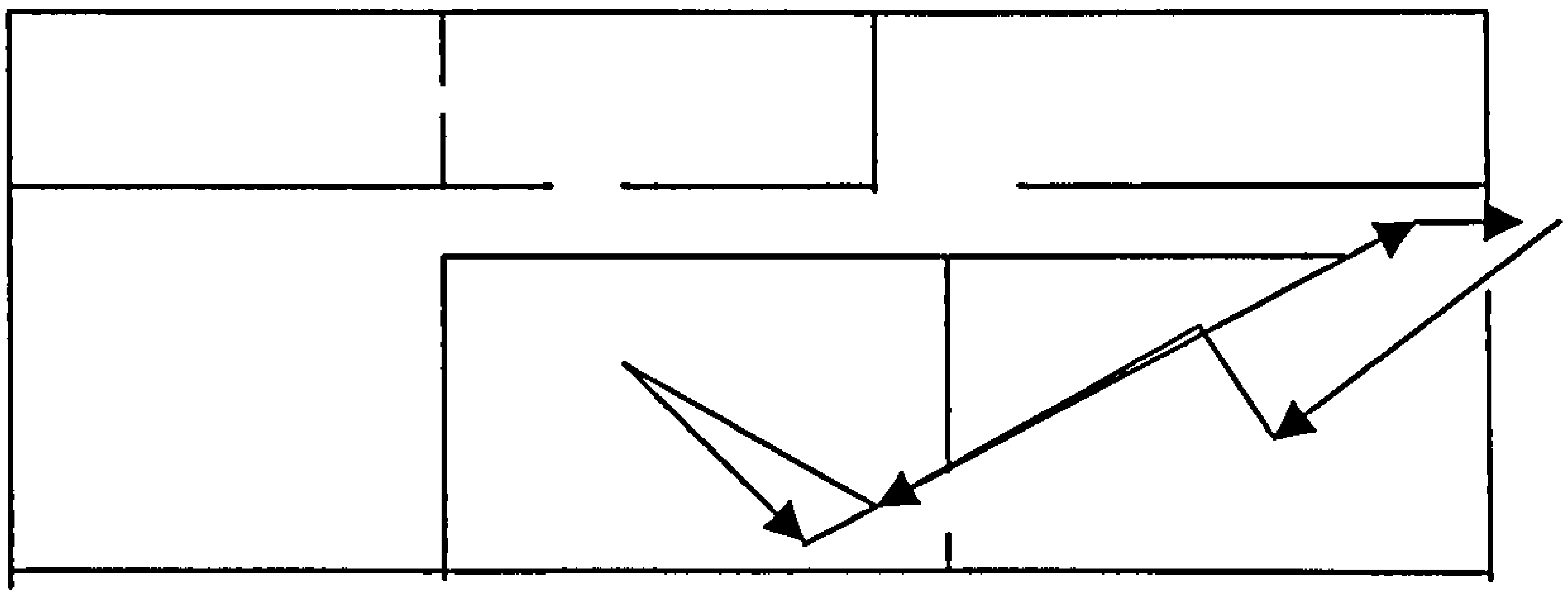
Example of map

3.1 Use **the next page** to draw a map of place you visited. (Example Above). The precision of your map is not important. It is a memory guide to help you answer questions later on in the study. Do not spend to much time on this task.

Draw your map here, please.

3.2 Use your plan to draw a line showing the path of your visit through the space. Place little arrows on the line to indicate the direction of movement. (see diagram below).

For your path of visit use your previous drawing, please.



Example of path. The path of visit is a thin curved line with arrows indicating direction of visit.

3.2 If 'Volume' is the total area of a space as defined by length, width and height, then rate each space from the smallest **volume** to the largest one. Attribute a 1 to the smallest, a 2 to the next largest and so on. If two spaces are the same size in volume, give each one the same value. Label those volumes directly on your plan. **Please use your drawing.**

3.4. Are there any spaces which were easier to 'size-up' than others (label them 'Easy' on the plan)? If so, explain why? (explain briefly)

....

....

....

....

3.5. Label the plan above with letters 'A' for the space which was most pleasant. Why was it the most pleasant space? (explain briefly)

....

....

....

....

3.6. Label the plan above with the letter 'F' for the space which was least pleasant. Why was it the least pleasant space? (explain briefly)

....

....

....

Part 4. Feeling of space

The following questions are presented as set of opposite adjectives and are meant to capture your perception of the room indicated during the tour (reception area?). Simply **circle the number** on the -5 to 5 scale which best qualifies how you perceived that space. If you feel the type of tour you took gave you insufficient information to answer a particular question, circle the option 'Can't say'.

Example. The space was...

Run down -5 -4 -3 -2 -1 0 1 2 3 [✓ 4] 5 New Can't say

1. The space was...

Cheerful -5 -4 -3 -2 -1 0 1 2 3 4 5 Gloomy Can't say

2. The space was...

Comfortable -5 -4 -3 -2 -1 0 1 2 3 4 5 Uncomfortable Can't say

3. The space was...

Complex -5 -4 -3 -2 -1 0 1 2 3 4 5 Simple Can't say

4. The space was...

Large -5 -4 -3 -2 -1 0 1 2 3 4 5 Small Can't say

5. The space was...

Private -5 -4 -3 -2 -1 0 1 2 3 4 5 Public Can't say

6. The space was...

Impressive -5 -4 -3 -2 -1 0 1 2 3 4 5 Unimpressive Can't say

7. The space was...

Inviting -5 -4 -3 -2 -1 0 1 2 3 4 5 Repelling Can't say

8. The space was...

Light -5 -4 -3 -2 -1 0 1 2 3 4 5 Dark Can't say

9. The space was...

Natural -5 -4 -3 -2 -1 0 1 2 3 4 5 Artificial Can't say

10. The space was...

Pleasant -5 -4 -3 -2 -1 0 1 2 3 4 5 Unpleasant Can't say

11. The space was...

Roomy -5 -4 -3 -2 -1 0 1 2 3 4 5 Cramped Can't say

12. The space was...

Threatening -5 -4 -3 -2 -1 0 1 2 3 4 5 Unthreatening Can't say

13. The space was...

Well scaled -5 -4 -3 -2 -1 0 1 2 3 4 5 Poorly scaled Can't say

14. The space was...

Warm -5 -4 -3 -2 -1 0 1 2 3 4 5 Cool Can't say

15. The space was...

Tidy -5 -4 -3 -2 -1 0 1 2 3 4 5 Untidy Can't say

16. The space was...

Well kept -5 -4 -3 -2 -1 0 1 2 3 4 5 Run down Can't say

Part 5. Description of Experience

5.1. How did you feel about your sense of orientation in the space?

Well oriented -5 -4 -3 -2 -1 0 1 2 3 4 5 Not at all well oriented

5.2. How frequently did you feel disoriented or confused about where you were in the space.

Never -5 -4 -3 -2 -1 0 1 2 3 4 5 Often

If yes, please rate your feelings...

Not the least worried -5 -4 -3 -2 -1 0 1 2 3 4 5 Very worried

5.3. During the walk through of the model, were would you say your mind was?

Always in Lab Half in Lab and half in model Always in Model

1 2 3 4 5 6 7 8 9 10

Part 6. Evaluation of Virtual Reality Interface (This part is for simulation viewers only)

Now we would like to get your reaction to the Virtual Reality Interface

6.1. General Reactions.

6.1.1. Please list up to three things which most annoyed you about the Virtual Reality Interface and that interfered with your ability to estimate lengths, width and heights.

1. ....

2. ....

3. ....

6.1.2. Please list up to three things which would make your estimates (lengths, heights and width) easier.

1. ....

2. ....

3. ....

6.2. Do you have any comments on any hardware issues?

....
....
....
....
....
....
....
....
....
....

6.3 Areas of improvement.

Architects could use this technology to predict the feel of the spaces create before they are built. But before they can do this, it is essential to measure exactly to what extent our sense of space in virtual reality models is predictive of how we will sense the real space. With this in mind, what most important improvements would you recommend to increase the fidelity of virtual spaces in predicting our perception of real volumes?

1...
....

2...
....

3...
....

4..
....

Part 7. Personal Data.

7.1 Profession/Occupation: ....

7.2 Age (circle one):

under 25 26-35 36-45 46-55 56-65 66-75 over 75

7.3 Gender (circle one): Male Female

7.4 Have you ever been to the VR Solutions Ltd.(VS) ? (circle one)

yes no

7.4.1 If yes; how many times have you visited VS?

1 2-4 5 and over

7. 4.2. How recent was your last visit (circle one)? Less than...

3 months ago 1 year ago 3 years ago 10 years ago

4.3. How well would you say you remember the spaces in the VS?

Vague memory -5 -4 -3 -2 -1 0 1 2 3 4 5 Know it like a palm of my hand

5. What is your experience with recent video games (last couple of years)?

Never played -5 -4 -3 -2 -1 0 1 2 3 4 5 Play every day

7.6 What is your experience with computer simulations (please list: Microsoft Flight Simulator etc...).

Simulation list	Experience (circle one)		
1.	Fair	Good	Excellent
2.	Fair	Good	Excellent
3.	Fair	Good	Excellent

7. Could we contact you at a later date for follow up experiments?

yes no

This is the end of the study. Thank you very much for your participation. Please call back around December 97 if you are interested in the results of the study. Again, thank you.

Appendix B Theories of Visual Perception.

There are, quite simply, many theories of perception. All of them have some merits and could have some implications for future theorists. However, it has to be stressed that there has not yet been one satisfactory general theory of perception. Below is a description of some of the chosen theories of perception.

1. Psychophysics.

Psychophysics is not a theory of perception. It is a set of techniques which has been developed by experimental psychologists in order to measure sensory and perceptual thresholds. However, we have to notice that psychophysics has many theoretical concepts and empirical methods which contribute to psychology. Psychophysics emphasises methods, but the concept with which it is dealing is fundamental to the psychology of perception. The constituent processes are; *detection*[17], *indetification*[18], *discrimination*[19], and *scaling*[20]. We explain these later.

The procedures introduced by psychophysics for measuring sensory and perceptual thresholds require

A set of stimuli displayed under controlled conditions.

---

[17] *Detection* is a psychological process concerned with awareness of the presence of stimulus.

[18] *Identification* is a psychological process concerned with naming stimuli.

[19] *Discrimination* is a psychological process concerned with noticing a differences between stimuli.

[20] *Scaling* is a psychological process concerned with a measuring how much of something is present.

2. A subject[21] or observer, who is instructed to make one of a restricted number of responses.

This method seems to be very simple. However, many discoveries made in the perceptual systems of humans or animals were applying psychophysical methods. It is a very impressive achievement. (Gordon, 1989)

Detection is a basic process for the sensory system. It involves detecting any present energy changes in the environment. It can involve electromagnetic (light), mechanical (sound, touch, and so on), and chemical (smell, taste) changes. Problems of detection are centred around the problem of how much of a stimulus is necessary for the individual to be consciously aware of its presence (that is, to see, to hear, or otherwise sense it) (Coren et al., 1994). Classically, this minimal amount of energy has been called *absolute threshold.* The threshold stimuli was defined by a German physicist Gustaw Fechner in 1860 as one that " lifted the sensation or sensory difference over the threshold of consciousness". The stimulus is not detected below some critical intensity. However, when the stimulus intensity exceeds thresholds we expect people detect it. To represent this relation (hypothetically), we can use a graph called a *psychometric function* (see Figure 33).

---

[21] There are in some quarters objections to referring to the people studied in psychological research as 'subjects'. Some psychologists argue that a false model of the human being is generated by referring to people studied in this rather "distant" or "cool" scientific manner. The British Psychological Society's 'Revised Ethical Principles for Conducting research with Human Participants' were in provisional operation from February 1992. It says that on the grounds of courtesy and gratitude, the terminology used about them should carry obvious respect. However, from 1993 to 1994 in the British Journal of Psychology, there was only one use of 'participants' in over 30 research reports (Coolican, 1994). We use the term 'subjects' with all due respect to all of the participants in our research.

Figure 26, presented below, shows the psychophysical function implied by the definition of a threshold simply as a step between two states of sensitivity. Along the vertical axis of the graph we plot the probability of an observer's "yes" answers to whether or not he/she can observe the presence of stimuli. Along the horizontal axis of the graph we plot the values of the stimulus magnitude.

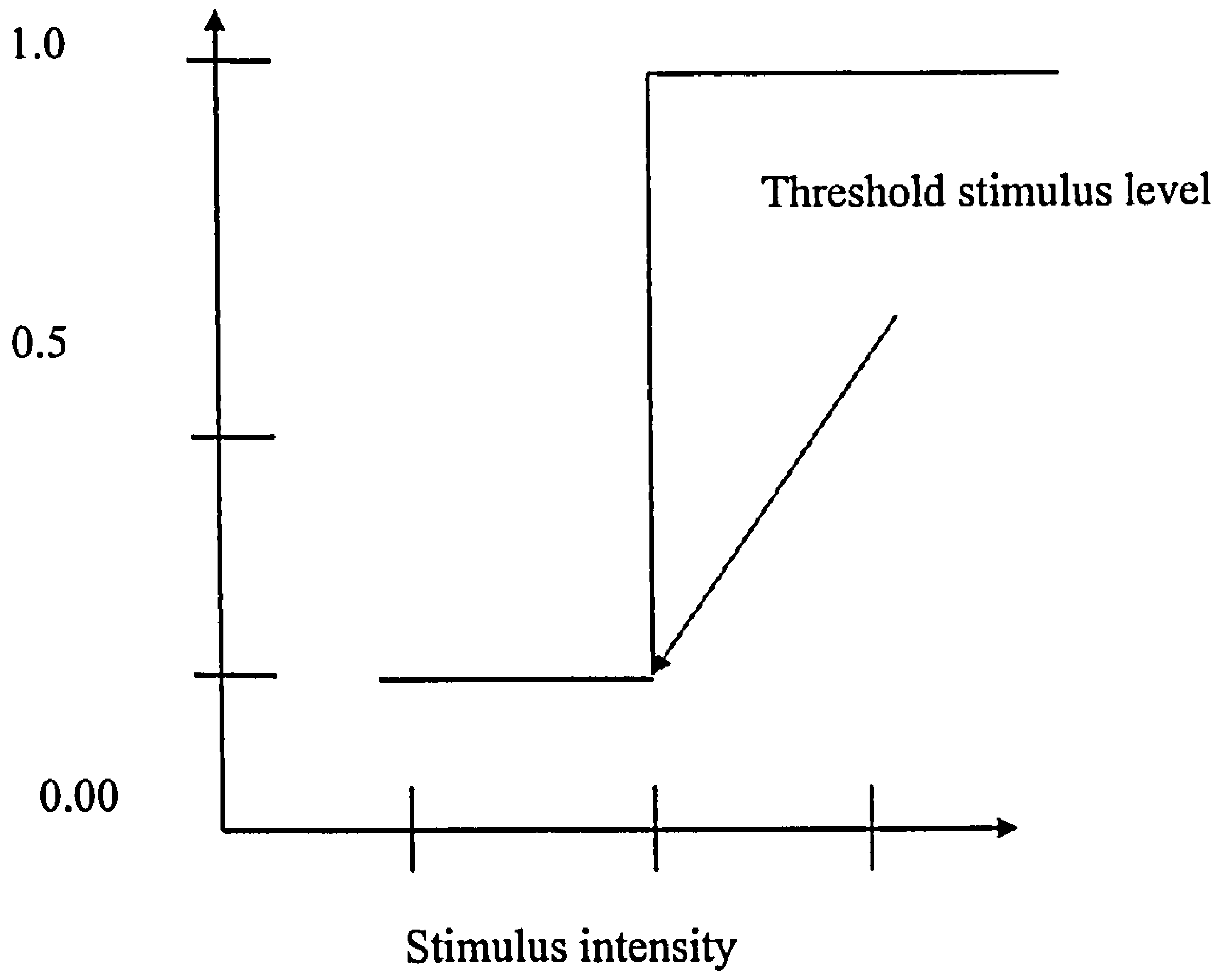


Figure 26 Psychometric Function.

To measure absolute threshold psychophysics we use the *method of constant stimuli*. The essence of this method is that the standard stimulus is presented with a particular comparison stimulus for several trials. During each trial the subject must say which of the pair of two stimuli is greater, or smaller, brighter, and so on. The proportion of correct answers is recorded and then we repeat the trial with another comparison stimulus. On each presentation we randomise spatial or temporal position. The threshold is found by calculating from the plot of comparison stimulus magnitude against the proportion of correct answers.

This method can give good estimates of absolute threshold. However, it is time-consuming. We have to do pretesting in order to find the general location of thresholds, and than we have to carry out a large number of trials for each intensity level. Many trials are "wasted" because they contain information about stimuli that are far from the threshold (Simpson, 1988; Watson & Fitzhugh, 1990; Coren *et al.*, 1994).

Another method for measuring thresholds is the *method of limits or minimal changes*. A standard stimulus is selected and the difference threshold is assessed by systematically changing the value of the comparison stimulus. For example, one wants to measure the difference threshold of brightness. First of all, one has to select an intensity of light for a standard and display it, say, as a ring. Than, the subject is presented with a second ring which is noticeably brighter. A subject will be able to notice, without any effort, that the second ring is brighter. Then one has to reduce the intensity of our stimuli by a fixed amount and present it to the subject again. This process is repeated up to the point when the subject says that the intensity of both rings is equal. Further changes are made to the comparison stimulus until our subject says that the ring is darker. At this point an experimenter has to stop the trial and make a note of points at which the response 'brighter' changes to 'equal', and then to 'darker'. The threshold on this trial is estimated as lying half way between the two changeover values. On the next trial experimenter sets a stimulus to a markedly darker value and move in the other direction towards the standard. One has to alternate these trials, with a starting point randomised somewhat to prevent memorising or counting by the subject. A typical threshold determination will require about twenty trials (Gordon, 1989). It is a very easy method to use and subjects find it simple and sensible. However, one could find that if is used the same value of intensity of the stimuli on the same subject over time, one could end up with a different set of threshold values. As early as 1888, Joseph Jastrow speculated that it could be due to lapses of attention, fatigue and, other psychological changes (Boring, 1950). Additionally, there are more fundamental causes of the fluctuation of threshold. There is background noise, e.g. spontaneous random activity within the observer. They are always present and should be taken into account.

Identification is specifically a process of stimulus identification. It is one of the major tasks performed by the perceptual system. The difficulty of any identification task depends, in part, on the number of possible stimulus alternatives between which the observer is asked to distinguish (Coren *op cit.*, 1994). To solve the problem of specifying the difficulty of an identification task, psychologists in the '50s turned to ideas developed by Shannon (1948). They decided that the problem of identification faced by psychologists is similar to that faced by engineers. Stimulus information is transmitted to an observer through the sensory channels, and is then decoded in the central nervous system. The degree to which the observer's identification of the stimulus corresponds to the actual stimulus input will be affected both by the ability of the sensory system to handle the stimulus input without distortion and by the complexity of the input (Coren *op cit.*, 1994). The quantitative system for specifying the characteristics of the input messages is known as *information theory*. We present information theory here as a system of measuring information.

According to Shannon, information can be defined as the reduction of uncertainty. Events which occur with high probability convey little information, since they do little to change one's knowledge of the world. Conversely, events with low probability are very informative. Formally, each set of events X_i which occur with probabilities $P(X_i)$ is said to have information content

$$I = \log_2 1/P(X_i)$$

Intuitively, the reason for the $1/P(X_i)$ is that less probable events should carry more information than more probable events. In essence, the log converts from number of events to number of bits needed to encode events.

For psychophysics, information theory is a quantitative system for measuring the difficulty of identification tasks in terms of the logarithm to the base 2 of the number of stimulus alternatives that must be distinguished.

Information transmission is the degree to which the output of an information channel (for example an observer in an identification experiment) reflects the information input to it. A generic human information channel is shown in Figure 27.

