PRESENCE AND CO-PRESENCE IN COLLABORATIVE VIRTUAL ENVIRONMENTS

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Abstract

Presence in Collaborative Virtual Environments (CVEs) can be defined into *personal presence* and *co-presence*. Personal presence is having a feeling of “being there” in the CVE yourself. Co-presence is having a feeling that one is in the same place as the other participants, and that one is collaborating with real people.

The focus of this research was to conduct exploratory studies to investigate and verify some of the factors believed to affect personal presence and co-presence in a CVE. This was achieved by designing and performing experiments in CVEs, and using subjective measures to assess the levels of personal presence and co-presence in the CVE. In addition, we have developed a subjective measure of co-presence in the form of a pencil-and-paper questionnaire. This co-presence questionnaire was used to measure the amount of co-presence experienced by the participants in the CVE.

In this dissertation we describe three experiments used to investigate some of the factors which might affect personal presence and co-presence in a CVE. Experiment 1 investigates the effects that small group collaboration and interaction have on personal presence and co-presence in a CVE. We hypothesise that collaboration and interaction enhances co-presence in a CVE. We found that group collaboration greatly enhances co-presence in a CVE beyond that afforded by merely having virtual representations of others. We also found that group collaboration affects personal presence. This might be explained by the fact that collaboration requires more involvement and attention which might enhance the sense of personal presence. Experiment 2 investigates the effects of presence on collaborative styles. We hypothesise that a high degree of presence might produce a higher level of collaboration and interaction between the participants. We did not find much of a difference between the interaction styles in two VEs designed to create different levels of presence. Experiment 3 investigates the effects of avatar appearance and functionality (gestures and facial expressions) on personal presence and co-presence. We found that the way one represents the participants in a CVE affects the sense of co-presence. We found that realistic human-like avatars produce a higher sense of co-presence than cartoon-like avatars, which in turn produce a greater sense of co-presence than simple realistic avatars. We also found that avatars having gestures and facial expressions enhance the level of co-presence experienced by the participants.

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Chapter 1

Introduction

Our research considered the issue of personal presence and co-presence in collaborative virtual environments. We conducted exploratory studies to investigate and verify some of the factors believed to affect personal presence and co-presence in a collaborative virtual environment.

In this chapter we present the aims of this research project. We firstly introduce the concept of *presence* and *co-presence* as applied to virtual environments, and indicate the importance of presence in VR research. Section 1.2 describes the aims of this research, by presenting the different hypotheses we are investigating in this dissertation. Section 1.3 describes the methodology used and the different experiments presented in this dissertation. Finally we provide an outline of the dissertation in Section 1.4.

1.1 Presence and Co-presence in Collaborative Virtual Environments

Collaborative Virtual Environments (CVEs) involve the use of a distributed architecture and advanced interactive user interfaces to create a "shared" space where multiple users, located in different geographical locations can interact and collaborate. CVEs are seen by many as the future of telecommunications [13, 76], where a multitude of people will be able to meet and interact with each other in the same 3D space as if they were in the same real space, with a full range of social interaction provided. However, in order for CVEs to be usable and successful, they need to provide the participants with a compelling experience and a high sense of *presence*. This will convince the participants that they are 'there' in the virtual environment, and that they are collaborating with real people.

Personal presence (or simply presence) refers to the psychological sensation of "being there", having a sense of being in the place specified by the virtual environment rather than just seeing images depicting that place. According to Steuer [64] presence means "The feeling of 'being in an environment'."

Co-presence is the feeling that the other participants in the virtual environment actually exist and are really present in the environment, and the feeling that one in interacting with real people. It is having the perception that the persons with whom one is engaged in two-way communication are in the same physical location and environment when in fact they are in a different physical locations.

We believe that presence is of primary importance in the study of virtual environments for numerous reasons. One would think that a high sense of presence should increase task performance in the virtual environment. However, as Ellis [20] points out, some factors which may increase presence may actually decrease task performance. In fact, task performance depends on many other factors such as user interface, personal skills and experiences, the nature of the task, etc. Nevertheless, Slater *et al* [51] indicate that the relationship between presence and task performance is the main justification for the importance of presence. They indicate that the issue is not whether presence enhances performance, but that the greater the sense of presence, the greater the chance that participants in a VE will behave in a similar manner to their behaviours in the real world. This is important since it enables knowledge-transfer from the virtual environment to the real world, which is important in training situations and therapy scenarios. Bystrom, Barfield and Hendrix [16] state that presence does not necessarily enhance task performance, but that having some sense of presence in an environment is a necessary condition for performance to occur.

One of the major challenges when dealing with presence is how to measure it. As Lombard and Ditton [35] point out that the "lack of a consensus regarding a conceptual definition of presence is one of the reasons that there is no standard technique or instrument for measuring presence". Held and Durlach [29], and Sheridan [46] also note that we don't have a working measure of presence.

There are two general approaches to measure presence: subjective and objective measures.

Subjective measures of presence require the participants to report a conscious, introspective judgment of their experience. The easiest way to do this is using a post-experiment questionnaire. Most researchers use subjective questionnaires to measure presence in their studies because there is evidence that they can be valid and reliable [41], and because questionnaires are easy and inexpensive to use. However, subjective measures have several important limitation. For example, the act of directly asking the participant about the experience may influence their responses to the questions in unpredictable ways so that it does not accurately reflect the participant's true experience. The main problem with subjective measures is that researchers use different sets of questionnaires which makes comparison between studies impossible. There is a need for the development of a standard subjective measurement which can be used in different studies of presence.

Objective measures of presence do not require conscious introspection, and they are typically administered during the participants' experience rather than after it. Objective measure include physiological measures (i.e., changes in skin conductance, blood pressure, heart rate, muscle tension, etc.), and behavioural measures (such as observing the behaviour of participants in the real world, reacting to different stimuli in the virtual world). While these objective measures avoid the problems associated with subjective measures, they are often expensive and difficult to administer.

1.2 Aims

The focus of this research was to conduct exploratory studies to investigate and verify some of the factors believed to affect personal presence and co-presence in a collaborative virtual environment. This was achieved by designing and performing experiments in collaborative virtual environments, and using subjective measures to asses the levels of presence and co-presence in the CVE. In addition, we have developed a subjective measure of co-presence in the form of a pencil-and-paper questionnaire. This co-presence questionnaire was used to measure the amount of co-presence experienced by the participants in the collaborative virtual environments.

In this dissertation, we present three experiments involving small groups of participants performing a task in the virtual environment. These experiments are used to investigate the following hypotheses, which are depicted in Figure 1:

1. We believe that group collaboration and interaction with other participants in the environment influences co-presence. It is believed that simply having a virtual representation of other users in the environment is not sufficient to create a high sense of co-presence. We believe that having the possibility to collaborate and interact with other participants in the shared environment increases the sense of co-presence.

2. We believe that personal presence and co-presence in a CVE are correlated. Slater *et al* [57] postulate that personal presence is a prerequisite for co-presence. It is useful to know whether these two types of presence are associated or not. If personal presence and co-presence are associated this could be because of common factors which influence both, or because they influence one another. If they are not associated, it might indicate that these two types of presence are orthogonal. Tromp *et al* [71] and Slater *et al* [53] found in one of their small group experiments that the personal presence and co-presence scores were positively correlated.

3. We believe that increasing the feeling of presence and co-presence within a group in a CVE changes the style of collaboration and interaction between group members.

4. The way one represents other participants in the virtual environment is very important to

enhancing the sense of co-presence. The important issue here is to determine how the appearance of the avatar affects co-presence.

5. We believe that providing simple gestures and facial expressions to the avatars will increase the sense of co-presence in the CVE, compared to having static avatars. Here we will address questions such as: Are fully functional avatars, with gestures and facial expressions necessary or are crude representations of avatars sufficient to maintain the sense of presence of others ? We also want to test the hypothesis that having realistic human-like avatars without any body movement could create a worse sense of co-presence than having unrealistic avatars without any body movement. This is because there is a conflict between the greater visual realism of the human-like avatar and the lack of bodily movement. On the other hand, having an unrealistic avatar makes it easier to understand that it is not functional.

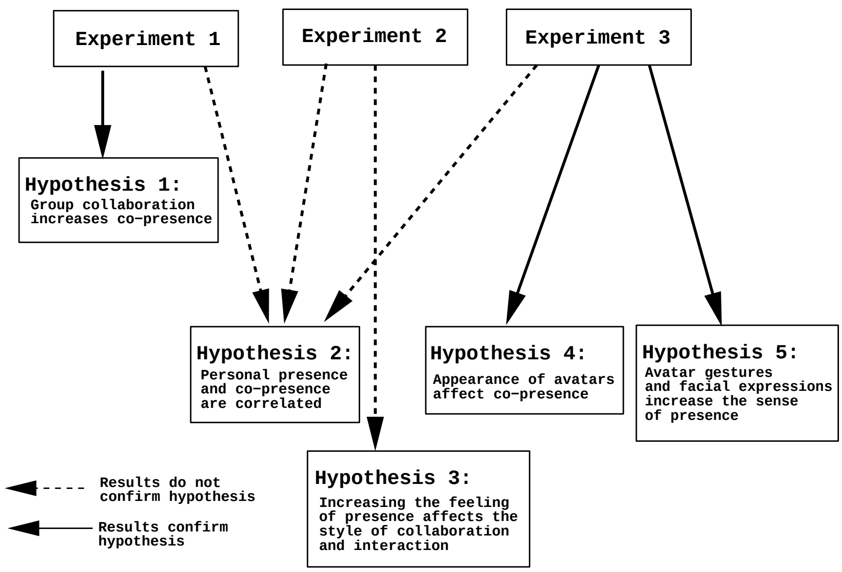

Figure 1: **The hypotheses investigated in this dissertation.** Experiment 1 (described in Chapter 5) is used to test hypotheses number 1 and 2. Experiment 2 (described in Chapter 6) is used to investigate hypotheses 2 and 3. Experiment 3 (described in Chapter 7) is used to investigate hypotheses 2, 4, and 5.The negative result of hypothesis 2 is a significant outcome of this dissertation.

The various factors contributing to increased presence have been studied quite extensively by differing researchers. We aim to consolidate this research by using some of these factors to create virtual environments which generate different levels of presence. We also aim to try and replicate some of the results found in the literature, namely the relation of personal presence and co-presence, and the relation of the immersive tendencies and presence.

1.3 Methodology

The approach that we adopted in this research was the following: We identified the different hypotheses to test. We then designed the experiments which involved the design of the collaborative virtual environments and experimental tasks. We selected appropriate subjective measures in the form of post-experiment questionnaires. We then performed the experiments with subject, gathered data, and then analysed and interpreted the results obtained to reach conclusions on the hypotheses tested.

In order to investigate the hypotheses described in Section 1.2, we designed three experiments involving groups of three participants performing an experimental task in a collaborative virtual environment. In all of these experiments, we made use of subjective measures in the form of post-experiment questionnaires to measure personal presence, co-presence, and the immersive tendencies of participants. The presence and immersive tendencies questionnaires were obtained from the literature, and we developed a co-presence questionnaire.

Experiment 1: This experiment was used to investigate the effects of group collaboration and interaction on personal presence and co-presence in a collaborative virtual environment. This experiment is presented in Chapter 5. The main aim of this experiment was to test whether personal presence and co-presence was increased by collaborating and interacting with other participants in the CVE. We used two collaborative virtual environments which were identical and only the experimental task differed. The task was used to create two different levels of group collaboration, a high-collaboration task and a low-collaboration task.

In this experiment, personal presence was measured using Slater *et al* presence questionnaire [58, 51, 55] which is described in Section 3.4. Co-presence was measured using a co-presence questionnaire that we developed, which is described in Section 3.5. We also measured group collaboration by using a collaboration questionnaire we developed and which is presented in Section 3.6. This collaboration questionnaire was used to make sure that we achieved our goal of having different levels of group collaboration in the two virtual environments. We also measured the immersive tendencies of participants using Witmer and Singer's Immersive Tendencies Questionnaire which is described in Section 3.3.

Experiment 2: This experiment was used to investigate the differences in collaboration patterns under different levels of presence. We used two collaborative virtual environments designed to engender different levels of presence (i.e., a high-presence VE and a low-presence VE). We then analysed the interaction and collaboration styles in the two environments. This experiment is presented in Chapter 6.

In this experiment, personal presence was measured using Witmer and Singer's presence questionnaire [79] which is described in Section 3.2. Co-presence was measured using our co-presence questionnaire which is described in Section 3.5. The immersive tendencies of participants were also measured using Witmer and Singer's Immersive Tendencies Questionnaire. Interaction and collaboration was analysed by categorizing the dialogue according to the schedule proposed by Bales [6].

Experiment 3: In this experiment, we investigated the effect of how one represents other participants in a collaborative virtual environment. Some participants might find it easy to maintain the sense of co-presence of others with just crude representations of avatars, while others might need highly realistic human-like avatars with gestures and facial expressions. The main aim of this experiment was to investigate the effects of avatar appearance and functionality on presence and co-presence in a collaborative virtual environment. Functionality of avatars included simple gestures and simple facial expressions.

Personal presence was measured using Slater *et al* presence questionnaire [58, 51, 55] which is described in Section 3.4. Co-presence was measured using our co-presence questionnaire which is described in Section 3.5.

1.4 Outline of this Dissertation

Chapter 2 In Chapter 2 we describe the background work relevant to our research. We first describe Collaborative Virtual Environments. We then describe the notion of presence in a virtual environment. We present a definition of presence and some of the theories of presence found in the literature. We also describe some of the factors believed to affect the sense of presence in virtual environments, and the different ways to measure presence in a virtual environment. After that, we present some background into virtual representation of participants (avatars) in collaborative virtual environments. We end the chapter with a brief introduction to group interaction and collaboration, by describing the importance of group collaboration and the influence of technology on interaction and collaboration.

Chapter 3 This chapter describes the different questionnaires used in the experiments presented in this dissertation. The questionnaires used were: Witmer and Singer's Presence Questionnaire and Immersive Tendencies Questionnaire [79], Slater *et al* Presence Questionnaire [58, 51, 55], and Co-presence and Collaboration Questionnaires which we developed. For each of these questionnaires, we present the design of the questionnaire as well as some reliability and validity analysis.

Chapter 4 In this chapter we present a description of the different collaborative virtual environments used in the experiments described in this dissertation. The collaborative virtual environments were implemented using the DIVE (Distributed Interactive Virtual Environment) system

[19, 18, 67]. DIVE is a toolkit for the development of multi-user distributed virtual environments, developed at SICS (The Swedish Institute of Computer Science). All the collaborative virtual environments used were ‘desktop’ virtual environments, which means that no head mounted displays or projection VR was used in any of the experiments.

Chapter 5 In Chapter 5 we present the experiment 1 mentioned in Section 1.3. We found that collaboration and interaction greatly enhanced personal presence and co-presence in a CVE beyond that afforded by merely having virtual representations of participants.

Chapter 6 In Chapter 6 we describe the experiment 2 mentioned in Section 1.3. In this experiment we found that even though we designed two virtual environments which should generate different levels of presence (by manipulating some of the factors believed to affect presence identified in the literature), the presence questionnaire used did not pick up any difference in presence between the two virtual environments. The findings related to interaction differences between the two virtual environments where negative. We did not find much of a difference between the interaction styles between the two virtual environments.

Chapter 7 In Chapter 7 we present the experiment 3 described in Section 1.3. We found that there was a significant difference between the co-presence scores generated by the avatars of different appearance, and that realistic human-like avatars produced a greater sense of co-presence that cartoon-like avatars, which in turn produces a greater sense of co-presence than unrealistic avatars. we also found that avatars having gestures and facial expressions produced a significantly higher level of co-presence when compared to static avatars.

Chapter 8 Finally, in Chapter 8 we end this dissertation with a summary of the obtained results, some concluding remarks and suggestions for future work.

Chapter 2

Background

In this chapter we discuss the background work which is relevant to our research, and in so doing we hope to provide a review of Collaborative Virtual Environments (CVEs) and its social implications, the sense of presence in Virtual Environments, the representation of participants in Collaborative Virtual Environments, and group interaction and collaboration.

Section 2.1 describes Collaborative Virtual Environments. It presents a description of CVEs as well as the some of the applications of CVEs. This is followed by some of the challenges one faces when developing collaborative virtual environments. Section 2.2 describes the notion of *presence* in a virtual environment. We present a definition of presence and some of the theories of presence found in the literature. We then identify the different categories of presence. We follow by indicating the importance of the sense of presence in virtual environments, and then describe some of the factors believed to influence presence in a VE. We end the section by presenting the different ways to measure the sense of presence in a virtual environment. Section 2.3 presents some background into virtual representations of participants in Collaborative Virtual Environments. Section 2.4 provides a brief introduction to group interaction and collaboration. It describes the importance of collaboration, and the influence of technology on interaction and collaboration. Finally, Section 2.5 provides a summary of the main points of this chapter.

2.1 Collaborative Virtual Environments

In this section we describe Collaborative Virtual Environments (CVEs). We present a definition of CVEs, and describe their characteristics and applications. We then describe some of the challenges that developers have to face when building collaborative virtual environments.

2.1.1 Defining Virtual Reality and Collaborative Virtual Environments

There is a debate within the community as to what exactly constitutes *virtual reality*. The term has being used to describe almost any situation where a user interacts with a computer using some sort of three-dimensional environment. Virtual reality started as a new form of human-computer interaction, but it has now almost become synonymous with three-dimensional graphics.

We regard Virtual Reality as a form of human-computer interface where the participants inhabit the same space as the data or other objects with which they are interacting. Both the data and the user co-exist in the same space. The computer, in that sense, becomes invisible to the users. Virtual reality may have the potential to radically alter and improve the way in which humans interact with computers. It seems therefore appropriate to describe and analyse VR systems from a 'user perspective', that is, from a viewpoint which takes into account human factors rather than in terms of hardware and software.

Virtual reality can therefore be defined in terms of the experience of *presence*. Presence refers to the feeling of "being there" in the virtual environment. Presence and its relevant properties are described in detail in Section 2.2. Steuer [64] defines *presence* as "the sense of being in an environment". He defines *telepresence* as "the experience of presence in an environment by means of a communication medium". Steuer indicates that defining virtual reality in terms of presence provides " (a) a concrete unit of analysis for VR, (b) a set of dimensions over which VR can vary, and perhaps most importantly, (c) a means for examining VR in relation to other types of mediated experience" [64]. By using the concept of presence (or telepresence), virtual reality can be defined as "a real or simulated environment in which a perceiver experiences telepresence" [64].

Collaborative Virtual Environments (CVEs) are computer-based systems which actively support human collaboration and communication [27]. These systems use VR to create a shared space where multiple users are able to meet and interact with each other as if they were in the same real space, with a full range of social interaction provided. The power of CVEs lies in their ability to enable users to work together on a specific task. Users can "see" other users in the collaborative environment, can communicate with them through some means, and are able to manipulate shared objects in the environment.

In CVE systems, participants are represented using some sort of virtual embodiment called *avatars*. Avatars are used, not only to represent the participants, but also as a means for interaction and communication with others in the environment. Avatars in a collaborative virtual environment are described in more detail in Section 2.3.

Collaborative Virtual Environments can be implemented using a variety of different user interfaces and distribution technologies. The interface can vary from plain text through 2D graphical user interfaces to fully immersive 3D virtual reality. The range of CVE systems vary from text-based virtual environments or MUDs (Multi-User Dimensions/Dungeons) at the one end to multi-user immersive virtual reality at the other end. In MUDs, users access the environment using a simple terminal program and all interaction is done using text messages. Multiple simultaneous users can "see" each other (i.e., read text descriptions of each other), "talk" to each other (i.e., type text messages) and "walk" about within the MUD's world by typing commands such as "go west". On the other hand, in multi-user immersive virtual environments, users can use Head Mounted Displays (HMDs), have their body movements, gestures and facial expression captured and conveyed, they can have real-time audio and video communications. In other words, users of an immersive virtual environment can see realistic articulated representations of other participants, can use gestures and expressions in conversation, and can speak to each other directly.

Given the fact that CVEs can be implemented using a wide range of platforms, the means by which interaction and collaboration are achieved differ immensely. One user might be viewing the environment from a monitor and using the keyboard to move around the shared space. Another might be using a HMD and a hand-operated controller. Another user might be using stereoscopic glasses in a CAVE, a room which has projected images of the virtual environment in its walls and thus the user is surrounded by the virtual environment. The more powerful HMD and CAVE, with wider field of view and increased depth perception, provide a more natural interface to the environment [8, 30].

There are a number of characteristics which are common to collaborative virtual environments:

- CVEs are multi-user computer-based systems which support geographically separated users.
- Users are able to communicate and collaborate in a number of different ways such as audio, text, and avatars with gestures and facial expressions.
- There is a space or world modeled in the computer – the virtual environment – in which this activity is situated.
- Each user is explicitly represented or "embodied" within the virtual environment and is made visible to others by means of this virtual representation called the avatar.
- Each user is autonomous and able to move about independently within the virtual environment.

Singhal and Zyda [49] describe the main features of multi-user networked virtual environment as follows:

- *A shared sense of space*: All users are presented with the illusion of being in the same place.

- *A shared sense of presence*: participants are represented by a virtual representation of themselves. When a participant enters a virtual environment, he/she can see the other participant's avatars and the other participants can see the new participant's own avatar.
- *Real time interaction*: multiple users, located in different physical locations, interact with each other in real time. In other words, participants should be able to see each other's behaviour as it occurs.
- *A way to communicate*: Virtual environments allow some sort of communication to occur among the participants. This communication may occur by gesture, by typed text, or by voice.

2.1.2 Properties of Collaborative Virtual Environments

Collaborative Virtual Environments are seen by many as the future in telecommunications [13, 76], where multiple participants located in different geographical locations are able to interact and collaborate with each other in an environment rendered by virtual reality. The application potential of CVEs becomes apparent when one considers the ways that collaboration and interaction between the participants can be supported by the CVE. Collaborative Virtual Environments support geographical distributed collaboration and interaction in ways which are far beyond what is possible with normal teleconferencing tools. CVEs provide a shared spatial environment where people can employ communicative resources which are unavailable to them in other teleconferencing systems [12]. For example, participants can have some control over that they view in a CVE which is not generally possible with tools using a camera and monitor system. Also, participants can use more natural ways for coordinating turn-taking in social interaction (for example, changes of gaze or body gestures), rather than some technical means such as floor control policies commonly used in traditional conferencing systems. Furthermore, because users in a CVE are embodied in it and their location and orientation are represented, a degree of mutual awareness of each other's activities is supported [9].

Greenhalgh [27] indicate that, in terms of collaboration support, CVEs are interesting for a number of reasons:

- CVEs support "natural" spatial communication: Space has a social significance which is important for real-world communication and interaction. Significant elements of communication such as gaze direction and gesture depend upon a spatial reference frame, and so space can be viewed as a resource for managing activity and interaction. Spatial factors such as position and orientation of participants, posture, speed of movement, etc, consciously and unconsciously convey information such as availability for conversation, interest and intended actions. The shared space in the CVE can be used to support some of these real-world functions.

- CVEs support peripheral awareness: Having participants working in a shared environment is a powerful method for supporting peripheral awareness. Greenhalgh indicates that workers situated in the same environment maintain and make use of an ongoing awareness of the activities of others within the environment even when not cooperating explicitly.

- CVEs unify communication and information: As an example, consider CVEs that are being used for visualization purposes. Having the visualization situated in the collaborative virtual environment allows the users to have combined access to the information and to facilities for cooperation and communication. These systems, where participants are virtually situated in the same place as the information with which they are working, are known as Populated Information Terrains (PITs). Benford *et al* [11] present an example of such a system.

- Maintaining autonomy: In a CVE, participants have independence of movement and activity. This is opposite to the approach used by 2D window based conferencing systems where participants see exactly the same view and are therefore limited to certain possible activities. In a CVE, participants can navigate freely and have spontaneous encounters, informal collaborations, and exploration of the virtual world and data in it.

- CVEs scale to a large number of participants: CVEs have a clear potential to support a large number of simultaneous participants, when compared to other real-time collaborative systems such as video and audio conferencing.

The type of collaborative virtual environment being considered in this document are three dimensional environments where each user is represented within the virtual environment by a graphical representation or *avatar* (refer to Section 2.3 for some background on avatars in CVEs), each user can move independently, and the position and orientation of each user's avatar provides information about what they are seeing and doing. As an example, Figure 2 shows an image of such an environment taken from [27].

2.1.3 Challenges in Development of Networked Virtual Environments

Signal and Zyda [49] indicate that networked virtual environments are complex systems which are difficult to implement correctly or effectively. They indicate that this is because networked virtual environments involve different disciplines of computer science such as distribution, computer graphics, etc.

Signal and Zyda [49] describe networked virtual environments as being:

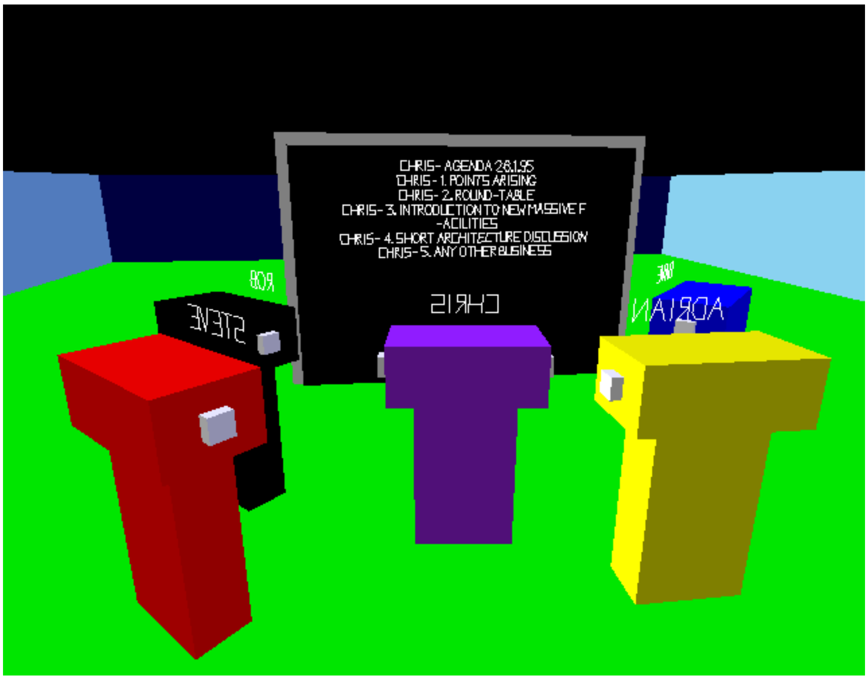

Figure 2: **A Collaborative Virtual Environment.** A small group of participants meeting in a Collaborative Virtual Environment. The CVE system used here is the MASSIVE system described in [27]

- distributed applications, meaning that they must deal with all the challenges and problems of managing network resources, such as network bandwidth, latency, scalability, data loss, network protocols, etc.
- Graphical applications, meaning that they must maintain smooth frame rates and provide realistic graphics.
- Interactive application, meaning that real time interaction is required.

Here are some challenges which have to be addressed when developing a networked virtual environment:

Scalability

Scalability is an important factor to consider when developing large scale virtual environments. Scalability refers to the effects of increasing the scale of a system, so a scalable system is one were the cost of increasing the scale is small [27].

There are a number of aspects which influence the scale of a collaborative virtual environment. Snowdon *et al* [61] indicate that the greatest challenge facing the development of large scale VR systems is that of scalability. They indicate that there are several dimensions to the problem of scale:

- *Network*: The network needs to be able to deliver information about many objects to many users, given limited bandwidth and unavoidable latencies. Sensible use of network protocols such as multicasting has the ability to reduce bandwidth requirements and thus increase the scalability of the VR system.
- *Computational*: The processors used need to be able to compute and render a very large number of complex objects.
- *Perceptual*: Users need to cope with perceiving all the other users and objects at the same time (cognitive/information overload).
- *Geographical*: Having a VE system spanning different continents poses some problems such as increased latency.

Distribution Model

There are different distribution models which correspond to the nature of the database representing the virtual world and the manner in which the data is made available to all participants in the virtual environment [26, 37]. The different approaches are:

- *Replicated database*: A copy of the database is maintained by all processes, and database updates are broadcasted to all processes (refer to Figure 3).
- *Centralised database*: The database is kept on a central machine, to which updates and requests for information are sent. This model is also called a *client-server* model (refer to Figure 3).
- *Distributed database*: A replicated database but guaranteed to be synchronized at all times, i.e., all the copies of the database are kept consistent at all times.

Network protocols

A protocol is an agreement between processes on how the communication is to proceed [69]. Two important issues that a network protocol must address are reliability and communication speed [26]. Unfortunately, these two issues are inversely related (i.e., higher levels of reliability incur more overhead, slowing communication [26]), and so networks provide more than one protocol, letting

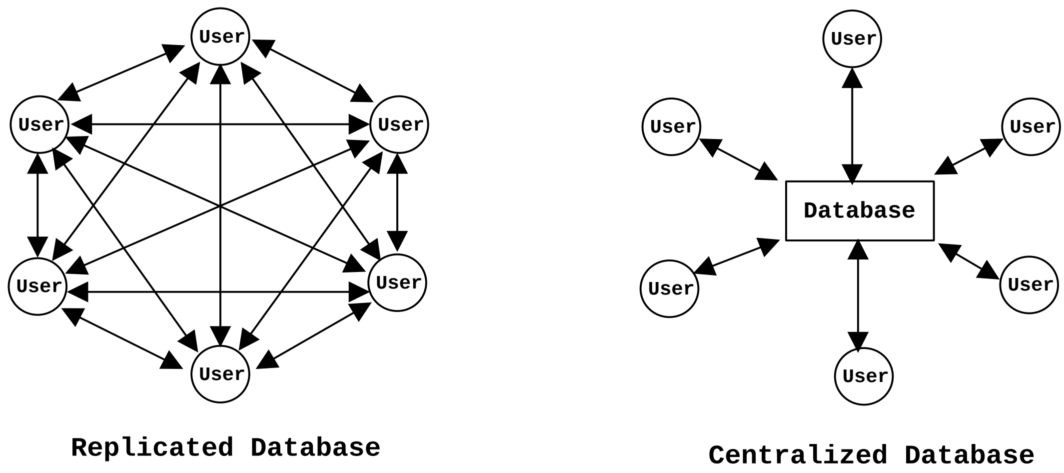

Figure 3: **Different distribution models.** The replicated database model and the centralised database model. In the replicated database model, a copy of the database is maintained by all users, and database updates are broadcasted to all participants. In the centralised database model, the database is kept on a central machine, which sends and receives updates to and from the users.

the developer decide which is appropriate for a given application. The two most popular protocols are TCP (Transmission Control Protocol) and UDP (User Datagram Protocol) [69, 65, 26, 49]. TCP provides a reliable service (messages are guaranteed to arrive), and UDP makes no guarantee, although the probability of a given message arriving is very high [69, 65]. The trade-off is that, while TCP provides a guarantee, applications using it may run as much as ten times slower than those written using UDP [26].

Another important consideration is whether to use *unicasting*, *broadcasting* or *multicasting* for sending the network messages [26]. Using unicast communications, if there are *n* users in the environment, then when a user process wants to send a message to all the other user processes, it must connect to *n-1* other processes and send *n-1* messages (refer to Figure 4). Using broadcasting, the sender can simply send one single message which allows all the other processes to read that single message. Multicasting is simply a subset of broadcasting, where groups of processes can be established, and only those processes in the group receive the message instead of every process in the network (refer to Figure 4). Therefore, broadcasting and multicasting significantly reduces the number of connections and messages being sent. Using multicast also simplifies the programming, since a participant joining a session in progress does not have to establish *n-1* connections with the other processes [26]. The new participant only needs to know the multicast group address to listen to messages and send updates. For an in depth description of multicasting see [69, 65, 15].

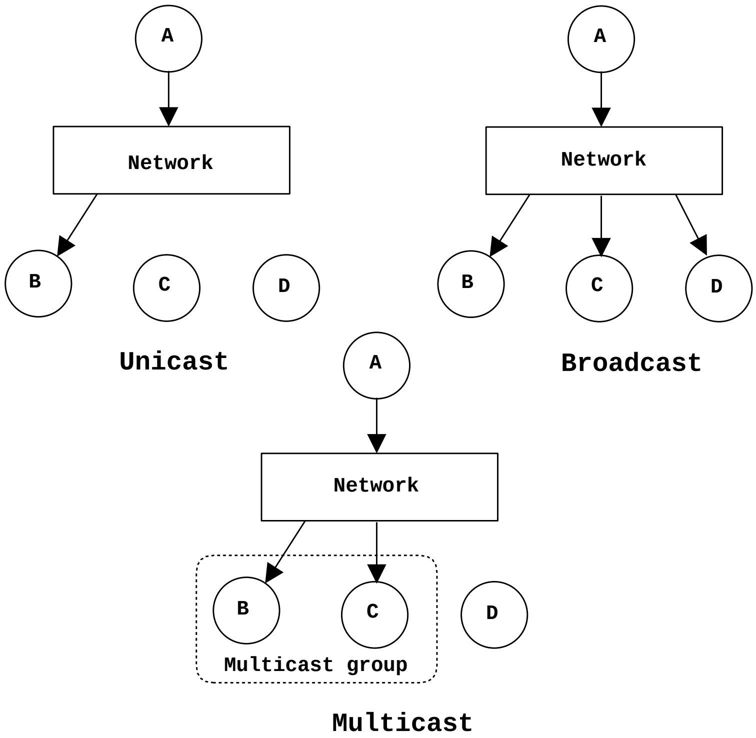

Figure 4: **Unicast, broadcast, and multicast communications.** Examples of sending one message using unicast, broadcast and multicast. Using unicast communications, one needs to send a message to each process. Using broadcast communications, the sender can simply send one single message and all other processes get that single message. Multicasting is very similar to broadcasting, but only those processes subscribed to the multicast group receive the message.

Bandwidth

Macedonia and Zyda [37] believe that the available network bandwidth determines the size and richness of a networked virtual environment. They indicate that as the number of participants increases, so do the bandwidth requirements, and therefore, high speed networks are critical for building virtual environments where a large number of participants can interact.

Latency

Latency is the delay between one user doing some action and the displays of the other users showing that action. Low latency is critical to virtual environments since it "controls the interactive and dynamic nature of the virtual environment" [37]. High latency increases the time taken to complete a

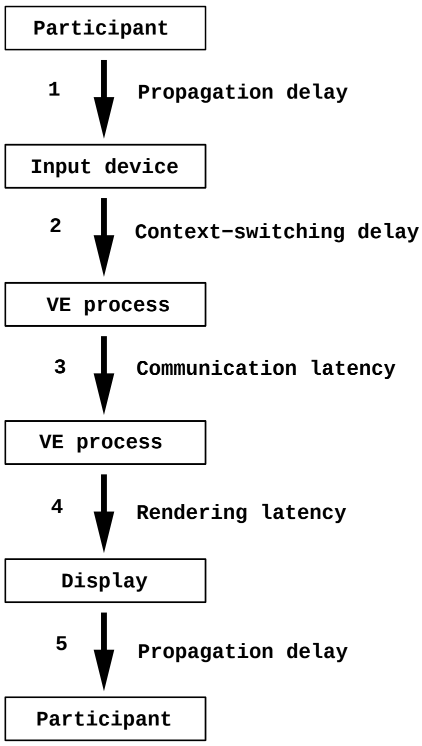

Figure 5: **Latency.** The delay between one participant doing some action and the display of the other participant showing that action. The most interesting stage is stage 3, the communication latency. This stage represents the latency generated when messages between two processes in different hosts are sent

task, and if this time is too high for a given collaborative task, human social protocols begin to break down. Figure 5 shows the different stages which contribute to latency. Some of the stages, such as stage 1 and 5 are only significant when one is using a very latency-critical environment. The most interesting stage is stage 3, the communication latency. This stage represents the latency generated when messages between two processes in different hosts are sent. Communication latency is very important because when the distribution distance of the CVE increases, so does the communication latency while the other stages remain more or less constant. A key challenge when implementing networked virtual environments is that one must deliver packets with minimal latency (less than 100 ms) to guarantee the illusion of reality [80].

Distributed Interaction

Singhal and Zyda [49] indicate that a networked virtual environment system must "mask" any artifacts that might arise from the distributed nature of the system, and must present the participants with real time interaction, where a user's actions are having an immediate impact on the environment. This is one of the main challenges facing distributed virtual environments, since it is very difficult to achieve because of network latency.

2.2 Presence in Virtual Environments

"A virtual reality is defined as a real or simulated environment in which a perceiver experiences telepresence"

— *Steuer [64]*

In order for virtual environments to be useful and hence successful, they need to provide the participants with compelling experience. This can be achieved by providing a high sense of presence, which means providing the participants with a sense of "being there", with a sense of being in the place specified by the virtual environment rather than just seeing images depicting that place, and forgetting being in the lab in favour of the virtual world. Enhancing the sense of presence in a virtual environment is a very important research objective since that leads to the "suspension of disbelief that they are in a world other than where their real bodies are located" , and "characterises the response of participants to the system" [55].

