An Experimental Exploration of Presence in Virtual Environments

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ABSTRACT

This paper discusses an experimental study on factors influencing presence in immersive participatory virtual environments - commonly known as virtual reality. We consider in particular the architectural walkthrough application context. The study was interested in whether the possession of a virtual body in the environment, which may be important in architectural walkthrough, was a contributory factor to presence. Presence was measured by reporting of the subjects in the experiment, and by observations on their behaviour under certain experimental conditions. After examining some intuitive ideas of what is likely to contribute to presence, we discuss the design of this pilot study and report on the results. We found that the speed at which subjects adapt to changes in their environment in real life, may be an important factor. This happened to be confounded with the experimental case-control design, so that no clear conclusions could be drawn about the influence of the virtual body. We report directly on the comments of the subjects, and also on a small follow-up and in-depth study.

1. Introduction

This paper describes a pilot study to examine the factors contributing to presence in a participatory immersive virtual environment (VE). We do not attempt a rigorous definition of presence for the time being but rather rely on the intuitive notion that it is the sense of the human subject that he or she has been "somewhere else" - somewhere other than where his/her real physical presence actually was during the time of the experience. This "somewhere else" is a virtual environment - where we follow Ellis' definition of virtualisation as "the process by which a human viewer interprets a patterned sensory impression to be an extended object in an environment other than that in which it physically exists" (Ellis, 1991). The sense of a human subject of being present in such an alternative, virtual environment may be determined by reports of the person involved, and by experimenters observing physical and physiological responses of the subject to events generated in the virtual environment.

Such immersive virtual environments were first proposed by Sutherland in 1965 and realised in 1968 with a head-mounted display, that could present a user with a stereoscopic 3-dimensional view slaved to a sensing device tracking the user's head movements (Sutherland 1965; 1968). The views presented at that time were simple wire frame models. The advance of computer graphics knowledge and technology, itself tied to the enormous increase in processing power and decrease in cost, together with the development of relatively efficient and unobtrusive sensing devices, has led to the emergence of participatory immersive virtual environments, commonly referred to as "virtual reality" (VR). (Fisher 1982; Fisher et. al. 1988; Teitel 1990; see also SIGGRAPH Panel Proceedings 1989,1990).

The important factor which distinguishes so-called VR from other forms of interaction is the *presence* of the human inside the virtual world. We call the human the *subject,* as distinct from the objects with which he or she interacts. This presence ideally must be maintained in the Visual, Auditory, Tactile and Kinesthetic (Haptic) fields. The subject no longer sees an agent of his or her activities from the outside (ie, through manipulating and watching a cursor), but experiences the virtual world, moves through, and interacts with it, from the unique perspective of that individual.

The work described in this paper is for a project on architectural walkthrough, that is a program that will allow architects and their clients, to navigate and modify virtual building structures, their contents and lighting (Brooks, 1987). An important aspect of such research is correct lighting visualisation, which has received great attention in the computer graphics literature, for example, the radiosity paradigm (Goral et. al., 1984; Cohen and Greenberg, 1985; Cohen et. al., 1988), and the achievement of interactive update rates for photo-realistic images, for example (Airey, 1990). Another partner in the project is concentrating on such issues (Harriss and McKellar, 1992). Our work, however, is concerned with the other side of the equation, that is the human response to the virtual environment - in particular the degree of presence, and the influence on this of the human having a virtual body within the VE. This is particularly important for architectural walkthrough, which can be deemed successful to the extent that the participant experiences a sense of having visited the locale that the virtual environment purports to simulate. Given the sense of presence in the virtual building the participant can make informed judgements based on first hand experience as to its aesthetic and functional qualities.

In Section 2 we discuss in more detail the idea of presence and factors believed to contribute to it. In Section 3 we describe the system in which our work was carried out, and the experimental design for the pilot study, with some results presented in Section 4. The major part of the study involved seventeen subjects, and information was gathered from them by (video taped) observation during the course of their virtual environment experience, and from follow up questionnaires. Even though this pilot study was with a relatively small number of people, a great deal of information was collected, and some general observations are presented in Section 5. There was a further in depth study of three other people, the results of which are described in Section 6. The overall conclusions and recommendations are given in Section 7.

2. Presence

2.1 Application Domain

Zeltzer notes that the meaning of presence is inseparable from a specification of the application domain and task environment in which the subject is to be present (Zeltzer, 1992). In architectural walkthrough, we have taken the point of view that the task is threefold:

2.1.1 Walkthrough: The client requires the ability to walk through, view and evaluate the simulated environment, in order to form a judgement about its aesthetic qualities. This may be concerned purely with the interior of the structure, in which case its lighting characteristics are particularly important. It may be concerned in addition with the exterior of the structure, in which case relationship to the environment becomes an important issue. In our research we are concentrating only on interior walkthrough.

2.1.2 Interact: The client requires the ability to rearrange the structure and contents of the interior design. This may involve changing the lighting conditions, rearranging furniture, and so on. This is based on the interactive facilities offered in the VE.

2.1.3 Operate: The client requires the ability to judge the functional characteristics of the structure - for example, to go through doors, the relationship between doors and light switches (can the client find the door after having switched off the lights at night?), spatial relationships, functional relationships between furniture and amenities and so on. In other words, the client must be able to effectively operate in the environment.

Task 2.1.1 in itself may not require full immersion in the VE - lighting effects, structural qualities relating to aesthetics may be ascertainable from exterior views, and from the relationship between such views (sketches, photo-realistic images and simulated walkthroughs on a display) and the mental model of the designer. Nevertheless, psychologically, it is quite fundamentally different to experience a structure from the "inside" compared to the outside, though the effects of such an associated perspective compared to a dissociated one on task performance remains unknown. The recent recommendations (NSF,1992) suggest studies to compare performance between these two situations.

Task 2.1.2 again, in itself, does not require full immersion - it is possible to adopt a "remote manipulation" paradigm and interact with a 3-dimensional environment from the outside, using suitable input devices, for example the six degree of freedom input device discussed by (Ware and Osborne, 1990).

Task 2.1.3 we believe is essentially impossible to simulate except with the client present in the VE. How can a judgement be formed about the ease of use of the facilities of the environment without, to some extent at least, being able to use them? Understanding the sense of being inside a building, understanding the spatial relationships between artifacts, knowing whether it is possible to open a door inwards on a small room, and still conveniently get out of the room requires that the client be in that room and try it out.

Task 2.1.3 is the most general purpose of all three, and effectively, is concerned with the issue "what is it like to be inside and operate effectively in this structure?" Held and Durlach (H&D) note that in such a general purpose problem, a high degree of presence is required "because the best general purpose system known to us (as engineers) is us (as operators)". (Held and Durlach, 1992). H&D were writing in the context of telepresence in the context of teleoperation systems, but the same applies to presence in a VE.

We suggest that the combination of all three tasks carried out inside the virtual environment provides the client with a richer appreciation of all three, a totality of the experience of being in that structure - though we have not addressed this issue in the current series of experiments.

2.2 Factors Contributing to (Tele)Presence

The concept of telepresence has received attention in the teleoperation literature (Akin et. al., 1983), and it is recognised that many of the same issues arise with respect to presence in VEs. In the first issue of the first scientific journal devoted to "teleoperators and virtual environments" (Presence) there is a discussion of the concept of telepresence including the factors contributing to it, and its measurement. (Held and Durlach op. cit.; Loomis, 1992; Sheridan, 1992; Zeltzer, op. cit.) although it is noted (H&D) that "there is no scientific body of data and/or theory delineating the factors that underlie the phenomenon".

