Human Factors in Virtual Environments

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This is the final report detailing the research conducted during a three-year project funded by the HP Laboratories External Research Program (1997-2000) in collaboration with the Department of Computer Science, University of Bristol, UK. The project's initial goals were centred on the investigation of human factors issues related to interacting with distributed computer graphics worlds in real-time over a network. These objectives were extended and focused on fidelity metrics for computer graphics simulations displayed on Head Mounted Displays. Theories from cognitive psychology were employed to devise these metrics which were, subsequently, validated by formally designed experiments involving human judgements of spatial memory awareness states.

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HP Laboratories External Research Project Report (1997-2000): Human Factors in Virtual Environments

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INTRODUCTION

This is the final report detailing the research conducted during a three-year project funded by the HP Laboratories External Research Program (1997-2000) in collaboration with the Department of Computer Science, University of Bristol, UK.

The project's generic goals were initially defined as the following:

- The construction of distributed computer graphics electronic spaces introduces critical problems of scale. Some issues to be considered are network-, processing- and perceptual scalability and the unavoidable latencies caused by the geographical separation of users and nodes (Demuynck, K, 1996). Development of a shared environment has to take into account all these limitations. Data management strategies will need to be introduced to reduce these communication latencies.
- How should socially inhabited electronic spaces be structured and what tools are needed to construct them? Furthermore, how should people be supported in exploring and navigating such spaces and how might the structure afford possibilities for social interaction? One of the most difficult issues is how to provide a sense of personal presence and awareness, both direct and peripherally, with other people within an electronic space and how to achieve this through user embodiment and other representation techniques. Most current systems have major difficulties conveying presence of other users, awareness of what other users are doing and providing mechanisms to represent a user as an embodiment within a single application.
- Techniques for integrating electronic spaces with physical spaces are going to be investigated. These environments are going to be addressed as inhabited social environments capable of supporting participation in many different activities.

The proposed research was defined in terms as "inhabited", "social interaction", "awareness", "spatial metaphors", "reactions". It had a view of virtual reality and related technologies as providing inhabited social spaces and by perceiving users as citizens and social beings both at work and play.

This report is going to be divided in three separate stages. STAGE 1 represents the initial investigations based on the generic goals stated above. STAGE 2 will present the revised directions and first experimental results and STAGE 3 will describe the final, formally designed experimental studies which formed the core of this project. STAGE 2 and 3 resulted in Katerina Mania's Ph.D. thesis[1] submitted in June 2001. Her Ph.D. degree was awarded in October 2001.

[1] Mania, K. (2001). Fidelity Metrics for Virtual Environment Simulations based on Spatial Memory Awareness States. Ph.D thesis, University of Bristol, UK, Dept. of Computer Science

STAGE 1[2]

SUMMARY

The general goal of Collaborative Virtual Environments (CVEs) is to provide a space within which people may interact. CVEs are increasingly being used to support collaborative work between geographically separated participants. User embodiment is concerned with the provision of users with a representation of their choice so as to make others (and themselves) aware of their presence in a virtual space. The taxonomy investigated in STAGE 1 detailed many of the existing networked virtual environments and examined the fundamental interaction interfaces which these systems provide. By initially discussing the features of communication which should be supported regardless of the medium available, the following investigation revealed an incomplete support for non-verbal communication cues over the range of the environments examined.

1. Background

The first application of networked computer graphics appeared in 1972 on ARPANET, the computer network developed by the Advanced Research Projects Agency. This network was mainly intended for co-operative work and for sharing information. Today, multi-user virtual environments are used for a variety of purposes, including shared scientific visualization, training, co-operative work, battlefield simulation and entertainment games. Several platforms exist for building multi-user virtual worlds, some of them free and easily accessible through the Internet. Obviously, the performance of these systems is different from high-end applications which are specialised, expensive and mostly running on dedicated networks. Although this gap is shrinking, the future of networked environments which are able to accommodate a large number of users and provide complex interfaces and rich user embodiments depends on aligning a number of technical (networks, computer graphics capabilities, etc.) and social issues (telephone companies, government regulators, etc.).

2. Non-Verbal Communication

New media such as distributed virtual environments, force researchers to analyse what is fundamental about communication. Conversation relies on all channels of communication through which information is exchanged by individuals during face-to-face interactions. Language is closely linked with and supported by, non-verbal communication which adds to the meaning of utterances, provides feedback, controls synchronisation and also plays a central role in human social behaviour (Argyle, 1976).

Facial expressions: The face is one of the most important areas for non-verbal signaling. In general, facial expressions are indicators of personality and emotions, serving also as interaction signals. Facial expressions provide feedback and information about the listener's level of understanding while revealing interest, puzzlement or disbelief. In addition, affective expressions

[2] This work has been published in detail here:
Mania, K. & Chalmers, A. (1998). A Classification for User Embodiment in Collaborative Virtual Environments. *Proc. of the 4th International Conference on Virtual Systems and Multimedia (VSMM 98)*, 177-182. IOS Press - Ohmsha, Ltd.

allow listeners to infer the speaker's current emotional state and communicate their audience's emotional reaction to what is being said.

Gaze: Gaze is a general indicator of attention and can be directed at other conversational participants in face-to-face interaction as well as at features of the physical environment. Gaze is closely coordinated with verbal communication. It is used to obtain feedback on the other's responses while talking and extra information about what is being said while listening. In addition, shifts of gaze are used to regulate the synchronisation of speech. Gaze is also used as a signal in starting encounters, in greetings, as a reinforcer and to indicate that a point is understood.

Gestures: The hands and to a lesser extent the head and feet can produce a wide range of gestures. Gestures are closely coordinated with speech and support multiple communication functions. They are used to co-ordinate conversational content, achieve reference and assist in turn taking. Conventional gestures are usually intended to communicate and are normally given and received with full-awareness.

Posture: This is the information supplied by the orientation of a conversational participant's body. Posture is an important means of conveying interpersonal attitudes and is associated with emotional states. Posture accompanies speech in a way similar to that of gesture and provides feedback to the speaker about how the message is being received. Body position and orientation can also be used to include or exclude people from the conversation.

Self-Representation: Self-representation can be regarded as a special kind of non-verbal communication. In general, the main purpose of manipulating appearance is to send messages about one-self. Thus, people send messages about their social status, their occupation, their personality or their mood. Appearance is also used to signal attitudes towards other people – for example, aggression, rebelliousness and formality.

Bodily Contact: Physical touch seems to have a primitive significance of heightened intimacy and it produces increased emotional arousal. Some forms of bodily contact are used as interaction signals like greetings and farewells or as attention signals. However, the precise meaning of a particular form of touch depends on the culture.

3. Taxonomy

Several distributed platforms were investigated.

DIVE: The Distributed Interactive Virtual Environment(DIVE) is an internet-based multiuser virtual reality system developed by the Distributed Systems Laboratory of the Swedish Institute of Computer Science (Carlsson & Hagsand, 1993). DIVE supports the development of shared multi-user virtual environments, user interfaces and applications. Embodiments in DIVE have the capability of head-movements, thus directing gaze while navigating.

MASSIVE: MASSIVE (Model, Architecture and System for Spatial Interaction in Virtual Environments), a laboratory prototype from the University of Nottingham, UK, is a virtual reality conferencing system which scales to large numbers of participants. Its users interact in the same virtual world through a variety of different equipment, media and user interfaces(2D, 3D, text, audio) (Benford et al., 1997). Head movement capabilities are available as well as a selection of simple pre-programmed gestures such as sleeping (which is also used to indicate the user's presence) and blushing.