2.2.1 Definition and Theory of Presence

The term *presence* in a virtual environment refers to a "mental state in which a user feels physically present within the computer-generated environment" [22]. Presence in a virtual environment is thus concerned with the subjective feeling of existence within the given virtual environment, or the sense of "being there" in the virtual environment [46, 64, 28, 59, 81, 79]. Equivalently, presence is the extent to which participants of a virtual environment have a sense that they are somewhere other than where they physically are while experiencing the virtual environment. This notion of presence, the feeling of "being there" in the virtual environment, is considered central to the use, and therefore the usefulness of virtual environments. Steuer emphasises the importance of presence in a virtual environment by indicating that presence is the defining feature of virtual reality: "A virtual reality is defined as a real or simulated environment in which a perceiver experiences telepresence" [64]. Sheridan [46] simply defines virtual presence as "feeling like you are present in the environment generated by the computer".

Presence has been defined by Lombard and Ditton [34] as “the perceptual illusion of non-mediation”. This definition says that providing a sense of presence is providing the user with an illusion that the experience is non-mediated. By a non-mediated experience they mean that the experience is experienced without any technology in the way. This illusion of non-mediation occurs when a person does not perceive the existence of a medium in his/her environment, and behaves as if the medium is not there. They indicate that presence is a multi-dimensional concept and identify different types of presence: presence as social richness (the “warmth” possible via a medium), realism (perceptual realism and social realism), transportation (the sense of “being there”, “we are together”), immersion (perceptual and psychological), social actor (social interaction).

Slater *et al* [51, 60] define presence as “a state of consciousness, the (psychological) sense of being in the virtual environment, and corresponding modes of behaviour”. They indicate that participants who are experiencing a high sense of presence should experience the virtual environment as “more the engaging reality than the surrounding world”, and consider the virtual environment as “places visited rather than images seen”. They also mention that while experiencing a high sense of presence, the behaviours of participants in the virtual environment should be consistent with the behaviours that would have occurred in everyday reality under similar conditions. This is an important factor which can be used to measure presence in virtual environments.

Witmer and Singer [79] define presence as “the subjective experience of being in one place or environment, even when one is physically situated in another”. As applied to a virtual environment, they indicate that presence refers to experiencing the computer-generated environment rather than the actual physical world.

These definitions of presence provide a common understanding of the concept, but do not describe the nature of the experience [79]. In addition, these definitions of presence are insufficient to provide an understanding of presence since they do not provide any theory of presence. Various theories of presence are described below. For the purpose of this dissertation, presence is defined as the sence of “being there” in the virtual environment.

Witmer and Singer [79] believe that presence is a normal awareness phenomenon, and is based on the interaction between sensory stimuli, environmental factors which encourage involvement, and internal tendencies to become involved. They say that presence in a VE depends on attention shift from the real world to the VE. However, it does not require the total removal of attention from the real world. The degree to which attention is shifted away from the real world determines the amount of presence felt by the user. Thus, presence is a matter of focus. However, they also present an alternative view, namely that presence may be similar to *selective attention*. Selective attention describes the tendency to focus on only relevant or interesting information. The argument is that experiencing presence in a VE requires the ability to focus on one set of relevant stimuli, those of the VE, to the exclusion of irrelevant stimuli from the real world. In this model, both *involvement* and *immersion* are necessary to experience presence. They define involvement as “a psychological state experienced as a consequence of focusing one’s energy and attention on a coherent set of stimuli or meaningfully related activities and events” [79], and indicate that as participants become more involved in the VE their sense of presence increases. They define immersion as “a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences” [79]. They indicate that a VE that produces a greater sense of immersion will produce higher levels of presence.

Slater *et al* [51] describes presence as “an increasing function of two orthogonal variables”. The first variable is the extent of the match between the displayed sensory data and the “internal representation systems and subjective world models typically employed by the participants”. The second variable is the extent of the match between proprioception and sensory data. Proprioception results in the formation of an unconscious mental model of the person’s body and its dynamics [56]. Therefore, in order to have a match between proprioception and sensory data, the changes to the display must ideally be consistent with changes caused by the person’s movement and locomotion. Slater *et al* [51, 60, 50] distinguish between immersion and presence.

They define immersion to be a description of the technology, describing the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding, and vivid illusion of the reality to the senses of a participant. *Inclusive* indicates the extent to which physical reality is shut out. *Extensive* indicates the range of sensory modalities accommodated. *Surrounding* indicates the extent to which this virtual reality is panoramic rather then limited to a narrow field. *Vivid* indicates the resolution, fidelity and richness of the sensory information. They also indicate that immersion requires a self-representation in the VE, i.e. an avatar. The avatar is both part of the perceived environment and represents the participant that is doing the perceiving. Slater [50] indicates that Witmer and Singer’s definition of immersion forms part of his understanding of presence and not immersion. Slater’s model predicts that the higher the level of immersion, the higher the level of presence.

Thie and van Wijk [70] present a different approach to the theory of presence. They state that interaction with a shared VE causes the creation of two mental models by the participant. The first model is that of the real world, and is responsible for presence. The second model is that of the virtual world, and is responsible for virtual presence. Within each model are two sub-models: that of the self (which causes personal presence in the real world, and personal virtual presence in the virtual world) and that of the non-self (which is a mental model of the environment as a participant experiences it). Thie and van Wijk [70] also mention that the way participants perceive presence depends on their susceptibility for presence. They mention that the susceptibility for presence has two main aspects: the first aspect is the conscious will to accept the signals from the virtual environment. The second is the subconscious ability of the participant’s brain to register signals from the VE and rule out other signals.

Prothero *et al* [39, 41] formalise the definition of presence as the feeling of "being in" an environment. Presence is explained as an illusion of position and orientation, i.e. that presence has to do with switching from using cues from the real environment to those defined by the virtual environment. Presence is then linked to visually-induced illusory self-motion, or vection. The hypothesis is that we maintain a subjective coordinate frame (the rest frame) with respect to which we determine positions, orientations, and motions. Incorrect or inappropriate choices of rest frames result in illusory, visually-induced perceived motion (vection) or illusory self-location and self-orientation - that is, presence.

Barfield and Hendrix [7] propose a "spatial fidelity" model of presence which indicates that the sense of presence is dependent on the degree to which spatial, auditory, and haptic transformations of objects in the virtual environment are similar to spatial, auditory and haptic transformations in the real world. Some of the factors influencing the fidelity of spatial transformations, for example, are the field of view, display update rates, motion parallax, and depth cues. They propose that display technologies and interaction methods that provide high-fidelity spatial transformations will tend to provide high levels of presence.

Bystrom Barfield and Hendrix [16] propose a model of interaction in virtual environments called the Immersion, Presence, Performance (IPP) model. This model is based on the models proposed by Barfield and Hendrix [7], and by Slater *et al*. This model describes the effects of display technology, task demands and attentional resource allocation on immersion, presence and performance in virtual environments. The IPP model is shown in Figure 6. The first two components describe the characteristics of the VE system, which include the display technologies used, and Slater's concept of immersion. The third component of the model represents the fidelity of the sensory information presented to the participant. This includes the degree to which the display and transformation of spatial, auditory, and haptic information in the VE is similar to that information in the real world. The next component of the model describes the need by the participants to allocate attentional resources to the objects and events within the environment in order to interact in the virtual environment. The requirements of the task will influence the amount of attentional resources that are allocated to the virtual environment. If the participants allocate sufficient attentional resources to the VE and if there is a sufficient degree of sensory fidelity, the participants may view the VE as an actual place, developing a sense of presence in the VE. Finally, the nature of the task, the sense of presence and the level of attentional resources allocated to the task may all affect the performance in the VE.

All these definitions and theories of presence proposed by different scholars cover different types or conceptualisations of presence, but overlap quite significantly. There is a need for a standard definition and theory of presence which will enable the development of a standardised measure of presence which can be used by researchers in different scenarios. They will enable a systematic research into the factors effecting presence, and will allow comparisons between different experiments. Many researchers [46, 41] have called for the development of a standardised measure for presence. Lombard *et al* [35] mention that the "lack of a consensus regarding a conceptual definition of presence is one of the reasons that there is no standard technique or instrument for measuring presence".

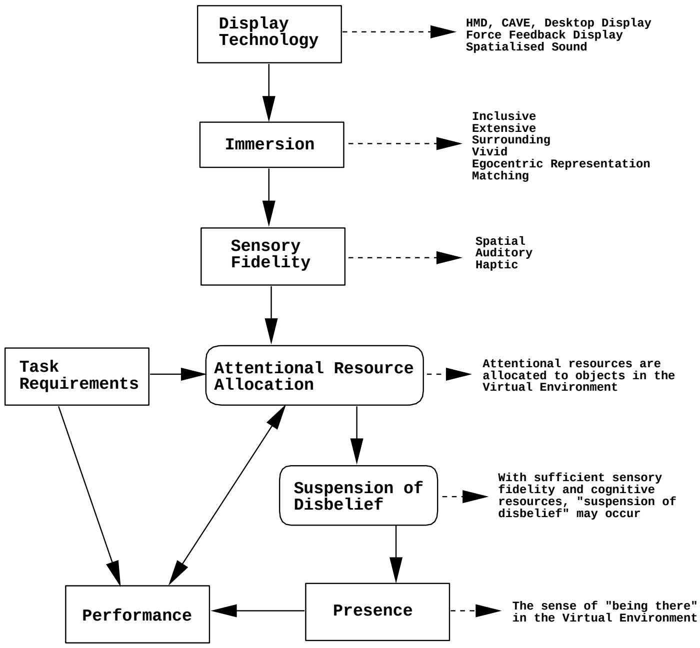

Figure 6: **The model on Immersion, Presence, and Performance (IPP) described in [16].** This model describes the effects of display technology, task demands and attentional resource allocation on immersion, presence and performance in virtual environments.

2.2.2 Clasification of Presence

Slater *el al* [55] indicate that there are two manifestations of presence, *subjective* presence and *behavioural* presence. Subjective presence refers to what an individual will express in response to question about "being there", in the virtual environment. They indicate that one can think of subjective presence as "being a verbal and necessarily conscious articulation of a state of mind" [55]. Behavioural presence refers to observable responses to stimuli, and one can think of it as being "automatic, unplanned non-conscious bodily responses" [55] to stimuli. Subjective presence is essentially an evaluation of an experience, whereas behavioural presence is concerned with the appropriate responses to events in the virtual environment.

Slater *et al* [57] classifies presence in a collaborative virtual environment into *personal presence* and *co-presence*. These two types of presence are related, but are conceptually different forms of presence. Personal presence relates to the sense of “been there”, and having a feeling of presence yourself. Personal presence has the subjective and behavioural manifestations described earlier, and has been explored in [46, 29, 28, 55]. Co-presence relates to the feeling of presence of others in the collaborative virtual environment. It has two aspects, for each individual: first, the sense of presence of other individuals in the virtual environment, and second the sense of being part of a group and a process, i.e., being present in a group and in the process which the group is working on during the meeting. Once again, this kind of presence has the subjective and behavioural manifestations described by Slater *et al* [55]. The subjective manifestation relating to each individual’s state of mind, and the behavioural relating to the observed behaviour of each member of the group, and the overall group behaviour.

Slater *et al* [57], identify the following relevant factor for co-presence:

- They postulate that personal presence is a prerequisite for co-presence.
- The notion of a virtual body or avatar is perhaps even more important for co-presence than for personal presence.
- The static existence of others is almost certainly not enough, there must be a sense of the possibility of interaction and the exchange of information.
- The representation of others is crucial to create a sense of co-presence: The way one represents other participants in the virtual environment is very important to enhance the sense of co-presence. Some persons might find it easy to maintain the sense of presence of others with just crude representations of avatars and text interaction only. Others might require fully functional avatars, with gestures and facial expressions.

Thie and van Wijk [70] indicate that when a person interacts with a CVE two mental models are activated: The model of the *Real World* and the model of the *Virtual World*, which is responsible for presence in the virtual environment. They distinguish two sub models within the model of the Virtual World: The first mental sub model is the model of the *self*. The self is the mental model that a participant develops of him or herself. This mental model is responsible for producing Slater’s personal presence. The second mental sub model is the model of the *non-self*. The non-self is the mental model of the environment as a participant experiences it. Furthermore, they argue that the mental model of the non-self can be divided into a social mental model and an environmental model, causing *social presence* and *environmental presence*. Social presence is taken to mean the feeling that there are other people present in the collaborative virtual environment. This is equivalent to Slater’s co-presence.

This categorization of presence is also mentioned by Heeter [28]. Heeter distinguishes three types of presence: personal presence, social presence, and environmental presence. Personal presence refers to the extent to which and the reasons why one feels like one is in the virtual world (i.e., the sense of "being there"). Social presence refers to the feeling that there are other participants present in the environment and reacting to you. This type of presence corresponds to the concept of co-presence mentioned by Slater *et al*. Environmental presence refers to the extent to which the environment itself appears to know that you are there and reacts to you. The argument is that if the environment knows you are there, that may contribute to you believing you are there.

Lombard and Ditton identify in [34] different types of presence. The major proposed dimensions of presence are: Presence as transportation: the sense of "being there" occurs when a person's perception fails to acknowledge the role of technology that makes it appear that she is in an environment different from her actual location in the real world. Presence as realism: Social realism occurs when a person's perception fails to acknowledge the role of technology that makes it appear that she is in an environment in which the social characteristics correspond to those in the real world. Immersion: engagement, involvement and immersion occurs when a person's perception is directed towards objects, and events created by the technology, and away from those in the physical world. Social presence: occurs when a person's perception fails to acknowledge the role of technology that makes it appear that she is communicating with other people. All of these broad dimensions of presence can be incorporated into their definition of presence: "the perceptual illusion of non-mediation".

For the purpose of our research, we distinguish two dimensions of presence in a collaborative virtual environment: personal presence and co-presence. These correspond to the classification presented by Slater *et al*.

2.2.3 The Importance of Presence

With so much research being done on presence, a natural question to ask is whether presence is of primary importance in the study of virtual environments. Ellis [20] points out that increasing presence in one part of a task may decrease task performance by inhibiting smooth transitions between distinct environments. In addition, some factors which may increase presence (for example, not being able to manipulate an object unless the avatar is close enough) may actually decrease efficiency. In such cases, Ellis states that the design of the virtual system should focus on efficient communication and interaction, with presence as a phenomenon of secondary importance.

However, as Prothero states in [39], presence is a common property of virtual interfaces, and thus any explanation for the psychology of interfaces must also explain presence. In addition, while presence may not directly affect the effectiveness of a virtual environment or interface, it appears to be related to many things which do. Factors which increase presence may make an interface easier to use, for example, spatialised sound and pictorial realism.

Witmer and Singer [79] also mention that many factors which appear to influence presence are known to enhance learning and performance, specifically with respect to their model of selective attention.

Slater and Wilbur [60] indicate that presence provides a direction for research in virtual environments. If one can find factors which contribute to the sense of presence, then these factors can guide the future of VE technology. Another important reason for researching presence is its relationship to task performance. Slater and Wilbur's view on this relationship is that there is no reason to expect a positive association between presence and task performance in the VE. They indicate that the most important issue with respect to task performance is the quality of the user interface. They also indicate that the importance of presence is due to the fact that the greater the degree of presence, the greater the chance that participants will behave as they would in real life. This behaviour is important when for example, one uses VEs in psychotherapy, where responses such as claustrophobia, fear of heights, and fear of flying have been observed in immersive VEs.

Barfield and Hendrix [7] postulate in their spatial realism model that the spatial fidelity of the virtual environment will enhance performance only if the demands of the task requires that a particular spatial cue be present in that environment. For example, if we have a task which does not depend on stereopsis as a depth cue, then performance would not benefit from the use of a stereoscopic display even if it will increase the level of immersion in the virtual environment.

Bystrom, Barfield and Hendrix [16] hypothesise that presence itself doesn't necessarily facilitate or hinder performance, but that having some sense of presence in an environment is a necessary condition for performance to occur. They also indicate that the nature of the task may also indirectly influence the level of presence experienced, since an engaging task may lead the participant to allocate more attentional resources to the VE, which will create a higher sense of presence.

The concept of presence is an important research area since it provides a means to understand how participants will behave in virtual environments. Being able to generate virtual environments creating a high sense of presence will enable participants to behave in a similar way as in the real world. Presence has become a design goal of virtual reality, in that the difference between virtual reality and other media is defined as a difference in the level of presence [64].

2.2.4 Factors Influencing Presence

There have been several experimental studies on a number of factors affecting the sense of presence in virtual environments [7, 77, 30, 31, 58, 56, 45]. The most significant factors studied have included the effect of visual display rates, the effects of the visual display characteristics, the influence of 3D sound on presence, the influence of head-tracking and interaction on presence. A fundamental goal is to determine how the sense of presence is influenced by the properties of the system that generates the virtual environment, by the characteristics of the environment itself, how it responds to people's action, and their own representations.

Barfield and Hendrix [7] examined the influence of the visual display update rate on subjective presence in a virtual environment. Update rates is the frequency (in frames per second) at which computer-generated images change in response to user action or to other dynamic aspects of the simulation. They found that presence generally increases with increasing update rate, but that the sense of presence was approximately constant between about 15 and 20 frames per second.

Welch *et al* [77] present a list of factors which might affect presence, categorised into environmental factors, social factors and individual factors. Environmental factors which might affect presence include: (1) the range of sensory experiences and/or modalities stimulated, (2) the amount of sensory resolution, (3) the degree of similarity between the observer's body and its visual representation, (4) the presence or absence of stereopsis, (5) black and white versus color presentation, (6) the presence or absence of perceptual constancy during movements of the body and/or sensory organs, (7) the familiarity of the scene. Social factors that might affect presence are: (1) whether other individuals are present in the VE and (2) the extent to which these others respond to or interact with the participant. Individual factors which might affect presence are: (1) the assumptions that observers bring to the VE, (2) the amount of practice they had on the VE task, (3) the length of their exposure, (4) the degree to which they have become familiar with the intersensory and sensorimotor discordances that may be present, and (5) individual predispositions to rely on or attend to one sensory modality (e.g., vision) over another (e.g., auditory). They also indicate that despite all these postulated factors which might affect presence, the literature provides only a few well-controlled studies which investigate some of these factors, and that there is a need for a systematic examination of these factors.

Welch *et al* [77] also investigated the effects that pictorial realism and delay in visual feedback have on presence in virtual environments. This experimental study was based on a driving simulator that had two levels of pictorial realism. They found that the more realistic virtual environment produced a significantly greater sense of presence than the less realistic one. They also found that a delay in visual feedback decreased the sense of presence. They indicate that a higher level of presence was reported under the conditions of minimal delay and that this is a more important factor that the level of pictorial realism.

Hendrix and Barfield [30] investigated the effects that stereopsis, and geometric field of view have on subjective presence in virtual environments. They found that each of these significantly affected the sense of presence, with stereopsis and a wider geometric field of view each enhanced the sense of presence reported by the users. They also investigated the effects that head-tracking has on the sense of presence. They found that head tracking significantly increased the sense of presence in virtual environments.

Hendrix and Barfield [31] investigated the sense of presence within stereoscopic virtual environments with and without auditory cues. The first study investigated the presence or absence of spatialised sound, and a second study compared spatialised to nonspatialised sound. They found that the addition of spatialised sound significantly increased the sense of presence in the virtual environment.

Slater *et al* [58] carried out an experiment to determine the effects of dynamic shadows on presence in an immersive virtual environment. The results suggested that for visually dominant subjects, the greater the extent of shadow phenomena in the virtual environment, the greater the sense of presence.

Slater and Usoh [56] argue that there is a logical connection between the degree of presence and the virtual body in an immersive virtual environment. They argue that if the match between proprioception and sensory data about the corresponding dynamics of the body is high, then the person immersed in the virtual environment is likely to identify with their virtual body. They indicate that proprioception results in the formation of an unconscious mental model of the person's body and its dynamics. If this mental model matches the displayed sensory information concerning the virtual body, then the virtual body is under immediate control of the person's actions, and since the virtual body is itself part of the displayed virtual environment, the participant will have a high sense of presence in the virtual environment. They conducted experiments and concluded that using a virtual body, and having a high match between proprioception and sensory data about the dynamics of the body, can increase the feeling of presence in a virtual environment. During these experiments, they investigated the effects virtual bodies had on personal presence, and on interaction techniques on immersive virtual environments. They found that the interaction techniques in virtual reality may also play a crucial role in enhancing the sense of presence, and that interaction techniques which maximise the match between proprioception and sensory data will also maximise presence.

Usoh *et al* [73] performed an experiment to investigate the sense of presence of participants using three different navigation techniques, namely real walking, walking in place, and flying. Real walking involved being able to walk freely around the entire virtual scene in the same manner as in a real environment. Walking in place involved reproducing the physical head movements generated during actual walking but without physically moving (i.e., mimicking the walk movement on the same spot). The changes in head position were fed to a neural network trained to recognize walking movements. The flying metaphor involved pushing a button on a 3D mouse to move forward in the direction of gaze. In this experiment, they found that the participants experiences a higher sense of presence when they navigated by walking in place than when they navigated by flying. They also found that presence was higher for real walkers than for participants walking in place, but the difference was statistically significant only in some models. They also found that real walking was significantly better than both walking in place and flying in simplicity, straightforwardness, and naturalness. Another important finding in this experiment was the fact that presence correlated with subjects' degree of association with their avatars. This implies that the sense of presence should be greatly enhanced by tracking all limbs and customizing avatar appearance to match the participants' appearance.

Lombard and Ditton [34] mentions known and suggested factors which might affect the sense of presence. The following are some of these factors:

- Number of sensory outputs: It is generally believed that the greater the number of human senses for which a medium provides stimulation, the greater the capability of the medium to produce a sense of presence.
- Visual display characteristics: Many characteristics of visual displays, such as image quality, image size, viewing distance, colour, dimensionality (e.g., stereoscopic images), etc, enhance the sense of presence.
- Sound characteristics: Audio is clearly important in generating presence. The main issues here are sound quality and 3D sound.
- Stimulating other senses: Visual and audio may be the most common senses stimulated, but there are others, each of which is likely to enhance presence: body movement, tactile stimuli, and force feedback.
- Interactivity: A major cause of presence is the ability to interact with the environment.

Durlach and Slater [23] indicate that in a collaborative virtual environment, given that the shared virtual environment is perceived as a common environment, the extent to which the participants feel present in this common environment depends on the same factors that influence presence in a single-user virtual environments. However, because the environment is shared between a number of participants, there are additional factors which influence the sense of presence and co-presence. For example, they indicate that it seems likely that the sense of presence and co-presence will be increased by fostering interactions with the environment. In such an environment, the alterations of the environment caused by actions of one participant must be clearly noticed by other participants. They also indicate that the sense of presence and co-presence will be increased even more by interactions where the environment changes are the result of collaborative work by a number of participants. For example, moving heavy objects which require cooperative lifting.

Witmer and Singer [79] have identified factors which might affect presence, based on the work by Sheridan [46] and Held and Durlach [29]. They have grouped those factor into the following major categories: Control Factors, Sensory Factors, Distraction Factors, and Realism Factors. They indicate thar the factors may exert their influence on presence by affecting involvement and immersion. These factor are:

- Control Factors
  - *Degree of control*: The more control a participant has in interacting with the virtual environment, the higher the sense of presence.
  - *Immediacy of control*: High delays between a user's actions and the associated consequences decreases the sense of presence [29]
  - *Anticipation of events*: Participants will probably experience a greater sense of presence if they are able to anticipate or predict what will happen next.
  - *Mode of control*: Presence may be increased if the interaction techniques are natural or well known to the participants [29].
  - *Physical environment modifiability*: Presence should increase if participants are able to "modify" objects in the environment [46]. For example, moving objects around, opening doors, etc.
- Sensory Factors
  - *Environmental richness*: The greater the extent of sensory information transmitted, the higher the sense of presence experienced [46]. An environment that has a lot of information to stimulate the senses should generate a strong sense of presence.
  - *Multimodal presentation*: The capability of experiencing a higher sense of presence is increased when all the senses are stimulated coherently and completely.
  - *Consistency of multimodal information*: The information received from all the different senses should be consistent with the description of the same virtual world.
  - *Degree of movement perception*: The sense of presence should be enhanced when participants can perceive self-movements through the VE.
- Distraction Factors
  - *Isolation*: Isolating the participants from their physical environment may enhance the sense of presence in a virtual environment. For example, devices such as head mounted displays, which isolate the user from the outside world, may increase presence in the virtual environment in comparison to a standard computer screen.

  - *Selective attention*: The participant's willingness and ability to focus on the VE stimuli, and to ignore distractions from other sources should enhance the sense of presence.
  - *Interface awareness*: Held and Durlach [29] indicate that unnatural, interface devices that interfere with the interaction and thus decreases the sense of presence in a virtual environment.

- Realism Factors
  - *Scene realism*: Presence should increase as a function of scene realism, which is affected by scene content, textures, light sources, etc. Real world content is not required according to Witmer and Singer [79], but many researchers feel that omitting physical laws may decrease presence if the absence of these laws directly affect the user's actions, as well as if the VE is attempting to model a real world situation
  - *Information consistent with objective world*: More presence should be experienced in a virtual environment when the information conveyed by a VE is consistent with the information experienced in the real world [29].
  - *Meaningfulness of experience*: The sense of presence should be increased when the experience presented by the VE is meaningful to the participants.

Romano *et al* [43], believe that it is possible to have a high level of presence in a virtual environment without having to stimulate every sensory system of humans. In fact, many current virtual environments successfully generate a sense of presence by stimulating only the visual and audio senses. This has a significance for producing presence in virtual environments, since constructing a fully immersive virtual environment has a lot of cost associated with it.

While there has been a good number of experiments investigating some of the factors believed to influence personal presence in a virtual environment, there has not been much research into the factors believed to affect co-presence in a multi-user collaborative virtual environment. There is a need for more research into the sense of co-presence in multi-user virtual environments. There is also a need for much more experimental data on the factors believed to affect personal presence and co-presence. There is not enough evidence of the replicability of some of the claims made.

We used the factors which affect presence mentioned by Witmer and Singer above, in order to create two virtual environments which generated different levels of presence. These two virtual environments were used in the experiment described in Chapter 6.

2.2.5 Measuring the Sense of Presence in Virtual Environments

One of the major issues when dealing with presence in virtual environments is how to measure it. Held and Durlach [29], and Sheridan [46] note that we don't have a working measure of presence.

Lombard and Ditton [35] point out that the "lack of a consensus regarding a conceptual definition of presence is one of the reasons that there is no standard technique or instrument for measuring presence". Suggested approaches to measure presence include:

1. User reported sense of presence: This involves asking the users about their sense of presence. This method has several important limitations: the questionnaires might have reliability problems which means that inconsistent results arise across different participants, time, and experiment settings. Another problem is that the type of questions used may lead participants to predict the type of response the researcher expects and this may influence their response.

2. Observation of user behaviours: This involves observing the behaviour of the participants in the real world, reacting to different stimuli in the virtual environment.

3. Task performance in the real and virtual environment: This assumes that if a user performs a task in the virtual environment as efficiently and in the same manner as in the real world then they must be present in the VE.

In order to measure presence, two main approaches exist: objective measures and subjective measures of presence. In scientific research, objective measures are generally held to be inherently better than subjective measures. Prothero *et al* [40] mention that the development of objective presence measures consistent with subjective measures is highly desirable. However, they go on to state that until such objective measures are developed, current subjective measures appear to be reliable and valid, citing an experiment by Hendrix and Barfield (1995) in which subjective measures were used to test participants' feelings of presence across three different VEs. Further support for subjective measures is found in Witmer and Singer [79], where Sheridan is mentioned as saying that presence is a subjective sensation, which is not easily amenable to objective physiological definition and measurement.

Subjective Measures of Presence

Since presence is a subjective experience, the simplest way to measure it is to make use of post-experiment questionnaires. In fact, the vast majority of studies measure presence through questionnaires, and are therefore evaluating subjective presence [58, 51, 55, 71, 52, 53, 79]. This is in part because subjective measures appear to be valid measures [41] and also because they are inexpensive and easy to perform.

According to Sheridan [46], presence is a subjective sensation or mental manifestation that is not easily amiable to objective physiological definition and measurement. Therefore, he indicates that “subjective report is the essential basic measurement (of presence)” [46], even though he does not totally dismiss an objective measures of presence.

Slater *et al* [58, 51, 55] have developed a questionnaire-based measure of personal presence based on three main attributes:

1. The sense of “being there” in the virtual environment as compared to being in a place in the real world.

2. The extent to which there were times when the virtual environment became the reality, i.e., the extent that the subject forgot that they were standing in a lab.

3. The extent to which the participant’s memory of the virtual environment is similar to their normal memory of a place.

When it comes to measure subjective co-presence (i.e., the feeling of presence of others in the VE), one can use a similar set of attributes as for personal presence above. Slater *et al* [57] indicate that the simplest types of questions that can be used to measure subjective co-presence are of the form:

- To what extent did you have a sense that you were in the same place as [person y] ?

- To what extend did you have a sense that [person y] was in the same place as you during the course of the experiment.

- To what extent did you have a sense of the emergence of a group/community during the course of the experiment ?

- To what extent did you have a sense of being “part of the group” ?

Witmer and Singer [79] use two questionnaires, one to measure presence, and the other to measure the susceptibility of participants to virtual presence. Thie and van Wijk [70] use two questinnaires derived from earlier research done by Psotka [42]. These two questionnaires measure the suceptibility of a person for virtual presence, and the amount of virtual presence a person experiences.

Witmer and Singer [79] have developed a presence questionnaire (PQ) based on: the factors believed to underlie presence, environmental factors that encourage involvement and enable immersion, and internal tendencies to become involved. They have also developed an Immersive Tendencies Questionnaire (ITQ), which measures the capability of an individual to become involved or immersed within a virtual environment. Most items in this questionnaire measure involvement in common activities, while some measure alertness and the ability to focus one's attention. Both questionnaires (PQ and ITQ) are described in more detail in Sections 3.2 and 3.3 respectively.

Lombard and Ditton [35] have developed a pencil-and-paper presence questionnaire containing items corresponding to each conceptualization of presence found in the literature. The main goals of this questionnaire is to test major theoretical conceptualisations of presence empirically, and to develop a standardised questionnaire for presence that can be used across different media, stimuli, and subject population.

Freeman *et al* [25] use methods of continuous assessment of TV picture quality, to measure presence. Participant rated their sense of presence directly while viewing a virtual environment. Presence was 'defined for observers as "a sense of being there" in a displayed scene or environment'. The participants had a hand-held slider which was used to continuously rate their sense of presence. The experiment used involved the effects of manipulating stereoscopic and motion parallax cues. They found that the presentation of both stereoscopic and motion-parallax cues was associated with higher presence ratings. They also found that prior training and and knowledge of experimental conditions influenced the subjective rating. The problem with such a procedure is that there is no control. The only response available to the participants is either to move the slider or to do nothing. Another major problem with this technique is that the hand-held slider is intrusive which affects the sense of presence felt by the participants.

Subjective measures of presence have several important problems. Apart from the reliability and validity of the presence questionnaires, the main problem is that most researchers use different questionnaires based of different conceptualisations of presence which means that is becomes very difficult to compare among different studies. The reliability and validity of questionnaires is discussed in Chapter 3.

Objective Measures of Presence

Some of the objective measures of presence proposed include measuring behavioural presence, task performance, and some physiological measures.

Behavioural presence cannot be evaluated using simple questionnaires, and so it requires a more complex method, based on observing the behaviour of participants in the real world, reacting to different stimuli in the virtual environment.

Held and Durlach [29], and Sheridan [46] both suggest that in order to measure behavioural presence one can record the "startle" or looming response of participants. For example, on can record whether subjects carry out involuntary movements in response to a suddenly threatening event (e.g., "If a virtual object is suddenly seen to be on a collision course with one's head, does the subject blink, or duck?" [46]). Other variants on this are the extent to which participants would avoid walking through objects, even though in principle they know that this is possible.

Slater *el al* [56] measure behavioural presence by observing the reactions of the subjects to danger, such as a virtual cliff, or objects thrown towards the participants head. The problem with behavioural measures is that they may be too complex to clearly identify and measure with clarity. Also, startle-based measurements may only be measuring isolated samples rather than measuring the overall presence created by the environment.

Slater *et al* [58] makes an attempt to measure behavioural presence by using contradictory information about an object represented in both the virtual and real environments. A radio was placed in the same position in both environments, and then the real radio was moved to a different position in the room. The real radio was suddenly turned on, and the participants where instructed to point to the radio to turn it off. This provided contradictory information, with the visual information coming from the VE and the auditory information from the real world. They extend to which the participants pointed to the virtual radio (hence responded to the visual information) indicated their degree of presence in the VE.

Slater and Steed [54] describe a new measure for presence in a virtual environment which can gather information unobtrusively during the course of the VE experience rather than when it is over. This technique does not use post-experiment questionnaires to measure presence. This presence measurement is based on the fact that at different times during an experience a participant will switch between two states: 'presence in the VE' (state V) and 'presence in the real world' (state R). The participants are asked to report transition from states V to R. Based on a stochastic model, an estimator for the proportion of time spent in the V state is constructed. This is used to measure the sense of presence felt by the participants in the VE. This technique is applied in an experiment to asses the relationship between presence and body movement in an immersive VE [54]. They found that this new measure gave results which were comparable to those obtained using post-experiment questionnaires.

Prothero *et al* [41] describes a behavioural measure related to the rest frame hypothesis. If presence has to do with a switch in the cues used to define position and orientation from those provided by real environment to those provided by virtual environment, then the level of presence should correspond to the level of identification with virtual cues over real cues.

Sheridan [46] and Hendrix and Barfield [30] suggest objective measures of presence based on task performance in the virtual environment. The problem with this method is that task performance may not necessarily correlate positively with presence, and that factors other than presence might influence task performance. One must find a specific task and show that presence correlates significantly and positively with the performance of that task.

Prothero *et al* [41] also mention using task performance as a measure of presence; however, it must first be established that presence correlates significantly and positively with task performance, which, as mentioned by Slater *et al* [51] may be in doubt.

Physiological measures have also been considered. Prothero *et al* [39, 41] mention that physiological measures are attractive, in part because they can be recorded unobtrusively. Some possible physiological measures mentioned by Prothero *et al* are posture, muscle tension, and ocular responses to virtual events. However, there is no evidence thus far that physiological measures correlate well with presence [39, 41].

2.3 Virtual Representation of Participants in Collaborative Virtual Environments

"The body social is many things: the prime symbol of self, but also of the society; it is something we have, yet also what we are; it is both subject and object at the same time; it is individual and personal, as unique as a fingerprint or odour-plume, yet it is also common to all humanities..."

— *Anthony Synnot [68]*

The motivation of using some sort of a virtual body to represent users within virtual reality systems becomes clear when one considers the role the body plays in everyday life. According to Slater *et al* [56], the body is our connection with reality, it is the means through which we participate in everyday reality. They indicate that "our sensory organs take in data about external reality which leads to perception, cognition and eventually to behaviour which converts this information into action." [56].

Our body performs several crucial functions in everyday life, most of which are so obvious that we take them for granted. Synnot indicates that the "possession of a body is so obvious that its major functions can be overlooked" [68]. Slater *et al* [56] describe the functions that the body fulfills in everyday reality as being the following:

- The physical embodiment of oneself.
- A medium of interaction, through the use of our bodies we interact with the world and are able to modify it.
- A medium for communication: our body allows us to communicate with other persons through the use of sound and gesture.
- It is the social representation of oneself: we recognise the existence of others through their bodies, and we also recognise different social status through the appearance of the body (i.e, decorating the body, etc).

Given the importance of the body in real life, the use of some sort of embodiment to represent participants in CVEs is crucial. In a CVE, the graphical representation of a user is termed an *avatar* [1] [74, 75]. For people communicating in a collaborative virtual environment, the avatar becomes a social as well as a personal object. The avatar is not only a representation of the user, and a means for interaction, but also a medium of communication with other participants.

In a multi-user virtual environment, a user's avatar has a main purpose: to signal the presence of that user to any other users who are currently in the environment. This provides other users with this user's location and point of view, which also facilitates awareness of ongoing activities [62].

The way one represents other participants in the environment is a major issue in enhancing the sense of co-presence. Some persons might find it easy to maintain the sense of presence of others with just crude representations of avatars. Others might require fully functional avatars, with gestures and facial expressions [57].

Benford *et al* [9] present a list of design issues for virtual representations (or avatars) within collaborative virtual environments:

- *Presence*: The main goal of an avatar is to convey a sense of co-presence (a sense of someone's presence in a virtual environment).

- *Location*: In shared space, it may be important for an avatar to show the location of the user. This might involve indicating both position and orientation. They argue that showing the orientation may be particularly important in collaborative systems because of the significance of orientation to everyday interaction. For example, participant could turn their backs on someone to indicate that they are not interested in communicating.