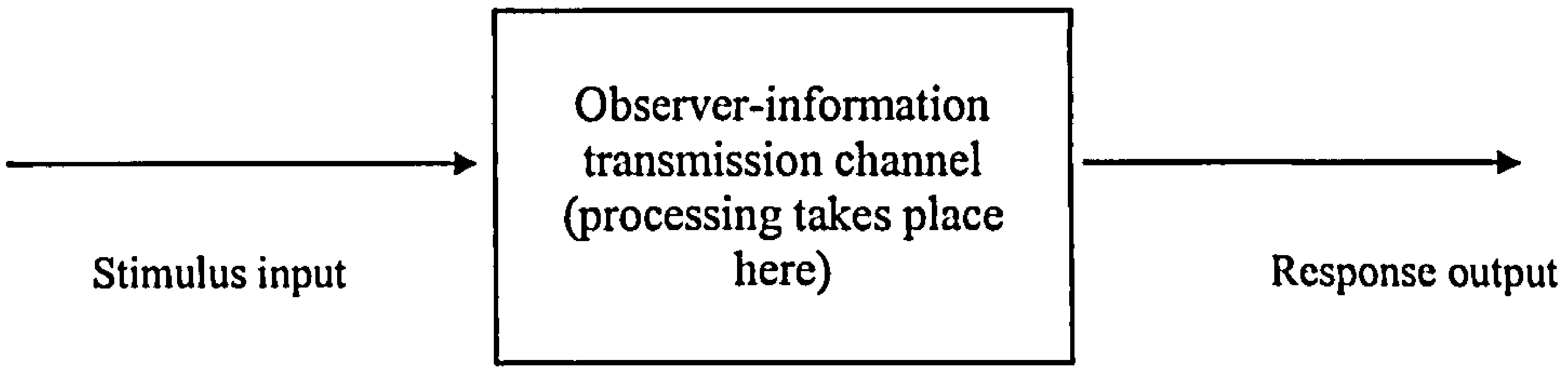


Figure 27 A human information channel.

If the response matches the stimulus perfectly for all stimuli, then the observer is a perfect information transmitter.

How many bits of stimulus information can an observer transmit perfectly? It was found from various research studies that humans can identify perfectly very small number of stimuli from a single *continuum*[22]. According to Pollack (1952) it is only 5 different tones which is 2 or 3 bits of stimulus information, and Garner (1953) found only 2,1 bits. Visual continua were measured by Eriksen and Hake in 1955. Their results were 2.34 bits for light intensity, 2.84 bits for size and 3.08 bits for wavelength. Overall, the number of stimuli that may be perfectly identified on any single continuum turns out to be the classic 7 plus or minus 2. It depends on the particular stimuli continuum being tested (Miller, 1956, quoted in Coren, Ward & Enns, op cit.). Even if we increase the amount of information available in the display, our observer will reach a limit of identification at around 2.5 bits and will not able to transmit more information.

Norwich (1981) explains that this limit is set by the response characteristics of sensory neurons and, it is the absolute limit for a single sensory continuum. Coren *et al.*, (1994), Braida *et. al.*, (1989) think that it is due to cognitive or response processes. Information theory was a very important concept in dealing with the difficult issue of identification. Sometimes methods like signal detection are used, but the fundamental underpinning theory is that of information.

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[22] *Continuum*, most generally, is any uninterrupted series of changes, any continuous, gradually changing sequence of value. Somewhat less formally it is any variable capable of being represented as a continuous series. In psychological work typically such continua are represented by polar labels; e.g., the "pleasantness" dimension runs from unpleasant to pleasant, with all intermediate points in principle existing.

Discrimination's basic question is centred on the problem of how much two stimuli must differ in order to be discriminated as not the same? Fechner, following the work of Ernst Weber (Der Tatsim und das Gemeingefühl, 1846), conducted a series of experiments where he made judgements between pairs of lifted weights. His concern was with the smallest difference which could be detected and how this varied with the absolute magnitude of the weights (Gordon, 1989). This relation between the size of the difference threshold and the magnitude of the standard is called *Weber's law*:

$$\Delta I = kI$$

where ΔI is the size of the difference threshold, I is the intensity of the standard stimulus, and k is a constant equal $\Delta I/I$. This constant is called the *Weber fraction.* The Weber fraction (usually less than 1) is a measure of overall sensitivity of the sensory system to differences along a stimulus continuum.

Signal Detection Theory in Discrimination originated in the context of detection but can also be extended to discrimination. It is based on techniques taken from Statistical Decision Making (Wald, 1950). In essence it is a theory based on the assumption that sensivity to a signal is not a merely a result of its intensity but is also dependent upon the amount of noise presented, the motivation of the subject and the criterion which the subject sets for responding. The difference in applying this theory in discrimination is that the observer does not say if the signal is present but has to, for instance, say from which two provided sources the signal comes from.

Scaling is a rule by which we assign numbers to objects or events. The scale tries to interpret numerically some property of those objects or events. The Direct Scaling Technique is associated with the work of S.S. Stevens and his colleagues (Gordon, 1989). In essence it is a procedure in which individuals are asked to assess directly the intensity of a sensation.

In the above short review of psychophysics we have tried to show how important it has been for brining scientific rigour to experimental and perceptual psychology. It introduced homogenous techniques for conducting experiments in laboratory environments. Its theories provided a lot of valuable data. It showed that experimentation is a credible and correct way of investigating the performance of the human. The methodology introduced was very simple but at the same time very effective. However, the drawback in psychophysics is the creation of the mechanistic model of the perceiver: stimuli causes responses. It has ignored the fact that sometimes the perceiver seeks stimuli in order to sample the environment and it used too simple stimuli which did not mirror those present in the real environment surrounding that same perceiver.

2. The Gestalt Theory.

The *Gestalt*[23] school of psychology was formed by Max Wertheimer (1880-1943), Kurt Koffka (1886-1941), and Wolfgang Köhler (1887-1964). They were influenced by philosophy- in particular by Emanul Kant's publication *Critique of Pure Reason* (1791). They believed in the relationship between the world and

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[23] Gestalt is a German word which has no exact English equivalent. Sometimes it is translated as form, whole, whole form, configuration, shape.

everyday experience: the world of meaningful objects and events. Their explanation was in terms of brain process.

Their main interest laid in processes causing the situation when the same elements seemed to be part of the same figure. At the same time other elements are part of another figure. Wertheimer (1923) published several laws of perception formulated by the Gestalt School. We will review some of them later. The basic idea was that any element within the pattern cannot operate independently. As Coren, Ward & Enns (1994, pp. 380) stated: "at the phenomenal level, there appear to be attractive "forces" among many elements that cause them to form a meaningful and coherent figure". They described how certain regular properties of elements within a pattern bring about the emergence of a stable figure.

Gestalt laws of organisation are centred on principles of organisation which identify the factors that lead to particular organised forms. A few of them are:

Law of closure- the shape in Figure 28 is seen as triangle although incomplete.

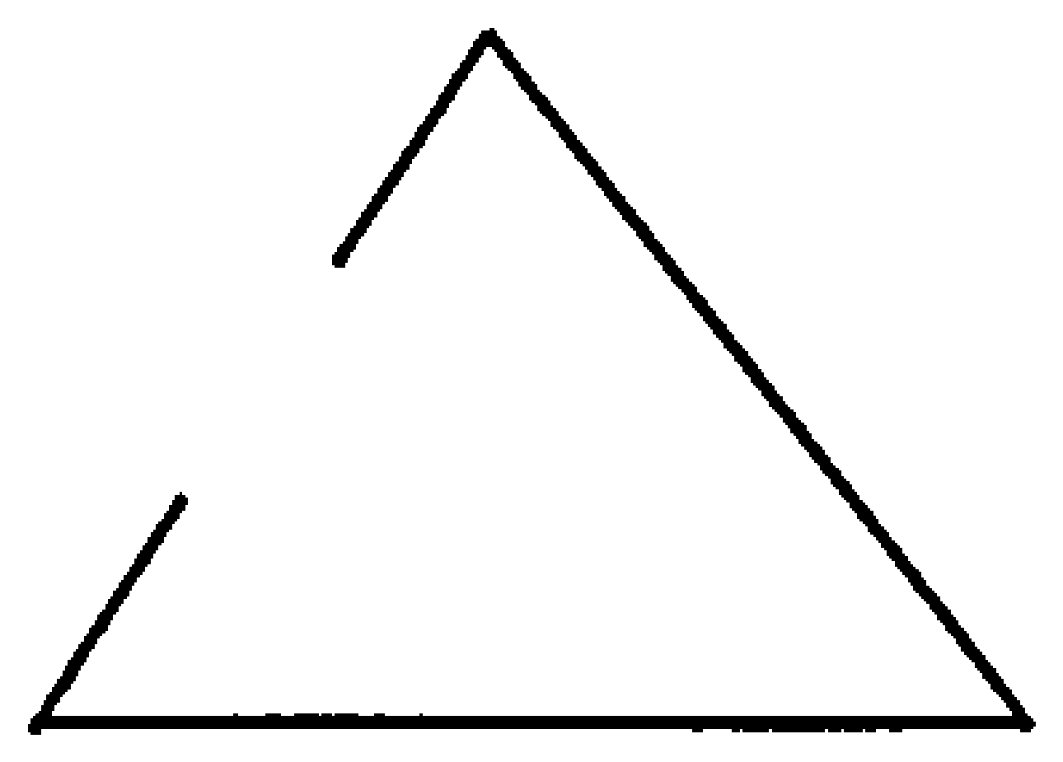


Figure 28 Closure.

Law of proximity- the pattern in Figure 29 is seen as three groups of two lines each.

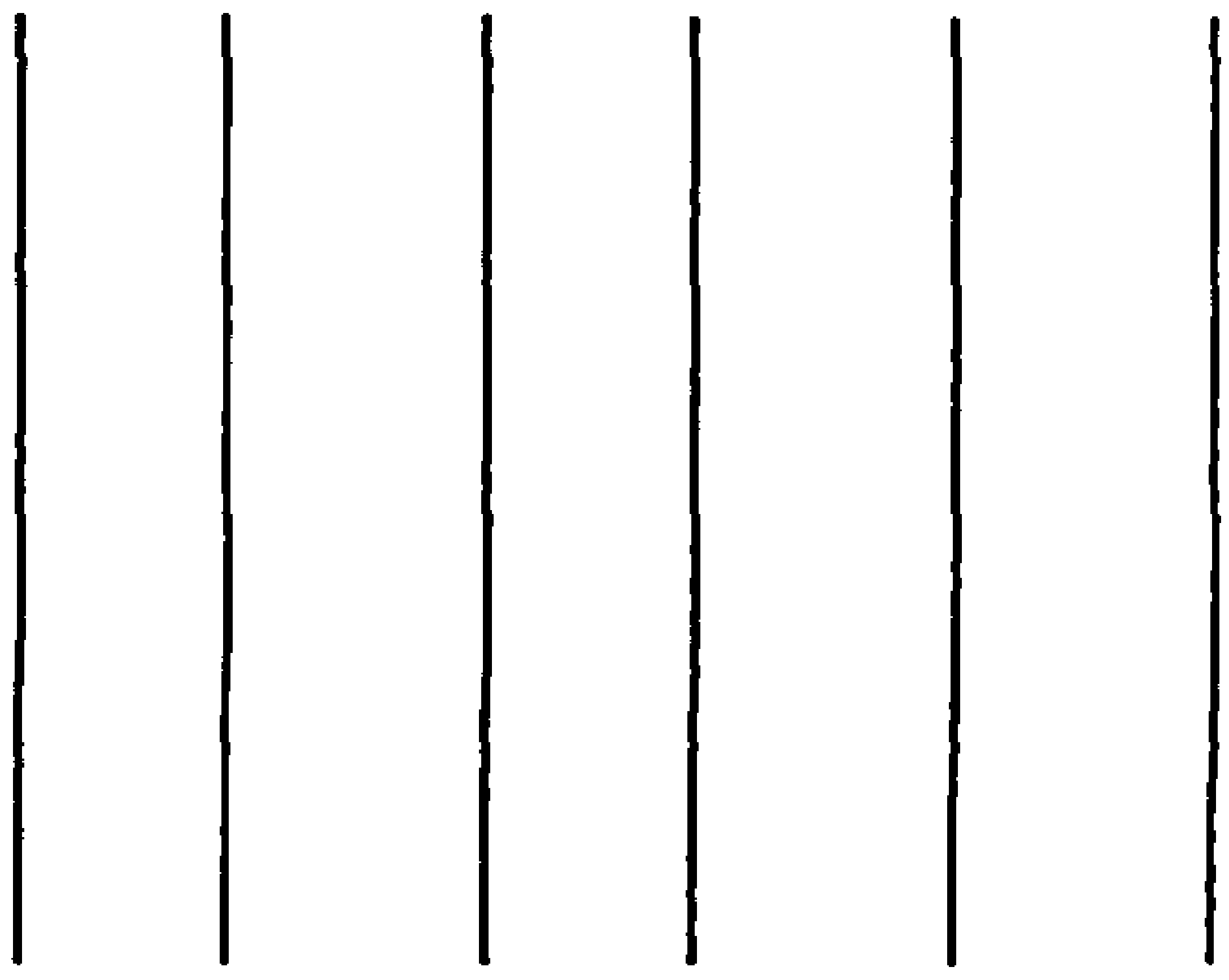


Figure 29 Proximity.

Law of continuation- the arrangement in Figure 30 is seen as a diamond between uprights not as a letter W on top of a letter M.

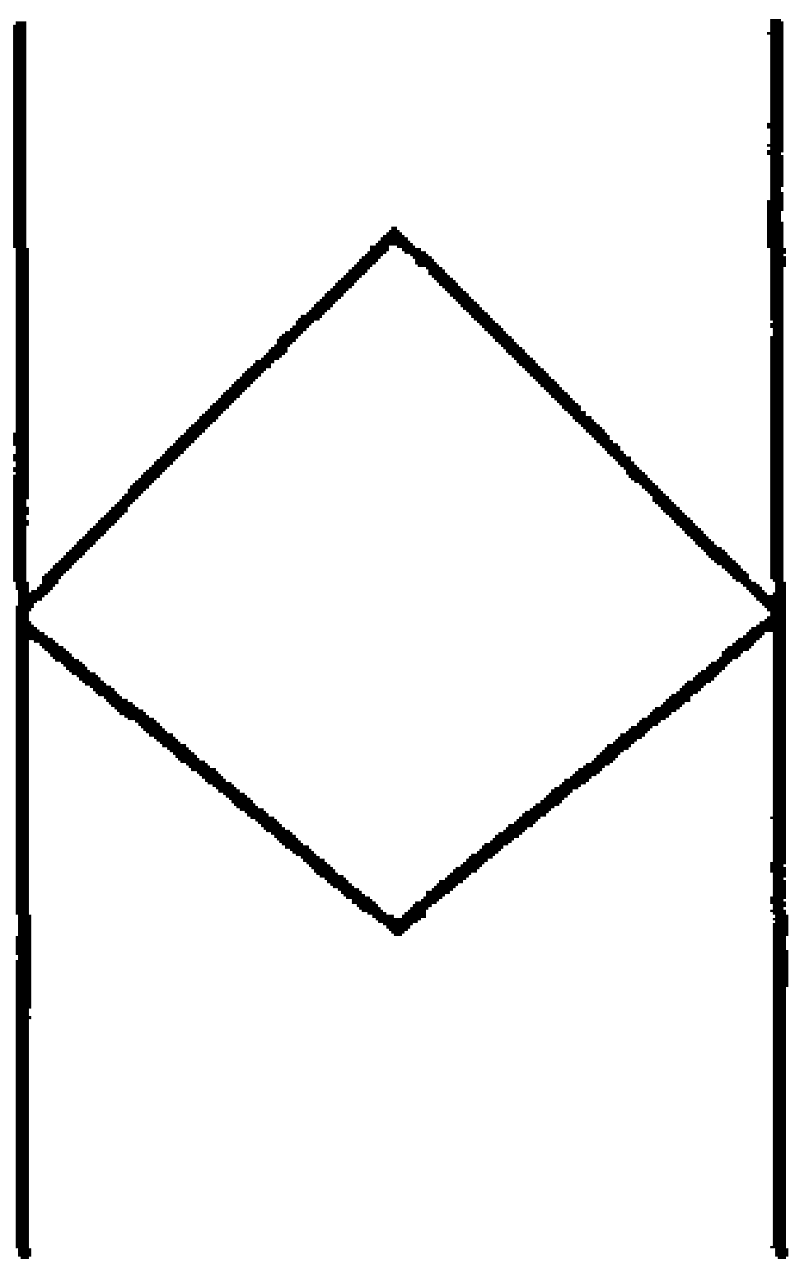


Figure 30 Continuation.

Law of similarity- the pattern in Figure 31 is seen with two columns of one kind of dot and two of another.

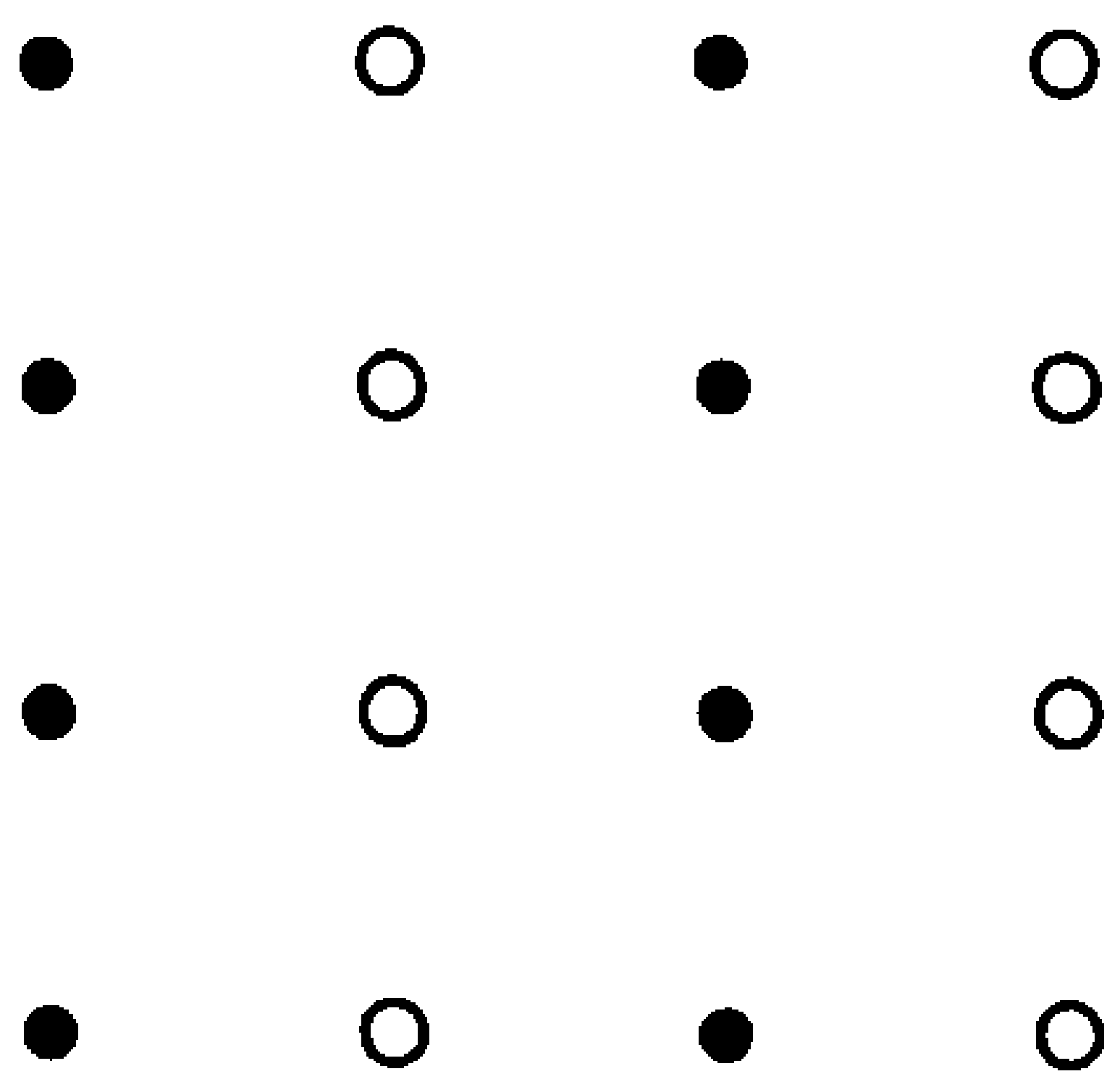


Figure 31 Similarity.

Gestalt psychologists thought that there must be one rule to support the numerous examples of organisation which they discovered. All the Gestalt laws operate to create the most stable, simple forms within a given visual array. This process was summarised by them in the *Law of Prägnanz,* which states that the organisation of the visual array into perceptual objects will always be as "good" as the prevailing conditions allow. By "good" they understand concepts such as regularity, simplicity, and symmetry. It is also a way of saying that perceptual systems produce a perceptual world which "conveys" the essence of the real world. This means that it makes sure that information about the real world is correctly interpreted (Coren, Ward & Enns, *op cit.*).