VLNet: VLNet(Virtual Life Network) is a networked virtual environment developed in the MIRALab of the University of Geneva and the Computer Graphics Lab of the Swiss Federal Institute of Technology (Guye-Vuilleme et al., 1998). The system uses 3D human figures for avatar representations. Virtual humans are directly controlled where face and joint representation is modified using sensors attached to the user's body; user guided where the user defines tasks for the embodiment to perform; and, autonomous that are self-governing and incorporate internal states of actions.

Additional platforms investigated were dVs, OnLive!, Community Place, Quake, Worlds Chat, SPLINE (Wilcox, 1998).

4. Discussion

The premise of this investigation was that communication is accomplished as a combination of speech/language and non-verbal communication features. In addition, face-to-face interaction is accompanied by involuntary expressions making communication live and more naturalistic. How existing multi-user platforms incorporate non-verbal communication and the respective interfaces concerned was examined. Most of the systems provided a limited set of gestures, facial expressions or actions which are activated by mouse clicks on relevant buttons.

At the end of this investigation, it was clear that researchers cannot simulate the perceptual complexity of real-world interactions and spaces in a straightforward way. Which aspects of these interactions are essential to convey what needs to be communicated? STAGE 2 of this research focused on simulating a real-world space and utilized an informal experimental design comparing user task performance in the real-world space and computer graphics simulation counterpart. The experimental methodology was based on a theory derived from cognitive psychology research.

STAGE 2[3]

SUMMARY

STAGE 2 outlines the experimental methodology employed and the relevant results derived from the first, informally designed, preliminary study which compared spatial perception and memory recall in a Virtual Environment (VE) displayed on a desktop monitor as well as on a Head Mounted Display (HMD) with its real situation counterpart. The goal of this study was to identify the *mental processes* participants followed after completing a memory task in addition to the amount of their accurate recollections. The general scope was to identify variations of cognitive strategies (awareness states) related to their processes of retrieval (visual or not visual) when task performance across conditions does not differ. The actual task consisted of two parts: non-visual information recall for participants experiencing a seminar-like situation and spatial recall of the environment where this experience was taking place. For the non-visual part of the task, an audio-only condition was also included in the experimental design. The computer graphics rendering of the real scene was non-photorealistic, e.g. flat-shaded rendering. This preliminary study was designed to acquire a basic set of data for the simplest rendering as well as HMD display (monocular, non-head tracked). This set of elements will be built up in STAGE 2 to include photorealistic rendering, stereo graphics imagery and more complex virtual interfaces such as head tracking. Participants were required, here, to complete a memory task and provide self-reports of their level of perceived presence and simulator sickness, the latter for the HMD condition.

1. Experimental Methodology

In STAGE 2, a methodology for simulation fidelity evaluation of VEs centred on a validated theory of memory recall awareness states (the remember/know paradigm) is presented. Please see STAGE 3 for a detailed description of this methodology from memory research. The actual task consisted of two parts: non-visual information recall for participants experiencing a seminar-like situation and spatial recall of the environment where this experience was taking place. The study investigated how exposure to a computer-generated replica of the environment, displayed on a typical desktop display and a HMD would compare to exposure to the same environment and memory recall task in the real world from a cognitive rather than a task point of view. Subjective measures such as memory awareness states selection and perceived presence assessments were incorporated together with objective measures of memory recall, in a comparative study of a VE against the real world. The remember/know paradigm focuses on the actual awareness states that participants employ in order to complete a memory task rather than on the actual scores of accurate memory recall. The resultant accurate seminar and spatial memory recall scores and awareness states as well as participants' sense of presence were compared with those obtained from an analogous experiment in the actual real world space. The extent to which judgements of memory recall, memory awareness states and presence in the physical and VE are similar provides a measure for the fidelity of the simulation in question.

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[3] This work has been published in detail here:

- Mania, K. & Chalmers, A. (2001). The Effects of Levels of Immersion on Presence and Memory in Virtual Environments: A Reality Centred Approach. *Cyberpsychology & Behavior, 4(2),* 247-264
- Mania, K., Chalmers, A., Troscianko, T., Hawkes, R. (2000). Presence and Task Performance: A Reality Centred Approach. Technical Sketch, Proc. of ACM SIGGRAPH 2000, USA, ISBN 1-58113209-3, 245-245

Four groups of 18 participants were recruited to participate in this study from the student population of the University of Bristol and Hewlett Packard Laboratories in Bristol, UK. 80% of the subjects from each group were male. All used computers frequently in their daily activities. Participants were randomly assigned to each group. A between-subject design was utilised balancing groups for age and gender. Participants in all conditions were informed that they could withdraw from participation at any time during the experiments and they were naïve as to the purpose of the experiment. They were also asked if they had any knowledge relevant to the historic topic of the seminar and if they did, they were excluded. Participants had either normal or corrected-to-normal vision. According to the group they were assigned to, participants completed the same memory task, in one of the following conditions:

1. In reality, attending to a 15-minute seminar in a seminar room in the University of Bristol; referred to as the **real-world condition.**
2. Using a computer graphics simulation of the real world space with the real-world audio on a desktop monitor; referred to as the **desktop condition.**
3. Using the same application on a monocular, non-head tracked HMD with the real world audio and with a mouse for navigation; referred to as the **HMD condition.**
4. Listening to the audio recorded during the real-world condition and completing the non-visual part of the task; referred to as the **audio-only condition.**

This study was based on the assumption that a 3D desktop display is less immersive than a HMD. Audio used in one condition as the only experimental sensory stimulus is perceived, in this study, as the least technologically 'immersive' condition.

Prediction

Presence and task performance were predicted to be significantly higher in the real-world condition relative to the desktop, the HMD and the audio-only conditions, thus offering a high benchmark. The main scope of this study was to show that by incorporating cognitive measures *together with* task performance measures, variations of participants' mental processes for memory recall would be revealed across conditions.

The Real Situation

The first group of 18 participants attended a seminar presentation that took place in a specific seminar room in the University of Bristol (Figure 1).

The seminar's duration was 15 minutes. The historic content was chosen as none of the participants had any prior knowledge on this matter. The lecturer utilised 12 slides on an overhead projector. The seminar was digitally video recorded using a digital video camera on a tripod. Subsequently, the audio was extracted (16-bit stereo, 44kHz) in order to be incorporated in the computer graphics application for the desktop and HMD conditions.