- *Identity*: A very important issue is recognising who someone is from their avatar. Benford *et al* indicate that firstly, an avatar should indicate that it represents a user as opposed to being a piece of scenery. Secondly, it should be possible to distinguish a user from other users (i.e., the avatars should be differentiable). Thirdly, it should be possible to recognise *who* an avatar represents (this could be done by using a name tag or using a texture map of the user's face).

- *Activity*: An avatar should provide some indication of the user's on-going activity. For example, the position and orientation of the avatar in a data space can indicate which data a given user is currently accessing.

- *Availability and degree of presence*: It is important to convey some sense of how busy and/or interruptible a person is. This might be achieved implicitly by displaying sufficient information about a person's current activity or explicitly through the use of some indicator on their

[1] The world avatar originates from Hindu mythology, and means the incarnation or the embodiment of a deity or a spirit in an earthly form.

avatar.

- *Gesture and facial expression*: Gesture is an important part of conversation. In order to support gestures, there must be some sort of 'limbs' present in the avatar. These limbs can be manipulated by providing a fixed set of gestures (e.g. waving, shaking the head, etc.), or by capturing information from the user using trackers. Facial expression also plays a major role in human interaction as the most powerful external representation of emotion, either conscious or sub-conscious. A simple way to approach this might be to texture map video onto the avatar. Another approach is to capture information from the user's face by using sensors. Benford *et al* also indicate that there is the issue of involuntary gestures and facial expressions. These involuntary expressions (such as looks of anger, fear, etc.) are also important but are much harder to support. This is because it is very difficult to capture these expression, as they require automatic capture of data about the user.

- *Efficiency*: There is always a limit on the available computing resources, and as a result, embodiments should be as efficient as possible by conveying the above information in simple ways. Approaches that attempt to reproduce the human physical form in as much detail as possible may be wasteful and more abstract approaches which reflect the above issues in simple ways may be more appropriate.

Bowers *et al* [12] describe an analysis of social interaction in an unstructured, small group, virtual meeting using the MASSIVE system. They investigate the relationship between the embodiment of participants through their avatars (they used quite simple blocky avatars), and communication issues such as turn taking in a conversation, and other aspects of social interaction. They found that even with simple block-like avatars (possessing no gestures or facial expressions), the avatars were sometimes used to supplement language as an additional mechanism in social interaction. Participants used their avatars in socially meaningful ways, such as to get a better view of the participant they wish to interact with, and use face-to-face communication. This shows that even simple avatars are not just a means of navigation and representation, but are also an important tool in social interaction. This suggests that avatars should support actions of social significance, such as gaze, body gestures and facial expressions.

Vilhjálmsson [75] has developed a system called BodyChat, which provides communicative behaviour to avatars. The systems automates the animation of important communicative behaviour such as raising eyebrows, gaze direction, blinking the eyes, smiles, nodding of the head, etc. This provides aliveness to the avatars, and enhance the communication and interaction between participants. For example, when two avatars pass each other while walking, they will automatically glance towards each other. If there is a willingness to communicate, they will smile at each other and perform a salutation such as waving. While two avatars are having a conversation, the avatars will automatically perform behaviour depending on the conversation. The BodyChat system shows that automating some of the communicative behaviour seems an excellent way forward in the design of compelling and useful avatars.

We recognise several important issues relating to avatars and co-presence that require further investigation. Giving simple gestures and facial expressions to the avatars might be important to enhance the sense of co-presence felt by participants in a CVE. The appearance of avatars is also an important factor which could be related to co-presence. The way one represents the other participants in the CVE could very well affect the sense of co-presence felt by the participants in a CVE.

2.4 Interaction and Collaboration

An important form of social interaction is collaboration or cooperation. An intuitive definition for cooperation is *an interaction pattern in which two or more people work together or coordinate their actions so that the outcomes of each are enhanced* [14]. This two-way, mutual assistance involves individuals or groups working together to attain shared goals [14].

Rosen [44] defines task groups as existing to organise some level of collective effort in pursuit of a parent organisation's goals, while simultaneously satisfying the needs of individual members. This definition applies equally well to any collaborative group, whether semi-permanent or temporary. Collaboration breaks down, however, when the needs of the individuals clash with the parent organisation's goals; or, in terms of the social psychology definition above, when the goal cannot be shared.

Underwood *et al* [72] mention that within a group of people working together towards a common (sharable) goal, members can choose to either take responsibility for subtasks, working *cooperatively*, or work together on all parts of the problem, that is, *collaboratively*. While a distinction is made here between collaborative and cooperative behaviours, this seems to be mainly a technical issue. Both behaviours involve *working together,* as is generally intended by both the terms cooperation and collaboration (both terms will be used synonymously hereafter). One important distinction, however, as mentioned by Underwood *et al* in [72], is that in the case of collaboration, the level of social interaction is necessarily high, whilst this may not necessarily hold for cooperation.

2.4.1 The Importance of Collaboration

Kelly and McGrath [32] found that given a task involving finding anagrams, groups solved more anagrams than individuals, but did so less efficiently (in terms of anagrams-per-person-per-minute) than individuals.

Underwood *et al* [72] found that while cooperative working with a computer led to performance gains, not all types of groups benefited equally. Mixed-gender pairs, in particular, show the least benefit of cooperative working.

Discussion of a problem has been seen to lead to success (Johnson *et al* in [72]). Verbalisation can help to locate gaps in information needed to solve a problem, and can then assist in finding the missing information (Van Lehn *et al* in [72]). Studies have shown that effective learners explain examples to themselves, leading to better acquisition of knowledge (Chi *et al* in [72]). Group discussions facilitate this as well as verbalisation — a group in which participants cooperate may result in one member producing a formal explanation which helps another to improve their understanding [72].

However, while cooperative group members may perform better than individuals, these advantages may disappear when members split up to work as individuals themselves. The greater success obtained by groups is not transferred to subsequent tasks [72]. In addition, lack of individual experience in the task before working as group may mean that members, while willing to cooperate, are unable to provide worthwhile support to the group [72].

In addition, two adverse phenomena often occur during collaborative work [24].

- Social loafing, the tendency of individuals to expend less effort when working together with others than when working alone, and
- Groupthink, the tendency of individual group members to engage in extreme concurrence seeking, leading to a lack of innovative thought

While cooperative group work may not be the best approach for all situations, cooperation in general is nevertheless essential to everyday life. No task is performed without some form of collaboration, whether knowledge sharing or general discussion.

2.4.2 The Influence of Technology on Interaction and Collaboration

Cairns tells us that social acts cannot be understood independently of the social context in which they are embedded because of the ongoing interchange between the person and their surrounds [17]. While "surrounds", in this context, does not mean the purely physical surroundings, this statement has relevance when investigating technology-mediated interactions. It suggests that interaction patterns in a virtual environment may well differ from those in a "real" environment.

This idea seems to be supported by practical investigation. Some of the results summarised by Teasley and Finholt in [24] are:

- Computer-mediated groups are better at generating ideas (also in [66]),

- Face-to-face groups are better at tasks involving problem-solving or achieving consensus on group preferences, (also in [66]),
- Participation in computer-mediated groups is more equal,
- Richer media (those conveying more social cues) improve performance for equivocal tasks,
- Effects seemingly associated with technology often stem from level of experience with the technology and the structuring of tasks imposed by the technology,
- Electronic monitoring at the group level reduces social loafing and reduces stress associated with monitoring,
- The use of group decision support systems result in increased decision quality, more equal participation, and greater focus on the task,
- Negative aspects of the use of group decision support systems include a longer time to reach a decision (possibly due to the time and effort required to communicate by reading and typing [66]), less overall consensus, and less satisfaction with the decision making process and outcome,
- Physically dispersed computer-mediated groups outperform all other types of groups while brainstorming,
- Members trust human partners more than human-like partners generated on a computer screen,
- Members of computer-mediated groups are less likely to exchange unshared information than face-to-face groups.

Possessing the technology to create virtual environments in which people can work and interact is not sufficient; these environments must also serve the same social and psychological functions as physical environments. The physical setting in which work occurs provides critical cues for coordination of collaborative tasks. Changing the circumstances of collaboration introduces new challenges due to the loss of shared physical setting. In particular, physically distributed collaborators have fewer social cues available, and thus there is a heavier burden on participants to explicitly communicate what would normally be tacitly understood [24]. Straus and McGrath [66] emphasis that communication media which transmit more social context cues will have a greater impact on group performance and satisfaction. Social context cues help participants regulate interaction, express information, and monitor feedback from others. A reduction in cues like eye contact, head nods, and voice inflection disrupts the flow of interaction. In addition, the lack of ability to perceive cues such as nodding, frowning, and questioning expressions reduces feedback as to whether others understood or agree with one's comments. Individuals feel that their ideas are less understood when communicating through information-poor media [66].

The lack of information about other members and their reactions may, in time, be reduced through the development of better avatars. Until such time, however, this lack of information reportedly leads to feelings of depersonalisation (Kiesler *et al*, 1984 in [66]), and a sense of anonymity (Short *et al*, 1976 in [66]). This, in turn, leads to decreased inhibitions in social interaction (Zimbardo, 1970 in [66]).

The degree of social context cues needed may differ for various types of tasks. Straus and McGrath [66] mention that for collaborative tasks such as idea generation, social context cues should have little impact on group performance. The anonymity engendered by the lack of cues may even be beneficial if inhibitions are decreased, resulting in more novel and diverse ideas. For intellective tasks (solving problems that have correct solutions), the presence of social context cues should be more important than in idea generation tasks, but is still not critical. Social cues will have more impact on group outcomes where there is a need for the expression and perception of emotions, for tasks requiring coordination and timing, when one is trying to persuade others, or when the task requires consensus amongst group members. These qualities are often present in judgment tasks [66].

2.5 Summary

In this chapter we have discussed the relevant background work needed for our research. We described Collaborative Virtual Environments, the sense of presence in virtual environments, the representation of participants in virtual environments, and group collaboration and interaction.

We provided some background on Collaborative Virtual Environments, where we defined virtual reality from a user perspective, in terms of the experience of presence. Virtual reality was therefore defined as "a real or simulated environment in which the perceiver experiences telepresence" [64]. Defining virtual reality in this way provides a concrete way of analysing virtual environments in terms of presence. We then described some of the characteristics of CVEs, and their application potential in terms of collaboration support.

We provided a discussion of the notion of presence in virtual environments, by presenting a definition and the available theories of presence found in the literature. We defined *presence* as the psychological sense of being in the virtual environment, and *co-presence* as the feeling that the other participants actually exist in that environment. We also described some of the factors believed to affect the sense of presence in virtual environments, as well as the importance of presence in virtual reality research. Identifying the factors which should influence the sense of presence is one of the main research focii at the moment. This is because if we know these factors, we could build systems which maximise the sense of presence. However, most of the factors believed to influence presence are purely theoretical, and more experimental research is needed to confirm those factors. Another important issue in presence research is the relation of presence to task performance in the VE. We believe that presence and task performance are not directly related, but that a bunch of factors (including presence) influence task performance. We also presented some of the ways in which the sense of presence in virtual environments can be measure. These include subjective measures making use of self-report questionnaire, and more objective measures such as observing the behaviour of participants to different stimuli in the VE, and physiological measures.

We presented some information into the representation of participants in virtual environments, where we described the different information provided by the avatars in a CVE. Avatars provide information such as presence of others, location of others, identity, activity, and availability. The avatars in a CVE are not only a means of navigation and representation, but that they are also an important means of social interaction, where having gestures and facial expression is an important factor.

To end this chapter, we described group collaboration and interaction, and presented some background on the influence of technology on group collaboration and interaction.

Chapter 3

Self-report Questionnaires

In this chapter, we present the design, reliability, and validity of the different questionnaires which we used in the experiments presented in this dissertation. These questionnaires are: Witmer and Singer's Presence Questionnaire (PQ) and Immersive tendencies Questionnaire (ITQ) [79], Slater *et al.*'s Presence Questionnaire [58, 51, 55], and our Co-presence and Collaboration Questionnaires. The main contribution of this chapter is found in Section 3.5, which describes the design and analysis of a co-presence questionnaire that we have developed in order to measure the amount of co-presence felt by participants in a collaborative virtual environment.

We also presents some background on the reliability and validity of subjective questionnaires in Section 3.1. Section 3.2 describes Witmer and Singer's Presence Questionnaire, which is used to measures the amount of personal presence felt by participants in a VE. We presents the design of the questionnaire, as well as reliability and validity of this presence questionnaire. Section 3.3 presents Witmer and Singer's Immersive Tendencies Questionnaire which measures the tendencies of individuals to become immersed in the media (such as the VE) and experience presence. We describe the Immersive Tendencies questionnaire and its reliability and validity. Section 3.4 describes Slater's Presence Questionnaire. We present the design of this presence questionnaire, and some reliability and validity analysis of the questionnaire. We have also developed a collaboration questionnaire which we use in one of our experiments. This questionnaire is described in Section 3.6. It measures collaboration and interaction, as well as the degree of enjoyment and comfort with individual members in the group. Finally, Section 3.7 presents a summary of the chapter.

3.1 Reliability and Validity of Questionnaires

Any self-report questionnaire must be shown to be both reliable and valid. In this section, we present some background information on test reliability and validity.

3.1.1 Reliability of Questionnaires

Reliability refers to the consistency of scores obtained by the same person when reexamined with the same test on different occasions, or with different sets of equivalent items, or under other variable examining conditions [4]. Test reliability indicates the extent that individual differences in test scores are attributable to true differences in the characteristics under consideration and the extent to which they are attributable to chance errors [4].

There are different methods to find the reliability of a given questionnaire. The most obvious method for finding the reliability of a questionnaire is by repeating the identical test on a second occasion. This is called *test-retest reliability*. The reliability coefficient (r_{tt}) is the correlation between the scores obtained by the same persons on the two administrations of the test. The error variance corresponds to the random fluctuations of performance from one test session to the other. These variations may result from uncontrolled testing conditions, (such as sudden noises and distractions). To some extent, however, they arise from changes in the conditions of the participants himself (such as fatigue, worry, recent experiences). Retest reliability shows the extent to which scores on a test can be generalized over different occasions. The higher the reliability the less susceptible the scores are to the random daily changes in the condition of the participant or the testing environment.

Another method to find the reliability of a given questionnaire is to use alternate forms of the test. This is called *alternate-form reliability*. The same person can be tested with one form on the first occasion and with another comparable form in the second. The correlation between the scores obtained on the two forms represents the reliability coefficient of the test. In the development of alternate forms, care should be taken to ensure that they are truly parallel. Fundamentally, parallel forms of a test should be independently constructed tests designed to meet the same specifications.

Another method for finding reliability is *split-half reliability*. Two scores are obtained for each person by dividing the test into comparable halves. This involves only one administration of the test. The first problem with split-half reliability is how to split the test in order to obtain the most nearly comparable halves. Once the two half-scores have been obtained for each person one can perform a correlation. To determine split-half reliability, one can use the Spearman-Brown formula [4]:

$$r_{tt} = \frac{2r_{hh}}{1 + r_{hh}}$$

where r_{hh} is the correlation of the half-tests.

A fourth method for finding reliability, which also uses a single test administration is the *Kuder-Richardson reliability* method. This is based on the consistency of responses to all items in the test. Inter-item consistency is found from a single administration of a single test. This technique is based on an examination of performance on each item. The Kuder-Richardson formula to calculate reliability is:

$$r_{tt} = \left(\frac{n}{n-1}\right)\frac{SD_t^2 - \sum pq}{SD_t^2}$$

where r_{tt} is the reliability coefficient of the whole test, n is the number of items in the test, SD_t is the standard deviation of total scores on the test, and $\sum pq$ is found by tabulating the proportion of persons who pass (p) and the proportion who do not pass (q) each item. The product pq is computed for each item and these products are then added for all items to give $\sum pq$. The Kuder-Richardson formula is applicable to tests whose items are scored right or wrong. Some tests, however may have multiple scored items. For such tests, a generalised formula has been derived known as *Cronbach's coefficient alpha* [21]. In this formula, the value $\sum pq$ is replaced by $\sum SD_i^2$, the sum of the variances of item scores. The procedure is to find the variances of all individuals' scores for each item and then to add those variances across all items. The formula for the coefficient alpha is then:

$$r_{tt} = \left(\frac{n}{n-1}\right)\frac{SD_t^2 - \sum SD_i^2}{SD_t^2} \quad (1)$$

3.1.2 Validity of Questionnaires

The *validity* of a test concerns "what" the test measures and "how well" it does so [4]. A scale is *valid* to the extent that it measures precisely what it is set out to measure and it measures it well. Validity is usually split into several sub-types such as *content validity*, *criterion validity*, and *construct validity*.

Content validity involves the systematic examination of the test content to determine whether it covers a representative sample of the behaviour domain to be measured.

Criterion validity indicates the effectiveness of a test in predicting an individual's behaviour in specified situations. For this purpose, performance on the test is checked against a criterion, i.e., a direct and independent measure of that which the test is designed to predict.

Construct validity refers to the coverage of the measured behavioural domain by the questionnaire items. Items should cover a representative sample of the behavioural domain in order for a scale to have high construct validity.

3.2 Witmer and Singer's Presence Questionnaire

Witmer and Singer [79] have developed a Presence Questionnaire (PQ) based on factors believed to underlie presence. This presence questionnaire measures the degree to which individuals experience presence in a VE (i.e., personal presence) and the influence of the possible contributing factors on the intensity of this experience. The Witmer and Singer Presence Questionnaire can be found in Appendix A.

3.2.1 Questionnaire Design

Witmer and Singer define *presence* as “the subjective experience of being in one place or environment, even when one is physically situated in another” [79].

They indicate that presence seems to be a matter of focus. The experience of presence in a VE may have aspects similar to the concept of *selective attention*. Selective attention refers to the tendency to focus on selected information that is meaningful and of particular interest to the participant. They argue that experiencing presence in a VE requires the ability to focus on one meaningfully coherent set of stimuli (in the VE) to the exclusion of unrelated stimuli (in the real world). Refer to Section 2.2.1 for a description of Witmer and Singer’s theory of presence.

Witmer and Singer have developed their Presence Questionnaire based on conceptual factors believed to influence presence by affecting either involvement, immersion, or both. The factors are grouped into the following major categories: Control Factors, Sensory Factors, Distraction Factors, and Realism Factors. The factors are described in detail in Section 2.2.4, and are listed in Table 1. One expects that Control Factors may affect immersion but not involvement, while Realism Factors should affect involvement but not immersion. Sensory Factors and Distraction Factors should affect both immersion and involvement. One has to note that while it is reasonable to hypothesise that these factors may be associated with presence, considerable empirical work is necessary before one can conclude that they affect presence. These factors are mainly based on the work by Sheridan [46], and by Held and Durlach [29].

The Witmer and Singer Presence Questionnaire can be found in Appendix A. The questionnaire uses a seven-point scale that is based on the semantic differential principle [4]. Like the semantic differential, each item is anchored at the ends by opposing descriptors. Unlike the semantic differential the scale includes a midpoint anchor as well.

3.2.2 Reliability of Witmer and Singer’s Presence Questionnaire

Reliability analyses were performed on the Presence Questionnaire by Witmer and Singer [79], using the combined data of four experiments [33, 78, 5, 48], which had similar PQ score distributions. They found internal consistency measures of reliability (Cronbach’s alpha) of 0.88 for the Presence Questionnaire. Since the value of Cronbach’s alpha (refer to equation 1) is close to 1, this indicated that the items are quite reliable and measure the same thing.

The Witmer and Singer Presence Questionnaire was used in the experiment described in Chapter 6. We performed reliability analysis on the obtained item scores and found a value for Cronbach’s

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

Table 1: **Factors contributing to Presence.** This table shows the factors hypothesised to contribute to a sense of presence according to Witmer and Singer [79]. These factors are mainly based on the work by Sheridan [46] and Held and Durlach [29].

alpha of 0.887. The alpha value we found was quite close to the one mentioned by Witmer and Singer. This supports their claims that the presence questionnaire contains items which are reliable.

3.2.3 Validity of Witmer and Singer's Presence Questionnaire

Content Validity

Content validity refers to the coverage of the measured behavioural domain by the questionnaire items. Items should cover a representative sample of the behavioural domain in order for a scale to have high content validity. Witmer and Singer indicate that the PQ items were based on factors believed to influence presence by affecting involvement and immersion, and they therefore indicate that the items in the Presence Questionnaire are valid.

However, Slater [50] indicates that Witmer and Singer's Presence Questionnaire does not give a measure of presence that is constructed independently from the factors that might influence it. Slater says that Witmer and Singer's PQ does not measure presence at all, and rather it is a measure of a person's responses to various aspects of the system, which of course is likely to be correlated with other measures of presence. Slater mentions that this questionnaire does not measure the sense of "being there" in the virtual environment which is the central aspect of presence. Instead, it measures the participant's opinion on the system factors thought to influence presence.

Construct Validity

A scale has construct validity to the extent to which it can be said to measure a theoretical construct or trait. If the PQ is a valid measure of the presence construct, then PQ scores should be associated in a predictable manner with other variables or constructs that in theory are related to presence.

Witmer and Singer indicate that a VE that stimulates all of the senses and allows natural modes of interaction should result in more presence than a less immersive VE. However, in one experiment on natural modes of interaction [5], they found no significant differences in presence as measured by the PQ between groups using different modes of interaction. This might indicate that the PQ is not associated in a predictable manner with a variable that in theory is related to presence, and so it might suggest that the PQ is not a valid measure of the presence construct.

Witmer and Singer also indicate that presence should relate positively to VE task performance, and indicate that the PQ was shown to be positively related to measures of task performance. However, we do not agree with Witmer and Singer's claim that presence should relate positively to task performance in the VE. Task performance depends on other factors such as user interface, personal skills and experience, the nature of the task, etc. But even accepting that presence and task performance should be positively correlated, Witmer and Singer indicate that they found a positive correlation between presence and task performance in only two of their four experiments.

Witmer and Singer indicate that individuals who have a greater tendency to become involved in a variety of activities as measured by the ITQ should report more presence on the PQ. Witmer and Singer found a significant correlation between ITQ and PQ scores only in two of the four experiment they conducted. In the experiment we performed (described in Chapter 6), we did not find a significant correlation between the ITQ and PQ scores (refer to Section 6.7 for a description of the results obtained). This failure to replicate these results could suggest that the validity of the PQ is open to doubt.

In the same experiment, which we performed to investigate group interaction and presence (the experiment is described in Chapter 6), we developed two VEs which differed in the amount of presence they should afford to the participants. This difference in presence between the two VEs was achieved by manipulating the factors thought to underlie presence as indicated by Witmer and Singer in [79]. However, we found no significant difference between the PQ scores in both VEs. This was highly surprising since the PQ was developed from the same factors thought to underlie presence (the results are described in detail in Section 6.7). Given the above evidence, Witmer and Singer's conclusion that presence as measured by their Presence Questionnaire is a valid construct is open to doubt, and further testing and analysis is required.

3.3 Witmer and Singer's Immersive Tendencies Questionnaire

Witmer and Singer [79] have also developed an Immersive Tendencies Questionnaire (ITQ) to measure the differences in the tendencies of individuals to experience presence. This questionnaire mainly assesses involvement in common activities. The Witmer and Singer Immersive Tendencies Questionnaire can be found in Appendix B.

3.3.1 Design of Witmer and Singer's Immersive Tendencies Questionnaire

The Immersive Tendencies Questionnaire consists of questions which measure involvement in common activities. Witmer and Singer indicate in [79] that increased involvement can result in more immersion, and therefore, one expects individuals who tend to become more involved will also have greater immersive tendencies.

Some of the questions in this questionnaire measure immersive tendencies directly, while others assess the participant's current fitness or alertness, or measure the ability to focus one's attention in a particular activity.

This questionnaire uses a seven-point Likert scale based on the semantic differential principle [4]. The ITQ score is calculated by adding the individual scores of each question in the questionnaire. Each question's score has a value from 1 to 7, and no reverse scoring is used.

3.3.2 Reliability and Validity of Witmer and Singer's Immersive Tendencies Questionnaire

Witmer and Singer performed reliability analyses on the ITQ in [79], using the combined data of four experiments [33, 78, 5, 48]. They found internal consistency measures of reliability of 0.81 (Cronbach's Alpha). Since the value of Cronbach's alpha is close to 1, this indicated that the questionnaire items quite reliable and measure the same thing.

We used Witmer and Singer's ITQ in the three experiments described in Chapters 5, 6, and 7. We performed a reliability analysis on the obtained item scores and obtained a value for Cronbach's Alpha of 0.835, which is quite a good indication that the ITQ is reliable.

Witmer and Singer indicate in [79] that the ITQ items were developed to identify individual differences that could affect how much presence might be experienced. These items assess the tendency of individuals to become involved in everyday activities and measure the ability to focus on particular activities. The ITQ items tap both involvement and immersion. Therefore, the ITQ items cover a representative sample of the behavioural domain, which gives it content validity.

3.4 Slater's Presence Questionnaire

Slater *et al* [58, 51, 55] have developed a Presence Questionnaire which measures the amount of personal presence felt by participants in a virtual environment. This Presence Questionnaire can be found in Appendix C.

3.4.1 Design of Slater's Presence Questionnaire

Slater *et al* have developed their presence questionnaire based on the following three attributes which describe presence:

- The sense of "being there" in the environment depicted by the virtual environment.
- The extent to which there were times when the virtual environment became the reality. i.e., the extent that the participant forgot he/she was standing on the lab. The extent that participants will tend to respond to events in the VE rather than in the real world.
- The extent to which participants, after the VE experience, remember it as having visited a "place" rather than just having seen images generated by a computer.

The first attribute is part of the generally accepted notion of presence (for example, Sheridan [46], Held and Durlach [29]) which is the sense of "being there" in the virtual environment. The other two attributes have been developed from observing participants in many experimental studies.

The second attribute indicates that participants react to stimuli in the VE even though they are situated in the lab. For example, this includes the looming response indicated by Sheridan [46] and Held and Durlach [29]: participants in a VE will duck when an object flies towards them, even though they know that there is nothing there. Another example of this is the visual cliff experiment conducted by Usoh *et al* [73, 36]. Participants know that they are not going to fall, but nevertheless they have symptoms of fear of heights.

The third category was also developed from listening to participants. After an experiment, participants usually report that they had an experience of being in a place, just like any other place they had been earlier in the day. This measures the extend to which their memory of the virtual environment is similar to their normal memory of a place. Slater [50] indicate that this "experiencing-as-a-place" is what he tries to convey as a meaning of presence in the VE: participants are "there", they respond to what is "there", and they remember the VE as a "place" visited rather than images seen. Slater indicates that if during the VE experience it was possible to ask to the participants the question "where are you?", an answer describing the virtual place would be a sign of presence in the VE.

3.4.2 Reliability and Validity of Slater's Presence Questionnaire

We have used Slater's presence questionnaire in two experiments described in Chapters 5, and 7. Using the scores obtained in these two experiments, we performed a reliability analysis and obtained a value for Cronbach's Alpha of 0.785. This value of alpha is somewhat closer to 1 than to 0 which indicates that the questionnaire's items are somewhat reliable.

Slater *et al* [60] mention that the fundamental idea of presence is that participants who are highly present should experience the VE as more the engaging reality than the surrounding physical world and consider the virtual environment as places visited rather than images seen. Since Slater's Presence Questionnaire has been developed from the three aspects mentioned in Section 3.4.1, which are the fundamental ideas behind Slater's presence definition, the questionnaire items cover the measured behavioural domain which gives it content validity.

If Slater's presence questionnaire is a valid measure of the presence construct, the questionnaire scores should be related to other variables or constructs which are related to presence in theory.

Slater *et al* [58] performed an experiment to determine the effects of having dynamic shadows on presence in a virtual environment. They found that the greater the extent of shadows in the VE, the greater the sense of presence reported by the participants. This indicates that the presence scores were related to pictorial realism of the VE, which is one of the factors thought to influence presence (refer to Section 2.2.4). This provides evidence towards the construct validity of Slater's presence questionnaire.

Slater and Usoh [56], Slater *et al* [55], and Usoh *et al* [73] have performed experiments to investigate the relation between the virtual body and presence in the VE. They investigate such issues as the effects of body movements, the participant's association to the virtual body, and walking techniques. In these experiments they found that having a virtual body and a high match between proprioception and sensory data about the corresponding dynamics of the body increased the reported level of presence in the VE. These experiments show that the presence scores collected by Slater's presence questionnaire are associated with some of the factors that, in theory, are related to presence. This evidence might indicate that Slater's presence questionnaire has construct validity.

3.5 Co-Presence Questionnaire

The main contribution of this chapter is the design and analysis of a co-presence questionnaire that we have developed to measure the amount of co-presence experienced by the participants in a collaborative virtual environment. Our co-presence questionnaire can be found in Appendix D.

3.5.1 Design of the Co-presence Questionnaire

Co-presence refers to the sense of being with other people in the virtual environment, and feeling part of a group. Refer to Section 2.2.2 for a description of co-presence.

Slater *et al* [53] use three questions to measure the sense of co-presence experienced by the participants in a small group experiment they performed. These questions are as follows:

1. In the last meeting, to what extent did you have the sense of the *other people being together with you?*
2. Continue to think back about the last meeting. To what extent can you imagine yourself *being now with the other two people* in that room?
3. Please rate how closely your sense of being together with others in a real-world setting resembles your sense of being with them in the virtual room.

Co-presence refers to having a sense that others are present in the VE, being part of a group, and having a feeling that one is collaborating with real people. We used these three defining characteristics of co-presence to develop six questions which measure such a state (refer to Appendix D for the co-presence questions).

3.5.2 Reliability and Validity of the Co-presence Questionnaire

We have used our co-presence questionnaire in the three experiments described in Chapters 5, 6, and 7. Using the co-presence scores obtained in these three experiments, we performed a reliability analysis and obtained a value for Cronbach's Alpha of 0.789 for the co-presence questionnaire. This value of alpha is close to 1 which indicates that the co-presence questionnaire contains somewhat reliable items.

The co-presence questions were developed from the defining characteristics of co-presence, namely that co-presence refers to having a sense that others are present in the VE, being part of a group, and having a feeling that one is collaborating with real people. This implies that the questionnaire items cover the measured behavioural domain which gives it content validity.

In order to measure construct validity, if the co-presence questionnaire is a valid measure of the co-presence construct, then the co-presence questionnaire scores should be associated in a predictable manner with other variables or constructs that in theory are related to co-presence. We believe that a construct which is related to co-presence is group collaboration and interaction. In the experiment described in Chapter 5, we found a significant correlation between the co-presence scores and the group collaboration scores. This significant association could be considered as some evidence that the co-presence questionnaire has construct validity (refer to Section 5.7 for the results obtained).

Another construct which is believed to be associated with co-presence is personal presence. Slater *et al* [57] indicate that personal presence is a prerequisite for co-presence. Tromp *et al* [71] and Slater *et al* [53] found that the personal presence and co-presence scores where correlated in one of their small group experiments. However, in the three experiments we performed we failed to obtain a significant correlation between the personal presence scores and the co-presence scores (refer to sections 5.7, 6.7, and 7.6 for the results obtained in the three experiments). This might indicate that the validity of the co-presence questionnaire is open to doubt, and that more testing and analysis is needed. On the other hand, it might be true that personal presence and co-presence are not associated after all.

3.6 Collaboration Questionnaire

In this section we discuss and analyse a collaboration questionnaire we have developed in order to assess collaboration and interaction between the participants in a collaborative virtual environment. This questionnaire also assesses the degree of enjoyment and comfort with individual members of the group. The collaboration questionnaire can be found in Appendix E.

3.6.1 Design of the Collaboration Questionnaire

In order to measure the degree of collaboration between the participants in a CVE, we have developed a subjective questionnaire which assesses collaboration and interaction by asking the participant to rate the perceived collaboration of the group and of the individual members of the group, as well as the talkativeness of the different group members. this questionnaire also assesses the degree of enjoyment and comfort with individual members of the group.

3.6.2 Reliability and Validity of the Collaboration Questionnaire

We have used our collaboration questionnaire in the experiment described in Chapter 5. Using the co-presence scores obtained in this experiment, we performed a reliability analysis and obtained a value for Cronbach's Alpha of 0.656 for the collaboration questionnaire. This indicates that the collaboration questionnaire's items are reliable to some extent.

The collaboration questions ask the participant to rate his/her collaboration level, as well as the perceived collaboration of the individual members of the group, and the overall group collaboration. It also asks to rate the talkativeness of the different group members, the degree of enjoyment and the degree of comfort with the individual members of the group. These questions asses collaboration directly and therefore it implies that the questionnaire items cover the measured behavioural domain which gives it content validity.

In order to measure construct validity, if the collaboration questionnaire is a valid measure of collaboration, then the questionnaire scores should be associated in a predictable manner with other variables or constructs that in theory are related to collaboration. As mentioned in the previous section, we found a significant correlation between the collaboration scores and to co-presence score in the experiment described in Chapter 5. This might indicate that the collaboration questionnaire is indeed a valid construct.

3.7 Summary

In this chapter we discuss and analyse the different questionnaires used in the three experiments presented in this dissertation.

The main contribution of this chapter is the discussion of a co-presence questionnaire that we have developed in order to asses co-presence in a collaborative virtual environment. Co-presence refers to having a sense that others are present in the VE, being part of a group, and having a feeling that one is collaborating with real people. We used these three defining characteristics of co-presence to develop the questions which will measure such a state. We discuss the design of the questionnaire as well as provide simple reliability and validity analysis.

We have also developed a simple collaboration questionnaire which measures the degree of collaboration felt by participants in a group. This questionnaire is only used in one of the experiments (described in Chapter 5). The collaboration questions ask the participant to rate his/her collaboration level, as well as the perceived collaboration of the individual members of the group, and the overall group collaboration. It also asks to rate the talkativeness of the different group members, the degree of enjoyment and the degree of comfort with the individual members of the group.

Witmer and Singer [79] have developed a Presence Questionnaire which measures the degree to which individuals experience presence in a VE (i.e., personal presence), by assessing the factors believed to influence presence by affecting either involvement, immersion, or both. They have also developed an Immersive Tendencies Questionnaire which consists of questions which measure involvement in common activities. Increased involvement can result in more immersion, and therefore, one expects individuals who tend to become more involved will also have greater immersive tendencies. Some of the questions in this questionnaire measure immersive tendencies directly, while others assess the participant's current fitness or alertness, or measure the ability to focus one's attention in a particular activity. We also show some reliability and validity analysis on these questionnaires.

The presence questionnaire developed by Slater *et al* [58, 51, 55] measures the sense of personal presence felt by the participants in a virtual environment. The questionnaire items are developed from the following three attributes which describe presence: The sense of “being there” in the virtual environment, the extent to which there were times when the virtual environment became the reality, and the extent to which participants, after the VE experience, remember it as having visited a “place” rather than just having seen images. We also perform some reliability and validity analysis on this questionnaire.

Chapter 4

Design of the Collaborative Virtual Environments

In this chapter we present a description of the different collaborative virtual environments used in the experiments described in Chapters 5, 6, and 7.

We begin by describing in Section 4.1, an initial prototype which we developed to provide a preliminary exploration into some of the issues concerning co-presence in a collaborative virtual environment. This prototype was not used in any of the three experiments, but served as a guide towards our co-presence work by indicating areas that required attention and highlighting important issues. Section 4.2 describes the two collaborative virtual environments used in Experiment 1 (refer to Chapter 5 for a description of the actual experiment). Section 4.3 describes the two collaborative virtual environments used in Experiment 2 (Chapter 6 describes the actual experiment). Finally, Section 4.4 describes the virtual environment used in Experiment 3 (Chapter 7 describes the experiment in detail). All the virtual environments described in Sections 4.2, 4.3, and 4.4 were implemented using the DIVE (Distributed Interactive Virtual Environment) system [19, 18, 67]. DIVE is a toolkit for the development of multi-user distributed virtual environments, developed at SICS (The Swedish Institute of Computer Science). All the collaborative virtual environments used were ‘desktop’ virtual environments, which means that no head mounted displays or projection VR was used in any of the experiments.

4.1 Initial Prototype

In this section we describe a prototype of a CVE which we developed in order to provide a preliminary investigation into some of the issues relating to co-presence in a Collaborative Virtual Environment. This prototype has served as a good basis towards our work towards co-presence by highlighting areas that require attention (such as providing communicative behaviour to the avatars), and indicating areas that need attention, such as the importance of how one represents the avatars of others in a CVE.

4.1.1 System Architecture

Our system uses a *distributed model* (refer to Section 2.1.3) as the communication model. Here, each program maintains its own local copy of the database as well as performing the rendering. When a program makes a change to its database, a message is sent to the other programs so that they update their local databases.

In order to reduce the number of connections and thus the number of messages being sent, we use UDP multicasting [69]. Refer to Section 2.1.3 for a description of unicasting, broadcasting and multicasting.