According to Gestalt psychologists, perception is a dynamic process and the perceived world is organised into patterns or configurations. They used a phenomenological approach to perception and were fascinated by geometrical illusions. They were good writers who wrote with conviction. However, the weakness of these theories lies in the naive approach to theory and explanation. Often they mistook description for explanation. They showed the scientific community that the use of strong, reliable data should always be used if we want to make any real discoveries (Gordon, *op cit.*).

3. Brunswik's Probabilistic Functionalism.

There is no school of followers for this theory. However, it was an important theory of perception.

Firstly, Brunswik was one of the first experimental psychologists who noticed that we should treat research phenomena as being as complex as possible. Before him psychologists were over-simplifying the phenomena. Secondly, he believed that if we are doing research into perceptual systems we should take into account evolution, and that systems have to have survival value. This is *functionalism.* He believed that the process of perception is a gamble. All cues coming out from the world are statistical or *probabilistic.* What we perceive is incomplete.

In essence, his theory is that perception is a process of discovering which aspects of stimulus provide the most useful or functional cues, those that produce the greatest probability of successfully reacting to the environment. He thought that, a perceiver, in order to survive, has to act as an intuitive statistician.

The above-mentioned points are important ones. It gave a new approach to deal with perceptual systems as being a living organism. Brunswik points out that we have to take into account an environment where the perceiver lives. This was later picked up by J.J. Gibson. His last book was entitled *The Ecological Approach to Visual Perception.* His theory is reviewed in this chapter.

4. The Neurophysiological approach.

Neurophysiological psychologists tried to explain the perceptual process as relating to our nervous system, how it works, the way in which the neurons interact the way they code and carry visual information, and the form in which they sent it to the higher visual pathways. All of this was possible thanks to the progress achieved in research into nervous system.

One of the very important discoveries made was the way successive neurons interact. It was observed that groups of neurons can behave in ways directly analogous to *logical gates*. As Gordon (1994) states they have the following features: 1) One neurone can excite or inhibit another, increasing or decreasing the chance that the latter will fire, 2) Logical gates are switches and can be used to build computing devices, 3) Because of the ways in which they interact, neurons can simulate logical gates, therefore neurons can do something akin to computing. This was a very important discovery in the history of neurophysiology. It also meant that neurons deal with changes. These discoveries could use Shannon's calculus (*Information Theory*): a nerve fibre fires according to an all-or-none principle and at certain rates. This transmission of discrete impulses can be viewed as a code and the rate of transmission can be assessed.

These discoveries found implications in many areas of the psychology of perception. There has been much significant research implementing neurophysiological approaches. There is well-known research into colour vision, for instance Young- Helmholtz Theory of Three Factors or Hering's Opponent Process Theory. However, as the scope of this chapter is only a brief introduction to theories of perception, we will only describe one of them. It is a work by Hubel and Wiesel (1962, 1977). For the quality of their work they received the 1981 Nobel Prize. Their work is still accepted by many physiologists as the most important in the history of neurophysiological psychology.

They were successful in recording the electrical responses of living cells in the visual cortex of the cat and the monkey to various patterns of stimulations. They used extremely fine microelectrodes to record responses. We have to stress that, at the time, this was a major achievement bearing in mind that cortical cells are microscopically small. They had to keep cells alive in order to record their responses. And the cells should not be damaged. The living organism (cat, monkey) had to be kept alive. After their trials they come out with the idea that there are orientation-specific receptive fields in the visual cortex of the cat. This means that the visual cortex of the cat contains cells which respond differentially to lines and edges according to the orientation of these stimuli. It suggests that the visual system analyses visual inputs into specific components, and that the mechanism which does this is connected into the nervous system. They seemed to solve an important problem in pattern perception- detection of features. Of course, they could not repeat their research on human beings because of the obvious ethical reasons.

Subsequent research discovered that visual systems convey information about spatial frequencies in tuned channels. We will return to this theory in the next sub-chapter.

To sum up the neurophysiological approach, we can state that the basic nature of vision can be described as follows; it begins with a series of analyses in which aspects of visual images are converted into neural codes. These analyses are independent. There are different mechanisms for coding colour than for coding spatial frequencies, for instance. Then neural analyses is followed by some kind of neural synthesis, and here there is much more uncertainty concerning possible mechanisms. It is suspected that it is somewhere later in position in the chain of visual processing, and must lie deeper in the central nervous system (Gordon, *op cit.*). However, it is going to be harder to find.

To conclude, we would like to stress that it is not a general theory of perception as it is deals only with some issues. Despite this it is a very interesting approach to visual perception which has many devoted believers. Some of the experiences carried out in the sixties or seventies cannot be repeated in the UK (at least) because of ethical reasons and animal rights issues.

5 The computational approach.

The computational approach to the psychology of visual perception has its roots in Artificial Intelligence. The theory was created by David Marr and described in his papers and posthumously published book *Vision* in 1982. He utilised ideas of Information Theory, Cybernetics and Computing as well as the neurophysiological approach to vision.

Marr stated that if people want to understand the process of visual perception they have to specify three different levels of theory. One should first formulate a *computational theory*, which has to describe what is being computed and why. Next, we have to define *algorithms* for achieving computation, and the *representations* which form the input to and output from these algorithms. Finally, we should describe the *implementation* of the algorithm. His theory is that vision is organised as an information-processing system and this system comprises some generic stages (Figure 32). For him the main role of vision was to derive a representation of shape. Brightness, colour, texture are secondary characteristics of the objects. His idea was to implement a computer model to deal with representation and problems.

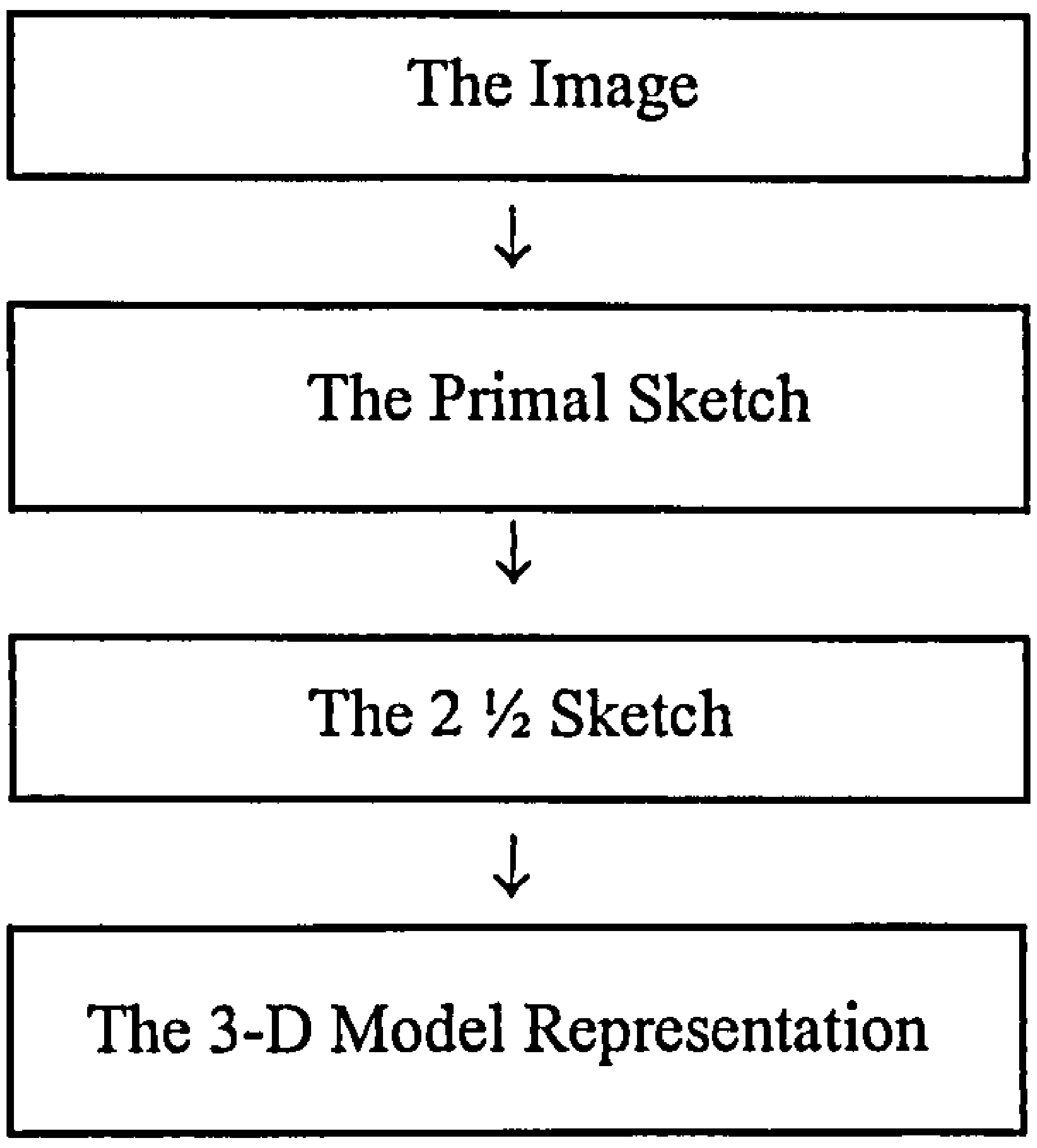


Figure 32 The stages of visual perception.

The *image* is the starting point of the process of seeing and represents a spatial distribution of intensity values across the retina. During the *primal sketch* stage the raw intensity values are transformed into certain forms. The information contained within the transformation is concerned with the spatial or geometrical distribution of intensity changes and the way they are organised. The *2 ½ sketch* is the phase when orientation and rough depth of visible surfaces are made explicit. The emerging picture is organised with reference to the viewer. It is not linked to the external environment. The final stage is the *3-D model representation* when shapes and their orientation become detectable and organised in an object-centred framework. It is independent of particular positions and orientations on the retina. By now, the perceiver has obtained a model of the external world.

Marr's theory of perception attracted many followers but some critics as well. The main point of criticism was that it is not possible to use computer models as bases of human perception. The computer is not equal to human. Humans are able to solve many problems and perception involves problem solving. If a computer is able to solve any problem it is thanks to the programmer who had solved the problem before putting the program into the computer. In the process of perception humans are able to distinguish between what is and is not important to the solution. Dreyfus (1972) believes that one should be very careful in accepting the computational approach towards human perception. However, some ideas recently appeared which could support Marr's theory. For instance, *Parallel Distributed Processing* (PDP). In essence, the PDP model consists of small units joined together in a complex network and interacting according to rules of weighting which vary the strengths of their connections. In other words, it is a system using simple components which can perform very complicated tasks, providing that these components are allowed to compete and interact. Might this be the way the brain utilises and organises its simple components? (Gordon, 1989).

The ideas introduced by Marr are very powerful. Particularly important is the explanation of different levels of processes of perception, mentioned above. His theory is very rigorous. To assess whether an idea actually works when compiled within a computer program is a powerful check against vagueness and imprecision.

6. Ecological approach to visual perception.

The ecological approach to visual space perception evolved over a 35-year period by J.J. Gibson.

His theory rejected the behaviouristic, neurological and "physical" approaches to visual perception. He believed that, "Ever since Descartes, psychology has been held back by the doctrine that what we have to perceive is the "physical" world that is described by physics. I am suggesting that what we have to perceive and cope with is the world considered as the environment" (Gibson, 1979). He stated that people should move their attention to perception of surfaces in the environment. Every surface is made up of texture elements. The environment is made of a collection of texture surfaces and edges which are themselves immersed in a medium (air) (Bruce and Green, 1995).

Because every surface has its own structure, the light reflected from these surfaces structure the light reaching the observer. Gibson argues that, thanks to the light structure, we are able to perceive the environment because the light carries information about this environment. He calls this process the entire *optic array.* The spatial pattern of light is a mixture of wavelengths and intensity of light. To be able to describe this pattern we need an ecological optics (Gibson, 1961).

Gibson does not believe that the retinal image is a starting point of visual perception. He claims that the total array of light beams reaching an observer, after structuring, provides all needed information about the environment and the movement of the observer. An observer actively samples the dynamic optic array. He claims that movement is essential for seeing. When the observer moves in any way in the world this locomotion will always be accompanied by flow in the optic array. The nature of optic flow patterns is specific to certain types of movement. Variants in information are produced by movement of the observer and the motion of objects in the world. For him "... perceiving is an act, not a response, an act of attention, not a triggered impression, an achievement not a reflex" (Gibson, 1979).

Latter in his life Gibson coined the concept of *affordance*, which stresses the importance of relationship between perceiver and environment. The environment has invariant information, the detection of which has survival value. In essence, affordance of some surface or object in the environment is what is "offered" to humans or animals- whether it can be eaten, trodden on or sat upon (Bruce and Green, 1995). It is clear that affordance is the meanings that an environment has for animals or humans. Gibson's approach to affordance is a very bold one. He believed that the abstract properties of things and objects could be perceived directly, without prior synthesis or analysis. Properties of objects which reveal that they are, for instance, graspable are perceived directly from the patterns of reflecting light.

In this section were outlined some of the main ideas introduced by Gibson into the psychology of perception. In his relatively new approach the emphasis is placed upon the study of the environment and its richness of light received by the eye of an active perceiver. He has reminded people that human is one of many perceiving animals.

Some of the weaknesses are that ecological psychologists have ignored some of the problems of visual perception (e.g. memory), as well as underestimating the achievements of psychologists in the rival experimental tradition.

Finally, we would like to quote Emanuel Kant who noticed back in the eighteenth century how difficult it is to understand some of the phenomena in our life. He wrote in his book (1787) that "The schematism by which our understanding deals with the phenomenal world... is a skill so deeply hidden in the human soul that we shall hardly guess the secret trick that Nature here employs.".

Appendix C. Estimates and Relative Error.

Room A

Subject		WIDTH	LENGTH	HEIGHT
1	Estimate	1.20	9.00	3.00
	Actual	1.50	9.00	2.50
	Relative Error	**-0.20**	**0.00**	**0.20**
2	Estimate	1.20	7.00	2.40
	Actual	1.50	9.00	2.50
	Relative Error	**-0.20**	**-0.22**	**-0.04**
3	Estimate	1.20	10.00	2.30
	Actual	1.50	9.00	2.50
	Relative Error	**-0.20**	**0.11**	**-0.08**
4	Estimate	2.00	7.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**0.33**	**-0.22**	**0.00**
5	Estimate	1.50	8.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**-0.11**	**0.00**
6	Estimate	1.00	5.00	2.30
	Actual	1.50	9.00	2.50
	Relative Error	**-0.33**	**-0.44**	**-0.08**
7	Estimate	1.50	8.00	3.00
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**-0.11**	**0.20**
8	Estimate	1.50	12.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**0.33**	**0.00**
9	Estimate	1.00	5.00	3.50
	Actual	1.50	9.00	2.50
	Relative Error	**-0.33**	**-0.44**	**0.40**
10	Estimate	1.50	9.00	2.30
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**0.00**	**-0.08**
11	Estimate	2.00	8.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**0.33**	**-0.11**	**0.00**
12	Estimate	1.50	8.00	2.40
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**-0.11**	**-0.04**
13	Estimate	2.00	9.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**0.33**	**0.00**	**0.00**
14	Estimate	2.00	9.00	2.30
	Actual	1.50	9.00	2.50
	Relative Error	**0.33**	**0.00**	**-0.08**
15	Estimate	1.20	10.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**-0.20**	**0.11**	**0.00**
16	Estimate	1.50	10.00	2.30
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**0.11**	**-0.08**
17	Estimate	1.50	7.00	2.30
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**-0.22**	**-0.08**
18	Estimate	1.50	8.00	2.40
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**-0.11**	**-0.04**
19	Estimate	2.00	9.00	2.30
	Actual	1.50	9.00	2.50
	Relative Error	**0.33**	**0.00**	**-0.08**
20	Estimate	2.00	9.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**0.33**	**0.00**	**0.00**
	Mean Relative Error	**-0.05**	**0.00**	**0.00**

Subject		WIDTH	LENGTH	HEIGHT
1	Estimate	1.40	7.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**-0.06**	**-0.22**	**0.00**
2	Estimate	1.00	5.00	2.60
	Actual	1.50	9.00	2.50
	Relative Error	**-0.33**	**-0.44**	**0.04**
3	Estimate	1.50	6.00	2.90
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**-0.33**	**0.16**
4	Estimate	1.00	6.00	3.00
	Actual	1.50	9.00	2.50
	Relative Error	**-0.33**	**-0.33**	**0.20**
5	Estimate	1.00	8.00	3.00
	Actual	1.50	9.00	2.50
	Relative Error	**-0.33**	**-0.11**	**0.20**
6	Estimate	1.30	9.00	3.00
	Actual	1.50	9.00	2.50
	Relative Error	**-0.13**	**0.00**	**0.20**
7	Estimate	1.50	6.00	2.60
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**-0.33**	**0.04**
8	Estimate	1.50	8.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**-0.11**	**0.00**
9	Estimate	1.00	9.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**-0.33**	**0.00**	**0.00**
10	Estimate	1.20	5.00	2.60
	Actual	1.50	9.00	2.50
	Relative Error	**-0.20**	**-0.44**	**0.04**
11	Estimate	1.20	7.00	2.30
	Actual	1.50	9.00	2.50
	Relative Error	**-0.20**	**-0.22**	**-0.08**
12	Estimate	1.20	7.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**-0.20**	**-0.22**	**0.00**
13	Estimate	1.50	8.00	2.50
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**-0.11**	**0.00**
14	Estimate	1.20	7.00	3.00
	Actual	1.50	9.00	2.50
	Relative Error	**-0.20**	**-0.22**	**0.20**
15	Estimate	1.20	7.00	3.00
	Actual	1.50	9.00	2.50
	Relative Error	**-0.20**	**-0.22**	**0.20**
16	Estimate	1.50	9.00	2.60
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**0.00**	**0.04**
17	Estimate	1.30	7.00	2.80
	Actual	1.50	9.00	2.50
	Relative Error	**-0.13**	**-0.22**	**0.12**
18	Estimate	1.50	7.00	2.30
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**-0.22**	**-0.08**
19	Estimate	1.50	7.00	2.30
	Actual	1.50	9.00	2.50
	Relative Error	**0.00**	**-0.22**	**-0.08**
20	Estimate	1.90	7.00	2.00
	Actual	1.50	9.00	2.50
	Relative Error	**0.27**	**-0.22**	**-0.20**
	Mean Relative Error	-0.12	0.24	0.05

Subject		WIDTH	LENGTH	HEIGHT
1	Estimate	8.00	15.00	2.70
	Actual	8.00	16.00	2.50
	Relative Error	**0.00**	**-0.06**	**0.08**
2	Estimate	10.00	15.00	2.40
	Actual	8.00	16.00	2.50
	Relative Error	**0.25**	**-0.06**	**-0.04**
3	Estimate	5.00	16.00	2.30
	Actual	8.00	16.00	2.50
	Relative Error	**-0.37**	**0.00**	**-0.08**
4	Estimate	7.00	10.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**-0.12**	**-0.37**	**0.00**
5	Estimate	8.00	16.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**0.00**	**0.00**	**0.00**
6	Estimate	10.00	16.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**0.25**	**0.00**	**0.00**
7	Estimate	10.00	15.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**0.25**	**-0.06**	**0.00**
8	Estimate	9.00	15.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**0.13**	**-0.06**	**0.00**
9	Estimate	10.00	14.00	2.20
	Actual	8.00	16.00	2.50
	Relative Error	**0.25**	**-0.12**	**-0.12**
10	Estimate	10.00	16.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**0.25**	**0.00**	**0.00**
11	Estimate	10.00	16.00	2.40
	Actual	8.00	16.00	2.50
	Relative Error	**0.25**	**0.00**	**-0.04**
12	Estimate	11.00	14.00	2.30
	Actual	8.00	16.00	2.50
	Relative Error	**0.38**	**-0.12**	**-0.08**
13	Estimate	10.00	18.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**0.25**	**0.13**	**0.00**
14	Estimate	10.00	16.00	2.40
	Actual	8.00	16.00	2.50
	Relative Error	**0.25**	**0.00**	**-0.04**
15	Estimate	12.00	16.00	2.30
	Actual	8.00	16.00	2.50
	Relative Error	**1.50**	**0.00**	**-0.08**
16	Estimate	6.00	9.00	2.20
	Actual	8.00	16.00	2.50
	Relative Error	**-0.25**	**-0.43**	**-0.12**
17	Estimate	10.00	10.00	2.00
	Actual	8.00	16.00	2.50
	Relative Error	**0.25**	**-0.37**	**-0.20**
18	Estimate	10.00	16.00	2.40
	Actual	8.00	16.00	2.50
	Relative Error	**5**	**0.00**	**-0.04**
19	Estimate	7.00	16.00	2.10
	Actual	8.00	16.00	2.50
	Relative Error	**-0.12**	**0.00**	**-0.16**
20	Estimate	7.00	16.00	2.30
	Actual	8.00	16.00	2.50
	Relative Error	**-0.12**	**0.00**	**-0.08**
Mean Relative Error		**-0.04**	**0.13**	**-0.04**