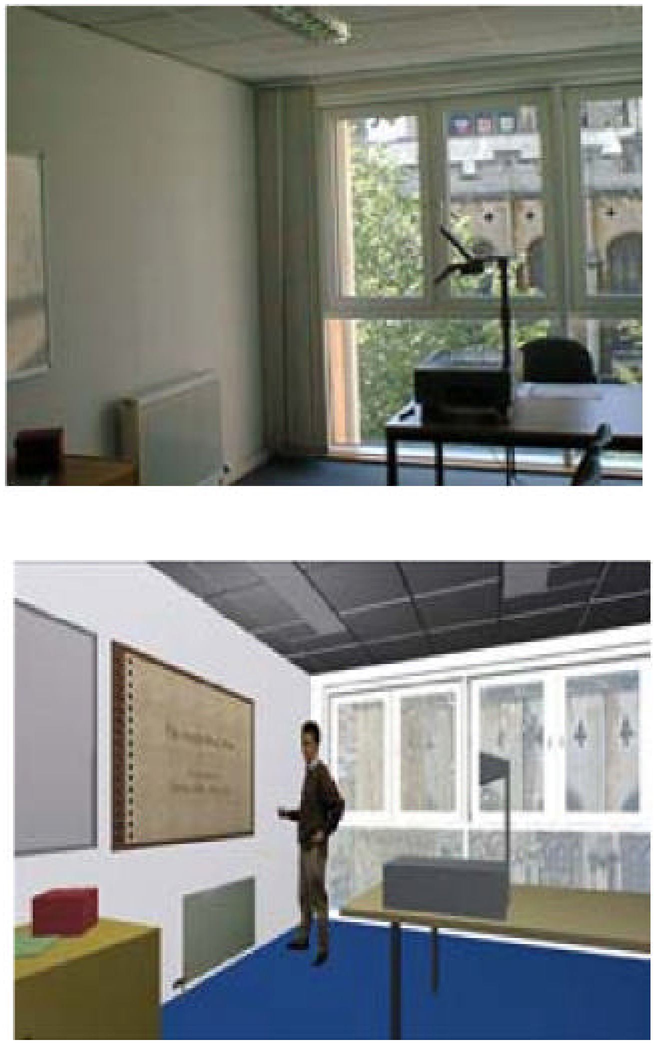

Figure 1 The real seminar room and the computer graphics environment.

Table 1 Technical characteristic comparison between the desktop monitor and the HMD.

	FoV (Field-of-View)	**Resolution**	**Input Device**
Desktop Monitor	38 degrees approx. hor.	1152*864	Mouse
HMD	30 degrees hor.	XGA(1024*764)	Mouse

The Graphical Simulation

The seminar room was modelled using the 3D Studio MAX modelling package and converted to VRML (Figure 1). The geometry in the real room was measured using a regular tape measure with accuracy of the order of one centimetre. The audio extracted during the real world seminar was incorporated in the computer graphics application. The application included a slide-show synchronised with the audio at the exact timings that the lecturer manipulated the slides in the real seminar. A static billboard with a texture displaying the lecturer (who was always facing the camera) was included in the application. The model was rendered flat-shaded and the application had an average update rate of 45 frames per second for both the desktop and HMD condition. The input device for navigation was a normal mouse in both the desktop and HMD conditions.

The second group of 18 participants used the desktop application which included the audio recorded from the real seminar for the specified duration of the lecture (15 minutes) and their navigation tendencies were informally monitored (desktop condition). The application was displayed on a 21-inch typical desktop monitor. The Field-of-View (FoV) was calculated in relation to the distance of the participant from the display. A third group of 18 participants used the same application displayed on the HMD (HMD condition). A fourth set of 18 participants just listened to the audio recorded during the real seminar and completed the part of the memory task related to the seminar information. Obviously, the spatial perception task was not completed since there was no visual stimulus for this group (audio-only condition).

The HMD employed was a HP Laboratories working prototype and, thus, was not a commercial product available in the market. It was described as an 'eye-glass' display which features two micro-displays and appropriate optics, one for each eye. Both eyes were presented with the same image allowing for monocular imagery. Eyeglass displays allow for periphery vision and tend to be smaller and much lighter than fully-fledged HMDs as shown in figures 4.3, 4.4. The resolution of the desktop monitor employed in the desktop condition was kept at 1152*864; respectively, the resolution of the HMD was 1024*764. This small difference of FoV and resolution between the desktop monitor (38 degrees horizontal) and HMD (30 degrees horizontal) was considered minimal since this study was preliminary (Table 1).

The real world was perceived as a control condition so the FoV of the participants in the real-world condition was not restricted in this study. Participants in the desktop and HMD condition were able to explore the room from a steady viewpoint, approximately placed in the centre of the room. They had the ability to rotate on a full circle, horizontally, as well as on a half circle vertically, approximately emulating the movement of the head, using a common mouse (Figure 3). The experimental room was not darkened and participants in all conditions utilising computer graphics imagery were aware of their surroundings.

Figure 2 The Hewlett Packard Laboratories HMD prototype.

Figure 3 Experimental set-up for the HMD condition (HP Laboratories, Bristol).

2. Materials

The four groups of participants were asked to fill in the same set of questionnaires after exposure. This included the memory task and memory awareness states questionnaire and the presence questionnaire (Slater et al., 1998) with the addition of the SSQ questionnaire (Kennedy et al.,

1993) for the HMD condition. These materials can be found in Appendix A1.

Memory recall task

The questionnaire relevant to the memory task was designed to test the participants' accurate memory recall of the information communicated in the seminar and their spatial awareness of the environment and was based on the Conway et al., 1997 methodology. Overall, there were twenty-two questions. Sixteen questions were related to the actual factual information communicated in the seminar. The same set was incorporated in the real-world, desktop, HMD and audio-only conditions. Six questions were relevant to the environment where the seminar took place; these were incorporated in the real-world, desktop and HMD conditions. The correct answers for nine of the questions related to the seminar were included in the slideshow and were also mentioned by the lecturer. The remaining seven were only mentioned verbally and not included in the actual slide show.

Each memory recall question had four possible answers and it included a confidence measure with five possible states: No confidence, Low confidence, Moderate confidence, Confident, Certain. Most importantly, it also included an awareness state measure with four possibilities: Remember, Know, Familiar and Guess. Participants were required to select the correct answer for each question according to their recollection, select a confidence level and also report on their strategy of retrieval as expressed by one out of the four awareness states. Prior to filling out the core of the questionnaire, participants were given instructions that were designed to explain what each of the memory awareness states depicted as follows (Conway et al., 1997):

- You remembered a specific episode or image from the seminar. In this case you might have images and feelings in mind relating to the recalled information. Perhaps you virtually 'hear' again or 'see' again the lecturer presenting some item of information or remember visually the specific slide that information was included into. Answers such as these are called REMEMBER answers.
- You might just 'know' the correct answer and the alternative you have selected just 'stood out' from the choices available. In this case you would not recall a specific episode and instead you would simply know the answer. Answers with this basis are called KNOW answers.
- It may be, however, that you did not remember a specific instance, nor do you know the answer. Nevertheless, the alternative you have selected may seem or feel more familiar than any of the other alternatives. Answers made on this basis are called FAMILIAR answers.
- You may not have remembered, known, or felt that the choice you selected have been familiar. In which case you may have made a guess, possibly an informed guess, e.g. some of the choices look unlikely for other reasons so you have selected the one that looks least unlikely. This is called a GUESS answer.

Presence

The second questionnaire was designed to measure participants' level of perceived presence on a Likert 7-point scale. The questions used in the Slater et al., 1998 study were adopted and the questionnaire was administered in all conditions including the real world one. This particular set of questions is exploring various aspects of the concept of presence itself and is not relevant to the technology or interface used for the application. For example, issues investigated were the dominance of the virtual world over the real one, the sense of visiting a ‘place’ versus viewing a scene or listening to a sound and the level that the memory of the experiment resembled everyday memories. Only questions of this nature could be applied to all four conditions without any per-condition tailoring. The questionnaire included additional questions regarding gender, ratings of background sounds, profession, level of computer-related expertise and level of losing track of time.

SSQ questionnaire

The widely used Simulator Sickness questionnaire (SSQ) was administered following participants’ exposure to the VE for the HMD condition only. 16 symptoms were employed indicated in the Kennedy et al., 1993 study. The questionnaire design is based on three components: Nausea, Oculomotor problems and Disorientation. Participants report the degree to which they experience each of the above symptoms as one of ‘none’, ‘slight’, ‘moderate’ and ‘severe’. These are scored respectively as 0,1,2,3.