Since UDP multicasting is an unreliable protocol, the system also has a TCP/IP server which provides reliable stream communications. In other words, the system provides different degrees of reliability to gain better real time performance. It provides a protocol that guarantees the reliability of certain packets by using TCP connections, and does not guarantee reliability for frequent non-critical data such as the state of the participants (position, direction...).

Figure 7 shows the distributed architecture of our system. During initialisation, the client makes a connection to the TCP server, and receives the multicast group address from the server. It then subscribes to the multicast group which allows him/her to listen for messages and send messages to all the participants in the same multicast group. Once a client quits, it sends a message to the TCP server, which closes the connection and indicates to the other client that a client has left the system.

The system uses OpenGL [2] to perform the rendering, and uses Glut3.6 together with the Fast Light Tool Kit (FLTK) [1] (which is a graphical user interface toolkit) for the window and menu systems. The system has been tested on SGI workstations running IRIX 5.3 and 6.2.

4.1.2 Enhancing the Sense of Co-Presence

In this section we present a preliminary exploration of ways in which co-presence might be enhanced in our collaborative virtual environment system. These include the use of avatars, providing simple communication and interaction with the environment.

Virtual Representation of Participants

In order to create a sense of co-presence, information on participant location, participant or group identity, participant attitudes, availability etc, must be addressed [10, 9]. This information is given

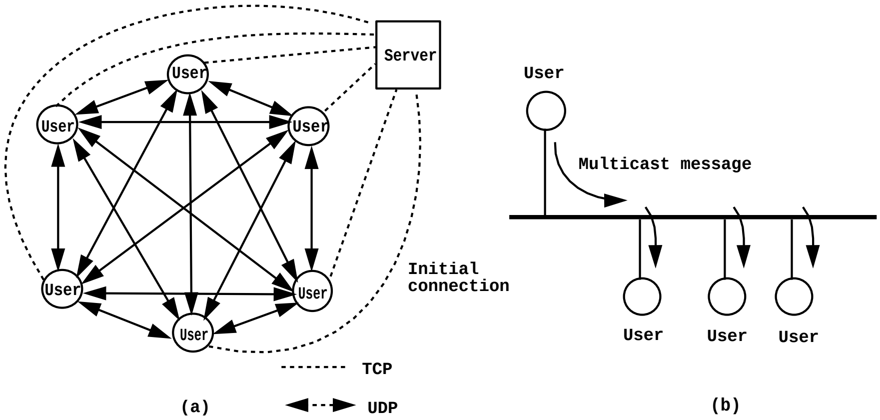

Figure 7: **Distribution model of initial CVE prototype.** The system uses a Distributed Model together with a Client-Server model (a). This provides different degrees of reliability to gain better real time performance. The system makes use of UDP Multicasting (b) to reduce the number of messages sent.

very effectively by using virtual representations of participants or avatars. The issues relating to avatars in collaborative virtual environments are presented in Section 2.3.

In order to fulfill some of the requirements described in Section 2.3 (namely presence, location, identity and viewpoint of the participants), the system provides the users with different avatars of varying complexity. It provides some body-like avatars and some simple avatars composed from a few basic graphics objects. The avatars do not possess any functionality in terms of gestures or facial expressions. The avatars positions and orientations are updated in the 3D space to indicate the viewpoints of the different users in the virtual world (see Figure 8 for some screenshots of the system).

To tell you who are you collaborating with, the systems keeps a menu of all the participants collaborating in the virtual world. This menu is updated every time a new participant joins or a participant leaves the collaboration session.

Navigation

Virtual reality technology gives users the freedom of navigation, and each participant can independently explore the environment to find out who else is there, what are they doing etc.

There are two types of navigation metaphors which are used by the system for individual navigation, the *walk* metaphor and the *fly* metaphor. The *walk* metaphor allows the user to move forward and backwards, and to turn left and right. The *fly* metaphor allows the participants to move their heading vector in any direction, thus enabling the participants to ‘look around’. It also allows the

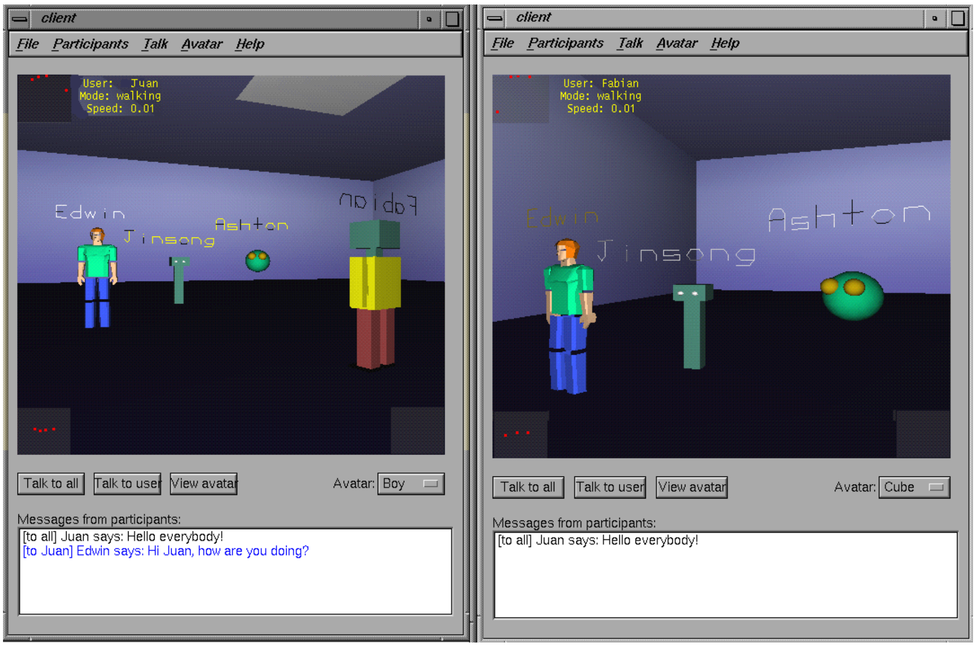

Figure 8: **Initial CVE prototype.** Screenshots of the initial prototype showing the views of two participants. Some of the avatars available are shown. In this system, the participants were able to move around the room, communicate with one another using text, and move some of the objects in the room.

participant to move in the direction of the heading vector, thus allowing the participants to 'fly'.

Navigation in the virtual world is facilitated by providing navigation aids, such as 2D maps of the world. There are three such maps, a front map, a back map and a map seen from the top. These maps indicate the current position of the participants in the virtual world, and are situated in the bottom and top left sides of the rendering window (see Figure 8).

Interaction

The participants can interact with the environment by picking objects and moving them around.

The system implements a simple ownership mechanism: If a participant clicks on an objects which is owned by no one, he becomes the owner of the object. Other participants cannot select this object until the owner releases the selected object. In other words, a participant cannot select objects which are owned by other participants.

As a primary focus of group interaction, there is the issue of efficient communication between participants. Communication is provided by a text based chat interface where users can type messages and send them either to all participants, or only to a specific participant. More sophisticated tools such as video and audio will provide more efficient communication, and can be considered as future improvements.

4.1.3 Experiences with the System

The system addresses the issue of co-presence mainly by using different avatars to represent the collaborating participants. This is a simple but very effective way to create a sense of presence of others in the environment. The system provides a variety of avatars. Some avatars are body-like, while others consist of basic geometric shapes (such as spheres and blocks). We found that, contrary to what one would think, semi-realistic avatars (such as the avatar in the left side of the rendering window in Figure 8) are less appealing than totally unrealistic ones (such as spheres, blocks or cartoon like avatars). This might be because in a virtual environment, the users have the possibility to take virtually any form they please, and so form other than our own and in particular humorous ones, are probably more appealing and effective.

We found that the avatars are very static and that one needs to provide avatars with behaviour. This includes providing gestures and facial expressions which are an important part of conversation since they can be used to convey visual cues to other participants.

We found that the system did not allow participants to know whether a particular user is available for interaction. A user has no way to tell if another participant is available to engage in a conversation or not. For example, a user might be busy having a private conversation with another user and does not want to be disturbed.

There is also the problem of knowing if the person behind the avatar is there or not. This arises because there is a strong separation between the avatar and the ‘mind’ behind it in a non-immersive virtual environment. In fact the person may have popped out of the lab for a few seconds leaving an “empty” avatar in the environment. This causes a number of problems such as the wasted effort involved in talking to an empty avatar. As a result it might be important to explicitly show the availability of users.

The system was useful in demonstrating the importance of avatars in a collaborative virtual environment. It showed that the use of simple avatars (without any gestures and facial expressions) was enough to create a sense of co-presence in the VE. The issues of avatars and co-presence was investigated further in Experiment 3 which is described in Section 4.4 and Chapter 7.

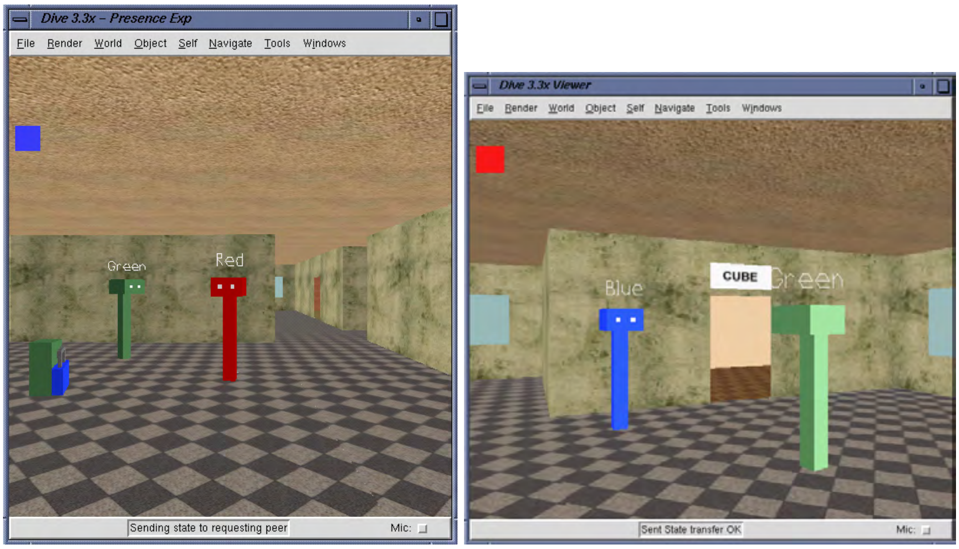

Figure 9: **The virtual environment used in Experiment 1.** The VE consisted of a set of rooms forming a simple maze-like setup. Participants were represented using simple avatars of different colours, and the task consisted of moving different geometric shapes to specified rooms.

4.2 Virtual Environment Prototypes used in Experiment 1

In this section we present the design of the virtual environments used in the experiment described in Chapter 5. The experiment required two virtual environment which engendered different levels of collaboration between the participants. These environments are called *high-collaboration VE* and *low-collaboration VE*.

4.2.1 Structure and Layout

The layout of these two environments (high-collaboration VE and low-collaboration VE) was the same, and consisted of a set of rooms which created a simple maze (see Figure 9). Each room had different textured walls to differentiate between them.

The only difference between the high-collaboration VE and the low-collaboration VE was the experiment task. In the low collaboration VE, the task required the participants to move shapes to specified rooms in the maze. The shapes consisted on cubes, pyramids, and rectangles, and were scattered around the rooms. The shapes were coloured red, green, or blue, and the participant's avatars were also red, green, or blue. So a participant could only pick up a shape which had the same colour as the participants' avatar. In the high-collaboration VE, the task was very similar, but was modified in order to make sure that the participants had to collaborate with each other in order to solve the task. Each shape was locked by a padlock which was also coloured red, green, or blue. Participants could not pick-up locked shapes, and a padlock could only be unlocked by the participant with the same colour avatar. This required two participants in order to pick-up a shape. For example, a red cube locked with a green padlock requires having the red participant and the green participant next to the shape. The green participant can then unlock the padlock which will automatically lock itself after six seconds. In those six seconds interval, the red participant can pick up the red cube.

The difference between the tasks in the two virtual environments made sure that the two VEs produced different levels of group collaboration and interaction.

4.2.2 Interaction

The DIVE system provides avatar gravity and collision detection. We made use of this in both the high and low-collaboration VEs, so that participants could not walk through walls or each other.

In both the low-collaboration and high-collaboration VE, participants were able to pick up and drop the shapes scattered in the virtual environment using the mouse. In the low-collaboration VE a participant could only pick up the shapes which were of the same colour as the participants' avatar. In the high-collaboration VE, a participant could only pick up the shapes which were of the same colour as the participants' avatar, and in addition the shapes needed to be unlocked by another participant. This required participants to collaborate with each other.

Picking-up a shape caused the shape to be attached to the participant's avatar which could move around the environment carrying the shape. Dropping a shape was achieved by clicking on the shape with the mouse which caused it to be dropped on the floor (refer to Figures 10 and 11 for examples of participants carrying shapes in both environments).

The method of inter-personal interaction available to the participants was the same in both VEs. Participants were able to use audio communication through the use of microphones and headphones. We used an audio software called RAT (Robust Audio Tool) developed at the University College London [3]. Even though the DIVE system provides its own spatialised audio, it proved to be too unreliable causing the system to crash several times. We therefore decided to use RAT even though it did not provide spatialised sound.

4.2.3 Avatars

Participants were embodied in the environment using identical avatars, consisting of a 'T' shaped block avatar called 'Blockie' (Blockie is the default avatar used by the DIVE system). The only difference between the participant's avatars were their colour being red, green or blue. The avatars

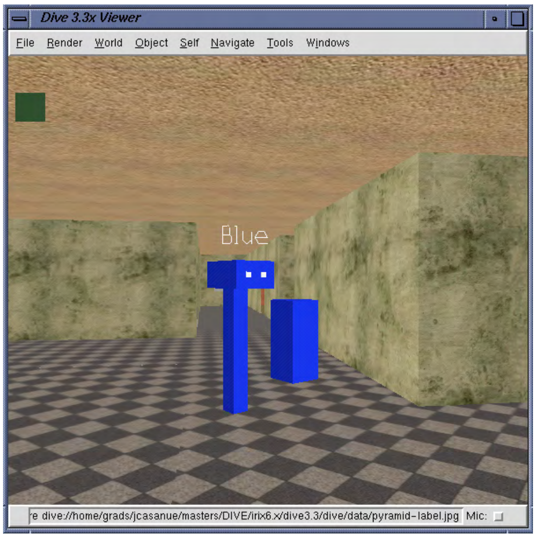

Figure 10: **Low-collaboration VE of Experiment 1.** A participant carrying a shape in the low-collaboration VE (Experiment 1).

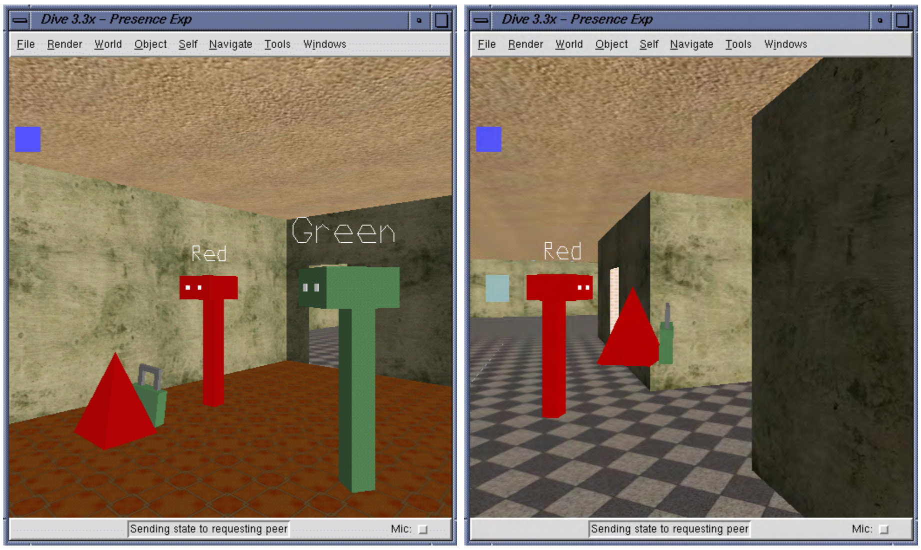

Figure 11: **High-collaboration VE of Experiment 1.** A participant carrying a shape in the high-collaboration VE (Experiment 1). In the high-collaboration VE, the shapes were locked with padlocks which needed to be unlocked before picking up a shape.

were labeled Red, Green, and Blue, and participants called each other by these names. Participants could not see their own avatar, and there was a coloured square situated at the top left side of the rendering windows which indicated the colour of the participant (refer to Figure 9 for pictures of the avatars). Knowing the colour of the participants' avatar was important in order to perform the task of the experiment (refer to Section 5.3 for a description of the task).

4.3 Virtual Environment Prototypes used in Experiment 2

In this section we describe some issues related to the design and implementation of the two virtual environments used in the experiment described in Chapter 6 (Experiment 2).

This experiment required participants to interact in two virtual environments which exhibit opposing degrees of presence. Thus, one would be a high presence environment while the other would be low presence. We named the two environment *high-presence VE* and *low-presence VE*. In order to achieve this difference in presence, each world exhibits different properties and perspectives according to the factors affecting presence described in Section 2.2.4.

4.3.1 Structure and Layout

Both virtual environments have a similar layout, consisting of an approximately square open central area with a maze-like series of rooms along each side (refer to Figures 12 and 13 for screenshots of the two VEs). This design was chosen in order to balance the participant's ability to find their way around the environment against the experimenter's aim to make the task harder for a user acting in isolation. The central area is easy to locate from any room within the maze, and therefore gives the participants a point of reference for navigation in the environment. On the other hand, the maze makes it difficult for any single user to complete the task without collaborating with the other participants in the environment.

In both the high-presence and low-presence VEs, we had ten cubes and ten rectangular billboards which were placed randomly around the world. These are used to perform the experimental task which was as follows: there were ten rooms in the VE which had a word printed on either the wall (in the high-presence environment) or on the floor (in the low-presence environment). Each one of those words had a letter missing, replaced by a '_' (for example we had "loa_"). The missing letters, which were all consonants, were scattered in the environment in the form of cubes which had the letter written in all the sides. The participants could pick up the cubes and move them around the environment. For each word, they had to find the missing letter and move it next to the word. The letters could be moved to a different room if it was later decided that the letter was placed in the wrong room. In both VEs, textures were used to display the necessary text on both the cubes and the billboards.

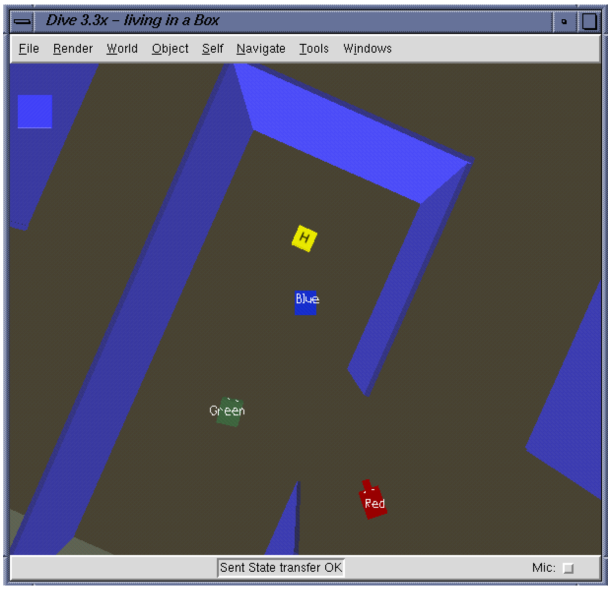

Figure 12: **The low-presence virtual environment used in Experiment 2.** The VE consisted of an open central area and maze-like series of rooms around it. The participants could see a top-down view of the world, and were represented using simple block-like avatars of different colours. There were yellow cubes with letter textures scattered around the rooms, which had to be moved to specified locations.

In the high-presence VE, textures were used in the walls and ceiling in order to enhance the visual realism of the world. In the low-presence VE, no such textures were used.

The view of the environment depends on which VEs the participant is using. In the low-presence VE, the participant has a third-person perspective in that the world is viewed from above, in a top-down fashion (refer to Figure 12 for a screenshot of the low-presence VE). In the high-presence VE, the participant has a first person 3D perspective. Participants can pan around the rooms and move forward and backwards using the arrow keys. While this view is more limited than its real-world counterpart, it remains closer to the natural perspective than that of the low-presence VE (refer to Figure 13 for a screenshot of the high-presence VE).

4.3.2 Interaction

We made use of gravity and collision detection to enhance presence in the high-presence VE and decrease it in the low-presence VE. In the high-presence VE, gravity and collision detection were enabled which meant that participants could not walk through walls and through each other's virtual representations. In the low-presence VE, gravity and collision detection were disabled. This made

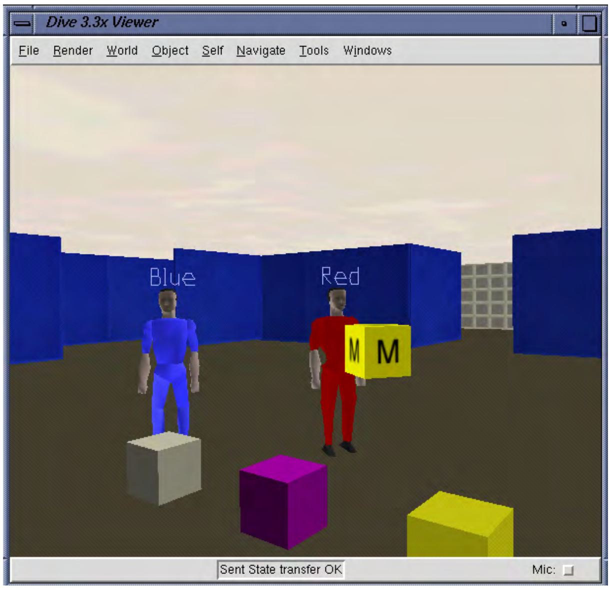

Figure 13: **The high-presence virtual environment used in Experiment 2.** The VE consisted of an open central area and maze-like series of rooms around it. The participants had a first-person perspective view of the world. They were represented by human-like avatars which had walking gestures (movement of legs and arms to mimic walk action when moving in the VE).

it possible for the participants to walk through walls and through each other's avatars. Despite explicitly not being told this, participants soon noticed that they could walk through solid objects in the low-presence VE.

In both the low-presence and high-presence VE, participants were able to pick up and drop the cubes scattered in the virtual environment. Participants could only pick up one cube at a time, by clicking on the cube with the mouse. This causes the cube to be attached to the participant's avatar and could move around the environment carrying the cube. Dropping a cube was achieved by clicking on the cube with the mouse which caused the cube to be dropped on the floor (refer to Figures 12 and 13 for examples of participants carrying cubes in both environments).

The method of inter-personal interaction available to the participants was dependant on which of the two VEs the participants were interacting. In the low-presence VE, communication between participants was achieved using typed text messages. The DIVE system handles this communication by providing a text based chat interface with dialogues for the entry and review of text messages. In the high-presence VE, participants were able to use audio communication through the use of microphones and headphones. We used an audio software called RAT (Robust Audio Tool) developed at the University College London [3].

4.3.3 Avatars

Participants were embodied in the virtual environment by making use of *avatars*. (refer to Section 2.3 for information about avatars in CVEs). The avatar positions were kept consistent in the different user databases, and updated in real time. This meant that each user could see every other user in the virtual environment, and could follow their actions.

The appearance and functionality of the avatars used in this experiment was dependent on the type of world in question (that is, the high or low presence VE).

In the low-presence VE, participants were embodied in the VE using a simple block shaped avatar (called “blockie”, which is the default avatar in DIVE), which was shaped as a letter “T” (see Figure 14). All the participants in the low-presence VE had the same avatar, and only the avatar colour was different. The “blockie” avatar did not possess any functionality in terms of gestures or body part movements, and had a very low polygon count. In the low-presence VEs, participants could see their own avatars because they had a top-down view of the environment.

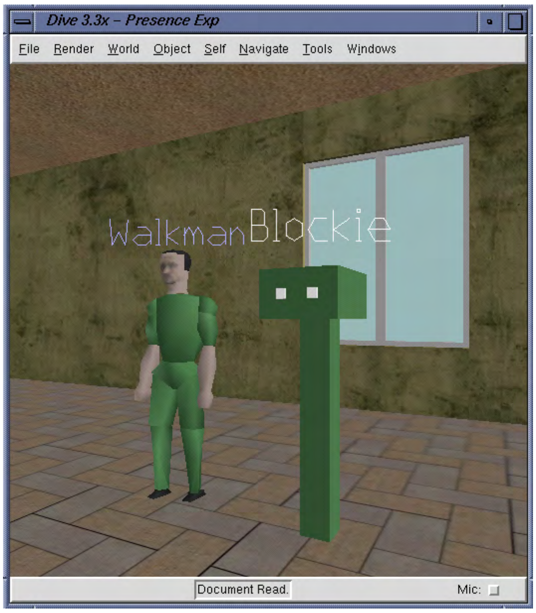

Figure 14: **Avatars used in Experiment 2.** Blockie and Walkman avatars used in Experiment 2. The Blockie avatar was used in the low-presence VE, and the Walkman avatar was used in the high-presence VE. The Walkman avatar had the ability to “walk”, which involved moving the legs and arms to mimic the walk action.

In the high presence world, a more realistic human-like avatar called “walkman” was used. This avatar was shaped as a simple yet effective human form. The shape was not highly detailed since having a high number of polygons in an avatar would have yielded a very poor performance in the rendering, which would have dropped the frame rate drastically in the high-presence VE. In order to make the avatar more realistic, it had the ability to “walk”. This implied moving the legs and arm to mimic the walk action. Also, there was a texture mapped on the avatar’s face (refer to Figure 14 for a picture of the “walkman” avatar). As in the low-presence VE, all the participants had the same avatar, and only the avatar’s colour differed. In this environment, the participants could not see their own avatars, and so we used a coloured strip on the monitor to indicate the colour of the participants.

4.3.4 Differences between Worlds

In Experiment 2, two virtual environments were created in order to engender different levels of presence. The main differences between these two VE are:

- A three-dimensional user perspective with walls, ceiling and floor in the high-presence VE, versus a flat two-dimensional top-down perspective of the world in the low-presence VE.
- Texture mapped surfaces in the high-presence VE, versus simple shaded surfaces in the low-presence VE.
- Advanced speech and sound capabilities using microphones and headphones in the high-presence VE, versus simple text-based interaction in the low-presence VE.
- Simplified representations of users using the “Blockie” avatar in the low-presence VE, versus more human representations using the “Walkman” avatar in the high-presence VE.
- Gravity and collision detection in the high-presence VE, versus no collision detection or gravity in the low-presence VE.

These differences can be compared in terms of the factors thought to underlie presence [79] (described in more detail in Section 2.2.4:

- *Mode of Control* - communication in the high-presence VE was more natural than in the low-presence VE (talking vs. typing)
- *Sensory Modality* - the textures in the high-presence VE meant that more visual stimulation was available than in the low-presence VE

- *Environmental Richness* - the high-presence VE conveyed more sensory information to participants than the low-presence environment (speech/sound, textures, etc)
- *Multimodal Presentation* - the high-presence VE stimulated more senses than the low-presence VE
- *Active Search* - in the high-presence VE, the participant's view of the VE changed as the avatar was rotated, while in the low-presence VE the view was independent of the direction in which the avatar was facing
- *Isolation* - the participants in the high-presence VE were more isolated from the physical environment due to the wearing of headphones (extraneous noises were not heard by high-presence participants, but were by the low-presence participants). In addition, the real-world intrusions described later in Chapter 6 contributed to decreasing the isolation of low-presence participants from the real world
- *Interface Awareness* - the high-presence interface with regard to communication was less obtrusive than that of the low-presence interface
- *Scene Realism* - the first-person view, addition of textures, and collision detection provided in the high-presence world added to the realism, while the third-person top-down view, flat polygonal shading of objects, and the ability to walk through walls detracted from the realism of the low-presence world
- *Consistency of VE Information with Real-world Experience* - the lack of gravity and the ability to walk through walls in the low-presence VE, as well as the static nature of the avatars, reduced the consistency of the VE information with the experiences learned by participants in the real-world

The two VEs thus differ greatly in the amount of presence which they should engender in participants.

4.4 Virtual Environment Prototype used in Experiment 3

In this section we describe the design and implementation of the virtual environment used in Experiment 3, which is discussed in Chapter 7. This experiment investigates the effects of avatar appearance and functionality on personal presence and co-presence.

The preliminary investigation we performed using the system described in Section 4.1 provided us with the need to investigate the importance of avatar appearance and functionality in a collaborative virtual environment. That initial prototype showed that the way one represents others in a

Figure 15: **The virtual environment used in Experiment 3.** The world consisted of a conference room where participants could meet around a table and have a discussion.

CVE is very important to create a sense of co-presence. It also highlighted the fact that providing gestures and facial expressions to the avatars might be essential in order to create a high sense of co-presence.

4.4.1 Structure and Layout

The virtual environment consists of a conference room where multiple users can meet around a table and have a discussion. Each participant has a book on the table which can be used to view a document. There is a white board which is used to help the participants with the experiment task (refer to Section 7.2 for a description of the task). The virtual environment is fully textured to enhance the visual realism (refer to Figure 15 for a screenshot of the virtual environment).

Participants are able to move around the room using the arrow keys. Cooperation is basically supported by directly embodying the users in the virtual environment using different avatars, and providing them with inter-user communication facilities such as an audio channel.

4.4.2 Avatars

We provide the participants with a range of avatars of varying appearance and functionality. These avatars include unrealistic avatars, cartoon-like avatars, and realistic human-like avatars. Some of

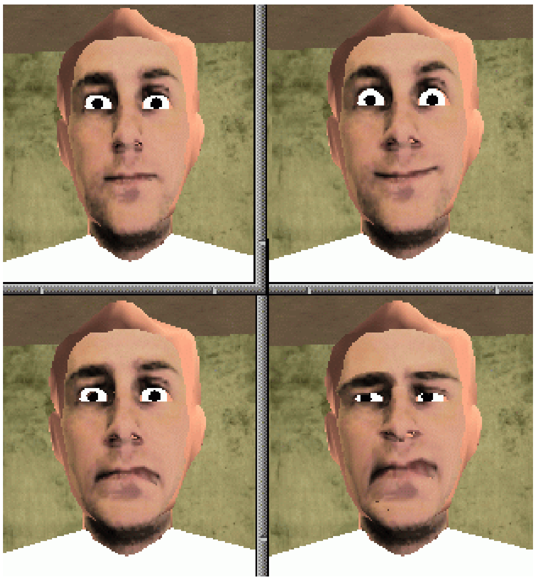

Figure 16: **Facial expressions used in Experiment 3.** Some of the facial expressions available for the realistic human-like avatars. From left to right, top to bottom: neutral, happy, sad, and furious.

these avatars have some functionality in terms of simple gestures (waving, raising arms, joy and sad gestures, movement of head such as yes, no, and perhaps, walking), and simple facial expression. Facial animation, based on the linear muscle model developed by Parke and Walters [38], provides some of the avatars with six expressions (happiness, surprise, sadness, anger, disgust, and furious). Figure 16 shows some of the facial expressions available. The gestures and facial expressions are controlled by means of a Graphical User Interface (GUI) which contains buttons to activate the various gestures and facial expressions (refer to Figure 17 for a screenshot of the gestures and facial expressions GUI). The participants had a 1st person perspective view of the world, and could not see their own avatar.

The different avatars available are the following:

Unrealistic avatars: we provide the participants with three simple unrealistic avatars named *Blockie*, *Cube*, and *Sphere*. These avatars have a very low polygon count, and do not provide any functionality in terms of gestures and facial expressions. Figure 18 shows a screenshot of these avatars.

Cartoon-like avatars: We also provide the participants with two cartoon-like avatars, namely *dilbert* and *cartoon*. The dilbert avatar has some simple gestures such as waving, raising arms, joy and sad gestures, movement of head, and walking movement. It does not provide any facial

Figure 17: **Gestures and facial expressions GUI.** The Graphical User Interface used to control the gestures and facial expressions of some of the avatars in Experiment 3.

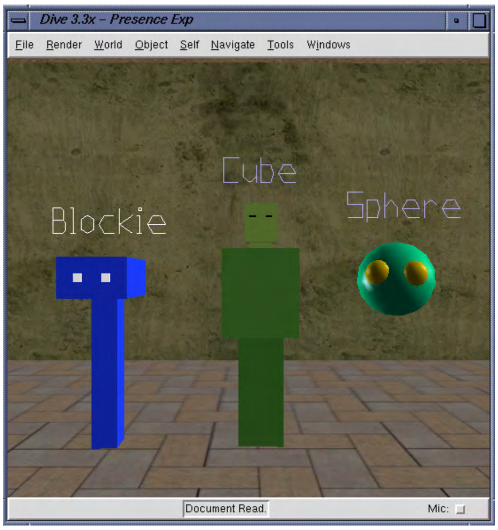

Figure 18: **The unrealistic avatars provided in Experiment 3.** These avatars had a low polygon count and did not provide any gestures or facial expressions.

expressions. The cartoon avatar does not posses any gestures or facial expressions. Figure 19 shows a screenshot of these two avatars.

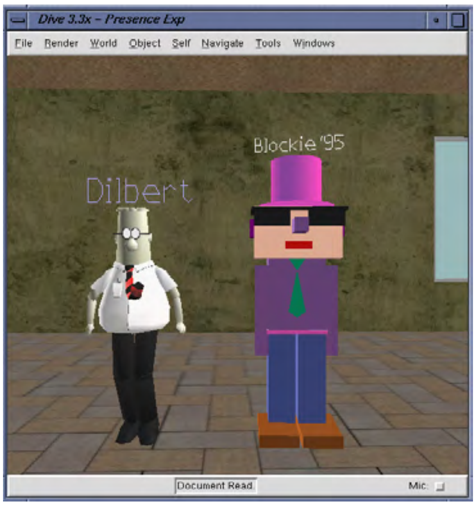

Figure 19: **The cartoon-like avatars provided in Experiment 3.** The “dilbert” avatar had some simple gestures but did not have any facial expressions. The “cartoon” avatar did not posses any gestures or facial expressions.

Figure 20: **The realistic human like avatars provided in Experiment 3.** The “Bob” avatar has simple gestures and facial expressions, while the “Man” avatar only has facial expressions.

Realistic human-like avatars: We also provide the participants with two realistic human-like avatars. Both avatars provide a simple range a facial expressions which can be controlled by means of a simple GUI. These avatars are called *Bob* and *Man*. The Bob avatar also provides simple gestures in the form of waving, raising arms, joy and sad gestures, movement of head, and walking movement. Figure 20 shows a screenshot of these two avatars.

4.5 Summary

In this chapter, we describe the virtual environments which we used in the different experiments described in Chapters 5, 6, and 7. All the virtual environments used in these experiments are screen based VEs, which means that we did not make use of head mounted displays or projection based VR.

We developed an initial prototype in order to provide a preliminary investigation into some of the issues relating to co-presence in a CVE. This initial prototype served as a good basis towards our investigation of co-presence by highlighting areas that require attention, and highlighting important issues and good prospects.

Experiment 1 required two collaborative virtual environments which generated different levels of group collaboration and interaction. The two virtual environments (named *low-collaboration VE* and *high-collaboration VE*) were identical and only the task that the participants had to perform differed. The task was used to generate different levels of collaboration and group interaction in the two VEs.

The virtual environments used in Experiment 2 were two VE which generated opposing degrees of presence. We named the two environments *high-presence VE* and *low-presence VE*.

In Experiment 3, we investigated the effects of avatar appearance and functionality (in terms of gestures and facial expressions) have on presence. We used a virtual environment which consisted of a conference room where a group of participants could meet and have a discussion. He provided the participants with a range of avatars of different appearance and functionality. We provided the participants with *unrealistic avatars* (consisting of simple block-shaped avatars without any gestures or facial expressions), *cartoon-like avatars*, and *realistic human-like avatars* (these avatars had gestures and facial expressions).

Chapter 5

Experiment 1: Group Collaboration and Interaction

In this chapter we present an experiment which was designed to investigate collaboration and interaction between small groups of three users in a CVE, and the effects that collaboration and interaction has on presence and especially co-presence in the CVE. The specific aim of this experiment is to test whether personal presence and co-presence is increased by collaborating and interacting with other participants in the CVE. This experiment aims to provide answers to the following questions:

1. Does the use of a 3D virtual environment and avatars create a high sense of co-presence ?

2. Does interaction and collaboration greatly enhance the sense of co-presence beyond that afforded by merely having virtual representations of others ?

3. Does the sense of personal presence and co-presence increase by collaborating and interacting with other participants in a collaborative virtual environment ?

In order to answer these questions, we have used the two collaborative virtual environments described in Section 4.2, which we named ‘high-collaboration VE’ and ‘low-collaboration VE’. Both VEs are identical and only the task differs. In the high-collaboration VE, participants can communicate and interact with one another, and have to collaborate to solve the given task. If they do not collaborate, the task cannot be completed. In the low-collaboration VE, participants can communicate with one another, but don’t need to collaborate to solve the given task.