Subject		WIDTH	LENGTH	HEIGHT
1	Estimate	5.00	10.00	2.60
	Actual	8.00	16.00	2.50
	Relative Error	**-0.37**	**-0.37**	**0.04**
2	Estimate	11.00	14.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**0.38**	**-0.12**	**0.00**
3	Estimate	7.00	20.00	2.60
	Actual	8.00	16.00	2.50
	Relative Error	**-0.12**	**0.25**	**0.04**
4	Estimate	8.00	15.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**0.00**	**-0.06**	**0.00**
5	Estimate	5.00	20.00	2.60
	Actual	8.00	16.00	2.50
	Relative Error	**-0.37**	**0.25**	**0.04**
6	Estimate	11.00	16.00	2.00
	Actual	8.00	16.00	2.50
	Relative Error	**0.38**	**0.00**	**-0.20**
7	Estimate	6.00	20.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**-0.25**	**0.25**	**0.00**
8	Estimate	6.00	15.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**-0.25**	**-0.06**	**0.00**
9	Estimate	6.00	14.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**-0.25**	**-0.12**	**0.00**
10	Estimate	4.00	18.00	3.00
	Actual	8.00	16.00	2.50
	Relative Error	**-0.50**	**0.13**	**0.20**
11	Estimate	8.00	15.00	3.00
	Actual	8.00	16.00	2.50
	Relative Error	**0.00**	**-0.06**	**0.20**
12	Estimate	9.00	10.00	2.40
	Actual	8.00	16.00	2.50
	Relative Error	**0.13**	**-0.37**	**-0.04**
13	Estimate	5.00	10.00	2.40
	Actual	8.00	16.00	2.50
	Relative Error	**-0.37**	**-0.37**	**-0.04**
14	Estimate	4.00	16.00	2.90
	Actual	8.00	16.00	2.50
	Relative Error	**-0.50**	**0.00**	**0.16**
15	Estimate	5.00	18.00	3.00
	Actual	8.00	16.00	2.50
	Relative Error	**-0.37**	**0.13**	**0.20**
16	Estimate	5.00	10.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**-0.37**	**-0.37**	**0.00**
17	Estimate	9.00	15.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**0.13**	**-0.06**	**0.00**
18	Estimate	6.00	20.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**-0.25**	**0.25**	**0.00**
19	Estimate	7.00	16.00	2.40
	Actual	8.00	16.00	2.50
	Relative Error	**-0.12**	**0.00**	**-0.04**
20	Estimate	5.00	10.00	2.50
	Actual	8.00	16.00	2.50
	Relative Error	**-0.37**	**-0.37**	**0.00**
		17.38	21.31	20.80
	Mean Relative Error	**-0.17**	**-0.05**	**0.03**

Room D

Subject		WIDTH	LENGTH	HEIGHT
1	Estimate	5.00	9.00	2.70
	Actual	6.00	9.00	2.50
	Relative Error	**-0.17**	**0.00**	**0.08**
2	Estimate	5.00	10.00	2.40
	Actual	6.00	9.00	2.50
	Relative Error	**-0.17**	**0.11**	**-0.04**
3	Estimate	7.00	10.00	2.30
	Actual	6.00	9.00	2.50
	Relative Error	**0.17**	**0.11**	**-0.08**
4	Estimate	8.00	9.00	2.50
	Actual	6.00	9.00	2.50
	Relative Error	**0.33**	**0.00**	**0.00**
5	Estimate	7.00	10.00	2.80
	Actual	6.00	9.00	2.50
	Relative Error	**0.17**	**0.11**	**0.12**
6	Estimate	6.00	5.00	2.30
	Actual	6.00	9.00	2.50
	Relative Error	**0.00**	**-0.44**	**-0.08**
7	Estimate	5.00	7.00	2.50
	Actual	6.00	9.00	2.50
	Relative Error	**-0.17**	**-0.22**	**0.00**
8	Estimate	5.00	10.00	2.50
	Actual	6.00	9.00	2.50
	Relative Error	**-0.17**	**0.11**	**0.00**
9	Estimate	5.00	6.00	3.50
	Actual	6.00	9.00	2.50
	Relative Error	**-0.17**	**-0.33**	**0.40**
10	Estimate	6.00	9.00	2.30
	Actual	6.00	9.00	2.50
	Relative Error	**0.00**	**0.00**	**-0.08**
11	Estimate	6.00	9.00	2.40
	Actual	6.00	9.00	2.50
	Relative Error	**0.00**	**0.00**	**-0.04**
12	Estimate	7.00	9.00	2.40
	Actual	6.00	9.00	2.50
	Relative Error	**0.17**	**0.00**	**-0.04**
13	Estimate	6.00	9.00	2.40
	Actual	6.00	9.00	2.50
	Relative Error	**0.00**	**0.00**	**-0.04**
14	Estimate	6.00	10.00	2.40
	Actual	6.00	9.00	2.50
	Relative Error	**0.00**	**0.11**	**-0.04**
15	Estimate	7.00	7.00	2.30
	Actual	6.00	9.00	2.50
	Relative Error	**0.17**	**-0.22**	**-0.08**
16	Estimate	5.00	7.00	2.40
	Actual	6.00	9.00	2.50
	Relative Error	**-0.17**	**-0.22**	**-0.04**
17	Estimate	5.00	9.00	2.30
	Actual	6.00	9.00	2.50
	Relative Error	**-0.17**	**0.00**	**-0.08**
18	Estimate	6.00	9.00	2.30
	Actual	6.00	9.00	2.50
	Relative Error	**0.00**	**0.00**	**-0.08**
19	Estimate	5.00	8.00	2.50
	Actual	6.00	9.00	2.50
	Relative Error	**-0.17**	**-0.11**	**0.00**
20	Estimate	5.00	7.00	2.50
	Actual	6.00	9.00	2.50
	Relative Error	**-0.17**	**-0.22**	**0.00**
Mean Relative Error		**-0.03**	**-0.06**	**-0.02**

Subject		LENGTH	HEIGHT	WIDTH
1	Estimate	6.00	2.60	4.50
	Actual	9.00	2.50	6.00
	Relative Error	**-0.33**	**0.04**	**-0.25**
2	Estimate	8.00	2.00	10.00
	Actual	9.00	2.50	6.00
	Relative Error	**-0.11**	**-0.20**	**0.67**
3	Estimate	9.00	3.00	5.00
	Actual	9.00	2.50	6.00
	Relative Error	**0.00**	**0.20**	**-0.17**
4	Estimate	9.00	2.60	8.00
	Actual	9.00	2.50	6.00
	Relative Error	**0.00**	**0.04**	**0.33**
5	Estimate	10.00	3.00	6.00
	Actual	9.00	2.50	6.00
	Relative Error	**0.11**	**0.20**	**0.00**
6	Estimate	9.00	2.50	5.00
	Actual	9.00	2.50	6.00
	Relative Error	**0.00**	**0.00**	**-0.17**
7	Estimate	10.00	2.90	5.00
	Actual	9.00	2.50	6.00
	Relative Error	**0.11**	**0.16**	**-0.17**
8	Estimate	6.00	2.30	6.00
	Actual	9.00	2.50	6.00
	Relative Error	**-0.33**	**-0.08**	**0.00**
9	Estimate	6.00	2.50	7.00
	Actual	9.00	2.50	6.00
	Relative Error	**-0.33**	**0.00**	**0.17**
10	Estimate	10.00	2.80	9.00
	Actual	9.00	2.50	6.00
	Relative Error	**0.11**	**0.12**	**1.50**
11	Estimate	5.00	2.00	3.00
	Actual	9.00	2.50	6.00
	Relative Error	**-0.44**	**-0.20**	**-0.05**
12	Estimate	8.00	2.90	5.00
	Actual	9.00	2.50	6.00
	Relative Error	**-0.11**	**0.16**	**-0.17**
13	Estimate	9.00	2.60	7.00
	Actual	9.00	2.50	6.00
	Relative Error	**0.00**	**0.04**	**0.17**
14	Estimate	5.00	2.00	5.00
	Actual	9.00	2.50	6.00
	Relative Error	**-0.44**	**-0.20**	**-0.16**
15	Estimate	8.00	2.60	7.00
	Actual	9.00	2.50	6.00
	Relative Error	**-0.11**	**0.04**	**0.17**
16	Estimate	10.00	2.10	3.00
	Actual	9.00	2.50	6.00
	Relative Error	**0.11**	**-0.16**	**-0.50**
17	Estimate	7.00	2.50	7.00
	Actual	9.00	2.50	6.00
	Relative Error	**-0.22**	**0.00**	**0.17**
18	Estimate	10.00	2.00	5.00
	Actual	9.00	2.50	6.00
	Relative Error	**0.11**	**-0.20**	**-0.17**
19	Estimate	10.00	2.00	6.00
	Actual	9.00	2.50	6.00
	Relative Error	**0.11**	**-0.20**	**0.00**
20	Estimate	9.00	2.50	6.00
	Actual	9.00	2.50	6.00
	Relative Error	**0.00**	**0.00**	**0.00**
Mean Relative Error		-0.09	-0.1	0.00

Appendix D. Confidence Results Experiment 1.

Participant	RWS	Participant	VS
1	4.00	1	5.00
2	2.00	2	4.00
3	1.00	3	4.00
4	5.00	4	5.00
5	1.00	5	1.00
6	3.00	6	2.00
7	3.00	7	1.00
8	2.00	8	1.00
9	5.00	9	1.00
10	1.00	10	1.00
11	1.00	11	2.00
12	1.00	12	2.00
13	2.00	13	3.00
14	2.00	14	2.00
15	1.00	15	2.00
16	1.00	16	1.00
17	1.00	17	1.00
18	2.00	18	5.00
19	2.00	19	3.00
20	1.00	20	2.00
TOTAL	**41.00**		**48.00**
MEAN	**2.05**		**2.4**

Independent Samples t Test

	t	df	Sig (2-tailed)	Mean Difference	Std. Error Difference
Equal variance assumed	-.794	38	.432	-.3500	.4405
Equal variance not assumed	-.794	37.57	. 432	-.3500	.4405

Test Statistics

Mann-Whitney U	172.500
Wilcoxon W	382.500
Z	-.781
Asymp. Sig. (2-tailed)	.435
Exact Sig. [2*(1-tailed Sig.)]	.461

Appendix E- **Questionnaire- Experiment 2.**

Methodology for Assessment of Cognitive Skills in Virtual Environments. Experiment 2

All data will be treated confidentially

1. Profession/Occupation ....

2. Age (circle one)

   Under 25 26-35 36-45 46-55 56-65

3. Gender (circle one) Male Female

4. How difficult were estimation tasks- (circle one)

Difficult					**Easy**
1	2	3	4	5	6

5. How confident were you during performing estimation tasks within 50 centimetres. (circle one)

Total Guess					**Highly confident**
1	2	3	4	5	6

6. Please list up to three things which most annoyed you about presentation and interfered with your ability to estimate lengths and heights.

   1...

   2...

   3...

7. Please list up to three things which would make your estimation of lengths and heights easier/better.

   1...

   2...

   3...

This is the end of the study. <u>Thank you very much for your participation.</u>

Appendix F. Estimates and Relative Error- Experiment 2 VS

Subject		1.5m h	2.0m h	2.5m h	1.5m v	2.0m v	2.5m v
1	Estimate	1.20	1.50	1.50	1.20	1.80	2.10
	Actual	1.50	2.00	2.50	1.50	2.00	2.5
	Relative Error	**-0.20**	**-0.25**	**-0.40**	**-0.20**	**-0.01**	**-0.16**
2	Estimate	3.00	3.5	4.00	3.00	4.00	4.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**1.00**	**0.75**	**0.60**	**1.00**	**1.00**	**0.60**
3	Estimate	1.00	1.50	1.75	1.50	1.75	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.25**	**-0.30**	**0.00**	**-0.12**	**-0.20**
4	Estimate	0.02	0.04	0.06	0.50	1.20	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.98**	**-0.98**	**0.97**	**-0.66**	**-0.40**	**-0.20**
5	Estimate	1.00	1.70	2.50	2.00	3.50	4.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.15**	**0.00**	**0.20**	**0.75**	**0.60**
6	Estimate	0.60	1.20	1.50	0.60	0.90	1.20
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.60**	**-0.40**	**-0.40**	**-0.60**	**-0.55**	**-0.52**
7	Estimate	1.00	1.53	1.5	1.00	1.33	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.23**	**-0.40**	**-0.33**	**-0.33**	**-0.20**
8	Estimate	1.00	3.00	2.50	3.00	3.00	5.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**0.50**	**0.00**	**1.00**	**0.50**	**1.00**
9	Estimate	1.00	1.50	2.20	1.50	2.10	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.25**	**-0.12**	**0.00**	**0.05**	**-0.20**
10	Estimate	1.20	1.80	2.50	1.40	2.00	2.20
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.20**	**-0.10**	**0.00**	**-0.06**	**0.00**	**-0.12**
11	Estimate	4.00	5.00	2.00	1.50	2.00	2.50
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**1.66**	**1.50**	**-0.20**	**0.00**	**0.00**	**0.00**
12	Estimate	2.00	1.50	1.75	1.25	1.50	2.75
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**0.33**	**-0.25**	**-.030**	**-0.16**	**-0.25**	**0.10**
13	Estimate	2.00	3.00	6.00	4.00	5.00	4.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**0.33**	**0.50**	**1.40**	**1.66**	**1.5**	**0.60**
14	Estimate	0.30	0.60	0.90	0.60	0.90	1.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.80**	**-0.70**	**-0.64**	**-0.60**	**-0.55**	**-0.6**
15	Estimate	0.90	1.30	1.82	0.90	1.30	1.40
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.40**	**-0.35**	**-0.27**	**-0.40**	**-0.35**	**-0.44**
16	Estimate	1.20	1.70	2.10	1.20	1.50	2.40
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.20**	**-0.15**	**-0.16**	**-0.20**	**-0.25**	**-0.04**
17	Estimate	1.50	1.80	2.20	1.00	2.00	2.50
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**0.00**	**-0.15**	**-0.16**	**-0.20**	**-0.25**	**-0.04**
18	Estimate	1.00	1.50	2.00	1.00	1.50	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.25**	**-0.20**	**-0.33**	**-0.25**	**-0.20**
19	Estimate	1.00	1.80	2.00	1.00	2.00	2.40
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.10**	**-0.20**	**-0.33**	**0.00**	**-0.04**
20	Estimate	1.00	1.50	1.80	1.20	1.50	1.80
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.25**	**-0.28**	**-0.20**	**-0.25**	**-0.28**
	Mean Relative Error	**-0.06**	**-0.01**	**0.00**	**0.7**	**0.11**	**0.1**

Subject		1.5m h	2.0m h	2.5m h	1.5m v	2.0m v	2.5m v
1	Estimate	1.00	1.70	2.00	1.00	1.80	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.15**	**-0.20**	**-0.33**	**-0.10**	**-0.20**
2	Estimate	1.20	2.00	2.20	0.90	1.70	2.10
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.20**	**0.00**	**-0.12**	**-0.40**	**-0.15**	**-0.16**
3	Estimate	1.10	1.50	2.00	1.10	1.90	2.20
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.26**	**-0.25**	**-0.20**	**-0.26**	**-0.05**	**-0.12**
4	Estimate	1.00	1.50	2.00	1.10	2.00	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.25**	**-0.20**	**-0.26**	**0.00**	**-0.20**
5	Estimate	0.90	1.50	2.50	1.20	1.80	1.90
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.44**	**-0.25**	**0.00**	**-0.20**	**-0.10**	**-0.24**
6	Estimate	1.20	1.70	2.00	1.30	2.00	2.20
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.20**	**-0.15**	**-0.20**	**-0.13**	**0.00**	**-0.12**
7	Estimate	1.00	2.00	1.80	1.30	1.70	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**0.00**	**-0.28**	**-0.13**	**-0.15**	**-0.20**
8	Estimate	1.20	2.00	1.90	1.00	1.50	2.10
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.20**	**0.00**	**-0.24**	**-0.33**	**-0.25**	**-0.16**
9	Estimate	1.00	1.80	1.50	1.00	1.80	1.80
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.10**	**-0.4**	**-0.33**	**-0.10**	**-0.28**
10	Estimate	1.50	1.70	1.80	1.00	1.80	1.85
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	0.00	-0.15	-0.28	-0.33	-0.10	-0.26
11	Estimate	1.50	2.00	2.00	1.30	2.00	1.90
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**0.00**	**0.00**	**-0.20**	**-0.13**	**0.00**	**-0.24**
12	Estimate	1.00	1.70	2.50	1.50	2.50	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.15**	**0.00**	**0.00**	**0.25**	**-0.20**
13	Estimate	1.00	1.80	2.00	1.20	2.00	2.50
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.10**	**-0.20**	**-0.20**	**0.00**	**0.00**
14	Estimate	1.30	1.50	1.80	1.00	1.80	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.13**	**-0.25**	**-0.28**	**-0.33**	**-0.10**	**-0.20**
15	Estimate	1.00	1.80	1.80	1.50	1.80	2.20
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.10**	**-0.28**	**0.00**	**-0.10**	**-0.12**
16	Estimate	1.50	1.70	1.50	1.50	1.70	2.50
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**0.00**	**-0.15**	**-0.40**	**0.00**	**-0.15**	**0.00**
17	Estimate	0.90	1.50	1.70	1.00	1.80	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.40**	**-0.25**	**-0.32**	**-0.33**	**-0.10**	**-0.20**
18	Estimate	1.00	1.50	1.70	1.00	1.70	2.30
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.25**	**-0.32**	**-0.33**	**-0.15**	**-0.08**
19	Estimate	1.00	1.80	1.90	1.20	2.00	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.10**	**-0.24**	**-0.20**	**0.00**	**-0.20**
20	Estimate	1.00	1.90	2.00	1.00	1.60	2.00
	Actual	1.50	2.00	2.50	1.50	2.00	2.50
	Relative Error	**-0.33**	**-0.05**	**-0.20**	**-0.33**	**-0.20**	**-0.20**
Mean Relative Error							