3. Summary of results

The incorporation of cognition-related measures, in this case, the report of the relevant memory awareness state for each item of the memory recall task offered a valuable input towards a more informative analysis. There was no statistical difference for the spatial memory task across conditions, but prior probabilities relevant to memory awareness states showed that the probability for an accurate response to fall under the ‘remember’ awareness state was higher for the HMD condition compared to the real-world condition. Since ‘remember’ responses are linked with visual mental imagery as a mechanism of retrieval, it could be argued that mental images and subsequent memory responses associated with the HMD condition are more ‘vivid’ or ‘realistic’ and that could have an effect on spatial perception retained in time. It is therefore suggested that usability studies involving only task performance measures while considering a possible design or technology such as the Hewlett Packard HMD prototype, are not sufficient to form conclusions regarding the effectiveness of the design or hardware in question. This is the major premise of this work.

In general, presence did not follow the same trend as task performance in all cases. For example, presence was significantly higher for the real-world condition compared to the desktop condition but that was not reflected on memory recall. There was no statistical difference between the scores for the spatial recall task between the real-world and the desktop condition. The presence questionnaire also revealed no significant difference between the technological conditions. This could mean that either these conditions do not have a varied effect on presence or that the measuring device, in this case, the presence questionnaire could not pick up that difference. Inherently, this could be an issue about the notion itself. There is an amount of ambiguity in terms of a scientific representation of the notion that might reflect onto any possible measuring instrument.

Although the preliminary study gave confidence in the memory semantics methodology based on the remember/know paradigm, the rendering used was basic and the spatial memory elements of the task were limited. The preliminary study demonstrated the potential of the memory semantics methodology as a simulation fidelity measure for VE applications in relation to the real world. This measure focuses on the awareness states participants employ in order to complete a memory task rather than on the actual scores of accurate completion commonly employed. The purpose of the preliminary study was to adjust the memory semantics methodology for VE immersive technology experimentation and reveal problems before a full study is made, therefore, the experimental design was not strict. STAGE 3 incorporated a simpler spatial memory task, a photorealistic stereo computer graphics simulation and head tracking. STAGE 3 forms the core of this research.

STAGE 3[4]

SUMMARY

This stage describes a methodology based on human judgments of memory awareness states for assessing the simulation fidelity of a *photorealistic* Virtual Environment (VE) in relation to its real scene counterpart. In order to demonstrate the distinction between task performance based approaches and additional human evaluation of cognitive awareness states, a photorealistic VE was created. Resulting scenes displayed on a Head Mounted Display (HMD) with or without head tracking and desktop monitor were then compared to the real world task situation they represented investigating spatial memory after exposure. Participants described how they completed their spatial recollections by selecting one of four choices of awareness states after retrieval in an initial test and a retention test a week after exposure to the environment. These reflected the level of visual mental imagery involved during retrieval, the familiarity of the recollection and also included guesses, even if informed. Experimental results revealed variations in the distribution of participants' awareness states across conditions while, in certain cases, task performance failed to reveal any. Experimental conditions which incorporated head tracking were not associated with confident visually-induced recollections. Generally, simulation of task performance does not necessarily lead to simulation of the awareness states involved when completing a memory task. The general premise of this research focuses on *'how'* tasks are achieved, rather than only on *'what'* is achieved. The extent to which judgements of human memory recall, memory awareness states and presence in the physical and VE are similar provides a fidelity metric of the simulation in question.

1. Introduction

The mapping from the real world environment to the computer graphics environment is mediated by *environmental* or *visual* fidelity (Waller et al., 1998). The term *visual fidelity* refers to the degree to which visual features in the Virtual Environment (VE) conform to visual features in the real environment. *Interface or interaction fidelity* refers to the degree to which the simulator technology (visual and motor) is perceived by a trainee to duplicate the operational equipment and the actual task situation. It is argued that training, for instance, in a VE with maximum fidelity would result in transfer equivalent to real-world training since the two environments would be indistinguishable (Waller et al., 1998). Robust metrics are essential in order to assess the fidelity of VE implementations comprising of computer graphics imagery, display technologies and 3D interaction metaphors across a range of application fields. Apart from optimisation of technological characteristics such as resolution, Field-of-View (FoV), latency, etc., one common belief is that efficient task performance measures should serve as fidelity metrics for any application that mainly targets transfer of training in the real world (Bailey &

[4] This work has been published in detail here:

- Mania, K., Troscianko, T., Hawkes, R., Chalmers, A. (2003). Fidelity Metrics for Virtual Environment Simulations based on Human Judgments of Spatial Memory Awareness States. Presence, Teleoperators and Virtual Environments Journal, 12(3), June 2003, MIT Press
- Mania, K., Chalmers, A., Troscianko, T., Hawkes, R. (2001). Simulation Fidelity Metrics for Virtual Environments Based On Memory Semantics. Technical Sketch, Proc. of ACM SIGGRAPH 2001, USA, ISBN 1-58113-403-7, 258-258

Witmer, 1994, Waller et al., 1998, Lathrop & Kaiser, 2002). A commonly employed strategy, therefore, for assessing the simulation fidelity of a VE is to compare task performance in a VE to task performance in the real world scene represented in the VE. Another common approach is to employ a cross-application construct, such as the sense of 'presence' to assess the effectiveness of a VE or aspects of a VE according to its success in enhancing presence. There is a widespread belief that presence should somehow improve task performance, although this has yet to be verified or indeed reasons offered as to why this should be the case (Stanney et al., 1998).

The research at this stage argues that because of the wide-range of VE applications and differences in participants across their background, ability and method of processing information, an understanding of *how* tasks are undertaken within a VE complementing *what* is achieved, is significant. This rationale is applied here to spatial memory recall. The utility of VEs, regardless of the applications they are proposed for is predicated upon the accuracy of the spatial representation formed in the VE. The framework to be presented has been drawn from traditional memory research adjusted to form an experimental procedure in order to compare real scenes and their computer graphics simulated counterparts. Here, participants could describe how they achieved their spatial recollections after exposure to an environment by selecting one of four awareness states ('remember', 'know', 'familiar' or 'guess') (Tulving, 1985, 1993, Conway et al., 1997, Gardiner, 2000). These judgments reflect the level of visual mental imagery involved at retrieval and the familiarity of the recollection including guesses, even if informed. In order to demonstrate the varied distribution of cognitive activity even when task performance remains the same, a photorealistic VE was created displayed on a Head Mounted Display (HMD) - incorporating either mono or stereo rendering with or without head tracking - and desktop display. Resulting scenes were then compared to the realworld task situation they represented employing memory recall of elements of the space as well as report of awareness states on an initial test and a retention test a week after the initial exposure. Central to this work is identifying whether experimental conditions such as the real-world one and those incorporating head tracking (thus including proprioceptive information) are associated with stronger visually-induced recollections ('remember' awareness state) compared to conditions associated with a typical mouse interaction interface. This work also aims to explore whether a cognitive shift between initial test and retest is going to signify a performance shift. This study extends a preliminary study by Mania & Chalmers, 2001.