We begin in Section 5.1 by presenting the different hypotheses we are investigating in this experiment. Section 5.2 presents some detail about the participants used during this experiment. Section 5.3 describes the experimental task that the participants had to perform during the course of the experiment. Task performance was not measured in this experiment, so the task was just used to control the collaboration and interaction levels in the two VEs. Section 5.4 describes the experimental procedure used in the experiment. Section 5.5 describes the different equipment used during the experiment. Section 5.6 indicates how presence, co-presence and collaboration were measured. Section 5.7 presents the analysis of the results which include a summary and a discussion of the obtained results.

5.1 Presence and Collaboration: Hypotheses

This experiment involves the testing of three hypotheses.

The *first hypothesis* is that group collaboration and interaction with other participants in the environment should influence co-presence. It is believed that simply having a virtual representation of other users in the environment is not sufficient to create a high sense of co-presence. Having the possibility to collaborate and interact with other participants in the shared environment should very much increase the sense of co-presence. This was tested by using two virtual environments, one of which was designed to have a task which creates the need to collaborate and interact with others in the environment, while the other was deliberately designed to have a task that does not need collaboration between participants (These collaborative virtual environments are described in Section 4.2). Groups were arbitrarily assigned to either the 'low-collaboration VE' or the 'high-collaboration VE' and the sense of presence and co-presence were measured. The results obtained were compared between the two virtual environments (see Section 5.7 for a description of the obtained results).

The *second hypothesis* is that personal presence and co-presence in a CVE could be correlated. Slater *et al* [57] postulate that personal presence is a prerequisite for co-presence. It would be useful to know whether these two types of presence are associated, since if personal presence and co-presence are associated this could be because of common factors which influence both, or because they influence one another. Tromp *et al* [71] and Slater *et al* [53] found in one of their small group experiments that the presence and co-presence scores were positively correlated. This hypothesis was tested by measuring the personal presence and co-presence scores and performing a correlation analysis on those scores in each of the two virtual environments.

While unlikely, a biased assignment of participants to the two virtual environments could have resulted in a large number of presence-susceptible participants being assigned to one of the two virtual environments as opposed to a random distribution between the two virtual environments. In order to make sure that this did not happen, we measured the immersive tendencies of participants in order to get the mean immersive tendencies score of participants for each virtual environment. This allowed us to check if we had a random distribution of participants between the two environments.

5.2 Subjects

The experiment involved 30 participants, divided into 10 groups of 3 users each. The participants used were paid volunteers and were mainly recruited from the second year psychology course at the University of Cape Town. The participants were recruited by means of announcements in lectures, as well as posters placed on the noticeboards in the psychology department. Some participants where recruited from other departments as indicated in Table 2.

Four volunteers were asked to sign up for a given session. Three of these volunteers were chosen to participate in the experiment while the fourth person was chosen as a surplus volunteer in case one of the other participants was unable to arrive to the session. Selecting an extra person for each group allowed us to minimize the risk of being unable to complete a session due to a lack of participants. The first three participants to arrive where selected to do the actual experiment, and if the fourth participant arrived, he/she was assigned a dummy task and was paid regardless.

The first four groups (12 participants) were assigned to the low-collaboration VE, and the next six groups (18 participants) to the high collaboration VE. Participants were not told which virtual environment they were assigned to. In fact none of the participants knew that there were two different VEs.

Due to the difficulty of obtaining volunteers, conditions such as age, gender, and previous computer experience could not be controlled. We chose second year psychology students because the course involves doing assignments on computers which means that they are familiar with a computer and its interface (e.g., using a mouse). On the other hand, unlike computer science students, few had been exposed to 3D first-person games. This is an important issue since some studies have shown that frequent exposure of 3D first-person games may affect the levels of presence experienced by participants in a VE [73].

5.3 Experimental Scenario

The task consisted of moving different geometrical shapes (pyramids, cubes, rectangles) into specified rooms. There were three rooms which had labels to indicate which shapes had to be brought to which room. The shapes were scattered around the virtual environment which forced the participants to navigate around the different rooms to find the shapes. The virtual environment consisted of a set of rooms which created a simple maze (Refer to Section 4.2 for a description of this VE). This meant that participants had to communicate with each other in order to navigate the maze and find the appropriate shapes more efficiently. All the participants had an identical avatar, consisting of a 'T' shaped block avatar called 'Blockie' (Blockie is the default avatar used by the DIVE system). The only difference between the participant's avatars was their colour being red, green or blue. The

	Group	Participant	Colour	Course
Low-collaboration Environment	1	1	Red	Psychology
		2	Green	Psychology
		3	Blue	Psychology
	2	4	Red	Psychology
		5	Green	Psychology
		6	Blue	Psychology
	3	7	Red	Psychology
		8	Green	Comp Sci 1
		9	Blue	Psychology
	4	10	Red	Psychology
		11	Green	Psychology
		12	Blue	Comp Sci 1
High-collaboration Environment	5	13	Red	Mathematics
		14	Green	Microbiology
		15	Blue	Mathematics
	6	16	Red	Psychology
		17	Green	Psychology
		18	Blue	Psychology
	7	19	Red	Psychology
		20	Green	Soc Sci
		21	Blue	Psychology
	8	22	Red	Psychology
		23	Green	B.Sc (1st year)
		24	Blue	Comp Sci 1
	9	25	Red	Psychology
		26	Green	Psychology
		27	Blue	Psychology
	10	28	Red	Psychology
		29	Green	Psychology
		30	Blue	Psychology

Table 2: **The Composition of Groups in Experiment 1.** Participants were mainly second year psychology students.

avatars were labeled Red, Green and Blue, and participants called each other by these names during the experiment.

In the high-collaboration VE, the task was designed to encourage collaboration between the participants. It involved observation and talking as well as physical collaboration. Each participant had an avatar of a given colour (red, green or blue), and the shapes where also red, green, or blue in colour. All the shapes were locked by a padlock (refer to Figure 11) and participants couldn't pick up locked shapes. The padlocks were also coloured red, green or blue. In addition, only the participant with the same colour as the shape could pick up that shape, and only the participant with the same colour as the padlock could unlock that padlock. Therefore, picking up a red shape locked by a blue padlock involves having the Red and Blue participants within a close range of the shape, and having the Blue participant unlock the blue padlock by clicking on it. Clicking on the padlock causes it to open for six seconds, after which it automatically locks itself. During those six seconds, the Red participant can pick up the shape by clicking on it. The shape gets attached to the Red avatar, and he/she can move around the environment and drop the shape in the appropriate room. This task was chosen because it can only be solved by collaboration since two participants are needed to pick up a shape. This meant that participants were forced to communicate with each other and get together in order to pick up a shape.

In the low-collaboration VE, the task was the same except that there were no padlocks locking the shapes. Therefore a given shape could be picked up by the user having the same colour as the shape, without needing the help of another participant. This meant that participants did not need the help of other participants in order to move the shapes around, and so this task could be completed without the need to collaborate with other participants in the environment.

There were eighteen shape in total in each of the two virtual environments as described in Table 3.

Environment	Cube	Pyramid	Rectangle
High-collaboration	Red (green padlock)	Red (green padlock)	Red (green padlock)
	Red (blue padlock)	Red (blue padlock)	Red (blue padlock)
	Green (red padlock)	Green (red padlock)	Green (red padlock)
	Green (blue padlock)	Green (blue padlock)	Green (blue padlock)
	Blue (red padlock)	Blue (red padlock)	Blue (red padlock)
	Blue (green padlock)	Blue (green padlock)	Blue (green padlock)
Low-collaboration	Red	Red	Red
	Red	Red	Red
	Green	Green	Green
	Green	Green	Green
	Blue	Blue	Blue
	Blue	Blue	Blue

Table 3: **Geometric shapes used in the two VEs in Experiment 1.** There were eighteen shapes in each VE, consisting of six cubes, six pyramids, and six rectangles. In the high-collaboration VE, the shapes were locked by coloured padlocks. In the low-collaboration VE there were no padlocks.

5.4 Experiment Procedure

Participants in a group meet for the first time in the virtual environment and could only communicate with one another through the virtual environment. This was accomplished by situating the workstations in different rooms within the same laboratory. In addition, participant were using headphones which blocked out extraneous noises.

As each participant arrived to the laboratory, they were taken to their respective rooms by the experimenter. Before starting the experiment, each participant was introduced to the system. This involved learning how to move in the environment and how to pick up objects and drop them somewhere else. Once every participant was familiar with the interface, they read the experiment instructions describing the task that they will have to perform in the virtual environment. In order to make sure that each participant had understood the task fully, the experimenter explained the task verbally to each participant answering any questions they had about the task.

When each participant indicated that they were ready to begin the experiment, the experimenter showed them to the virtual environment indicating which colour was associated with their avatar (as indicated by a colour strip on the monitor). The participants greeted one another using speech and started the task.

The task had a time limit of 25 minutes, but this was not mentioned to the participants as knowledge of the time limit might affect task performance [32]. Once the time was up, the participants where instructed to stop. After that, each participant was required to fill in three questionnaire: the Witmer and Singer Immersive Tendencies Questionnaire (ITQ), the Presence/Co-presence questionnaire, and the Collaboration Questionnaire. These questionnaires are described in more detail in Chapter 3 and Section 5.6.

5.5 Equipment

The experiment used ‘desktop’ virtual environment, meaning that no immersive equipment (such as head-mounted displays or projection VR) were used. Movements through the virtual environment was accomplished using the arrow keys. Objects in the virtual environment could be picket up and dropped by clicking on them with the mouse.

During the experiment the following workstation configurations were used:

- Red participant: SGI Onyx RealityEngine2 with four 200-MHz R4400 processors, 128 Mbytes of RAM, and 21 inch screen.
- Blue participant: SGI O2 with a 175-MHz R10000 processor, 128 Mbytes of RAM, and 21 inch screen.

- Green participant: SGI O2 with a 195-MHz R10000 processor, 256 Mbytes of RAM, and 17 inch screen.

In addition, participants used headphones and microphones for audio communications. The software used for audio communication was RAT (Robust Audio Tool) which is a multicast audio tool developed at University College London [3].

5.6 Measuring Presence and Group Collaboration

In this section we describe the gathering of data in this experiment. We used subjective questionnaires to get scores for presence, co-presence and collaboration. We also measured the immersive tendencies of the participants who took part in the experiment. We used a subjective measure of presence and co-presence due to the fact that no practical, effective objective measure of presence has yet been developed (refer to Section 2.2.5). Subjective measures of presence have been used in the vast majority of presence experiments, and have been accepted and validated as a measure of presence (refer to section 2.2.5).

5.6.1 Presence and Co-presence

In order to measure the degree of presence and co-presence felt by the participants during the experiment, users were asked to fill in a presence/co-presence questionnaire once the experiment concluded. The presence/co-presence questionnaire contains questions to measure both presence and co-presence.

The presence section of the questionnaire was based on the presence questionnaires developed by Slater *et al* [58, 51, 55]. This presence questionnaire is described in detail in Section 3.4.

The co-presence questions are described in detail in Section 3.5.

The Immersive Tendencies Questionnaire (ITQ) developed by Witmer and Singer [79], was used to measure differences in the tendencies of individuals to become immersed. The questions in this questionnaire mainly measure involvement in common activities. Since increased involvement can result in more immersion, we expect individuals who tend to become more involved will also have a greater immersive tendencies. We use this questionnaire to make sure that there is no significant difference in immersive tendencies between the participants in the high-collaboration VE and the low-collaboration VE. This is used to check that we have a random distribution of participants. The Immersive Tendencies Questionnaire (ITQ) is described in more detail in Section 3.3, and can be found in Appendix B.

The ITQ questionnaire also uses a seven-point Likert scale based on the semantic differential principle. The IT score is calculated by adding the individual scores of each question in the questionnaire. Each question's score has a value from 1 to 7, and no reverse scoring is used.

5.6.2 Group Collaboration

Group collaboration was also measured subjectively. We asked the participants to fill in a collaboration questionnaire once the experiment ended. This collaboration questionnaire is used to make sure that the two VEs (i.e., the high-collaboration VE and the low-collaboration VE) produced different levels of group collaboration and interaction.

We developed a collaboration questionnaire to assess collaboration and interaction by asking the participant to rate the perceived collaboration of the group and of the other members of the group, as well as the talkativeness of the different group members. It also assesses the degree of enjoyment and comfort with individual members of the group. This collaboration questionnaire is described in detail in Section 3.6.

The collaboration questionnaire used in the experiment can be found in Appendix E. It also used a seven-point Likert scale, and the collaboration score is calculated by adding the individual scores of all the questions in the questionnaire.

5.7 Analysis of Results

In this section we describe the results obtained in the experiment. We firstly present the different variables measured and the hypotheses on those variables, followed by a summary and a discussion of the obtained results.

5.7.1 Variables and Hypotheses

There are three hypotheses which we wish to test by means of this experiment. The first hypothesis is that a sense of presence (personal and co-presence) in the CVE is created by embodying the participants in the virtual environment by means of virtual representations. The second hypothesis is that having visual representations of others is not sufficient to create a high sense of co-presence, and that group collaboration and interaction is required to enhance co-presence. The third hypothesis is that personal presence and co-presence could be related in some sort.

Using the questionnaire mentioned in Section 5.6, we have measured the following variables:

The presence score P: P measures the sense of personal presence experienced by the participants. It is measured using Slater's presence questionnaire found in Appendix C.

The co-presence score CO-P: The CO-P variable measures the sense of co-presence experienced by the participants during the course of the experiment. It is measured using our co-presence questionnaire found in Appendix D.

The collaboration score COLL: The COLL variable measures the degree of group collaboration and interaction. This variable is measured using our collaboration questionnaire described in Section 3.6, and which can be found in Appendix E.

The immersive tendencies score IT: The IT variable measures the tendencies of individuals to experience presence. It is measured using the ITQ questionnaire developed by Witmer and Singer [79]. This questionnaire can be found in Appendix B.

The hypotheses for the above variables are: We expect COLL to be higher in the high-collaboration VE than in the low-collaboration VE. This will show that there was indeed a difference in collaboration between the two virtual environments. We expect the CO-P score to be higher in the high-collaboration VE than in the low-collaboration VE. This will support our hypotheses that interaction and collaboration enhances co-presence in a CVE. Witmer and Singer [79] indicate that the IT score (as measured by their immersive tendencies questionnaire) predicts the presence score (as measured by their presence questionnaire). It is important to check if this correlation is replicated in this experiment, which uses a different presence questionnaire (developed by Slater *et al*). It is also important to check if there is a relationship between P and CO-P scores. Tromp *et al* [71] indicate that they found a positive correlation between the personal presence and co-presence scores in one of their experiments. This experiment is described in more detail in Slater *et al* [53].

5.7.2 Summary of Results

For each virtual environment (i.e., the low-collaboration VE and the high-collaboration VE), we measured the presence score (P), the co-presence score (CO-P) , the collaboration score (COLL), and the immersive tendencies score (IT). The scores were averaged across each virtual environment to obtain means (together with their standard deviations) for each variable in each of the two VEs. The scores obtained in the low-collaboration VE are shown in Table 4, and the scores obtained in the high-collaboration VE are shown in Table 5.

In order to check if sampling errors occurred during the experiment, we compared the P scores and the CO-P scores within the same conditions (i.e., in the low-collaboration VE and then in the high-collaboration VE). For each VE, we performed a one-way Analysis of Variance (ANOVA) on group number and P score. We found no significant difference in either VE at the 0.05 confidence level. For the low-collaboration VE, we have $F(3, 8) = 0.256, p > 0.05$. For the high-collaboration VE, we have $F(5, 12) = 1.476, p > 0.05$. For each VE, a one-way ANOVA on group number and CO-P score was also performed. Again, we found no significant difference in either VE at the 0.05 confidence level. For the low-collaboration VE, we found $F(3, 8) = 0.873, p > 0.05$. For the high-collaboration VE, we found $F(5, 12) = 0.984, p > 0.05$. This indicates that there were no

Participant	Presence (P)	Co-presence (CO-P)	Collaboration (COLL)	Immersive tendencies (IT)
1	53	16	25	93
2	22	12	25	72
3	50	21	20	87
4	45	26	19	96
5	32	8	28	63
6	56	25	20	84
7	30	14	21	76
8	44	10	23	84
9	37	12	20	71
10	30	19	23	78
11	47	13	23	85
12	36	18	22	56
Mean	40.16667	16.16607	22.41667	78.75
Std Dev.	10.56436	5.74984	2.644319	11.84080

Table 4: **Results for the low-collaboration VE in Experiment 1.** For each participant in the low-collaboration VE, we measured the presence score (P), the co-presence score (CO-P), the collaboration score (COLL), and the immersive tendencies score (IT).

significant sampling errors with the P and CO-P scores.

In order to check if different equipment played a role in the results, we performed for each VE an ANOVA on colour and P score. We found no significant difference in either VE at the 0.05 confidence level. For the low-collaboration VE we have $F(2,9) = 0.613, p > 0.05$. For the high-collaboration VE we have $F(2,15) = 0.108, p > 0.05$. Also, we performed an ANOVA on colour and CO-P score for each VE. Again, we found no significant difference in either VE at the 0.05 confidence level, with $F(2,9) = 4.22, p > 0.05$ for the low-collaboration VE and $F(2,15) = 1.067, p > 0.05$ in the high-collaboration VE. This shows that the different equipment did not lead to significant differences in P and CO-P scores.

We performed a t-test on the mean IT score in each condition (i.e., low-collaboration and high-collaboration VEs) to ensure that we had an even distribution of participants with regards to the IT score. The results of the t-tests showed that there was no significant difference at the 0.05 confidence level.

In order to check that both VEs produced a different level of collaboration, we performed a one-way ANOVA to check the difference in COLL score between the low-collaboration VE and the high-collaboration VE. we found that, as expected, there was a very large difference in COLL score

Participant	Presence (P)	Co-presence (CO-P)	Collaboration (COLL)	Immersive tendencies (IT)
13	46	26	87	86
14	49	36	83	70
15	49	37	85	61
16	44	34	78	83
17	51	36	70	74
18	46	27	61	73
19	66	31	71	85
20	45	36	70	66
21	49	37	78	54
22	47	39	84	67
23	52	37	56	78
24	44	28	69	71
25	51	36	45	66
26	65	37	81	96
27	63	38	82	112
28	46	17	44	98
29	47	29	53	75
30	61	36	73	97
Mean	51.16667	33.16667	70.55556	78.4444
Std Dev.	7.35047	5.72148	13.60027	14.97536

Table 5: **Results for the high-collaboration VE in Experiment 1.** For each participant in the high-collaboration VE, we measured the presence score (P), the co-presence score (CO-P), the collaboration score (COLL), and the immersive tendencies score (IT).

between both VEs, with $F(1, 28) = 145.025, p < 0.001$. This shows that participants felt that they collaborated quite a lot in the high-collaboration VE, and not at all in the low-collaboration VE.

We then compared the difference in the P scores between the low and high-collaboration VEs. This was done using a one-way ANOVA, and we found that there was a significant difference at the 0.05 confidence level, with $F(1, 28) = 16.366, p < 0.05$. This indicates that participants had a higher P score on the high-collaboration VE.

We also compared the CO-P scores between the low and high-collaboration VEs. This was achieved by doing a one-way ANOVA on CO-P scores for both VEs. We found that there was a very significant difference, having $F(1, 28) = 63.317, p < 0.001$. This difference indicates that participants in the high-collaboration VE had a greater sense of co-presence than participants in the low-collaboration VE.

A correlation analysis was performed on the P, CO-P, and IT variables in each VE, to check if there were significant relationships between them. We performed two-sided tests in both the low and high collaboration VE, and we obtained the following results (see Tables 6 and 7 for the correlation matrices for both the low and high collaboration VEs):

Low-collaboration VE:

- *Correlation between P and IT scores*: $r = 0.6537, t = 2.7317$ and $p = 0.021132 < 0.05$. At a significance level of 0.05, with $N = 12$ and 10 degrees of freedom we get $t = 2.228$, and a critical value of r (r_{crit}) equal to 0.5759. This indicates that P and IT were significantly correlated.

- *Correlation between CO-P and IT scores*: $r = 0.6708, t = 2.7140$ and $p = 0. < 0.05$. At a significance level of 0.05, with $N = 11$ and 9 degrees of freedom we get $t = 2.262$, and a critical value of r (r_{crit}) equal to 0.6020. We can see that the CO-P and IT scores were significantly correlated. However this significant correlation was achieved after an outlier data point (see Figure 21) has been removed as explained later in this section.

- *Correlation between P and CO-P scores*: $r = 0.4919, t = 1.7865$ and $p = 0.10434 > 0.05$. At a significance level of 0.05, with $N = 12$ and 10 degrees of freedom we get $t = 2.228$, and a critical value of r (r_{crit}) equal to 0.5759. Here, the P and CO-P scores were not significantly correlated.

- *Correlation between P and COLL*: $r = -0.370441$, $t = -1.26116$ and $p = 0.235878 > 0.05$. Here, the P and COLL scores were not significantly correlated.

- *Correlation between CO-P and COLL*: $r = -0.686603, t = -2.98643$ and $p = 0.013657 < 0.05$. Here, the CO-P and COLL scores were significantly correlated.

- *Correlation between IT and COLL*: $r = -0.353493, t = -1.19500$ and $p = 0.259659 > 0.05$. Here, the IT and COLL scores were not significantly correlated.

High-collaboration VE:

- *Correlation between P and IT scores*: $r = 0.5764, t = 2.8217$, and $p = 0.012280 < 0.05$. At a significance level of 0.05, with $N = 18$ and 16 degrees of freedom we get $t = 2.12$, and a critical value of r (r_{crit}) equal to 0.4682. We can see that the P and IT scores were significantly correlated.

- *Correlation between CO-P and IT scores*: $r = -0.239145$, $t = -0.985164$, and $p = 0.339208 > 0.05$. At a significance level of 0.05, with $N = 18$ and 16 degrees of freedom we get $t = 2.12$, and a critical value of r (r_{crit}) equal to 0.4682. We can see that the

	Presence (P)	Co-presence (CO-P)	Collaboration (COLL)	Immersive tendencies (IT)
P	1			
CO-P	0.4919	1		
COLL	-0.3704	**-0.6866**	1	
IT	**0.6537**	**0.6708**	-0.3535	1

Table 6: **Correlation matrix for the low-collaboration VE of Experiment 1.** Results with $p < 0.05$ are marked in bold. We can see that in the low-collaboration VE P/IT, CO-P/COLL, and CO-P/IT are significantly correlated.

	Presence (P)	Co-presence (CO-P)	Collaboration (COLL)	Immersive tendencies (IT)
P	1			
CO-P	0.3420	1		
COLL	0.1814	**0.4727**	1	
IT	**0.5764**	-0.2391	0.0056	1

Table 7: **Correlation matrix for the high-collaboration VE of Experiment 1.** Results with $p < 0.05$ are marked in bold. We can see that in the high-collaboration VE P/IT, and CO-P/COLL are significantly correlated.

CO-P and IT scores were not significantly correlated.

- *Correlation between P and CO-P scores*: $r = 0.341985$, $t = 1.45571$, and $p = 0.164814 > 0.05$. At a significance level of 0.05, with $N = 18$ and 16 degrees of freedom we get $t = 2.12$, and a critical value of r (r_{crit}) equal to 0.4682. The P and CO-P scores were not significantly correlated.

- *Correlation between P and COLL*: $r = 0.181430$, $t = 0.737967$ and $p = 0.471220 > 0.05$. Here, the P and COLL scores were not significantly correlated.

- *Correlation between CO-P and COLL*: $r = 0.472723$, $t = 2.145790$ and $p = 0.047576 < 0.05$. Here, the CO-P and COLL scores were significantly correlated.

- *Correlation between IT and COLL*: $r = 0.005648$, $t = 0.022592$ and $p = 0.982255 > 0.05$. Here, the IT and COLL scores were not significantly correlated.

We plotted a scatterplot of the CO-P scores vs the IT scores in the low-collaboration VE to check if we had any outliers in the data points. The plot shows that we have a data point that is clearly an outlier (refer to Figure 21). If we do not remove this data point we get the following changes to the correlation calculated above. Correlation between CO-P and IT scores $r = 0.4706$ and $t = 1.6870$. At a significance level of 0.05, with $N = 12$ and 10 degrees of freedom we get $t = 2.228$, and a critical value of r (r_{crit}) equal to 0.5759. This indicates that the CO-P and IT scores are not significantly correlated in the low-collaboration VE, if we do not remove the outlier.

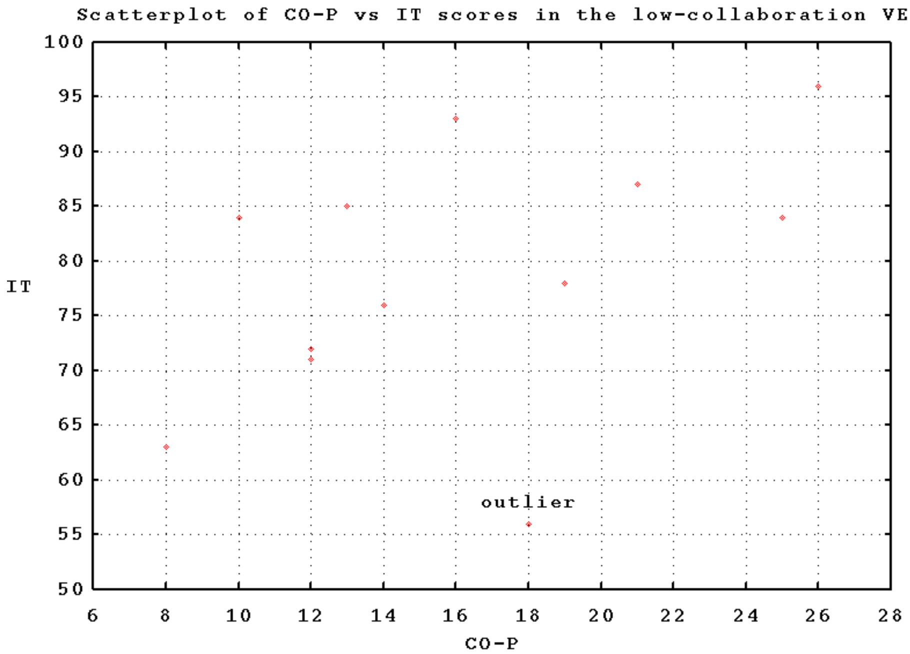

Figure 21: **Scatterplot of the CO-P scores vs the IT scores in the low-collaboration VE in Experiment 1.** We can clearly see an outlier (18,56) in the data points.

We plotted a scatterplot of the P scores vs the CO-P scores in the low-collaboration VE, to check for outliers (refer to Figure 22). It can be seen that there are no clear outliers on this scatterplot.

We also plotted a scatterplot of the CO-P scores vs the IT scores in the high-collaboration VE. The plot shows an outlier (refer to Figure 23). If we remove this data point we get the following changes to the correlation calculated above. Correlation between CO-P and IT scores: $r = -0.01392$ and $t = -0.05391$. At a significance level of 0.05, with $N = 17$ and 15 degrees of freedom we get $t = 2.131$, and a critical value of r (r_{crit}) equal to 0.482068. This indicates that in the high-collaboration VE, the CO-P scores and the IT scores were not correlated even when we removed the outlier data point.

The scatterplot of the P scores vs the CO-P scores in the high-collaboration VE shows that we

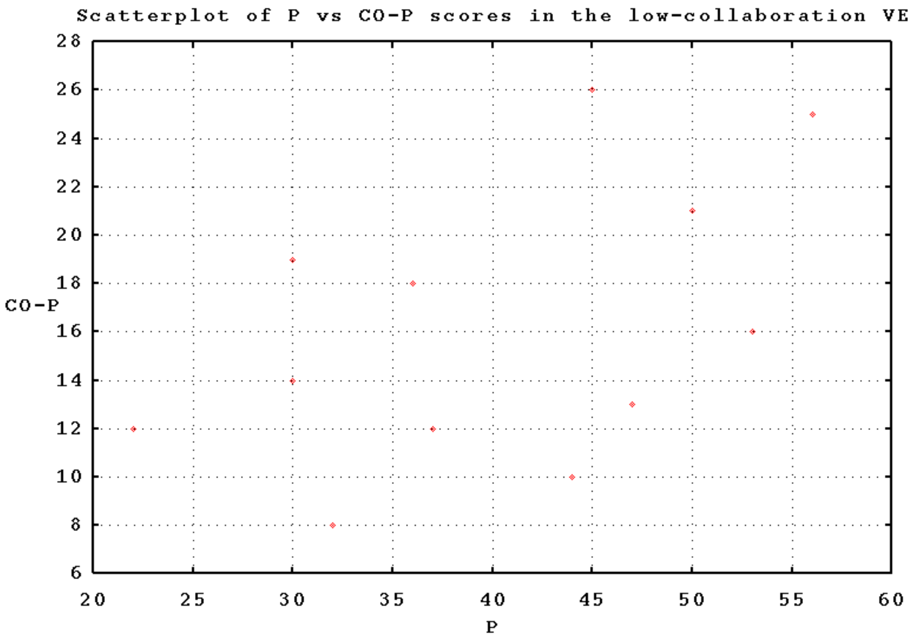

Figure 22: **Scatterplot of the P scores vs the CO-P scores in the low-collaboration VE in Experiment 1.** There are no clear outliers.

have a data point which is an outlier (refer to Figure 24). Removing this data point causes the following changes to the correlation between P and CO-P in the high-collaboration VE. Correlation between P and CO-P scores: $r = 0.3127$ and $t = 1.275$. At a significance level of 0.05, with $N = 17$ and 15 degrees of freedom we get $t = 2.131$, and a critical value of r (r_{crit}) equal to 0.482068. This shows that in the high-collaboration VE, the P scores and the CO-P scores were not correlated even when we removed the outlier data point.

5.7.3 Discussion of Results

The results show that there was a very large difference in the collaboration score (COLL) between the low and high-collaboration VEs. This indicates that we succeeded in our goal of creating a large difference in collaboration between the two virtual environments, which was picked up by the collaboration questionnaire.

In the analysis of the co-presence score, we found that there was a very large difference in co-presence between the two environments. The co-presence score was much higher in the high-collaboration VE when compared to the low-collaboration VE. This supports our hypothesis that collaboration and interaction greatly enhance co-presence in a CVE beyond that afforded by merely

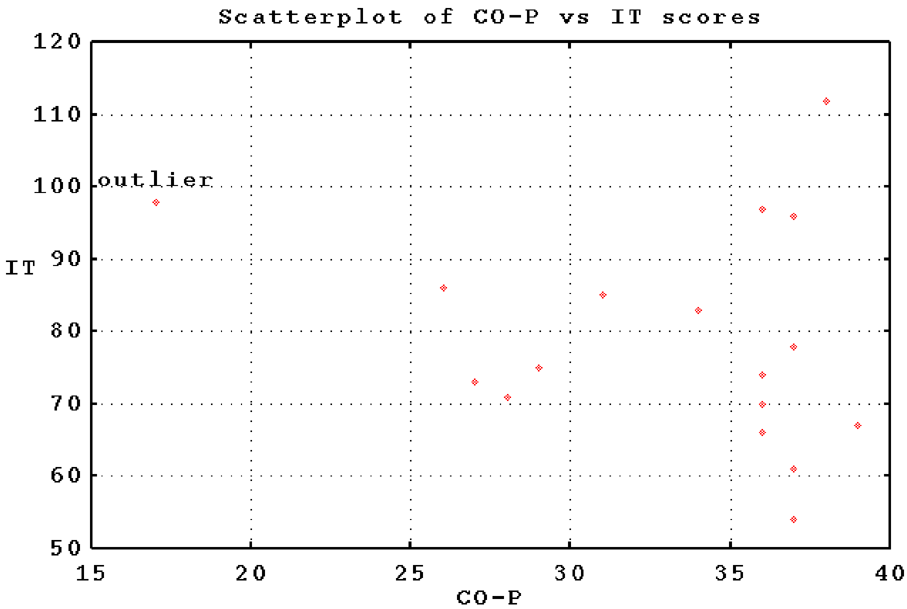

Figure 23: **Scatterplot of the CO-P scores vs the IT scores in the high-collaboration VE in Experiment 1.** We have an outlier (17,98) in the data points.

having virtual representations of others.

When looking at the presence scores, we found that the presence score (P) was higher in the high-collaboration VE than in the low-collaboration VE. This is an interesting result since it might indicate that collaboration and interaction with others participants affect personal presence. This might be explained by the fact that since the high-collaboration task was more challenging, it required the participants to be more involved in the experience and hence enhanced the sense of personal presence.

Witmer and Singer [79] indicate that their Immersive Tendencies Questionnaire (ITQ) predicts the level of presence as measured by their presence questionnaire in a VE. However, in the experiment described next in Chapter 6, we failed to replicate Witmer and Singer's result using their presence questionnaire (rather than Slater's) and their immersive tendencies questionnaire. Since in this experiment we have used a different presence questionnaire developed by Slater *et al*, it is important to see if we can replicate Witmer and Singer's results with Slater's questionnaire. We found that in both the low and high-collaboration VEs, the presence score (measured by Slater's presence questionnaire) and the IT score (measured by Witmer and Singer's immersive tendencies questionnaire) were positively correlated. This might indicate that there is a relation between the

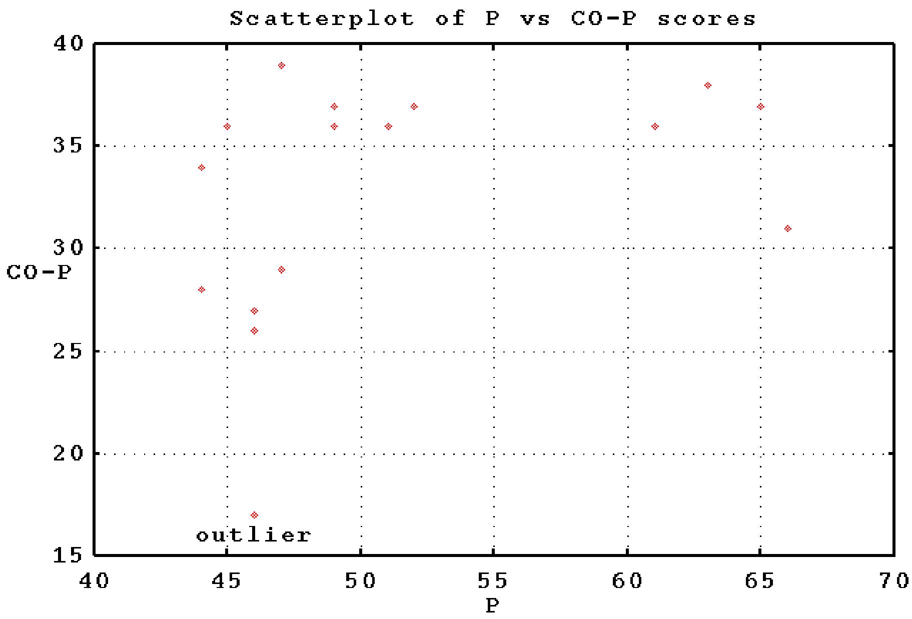

Figure 24: **Scatterplot of the P scores vs the CO-P scores in the high-collaboration VE in Experiment 1.** We can see an outlier (46,17) in the data points.

immersive tendencies scores and the presence scores. The immersive tendencies score could act as a predictor of the presence score. When we compared the co-presence (CO-P) scores and the immersive tendencies (IT) scores, we found that in the low-collaboration VE they were significantly correlated if we removed an outlier data point. On the other hand, we did not find a correlation between the CO-P scores and the IT scores in the high-collaboration VE. We therefore cannot say if the immersive tendencies score can act as a predictor of the co-presence score in a CVE, and more research needs to be done in this area.

When we compared the presence (P) an co-presence (CO-P) scores, we found that there was no correlation between them in any of the two conditions. We therefore failed to replicate the results found by Tromp *et al* [71] and by Slater *et al* [53] which indicate that they found a positive correlation between personal presence and co-presence. More research needs to be done in this area in order to confirm if there is a relationship between the sense of presence and co-presence in a CVE.

We found a significant correlation between the co-presence (CO-P) and collaboration scores (COLL) in both the low-collaboration VE and high-collaboration VE. This indicates that group collaboration and co-presence are related. We did not found any significant correlation between P and COLL or between IT and COLL in any of the two VEs.

Some interesting issues that we noticed by observing the participants during the session were the fact that participants usually avoided walking through other people's avatars, and even apologised if they walked too close to other people's virtual representations. This seems to indicate that they had some respect for the avatars of others, even though the avatars were quite crude representations. There was also quite a lot of excitement and enjoyment during the session, and participants were a bit disappointed when the experimenter indicated that it was time to end the experiment.