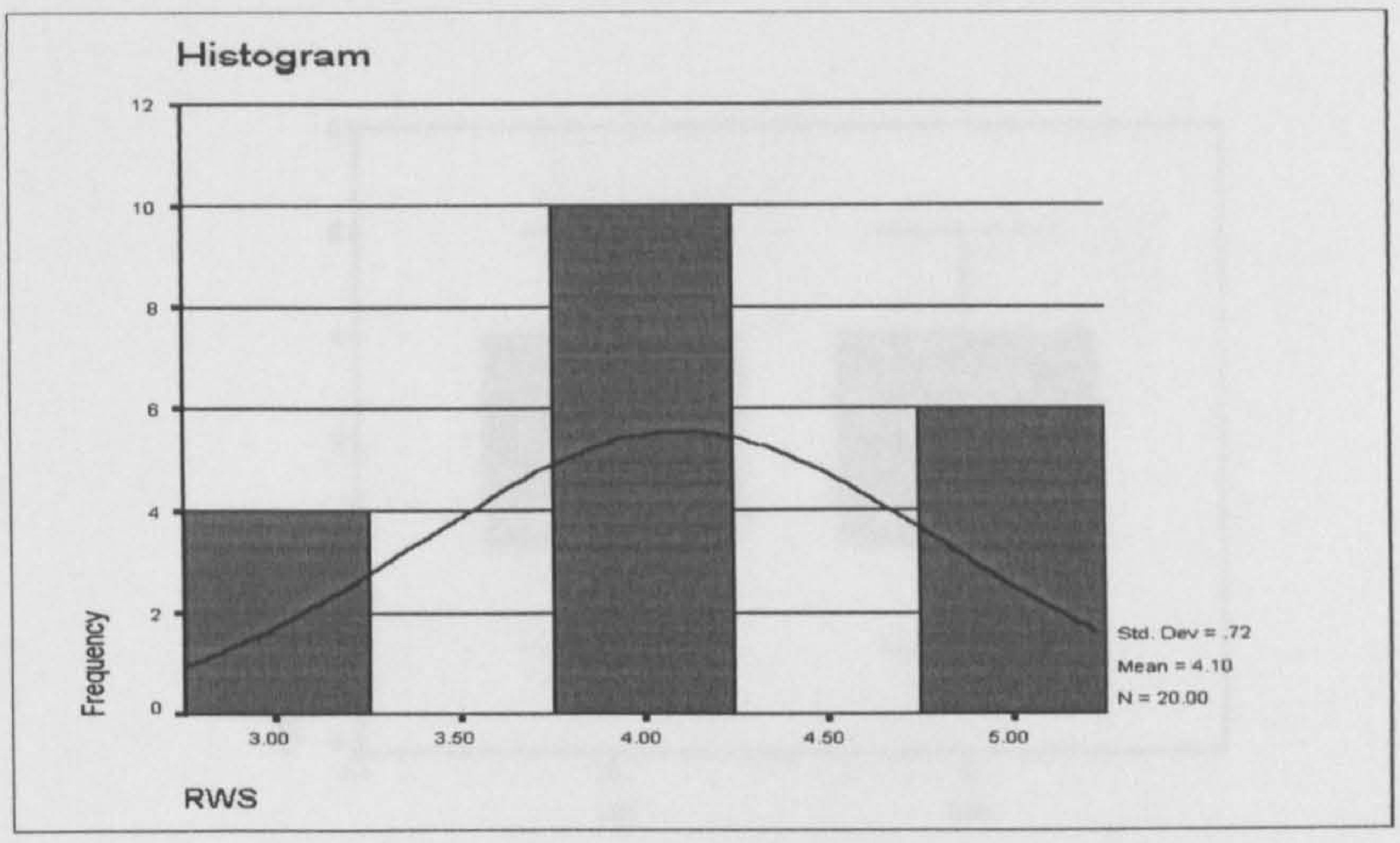
h- height

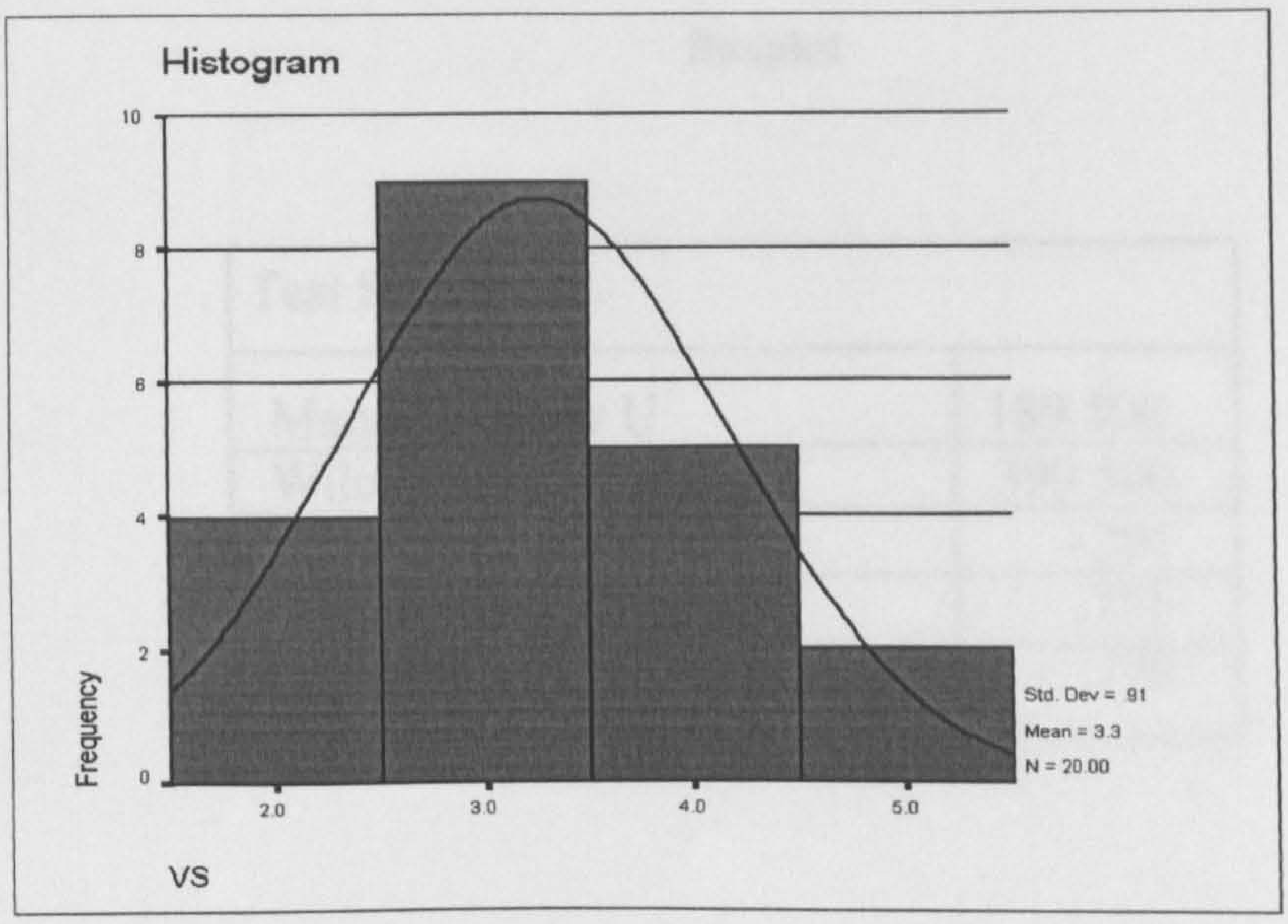
v- length

Appendix G. Difficulty of Estimation Tasks –Experiment 2.

Statistics

	N		Mean	Median	Mode	Std. Deviation	Skewness	
	Valid	Missing						
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
VS	20	21	3.2500	3.0000	3.00	.9105	.378	.512
RWS	20	21	4.1000	4.0000	4.00	.7182	-.152	.512





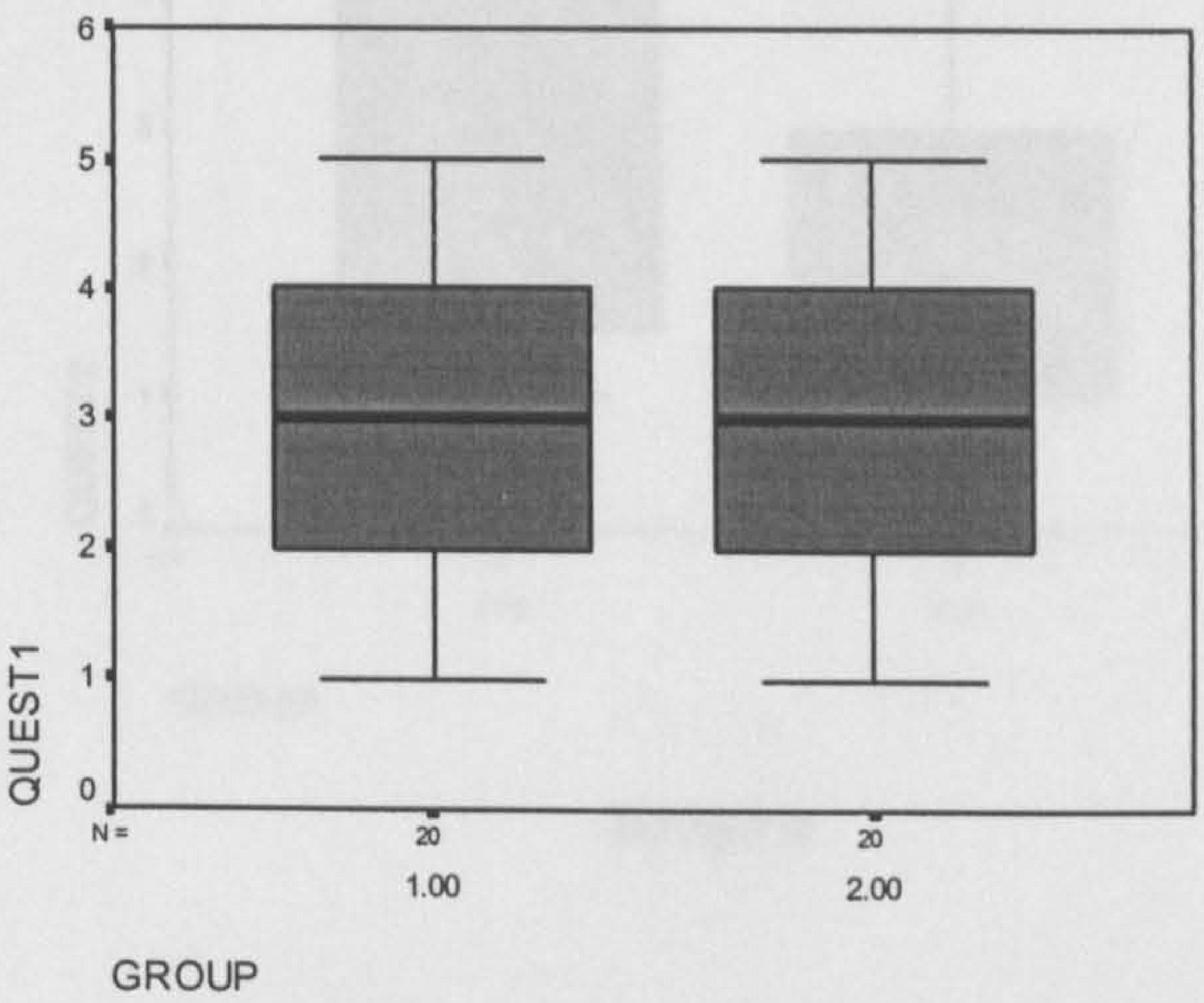
Appendix H. Questionnaire- statistical calculations.

Question 1. Cheerful- Gloomy

Group Statistics

RWS- Group 1
VS - Group 2

	GROUP	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**Variance**
QUEST1	1.00	20	2.9500	1.3563	.3033	1.839
	2.00	20	2.8500	1.1821	.2643	1.397



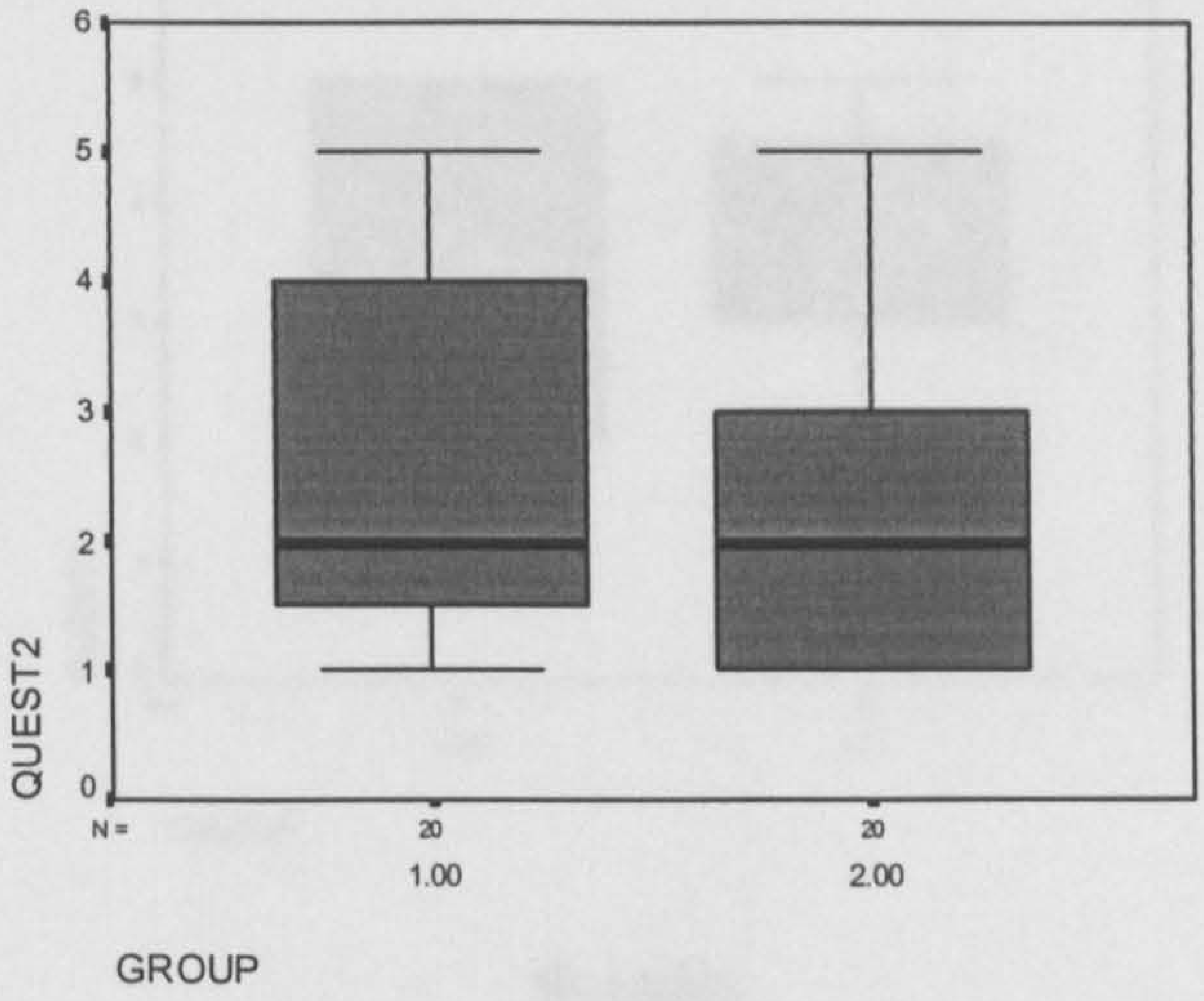
Boxplot

Test Statistics	
Mann-Whitney U	189.500
Wilcoxon W	399.500
Z	-.291
Asymp. Sig. (2-tailed)	.771
Exact Sig. [2*(1-tailed Sig.)]	.779

Question 2. Comfortable- Uncomfortable

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUEST2	1.00	20	2.6500	1.3870	.3101	1.924
	2.00	20	2.3500	1.2680	.2835	1.608



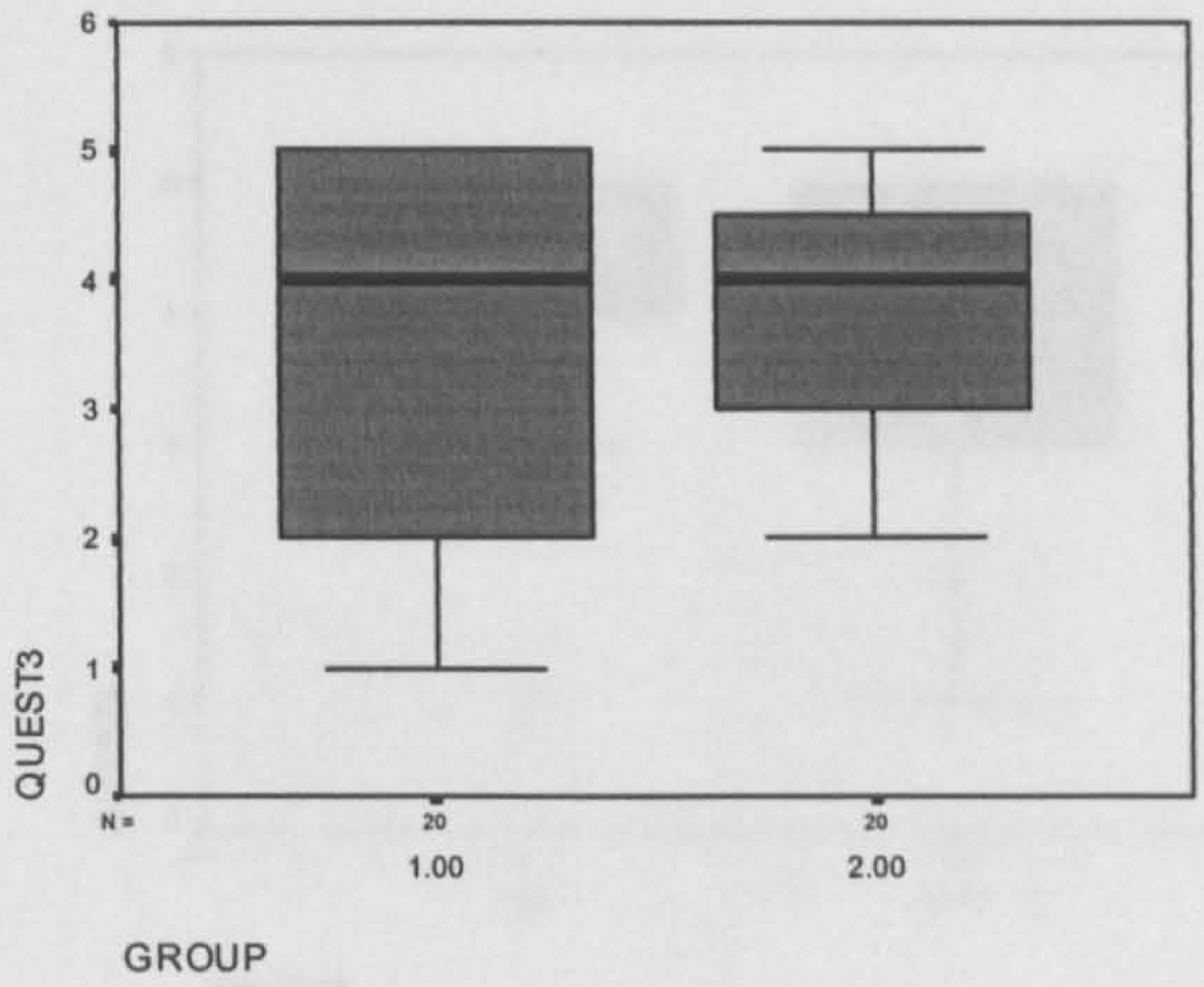
Boxplot

Test Statistics	
Mann-Whitney U	175.500
Wilcoxon W	385.000
Z	-.696
Asymp. Sig. (2-tailed)	.486
Exact Sig. [2*(1-tailed Sig.)]	.512

Question 3. **Complex- Simple**

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUEST3	1.00	20	3.0450	1.6376	.3662	2.682
	2.00	20	3.7000	1.0809	.2417	1.168



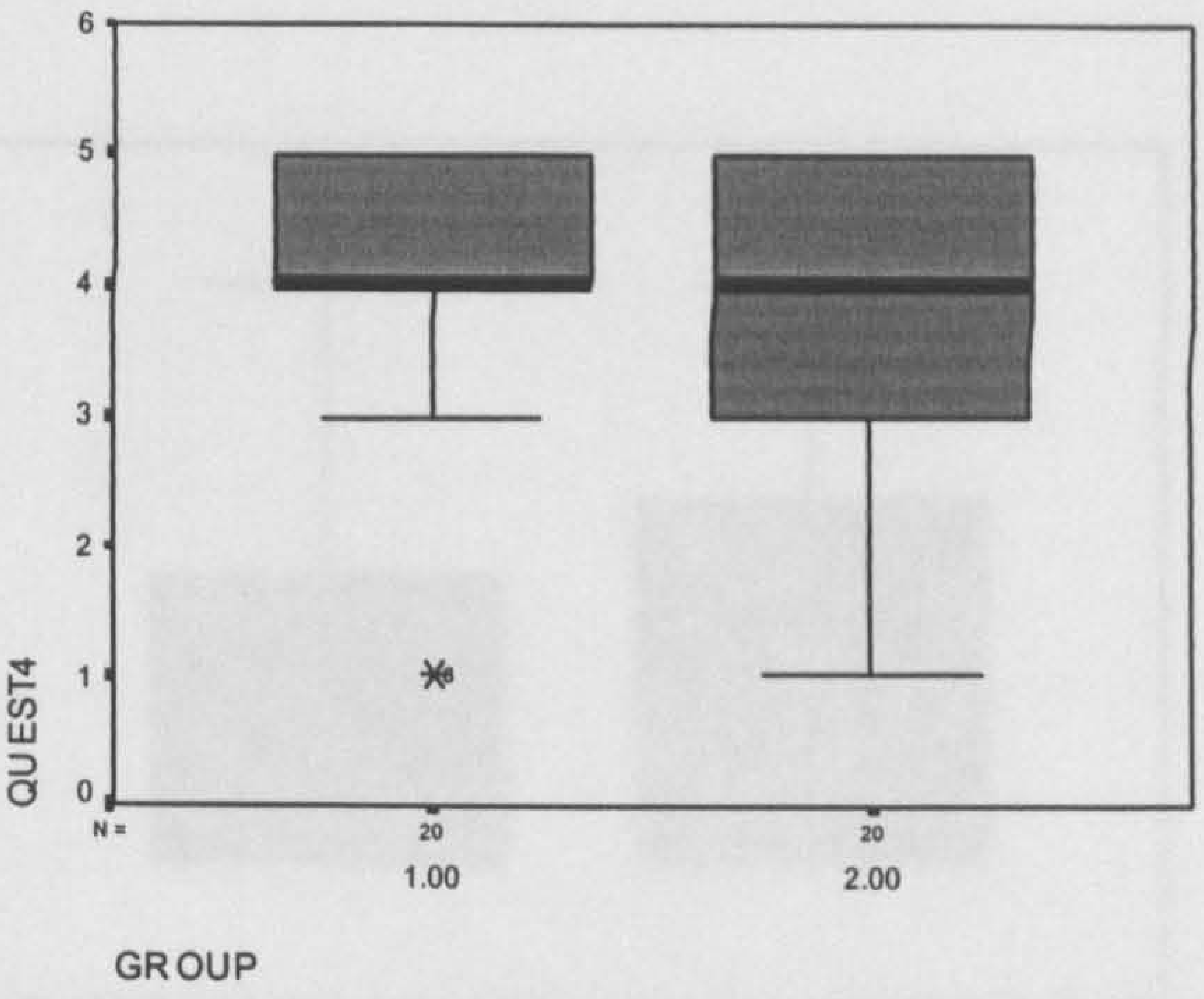
Boxplot.