To summarise the contributions of these authors, presence is likely to increase when:

2.2.1 high resolution information is presented to the appropriate sensory organs;

2.2.2 the information is free from signals that indicate the existence of the input device, or display (such signals would include three categories - those directly due to the information display systems, such as aliases, slow update rates; the input systems - such as interference caused by metalic objects in the polhemus sensors; and the physical properties of the devices themselves - weight, cables, and so on);

2.2.3 there is a wide range of interactions based on movement of the subject's sensory organs - such as movement of head to change viewpoint or modify binaural hearing, ability to search using the sense of touch;

2.2.4 the operator can view effector movements - for example, move his/her hands and see them move;

2.2.5 there is a high correlation between movements of the operator sensed directly and the actions of the slave robot;

2.2.6 there is the ability to change the physical environment;

2.2.7 the information received through channels to all sensory organs should describe a consistent world;

2.2.8 there is an identification between the operator's own body with that of the slave robot;

2.2.9 there is a similarly in visual appearance of the operator and slave robot;

2.2.10 there is adaptation through learning over time and thus an increase of operator familiarization with the relationship between motor actions, controls and feedback through the input channels to the senses.

Loomis notes the similarity between the concept of telepresence and "distal attribution": "most of our perceptual experience, though originating with stimulation of our sense organs, is referred to external space beyond the limits of the sensory organs". Loomis, following White (White, 1970) hypothesizes that distal attribution (and by implication presence) results "when afferance is lawfully related to efference" - that is in the feedback loop from operator (use of motor effectors) to system to operator (the effects experienced by the operator as a result of operator actions) form a consistent and lawful whole. Loomis goes on to postulate that distal attribution also requires that the operator model the linkage (between afference and efference) and that the linkage becomes transparent. This would be as if the operator actions were directly causing the observed results, rather than being mediated via a complex person-machine interactive system. If the means of controlling the system is so complex that the operator cannot over time model the system, then distal attribution cannot occur.

2.3 Achievement of Presence

If we take each of the factors 2.2.1 through 2.2.10 thought to contribute to telepresence, and consider these in relation to presence in VEs, we find that there is a great amount of progress to be made. The subject controls a polhemus based tracker, such as the VPL DataGlove, or DIVISION 3D mouse, and sees a representation of his/her hand in the VE, or as an alternative in the case of DIVISION's ProVision system, a three dimensional arrow - in each case slaved to the movements detected by the sensors. In such systems, the subject is present through a disembodied viewpoint, and a disembodied limb - respectively controlled by sensors on the headmounted display and hand held tracking device or data glove.

Requirements 2.2.1 through 2.2.3 are met to only a limited degree. Typically, today's systems present only visual and auditory information to the subject - with no tactile or kinesthetic feedback - though there have been advances with respect to this (Brooks et. al. 1990; Hannford, 1989; Iwata, 1990; Kaufman, et. al., 1990; Marcus, 1992). The visual information is low resolution, with a restricted field of view (little peripheral vision), and does not attempt a complete compatibility with the way that the human visual system operates. For example, no allowance is made for accommodation. Some recent research and products point the way to an improvement of this state of affairs, for example, (Liang et. al, 1991; Deering, 1992). For a discussion of progress in auditory systems see (Wenzel, 1992).

The display and input devices themselves may be relatively heavy, clumsy and obtrusive - and sensing devices require that the subject stay within a limited area. Substantial lags may be introduced in the system, through the sense ∅ compute∅ display cycle involved in responding to every motor action of the subject. Artifacts and aliases are introduced into the display system, through the low resolution and relatively poor shading models.

Requirements 2.2.4 and 2.2.5 are usually satisfied to the extent that the subject's body is mapped by sensors. With the VPL entire body suit (see Panel Proceedings, SIGGRAPH 1989) it would be possible to monitor a wide range of motor actions with the subject being able to see the results of such actions. When there are only head and hand movements monitored, it is the case that the subject experiences the results of head movements as changes in view and sees the results of hand movements.

Requirement 2.2.6 is satisfied to the extent that typically the subject can select and move objects - and thus alter the VE. Requirement 2.2.7 that the information received on all channels should describe a consistent world may be satisfied within the constraint imposed by the lag time.

Requirements 2.2.7 and 2.2.8 are typically not satisfied - the subject becomes a disembodied viewpoint with a disembodied limb in the VE - unlike teleoperation, there is no virtual body with which the subject can identify.

Requirement 2.2.10, concerning adaptation over time - there is nothing special in VEs concerning this factor - except that unlike, say, standard point and click user interfaces, there is a high probability that the subject may suffer discomfort, such as motion sickness - and thus discourage the possibility of experimentation and long term familiarisation.

Loomis' point about the lawful relationship between efference and afferance perhaps implies that the world experienced by the senses not only be consistent, but also consistent with the reality domain simulated by the VE (if indeed there is one). For example, does "lawful relationship" require that when the subject attempt to walk through a virtual wall, that he bounces off - experiences pain, hears the associated noise that would accompany this event in everyday reality?

Given the small extent to which typical VR systems match the requirements thought to influence presence, it is remarkable that any degree of presence is achieved at all. Yet anecdotal stories, subjective experience of the authors, and the results of the pilot study to be described in this paper do support the fact that sometimes some subjects report a very high degree of presence, and their observable actions while in the VE support this claim. Probably the degree of presence is not a simple additive consequence of factors 2.2.1 to 2.2.10, but is a non-linear, maybe catastrophic response with some factors outweighing others - with the precise combination of factors needed is likely to depend greatly on the psychological make-up of the individual. For example, just being immersed in a VE by means of a HMD viewing an animation might not lead to any degree of presence, but being able to effect changes of view by head movements is likely to lead to a qualitative jump in the degree of presence, and being able to intervene changing the course of the animation is likely to lead to yet another qualitative jump; being able to feel the objects touched in the interaction, and hear the results of actions to a further jump; and so on. For another person, however, each of these factors might be outweighed by the time lag and screen flicker - such a person when mounting the HMD would only ever see pixels.

2.4 Measuring Presence

Both Held and Durlach, and Sheridan note that there are currently no accepted measures of the degree of telepresence experienced by an operator. Such measures are crucial to advance our understanding of the factors relating to presence, and to allow appropriate empirical studies of the phenomenon. They suggest measures embodying:

• subjective report;

• objective response, that is measures based on observable behaviour of the operator - such as the reaction to danger in the virtual environment;

• socially conditioned response - that is the extent to which the operator responds automatically to social encounters within the virtual environment.

3. The Pilot Study

3.1 Background

Our aim was to gain an overall understanding of presence in a VE, particularly related to architectural walkthrough, so as to guide the design of the subject oriented interface in future versions of the walkthrough software. We realised that there is so little existing knowledge in this area, that it would be impossible to conduct a full-scale study immediately, rather a pilot study was planned in order to gather initial information, and thereby help in the design of a later and more complete study.

In this work, the only factors under our control were those relating to the software implementing the subject interaction with the environment, and the structures displayed in the VE. We had a given hardware configuration and thus factors in Section 2.2 that are hardware dependent could not be changed.

The experiments described in this paper were implemented on a DIVISION ProVision system, a parallel architecture for implementing virtual environments running under the dVS (v0.1) operating environment. The ProVision system is based on a distributed memory architecture in which a number of autonomous processing modules are dedicated to a part of the virtual environment simulation. These processing modules or Transputer Modules (TRAMs) are small self-contained parallel processing building blocks complete with their own local memory and contain at least one Inmos Transputer which may control other specialised peripheral hardware such as digital to analog converters (DAC). Several modules exist. These include

• the module to act as the module manager.
• the DAC module for audio output.
• polygon modules for z-buffering and Gouraud shading.
• application specific module for the user application.