2. Memory awareness states methodology

Memory, in the sense of 'information' for subsequent analysis, plays an important role in perceptual systems such as the visual, auditory, haptic and kinesthetic. Memory is not a unitary system (Baddeley, 1997). In the process of acquiring a new knowledge domain, visual or non-visual, information retained is open to a number of different states. Some elements of a learning experience or of a visual space may be 'remembered' linked to a specific recollection event and mental image or could just pop-out, thus, could be just 'known'. According to Tulving, 1985 recollective experiences are the hallmark of the episodic memory system. Knowing refers to those in which there is no awareness of reliving any particular events or experiences, a mental theasurus (semantic memory). Tulving, 1985 introduced a distinction between *'remember'* and *'know'* responses and provided the first demonstration that these responses can be made in a memory test, item by item out of a set of memory recall questions, to report awareness states as well. He reported illustrative experiments in which participants were instructed to report their states of awareness at the time they recalled or recognised words they had previously encountered in a study list. If they remembered what they experienced at the time they encountered the word, they made a 'remember' response. If they were aware they had encountered the word in the study list but did not remember anything they experienced at that time, they expressed a 'know' response. The results indicated that participants could quite easily distinguish between experiences of remembering and knowing.

There is some preliminary evidence that the distinction between 'remembering' and 'knowing' reflects a difference in brain activity at the time of encoding (Smith, 1992). It is assumed that recognition memory can be based largely on knowing, with little or no remembering. All that is necessary for encoding into the semantic system is some initial awareness of events. In contrast, encoding into episodic memory must depend on greater conscious elaboration of the events. Gregg & Gardiner, 1994 showed that estimates of the strength of the memory trace are greater when derived from remember plus know responses than when derived from only remember responses. Knowing, thus, reflects an additional source of memory, not merely a difference in response criteria. Although, 'remember' and 'know' awareness states have been controversially linked to episodic and semantic memory types with 'know' responses more theoretically problematic, recent research emphasised that 'they can be used without commitment to any theory, but simply to provide information on how various phenomena, including memory disorders, are characterised experientially' (Gardiner, 2000). In a relevant study, overall recognition performance in two groups of participants was very similar, however, the reported states of awareness differed markedly. One cannot make assumptions on what participants experience mentally from only their performance, therefore, there is no alternative to the use of subjective reports. Thus, additional information of awareness states provides an invaluable input into 'how' participants complete recollections. Subsequent research to Tulving, 1985, summarised in Gardiner, 2000 demonstrated that some variables affect one or the other of the two states of awareness, that some variables have opposing effects on them and that some variables have parallel effects on them. This finding indicates that the two states of awareness are functionally independent.

Conway et al., 1997 argued that 'familiarity' can be defined as the feeling that something has been encountered or experienced recently, although nothing about this recent occurrence can be remembered. 'Know' responses, on the other hand, represent highly familiar memory items that may come to mind without recollecting any particular encounter or any feeling of a recent encounter and cannot be placed. Conway et al., 1997 showed that these finer grained judgements could be dissociated from each other, just as different source memory judgements can. A confidence scale cannot communicate awareness states. It is also suggested that when a new knowledge domain is to be acquired, memory is represented initially in an episodic way. As time goes by, the underlying representations may change such that they do not represent recollective experiences and are simply 'known' leading to a semantic representation and schematised conceptual knowledge. There is little evidence that feelings of familiarity reflect the semantic memory system that supports highly familiar long-term knowledge. Gardiner, 2000, concludes: '… psychology of memory should take on board subjective reports of conscious states and not just rely on more conventional measures of performance. This evidence has established that the essential subjectivity of remembering and knowing does not make reports of these states of awareness intractable to science'.

3. Experimental methodology

Five groups of 21 participants were recruited to participate in this study, from the University of

Bristol, UK undergraduate and M.Sc. student population and they received course credits for their participation. 80% of the participants from each group were male. All used computers a great deal in their daily activities. A between-subject design was utilised balancing groups for age and gender. Participants in all conditions were informed that they could withdraw from participation at any time during the experiments and they were naive as to the purpose of the experiment. Participants had either normal or corrected-to-normal vision (self–report). According to the group they were assigned to, participants completed the same memory task in one of the following conditions:

1. In reality, wearing custom made goggles to restrict their FoV, allowing for monocular vision; referred to as the **real-world condition.**
2. Using a photorealistic computer graphics simulation on a monocular head-tracked HMD; referred to as the **HMD mono head tracked condition.**
3. Using the same application on a stereo head-tracked HMD; referred to as the **HMD stereo head tracked condition.**
4. Using the same application on a monocular HMD with a mouse interface; referred to as the **HMD mono mouse condition.**
5. Using the same application displayed on a typical desktop monitor with a mouse interface, wearing the same restrictive goggles as in the real-world condition; referred to as the **desktop condition.**

A week after their experience, all participants were retested on the same memory task.

The Real Environment

The real environment consisted of a four by four meters room (Figure 4). Each wall of this room had a different landmark; one wall consisted of a door and shelves, one wall of a door and a greenboard, the third wall of a whiteboard and the fourth of smaller shelves on both its ends. The existing window in the room was firmly covered with black lining to keep natural light out. The light fixtures in the room were replaced with a standard incandescent bulb (assumed diffuse, light emission in all directions). Several tables were placed close to the walls and 21 primitive objects of approximately the same size (seven boxes, seven spheres and seven pyramids) were scattered around the room, on the tables and shelves. All the objects were painted one shade of blue using the same diffuse paint. A swivel chair was placed in the middle of the room.

The Computer Graphics Simulation

There was tight control over the visual appearance of the experimental space across realworld and simulated conditions. The geometry in the real room was measured using a regular tape measure with accuracy of the order of one centimetre. A photometry instrument (Minolta Spot Chroma meter CS-100) was employed to measure the chromaticity CIE(x,y) and luminance (Y) values of the light and materials in the real room. The Minolta chroma meter is a compact, tristimulus colorimeter for non-contact measurements of light sources or reflective surfaces. Luminance relates to the quality of a colour that most resembles the human's notion of brightness. Bright colours are generally of a high luminance and dark colours are generally of a low luminance. The illuminant (light source) was measured by placing a white sheet of paper in a specific position. Most of the materials (walls, objects, shelves, floor, plugframes) were measured at the same position. To ensure accuracy, five measurements were recorded for each material, the highest and lowest luminance magnitudes were discarded and an average was calculated of the remaining three triplets. However, as this is a room in daily use some variations exist in all of the surfaces due to texture, ageing and dirt.

The CIE (1931) colour space is based on colour matching functions derived by human experimentation and it incorporates the trichromacy of the HVS. The usefulness of the CIE(x,y) representation is that it allows colour specification in one language, however, equal geometric steps of CIE(x,y) space do not correspond to equal perceptual steps. Before specifying display colours, it is necessary to compute the tristimulus matrix of the display in question. In order to compute the RGB tristimulus matrix, the chromaticity coordinates of the three display phosphors in CIE(x,y) space are required. In addition, the chromaticity co-ordinates of the white that the three phosphors of the display produce when turned on at their maximum are also required (Travis, 1991). Generally, the RGB system is a means for describing colours on a display monitor. It does not take into account the energy that is produced in the physical world in terms of the distribution over wavelength and also how the Human Visual System (HVS) responds to this distribution.

For the final measurements, the illuminant had to be taken into account. Measuring a diffuse surface under a given light source results in Yxy values which include the contribution of the light source itself. Incandescent bulbs are quite orange and fluorescent light is quite green, however, the HVS perceives light in relative values and not as absolute measurements such as the ones out of the chromameter. For example, if 1000 is the luminance in the real world, 100 the luminance of a real-world material but 100 the luminance in the computer graphics simulation, then the luminance for the *simulated* material needs to be 10 for the same *ratio* to be preserved.