Test Statistics	
Mann-Whitney U	195.500
Wilcoxon W	405.500
Z	-.126
Asymp. Sig. (2-tailed)	.900
Exact Sig. [2*(1-tailed Sig.)]	.904

Question 4. Large- Small

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUEST4	1.00	20	4.0500	1.2344	.2760	1.524
	2.00	20	3.8000	1.2397	.2772	1.537



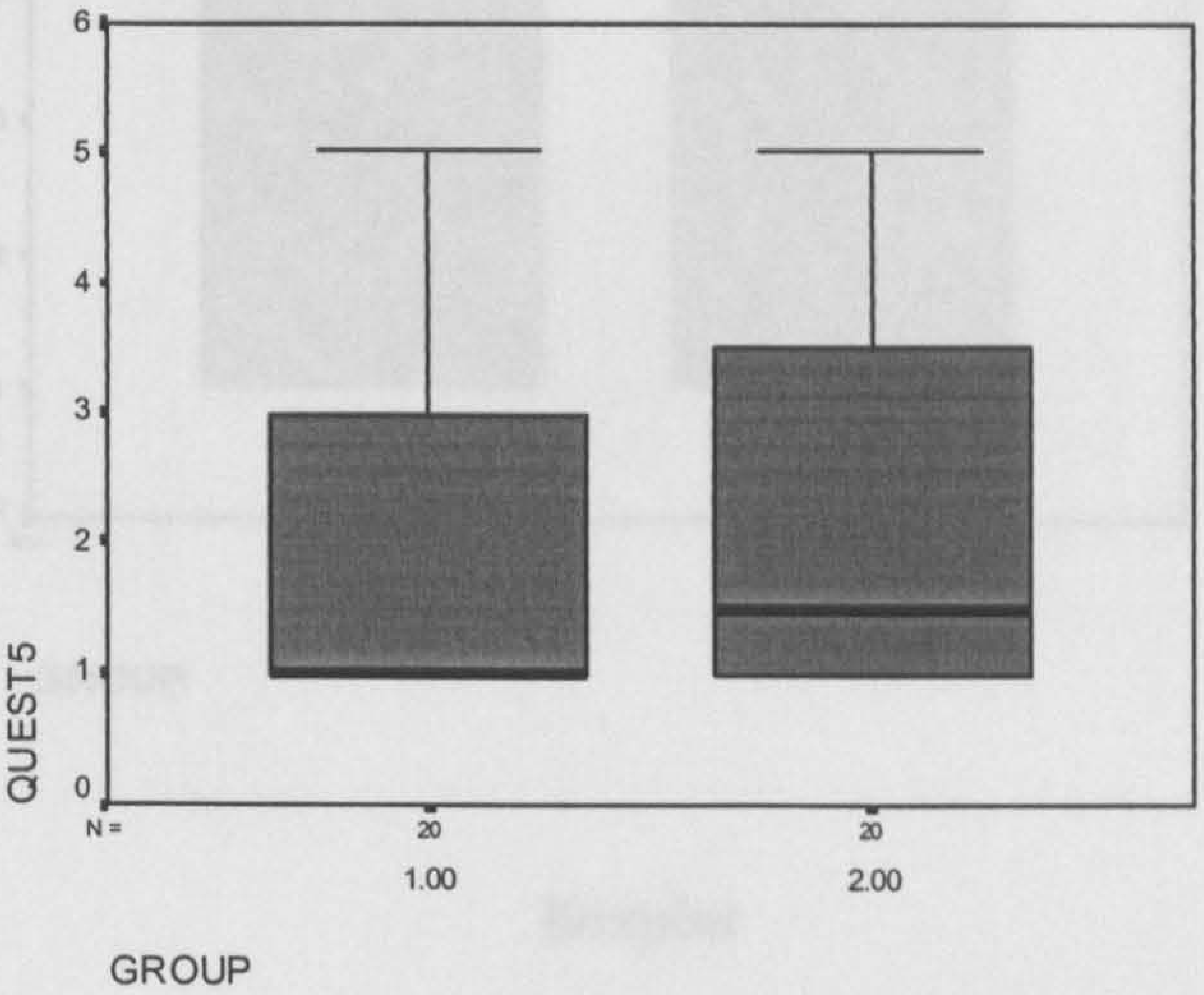
Boxplot

Test Statistics	
Mann-Whitney U	170.500
Wilcoxon W	380.500
Z	-.843
Asymp. Sig. (2-tailed)	.399
Exact Sig. [2*(1-tailed Sig.)]	.429

Question 5. Private- Public

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUEST5	1.00	20	2.2500	1.6182	.3618	2.678
	2.00	20	2.4000	1.6351	.3656	2.674



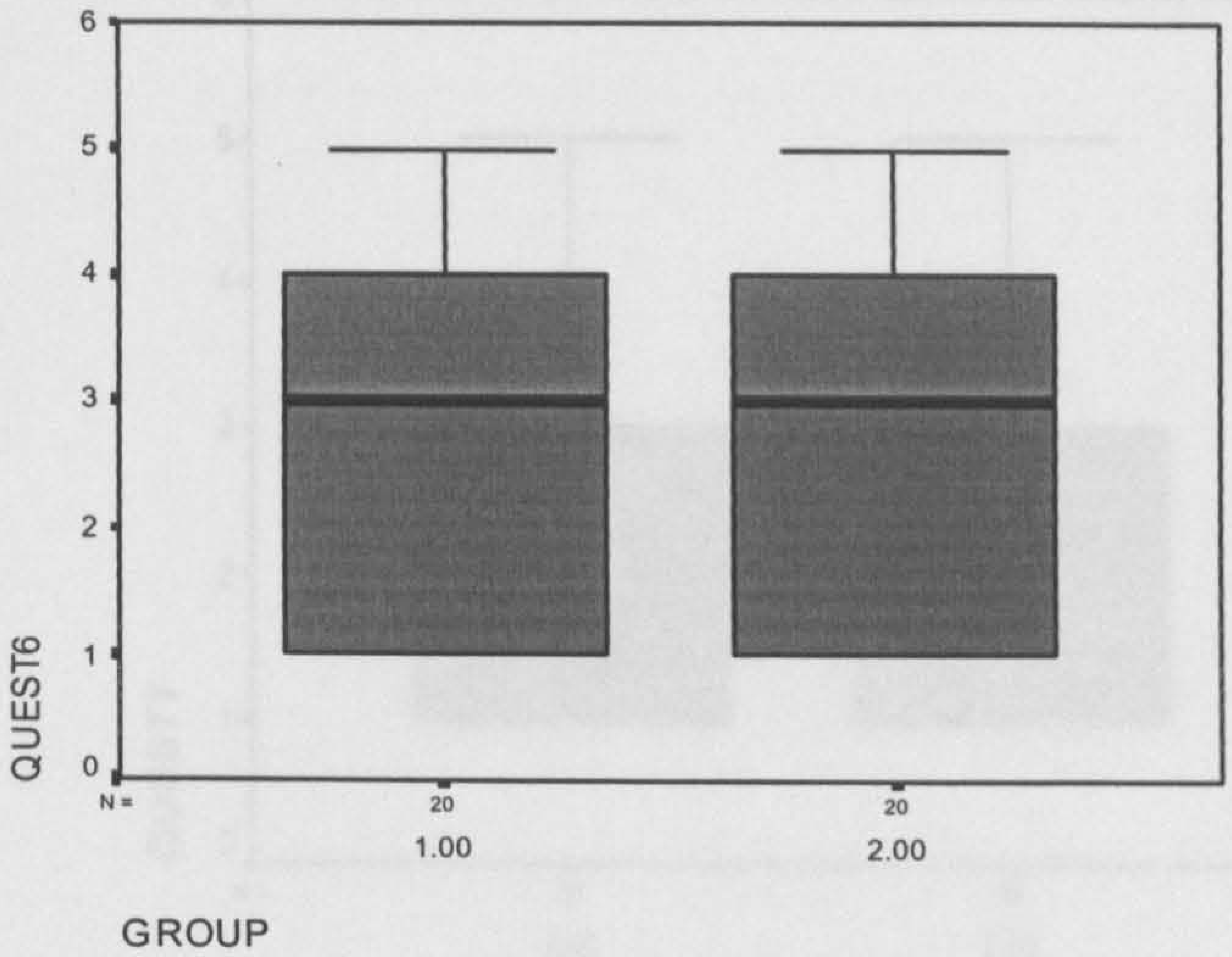
Boxplot

Test Statistics	
Mann-Whitney U	189.500
Wilcoxon W	399.500
Z	-.310
Asymp. Sig. (2-tailed)	.757
Exact Sig. [2*(1-tailed Sig.)]	.779

Question 6. Impressive- Unimpressive

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUEST6	1.00	20	2.7500	1.4464	.3234	2.092
	2.00	20	2.7500	1.4464	.3234	2.092



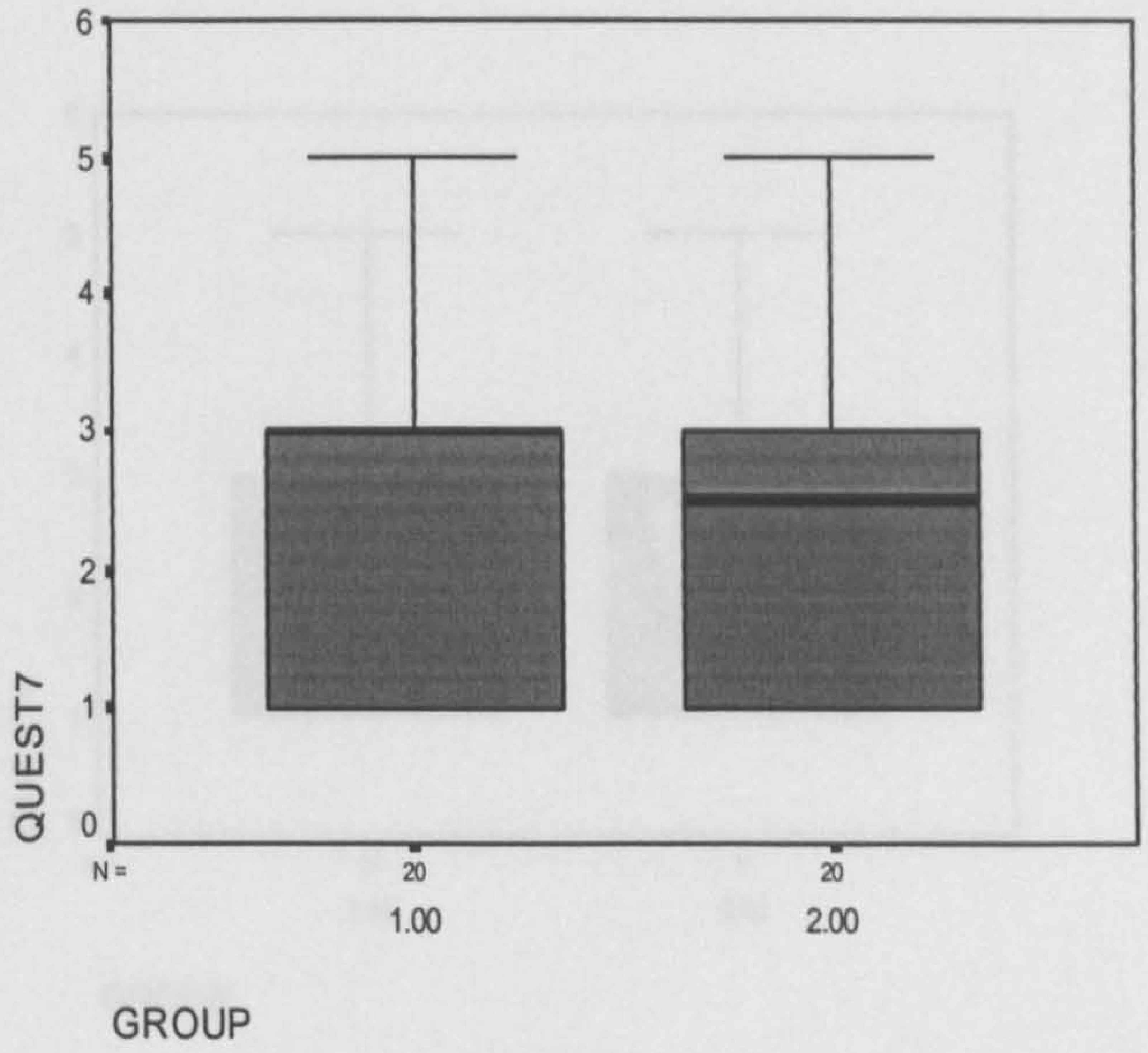
Boxplot

Test Statistics	
Mann-Whitney U	200.000
Wilcoxon W	410.000
Z	.000
Asymp. Sig. (2-tailed)	1.000
Exact Sig. [2*(1-tailed Sig.)]	1.000

Question 7. Inviting- Repelling

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUEST7	1.00	20	2.4500	1.1910	.2663	1.418
	2.00	20	2.4000	1.1877	.2656	1.411



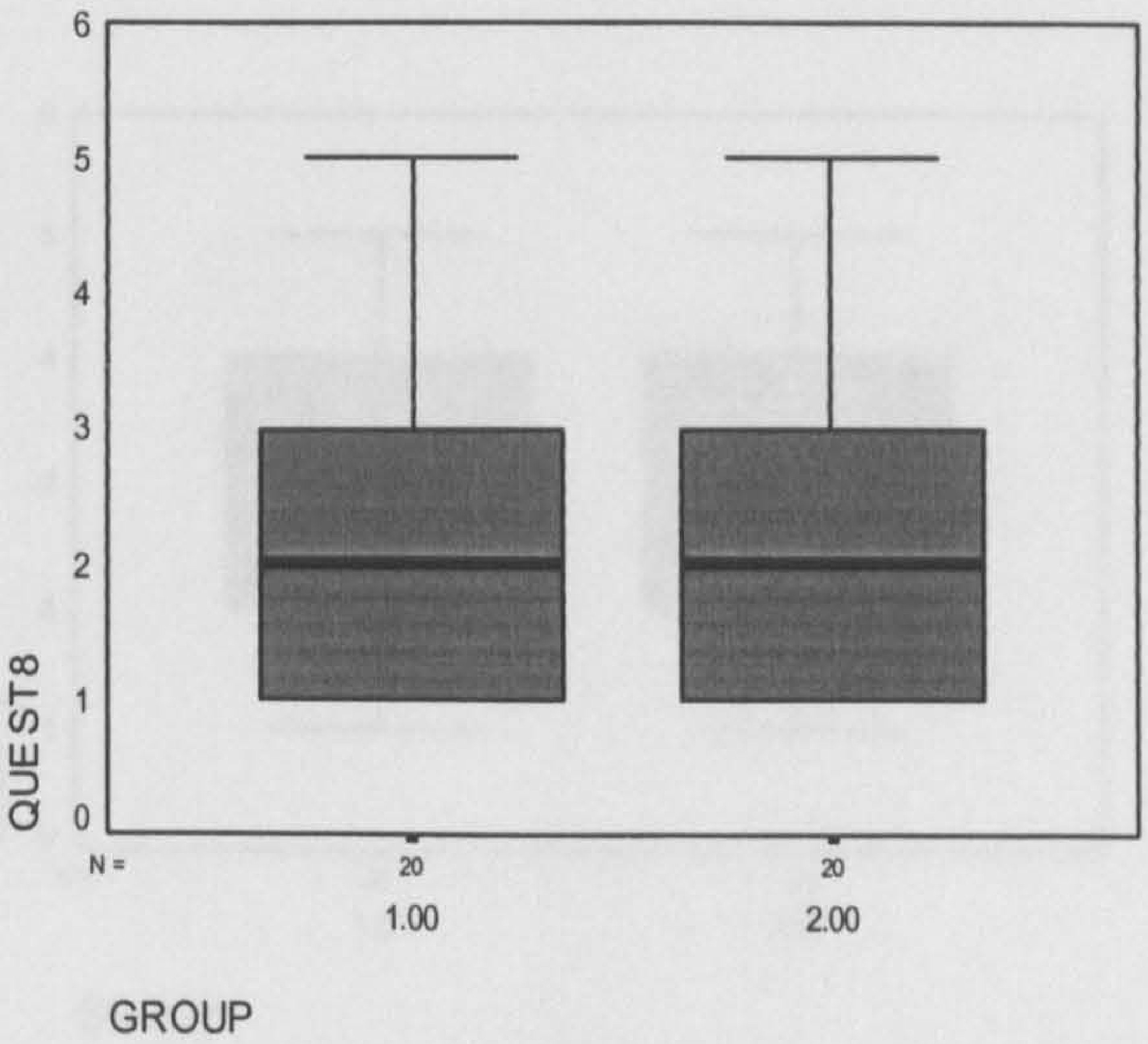
Boxplot

Test Statistics	
Mann-Whitney U	194.500
Wilcoxon W	404.500
Z	-.156
Asymp. Sig. (2-tailed)	.876
Exact Sig. [2*(1-tailed Sig.)]	.883

Question 8. Light- Dark

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUEST8	1.00	20	2.0000	1.1698	.2616	1.368
	2.00	20	2.1000	1.2096	.2705	1.463