The dVS operating environment (Grimsdale, 1991) is based on distributed Client/Server principles. Each TRAM or processing cluster is controlled by an independent parallel process known as an 'Actor'. Each provides a set of services relating to the elements of the environment which it oversees. Such elements presently consist of lights, objects, cameras, controls (i.e. input devices), and collisions between objects. Thus, an Actor provides a service such as scene rendering (visualisation actor). Another Actor may be responsible for determining when objects have collided (collision actor) and yet another for hand tracking and input device scanning (gls actor). All these Actors are co-ordinated by a special Actor called the

Director. Communication between the different Actors can only be made via the Director. The Director also ensures consistency in the environment by maintaining elements of the environment which are shared by the different Actors.

The Virtual Reality system itself is comprised of a standard ProVision system, a DIVISION 3D mouse (the input device), and a Virtual Research Flight Helmet™ as the head mounted display (HMD). A flock of two Ascension Birds™ is used for position tracking of the head and the mouse and readings are measured in inches. The PAZ scene renderer is used to generate the images. This is performed using an Intel i860 microprocessor (one per eye) to create an RGB RS-170 video signal which is fed to an internal NTSC video encoder and then to the displays of the Flight Helmet™. These displays (for the left and right eye) are colour LCDs with a 360 ∞ 240 resolution and the HMD provides a field of view of about 100□ along the horizontal with a consequent loss of peripheral vision.

3.2 Objectives

Task 2.1.1 (walkthrough) in architectural walkthrough, does not especially demand presence, however, if there is immersive presence, then it might be useful for the client to have a Virtual Body (VB) - in order to judge spatial dimensions. Task 2.1.2 (interaction) does not demand presence, but it does demand that the client have some representation in the VE with which to effect changes. Task 2.1.3 (effective operation) not only demands presence, but also requires that the client have a virtual body (VB). Recall that this task requires that the client get through doors, reach light switches, navigate through rooms with furniture (maybe at night with the lights off), and so on. These tasks are intrinsically connected to the relationship between the body of the client and the physical surroundings in which it exists. Factors 2.2.8 and 2.2.9 also require that the subject have a body in the VE, thought to contribute to an increased sense of presence. An objective of the research, in addition to studying factors related to presence was in particular to study whether granting the subject with a body made any difference to the sense of presence.

A second objective was to begin the process of constructing a measure of presence. Subjective reporting is one approach, but probably insufficient. People are often unreliable witnesses of their own behaviour - so that external verifications of the degree of presence also seemed appropriate. These were based on the reactions of subjects to relatively "dangerous" events presented to them in the VE, to their response to a socially conditioned situation, and the extent to which they would react to or remember disturbances that occurred outside of the VE.

3.3 Experimental Design

Twenty students studying human computer interaction on a Masters program were invited to take part in the study as subjects. They were told nothing about the purposes of the study, except that it involved "virtual reality". They were divided into two groups - roughly matched with respect to sex and whether or not they were native English speakers, and half assigned to a control group and the other half to the experimental group. Finally seventeen actually students participated in the study, nine of whom were in the experimental group.

Each subject was told not to discuss the experiment with anyone else until after a certain date, shown the equipment (HMD and mouse), and then entered into the VE by putting on the HMD. The subject was also told that they could "end the experiment at any time they wanted".

The environment consisted of a corridor showing six doors on the left hand side (Figure 1). On the floor in the middle of the corridor was a cube. The subject was told how to operate the controls for navigation - pressing the thumb down left would move the subject forward, and the thumb down right, backwards. Direction of movement was a function of where the subject was pointing.

The subject was then told to go to the far end of the corridor and stop, and then told to reverse until the block in the center of the corridor was visible. The subject was then instructed to pick up the block by "touching" it, and pulling in the first finger. The subject was encouraged to move the block around and then drop it. A successful object selection would be accompanied by a sound, indicating that the object had been grabbed. The environment in which the experiments took place did have gravity, but objects did not have a center of gravity so that a falling object would stop falling as soon as any part of it touched the floor (for example, on a corner or an edge). Although dVS supports object collision detection, this was not made use of in order to prevent the interpenetration of objects. In particular the representation of the subject's "hand" would penetrate an object that was to be lifted.

The subjects were directed in through the door leading to the first room. Entry through a door occurred by touching the door with their "hand" - then it would open and the subject could enter inside. Accompanying the opening door, the subject would hear a sound on the HMD earphones - something like a door creaking open. Inside the first room a particular experiment was conducted, and then the subject would be directed to leave the room and return to the corridor, enter the next room, and so on for each of the six rooms. There was nothing to stop a subject going through a corridor wall, or through the wall of a room, except this would lead to "nowhere" - ie, a black void.

Each of the subjects were instructed by the same guide. The view seen by the subjects in the VE was also displayed on a TV monitor, hidden from them. For each experiment there would be at least two experimenters in the room, one acting as guide and the other as an observer taking notes on the subject's reactions. The proceedings were videotaped - both the responses of the real subject, and the view seen in the VE as shown on the monitor. The subjects were in the virtual environment for between 13 and 27 minutes.

At the end of the experiment, the HMD was removed, and the subject immediately asked "How are you right now?" A questionnaire was then given, and the subject taken to another room to complete this. The questionnaire was in two parts, the first to be completed immediately, and the other to be taken away and completed twenty four hours later. The first part consisted of a number of open ended questions relating to the subject's physical and mental reactions, a direct question on their sense of presence and the factors that increased or decreased this, information regarding their sex, previous experience with VR, and extent of computer games playing. There were supplementary questions on their automobile and bicycle driving experience, their frequency of movie watching, and the extent to which they "identify" with characters or the situation in movies. The final question asked about their speed of adaptation to new surroundings, for example when visiting another country. The first questionnaire was collected before they left the building. The Appendix shows an extract from the questionnaire, and some of the responses to the open-ended questions.

The second part of the questionnaire was to ask the subjects to recall their experiences in the VE, and to write down anything else that they wanted in relation to the experience, especially anything concerning their sense of presence. The purpose of this was to test the extent and quality of their memory of the experience, and to provide a cross check against their answers to the first part of the questionnaire, and to their reactions as recorded by the observer.

3.4 The Virtual Body

The control group subjects were endowed only with a disembodied three dimensional arrow cursor, that responded correctly to hand movements with the 3D mouse in terms of orientation. The experimental group were bestowed a virtual body. This consisted of a hand that correctly responded to use of the controls on the 3D mouse - for example, when the subject pressed the left thumb button, their virtual left thumb would move appropriately, and similarly for the middle and right thumb buttons. The initial configuration of the virtual hand essentially matched the subject's true hand position while holding the 3D mouse - except that the first finger was shown pointing. When the subject pulled the first finger on the trigger, then again, the virtual first finger would correspondingly bend. The hand was connected to an arm, and the subject could easily bend and twist the arm and hand - for example, bring the palm or back of the hand to his/her eyes in order to look at it.

The subjects were given a complete and connected body. When they looked down to the left they would see another arm, and all the way down, feet on the ground (Figure 2). Of course, only the virtual right hand and head could be moved directly. However, the system was programmed so that when the subject moved his/her head around by an angle greater than 60 degrees, the entire body would be rotated accordingly. For example, if the subject moved his real entire body around greater than this angle then the virtual body would rotate correctly. If the subject turned only his head by greater than this angle and then looked down while turned, his virtual feet would be out of alignment with his real feet.

We found when using the system that we had a strong desire to align our real body with the view of our virtual body - for example, to align our left hand with the immovable virtual left hand, and to keep our real feet and body orientation to the virtual. Often we would be doing this unconsciously, and an observer would note the fact. It was as if the loop went both ways - use of our real bodies obviously determining the virtual body, but the virtual body also determining the posture of the real body. An interesting subsidiary objective of the experiment was to see if this two-way feedback could be observed in subjects other than ourselves, and also the extent to which this correlated with presence.