5.8 Summary

In this chapter we have presented the design and results of an experiment aimed at investigating collaboration and interaction between a small group of participants in a Collaborative Virtual Environment. This experiment is used to test the following hypotheses:

1. Group collaboration and interaction with other participants in the environment should influence co-presence. It is believed that interaction and collaboration greatly enhance the sense of co-presence beyond that afforded by merely having virtual representation of others. We found that the sense of personal presence and co-presence was enhanced by collaborating and interacting with others in the group.

2. Personal presence and co-presence in a CVE could be correlated. This is a useful issue to investigate, since if personal presence and co-presence are associated this could be because of common factors which influence both, or because they influence one another. If they are not correlated it might indicate that they are orthogonal to each other. In this experiment, we did not find any correlation between personal presence and co-presence in any of the two virtual environments.

These hypotheses were tested through the creation of two screen-based virtual environments named low-collaboration VE and high-collaboration VE. These VEs are identical and only the task differs. In the high-collaboration VE, participants have to collaborate in order to solve the task. If they do not collaborate, the task cannot be completed. In the low-collaboration VE, participants don't need to collaborate to solve the given task. In both VEs participants can communicate with one another using an audio channel.

We performed a one-way ANOVA to check the difference in COLL score between the low-collaboration VE and the high-collaboration VE. We found that there was a very large difference in COLL scores between the two VEs. This indicates that we succeeded in our goal of creating a large difference in collaboration between the low-collaboration VE and the high-collaboration VE.

We found that the presence score (P) and the co-presence score (CO-P) were significantly higher in the high-collaboration VE than in the low-collaboration VE. This supports the hypothesis that collaboration and interaction greatly enhance personal presence and co-presence in a CVE beyond that afforded by merely having virtual representations of others.

We performed a correlation analysis on the presence (P), co-presence (CO-P), collaboration (COLL), and immersive tendencies (IT) variables in each of the two VEs, to check if there were significant relationships between them. We found that in both of the two VEs the P score and the IT score were positively correlated. This might indicate that the immersive tendencies score act as a predictor of the presence score. We found that the CO-P score and the IT score were only correlated in the low-collaboration VE (once we had removed an outlier data point), but there was no correlation in the high-collaboration VE. We therefore cannot say if the IT score can predict the co-presence score. We found no significant correlation between the presence and co-presence scores in this experiment. We therefore failed to replicate the results found by Tromp *et al* [71], and Slater *et al* [53] which indicate that they found a positive correlation between personal presence and co-presence. More research needs to be conducted in this area in order to confirm if there is a relationship between these two types of presence. We found a significant correlation between the co-presence (CO-P) and collaboration scores (COLL) in both the low-collaboration VE and high-collaboration VE. This indicates that group collaboration and co-presence are related. We did not found any significant correlation between personal presence and collaboration or between immersive tendencies and collaboration in any of the two VEs.

Chapter 6

Experiment 2: Group Collaboration and Interaction

In this chapter we present an experiment which is designed to investigate collaboration and interaction between small groups of three users in a CVE, and the effects that presence and co-presence have on collaboration and interaction in the CVE. In this experiment, we examined the effects of altering presence on collaborative interaction styles between members of a small group of participants in a virtual environment. We examined the differences in collaborative patterns when the presence of the virtual environment is altered. By varying this factor of presence in the virtual environment, and seeing the resulting effects on users, we aim to show that an increased degree of presence in a virtual environment might result in a higher degree of interaction and collaboration between users performing a task in the virtual environment.

Our aims were two-fold. We wish to study:

- *How presence is increased in a collaborative virtual environment*: The various factors contributing to increased presence have been studied quite extensively by differing researchers. We aim to consolidate this research and combine all the factors, hopefully creating a highly present virtual environment.

- *The effects of both personal and co-presence on collaborative interaction styles*: In this study two virtual environments, with varying degrees of presence, are used by subjects in solving a collaborative task. We aim to study, all else being equal, how the differences in personal and co-presence affect participants' collaborative styles with other participants in the virtual environment.

We proposed and supervised this experiment as a 4th year computer science honours project. The programming and experiment as well as the recording of results and much of their analysis was conducted by Cathryn Johns, Marc Daya, and Duncan Sellars, three honours students under our supervision in the Department of Computer Science at the University of Cape Town. Our role consisted of providing the underlying theory, as well as constant involvement in the design of the experiment, the implementation of the virtual environments, and the actual experiment set-up and the performing of the experiment.

We begin by stating the hypotheses we wish to test, in Section 6.1. Section 6.2 describes the participants used in the experiment. Section 6.3 describes the experiment task that the participants had to perform during the course of the experiment. Section 6.4 describes the procedure employed in this experiment. Section 6.5 describes the equipment used . Section 6.6 indicates how presence, co-presence and interaction were measured, and how the data was gathered. Section 6.7 presents the analysis of the results which include a summary of the obtained results. Section 6.8 presents a discussion of the obtained results.

6.1 Hypotheses

This experiment involved the testing of two hypotheses. The first and main hypothesis is that increasing the feeling of presence and co-presence within a group in a CVE would change the style of collaboration and interaction between group members. In order to test this hypothesis, we created two screen-based virtual environments, one of which was designed to engender a high sense of presence, while the other was deliberately designed to disrupt and decrease the sense of presence felt by the participants. The design of these two virtual environments as well as the differences between them are described in Section 4.3. Groups were arbitrarily assigned to either the high-presence or low-presence environments, and the interaction and collaboration styles of group members were analysed and the results were compared across the two environments.

The second hypothesis we tested was that creating the two virtual environments as described would result in a greater sense of presence and co-presence being felt by the participants assigned to the high-presence VE, and lower sensations of presence and co-presence being felt by the participants in the low-presence VE. In order to test this assumption, we used subjective questionnaire designed to asses the sense of presence and co-presence felt by the participants.

6.2 Subjects

The experiment involved 20 participants, divided into six groups of three users each, and one group of two participants. The participants were paid volunteers and were recruited mainly from the second year psychology course at the University of Cape Town. Subjects were recruited by means of announcements in lectures as well as posters placed on the notice boards. Some participants were recruited from other departments as indicated in Table 8.

	Group	No. Male	No. Female	Data No.	Colour	Majors
Low-Presence Environment	1	1	2	1	Red	Psychology (Hons)
				2	Blue	Psychology
				3	Green	Psychology
	2	0	3	4	Red	Psychology
				5	Green	Psychology
				6	Blue	Comp Sci/Psychology
	3	2	1	7	Blue	Psychology 3
				8	Red	Comp Sci 1
				9	Green	(unknown)
	4	2	1	10	Red	Psychology/Physiology
				11	Green	Psychology 3
				12	Blue	B.Sc (2nd year)
High-presence Environment	5	2	1	13	Blue	Psychology
				14	Green	Comp Sci
				15	Red	Psychology
	6	1	2	16	Blue	BA (3rd year)
				17	Green	BA (3rd year)
				18	Red	Soc Sci (3rd year)
	7	1	1	19	Blue	Biochemistry
				20	Red	B.Sc (1st year)

Table 8: **The Composition of Groups in Experiment 2.** Most of the participants were recruited from the second year psychology course.

Originally, it was planed that eight groups would take part in this experiment. For each group, six volunteers were asked to sign up. From this pool, four volunteers were randomly selected. Out of these four participants, three were selected to participate in the actual experiment while the fourth one was chosen as a surplus volunteer in case one of the other participants was unable to attend. If all of the four participants did arrive, the last person to arrive was assigned a dummy task and was paid regardless. For ethical reasons, the participants assigned to the dummy task were not told that they were not talking part in the experiment.

During two of the high-presence sessions, we suffered some equipment failure which forced us to discard the data obtained during these two sessions. As a result of this, an extra session was scheduled. For this session, we recruited two first year students from the Science Faculty computer laboratory. The third subject was a fourth year biochemistry student, who was the sister of one of the experimenters. Despite this, she had no prior knowledge of the experiment. During this last session, one of the computers crashed, which reduced the number of participants to two. The data obtained in this final session was included in the analysis with the exception that the participant who suffered equipment failure did not complete any questionnaires. This caused our overall number of participants to be reduced to 20 subjects divided into six groups of three participants each, and one group of two participants. The first four groups participated in the low-presence VE, while the last three groups participated in the high-presence VE. Participants were not told which environment they were assigned to. In fact they were unaware that we used more that one virtual environment in the experiment.

Due to the difficulty of obtaining volunteers, we were unable to control conditions such as age, gender, and previous computer experience. Table 8 shows the gender distribution within each group. This is an important factor since mixed-gender groups interact differently to single-gender groups [72]. Fortunately, we can see that in all the groups except group 2 we had a mixed-gender situation. It is also important to have a mixed distribution across the two different environments, as Slater *et al* [63] have shown gender difference in presence susceptibility. We can see that the gender distribution across the two environments was fairly equal. The low-presence VE had five male and seven female participants, while the high-presence VE had four male and four female participants.

6.3 Experimental Scenario

The experiment requires participants to interact in two virtual environments which exhibit opposing degrees of presence. Thus, one would be a high presence environment while the other would be low presence (refer to Section 4.3 for a description of both environments).

All the participants in a group had an identical avatar. The only difference between the participant's avatars was their colour being red, green or blue. The avatars were labeled Red, Green and Blue, and participants called each other by these names during the experiment.

The task was a language-based task designed to encourage discussion and collaboration. It was designed to encourage intellectual collaboration rather than physical collaboration, while still providing enough opportunities for participants to interact with the environment.

The task to be performed by the participants was as follows: there were ten rooms in the VE which had a word printed on either the wall (in the high-presence environment) or on the floor (in the low-presence environment). Each one of those words had a letter missing, replaced by a '_' (for example we had "loa_"). The missing letters, which were all consonants, were scattered in the environment in the form of cubes which had the letter written in all the sides. The participants could pick up the cubes and move them around the environment. For each word, they had to find the missing letter and move it next to the word. The letters could be moved to a different room if it was

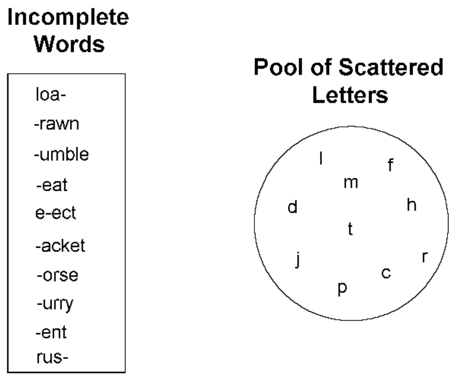

Figure 25: **Task of Experiment 2.** The words used in the task of Experiment 2, and the letters available to the participants.

later decided that the letter was placed in the wrong room.

In order to encourage collaboration and interaction between the participants, we complicated the task by making sure that the letters could be used in more than one word, but if it was used in the wrong word the puzzle could not be completed correctly. Figure 25 shows the words and missing letters used in the experiment.

6.4 Experimental Procedure

As each participant arrived to the lab, they were taken to their computer by the experimenter assigned to them for the session. Each participant was greeted using a standard greeting speech in order to prevent giving more information to any single participant. Participants were given an instruction sheet to read. This instruction sheet included a detailed description of the task that they would have to complete in the virtual environment.

When each participant had finished reading the instructions and indicated that they were ready to start, their experimenter showed them the virtual environment on the screen, indicating which colour was associated with their avatar (as indicated by a colour strip on the monitor). When all participants in the group were ready, they were greeted in the virtual environment by an avatar controlled by another experimenter (in the low-presence VE this was done using text, and in the high-presence VE this was done verbally in order to draw their attention to the fact normal speech was possible in this environment). The experimenter started a practice session were the participants could get familiar with the interface. It involved learning how to move in the environment, how to communicate with each other (either using text or audio depending if in the low-presence VE or in the high-presence VE), how to pick-up and drop objects. Once all the members of the group were comfortable with the interface and indicated their readiness to start the actual task, they were told by the experimenter's avatar that they could go ahead and start the task. At this point, the experimenter's avatar left the area in which the practice portion of the session took place, and once out of sight it was made invisible so that the group could be inconspicuously monitored by the experimenter.

As mentioned earlier, each participant had an experimenter assigned to them. The role of the experimenters varied between the low-presence VE and the high-presence VE. In the low-presence VE, the experimenters were there in case severe interface difficulties occurred, but also they were there to increase distraction and real-world intrusion in order to decrease the sense of presence felt by the participants. In order to do this, the experimenter interrupted the participant nine minutes into the session in order to ask them if they would like a soft drink, and of what flavour. A few minutes later they were interrupted again when the drink arrived. In addition, the drinking of the soft drink served as a continual real-world intrusion. In the high-presence VE, the experimenter left the room once the participant started using the virtual environment.

The task had a time limit of 25 minutes, but this was not mentioned to the participants as knowledge of the time limit might affect task performance and the type of group interaction [32]. Once the time was up, the experimenter's avatar appeared in the environment and instructed the participants to stop. After that, each participant was required to fill in two questionnaires: Presence and Co-Presence Questionnaire (PQ) and the Immersive Tendencies Questionnaire (ITQ). These questionnaires are described in more detail in section 6.6 and in Chapter 3.

6.5 Equipment

The participants all used SGI workstations. As the CVE's were screen-based, no immersive equipment (e.g. head-mounted displays) was used. Movement through the virtual environment was accomplished using the cursor keys on the keyboard. Objects in the virtual environment could be picked up and dropped by clicking on them with the left mouse button.

The following workstation configurations were used for the experiment:

- Hamachi, an SGI Onyx RealityEngine2 with 128 Mbytes of RAM, a 21 inch screen, SGI 101 keyboard and 3-button SGI mouse (used for the participant assigned the colour Red)
- Aji, an SGI O_2 with an R10000 processor, 256 Mbytes of RAM, a 17 inch screen, SGI 101 keyboard and 3-button SGI mouse (used for the participant assigned the colour Green)
- Masu, an SGI O_2 with an R10000 processor, 128 Mbytes of RAM, a 21 inch screen, SGI 101 keyboard and 3-button SGI mouse (used for the participant assigned the colour Blue)

The experimenter taking part in the initial introductory portion of the experiment initially used a NT Workstation, but due to equipment failure moved to a SGI workstation after the first two sessions.

In addition, participants assigned to the high-presence environment used headphones for audio communication, as well as to block out extraneous real-world sounds. An additional workstation (an SGI Indy) was used to record the dialogue in the high-presence environment. The audio tool used was RAT (Robust Audio Tool) developed at UCL [3].

The mike socket of a Sony TCM 7.5V tape-recorder was plugged into the audio-out socket of the additional workstation in order to provide a backup recording of the dialogue in the high-presence worlds.

6.6 Measuring Presence, Interaction and Collaboration

In this section we describe how the gathering of data took place. We used a post experiment questionnaire to measure the degree of presence and co-presence felt by the participants. We also used an immersive tendencies questionnaire to measure the participant's tendencies to become immersed. In order to investigate interaction and collaboration, we recorded all the dialogue between participants during the sessions. This dialogue was analysed using Interaction Process Analysis proposed by Bales [6].

6.6.1 Presence and Co-Presence

To measure the degree of presence and co-presence felt by each participant in the study, they were asked to fill in a questionnaire after exiting from the virtual environment. This questionnaire contained questions to measure personal presence and questions to measure co-presence. The personal presence part of this questionnaire is the Presence Questionnaire (PQ) developed by Witmer and Singer [79, 47], which is described in Section 3.2 and can be found in Appendix A. The co-presence part of the questionnaire is described in Section 3.5, and can be found in Appendix D.

The Immersive Tendencies Questionnaire (ITQ), also developed by Witmer and Singer [79, 47], was used to measure the innate susceptibility of participants to presence. The ITQ is described in more detail in Section 3.3. The ITQ can be found in Appendix B.

6.6.2 Interaction and Collaboration

All dialogue between group members during the task was logged. Text communication was sequentially written to a log file, while verbal communication was recorded by means of a tape recorder as well as via the sound tool used. In the high-presence environment, the identity of the person speaking was not recorded. The identity of the person typing was written to the log file, but this information was not used in the analysis.

All dialogue between group members was categorised according to the schedule proposed by Bales [6] and described in [72]. Briefly, there are four main categories of statements:

- *Category A*: positive socio-emotional content; group solidarity; satisfaction; general agreement
- *Category B*: attempted answers; giving suggestions, opinions, or orientation
- *Category C*: asking for suggestions, opinions, or orientation
- *Category D*: negative socio-emotional content; disagreement, tension or antagonism

Each of these can be broken down into three sub-categories, described in more detail in 6.7.2. The dialogue of each group was broken down and categorised into these twelve categories.

6.7 Analysis of Results

In this section, we present the results obtained in this experiment. We firstly describe the analysis of the presence, co-presence and immersive tendencies data, followed by the analysis of the interaction and collaboration styles.

6.7.1 Presence, Co-presence and Immersive Tendencies

Presence and Immervise Tendencies scores (P and IT scores) were obtained for each participant by computing the questionnaires' total scores according to Witmer and Singer's instructions [79, 47]. The co-presence score was obtained by adding the scores of the co-presence questions in the PQ, to form a co-presence score (CO-P). The P and CO-P scores were then weighted and added together to form a total presence score (TP). The scores obtained in the low-presence VE and in the high-presence VE are shown in Tables 9 and 10 respectively.

T-tests were performed on these values to determine whether the differences in mean scores between the high-presence VE and the low-presence VE were significant. For a significant level of 0.05 (5%) we found:

- The difference between the mean P score in the high-presence VE and the mean P score in the low-presence VE was not significant at $p = 0.0599$.
- The difference between the mean CO-P score in the high-presence VE and the mean CO-P score in the low-presence VE was significant at $p = 0.0288$.

Subject	Presence (P)	Co-Presence (CO-P)	Total Presence (TP)	Immersive Tendencies (IT)
1	116	33	75.311	63
2	107	35	74.896	99
3	114	39	81.832	93
4	122	30	73.602	96
5	92	19	51.191	89
6	101	35	73.033	93
7	111	31	71.377	72
8	82	25	55.228	94
9	84	34	66.563	52
10	75	27	55.435	74
11	115	36	78.571	115
12	118	36	79.503	92
Mean	103.083	31.667	69.712	86
Std Dev	15.986	5.646	10.335	17.430

Table 9: **The Questionnaire Scores for the Low-Presence VE of Experiment 2.** For each participant we measured the presence score (P), the co-presence score (CO-P), the total presence score (TP), and the immersive tendencies score (IT).

Subject	Presence (P)	Co-Presence (CO-P)	Total Presence (TP)	Immersive Tendencies (IT)
13	82	24	54.037	62
14	132	36	83.851	74
15	142	40	91.718	88
16	98	39	76.863	55
17	134	39	88.043	94
18	108	40	81.159	106
19	133	39	87.733	81
20	106	37	76.967	66
Mean	116.875	36.75	80.047	78.250
Std Dev	21.324	5.339	11.778	17.294

Table 10: **The Questionnaire Scores for the High-Presence VE of Experiment 2.** For each participant we measured the presence score (P), the co-presence score (CO-P), the total presence score (TP), and the immersive tendencies score (IT).

- The difference between the mean TP score in the high-presence VE and the mean TP score in the low-presence VE was significant at $p = 0.0264$.

- The difference between the mean IT score in the high-presence VE and the mean IT score in the low-presence VE was not significant at $p = 0.31179$.

In addition, the P scores within each VE were analysed. A one-way Analysis of Variance (ANOVA) on group number and P score showed no significant difference at the 0.05 significance level, in P scores across groups for either VE. In the high-presence VE we have $F = 0.0488$ and $p = 0.9527$. In the low-presence VE we have $F = 0.7467$ and $p = 0.55396$. This indicates that there were no significant sampling errors with the P scores in either VE.

In order to check if different equipment played a role in the results, we performed for each VE a one-way ANOVA on colour and P score. This showed that no colour had higher P scores than any other for either VE. In the high-presence VE we had $F = 1.1478$ and $p = 0.3888$. In the low-presence VE, $F = 0.376$ and $p = 0.6964$. These differences were not significant at a 0.05 significance level, and shows that the different equipment did not lead to significant differences in P scores.

In order to determine if the IT scores obtained in this experiment could be compared to that of Witmer and Singer [79, 47], it must be determined whether there is a difference between the mean IT score obtained in this experiment (across both VEs), and the mean IT score reported by Witmer and Singer. The sample IT mean of this experiment was found to be 82.9, with a sample standard deviation of 17.357. The 95% confidence for this sample mean is thus $(74.77, 91.02)$. Witmer and Singer's reported IT mean is 76.7 [79, 47], which falls into this confidence interval. The sample used in this experiment was thus drawn from the same population as that of Witmer and Singer.

A correlation analysis was performed on the P, CO-P and IT variables in order to investigate if there were significant relationship between them. For correlation of variables with IT scores, a one-sided test was used as there was a strong theoretical basis for supposing that any correlation found would be positive (Witmer and Singer [79] have found that higher IT scores lead to higher P scores). For a one-sided test and a significance level of 0.05 (5%), the critical value (r_{crit}) was 0.6215 for the high-presence VE (n=8, degrees of freedom = 6) and 0.4973 in the low-presence VE (n = 12, degrees of freedom = 10). For a two sided test, as used for P/CO-P correlations, a significance level of 0.05 gives a critical value of r (r_{crit}) of 0.7067 for the high-presence VE and of 0.5760 for the low-presence VE.

In the high-presence VE, a scatterplot of the P scores vs the IT scores reveals that on of the data points is an outlier (refer to Figure 26), as it occupies a quadrant which does not contains any other points. We removed this data point and obtained the following correlations:

- In the high-presence VE, we found that P was significantly correlated to IT ($r = 0.86, r_{crit} = 0.6694$). CO-P was not significantly correlated to IT ($r = 0.49, r_{crit} = 0.6215$). TP was not significantly correlated to IT ($r = 0.57, r_{crit} = 0.6215$). P was not significantly correlated to CO-P ($r = 0.65, r_{crit} = 0.7067$).
- In the low-presence VE we found that P was not significantly correlated to IT ($r = 0.36, r_{crit} = 0.4973$). CO-P was not significantly correlated to IT ($r = 0.11, r_{crit} = 0.4973$). TP was not significantly correlated to IT ($r = 0.24, r_{crit} = 0.4973$). P was not significantly correlated to CO-P ($r = 0.55, r_{crit} = 0.5760$).

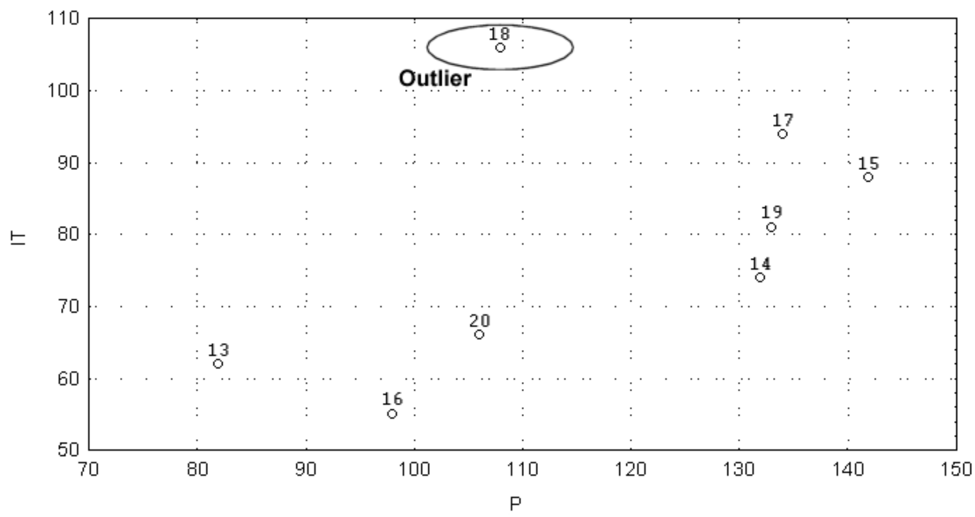

Figure 26: **Scatterplot of P vs IT scores in the high-presence VE of Experiment 2.** Data point 18 is an outlier.

Having found an outlier in the high-presence VE P vs IT scatterplot, we plotted the corresponding scatterplot for the low-presence VE (refer to Figure 27). In this plot we can see that there are no clear outliers.

6.7.2 Interaction and Collaboration

The unit of analysis for the interaction and collaboration results was the group. All dialogue between group members was categorised according to the schedule proposed by Bales [6] and used

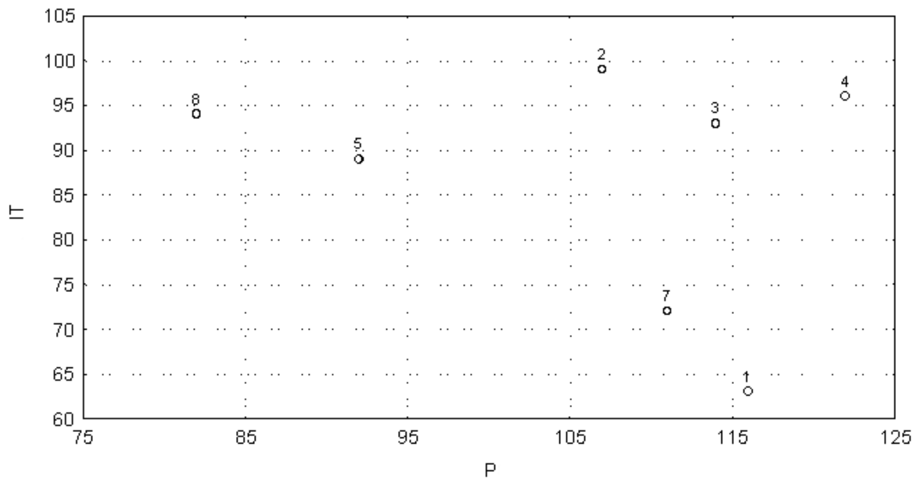

Figure 27: **Scatterplot of P vs IT scores in the low-presence VE of Experiment 2.** There are no clear outliers in the data pints.

by Underwood *et al* [72]. The schedule has four basic areas, namely:

- Positive Reactions
- Attempted Answers
- Questions
- Negative Reactions

Each of these categories are subdivided into three sub-categories, giving twelve categories altogether [6]:

1. *Shows solidarity,* raises other's status, gives help, reward
2. *Shows tension release*, jokes, laughs, shows satisfaction
3. *Agrees,* shows passive acceptance, understands, concurs, complies
4. *Gives suggestion,* direction, implying autonomy for other
5. *Gives opinion,* evaluation, analysis, expresses feeling, wish

6. *Gives orientation,* information, repetition, confirmation
7. *Asks for orientation,* information, repetition, confirmation
8. *Asks for opinion,* evaluation, analysis, expression of feeling
9. *Asks for suggestion*, direction, possible ways of action
10. *Disagrees,* shows passive rejection, formality, withholds help
11. *Shows tension*, frustration, withdraws out of field
12. *Shows antagonism,* deflates other's status, defends or asserts self

Bales [6] indicates that the rate of activity in Category 6 may be taken as an index of the amount of interaction which the group devotes to attempted solutions to the problems of perception and communication, while the rate of activity in Category 7 may be taken as an index of the amount of interaction devoted to indicating to each other that problems of perception and communication exist. Their ratio, then, can be used to calculate an index of difficulty of communication, where the higher the value of the index, the greater the difficulty of communication:

$$Index\ of\ Difficulty\ of\ Communication = \frac{7}{7+6}$$

(The numbers in this formula, as for the following formulae, are the category numbers, and indicate the raw number of scores within that category.)

If communication problems are not addressed, group members are unable to cooperate, and insecurity will result. If insecurity persists, expressive-malintegrative behaviour will result [6]. An index of expressive-malintegrative behaviour can be defined as:

$$Index\ of\ Expressive - Malintegrative\ Behaviour = \frac{10+11+12}{(10+11+12)+(1+2+3)}$$

Difficulty of evaluation refers to the fact that group members need to be able to establish adequate, ongoing evaluation and inference as to what they consider valuable, desirable, beneficial and likely about their situation and activities as a group in order for cooperation to occur. An index for this concept can be defined as follows, where a higher value for the index indicates a greater difficulty in evaluation [6]:

$$Index\ of\ Difficulty\ of\ Evaluation = \frac{8}{8+5}$$

The index of difficulty of control over situation indicates the degree to which group members feel they are able to apply their efforts and skills in a way which is effective in producing changes to their situation [6]:

$$Index\ of\ Difficulty\ of\ Control\ over\ Situation = \frac{9}{9+4}$$

Directiveness of control indicates the degree to which individuals within the group feel that they are able to exercise control over the cooperative efforts, and limit the degree and circumstances under which particular group members exert their potential power over each other. Activities in Category 6 is the least directive, that in Category 5 more directive, while activity in Category 4 is the most directive; thus, the derivation of the formula for the index:

Category	Group 1	Group 2	Group 3	Group 4	Mean	Std Dev
1. Shows solidarity	4	7	10	8	7.25	2.500
2. Shows tension release	1	0	0	12	3.25	5.852
3. Agrees	10	12	5	12	9.75	3.304
4. Gives suggestion	7	10	6	11	8.50	2.381
5. Gives opinion	7	7	1	9	6.00	3.464
6. Gives orientation	34	27	28	38	31.75	5.188
7. Asks for orientation	17	12	13	32	18.50	9.256
8. Asks for opinion	10	1	0	3	3.50	4.509
9. Asks for suggestion	2	0	3	1	1.50	1.291
10. Disagrees	3	0	2	5	2.50	2.082
11. Shows tension	1	0	2	5	2.00	2.160
12. Shows antagonism	1	0	3	1	1.25	1.258
Total No. of Statements	97	76	73	137	95.75	29.500

Table 11: **Dialogue Categorisation for the Low-Presence Environment of Experiment 2.** Values are given as number of statements made by group.

$$Index\ of\ Directiveness\ of\ Control = \frac{\frac{4}{4+6} + \frac{5}{5+6}}{2}$$

A group in which members are collaborating freely will be expected to have more verbalisations indicating exchange of information, suggestions, and opinion, as well as agreement. Relatively few verbalisations from the last three categories would be expected in a collaborative group. An "index of collaboration" could then be defined as:

$$Index\ of\ Collaboration = \frac{3+4+5+6+7+8+9}{(3+4+5+6+7+8+9)+(10+11+12)}$$

All the statements in the different groups were assigned into the 12 categories described above. Tables 11 and 12 give the raw number of statements per session per category for each the low-presence VE and the high-presence VE, as well as the mean number of statements per category

Category	Group 5	Group 6	Group 7	Mean	Std Dev
1. Shows solidarity	16	9	6	10.33	5.132
2. Shows tension release	22	63	14	33.00	26.287
3. Agrees	63	171	73	102.33	59.677
4. Gives suggestion	27	104	45	58.67	40.278
5. Gives opinion	35	46	16	32.33	15.177
6. Gives orientation	109	259	94	154.00	91.241
7. Asks for orientation	78	118	49	81.67	34.646
8. Asks for opinion	5	19	9	11.00	7.211
9. Asks for suggestions	6	13	3	7.33	5.132
10. Disagrees	4	18	4	8.67	0.083
11. Shows tension	6	23	10	13.00	8.888
12. Shows antagonism	0	1	0	0.33	0.577
Total Number of Statements	372	844	323	512.67	287.945

Table 12: **Dialogue Categorisation for the High-Presence Environment of Experiment 2.** Values are given as number of statements made by group.

along with the standard deviation. Tables 13 and 14 show the number of statements per session per category as a percentage of the total number of statements made by each group.

The percentage values shown in Tables 13 and 14 can be used to draw Interaction Profile Charts for each VE. Such charts are shown in Figure 28 and 29, and show the mean number of statements per category.

In order to check if the category means were significantly different between the two VEs, 95% confidence intervals were calculated for each category mean and shown in Tables 15 and 16. These confidence intervals were then plotted on a graph (refer to Figure 30) in order to determine whether the two VEs confidence intervals overlapped for the different categories (overlapping confidence intervals implies that the two means are not significantly different).

The graph in Figure 30 shown that only the means of Category 3 were significantly different at the 0.05 confidence level, between the two VEs. Category 3 includes statements falling under ”agrees, shows passive acceptance, understands, concurs, complies”.

The dialogue was further analysed by calculating the indices described earlier in this section. The indices were calculated for each group and using the mean number of statements per category. The results are shown in Table 17 for the low-presence VE, and Table 18 for the high-presence VE. In order to determine if the index means were significantly different between the two VEs, 95% confidence intervals were calculated for each index mean. This is shown in Table 19 for the low-presence VE and Table 20 for the high-presence VE. These confidence intervals were then plotted

Category	Group 1	Group 2	Group 3	Group 4	Mean	Std Dev
1. Shows solidarity	4.1237	9.2105	13.6986	5.8394	8.22	4.2207
2. Shows tension release	1.0309	0	0	8.7591	2.45	4.2357
3. Agrees	10.3093	15.7895	6.8493	8.7591	10.43	3.8450
4. Gives suggestion	7.2165	13.1579	8.2192	8.0292	9.16	2.7033
5. Gives opinion	7.2165	9.2105	1.3699	6.5693	6.09	3.3425
6. Gives orientation	35.0515	35.5263	38.3562	27.7372	34.17	4.5285
7. Asks for orientation	17.5258	15.7895	17.8082	23.3577	18.62	3.2820
8. Asks for opinion	10/3093	1.3158	0	2.1898	3.45	4.6582
9. Asks for suggestion	2.0619	0	4.1096	0.7299	1.73	1.8042
10. Disagrees	3.0928	0	2.7397	3.6496	2.37	1.6242
11. Shows tension	1.0309	0	2.7397	3.6496	1.86	1.6456
12. Shows antagonism	1.0309	0	4.1096	0.7299	1.47	1.8137

Table 13: **Dialogue Categorisation for the Low-Presence Environment of Experiment 2.** Values are given as percentage of total number of statements made by group.

Category	Group 5	Group 6	Group 7	Mean	Std Dev
1. Shows solidarity	4.3127	1.0664	1.8576	2.41	1.6927
2. Shows tension release	5.9299	7.4645	4.3343	5.91	1.5651
3. Agrees	16.9811	20.2607	22.6006	19.95	2.8228
4. Gives suggestion	7.2776	12.3223	13.9319	11.18	3.4718
5. Gives opinion	9.4340	5.4502	4.9536	6.61	2.4560
6. Gives orientation	29.3801	30.6872	29.1022	29.72	0.8464
7. Asks for orientation	21.0243	13.9810	15.1703	16.73	3.7703
8. Asks for opinion	1.2477	2.2512	2.7864	2.13	0.7271
9. Asks for suggestion	1.6173	1.5403	0.9288	1.36	0.3772
10. Disagrees	1.0782	2.1327	1.2384	1.48	0.5683
11. Shows tension	1.6173	2.7251	3.0960	2.48	0.7694
12. shows antagonism	0	0.1158	0	0.04	0.0684

Table 14: **Dialogue Categorisation for the High-Presence Environment of Experiment 2.** Values are given as percentage of total number of statements made by group.

on a graph in order to determine if the two VEs confidence intervals overlapped for each category. Overlapping confidence intervals implies that the two means are not significantly different. The graph is shown in Figure 31, and as one can see from the graph, the differences in means index

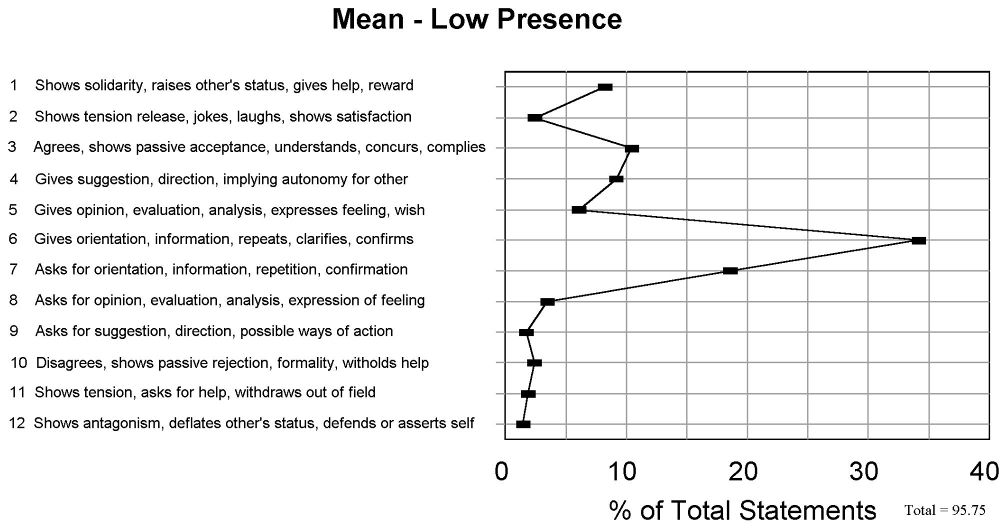

Figure 28: **Mean Interaction Profile for the low-presence groups.** Total value shown is the mean total number of statements made by the groups.