The colour constancy attribute of the HVS, generally, is responsible for humans perceiving a white sheet of paper as white under a wide range of illumination. If a participant is *immersed* into a synthetic space on a display, theoretically, this should be true as well, however, the small size of the displays prevents colour constancy from occurring. In relevant calculations for simulating real-world illumination in a synthetic world, therefore, colour constancy needs to be enforced in the rendering process since the HVS does not function as in the real world due to the nature of the displays. The colour of the illuminant in RGB values was set as (1,1,1) for the radiosity rendering, e.g. white.

In order to render the scene, the materials' diffuse colour needs to be specified not the colour observed under a particular light source. The final colour for each measured material in the scene is estimated by dividing its RGB value by the RGB value of the observed white in the scene, which is the colour of the light source in the scene. Using the relevant geometry and surfaces and illuminant measurements converted to RGB triplets as input, the rendered model was created using a radiosity rendering system (Figure 4). The final radiosity solution consisted of a finely meshed model which could be interactively manipulated. This was the basis for the application displayed on the desktop monitor and on the HMD. The desktop monitor and the HMD were gamma corrected using the Minolta Spot Chromameter CS-100 in order to acquire relevant luminance readings. When accurate colour specification is required as is often the case in scientific applications, the non-linear relationship between display luminance and voltage is a significant source of error and needs to be corrected to linearity.

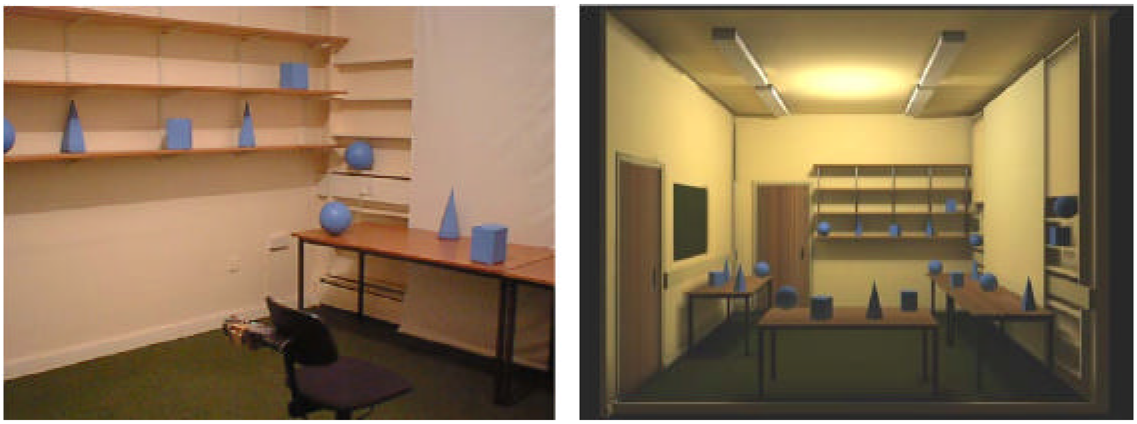

Figure 4 The real-world and the computer graphics simulation.

Figure 5 The real-world and HMD mono/stereo condition (head-tracked).

3. Materials

The five groups of participants were asked to fill in the same set of questionnaires. This set included the SSQ questionnaire (Kennedy et al., 1993) before and after the task, the memory task and memory awareness states questionnaire and the presence questionnaire (Slater et al., 1998).

All participants across the five conditions completed the same memory task a week after the initial experiment reporting on memory recall, confidence and awareness states.

Memory recall task

The memory recall questionnaire was designed to test the participants' memory recall of the positions and geometric shape of the 21 objects in the room. A diagram for each wall in the room included numbered positions of objects in various locations. The diagrams were administered together with the task questionnaire which consisted of 21 multiple choice questions representing the 21 objects in the scene. Every question included three possible answers (box, sphere or pyramid) and a confidence scale with five possible states: No confidence, Low confidence, Moderate confidence, Confident, Certain. Every question also included an awareness states report for every recollection, based on the memory awareness methodology offering four choices: Remember, Know, Familiar or Guess. The participants were required to report on the shape of the object in each numbered position on the diagram, starting with the positions they were more confident they remembered. The design, thus, of the task questionnaire did not force participants to start from a specified position in the room offering the capability to report, initially, their most confident recollections. A pilot study was conducted in order to determine the number of objects and, therefore, the number of questions of recall in relation to the exposure time so as to avoid possible floor or ceiling effects (the task being too easy or too hard). Prior to filling out the core of the task questionnaire, participants were given instructions designed to explain what the memory awareness states depicted as follows:

- REMEMBER means that you can visualise clearly the object in the room in your head, in that particular location. You virtually 'see' again elements of the room in your mind.
- KNOW means that you just 'know' the correct answer and the alternative you have selected just 'stood out' from the choices available. In this case you can't visualise the specific image or information in your mind.
- FAMILIAR means that you did not remember a specific instance, nor do you know the answer. It may seem or feel more familiar than any of the other alternatives.
- GUESS means that you may not have remembered, known, or felt that the choice you selected have been familiar. You may have made a guess, possibly an informed guess, e.g. you have selected the one that looks least unlikely.

Other measures

The presence questionnaire developed by Slater et al. 1998 was designed to measure the level of presence on a Likert 7-point scale and was administered after the initial memory recall task across conditions. The widely used Simulator Sickness questionnaire (SSQ) was administered before and following participants' exposure across conditions (Kennedy et al., 1993).

4. Procedures

The real-world condition

The SSQ questionnaire was administered before exposure. Following this procedure participants were asked to wear any glasses or contact lenses they normally use when they have to focus at 2 meters distance (self-report). Subsequently, their dominant eye was identified by a widely used 'sighting' test. A pre-determined viewing position was set by manipulating the height of the swivel chair according to the individual. Appropriate goggles were worn which restricted participants' FoV to 30 degrees to match the desktop and HMD's FoV allowing for monocular vision through the dominant eye only (Figure 5). The FoV was restricted in the real-world condition to match the FoV of the displays. Although this action resulted in a 'window' to the real world through the goggles, it was considered necessary in order to keep the FoV constant across conditions. Participants were instructed that they would be guided to a room where they would spend three minutes observing by rotating the swivel chair they would sit on placed in the middle of the room, however, they were not aware of the post-exposure task. Navigational patterns and idle time were monitored and recorded during exposure through a digital compass attached on the swivel chair (Mania & Randell, 2002). After the set exposure time of three minutes, participants were guided to the test room where the questionnaire pack was administered together with the appropriate instructions.

The display conditions

The computer graphics application was displayed on a Kaiser Pro-View 30, gamma corrected HMD (Figure 5). The viewpoint was set in the middle of the room and navigation was restricted to a 360 degrees circle around that viewpoint and 180 degrees vertically in order to simulate participants' movement on the swivel chair in the real room (3 degrees of freedom). The geometric FoV was calculated to be the same as the visual angle, through the goggles, in the real room. For the HMD monocular conditions (headtracked and non-head-tracked) the dominant eye was identified and the appropriate screen of the HMD was covered allowing for vision only through the dominant eye. For the HMD stereo head tracked condition each participant's interpupilary distance (IPD) was measured and the stereo application's parallax was set accordingly for the individual. For the desktop condition utilizing a gamma corrected typical 21-inch desktop monitor, each participant's dominant eye was identified and the appropriate goggles were subsequently worn as in the real-world condition. The frame of the monitor was covered with black cardboard to achieve a foreground occlusion effect resulting in a stronger sense of depth. Horizontal rotation was monitored across all conditions (Mania & Randell, 2002). There was no other source of light besides the HMD or desktop display during exposure. The frame rate was retained at 14 frames per second across all conditions. Although this is not a particularly high frame rate, it was considered adequate. The display resolution was 640*480 (HMD maximum resolution) across technological conditions and the FoV was constant (30 degrees) across all conditions including the realworld condition with restrictive goggles fitted. The computer graphics rendering was computed taking into account real world photometric measurements resulting in a photorealistic rendering as described in the previous section. Texture mapping was applied only on the doors and tables in the room.