In everyday reality we are visually aware of our bodies through peripheral vision. In the VE this was not the case - subjects in both groups were encouraged on entering each room to look "all around and up and down" to ensure that those with a body were able to see it during the course of the experiment.

A script for the guide was prepared and tested, and adhered to as far as possible to ensure uniformity of instruction for all subjects.

3.5 The Rooms

Each of the six rooms had a particular purpose with respect to the objectives of the experiment.

Room 1: Navigation

This room was filled with everyday objects such as furniture, tables, chairs and so on, as might be seen in any office - except perhaps for the number of objects and their layout (Figure 3). The subject was instructed to "go to the other side of the room and then stop" and then to locate the door back to the corridor and to go there and back out of the corridor. The purpose of this experiment was to record the number of collisions made with the furniture - this was recorded automatically by the software. The hypothesis behind this experiment was that those with a body would be likely to make less collisions - perhaps through having a body being more careful, or maybe just by the fact of being able to judge their spatial relationship to objects in the room better than those just with the disembodied arrow 3D cursor.

Room 2: Flying Objects to the Body

When the subject entered this room various objects would fly toward the subject at the body level. The idea behind this was to see whether those with a body would react differently to those without - would it be a significant event for those with a body, and not for those without? Unfortunately, this experiment failed - most subjects did not actually see the objects flying towards them at all - but only the effect of objects attaching themselves at chest level to their virtual person (whether with or without body). That is, invariably while the objects were flying towards them, the subjects happened to be looking elsewhere - a failure of the software implementation rather than the idea of the experiment itself.

Room 3: Building a Pile

This room consisted of a set of different coloured blocks. The subjects were instructed to build a pile, using all of the blocks. There were several purposes to this: first, when an experimental group subject picked up a block, he or see would clearly see his lower body and left arm during the process of lifting (Figure 4). Second, on selection of a certain colour, the experimental group subject's virtual body would disappear leaving only the hand. The purpose of this was to see if the subject would react to disappearance of the body. Third, this was giving all subjects a definite and relatively complex task to do - involving both moving and manipulating. We wanted to assess the extent to which subjects would later report an increased sense of presence while in this room.

Room 4: Flying Objects to the Face

This was similar to Room 2, except that the path of the objects would be towards the face of the subjects. We were interested in whether the subject would show any "ducking" reaction. All subjects did notice these flying objects, although their responses differed.

Room 5: Upside Down

This room had the standard floor pattern painted on the ceiling, and the standard ceiling pattern on the floor. All subjects were asked to look up, and those with a virtual body would see their feet up above them - as if they were upside down. Our purpose was to see the effect of great disparity between subjects sense of orientation and the information presented to their visual system.

Room 6: Walk the Plank

The final room consisted of a chess board with two pieces, and a plank over the abyss (Figure 5). The subjects were asked to look around, and then pick up a chess piece and carry it onto the edge of the plank. The plank overlooked another chess board about eighteen feet below. The subjects were asked to drop the chess piece over the edge of the plank and then watch it fall down. While "standing" on the plank, the view for those with a body could be quite dramatic. They would see their feet standing on the plank, with a significant drop just inches away. We were interested to see whether subjects generally would show any observable fear reaction (or report such a reaction during the experiment itself) - and again whether those with a body would react differently to those without.

4. Results

With only seventeen subjects in the main study, we can only generate further hypotheses, and gain experience in designing a later study - in particular which factors it might be important to control for in attempting to look for significant differences between the experimental and control group. In this study it was not possible to match the two groups on significant variables in order to assess the affect of the virtual body on presence - simply because we had no idea about what the significant variables might be. Further, given the small number of subjects and the fact that they were not chosen as a random sample from a well-defined population, it is not possible to use any statistical measures to judge correlations in cross tabulation tables.

4.1 The Independent Variables: Attempted Measures of Presence

There were two main ways in which presence was measured. The first was a subjective report as one of the questions in the first part of the questionnaire. The question and responses are shown in Table 1.

Table 1
Subjective Reporting on Presence

To what extent did you experience a sense of being “really there” inside the virtual environment?	number
(1) not at all really there	1

(2) there to a small extent	2
(3) there to some extent	5
(4) a definite sense of being there	3
(5) a strong experience of being there	5
(6) totally there	1

The second method for measuring presence was by observation of the subject responses in Room 4 (flying objects to the face) and Room 6 (walking the plank). In Room 4 we noted whether or not the subject attempted to move out of the way of the object flying towards his/her face. In Room 6 we noted whether the subject was clearly unbalanced, or verbally reported reactions to the height during the time that s/he was virtually on the plank. The results are shown in Table 2(a)-(c).

Table 2(a)
Observed Response to Flying Objects to the Face

	number
no response	10
response	7

Table 2(b)
Observed Response to Being on the Plank

	number
no response	10
response	7

Table 2(c)
Observed Response to Either Situation

	number
no response	5
response	12

It is interesting to examine whether there is any relationship between the subjective reporting response, and the observed fear responses. Collapsing responses 1-3 and 4-6 in Table 1, we can construct cross tabulation tables showing reported degree of presence as against observed "ducking" in response to flying objects, and observed fear reactions on the plank. We find that there is no relationship between these different measures considered separately. Table 3 though shows a cross tabulation of the subjective report against the observed response to at least one of the situations.

Table 3
Reported Sense of Presence by Reaction to Flying Objects or Plank

	observed responses	
reported sense of presence	no response	response
(1)-(3)	1	7
(4)-(6)	4	5

If we computed the expected frequencies under the hypothesis that the counts in the body of the table were random given the marginal totals we would conclude that there is insufficient evidence to suggest any relationship between the two variables, reported sense of presence and observed responses. However, it is the case that *for this group* of seventeen people, those who reported a lesser sense of presence were more likely than not to show a response to one of the two "dangerous" situations.

One reason for this is simply as noted earlier, that people's subjective reporting does not necessarily correlate with what actually happened, and may change over time. For example, one subject who ticked category (2) ("there to a small extent") on the first part of the questionnaire, wrote in the second part about the factors responsible for his relatively low sense of presence - concerning the fact that the VE did not obey the normal everyday laws of physics. He went on to write "...These are the reasons why I think I did not get very far out of the real world, although I now think that I was deeper in the virtual world than I thought after the experiment. Now I'm confused about it..." Another subject who ticked category (3) "there to some extent" also wrote in the second part of the questionnaire "The 'best' room was as far as I remember, the one with the plank. I really felt as if I would fall off the plank". Another who ticked the same category wrote "Most of the time the experience was pretty convincing". The one mentioned above who ticked category (2)wrote: "...I thought I could fall down to the lower 'chess level' if I made one step further". Of course, the meaning of the subjective categories would vary amongst people in any case.

A second reason is that the question noted in Table 1 is not a good question. This is because the data suggests quite strongly that the sense of presence varied greatly for each person during their experience in the VE. In answer to a blanket question, they might be more likely to give their overall, as it were *average* impression, rather than their strongest impression - which anyway might only last for a short time compared to the length of the experience.

A third possible reason, is that those who were least present for most of the time, would be those most startled by a sudden and unexpected confrontation with a potential danger. This would shock them, and thus produce a response that could be noticed by an observer. They would quickly recover, however, and the sense of presence would be reduced. Their overall impression would be of a relatively low degree of presence. For example, one subject who ticked category (2) wrote: "The most exciting experience for me was on the plank. When I looked down, I had to remind myself that nothing could happen to me, even if I'd walk further on. But this took a moment and I think my pulse went up. I turned on the plank very carefully ... In fact, I didn't consider I could fall down, even in the virtual world if I'd left the plank...."