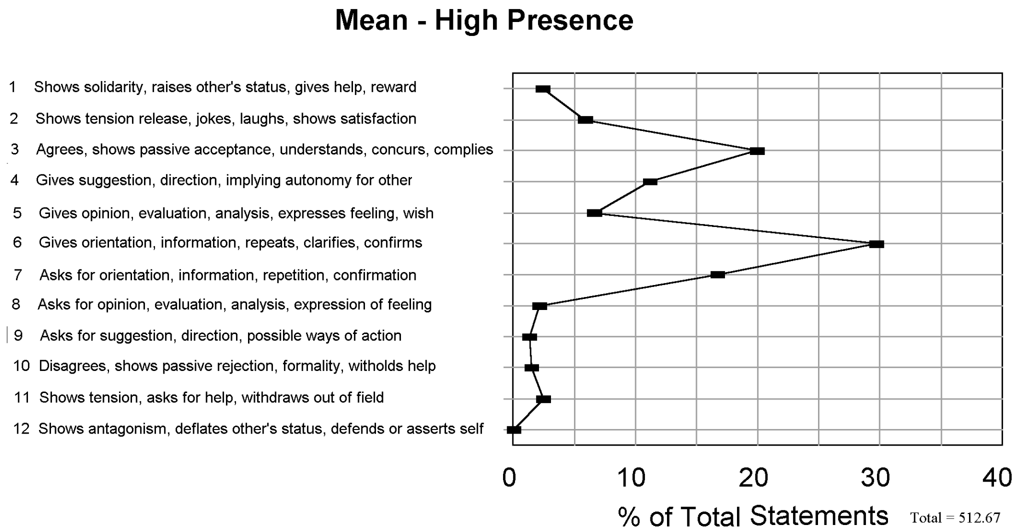

Figure 29: **Mean Interaction Profile for the high-presence groups.** Total value shown is the mean total number of statements made by the groups.

Category	Mean	Left Value	Right Value
1. Shows solidarity	0.0822	0.0272	0.1372
2. Shows tension release	0.0245	-0.0065	0.0554
3. Agrees	0.1043	-0.0431	0.1655
4. Gives suggestion	0.0916	0.0338	0.1493
5. Gives opinion	0.0609	0.0130	0.1088
6. Gives orientation	0.3417	0.2467	0.4367
7. Asks for orientation	0.1862	0.1082	0.2642
8. Asks for opinion	0.0345	-0.0020	0.0732
9. Asks for suggestion	0.0173	-0.0088	0.0433
10. Disagrees	0.0237	-0.0068	0.0542
11. Shows tension	0.0186	-0.0085	0.0541
12. Shows antagonism	0.0147	-0.0094	0.0388

Table 15: **95% Confidence Intervals for Dialogue Categorisation of the Low-Presence Environment.**

Category	Mean	Left Value	Right Value
1. Shows solidarity	0.0241	0.0109	0.0374
2. Shows tension release	0.0591	0.0387	0.0795
3. Agrees	0.1995	0.1649	0.2341
4. Gives suggestion	0.1118	0.0845	0.1391
5. Gives opinion	0.0661	0.0446	0.0876
6. Gives orientation	0.2972	0.2577	0.3368
7. Asks for orientation	0.1673	0.1350	0.2000
8. Asks for opinion	0.0213	0.0088	0.0338
9. Asks for suggestion	0.0136	0.0036	0.0237
10. Disagrees	0.0148	0.0044	0.0253
11. Shows tension	0.0248	0.0113	0.3826
12. Shows antagonism	0.0004	-0.0013	0.0021

Table 16: **95% Confidence Intervals for Dialogue Categorisation of the High-Presence Environment.**

values for the two VEs are not significant at a 0.05 significance level.

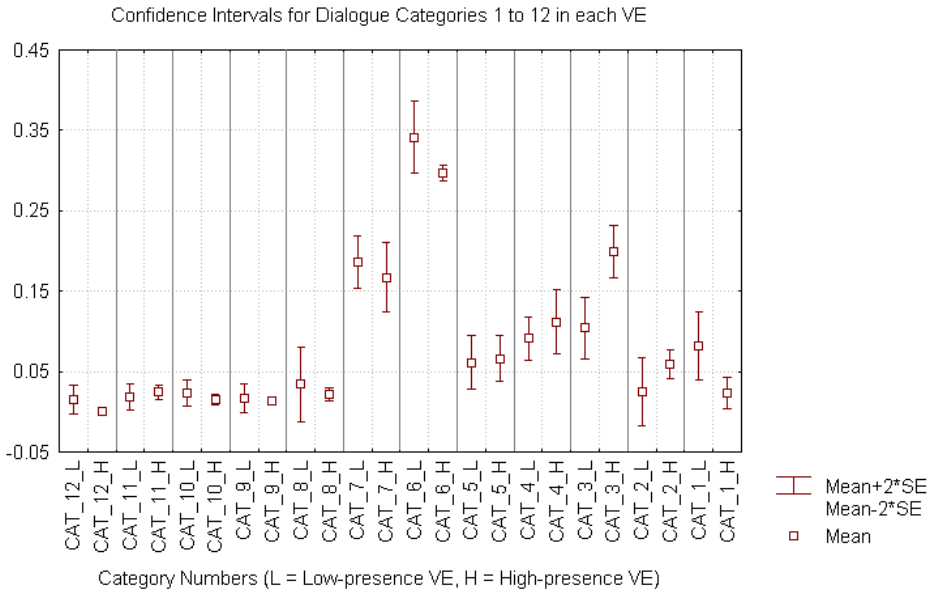

Figure 30: **95% Confidence Intervals of the mean number of statements in each category.** If high-presence and low-presence confidence intervals overlap, the difference in means is not significant.

6.8 Discussion of Results

In this section we present a discussion of the results obtained during this experiment. Firstly, we discuss the results concerning presence, co-presence and the immersive tendencies. After that, we present a discussion of the results obtained during the dialogue analysis.

6.8.1 Presence, Co-presence and Immersive Tendencies

We have shown that participants were randomly assigned between the two VEs, as the mean IT scores for each VE were not significantly different. This also implies that any difference in P, CO-P or TP scores between the two VEs cannot be attributed to a difference in IT (i.e., that any difference in presence found between the two VEs cannot be explained by a difference in immersive tendencies of participants).

The mean co-presence scores were significantly different between the two environments, indicating that participants in the high-presence VE felt more as though they were part of a real group, interacting with real people, than the participants of the low-presence VE did. This means that the manipulations of the VEs, with regard to increasing co-presence, were successful. While more

	Group 1	**Group 2**	**Group 3**	**Group 4**	**Mean**	**Std Dev**
Index of Difficulty of Communication	0.3333	0.3077	0.3171	0.4571	0.35	0.0697
Index of Expressive-Malintegrative Behaviour	0.2500	0	0.3182	0.2558	0.21	0.1408
Index of Difficulty of Evaluation	0.5882	0.1250	0	0.2500	0.24	0.2531
Index of Difficulty of Control over Situation	0.2222	0	0.3333	0.0833	0.16	0.1476
Index of Directiveness of Control	0.1707	0.2381	0.1055	0.2080	0.18	0.0571
Index of Collaboration	0.9451	1.0000	0.8889	0.9060	0.94	0.0494

Table 17: **Dialogue Indices calculated for the Low-Presence Environment.** Values range between 0 and 1.

	Group 5	**Group 6**	**Group 7**	**Mean**	**Std Dev**
Index of Difficulty of Communication	0.4171	0.3130	0.3427	0.36	0.0536
Index of Expressive-Malintegrative Behaviour	0.0901	0.1474	0.1308	0.12	0.0295
Index of Difficulty of Evaluation	0.1250	0.2923	0.3600	0.26	0.1210
Index of Difficulty of Control over Situation	0.1816	0.1111	0.0625	0.12	0.0600
Index of Directiveness of Control	0.2208	0.2187	0.2346	0.22	0.0087
Index of Collaboration	0.9700	0.9446	0.9538	0.96	0.0124

Table 18: **Dialogue Indices calculated for the High-Presence Environment.** Values range between 0 and 1.

study on the subject would be needed, it seems likely that the two factors which most increased the sense of co-presence in the high-presence VE was the realistic nature of the avatars and the ability to converse naturally, through speech, with the other participants.

According to the factors thought to underlie presence presented by Witmer and Singer [79], the two VEs created for this experiment should have engendered differing subjective feelings of

	Mean	Left Value	Right Value
Index of Difficulty of Communication	0.35	0.2391	0.4609
Index of Expressive-Malintegrative Behaviour	0.21	-0.0140	0.4340
Index of Difficulty of Evaluation	0.24	-0.1627	0.6427
Index of Difficulty of Control over Situation	0.16	-0.0748	0.3948
Index of Directiveness of Control	0.18	0.0892	0.2709
Index of Collaboration	0.94	0.8125	1.0577

Table 19: **95% Confidence Intervals for Indices calculated for the Low-Presence Environment.**

	Mean	Left Value	Right Value
Index of Difficulty of Communication	0.36	0.2268	0.4932
Index of Expressive-Malintegrative Behaviour	0.12	0.0467	0.1933
Index of Difficulty of Evaluation	0.26	-0.0406	0.5606
Index of Difficulty of Control over Situation	0.12	-0.0291	0.2691
Index of Directiveness of Control	0.22	0.1984	0.2416
Index of Collaboration	0.96	0.9256	0.9873

Table 20: **95% Confidence Intervals for Indices calculated for the High-Presence Environment..**

presence in the participants. However, the difference between the mean P scores between the high-presence VE and the low-presence VE were not significant, implying that the manipulations of the two VEs to create a greater sense of presence in the high-presence VE was not successful. This might be because there was no difference in the presence felt by the participants, or it might be that the presence questionnaire used was not sensitive enough to pick up any difference that existed. Whether this comments on the size of the difference in presence, or on the sensitivity of the presence questionnaire, cannot be determined from this single experiment.

The TP scores (Total Presence scores) of the two VEs did show a significant difference. This is most likely due to the significant difference in CO-P scores. However, it does still show that overall, the amount of total presence (being a mixture of personal and co-presence) was felt to be higher by participants of the high-presence environment than the low-presence environment.

In order to check if different equipment lead to different levels of presence felt by the participants, we performed a one-way ANOVA on avatar colour and P scores. This ANOVA showed that, within each VE, P scores were not significantly different between participants with different colour avatars. This indicates that the colour avatar that was assigned to the participant did not affect

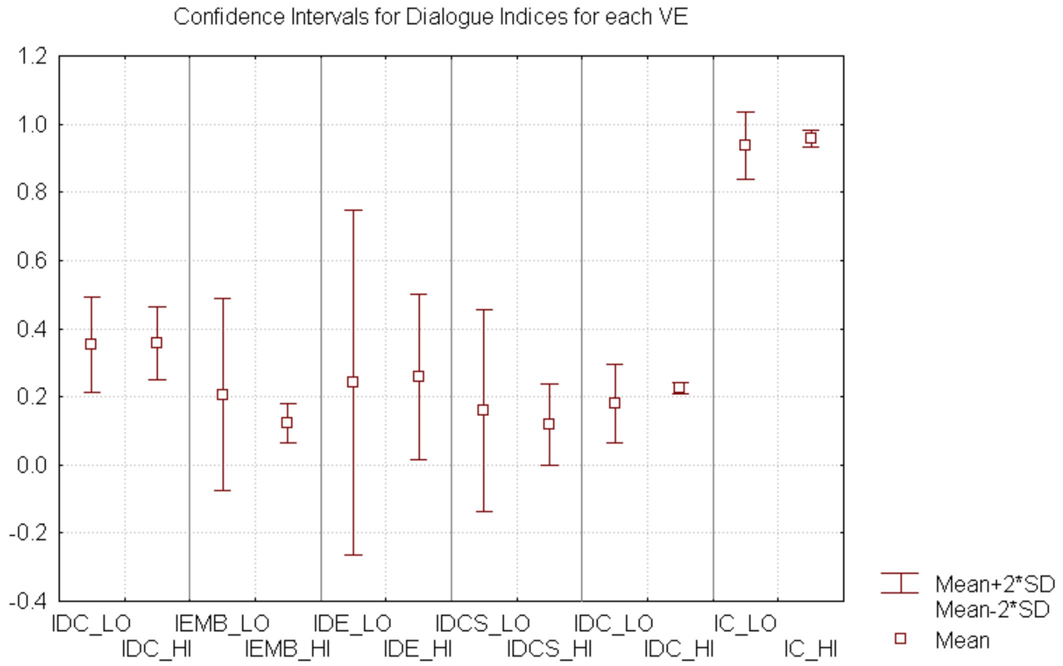

Figure 31: **95% Confidence Intervals of the indices.** If high-presence and low-presence confidence intervals overlap, the difference in means is not significant.

the degree of presence felt by that participant during the experiment. Since different workstation configurations were used for different avatar colours, this result also indicates that the particular workstation configuration used by a participant did not affect the level of presence felt by that participant during the course of the experiment.

We found that the mean IT score in this experiment was not significantly different to the one reported by Witmer and Singer [79, 47]. This indicates that the sample of participants used in this experiment was drawn from the same population as the participants used by Witmer and Singer in their experiments. This implies that the questionnaire scores obtained in this experiment can be compared to the ones obtained by Witmer and Singer in their experiments. Witmer and Singer found a correlation between the P scores and the IT scores. In other words, they found that the immersive tendencies predicted the level of presence as measured by their presence questionnaire. The correlation analysis in this experiment showed that the P scores were significantly correlated to the IT scores only in the high-presence VE, after we removed an outlier data point. The P/IT scores were not correlated in the low-presence VE.

The P/IT correlation found by Witmer and Singer thus seems to hold only under certain conditions. However, it is unclear what these conditions are, as the only independent measure used in this study that showed a difference between the two VEs was the CO-P, which was shown not to interact with either IT scores or P scores. It seems clear that there must be some other factor interacting with the P and IT. This factor seems to be related to some difference in the two VEs that wasn't measured in this study. It is possible that in the production of a high- and low-presence VE, a difference in immersion was inadvertently created, and that this is the condition which has to be above a certain level in order for the P/IT correlation to hold. Further studies should be carried out in an attempt to confirm this idea, as well as to develop a method for determining the immersive quality of a virtual environment. In Experiment 1 and Experiment 3, which are described in Chapters 5 and 7 respectively, we did find a correlation between the P scores (measured using Slater's presence questionnaire) and the IT scores (measured using Witmer and Singer's immersive tendencies questionnaire). We therefore failed to replicate Witmer and Singer's results indicating that the immersive tendencies score act as a predictor of the presence score using their presence questionnaire, but we did find a correlation between P and IT when we used Slater's presence questionnaire instead.

The correlation analyses showed that neither the CO-P nor TP scores were correlated to the IT scores in either of the two VEs. This indicates that an individual's immersive tendencies as measured by Witmer and Singer's Immersive Tendencies Questionnaire [79, 47], cannot predict the level of co-presence felt by a participant within a collaborative virtual environment.

A further correlation analysis showed that the P scores and the CO-P scores were not significantly correlated in either of the two VEs. We therefore failed to replicate the results found by Tromp *et al* [71] in one of their experiments were they found that the presence and co-presence scores had a significant positive correlation. This small group experiment is described in more detail in Slater *et al* [53]. More research is needed in this area in order to confirm or dismiss the relationship between presence and co-presence in a CVE.

6.8.2 Interaction and Collaboration

Dialogue between group members was categorised according to the schedule proposed by Bales [6], and used for similar purposes by Underwood *et al* [72] and Kelly & McGrath [32]. Due to time constraints, it was not possible to train several observers in this method. Given this constraint, it was decided to maintain internal consistency by using only one observer, who attempted to follow the instructions given by Bales [6] as closely as possible. The categorisations obtained are thus consistent within this experiment.

The most noticeable difference in the dialogue analysis of the two VEs is in the number of statements made by the groups in each VE. While this data is shown in Tables 11 and 12 in Section

6.7.2, it shown in a more comparative format in Table 21. It is clear that the high-presence VE groups were far more communicative than the low-presence groups, which may be taken as meaning that, in the sense of communicating freely, the high-presence groups were more collaborative than the low-presence groups. This is most probably due to the fact that participants were communicating using speech in the high-presence VE, and text in the low-presence VE. While it is tempting to note that the number of statements made by groups varied more in the high-presence VE than in the low-presence VE, it must be remembered that the final group in the high-presence VE was reduced to only two members as a result of equipment failure and thus these figures cannot be directly compared.

	Group 1	**Group 2**	**Group 3**	**Group 4**	**Mean**	**Std Dev**
Low-presence VE	97	76	73	137	95.75	29.500
High-presence VE	372	844	323	-	512.67	287.945

Table 21: **Number of statements per group in each VE, along with the mean and standard deviation for each VE.**

While the Interaction Profile Charts appear to show some interesting differences between the two VEs, the only significant difference is in Category 3. The high-presence VE groups made more statements showing agreement, passive acceptance, understanding, concurring and compliance than the low-presence VE groups. This is understandable in terms of the VE setup, as group members are more likely to verbalise agreement statements (eg: "uh-huh") than type them.

The ranking of the categories for each VE showed interesting results (reproduced in Table 22 below for convenience) - categories 3 and 7 swapped positions, categories 1 and 2 were ranked in radically different places - and the differences were found to be significant.

This means that while groups in both VEs made more orientation and information giving statements than any other kind of statement, the high-presence VE made more agreement statements than asking for orientation and information. This is reversed in the low-presence VE. The showing of solidarity (including general politeness) was ranked much higher in the low-presence VE than in the high-presence VE, which is slightly contrary to expectations when bearing in mind the ease of speaking naturally as opposed to typing. In addition, the low-presence world had a much higher proportion of statements indicating tension release than indicating tension, while in the high-presence VE these two categories are ranked much closer together.

More of these types of comparisons can be found simply by looking at the comparative rankings in Table 22. However, it is important to bear in mind the fact that the rank correlation co-efficient merely says that the two rankings are different overall. It cannot comment on, for example, whether the fact that category 10 is in position 9 in the low-presence VE ranking and position 10 in the high-presence VE ranking is significant or not. In addition, it is *only* the relative positioning of the categories that can be compared - while it is tempting to say that category 1 is ranked higher in the low-presence rankings than in the high-presence rankings and thus the low-presence groups showed more solidarity than the high-presence groups, this is not a valid conclusion (this is emphasised by the fact that the only difference in the number of statements per category found between the two VEs was in category 3).

Position	Category Numbers (Low-Presence)	Category Numbers (High-Presence)
1	6	6
2	7	3
3	3	7
4	4	4
5	1	2
6	5	5
7	8	11
8	2	8
9	10	1
10	11	10
11	9	9
12	12	12

Table 22: **Ranking of Dialogue Categories by mean no. of statements.**

The comparison of dialogue indices between the two VEs provides another means of comparing the dialogue of groups within the two VEs. The fact that none of these indices are significantly different between the two VEs indicates once more that group dialogue was fairly constant, regardless of which VE the group was assigned to.

6.9 Summary

In this chapter we have presented the design and results of an experiment aimed at testing the following two hypotheses:

- Increasing the subjective feeling of presence and co-presence within a group in a Collaborative Virtual Environment would change the style of collaboration and interaction between group members.

- Creating the two virtual environments as described would results in a greater subjective sensation of presence and co-presence felt by the participants in the high-presence VE, and a lower sensation of presence and co-presence felt in the low-presence VE.

The first hypothesis was tested through the creation of two virtual environments which were designed to engender different levels of presence. The second hypothesis was tested using subjective questionnaires which measure the levels of presence and co-presence felt by the participants in the CVEs.

After the experiment, participants were asked to fill out two questionnaire: a Presence Questionnaire (PQ) designed to measure the degree of personal presence and co-presence, and the Immersive Tendencies Questionnaire (ITQ). The PQ used was the presence questionnaire developed by Witmer and Singer [79, 47]. Questions measuring the sense of co-presence were added to this questionnaire. These co-presence questions are described in Section 3.5. The ITQ was also developed by Witmer and Singer [79, 47], and was used to measure the innate susceptibility of participants to immersion and presence.

The results obtained regarding presence, co-presence, and immersive tendencies were calculated for each participant from their questionnaire scores.

- The difference between the mean high-presence VE P score and the mean low-presence VE P score was not significant at $p = 0.0599$.
- The difference between the mean high-presence VE CO-P score and the mean low-presence VE CO-P score was significant at $p = 0.0288$.
- The difference between the mean high-presence VE TP score and the mean low-presence VE TP score was significant at $p = 0.0264$.
- The difference between the mean high-presence VE IT score and the mean low-presence VE IT score was not significant at $p = 0.311798$.

The following results were found with relation to the P, CO-P, and IT scores:

- The P scores showed that participants felt approximately the same level of presence regardless of with VE they were assigned to.
- The P/IT correlation was only found in the high-presence VE, and not in the low-presence VE. There must be some other factor interacting with the P and IT. This factor seems to be related to some difference in the two VEs that wasn't measured in this study. Further studies should be carried out in order to develop a method for determining the immersive quality of a virtual environment.

- We found no correlation between the P and CO-P scores in either VE. This indicates that we failed to replicate the results found by Tromp *et al* and Slater *et al* [53], which indicated that they found a positive correlation between presence and co-presence.
- IT scores and CO-P scores were not correlated in either VE.

In order to analyse the interaction and collaboration styles, the dialogue between the participants was recorded and then all the statements were categorised into the categories proposed by Bales [6] and described by Underwood in [72]. The findings related to interaction and collaboration differences between the two VEs were, on the whole, negative. We did not find much of a difference between the interaction styles in the two VEs. This suggests it might be very difficult to create a CVE in which people does not react and interact in much the same way as they would in real live, regardless of the level of co-presence experienced. The only difference found between the two VEs with respect to interaction was that participants in the high-presence VE made more comments indicating agreement, understanding, and compliance than participants in the low-presence VE.

Chapter 7

Experiment 3: Avatar Appearance and Functionality

The way one represents other participants in a collaborative virtual environment is a major issue in enhancing the sense of co-presence. Some participants might find it easy to maintain the sense of co-presence of others with just crude representations of avatars while others might require highly realistic human-like avatars with gestures and facial expressions.

In this chapter we present an experiment which is designed to investigate the effects that avatar appearance and functionality (in terms of simple gestures and facial expressions) have on co-presence in the collaborative virtual environment.

In this experiment, we try to address the following issues:

1. The effects that unrealistic avatars have on co-presence as opposed to human-like avatars. The important issue to determine here is how does the appearance of different avatars affect the sense of co-presence in the CVE.

2. The effects that avatar functionality has on co-presence in the virtual environment. By functionality we mean avatars having simple gestures (waving, raising arms, joy and sad gestures, head movements such as yes, no and perhaps, walking) and facial expressions (sad, happy, neutral, surprised, disgusted, angry and furious).

In order to address the issues mentioned above, we divided the experiment into two parts. The first part (Part A) investigates the effects of avatar appearance on co-presence, and the second part (Part B) investigates the effects of avatar functionality on co-presence in the CVE.

We begin, in Section 7.1 by presenting the different hypotheses we are investigating in this experiment. Section 7.2 describes the experiment task and procedure, and Section 7.3 shows the different avatars used by the different participants in the experiment. Section 7.4 presents the different equipment used by the participants in the experiment. Section 7.5 indicates how presence and co-presence were measured in this experiment. Section 7.6 presents the results obtained, as well as a discussion of these results, and finally Section 7.7 provides a summary of this chapter.

7.1 Presence and Avatars: Hypotheses

This experiment involves the testing of two hypotheses.

The *first hypothesis* is that the way one represents other participants in the virtual environment is very important to enhancing the sense of co-presence. The important issue here is to determine how the appearance of the avatar affects co-presence. In order to test this hypothesis, we provided the participants with avatars having differing appearances. The avatars include realistic human-like avatars, cartoon-like avatars, and simple unrealistic avatars (refer to Section 4.4 for a description of the VE and avatars used).

The *second hypothesis* states that simply having static avatars is not sufficient to create a high sense of co-presence in the collaborative virtual environment. We believe that providing simple gestures and facial expressions to the avatars will increase the sense of co-presence in the CVE. Here we will address questions such as: Are fully functional avatars, with gestures and facial expressions necessary or are crude representations of avatars sufficient to maintain the sense of presence of others? We also want to test the hypothesis that having realistic human-like avatars without any body movement could create a worst sense of co-presence than having unrealistic avatars without any body movement. This could be because there is a conflict between the greater visual realism of the human-like avatar and the lack of bodily movement. On the other hand, having an unrealistic avatar could make it easier to understand that it is not functional.

In order to investigate the hypotheses mentioned above we divided this experiment into two parts, which use the same virtual environment and have the same experimental scenario. Only the avatars provided to the participants differ between the two parts. In the first part (Part A), we investigate the effects of avatar appearance on co-presence. In the part (Part B), we investigate the third hypotheses which involves the effects of having gestures and facial expressions on the avatars.

7.2 Experiment Scenario

Part A used 18 participants, divided into 6 groups of 3 users each. Part B involved 30 participants divided into 10 groups of 3 users each. The participants were recruited from the second year psychology course at the University of Cape Town. Participants were recruited by means of announcements in lectures, as well as posters placed on the noticeboards in the psychology department.

Four participants were asked to sign up for a given session. Three of these volunteers were chosen to participate in the experiment, while the fourth was chosen as a surplus volunteer in case one of the other participants was unable to arrive to the laboratory.

Participants in a group met for the first time in the virtual environment and could only communicate with one another through the virtual environment. This was accomplished by situating the workstations in different rooms within the same laboratory. Each participant used headphones which blocked out the noises from the real world.

As each participant arrived to the laboratory, they were taken to their respective rooms by the experimenter. Before starting the actual experiment, each participant was introduced to the system. This involved learning how to control the avatar's gestures and facial expression if provided, move through the environment, pick up objects, etc. The participants could not see their own avatar. Once every participant was familiar with the interface, they read the experiment instructions stating the task that they will have to perform in the virtual environment. In order to make sure that the participants had understood the task completely, the experimenter explained the task verbally, answering any questions that the participants had about the task.

The task consists of reading a story (4 short paragraphs) by accessing the book on the table in the VE. Once each participant has read the story, they have to agree on a ranking for the five characters in the story. The ranking is as follows: the best character is assigned a "1" and the worst a "5". There was a white-board on the VE which had a simple grid with the names of the five characters of the story. At the bottom of the board there were five numbers which could be moved around the board, so that the participants could assign the ranking to each character in the story. The participants had to argue with one another and arrive to a group agreement. This task required communication to argue or agree with the other participant's rankings.

The avatars used by the participants were labeled Red, Green or Blue, and participants called each other by these names during the experiment. Since the participants could not see their own avatars, there was a colour strip on the monitor used to indicate the colour associated with the participant.

The task had a time limit of 20 minutes, and after that each participant was required to fill in two questionnaires: Witmer and Singer's Immersive Tendencies Questionnaire (ITQ), and the Presence/Co-presence Questionnaire. The Immersive Tendencies Questionnaire is described in more detail in Section 3.3. The presence questions are described in Section 3.4, and the co-presence questions in Section 3.5.

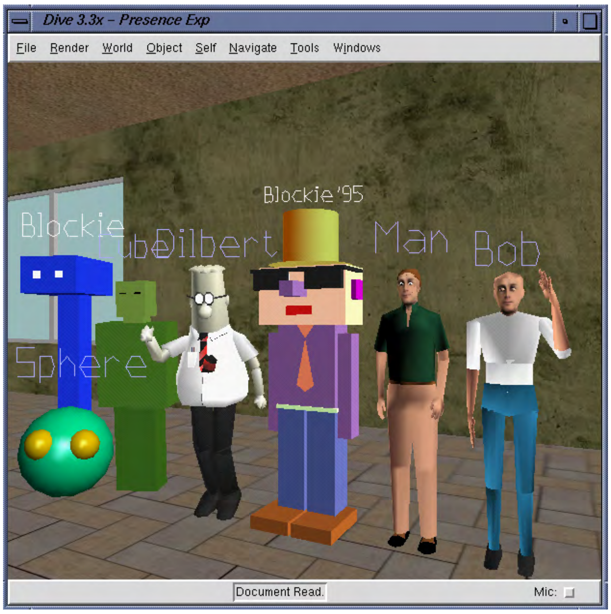

Figure 32: **The different avatars used in Experiment3.** From left to right: *Blockie, sphere, cube, dilbert, cartoon, man*, and *bob*.

7.3 Avatars

In this section we describe the different avatars used in both part of this experiment. The participants cannot see their own avatar, so none of the subjects had an idea of how they were portrayed.

7.3.1 Part A: Effects of Avatar Appearance on Co-Presence

In the first part of the experiment, in order to investigate the effects of unrealistic avatars as opposed to human-like avatars, we provided a set of avatars divided into three categories: *realistic human-like avatars*, *cartoon-like avatars*, and simple *unrealistic avatars* (refer to Table 23 and Figure 32). Each group consisted of three participants, and each participant in the group had an avatar from one of the categories (refer to Table 24). None of the avatars used in this experiment had gestures or facial expressions.

7.3.2 Part B: Effects of Avatar Functionality on Co-Presence

In the second part of this experiment, in order to investigate the effects of avatar functionality, we provided the set of avatars described in Table 25 (refer to Figure 32). Each group consisted of 3 participants, using the avatars described in Table 26.

Avatar name	Avatar description
bob, man	Realistic human-like avatar
cartoon, dilbert	Cartoon-like avatar
blockie, sphere, cube	Unrealistic avatar

Table 23: **Avatars available for Part A of Experiment 3.** This part of the experiment investigates the effects of avatar appearance on co-presence.

group	Participant 1	Participant 2	Participant 3
Group 1	blockie	dilbert	man
Group 2	sphere	cartoon	bob
Group 3	cube	cartoon	bob
Group 4	blockie	dilbert	bob
Group 5	blockie	dilbert	man
Group 6	cube	cartoon	man

Table 24: **Avatars used in each group for Part A of Experiment 3.** Participant 1 used unrealistic avatars, participant 2 used cartoon-like avatars, and participant 3 used realistic human-like avatars.

Groups 1 to 6 in Table 26 are used to investigate static avatars vs. avatars with gestures and facial expressions. Groups 7 to 10 in Table 26 are used to investigate the claims that having realistic human-like avatars without any body movement could create a worst sense of co-presence than having unrealistic avatars without any body movements. By "functionality" we mean that the avatars

Avatar name	Avatar description
blockie, cube	Unrealistic avatars with no functionality
dilbertNoGesture	Cartoon avatar with no functionality
dilbert	Cartoon avatar with functionality
bobNoGesture, man	Realistic avatar with no functionality
bob	Realistic avatar with functionality

Table 25: **Avatars available for Part B of Experiment 3.** This part of the experiment investigates the effects of avatar functionality on co-presence. By functionality we mean that the avatars have a range of gestures (waving, raising arms, joy and sad gestures, head movements such as yes, no and perhaps, walking) and facial expressions (sad, happy, neutral, surprised, disgusted, angry and furious)

Groups	Participant 1	Participant 2	Participant 3
Group 1	man	bobNoGesture	bob
Group 2	dilbertNoGesture	dilbertNoGesture	dilbert
Group 3	man	bobNoGesture	bob
Group 4	dilbertNoGesture	dilbertNoGesture	dilbert
Group 5	man	bobNoGesture	bob
Group 6	dilbertNoGesture	dilbertNoGesture	dilbert
Group 7	blockie	cube	bobNoGesture
Group 8	blockie	cube	bob
Group 9	blockie	cube	bobNoGesture
Group 10	blockie	cube	bob

Table 26: **Avatars used in each group for Part B of Experiment 3.** Groups 1 to 6 are used to investigate static avatars vs. avatars with gestures and facial expressions. Groups 7 to 10 in are used to investigate the claims that having realistic human-like avatars without any body movement could create a worst sense of co-presence than having unrealistic avatars without any body movements.

have a range of gestures (waving, raising arms, joy and sad gestures, head movements such as yes, no and perhaps, walking) and facial expressions (sad, happy, neutral, surprised, disgusted, angry and furious). In order to control the gestures and facial expression, there is a graphical user interface (GUI) which allows the user to select the gesture/expressions (see Section 4.4, and Figure 17).

7.4 Equipment

The experiment used 'desktop' virtual environment, meaning that no immersive equipment (such as head-mounted displays) were used. Movements through the virtual environment was accomplished using the arrow keys. Objects in the virtual environment could be picked up and dropped by clicking on them with the mouse. Some of the avatars had simple gestures and facial expressions which were controlled with the mouse, using a graphical user interface (GUI).

During the experiment the following workstation configurations were used:

- Red participant: SGI Onyx RealityEngine2 with four 200-MHz R4400 processors, 128 Mbytes of RAM, and 21 inch screen.

- Blue participant: SGI O2 with a 175-MHz R10000 processor, 128 Mbytes of RAM, and 21 inch screen.

- Green participant: SGI O2 with a 195-MHz R10000 processor, 256 Mbytes of RAM, and 17 inch screen.

In addition, participants used headphones and microphones for audio communications. The software used for audio communication was RAT (Robust Audio Tool) which is a multicast audio tool developed at University College London [3].

7.5 Measuring Presence and Co-presence

In this section we indicate which questionnaires were used to gather the data in this experiment. In this experiment we measured the degree of personal presence felt by the participants, the degree of co-presence felt by the participants, and also the immersive tendencies of the different individuals taking part in the experiment.

In order to measure the degree of presence and co-presence felt by the users during the experiment, we used a subjective questionnaire. We used one questionnaire (which we call presence/co-presence questionnaire) to measure both personal presence and co-presence.

The personal presence section of the questionnaire is based on the presence questionnaires developed by Slater *et al* [58, 51, 55], which is described in more detail in Section 3.4, and can be found in Appendix C.

The co-presence questions we have developed are described in detail in Section 3.5, and can be found in Appendix D.

We also used the Immersive Tendencies Questionnaire (ITQ) developed by Witmer and Singer [79, 47] to measure the differences in the tendencies of the individuals to become immersed. This questionnaire mainly assesses involvement in common activities. The ITQ can be found in Appendix B and is presented in Section 3.3.

7.6 Analysis of Results

In this section, we present the results obtained in the experiments. The central idea was to investigate the effects on co-presence of having avatars of different appearances, and providing simple gestures and simple facial expressions to the avatars. The most interesting results obtained were the fact that the sense of co-presence was affected by the appearance of the avatars. Co-presence was increased by having realistic human-like avatars. Also, co-presence was increased by providing gestures and facial expressions to the avatars. Another interesting result was that the immersive tendencies scores and the presence score were associated which indicates that the immersive tendencies of participants could act as a predictor for the presence scores. These results can be found in Section 7.6.2

We firstly describe the different variables measured and the hypotheses we are investigating. We then present a summary and a discussion of the obtained results.

7.6.1 Variables and Hypotheses

Part A: Effects of Avatar Appearance on Co-Presence

There are two hypotheses which we wish to test by means of Part A of Experiment 3. One is that a sense of presence (personal presence and co-presence) in the CVE is created by embodying the participants in the virtual environment by means of virtual representations. The second hypothesis is that realistic human-like avatars should create a higher sense of co-presence than cartoon-like avatars, which in turn should create a higher sense of co-presence that simple unrealistic avatars.

In order to test the above hypotheses, we measure the following variables:

The presence score, P: This variable is measured by making use of Slater's presence questionnaire described in Section 3.4. It measures the degree of personal presence experienced by the participant.

The immersive tendencies score, IT: This variable is measured using Witmer and Singer's immersive tendencies questionnaire described in Section 3.3. It measures the tendencies of individuals to become involved and immersed in the experience.

Co-presence of realistic human-like avatars, CO-P-RHA: This variable measures the participant's sense of presence of other participants using realistic human-like avatars. This variable is measured using the co-presence questionnaire described in Section 3.5.

Co-presence of cartoon-like avatars, CO-P-CA: This variable measures the participant's sense of presence of others using cartoon-like avatars. It is measured using the co-presence questionnaire described in Section 3.5.

Co-presence of simple unrealistic avatars, CO-P-UA: This variable measures the participant's sense of presence of other participants using unrealistic avatars. This variable is measured using the co-presence questionnaire described in Section 3.5.

The co-presence score, CO-P: This variable measures the overall co-presence experienced by the user. This variable is the sum of the individual co-presence variables (CO-P-RHA, CO-P-CA, and CO-P-UA).

The hypotheses for the above variables are: We expect CO-P-RHA to be higher than CO-P-CA, which in turn should be higher than CO-P-UA. Witmer and Singer [79] indicate that the IT score, as measured by their immersive tendencies questionnaire, predicts the presence score, as measured by their presence questionnaire. In this experiment, as in Experiment 1 described in Chapter 5, we use a different presence questionnaire (developed by Slater *et al*), so it is important the check if the relationship still holds. It is important to see if there is a correlation between the P score and the CO-P score. Tromp *et al* [71] indicate that they found a positive correlation between personal presence and co-presence in one of their experiments. This small group experiment is described also in Slater *et al* [53].