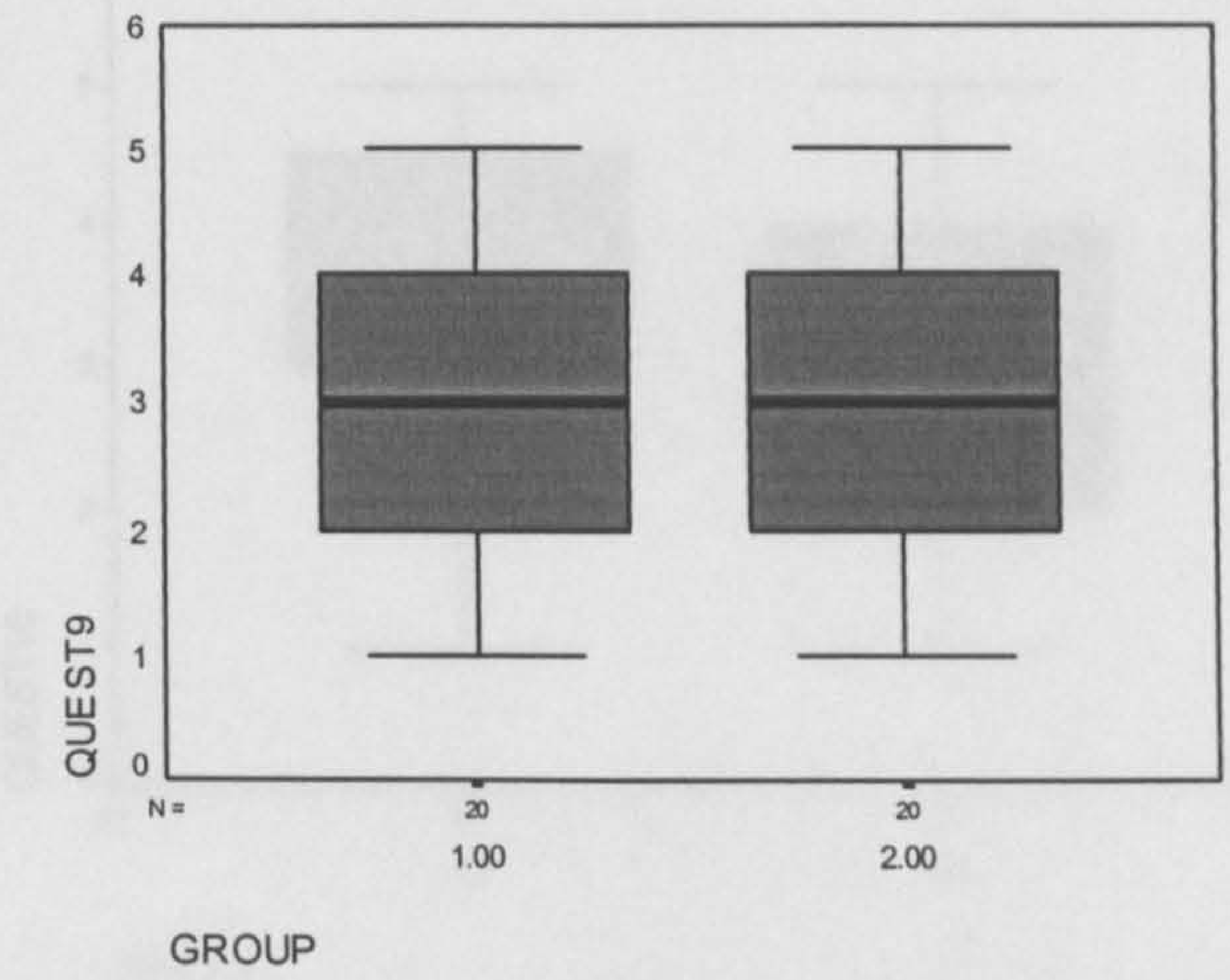
Boxplot

Test Statistics	
Mann-Whitney U	190.500
Wilcoxon W	400.500
Z	-.271
Asymp. Sig. (2-tailed)	.786
Exact Sig. [2*(1-tailed Sig.)]	.799

Question 9. Natural- Artificial

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUEST9	1.00	20	2.8500	1.2258	.2741	1.503
	2.00	20	2.7500	1.2927	.2891	1.671



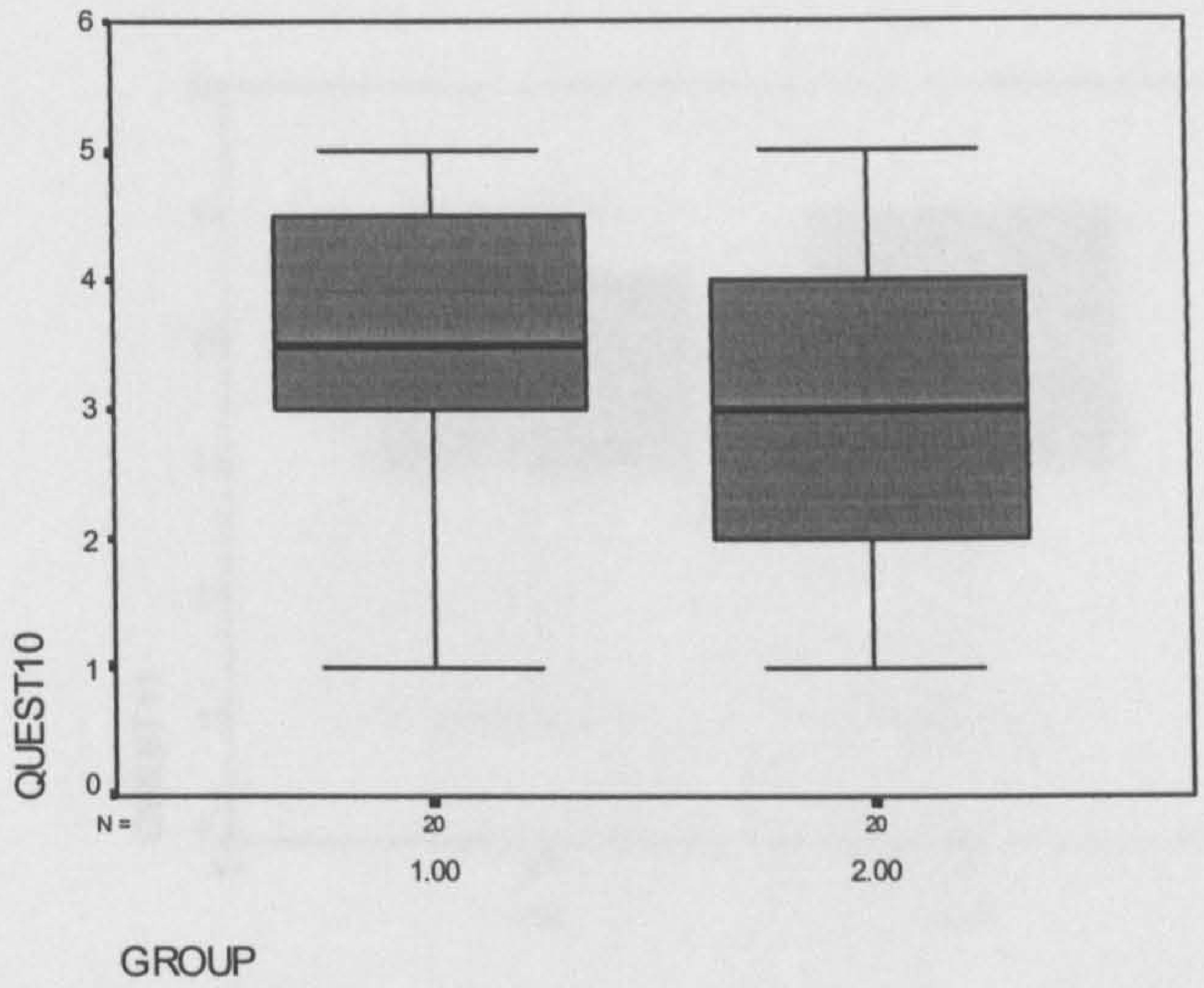
Boxplot

Test Statistics	
Mann-Whitney U	190.500
Wilcoxon W	400.500
Z	-.264
Asymp. Sig. (2-tailed)	.792
Exact Sig. [2*(1-tailed Sig.)]	.799

Question 10. Pleasant- Unpleasant

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUES10	1.00	20	3.4000	1.3534	.3026	1.832
	2.00	20	3.1500	1.4244	.3185	2.029



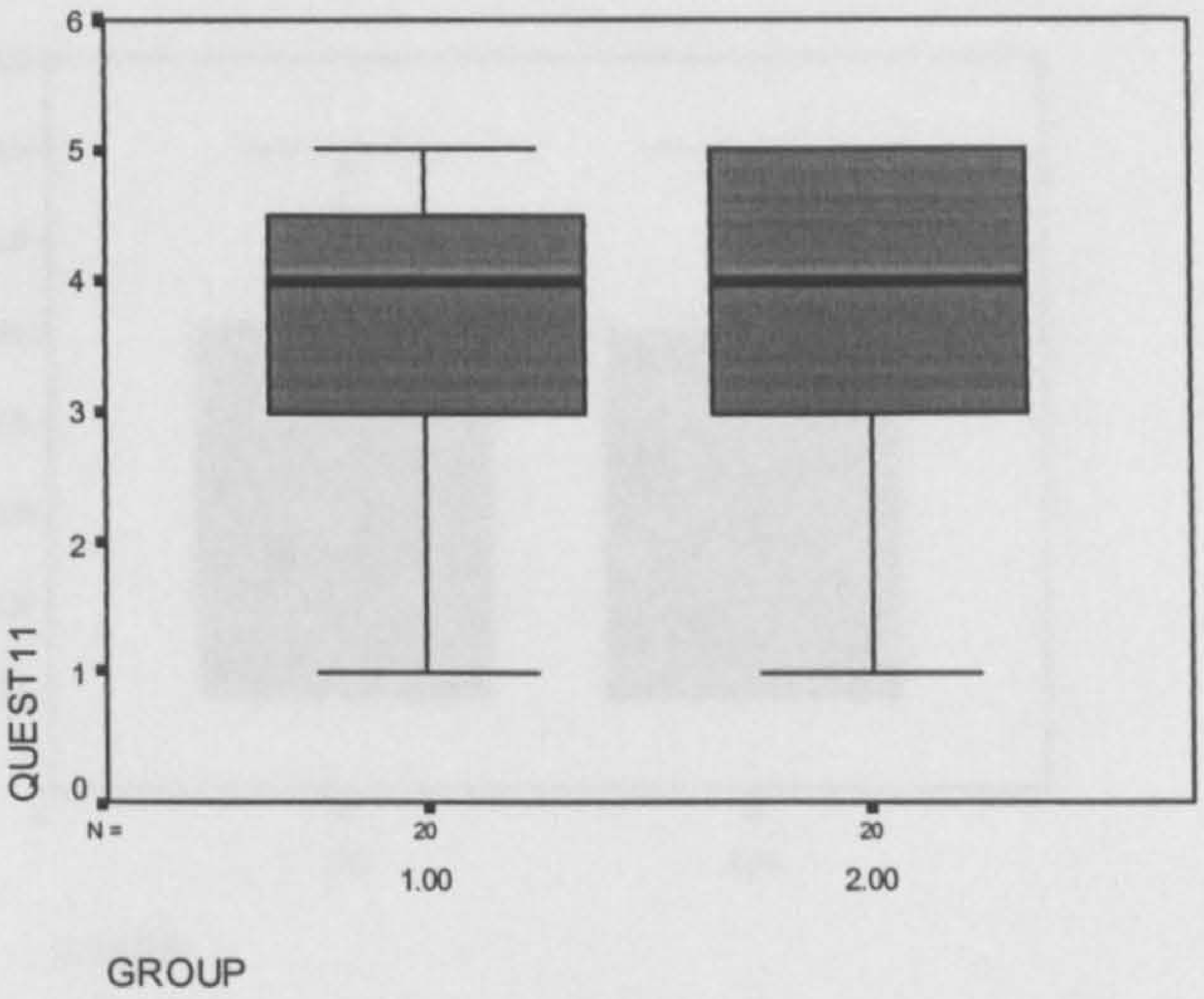
Boxplot

Test Statistics	
Mann-Whitney U	180.500
Wilcoxon W	390.500
Z	-.542
Asymp. Sig. (2-tailed)	.588
Exact Sig. [2*(1-tailed Sig.)]	.602

Question 11. Roomy- Cramped

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUES11	1.00	20	3.6000	1.1877	.2656	1.411
	2.00	20	3.7500	1.1642	.2603	1.355



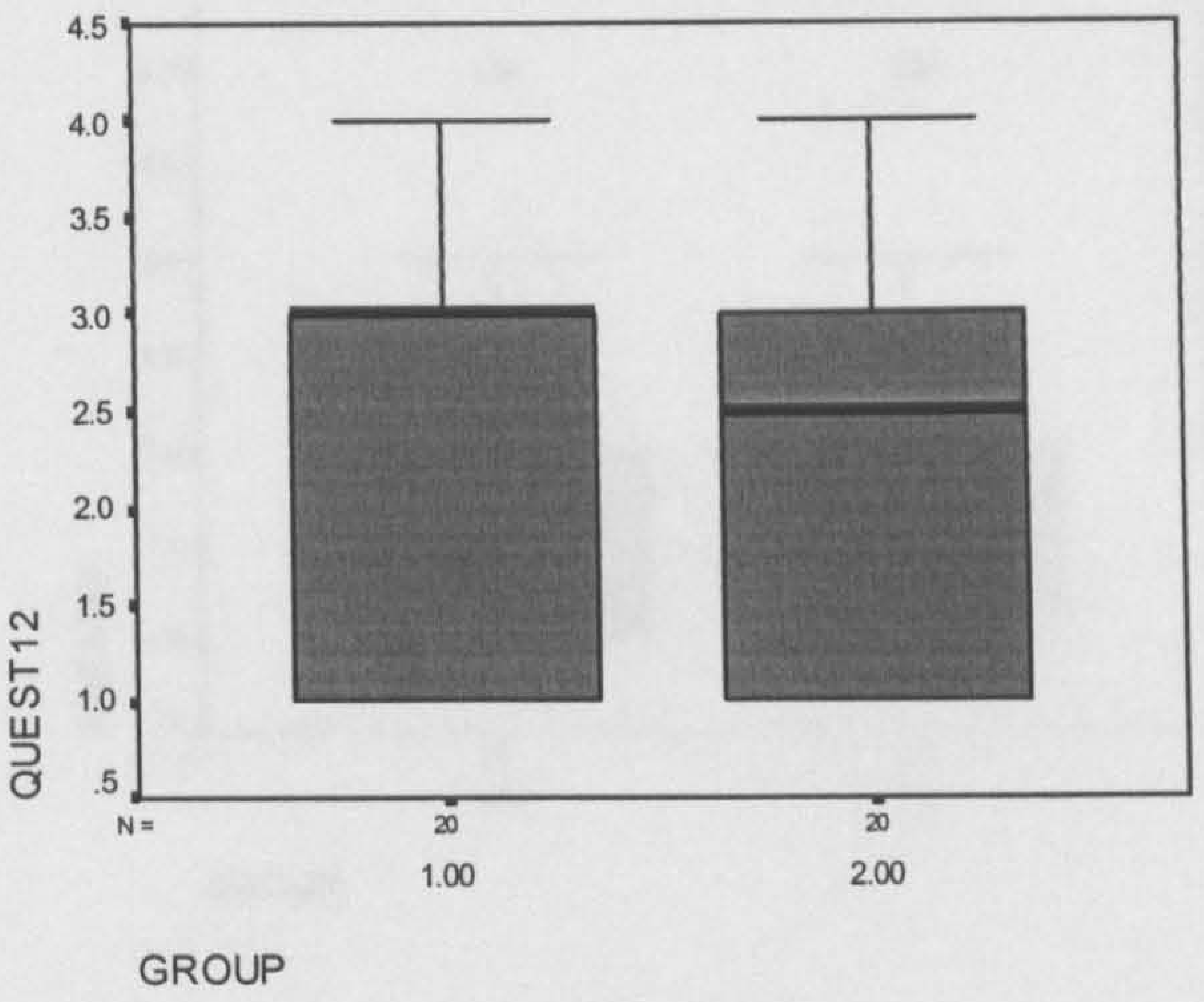
Boxplot

Test Statistics	
Mann-Whitney U	185.000
Wilcoxon W	395.000
Z	-.421
Asymp. Sig. (2-tailed)	.673
Exact Sig. [2*(1-tailed Sig.)]	.698

Question 12. Threatening- Unthreatening

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUES12	1.00	20	2.4000	1.1877	.2656	1.411
	2.00	20	2.4000	1.1425	.2555	1.305



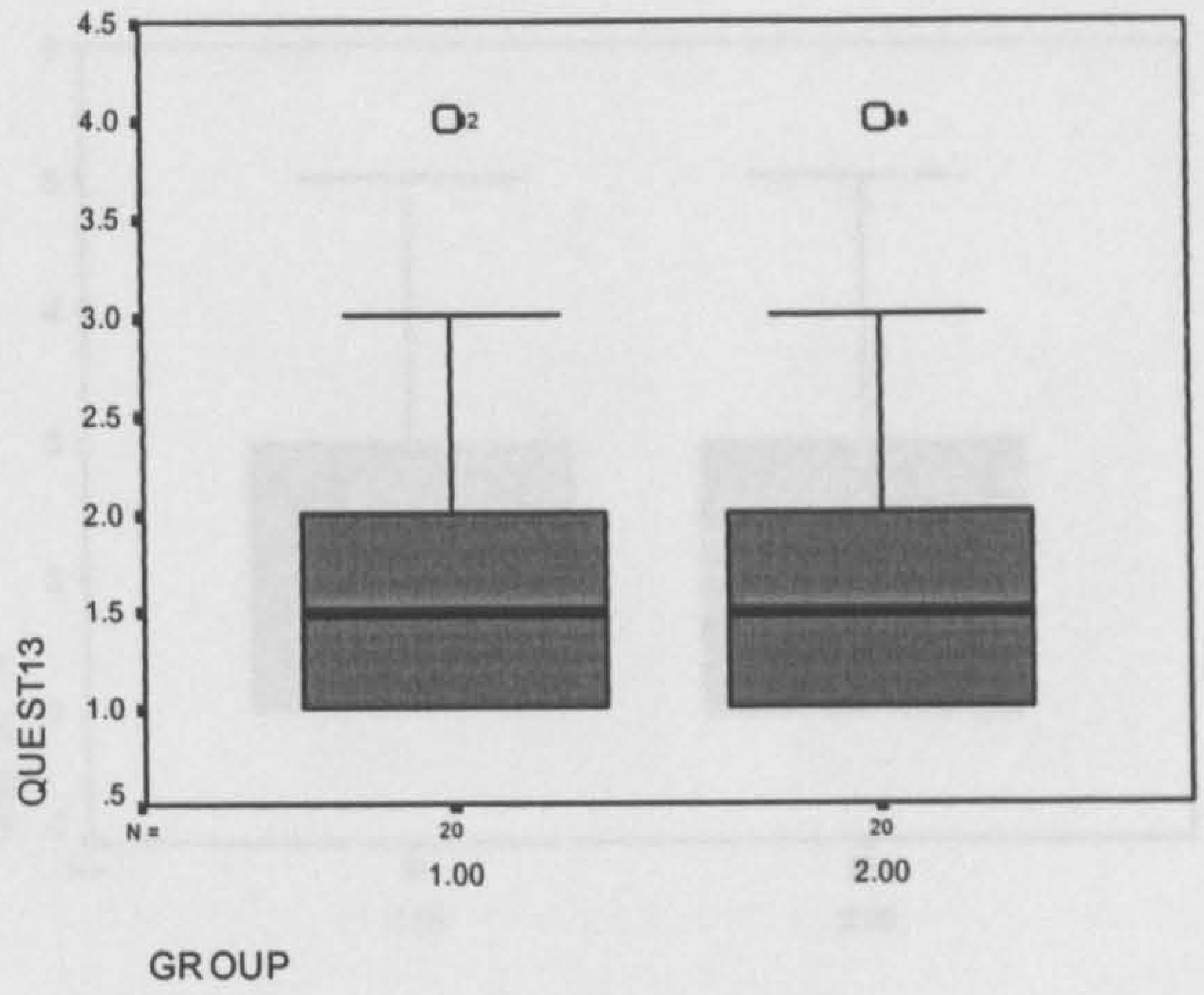
Boxplot

Test Statistics	
Mann-Whitney U	200.000
Wilcoxon W	410.000
Z	.000
Asymp. Sig. (2-tailed)	1.000
Exact Sig. [2*(1-tailed Sig.)]	1.000

Question 13. Well scaled- Poorly scaled

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUES13	1.00	20	1.8000	1.0052	.2248	1.011
	2.00	20	1.8000	1.0052	.2248	1.011