It is impossible to have a fear reaction without "being there". Being there does not require an immersive environment, as devotees of horror movies will agree. This discussion highlights one of the fundamental difficulties of studies on presence - we do not really know what it is that we're attempting to measure. Is it people's reported sense of presence, or some observable responses that are impossible to generate without a sense of presence? Is it the case that presence is really necessary to generate such a fear response? It could be argued that it is an automatic reaction to duck if something is aiming towards your face irrespective of "presence". One subject reported that since he had already experienced the fact that his hand could pass through objects, he allowed the flying objects to pass through his head without taking any notice. He knew that since his hand could pass through objects, the world was not behaving "lawfully" (cf. Loomis) in this regard and so the flying objects could present no danger. This was the same person whose pulse went up while telling himself that "nothing could happen to me" - he had not yet had any experience to prove that heights were not a danger - could not infer from the earlier experience of unreality that this was safe too. No doubt people attempt to construct consistent mental models of how the VE works, and react on that basis.

4.2 Influence of the Virtual Body on Reported Presence

One of our main interests was the influence of the virtual body on the sense of presence, although we did not ask any questions directly related to this, and no subject amongst the seventeen people had the opportunity to experience virtual existence for some time with and some time without a body. The follow up and more in depth study did provide this opportunity, and this is discussed in Section 6.

First we consider the results in relation to the subjective reports of presence shown in Tables 4(a) and 4(b).

Table 4(a)
Sense of Being There by Self Representation

	cursor	body	total
(1) not at all really there	1	0	1
(2) there to a small extent	0	2	2
(3) there to some extent	1	4	5
(4) a definite sense of being there	1	2	3
(5) a strong experience of being there	4	1	5
(6) totally there	1	0	1

The data indicate that amongst this set of people those with the disembodied cursor self-representation were more likely to report a higher subjective sense of presence. For example, 4 out of the 5 who were "there to some extent" were in the experimental group, whereas 4 out of 5 who had "a strong experience of being there" were in the control group.

Table 4(b)
Sense of Being There by Self Representation

	cursor	body	total
(1)-(3)	2	6	8
(4)-(6)	6	3	9

Let us consider some more information regarding the experiences of the experimental and control groups. Table 5 shows a classification of responses to the first question on the questionnaire, given to the subjects immediately after leaving the VE. It shows that those with the virtual body suffered from the classic motion sickness symptoms (nausea, eye strain, headaches) more often than those without.

Table 5
Immediate Response by Self Representation

Describe how you feel now immediately after leaving the virtual environment?	cursor	body
fine/excited	1	2
hot	2	1
nausea/ eye strain/headache	2	8
confusion/reality check	3	1

Table 6(a)
Predisposition to Various Kinds of Sickness by Self Representation
(subjects could tick more than one category)

Do you usually experience any of the following (under the appropriate circumstances)?	cursor	body
1. car sickness	2	1
2. sea sickness	2	1
3. vertigo	3	2
4. air sickness	0	1
5. general travel sickness	1	0
6. other related conditions (please detail)	0	0
7. None of the above.	4	6

Table 6(b)
Predisposition to Travel Sickness by Self Representation

	cursor	body
travel sick	4	3
never travel sick	4	6

Table 6 shows that the experimental group were slightly less predisposed to travel sickness than the controls, so that the possibility of predisposition cannot explain the results of Table 5.

Table 7 introduces another possible explanation of the results of Table 5. Notice that those in the experimental group more often report problems with the display as contributing to a decrease in the sense of presence (compare with 2.2.2). It occurred to us that the mere presence of the virtual body might decrease the frame rate - due to the additional polygons involved, and thus cause an increase in the time lag - and therefore an increase in motion sickness or nausea for those in the experimental group. However, further timings ruled this out as a possibility. However, it is the case that those with a virtual body tended to spend more time looking at objects closer to their viewpoint - such as at their virtual hand, down at their body, at their feet, and so on. The reported increase in sickness could be associated with the induced eyestrain caused by incorrect accommodation in these circumstances.

Table 7
Factors Decreasing Reported Sense of Presence by Self Representation
(Classification of an open ended question)

Were there any circumstances that especially *decreased* your sense of being "really there"?	cursor	body
outside events (including instructor)	2	2
screen/updates/lag/resolution	1	5
things don't behave naturally (laws of physics are violated)	6	4
things aren't done naturally	4	5
body doesn't behave naturally	0	3

Table 8
Sense of Being There by Predisposition to Travel Sickness

	no sickness	sickness
(1) not at all really there	1	0
(2) there to a small extent	1	1
(3) there to some extent	4	1
(4) a definite sense of being there	1	2
(5) a strong experience of being there	0	5
(6) totally there	0	1

Table 8 shows that those who reported less of a sense of being present were much less predisposed to travel sickness than those who reported a higher degree of presence. For example, 4 out of 5 of those who reported in category (3) were not predisposed to travel sickness, compared with all of those in category (5) being predisposed.

Now consider a possible concomitant of a predisposition to travel sickness - this is to do with speed of adaptation to new circumstances. This was suggested by one of the subjects of the in-depth study, who pointed out that when he goes sailing it takes him time to adapt to the motion, and when he returns from sailing to dry land, again it takes time to readapt. As a result of this a further question was asked of as many of the subjects as possible in the time available, concerning their adaptation to new circumstances.

Table 9
Adaptation to new circumstances

People often have to change their physical situation, for example, moving to a new house, visiting a different country, experiencing for the first time a new form of travel, and so on. How soon do you adapt to such changes in situation?	number
1. very slowly	0
2. slowly	2
3. in a reasonable time	3
4. quickly	5
5. very quickly	1

Table 10
Recall of an Outside Disturbance
(classification of an open ended question).

During the sessions, an "outside disturbance" occurred. Please write down what you remember about it.	number
nothing	6
instructor commands or touching	5
banging head - interaction with reality	2
wiring/equipment generally	1
displacement (that is, reinterpretation of an outside event, such as teacup, as some connection with something happening inside the environment).	1
teacup specific	1
"something" outside dropped	3

Intuitively we may expect that those who can adapt quickly take greater notice of their surroundings, a necessary condition of being able to change their behaviour to meet the new circumstances. Now another question asked in the first part of the questionnaire related to a deliberate "outside disturbance" caused by the experimenters during the session. This involved dropping a tea cup and saucer to make a loud noise. The observer watched for any reaction of the subject, and noted it if there was one, and a question was asked, as shown in Table 10. Only five of the seventeen either reacted at the time, or recalled that something happened. One of these five reinterpreted the event as something that happened inside the VE - the noise was caused while he was building the pile of blocks in Room 3, and he said at the time, and recalled later "I thought I broke something".

Now it is interesting to examine if those who report themselves as being able to quickly adapt to circumstances were the same people who noticed and reacted to the disturbance.

None of the subjects who reported that they adapt to new circumstances "slowly" or "in a reasonably time" reacted to or later remembered the noise (Table 11). Half of those who adapt quickly or very quickly did react or remember the noise. There is also a relationship, for this group of people, between adaptation and reported sense of presence (Table 12).

Table 11
Adaptation by Reaction to Outside noise

	did not react to noise	did react to noise
slowly or in a reasonable time	5	0
quickly or very quickly	3	3

Table 12
Sense of Being There by Adaptation

	slowly or in a reasonab le time	did react to noise
(1) not at all really there	0	0
(2) there to a small extent	0	2
(3) there to some extent	1	3
(4) a definite sense of being there	3	0
(5) a strong experience of being there	0	1
(6) totally there	1	0
total	5	6

Generally, 5 out of 6 those who are fast adapters, reported a lesser sense of presence, whereas 4 out of 5 of those who are slower adapters reported a higher sense of presence. An interesting fact is that the one person who did report a high sense of presence amongst those who are fast adapters was the same person who reinterpreted the noise as the result of his own actions in the VE ("I thought I broke something").