5. Memory awareness states' statistical analysis

Awareness state data were represented as *prior* and *posterior* probabilities. Koriat & Goldsmith, 1994 have drawn an important distinction between the amount or quantity remembered compared to the accuracy or quality of what is remembered. In the quantity analysis memory awareness states data are represented as *a priori* or *prior probabilities.* Although this notation does not follow the Bayesian probability theory principles for 'prior' probabilities, it is going to be adopted as such in this paper following the characterisations of Koriat & Goldsmith, 1994 as well as Conway et al., 1997. Prior probabilities are obtained by calculating the proportions of correct answers falling in each of the four memory awareness categories for each participant. In the accuracy analysis, correct recall scores are represented as *posteriori* or *posterior probabilities*. In order to calculate posterior probabilities, the proportion of correct answers from the total of answers given in each memory awareness category is computed for each participant.

For participant *n*,

x_{in} is the number of correct answers for the *i* awareness state,

$x_{in}^{'}$ is the number of correct answers for the *i* awareness state,

i = { remember, know, familiar, guess } = { 1, 2, 3, 4 } then,

P_{in} is the prior probability for awareness state *i* related to participant ***n*** (Equation 3.1),

$$P_{in} = \frac{x_{in}}{\sum_{i=1}^{4} x_{in}}$$

$P_{in}^{'}$ is the posterior probability for awareness state *i* related to participant ***n*** (Equation 3.2),

$$P_{in}^{'} = \frac{x_{in}}{x_{in} + x_{in}^{'}}$$

Generally, prior probabilities reflect the following: Given that the response of a participant is correct, what is the probability that the participant has chosen a particular state on that question? Posterior probabilities, on the other hand, pose the following question: Given that a response of a participant was assigned to one of the four memory awareness response categories, what is the probability that the response is correct? For the purpose of this study each memory recall question included a 5-scale confidence scale and a choice between 'remember', 'know', 'familiar' as well as 'guess' awareness states. The goal of this strategy was to identify the distributions of awareness states responses across conditions focusing on visually induced recollections. This could reveal variations that wouldn't be possible by just counting right and wrong answers.

6. Discussion and summary of results

This investigation focuses on the effect of different viewing conditions (direct perception of objects in a real-world setting versus perception of the computer graphics representation of this setting) on observers' attributions regarding object-location memory. Accuracy of performance per se is an imperfect reflection of the cognitive activity that underlies performance in memory tasks. Accurate memory can be supported by either a recollection of prior specific experience (remembering) or reliance on a general sense of knowing with little or no recollection of the source of this sense (knowing) including familiarity and guesses even if informed. Training in a VE system capable of perfectly simulating the real world should result in the same training effect as that in the real world. The participants who mentally visualised the room and the objects in the room during retrieval had a higher proportion of correct responses under the 'remember' awareness state. The participants that employed mnemonics' strategies based on words instead of visually retaining elements of the space reported the 'know' awareness state which resulted in a proportion of correct responses linked with the 'know' awareness state. If a weaker trend of non-visually induced recollections is employed by participants towards stronger visually induced recollections linked to the 'remember' awareness state, it could be assumed that their mental representation of a space involved more 'vivid' recollections.

There was a significant main effect of condition upon the 'remember' awareness state. It was anticipated that the amount of correct 'remember' responses would be higher in conditions incorporating more 'naturalistic' interfaces such as head tracking. However, results revealed that the proportion of correct responses linked with the 'remember' awareness state was significantly higher for the HMD mono mouse condition compared to the HMD mono head tracked and HMD stereo head tracked conditions (initial task). Crucially, these responses correlated positively with confidence scores. Therefore, an interface of high simulation fidelity such as head tracking does not always correspond to visually induced memory awareness states. A similar result was revealed in a preliminary study by Mania & Chalmers, 2001. If specific applications require a high amount of recollections based on visual mental imagery, a 'natural' interface such as head tracking may not be appropriate. Therefore, desirable variations of awareness states for specific application purposes could be identified. It could be true, for instance, that for flight simulation applications it is crucial for trainees to achieve a high level of visually induced recollections related to instruments as opposed to feelings of familiarity of even confident recollections which are not accompanied by visual imagery. If 'reality' is associated to the degree of similarity to the real world task situation then, in this case, the HMD mono mouse condition is not very 'real'. The awareness states distribution is affected by the degree of 'realism' of the motor response. Word based mnemonics and, generally, recollections that were not linked to visually induced recollections were identifiable by the high proportion of correct 'know' responses. The utilisation of a viewing method such as the HMD together with an 'unreal' motor response such as the mouse, appeared to have prevented participants employing non-visually induced recollections and resulted in a larger distribution of correct responses assigned to the 'remember' awareness state. By decreasing the degree of 'reality' of the motor response, participants -paradoxically adopted visually induced recollections. Achieving high fidelity could incorporate the need for similar awareness states between a real-world task situation and its computer graphics simulation. Here, something less 'real', therefore, less computationally expensive but more demanding because of its novelty may restore a more 'naturalistic' or desirable awareness state. Research could identify such issues by using methodologies that allow investigations based on the cognitive activity expressed by awareness states responses. Additionally, a significant shift of correct 'remember' responses in the initial task to correct 'guess' responses in the retest was observed. This shift was observed across all conditions and it did signify a lower amount of correct recollections between initial test and retest.

The task employed in this study did not allow for free navigation around the experimental space. The FoV was restricted in the real-world setting to match the FoV of the displays for methodological reasons. Future work could include a task which would allow freedom of navigation and also a testing strategy which would incorporate transfer of training in the real-world. Matching participants' performance in simulations to performance in a real-world situation does not guarantee that the cognitive activity linked with performance will be similar across the simulated conditions.

Task performance scores could, therefore, be taken into account according to specific awareness states. By employing methodologies, such as the memory awareness states methodology, computer graphics and VE technology research could exploit human perceptual mechanisms towards successful applications.

REFERENCES

Argyle M. (1976). Bodily Communication, Methuen & Co Ltd, London. Baddeley, A.

(1997). *Human Memory, Theory and Practice.* Psychology Press.

Bailey, J.H., Witmer, B.G. (1994). Learning and Transfer of Spatial Knowledge in a Virtual Environment. *Proc. of the Human Factors & Ergonomics Society 38th Annual Meeting,* 1158-1162, Santa Monica, CA: Human Factors & Ergonomics Society.

Benford S., Bowers J., Fahlen L.E., Greenlhalgh C., Snowdon D. (1997). Embodiments, avatars, clones and agents for multi-user, multi-sensory virtual worlds, *Multimedia Systems,* Springer-Verlag.

Carlsson C. Hagsand, O. (1993).DIVE A multi-user virtual reality system", IEEE Virtual Reality Annual International Symposium (Cat. No.93CH3336-5).