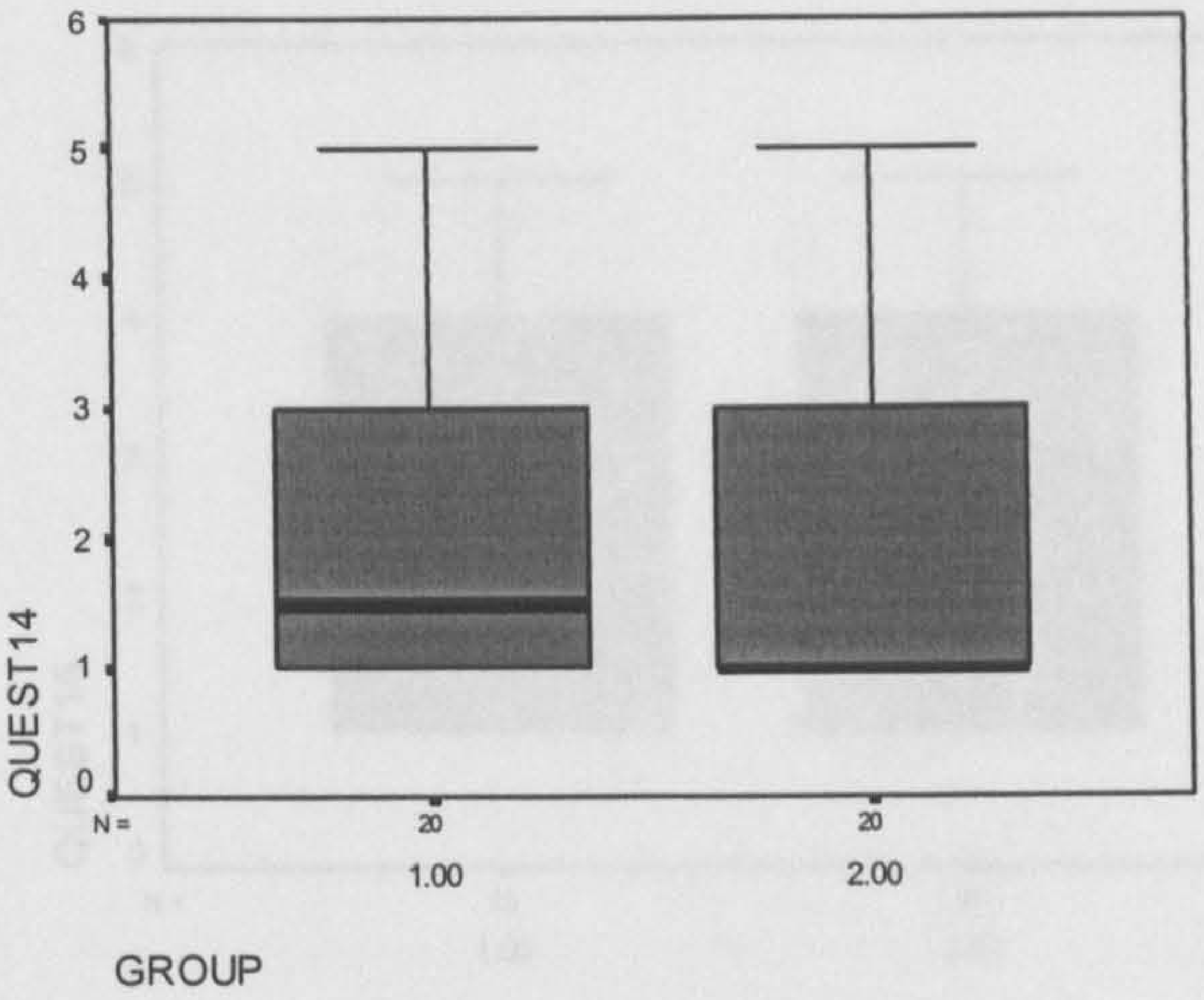
Boxplot

Test Statistics	
Mann-Whitney U	200.000
Wilcoxon W	410.000
Z	.000
Asymp. Sig. (2-tailed)	1.000
Exact Sig. [2*(1-tailed Sig.)]	1.000

Question 14. Warm- Cool

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUES14	1.00	20	2.1500	1.4244	.3185	2.029
	2.00	20	2.0500	1.4318	.3202	2.050



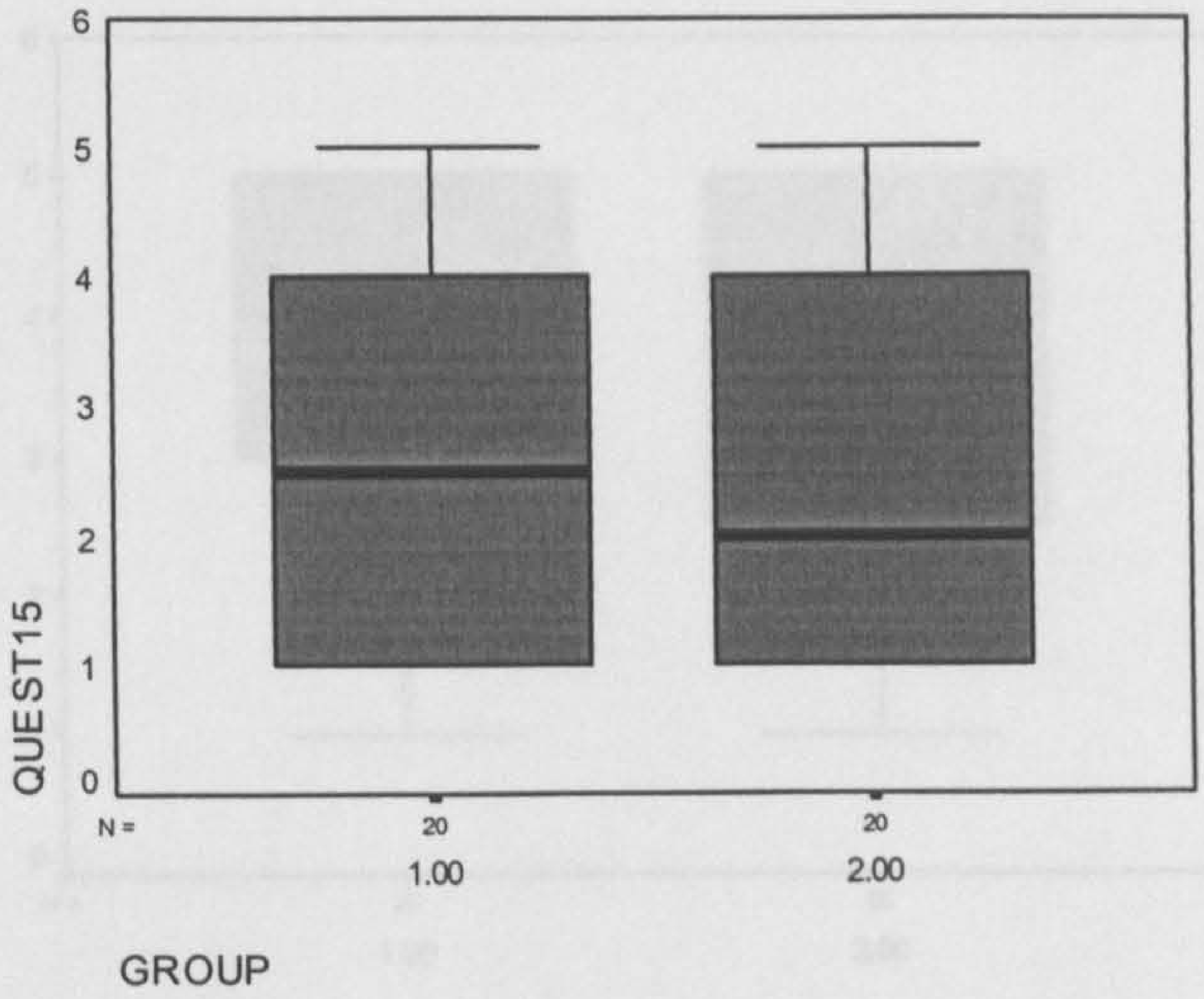
Boxplot

Test Statistics	
Mann-Whitney U	190.500
Wilcoxon W	400.500
Z	-.279
Asymp. Sig. (2-tailed)	.780
Exact Sig. [2*(1-tailed Sig.)]	.799

Question 15. **Tidy- Untidy**

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUES15	1.00	20	2.6000	1.3534	.3026	1.832
	2.00	20	2.6000	1.4290	.3195	2.042



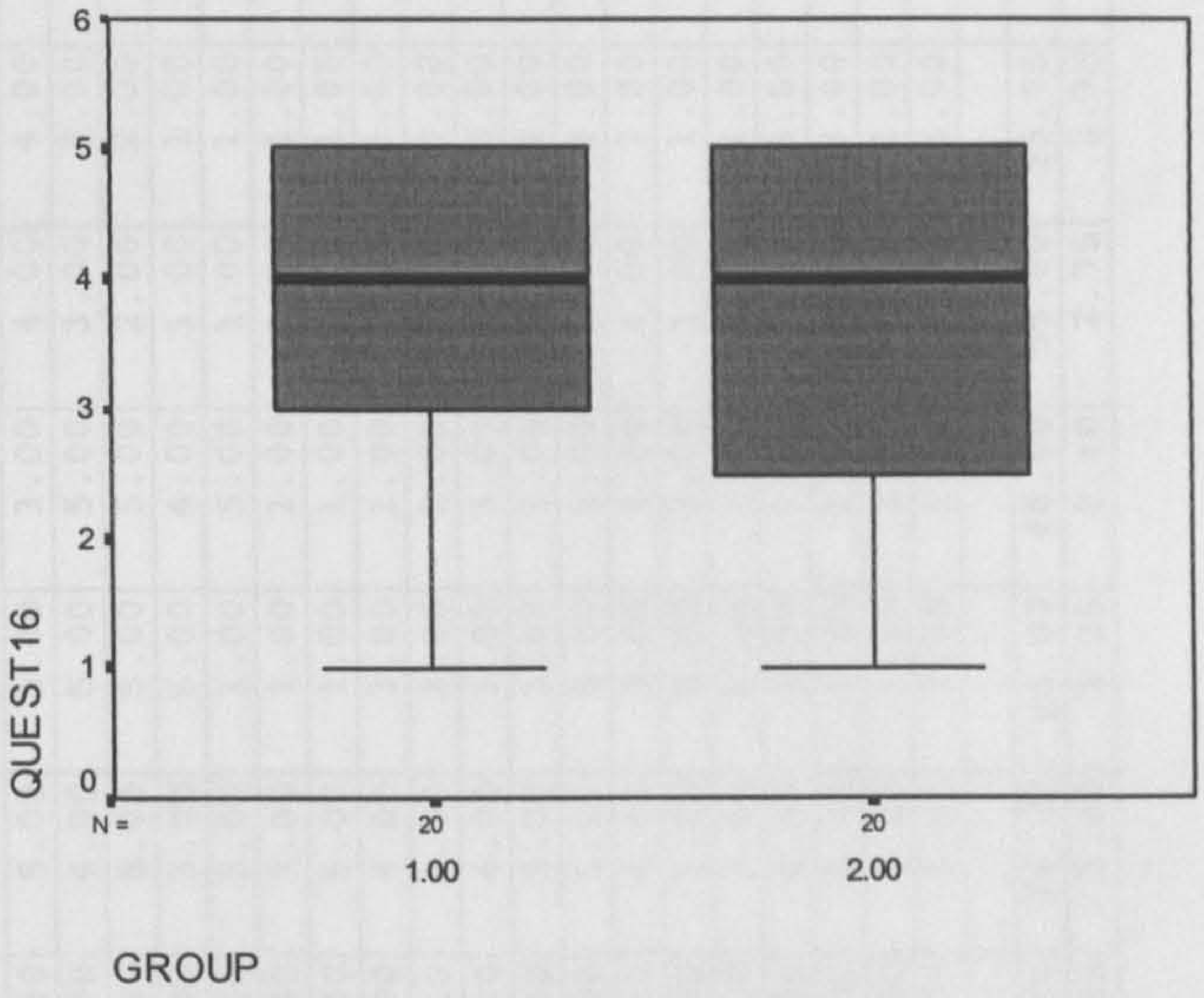
Boxplot

Test Statistics	
Mann-Whitney U	200.000
Wilcoxon W	410.000
Z	.000
Asymp. Sig. (2-tailed)	1.000
Exact Sig. [2*(1-tailed Sig.)]	1.000

Question 16. Well kept- Run down

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean	Variance
QUES16	1.00	20	4.0000	1.1698	.2616	1.368
	2.00	20	3.5500	1.5035	.3362	2.261



Boxplot

Test Statistics	
Mann-Whitney U	170.000
Wilcoxon W	380.000
Z	-.852
Asymp. Sig. (2-tailed)	.390
Exact Sig. [2*(1-tailed Sig.)]	.429

Appendix I. Questionnaire Results and Statistical Calculations.

Participant	Q1	VQ1	Q2	VQ2	Q3	VQ3	Q4	VQ4	Q5	VQ5	Q6	VQ6	Q7	VQ7	Q8	VQ8
1	3.00	3.00	4.00	1.00	5.00	3.00	5.00	5.00	1.00	1.00	5.00	5.00	4.00	4.00	3.00	3.00
2	4.00	4.00	1.00	3.00	4.00	4.00	5.00	5.00	3.00	3.00	4.00	4.00	3.00	3.00	4.00	4.00
3	4.00	3.00	4.00	1.00	1.00	4.00	5.00	4.00	5.00	5.00	3.00	3.00	5.00	5.00	3.00	3.00
4	4.00	2.00	2.00	1.00	5.00	3.00	5.00	5.00	5.00	5.00	2.00	2.00	3.00	3.00	1.00	2.00
5	2.00	1.00	2.00	2.00	2.00	4.00	1.00	3.00	5.00	4.00	1.00	1.00	1.00	2.00	2.00	1.00
6	3.00	5.00	1.00	1.00	1.00	5.00	3.00	3.00	1.00	5.00	1.00	1.00	3.00	2.00	1.00	1.00
7	5.00	5.00	5.00	3.00	5.00	5.00	4.00	3.00	1.00	1.00	1.00	1.00	2.00	1.00	5.00	5.00
8	1.00	4.00	1.00	4.00	2.00	3.00	1.00	5.00	1.00	1.00	3.00	1.00	2.00	1.00	2.00	2.00
9	3.00	1.00	3.00	3.00	5.00	5.00	4.00	4.00	3.00	1.00	3.00	3.00	3.00	3.00	3.00	4.00
10	3.00	2.00	2.00	2.00	5.00	5.00	4.00	5.00	3.00	3.00	5.00	3.00	3.00	3.00	1.00	2.00
11	2.00	3.00	1.00	2.00	5.00	5.00	5.00	4.00	1.00	3.00	4.00	5.00	4.00	4.00	2.00	1.00
12	1.00	4.00	2.00	1.00	4.00	4.00	4.00	3.00	1.00	1.00	3.00	4.00	3.00	3.00	1.00	1.00
13	4.00	2.00	3.00	3.00	3.00	2.00	5.00	1.00	5.00	5.00	1.00	2.00	1.00	1.00	1.00	2.00
14	5.00	2.00	4.00	1.00	4.00	2.00	3.00	4.00	3.00	3.00	1.00	3.00	2.00	2.00	2.00	2.00
15	5.00	3.00	2.00	3.00	2.00	4.00	4.00	1.00	2.00	2.00	1.00	1.00	1.00	2.00	1.00	1.00
16	1.00	2.00	2.00	2.00	1.00	2.00	5.00	3.00	1.00	1.00	2.00	1.00	1.00	1.00	3.00	3.00
17	3.00	2.00	1.00	1.00	1.00	2.00	4.00	4.00	1.00	1.00	3.00	3.00	3.00	3.00	2.00	2.00
18	3.00	4.00	4.00	4.00	4.00	4.00	5.00	5.00	1.00	1.00	3.00	3.00	1.00	1.00	1.00	1.00
19	2.00	2.00	5.00	5.00	5.00	4.00	4.00	4.00	1.00	1.00	4.00	4.00	1.00	1.00	1.00	1.00
20	1.00	3.00	4.00	4.00	5.00	4.00	5.00	5.00	1.00	1.00	5.00	5.00	3.00	3.00	1.00	1.00
Total	59.00	57.00	53.00	47.00	69.00	74.00	81.00	76.00	45.00	48.00	55.00	55.00	49.00	48.00	40.00	42.00
Mean	2.95	2.85	2.65	2.35	3.45	3.70	4.05	3.80	2.25	2.40	2.75	2.75	2.45	2.40	2.00	2.10

Q- RWS Question
VQ- VS Question

Participant	Q9	VQ9	Q10	VQ10	Q11	VQ11	Q12	VQ12	Q13	VQ13	Q14	VQ14	Q15	VQ15	Q16	VQ16
1	3.00	3.00	3.00	3.00	4.00	4.00	3.00	3.00	2.00	2.00	5.00	5.00	4.00	4.00	5.00	5.00
2	5.00	5.00	4.00	4.00	5.00	5.00	4.00	4.00	1.00	1.00	3.00	3.00	4.00	4.00	5.00	5.00
3	4.00	4.00	4.00	4.00	5.00	5.00	4.00	4.00	1.00	1.00	1.00	1.00	4.00	5.00	5.00	5.00
4	3.00	3.00	4.00	1.00	3.00	3.00	3.00	3.00	1.00	1.00	5.00	5.00	1.00	1.00	4.00	4.00
5	4.00	3.00	1.00	1.00	2.00	3.00	1.00	1.00	1.00	1.00	4.00	4.00	4.00	4.00	5.00	5.00
6	1.00	1.00	1.00	5.00	1.00	1.00	1.00	3.00	1.00	2.00	1.00	1.00	2.00	2.00	1.00	1.00
7	5.00	5.00	5.00	1.00	4.00	4.00	3.00	1.00	2.00	1.00	1.00	1.00	5.00	5.00	5.00	5.00
8	2.00	2.00	1.00	3.00	2.00	2.00	1.00	1.00	1.00	4.00	2.00	1.00	1.00	1.00	2.00	2.00
9	1.00	2.00	3.00	3.00	4.00	4.00	3.00	2.00	4.00	2.00	1.00	1.00	3.00	3.00	3.00	3.00
10	4.00	4.00	3.00	3.00	4.00	4.00	3.00	3.00	2.00	1.00	1.00	1.00	4.00	2.00	5.00	4.00
11	3.00	3.00	3.00	4.00	4.00	4.00	4.00	4.00	1.00	4.00	1.00	3.00	3.00	1.00	5.00	3.00
12	2.00	2.00	4.00	4.00	3.00	5.00	1.00	3.00	4.00	3.00	3.00	2.00	2.00	4.00	4.00	1.00
13	2.00	2.00	5.00	5.00	2.00	2.00	1.00	1.00	3.00	2.00	2.00	1.00	2.00	1.00	3.00	5.00
14	1.00	1.00	5.00	2.00	3.00	3.00	2.00	1.00	2.00	1.00	1.00	2.00	1.00	1.00	4.00	5.00
15	4.00	4.00	2.00	2.00	4.00	4.00	3.00	2.00	1.00	1.00	1.00	1.00	3.00	2.00	4.00	1.00
16	3.00	1.00	3.00	4.00	5.00	3.00	4.00	3.00	1.00	1.00	3.00	1.00	4.00	3.00	5.00	5.00
17	2.00	1.00	3.00	1.00	5.00	5.00	3.00	4.00	1.00	1.00	4.00	4.00	1.00	4.00	5.00	2.00
18	3.00	2.00	4.00	3.00	4.00	5.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	2.00	4.00	3.00
19	2.00	4.00	5.00	5.00	5.00	4.00	1.00	1.00	3.00	3.00	2.00	2.00	1.00	1.00	3.00	4.00
20	3.00	3.00	5.00	5.00	3.00	5.00	1.00	2.00	2.00	2.00	1.00	1.00	2.00	2.00	3.00	3.00
Total	57.00	55.00	68.00	63.00	72.00	75.00	48.00	48.00	36.00	36.00	43.00	41.00	52.00	52.00	80.00	71.00
Mean	2.85	2.75	3.40	3.15	3.60	3.75	2.40	2.40	1.80	1.80	2.15	2.05	2.60	2.60	4.00	3.55

Appendix J- Confidence and Difficulty task results.

	Confidence		Difficulty	
Participant	RWS	VS	RWS	VS
1	4	5	5	5
2	3	2	4	2
3	3	4	5	4
4	4	3	4	2
5	4	4	4	4
6	5	4	5	5
7	4	5	5	3
8	5	4	4	4
9	3	3	4	3
10	4	4	3	4
11	4	3	5	3
12	5	4	5	3
13	5	1	4	3
14	4	5	4	3
15	4	3	4	2
16	3	4	4	4
17	3	2	3	3
18	4	4	3	2
19	4	4	4	3
20	4	4	3	3