(This recalls Freud's observations in the *Interpretation of Dreams*, that dreamers weave outside events into the fabric of their dreams. Maury's famous dream about being guillotined was prompted by something falling on his neck while sleeping).

What has this got to do with the issue of the influence of the body on reported sense of presence? An accident of the assignment of individuals to the experimental or control groups was that 5 out of the 6 people who reported that they were fast adapters happened to be in the experimental group. Hence differences between the two groups might be the result of this difference. It is not clear why fast adapters would tend to report a lesser sense of presence. If it is the case as the data hints that fast adapters are better observers, then it could be the case that these fast adapters would be more likely to notice things wrong with the VE. Four out of the six fast adapters mentioned screen flicker etc. as contributing to reducing their sense of presence, whereas none of the slower adapters mentioned these factors. Of course, it is impossible to tell the direction of causality (if any) - whether possession of the virtual body is responsible for these results, or the speed of adaptation.

A hypothesis generated from this is that adaptation to environment may be an important factor related to presence in VEs. This could be tied up with Loomis' transparency of linkage between efference and afference. If the fast adapters are more observant of their environment, then faults in the VE may be more difficult for them to overcome - their actions in the VE and the concomitant reactions of the VE may be difficult for them to understand in the short term, and thus prevent them from forming an appropriate mental model. Being unable to model the virtual environment, they would not be "in" it.

4.3 Influence of the Virtual Body on Observed Reaction to Danger

Next we consider the observed reaction to "danger" in the VE as a measure of presence and consider the influence of the virtual body on this. Table 13 shows that all of those with the virtual body responded either to the plank or the flying objects or both. Five out of the 8 in the control group did not respond to either situation, or putting it another way, all of those who did not respond were in the control group.

Table 13
Observed Response by Self Representation

Observed Response to Either Situation	cursor	body
no response	5	0
response	3	9

We have to note, however, that all six of the fast adapters responded to one of the situations, although 3 out of the 6 slower adapters also responded. Again, given such a small number of subjects, it is impossible to untangle any causality here.

4.4 Number of Collisions

An important question was the effect of the virtual body in relationship to objects in the environment. In the first room that the subjects entered after the corridor, they were asked to find their way to the far end of a room cluttered with furniture, and return. The number of collisions was recorded.

The results in Table 14 show that overall, the experimental group made less collisions than the controls. However, on watching the subjects perform this task, we noticed that almost all of them seemed to be attempting to navigate around the pieces of furniture in order to find a path that would be correct with respect to everyday reality. The possession of a virtual body may have influenced the extent of the accuracy of movement in relation to other objects. Note that the control group subjects did in fact have a body - but it was set to be invisible - so that each group had the same chance of making collisions.

Table 14
Number of Collisions by Self Representation

Number of Collisions	cursor	body
Minimum	1	2
Maximum	15	13
Mean	8.0	6.3
Median	8	4

4.5 A Socially Conditioned Response

In the days prior to the actual experiment, one of the authors asked the time of someone in the VE, and he automatically lifted his arm in order to see his watch, followed by confusion when in the VE he did not see what he expected to see. In the experimental situation we were aware that not all subjects wore their watches, and so at first we tried the idea of sticking a small piece of paper (an "alert pad") on the left hand of each of the subjects, after they had entered the VE, and telling them to "leave it alone for now". Later we asked each subjects to report what was on his/her left hand. Each subject went through the same motion of lifting their left hand to their face, followed by confusion. We realised, however, that this was not really testing a socially conditioned response. For the second day of experimentation we reverted to asking the subjects for the time. The response was almost uniform - nearly all went through the same motion of attempting to see their watch while in the VE, followed by a moment of observable confusion when they could not see the result of lifting their left arm up to their face. Many of the subjects reported this as the "outside disturbance" mentioned in the questionnaire, or as a factor that decreased their presence in the VE.

4.6 Invisible Body

We postulated that if the body was mentally significant, then its disappearance would be noted. All subjects in the experimental group had their body disappear for a short while during their task of building a pile of blocks in Room 3. No subject reacted to or mentioned this fact at the time, and one mentioned it in the subsequent writeup. Although the body and arm disappeared, the hand did not. For most of the time the body and arm were out of view - although the time of picking up an object would be when it was most in view.

4.6 Summary

As is the nature of a pilot study, we can come to no firm conclusions. We were attempting to assess the influence of a virtual body on presence, and to look for other factors that might be related to this phenomenon. We were also avoiding any attempt to construct a precise definition of presence - rather relying on self reporting and some observable measures believed *a priori* to relate to presence. Due to an accident of design we found that an important factor - degree of "adaptability" to a new situation - was highly correlated with the factor of interest - the possession of a virtual body. It seems to be the case that possession of a VB is associated with a decrease in reported "presence" but an increase in observed reactions that can only be possible if the subject has a high degree of presence. However, since those with a body also happen to be those who adapt quickly to new situations, it might be the case that the effect is due to this.

5. Observations

In the previous section we have presented results statistically, in this section we allow the subjects to speak for themselves. The statistics cannot capture the variation of responses to the experiences in the VE, and do not highlight what for us was the very significant result - the very great differences in responses of people.

5.1 Some Reactions to the VE

Those who by now have spent many hours in VEs should pause to remember the very first time that it was experienced and recall the reactions. For many people it is a most remarkable experience.

"After a few minutes in the environment I became unaware of my natural/real surroundings... I completely lost track of time and had no idea how long I was in the environment".

"Looking back it feels more like somewhere I visited, rather than something I saw (as in a film), so I suppose I must have felt I was in the scene. I did feel quite immersed in it at the time, but was aware also that at the same time I was standing in the corner of a room with a helmet on."

"In fact the 'virtual reality' world was more real than I was expecting. I had the impression that I was in a real room. Of course I felt rather strangly when I passed through a wall....I was really impressed when I was trying to put the last cube on the top of the stack and I couldn't reach the top..."

"My feeling when carrying on with the experiment was that of being in another part of the building where the experiment was held...."

"[The] sensation is similar to being in a dream you know is a dream. Like you're*there* but you know it's not real."

5.2 A Mixed Metaphor

Imagine that the common 2D mouse had been designed so that moving it from left to right moved the cursor correspondingly, but that the only way to move the cursor up and down would be by pressing a "left" and "right" button. This is something like moving in a VE. The movement is effected partly by movement of the real body, and the sense impressions correspond to the observed movement in the VE. However, movement is also through using controls - pressing buttons, or making hand gestures, depending on the input device. This is like a "mixed metaphor" - again, those of us who are used to it have maybe forgotten that it can be very strange and tiring for a novice.

"Sometimes [I had] a desperate need to actually walk when virtually walking, there does seem to be a conflict between what the eyes see and the body feels - eg, my feet appear to be floating but I can feel my feet on the ground."

"Trying to separate virtual and physical movement: constantly being aware - my initial response was to make the physical move then forcing myself to use the mouse instead... The amount of concentration I had to use was something I remember particularly. Moving around with the mouse, forwards and backwards - and with the helmet turning around - it was difficult to reconcile the two ways of moving."

5.3 Judging Spatial Relationships

One interesting possibility that emerged was that the virtual body could be used to assess the relationship to an object in the process of trying to select it. One of the subjects in the follow up study pointed this out during the experience in Room 3. One control in the main study wrote:-

"It was hard to judge the size of the room in terms of foot measurements, but I could describe it as medium size... I found it difficult to tell my relationship to an object. In the real world I can see an object and judge the distance, then by touching it I can assess its physical space, whereas this was not really possible during the experience. Objects did not react in the way I expected them to, that is, I didn't experience their physical space, weight solidness, touch, etc."