Conway, M.A., Gardiner, J.M., Perfect, T.J., Anderson, S.J., Cohen, G.M. Changes in memory Awareness during Learning: The Acquisition of Knowledge by Psychology Undergraduates. *Journal of Experimental Psychology, Vol. 126, No4,* 393-413, 1997.

Coolican, H. (1999). *Research Methods and Statistics in Psychology,* 3rd edition. Hodder & Stoughton.

Demuynck, K. Broeckhove, J. Arickx, F. (1996) "The impact of communication mechanisms on the performance in a distributed virtual reality system", *Proc. Of the International Conference and Exhibition HPCN EUROPE.*

Gardiner, J.M. (2000). Remembering and Knowing. In the E. Tulving and F.I.M. Craik (Eds.) *Oxford Handbook on Memory.* Oxford University Press.

Gregg, V.H., Gardiner, J.M. (1994). Recognition Memory and Awareness: A Large Effect of Study-Test Modalities on 'Know' Responses Following a Highly Perceptual Orienting Task. *European Journal of Cognitive Psychology, 6(2),* 131-147.

Guye-Vuilleme A., Capin T. K., Pandzic I.S., Thalmann N.M, Thalmann D. (1998). Nonverbal Communication Interface for Collaborative Virtual Environments, *Proc. of CVE'98,* Manchester, UK.

Kennedy, R.S., Lane, N.E., Berbaum, K.S., Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An Enhanced method for Quantifying Simulator Sickness. *The International Journal of Aviation Psychology, 3(3),* 203-220.

Koriat, A., Goldsmith, M. (1994). Memory in Naturalistic and Laboratory Contexts: Distinguishing the accuracy oriented and quantity oriented approaches to memory assessment. *Journal of Experimental Psychology: General,* 123, 297-315.

Lathrop, W.B. Kaiser, M.K. (2002). Perceived Orientation in Physical and Virtual Environments: Changes in Perceived Orientation as a Function of Idiothetic Information Available. *Presence: Teleoperators and Virtual Environments*,11(1), 19-32. MIT Press.

Mania, K. (2001). On Simulation Fidelity and Naturalism of Virtual Interfaces (2001). *Proc. of the IEEE VR 2001 workshop on 'The Future of VR and AR Interfaces: Multimodal, Humanoid, Adaptive and Intelligent'*, GMD Publications.

Mania, K. (2001). Connections between Lighting Impressions and Presence in Real and Virtual Environments: An Experimental Study. *Proc. of Afrigraph 200.* ACM Publications.

Mania, K. (2001). Fidelity Metrics for Virtual Environment Simulations based on Spatial Memory Awareness States. Ph.D thesis, University of Bristol, UK, Dept. of Computer Science.

Mania, K. (2001). Strategies for the Assessment of Simulation Fidelity in VEs. In Billinghurst, M., Ellis, S., Mania, K., Steed, A. Usability Evaluation Techniques for Virtual Reality Technologies course notes, IEEE Virtual Reality 2001, Japan, 5-27.

Mania, K. (2002). Spatial Perception, Memory and Performance in Synthetic Worlds. In Biocca, F., Brooks, F.P. Jr., Ellis, S., Mania, K., Slater, M., Steed, A., Whitton, M. Understanding Virtual Environments: Immersion, Presence, and Performance. ACM Siggraph 2002 course notes, San Antonio, USA, full-day course.

Mania, K. (2002). Realism and Fidelity in Computer Graphics. In Billinghurst, M., Ellis, S., Mania, K., Steed, A. Usability Evaluation Techniques for Virtual Reality Technologies: Human Factors Issues, course notes, IEEE Virtual Reality 2002, USA, 3068.

Mania, K. & Chalmers, A. (1998). A Classification for User Embodiment in Collaborative Virtual Environments. *Proc. of the 4th International Conference on Virtual Systems and Multimedia (VSMM 98),* 177-182. IOS Press - Ohmsha, Ltd.

Mania, K. & Chalmers, A., (1999). Between Real and Unreal: Investigating Presence and Task Performance, A Pilot Study. *Proc. of 2nd International Workshop on Presence,* University of Essex, Colchester, UK. ISBN 9-386-1571-X.

Mania, K. & Chalmers, A. (2000). A User-Oriented Methodology for Evaluating Virtual Environment Applications. *Proc. of 3rd International Workshop on Presence,* Delft, Netherlands. ISBN 9-386-1571-X.

Mania, K. & Chalmers, A. (2001). The Effects of Levels of Immersion on Presence and Memory in Virtual Environments: A Reality Centred Approach. *Cyberpsychology & Behavior*, *4(2),* 247-264.

Mania, K., Chalmers, A, Troscianko, T., Hawkes, R. (2000). Presence and Task Performance: A Reality Centred Approach. Technical Sketch, *Proc. of ACM SIGGRAPH 2000,* 245.

Mania, K., Chalmers, A., Troscianko, T., Hawkes, R. (2001). Simulation Fidelity Metrics for Virtual Environments based on Memory Semantics. Technical Sketch, *Proc. of ACM SIGGRAPH 2001,* 258-258.

Mania, K., Chalmers, A. (2001). The Effects of Levels of Immersion on Presence and Memory in Virtual Environments: A Reality Centred Approach. *Cyberpsychology & Behavior, 4(2),* 247-264.

Mania, K., Randell, C. (2002). Monitoring Navigational Strategies and Idle Time in Real and Virtual Environments: An Experimental Study. *Proc. of the 8th International Conference on Virtual Systems and Multimedia 2003 (VSMM),* Korea, Kiwisoft Company Ltd., 327-335.

Slater, M., Steed, A., McCarthy, J., Maringelli, F. (1998). The Influence of Body Movement on Subjective Presence in Virtual Environments. *Human Factors: Journal of the Human Factors Society,* 40(3), 469-477.

Smith, M.E. (1992). Neurophysiological Manifestations of Recollective Memory Experience during Recognition Memory Judgements. *Journal of Cognitive Neuroscience,* 5, 1-13.

Stanney, K.M., Salvendy, G., Deisigner, J., DiZio, P., Ellis, S., Ellison, E., Fogleman, G., Gallimore, J., Hettinger, L., Kennedy, R., Lackner, J., Lawson, B., Maida, J., Mead A., Mon-Williams, M., Newman, D., Piantanida, T., Reeves, L., Riedel, O., Singer, M., Stoffregen, T., Wann, J., Welch, R., Wilson, J., Witmer, B. (1998). Aftereffects and Sense of Presence in Virtual Environments: Formulation of a research and development agenda. Report sponsored by the Life Sciences Division at NASA Headquarters. *International Journal of Human-Computer Interaction,* 10(2), 135-187.

Travis, D. (1991). *Effective Color Displays.* Academic Press.

Tulving, E. (1985). Memory and Concioussness. *Canadian Psychologist, 26,* 1-12.

Tulving, E. (1993). Varieties of Concioussness and Levels of Awareness in Memory. In A.D. Baddeley and L. Weiskrantz (Eds.), *Attention: Selection, Awareness and Control.* A tribute to Donald Broadbent, 283-299. London: Oxford University Press.

Waller, D., Hunt, E., Knapp, D. (1998). The Transfer of Spatial Knowledge in Virtual Environment Training. *Presence: Teleoperators and Virtual Environments, 7(2),* MIT Press.

Wilcox S.K. (1998). Guide to 3D Avatars, John Wiley and Sons Inc.