5.4 Strong Virtual Body Reactions

One subject's reactions were fascinating in terms of her response to the VB. When she first looked down she moved her left arm - which of course did not move virtually. She then moved her real left hand back and forwards very fast - in a way that the observer could only ascribe to near panic. This same subject actually jumped backwards out of the way each time she dropped a virtual block (for example, while building the pile in Room 3) as if she were trying to avoid it falling on her toes. This subject reported the sense of presence at level 5 "a strong sense of being there".

Another subject wrote: "Sometimes I was pretty sure of what I was doing and I could react properly ... But it occurred that I was trying to move my left arm and it wouldn't respond, and I was thinking that there was something wrong with my arm."

We wrote earlier about our personal experience of matching the position of our real limbs with those seen on our virtual ones - for example, standing with our feet in the same position as the virtual feet, and our left arm the same as the virtual one. There was one person clearly observed to be responding to this same effect. The observer wrote "His left hand twitched when he first saw the virtual left hand...Real left hand very similar to virtual left hand". This subject wrote in answer to the question "Were there any circumstances that especially increased your sense of being 'really there'?" - "The way in which I could look at my hands and body". This subject reported the sense of being there as 4 - "a definite sense of being there" and he responded both to objects flying towards his face, and to the plank experience.

5.5 Infectious Virtual Reality

The experimenters spent about 10 hours guiding and watching the subjects perform in the real and virtual environments. Towards the end of the experiment, the guide was standing quite close to the subject while she was lifting and dropping blocks in Room 3. When she dropped a block to the floor, the guide instinctively stepped back to get out of the way - influenced by the image on the monitor of the falling block. The observer reported that he simultaneously thought "Look out!" while this was happening.

6. Followup Study

In the main experiment the subjects experienced either a virtual body or the arrow cursor. We thought it worth while to see the effects of running each situation with a number of people, so that they could compare their experiences. Three people participated in this stage of the study, say A, B and C. A and B were males and C was female. Only Rooms 3,4 and 6 were used.

6.1 Experience with Subject A

This subject was first entered into the VE with a body, and then after a short break re-entered with the arrow cursor. Person A spent a long time building and admiring the structure he built in Room 3. He later wrote in response to the question about experiences that increased presence:

"Interest - ie, when I was concentrating more on the scene's content, not the way it looked. The *fact* of the sculpture of blocks, the *fact* of the chess board, the plank."

Entering Room 4, the objects flew towards his face. He immediately reacted trying to get out of the way. He particularly mentioned this experience as an "unusual effect" in the questionnaire. When he returned to the room later, without the VB, the scare reaction was no longer there, he speculated that it was because the surprise had gone.

When he went onto the plank his verbal and obvious physical reaction was genuine fear. "Scary" he said, "I didn't realise that it could be so scary. My heart rate has gone up". He later wrote in answer to the question "Describe how you feel right now immediately after leaving the virtual environment": "A bit shaky - I saw some potential for being scared standing on the edge of that plank." When he returned to the plank room later, without a body, his reaction was quite different - he felt "free" and wanted to "fly down" to the lower level chess board." He wanted to "play", and had no fear of moving backwards, a fear which he had verbalised when earlier having a VB.

6.2 Experience with Subject B

Subject B also entered first with the body and then later without. This subject was quite obviously unbalanced in the first experience. He was "feeling very drunk", "unstable on my feet, I'm going to fall over". He later wrote that his immediate feelings were "Dizzy ... that kind of annoying drunken dizziness where the world won't quite sort itself out". Even after completing all the other questions on the questionnaire he wrote: "Still hung over, I wouldn't like to ride a motorbike right now."

He wrote that he had "confusion about the use of the body." At one point he looked down through his body and exclaimed "Ugh! I'm looking into my body". He wrote as a factor that decreased his sense of presence "The body being non-functional - looking back through my body and seeing my arms swap over."

When he tried to go onto the plank he said "Oh God, I'm off the plank, I'd rather be on it". He noticed that it was very strange being off the plank - the chess pieces could fall down, but he couldn't. He said that since he had a body, he expected it to behave like one, and actually respond to gravity like other objects. When he later returned to the plank room without the body he seemed more comfortable. He said that to him the cursor was just a "tool", just a "flying thing" - just being a flying cursor was "more safe".

This subject waited a long time after the experiment before actually using his motorbike. He reported the next day that while riding the bike he felt completely normal. However, when he got home, and entered the apartment building, which has a long corridor at the entrance, it immediately threw him back into the dizzy state he'd experienced in the VE.

6.3 Experience with Subject C

Subject C first entered the VE without a virtual body and later with. By the time she had entered Room 3 she was clearly feeling very dizzy and tired, to the extent that the guide asked her again whether she wished to end the experiment. She later wrote that she had felt "sick, depressed and giddy", but "forced" herself to continue with the experiment. Constructing the pile of blocks was clearly an arduous task for her.

When she returned later to the same room, this time with a VB, she was far more at ease. The dizziness and sickness had abated. She said "I can see my hands on the cube, and that's what you really do - you put your hands over, so more real". She wrote in answer to the question about factors that increased the sense of presence (she had put that her sense of being there as category 6 - "totally there"): "When I saw myself in the second experiment definitely... The arrow - it was as if I was in a normal computer interface, I was 'snorkeling', not 'diving' into the experiment".

This subject was too sick to stay in the plank room in the first experiment, but when she returned later she seemed happy to explore the room in detail, and then return out to the corridor and to explore the other rooms that had not formed part of the experiment. The level of discomfort had clearly decreased. However, she reported later that the dizziness did return and last for some time after the end of the experiment.

6.4 Comments

The problem of allowing a subject to experience both conditions is that the first might contaminate the second, or that learning and adaptation might take place. In all three experiments the subject had a more pleasant experience the second time in, compared to the first.

Observing these experiments, there was little doubt that the presence or absence of a VB was an important aspect of the experience. However, the effects were quite different for the different people. For one, having a body was cumbersome - almost like a dead weight - it did nothing, and could cause a feeling of disgust. For another, the VB seemed to enhance fear reactions, and the absence of a body led to a sense of play and experimentation - though also to disorientation. For the third, the cursor as self representation seemed to be highly inappropriate, and the VB led to a sense of experimentation and play. Whether the results are spurious due merely to an ordering effect, or a response to the differing conditions is impossible to say.

For a subsequent experiment, we will be allowing a subject to experience each self representation for a short while within the same session, and give them the ability to switch at will between the representations.

7. Conclusions

This paper has described a pilot study investigating factors related to presence, in particular the influence of a virtual body as self representation. The context is one of architectural walkthrough, where the relationship of the body to the virtual environment would seem to be important *a priori.*

The data suggest that adaptation to changed circumstances could be an important factor in determining the degree of presence. Since this was confounded with the experimental design, and given the small number of subjects, it is not possible to separate out the influence of the virtual body. Nevertheless, there seems to be a positive association between possession of a virtual body and observed reaction to "danger", and a negative association to reported self assessment of the degree of presence. However, the relationship between adaptation and presence could be used to explain this away.

The real purpose of the study was, of course, to help design a further study. This requires a working definition of presence, that can be "operationalised" and used to construct a metric. We have seen that subjective assessment and "objective" observations of subjects' actions were in fact negatively associated in this study, and that subjects' reporting of their own state was sometimes confused. In addition, it is not possible to ask overall questions about the degree of presence, since presence clearly varies during an experience - and the subject is likely to give an "average" rather than a modal response.

There are a few small (or perhaps tall) points worth making - these are the kinds of things that only become apparent when conducting an experiment. For example, since the polhemus sensors have a limited range, subjects who are particularly tall will probably experience greater flicker, being permanently just outside of the recommended range. Matching experimental and control groups across height is probably necessary! Second, it is contradictory to conduct an experiment on presence in a VE, when all the instructions to the subject are coming in the auditory channel from outside that environment. Some subjects reported as factors decreasing their sense of presence being told what to do by the guide, and also occasionally being physically moved by the guide back within sensor range. Third, it is very difficult to get the information required, without putting possible answers into the minds of the subjects. Finally, although we did emphasise that the subject could end the experiment whenever he or she wanted, we think that this point could have been made in a stronger way - since some people did experience unpleasant effects, that could ultimately have been dangerous. There is a paradox here, since just by suggesting to the potential subject prior to the session that there might be unpleasant side effects, and for example to refrain from driving for some time after the end of the experiment, might open up a possibility that otherwise might not have existed.

There is a vast amount of further interesting information that we found during the course of this work. This is being prepared for a subsequent report. A further study, with potential clients of architectural walkthrough is now being designed.

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Appendix

Extract from the Questionnaire and Unstructured Answers

Note answers are separated by semi-colons; separation across lines is not significant.

1. You have just spent time in the virtual environment. These questions relate to your experiences.

QUESTION	ANSWER
(a) Describe how you feel now immediately after leaving the virtual environment?	as if I was in another building; excited; enjoyable; hot after removing HMD a little disorientated; heavy head;headache; tired feet; not ill, not uncomfortable in any way; coming back to reality; eyes took time to refocus; eyes took time to get used to light; dizzy; slightly nauseous; little irritated (points to eyes); slightly dicey; slight headache; as if I'd been concentrating very hard; can't focus eyes properly; head feels sweaty; feel quite light; eyes feel a bit strained; impressed; an interesting new experience; like a dream; more aware of complexities and details of real world and the way it surrounds me; very slightly disoriented at the moment of taking off headset;
(c) Were there any unusual, and primarily *physical effects* that you experienced during the sessions? If so describe these effects, or write "NONE".	that I could walk over cubes; right arm ached for a while; not having to move my limbs to walk and move; hitting the real wall; felt lost; couldn't figure if standing on something or floating; tried to move parts of body as if in real world; heavy helmet - uncomfortable; headache (has cold though); loss of balance; nausceous near beginning of session; moving in VR but not in reality felt odd; flickering of images unsettling; strange feeling occured when reaching doors and walls and seeing them suddenly in front of me; hot; head tense and heavy; tired; stressful because of the wires wrapping around; picking objects was hard and needed practise; slight headache when large jumps in movement update; loss of balance - which was suprising and then disorienting; chess room and teapot room quite severe effects (loss of balance); legs floating above me disorienting;

(d) If you did experience any unusual physical effects, how, if at all, did these effects vary during the course of the session?	right arm stopped aching with time; more accustomed with apparatus over time; kept bumping into walls; tried to move left arm, and didn't move so felt something wrong with arm; loss of balance got worse, especially on plank; right arm felt heavy towards the end; nausea early, went quite soon; hotter as time progressed; more tense as time progressed; more tired as time progressed; picking objects became easier;
(e) Were there any unusual, and primarily *mental effects* that you experienced during the sessions? If so describe these effects, or write "NONE".	dizzy in last room; did not at first see everything there; objects seem to float around; confused about some objects; disorienting when many screen updates; confused about things around me; uncertain about the state of my body; brought back to normal by touching real wall confusion; sense of being cut off from outside world; trying to separate virtual from physical movement; annoyance at objects flying towards me; concentration; difficult to understand how I could catch objects; sometimes when turning head not easy to distinguish walls and ceiling; uneasy about the situation at the beginning; didn't like to stay there much long - felt as if had to think even to move back and forwards; felf off-balance; not quite as clear in thought; need to check things increased - stacking of blocks felt arduous;

(f) If you did experience any unusual mental effects, how, if at all, did these effects vary during the course of the session?	dizzy in last room only; more aware of surroundings with time; easier to move around over time; scared to look behind on plank because of fear of falling; objects disappeared or followed - seemed real; nothing early on, but depended on room and whether touching wall or not; confusion diminished over time; afraid to collide with objects; thought going to fall off the plank; getting used to moving with mouse improved a bit; concentration had to be kept up; became easier to move through doors and objects; unease about the situation decreased with time; ok at the start but got tired towards the end;
(g) Overall, was your experience in the virtual environment primarily pleasant or unpleasant?or describe your experience briefly in any way appropriate.	pleasant; real; enjoyable;very pleasant primarily pleasant;slightly unpleasant; requires getting used to; interesting;increasingly curious about next room; did not feel in control of the environment; pleasant because experiencing something not possible in real life; strange, odd;unusual; annoying and cumbersome at times; nearer to actual world than expecting; like playing a game - preferably for a short while;
(h) To what extent did you experience a sense of being "really there" inside the virtual environment?	*Please clearly circle one of the numbers:* (1) not at all really there (2) there to a small extent (3) there to some extent (4) a definite sense of being there (5) a strong experience of being there (6) totally there Describe briefly this aspect of your experience in any way appropriate if none of the above applies... touching the real wall brought me back; experience convincing most of the time - especially when interacting with objects; strong sense of being there, but not enough to continually forgot that I wasn't there - most of the time I was totally absorbed, but could reconnect to events outside;

(i) Were there any circumstances that especially *increased* your sense of being "really there"? If so write them down, or else write "NONE".	being able to move around; being able to move objects; trying not to walk into objects in room 1; being able to pick up objects; upside down room; looking down the plank; when throwing the chess piece from the second floor; when I thought I could fall off the plank; when just about to drop the chess piece; being at the end of the plank and having sensation of looking down at a height; coordinated movement of head/foot turns; being able to go in and out of different doors, and find different things; Having to physically turn left right up down; being able to pick things up; when I saw my hand and body representation that increased the sense of being there; the way in which I could look at my hands and body; having to concentrate - particularly when asked to do tasks; when putting objects on top of each other;

(j) Were there any circumstances that especially *decreased* your sense of being "really there"? If so write them down, or else write "NONE".	could walk over cubes; awkwardness of walking through doors; objects seemed to disappear when touched; objects intersected each other; looking at feet when moving; update of screen; picking things up by pressing a button; moving by pressing a button; touching wall of real room; passing through a wall; seeing the corners of helmet; using the mouse; delay when wanted to move; when looked behind and other rooms not rendered well; flickering view; graniness and jerkiness of picture; overlapping boxes; couldn't identify plank before told it was one; backwards and forwards being controlled by a mouse rather than real movement; having only one hand; being able to walk through things; couldn't relate walking representation while feet firmly on the ground; the way in which I entered doors was not realistic and off-putting to the experience; being told to say things - made me think of things to say rather than being in the vr; external noises - something being dropped; looking down at watch on request; concentrating on trying not to make the physical movements of walking and turning; moving off the plank, expected to fall; going through doors; banging against the real wall; holding objects and moving them around;

(k) During the sessions, an “outside disturbance” occurred. Please write down what you remember about it.	being told what to do; being physically moved; none - lost in the virtual world; something being stuck to hand; banged my head; banging real wall; mixed up with wires; when picking up the blsck box to finish my pile the room seemed to turn upside down for a while; boxes kept moving about, lost sense of perspective and didn’t know where anything would be; hit by a teapot; some noise at the back; something dropped - it made me jump; being asked the time; sound of breaking glass while opening a door - (first thought was that it really happened);
(l) Now that you have been out of the virtual environment for several minutes, how do you feel right now?	excited; I want to get back; cooler; could be improved by a speech saying something about the environment; normal; trying to remember every sequence keep thinking about it - OK; I liked it; a bit better (after being dizzy); still good; interested in results and my performance; perfectly ordinary; fine; eyes back to normal; can concentrate better; less disoriented; not so hot; head ok now; neck sore; ok -earlier feelings have gone;it is hard to believe; slightly nauseous; head muzzy slight headache and disorientation;