Part B: Effects of Avatar Functionality on Co-Presence

There are three hypotheses which we wish to test by means of Part B of this experiment. The first hypothesis is that a sense of presence (personal and co-presence) in the collaborative virtual environment is created by representing the participants in the virtual environment by means of avatars. The second hypothesis is that avatars with gestures and facial expressions will enhance the sense of co-presence in a CVE. The third hypothesis indicates that having realistic human-like avatars without any body movement could create a worst sense of co-presence than having simple unrealistic avatars without any body movements. This is because there is a conflict between the greater visual realism of the human-like avatar and the lack of body movements. On the other hand, having a simple unrealistic avatar makes it easier to understand that it is not functional.

In order to test the first and second hypotheses, we measure the following variables:

The presence score, P: This variable measures the degree of personal presence experienced by the participants. It is measured by making use of Slater's presence questionnaire described in Section 3.4.

The immersive tendencies score, IT: This variable is measured using Witmer and Singer's immersive tendencies questionnaire described in Section 3.3. It measures the tendencies of individuals to become involved and immersed in the experience.

Co-presence of functional avatars, CO-P-F: This variable measures the participant's sense of co-presence of the other avatars with gestures and facial expressions.

Co-presence of static avatars, CO-P-S: This variable measures the participant's sense of co-presence of the other static avatars (i.e., avatars without gestures and facial expressions).

Co-presence score CO-P: The CO-P variable measures the overall co-presence experienced by the user. This variable is a sum of the individual co-presence variables (CO-P-F and CO-P-S above).

The hypotheses for the above variables are as follows: We expect CO-P-F to be significantly higher than CO-P-S. Also, we might find a correlation between P and CO-P.

In order to test the third hypothesis, which says that having realistic human-like avatars without any body movement could create a worst sense of co-presence than having simple unrealistic avatars without any body movements, we measure the following variables:

Co-presence of unrealistic static avatars CO-P-U: This variable measures the participant's sense of co-presence of the other participants using unrealistic avatars without any gestures or facial expressions.

Co-presence of realistic, static human-like avatars CO-P-RS: This variable measures the participant's sense of co-presence of the other participants using realistic human-like avatars without any gestures or facial expressions.

Co-presence of realistic human-like avatars with gestures CO-P-RF: This variable measures the participant's sense of co-presence of the other participants using realistic human-like avatars with gestures or facial expressions.

7.6.2 Summary of Results

Part A: Effects of Avatar Appearance on Co-Presence

For each participant, we measured the presence score (P), the immersive tendencies score (IT), the co-presence score of realistic human-like avatars (CO-P-RHA), of cartoon-like avatars (CO-P-CA), of unrealistic avatars (CO-P-UA), and the total co-presence felt by the participants (CO-P). The scores obtained are shown in Table 27

We compared the co-presence scores generated by the different avatars by performing a one-way ANOVA on the CO-P-RHA, CO-P-CA, and CO-P-UA scores. We found that there was a significant difference, having $F(2, 33) = 20.438, p < 0.001$. This difference indicates that the way one represents the avatars affects the feeling of co-presence felt by the participants.

A correlation analysis was performed on the P, CO-P, and IT variables to check if there were any significant relationship between them. We performed two-sided tests and obtained the following results (refer to Table 28 for the correlation matrix):

- *Correlation between P and IT scores*: $r = 0.50325$, $t = 2.3295$, and $p = 0.033255 < 0.05$. At a significance level of 0.05, with $N = 18$ and 16 degrees of freedom we get $t = 2.12$, and a critical value of r (r_{crit}) equal to 0.46829. This indicates that P and IT were significantly correlated.

- *Correlation between CO-P and IT scores*: $r = -0.25707$, $t = -1.0640$, and $p = 0.303101 > 0.05$. At a significance level of 0.05, with $N = 18$ and 16 degrees of freedom we get $t = 2.12$, and a critical value of r (r_{crit}) equal to 0.46829. This indicates that CO-P and IT were not significantly correlated.

- *Correlation between P and CO-P scores*: $r = 0.20746$, $t = 0.8483$, and $p = 0.4087 > 0.05$. At a significance level of 0.05, with $N = 18$ and 16 degrees of freedom we get $t = 2.12$, and a critical value of r (r_{crit}) equal to 0.46829. This indicates that P and CO-P were not significantly correlated.

Participant	P	IT	CO-P-RHA	CO-P-CA	CO-P-UA	CO-P
1	61	66	17	14	–	52
2	46	86	19	–	10	54
3	52	78	–	17	13	54
4	44	71	18	12	–	57
5	66	96	16	–	9	48
6	49	75	–	16	11	54
7	47	85	15	10	–	44
8	38	54	20	–	12	56
9	57	111	–	14	13	47
10	46	98	15	9	–	49
11	31	73	16	–	6	39
12	51	87	–	12	13	47
13	53	92	14	12	–	52
14	64	87	17	–	8	49
15	48	74	–	16	14	48
16	47	79	14	12	–	49
17	46	85	18	–	8	51
18	31	68	–	14	10	45
Mean	48.722	81.3889	15.5	11.5	10.58333	49.333
Std Dev.	9.6394	13.3863	1.643168	1.760682	2.503028	4.79267

Table 27: **Results obtained during the first part of Experiment 3.** This experiment investigates the effects of avatar appearance on co-presence. For each participant we measured the presence score (P), the immersive tendencies score (IT), the co-presence score of realistic human-like avatars (CO-P-RHA), of cartoon-like avatars (CO-P-CA), of unrealistic avatars (CO-P-UA), and the total co-presence felt by the participants (CO-P).

	Presence (P)	**Co-presence (CO-P)**	**Immersive tendencies (IT)**
P	1		
CO-P	0.2075	1	
IT	**0.5032**	-0.257	1

Table 28: **Correlation matrix for Part A of Experiment 3.** Results with $p < 0.05$ are marked in bold. We can see that P and IT are significantly correlated.

We plotted a scatterplot of the CO-P scores vs the IT scores to check if we had any outlier in the data points (refer to Figure 33). The plot shows that there are no clear outliers in the data. We

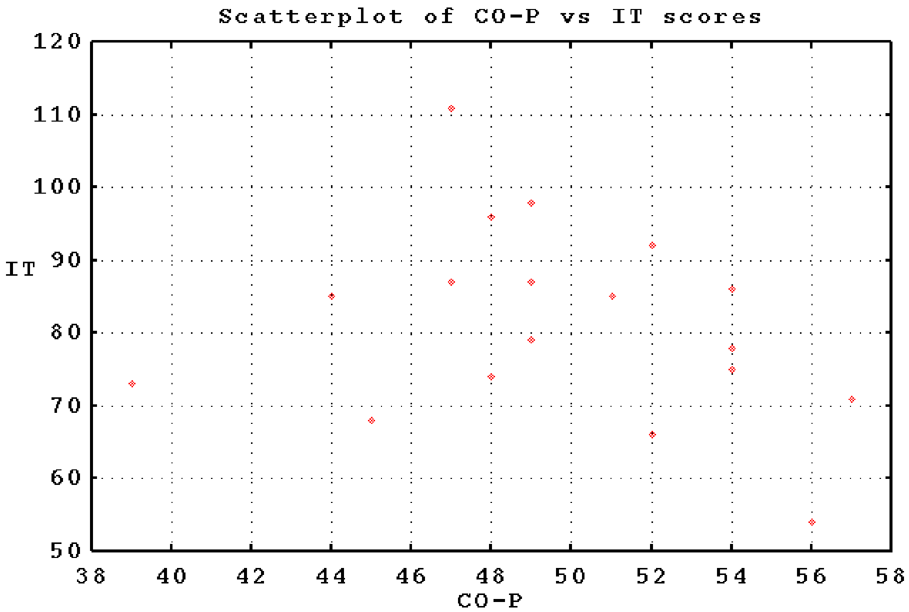

Figure 33: **Scatterplot of the CO-P scores vs. the IT scores for the first part of Experiment 3.**

also plotter a scatterplot of the P scores vs the CO-P scores to check for outliers (refer to Figure 34). Once again, the plot shows that there are no clear outliers in the data points.

Part B: Effects of Avatar Functionality on Co-Presence

For the first 18 participants (groups 1 to 6), we measured the presence score (P), the immersive tendencies score (IT), the co-presence score of functional avatars (CO-P-F), the co-presence score of static avatars (CO-P-S), and the total co-presence score (CO-P). The scores obtained for these variables are shown in Table 29.

We compared the co-presence scores generated by static avatars (CO-P-S) and by avatars with gestures and facial expressions (CO-P-F), by performing a one-way ANOVA on the two variables. We found that there was a significant difference, having $F[1,22] = 6.00678, p < 0.05$. This indicates that the avatars with gestures and facial expressions did create a significantly greater sense of co-presence.

We performed a correlation analysis on the P, IT, and CO-P scores to check if there was any significant relationship between these variables. We performed two-sided tests and obtained the following results (refer to Table 30 for the correlation matrix):

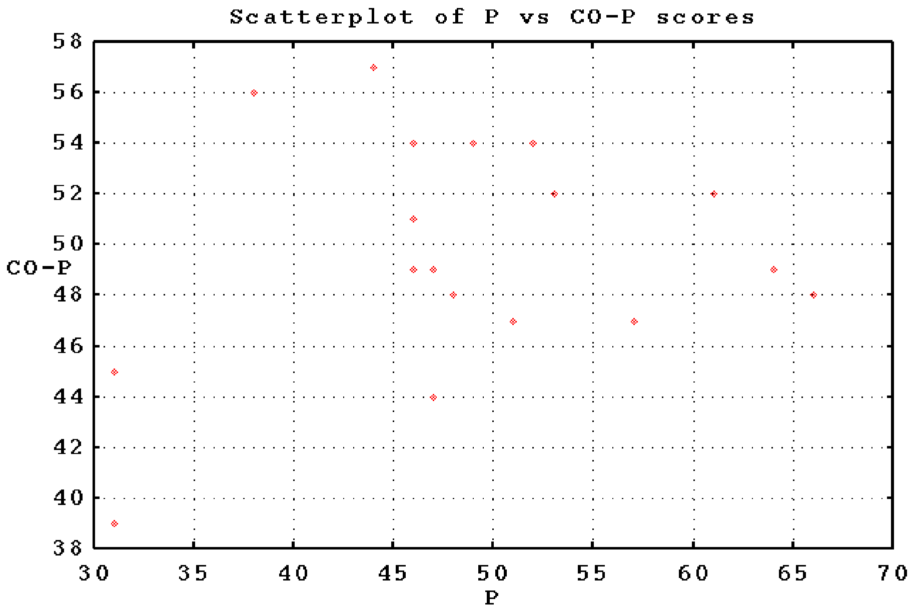

Figure 34: **Scatterplot of the P scores vs the CO-P scores for the first part of Experiment 3.**

- *Correlation between P and IT scores*: $r = 0.587179, t = 2.901595$, and $p = 0.010406 < 0.05$. At a significance level of 0.05, with $N = 18$ and 16 degrees of freedom we get $t = 2.12$, and a critical value of r (r_{crit}) equal to 0.46829. This indicates that P and IT were significantly correlated.

- *Correlation between CO-P and IT scores*: $r = -0.03871, t = -0.1225$, and $p = 0.904928 > 0.05$. At a significance level of 0.05, with $N = 12$ and 10 degrees of freedom we get $t = 2.228$, and a critical value of r (r_{crit}) equal to 0.575959. This indicates that CO-P and IT were not significantly correlated.

- *Correlation between P and CO-P scores*: $r = 0.049294, t = 0.15607$, and $p = 0.8790 > 0.05$. At a significance level of 0.05, with $N = 12$ and 10 degrees of freedom we get $t = 2.228$, and a critical value of r (r_{crit}) equal to 0.575959. This indicates that P and CO-P were not significantly correlated.

We plotted a scatterplot of the CO-P scores vs the IT scores to check if we had any outlier data points. The plot in Figure 35 shows that there were no clear outliers in the data. We also plotted a scatterplot of the P vs CO-P scores to check for outliers. We can see in Figure 36 that there were no

Participant	**P**	**IT**	**CO-P-F**	**CO-P-S**	**CO-P**
1	65	84	17	14	51
2	45	77	15	11	44
3	48	70	–	–	–
4	43	71	16	14	47
5	38	93	19	13	57
6	46	90	–	–	–
7	42	84	10	9	41
8	51	69	12	8	39
9	49	67	–	–	–
10	31	58	16	12	52
11	52	71	20	17	58
12	47	93	–	–	–
13	36	85	14	12	42
14	26	51	18	16	52
15	32	62	–	–	–
16	68	98	20	16	59
17	32	60	19	17	62
18	41	72	–	–	–
Mean	44	75.278	16.33	13.25	50.333
Std Dev.	11.0613	13.485	3.17185	2.9886	7.7264

Table 29: **Results obtained during the second part of Experiment 3.** This experiment investigates the effects of avatar functionality on co-presence. For each participant we measured the presence score (P), the immersive tendencies score (IT), the co-presence score of avatars with gestures and facial expressions (CO-P-F), of static avatars (CO-P-S), and the total co-presence felt by the participants (CO-P).

	Presence (P)	**Co-presence (CO-P)**	**Immersive tendencies (IT)**
P	1		
CO-P	0.0493	1	
IT	**0.5872**	-0.0387	1

Table 30: **Correlation matrix for Part B of Experiment 3.** Results with $p < 0.05$ are marked in bold. We can see that P and IT are significantly correlated.

outliers in the data points.

In order to test the hypothesis indicating that having realistic human-like avatars without any

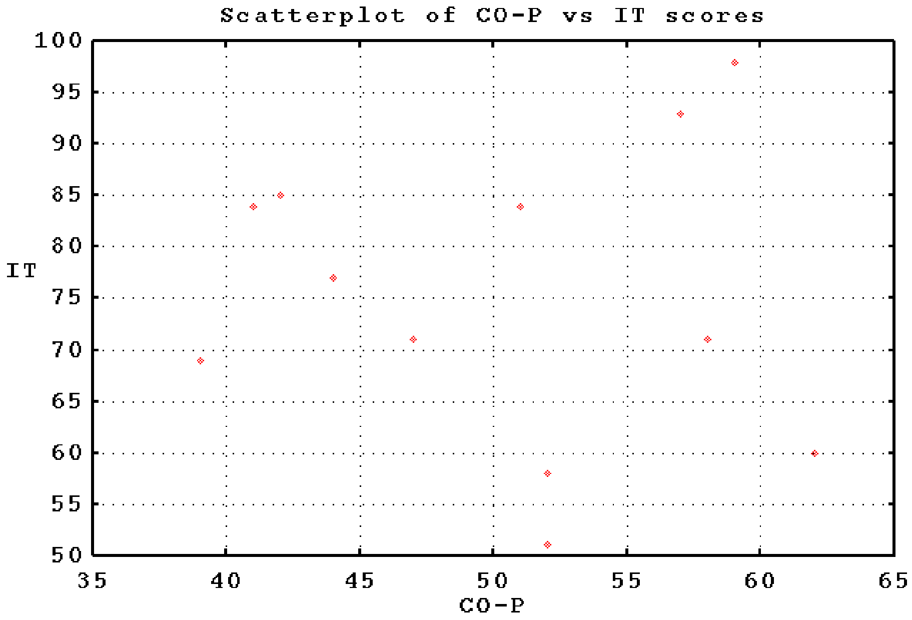

Figure 35: **Scatterplot of the CO-P scores vs the IT scores for the second part of Experiment 3.**

body movement could create a worse sense of co-presence than having unrealistic avatars without any body movement, we used groups 7 to 10. We measured the co-presence created by unrealistic avatars (CO-P-U), the co-presence created by realistic human-like avatars without gestures (CO-P-RS), and the co-presence created by realistic human-like avatars with gestures (CO-P-RF). The obtained scores are shown in Tables 31 and 32.

Participant	CO-P-U	CO-P-RS
19	12	14
20	13	15
25	10	16
26	14	15

Table 31: **Results obtained for the second part of Experiment 3.** Scores obtained for the co-presence created by unrealistic avatars (CO-P-U) and the co-presence created by realistic human-like avatars without gestures or facial expressions (CO-P-RS). These scores are used to test the hypotheses that having realistic human-like avatars without any body movement could create a worst sense of co-presence than having unrealistic avatars without any body movement.

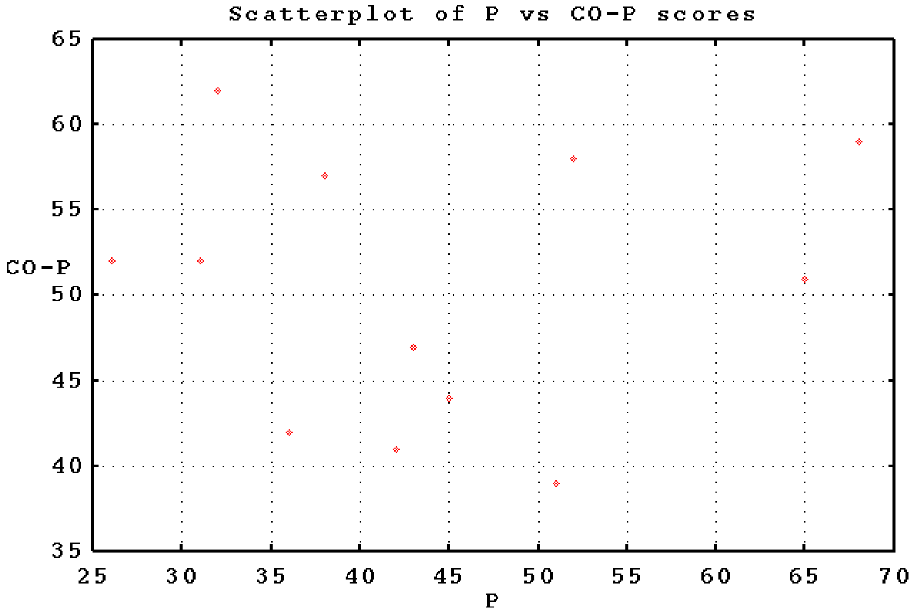

Figure 36: **Scatterplot of the P scores vs the CO-P scores for the second part of Experiment 3.**

Participant	CO-P-U	CO-P-RF
22	13	16
23	11	15
28	9	18
29	10	14

Table 32: **Results obtained for the second part of experiment 3.** Scores obtained for the co-presence created by unrealistic avatars (CO-P-U) and the co-presence created by realistic human-like avatars with gestures and facial expressions (CO-P-RF). These scores are used to test the hypotheses that having realistic human-like avatars without any body movement could create a worst sense of co-presence than having unrealistic avatars without any body movement.

We then performed one-way ANOVAs on CO-P-U and CO-P-RS, and on CO-P-U and CO-P-RF. We found that the realistic human-like avatars (with or without gestures) produce a greater sense of co-presence than the unrealistic avatars. The difference is that the realistic human-like avatars with gestures and facial expressions produce a greater difference in co-presence (having $F(1,6) = 17.14286, p < 0.01$ for CO-P-RF and $F(1,6) = 8.44186, p < 0.05$ for CO-P-RS).

7.6.3 Discussion of Results

In this section, we discuss the results obtained in both parts of this experiments. Firstly, we present a discussion of the results obtained in investigating the effects of avatar appearance on co-presence in the CVE. This is followed by a discussion of the results obtained in investigating the effects of avatar functionality on co-presence in the CVE. The most interesting results obtained were the fact that the sense of co-presence was affected by the appearance of the avatars. Co-presence was increased by having realistic human-like avatars. Also, co-presence was increased by providing gestures and facial expressions to the avatars. Another interesting result was that the immersive tendencies scores and the presence score were associated which indicates that the immersive tendencies of participants could act as a predictor for the presence scores.

Part A: Effects of Avatar Appearance on Co-Presence

The results show that there was a large and significant difference between the co-presence scores generated by the different types of avatars. The co-presence generated by the realistic human-like avatars was greater than that generated by the cartoon-like avatars, which in turns was greater than the co-presence generated by unrealistic avatars. None of the avatars had any gestures or facial expressions. This indicates that realistic avatars having a human-like form engender a greater sense of co-presence that totally unrealistic simple avatars.

Witmer and Singer [79] show that their Immersive Tendencies Questionnaire (ITQ) predicts the level of presence measured by their presence questionnaire. However, in the experiment described in Chapter 6, we failed to replicate Witmer and Singer's result using their presence questionnaire (rather than Slater's) and their immersive tendencies questionnaire. Since in this experiment we used a different presence questionnaire developed by Slater *et al*, it is important to see if we can replicate Witmer and Singer's results with Slater's questionnaire.

We found that the presence score measured by Slater's presence questionnaire and the IT score measured by Witmer and Singer's immersive tendencies questionnaire were correlated. This might indicate that the immersive tendencies score could act as a predictor of the presence score. This result was also found in the experiment described in Chapter 5. We also compared the co-presence (CO-P) scores and the immersive tendencies (IT) scores, and we found that there was no correlation between the CO-P scores and the IT scores. When we compared the presence (P) an co-presence (CO-P) scores, we found that there was no correlation between them. We therefore failed to replicate the results found by Tromp *et al* [71] and by Slater *et al* [53] which indicate that they found a positive correlation between personal presence and co-presence in one of their small group experiments.

Part B: Effects of Avatar Functionality on Co-Presence

The results show that the co-presence generated by avatars having gestures and facial expressions was significantly higher than that generated by static avatars. This supports our hypothesis that states that providing simple gestures and facial expressions to the avatars will enhance the sense of co-presence in a collaborative virtual environment. It is important to note that the participants which had avatars with gestures and facial expressions had to use the GUI to control their gestures and expressions. This might have disrupted the sense of co-presence felt by those participants and so might have influenced our results.

We also found that the presence score (measured by Slater's presence questionnaire) and the IT score (measured by Witmer and Singer's immersive tendencies questionnaire) were correlated. This supports Witmer and Singer's result indicating that the immersive tendencies score act as a predictor of the presence score. When we compared the co-presence (CO-P) scores and the immersive tendencies (IT) scores, we found that there was no correlation between them. When we compared the presence (P) and co-presence (CO-P) scores, we found again that there was no correlation between them. We therefore failed to replicate the results found by Tromp *et al* [71] and Slater *et al* [53] in one of their small group experiments.

We wanted to test the hypothesis that having realistic human-like avatars without any body movement could create a worst sense of co-presence than having unrealistic avatars without any body movement. We found that realistic human-like avatars, with or without gestures and facial expressions, did create a higher sense of co-presence than unrealistic avatars without any body movement.

7.7 Summary

In this chapter we have presented the design and results of an experiment aimed at testing the following hypotheses:

- The first hypothesis said that the way one represents other participants in the virtual environment is very important to enhance the sense of co-presence. The important issue here is to determine how does the appearance of the avatar affects co-presence.

- The second hypothesis stated that simply having static avatars is not sufficient to create a high sense of co-presence in the collaborative virtual environment. We believe that providing simple gestures and facial expressions to the avatars will increase the sense of co-presence in the CVE. We also want to test the hypothesis that having realistic human-like avatars without any body movement could create a worst sense of co-presence than having unrealistic avatars without any body movement. This is because there is a conflict between the greater visual realism of the human-like avatar and the lack of bodily movement. On the other hand, having an unrealistic avatar makes it easier to understand that it is not functional.

In order to test these hypotheses, we provided the participants with a range of avatars having different appearance and functionality. The avatars included realistic human-like avatars, cartoon-like avatars, and simple unrealistic avatars. Some of the avatars (such as the human-like avatars) had simple gestures and facial expressions.

We divided this experiment into two parts, having the same scenario and virtual environment. The only difference between these two parts were the avatars used. The first part (Part A) was used to investigate the effects of avatar appearance on co-presence, and the second part (Part B) was used to investigate the effects of avatar functionality on co-presence.

In Part A, we found that there was a significant difference between the co-presence scores generated by the avatars of different appearance. The realistic human-like avatars produced a greater sense of co-presence that cartoon-like avatars, which in turn produces a greater sense of co-presence than unrealistic avatars. In Part B, we found that avatars having gestures and facial expressions produced a significantly higher level of co-presence when compared to static avatars. We also found that realistic human-like avatars, with or without gestures and facial expressions, did create a higher sense of co-presence when compared to unrealistic avatars without any body movement.

Another interesting result was that the immersive tendencies scores measured using Witmer and Singer's Immersive Tendencies Questionnaire and the personal presence scores measured using Slater's presence questionnaire were associated. This might indicates that the immersive tendencies of participants could act as a predictor for the presence scores. This result was also found in Experiment 1 (refer to Chapter 5).

Chapter 8

Conclusion

The focus of this research was to conduct experiments to investigate and verify some of the factors believed to affect personal presence and co-presence in a collaborative virtual environment. We designed and performed three experiments in collaborative virtual environments, using subjective measures to asses the levels of presence and co-presence in the CVE. In addition, we developed a subjective measure of co-presence in the form of a pencil-and-paper questionnaire. This co-presence questionnaire was used to measure the amount of co-presence experienced by the participants in the collaborative virtual environments.

8.1 Aims

As mentioned in Section 1.2, the experiments were designed to test following aims:

- Group collaboration and interaction with other participants in the environment influence co-presence. We confirmed this hypothesis in Experiment 1 (refer to Chapter 5), were we found that group collaboration and group interaction enhanced the sense of co-presence reported by the participants beyond that afforded by simply having avatars of others.

- Personal presence and co-presence in a CVE are correlated. We tested this hypothesis in all three of the experiments performed. We did not find any correlation between the sense of presence and co-presence in any of the three experiments.

- Increasing the feeling of presence and co-presence within a group in a CVE changes the style of collaboration and interaction between group members. We tested this hypothesis in Experiment 2 (refer to Chapter 6). We did not find any significant difference in interaction styles under different levels of presence.

- The various factors contributing to increased presence have been studied quite extensively by differing researchers. We aimed to consolidate this research by using some of these factors to create virtual environments which generate different levels of presence. We also aimed to try and replicate some of the results found in the literature, namely the relation of personal presence and co-presence, and the relation of the immersive tendencies and presence. We failed to replicate the relation of personal presence and co-presence mentioned in the literature. The relation between the immersive tendencies of participants and personal presence did hold only under certain conditions.

- The way one represents other participants in the virtual environment is very important to enhancing the sense of co-presence. This hypothesis was tested in Experiment 3 (refer to Chapter 7). We found that the sense of co-presence was greater when the other participants were portrayed using realistic human-like avatars, as opposed to cartoon avatars or unrealistic avatars.

- We believe that providing simple gestures and facial expressions to the avatars will increase the sense of co-presence in the CVE, compared to having static avatars. This hypothesis was investigated in Experiment 3 (refer to Chapter 7). We found that portraying the other participants with avatars having gestures and facial expressions enhanced the sense of co-presence reported by the participants. We also tested the hypothesis that having realistic human-like avatars without any body movement could create a worst sense of co-presence than having unrealistic avatars without any body movement. We found that this hypothesis did not hold. Realistic human-like avatars without any body movement created more co-presence than having unrealistic avatars without any body movement .

8.2 Results Obtained in this Dissertation

In this section, we summarise the main results obtained in the three experiments presented in this dissertation. These experiments were designed to investigate different factors affecting personal presence and co-presence is multi-user collaborative virtual environments.

8.2.1 Factors Influencing Personal Presence and Co-presence

In this research, we aimed to investigate and verify some of the factors believed to affect personal presence and co-presence in a collaborative virtual environment. The main results concerning the factors believed to affect presence and co-presence obtained in the three experiments are the following:

Personal Presence

The first experiment was designed to investigate the effects of small group collaboration and interaction on personal presence and co-presence in a CVE. We found that the personal presence scores were higher in the high-collaboration VE when compared to the low-collaboration VE. This result indicates that group collaboration affects personal presence. This might be explained by the fact that the task in the high-collaboration VE was more challenging and required more involvement, which might enhance the sense of personal presence.

The second experiment was designed to investigate the effects of presence on collaboration styles in collaborative virtual environments. We created two virtual environments designed to create different levels of presence (i.e., a high-presence VE and a low-presence VE), by considering some of the factors believed to affect presence mentioned by Witmer and Singer in [79]. We found that even though the two virtual environments were specifically designed to create different levels of presence, we did not find a significant different in the presence scores obtained using Witmer and Singer's presence questionnaire. This shows that the presence questionnaire could not be used to compare the levels of presence across different VEs. In the analysis of the interaction and collaboration, we did not find much of a difference between the interaction styles in the high and low-presence VEs. The only different found between the two VEs was that participants in the high-presence VE made more comments indicating agreement, understanding, and compliance than participants in the low-presence VE.

Co-presence

The first experiment was designed to investigate the effects of small group collaboration and interaction on personal presence and co-presence in a CVE. We found that the co-presence scores were significantly higher in the high-collaboration VE when compared to the low-collaboration VE. This supports our hypothesis that group collaboration and interaction greatly enhanced co-presence in a CVE beyond that afforded by merely having virtual representations of others.

The third experiment was designed to investigate the effects of avatar appearance and functionality (in terms of simple gestures and facial expressions) on co-presence. We found a significant difference in the co-presence scores of the avatars of different appearance. The realistic human-like avatars produced a greater sense of co-presence than cartoon-like avatars, which in turn produces a greater sense of co-presence than unrealistic avatars. We also found that avatars having gestures and facial expressions produced a significantly higher level of co-presence when compared to static avatars. We also found that realistic human-like avatars, with or without gestures and facial expressions, did create a higher sense of co-presence when compared to unrealistic avatars without any body movement.

8.2.2 Usefulness of Questionnaires Used

During these experiments, we used different subjective measures in the form of questionnaires to asses the levels of personal presence, co-presence, immersive tendencies, and group collaboration. Two presence questionnaires found in the literature were used, namely Witmer and Singer's presence questionnaire [79], and Slater *et al* presence questionnaire [58, 51, 55]. We also used Witmer and Singer's Immervise Tendencies Questionnaire to measure the immersive tendencies of participants. In order to measure co-presence, we developed a co-presence questionnaire. We also developed a collaboration questionnaire to asses group collaboration in the CVE.

The second experiment was designed to investigate the effects of presence on collaboration styles in collaborative virtual environments. We created two virtual environments designed to create different levels of presence (i.e., a high-presence VE and a low-presence VE), by considering some of the factors believed to affect presence found in the literature. We found that even though the two virtual environments were specifically designed to create different levels of presence, we did not find a significant difference in the presence scores obtained using Witmer and Singer's presence questionnaire. This implies that the manipulations of the two VEs to create a greater sense of presence in the high-presence VE was not successful. This might be because there was no difference in presence felt by the participants, or it might be that the presence questionnaire used was not sensitive enough to pick up any difference that existed. Whether this comments on the size of the difference in presence, or on the sensitivity of the presence questionnaire, cannot be determined from this experiment. This could also indicate that Witmer and Singer's presence questionnaire could not be used to compare the levels of presence across different VEs.

8.2.3 Relationships Between Personal Presence, Co-presence and Immersive Tendencies

In these three experiments, we performed correlation analyses to investigate the different relationships between the personal presence, co-presence, immersive tendencies and collaboration scores reported by the participants.

In Experiment 1, we found a significant correlation between the collaboration scores and the co-presence scores. This provides further evidence that working together with the other participants in the CVE increases the sense that they are truly in the space with you.

One of the aims of this research was to try and replicate some of the claims found in the literature regarding the relationship of personal presence and co-presence, as well as personal presence and immersive tendencies.

In all three experiments we performed, we did not find any relationship between the personal presence and co-presence scores reported by the participants. We therefore failed to replicate the results found by Tromp *et al* [71] which indicate that they found a positive correlation between personal presence and co-presence in one of their small group experiments. This evidence might indicate that the sense of personal presence and co-presence are orthogonal to each other as indicated by Slater *et al* in [53].

Witmer and Singer indicate in [79] that they found a correlation between the presence scores and the immersive tendencies scores in their experiments, using their presence and immersive tendencies questionnaires. In Experiments 1 and 3, we found a correlation between the personal presence scores (measured using Slater's presence questionnaire) and the immersive tendencies scores (measured using Witmer and Singer's Immersive Tendencies Questionnaire). However, in Experiment 2, we did not find a correlation between the personal presence scores (measured using Witmer and Singer's presence questionnaire) and the immersive tendencies scores (measured using Witmer and Singer's Immersive Tendencies Questionnaire) in some of the scenarios. This indicates that the presence/immersive tendencies correlation found by Witmer and Singer seems to hold only under certain conditions, which are unclear. However, the fact that we found a correlation between presence and immersive tendencies using Slater's presence questionnaire in two experiments indicates that there might be a relationship between them.

8.3 Future Work

There is a need for more systematic research into the concept of presence in virtual environments, the factors that contribute to a sense of presence and the consequences that it produces. Lombard and Ditton [34] indicate that "it has not yet been carefully explicated, operationalized, or studied", and that "Previous discussions of presence have typically been based on informed conjecture rather than research". Held and Durlach [29] say that "There is no scientific body of data and/or theory delineating the factors that underlie the phenomenon". Durlach and Slater [23] indicate this lack of research by noting that there are a lot of important unresolved issues concerning presence in a virtual environment. These issues include (a) the definition of presence, (b) how to measure presence, (c) which factors enhance presence, (d) the relation of presence to work performance. Lombard *et al* [35] mention that the "lack of a consensus regarding a conceptual definition of presence is one of the reasons that there is no standard technique or instrument for measuring presence".

We believe that there is a need to formulate a theoretical underpinning for the notion of presence in virtual environments. In order to develop meaningful measures of presence there is a need for a theoretical understanding of presence. At the moment, presence is understood in terms of its component variables and how these relate to other variables. This is not enough to create a true understanding of user behaviours in virtual environments. An understanding of the cognitive process underpinning the experience of presence would be required for this purpose. Once a standardised definition and theory of presence has been developed, it will also allow the development of standardised measures of presence which could be used to compare results between different studies.

There is also a need for more experimental data. There is not enough evidence of the replicability of some of the results found in the literature. Replicability and convergence of findings from independent sources remains important to establish the validity of claims made and of presence measurement methods.

Appendix A

Witmer & Singer's Presence Questionnaire

1. How much were you able to control events?
   1 Not at all ... 4 Somewhat ... 7 Completely

2. How responsive was the environment to actions that you initiated
   1 Not responsive ... 4 Moderately responsive ... 7 Completely responsive

3. How natural did your interactions with the environment seem?
   1 Extremely artificial ... 4 Borderline ... 7 Completely natural

4. How much did the visual aspects of the environment involve you?
   1 Not at all ... 4 Somewhat ... 7 Completely

5. How much did the auditory aspects of the environment involve you?
   1 Not at all ... 4 Somewhat ... 7 Completely

6. How natural was the mechanism which controlled movement through the environment?
   1 Extremely artificial ... 4 Borderline ... 7 Completely natural

7. How aware were you of events occurring in the real world around you?
   1 Very aware ... 4 Somewhat ... 7 Not aware

8. How aware were you of your display and control devices?
   1 Very aware ... 4 Somewhat ... 7 Not aware

9. How compelling was your sense of objects moving through space?
   1 Not at all ... 4 Moderately compelling ... 7 Very Compelling

10. How inconsistent or disconnected was the information coming from your various senses?
    1 Very inconsistent ... 4 Somewhat inconsistent ... 7 Very consistent

11. How much did your experience in the virtual environment seem consistent with your real-world experiences?
    1 Not consistent ... 4 Moderately consistent ... 7 Very consistent

12. Were you able to anticipate what would happen next in response to the actions that you performed?
    1 Not at all ... 4 Somewhat ... 7 Completely

13. How completely were you able to actively survey or search the environment using vision?
    1 Not at all ... 4 Somewhat ... 7 Completely

14. How well could you identify sounds?
    1 Not at all ... 4 Somewhat ... 7 Completely

15. How compelling was your sense of moving around inside the virtual environment?
    1 Not compelling ... 4 Moderately compelling ... 7 Very compelling

16. How closely were you able to examine objects?
    1 Not at all ... Pretty closely ... 7 Very closely

17. How well could you examine objects from multiple viewpoints?
    1 Not at all ... 4 Somewhat ... 7 Extensively

18. How well could you move or manipulate objects in the virtual environment?
    1 Not at all ... 4 Somewhat ... 7 Extensively

19. How involved were you in the virtual environment experience?
    1 Not involved ... 4 Mildly involved ... 7 Completely engrossed

20. How distracting was the control mechanism?
    1 Very distracting ... 4 Somewhat distracting ... 7 Not at all

21. How much delay did you experience between your actions and expected outcomes?
    1 No delays ... 4 Moderate delays ... 7 Long delays

22. How quickly did you adjust to the virtual environment experience?
    1 Not at all ... 4 Slowly ... 7 Less than one minute

23. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?
1 Not proficient ... 4 Reasonably proficient ... 7 Very proficient

24. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?
1 Not at all ... 4 Interfered somewhat ... 7 Prevented task performance

25. How much did the control devices interfere with the performance of assigned tasks or with other activities?
1 Not at all ... 4 Interfered somewhat ... 7 Interfered greatly

26. How well could you concentrate on the assigned tasks or required activities rather than on the mechanism used to perform those tasks or activities?
1 Not at all ... 4 Somewhat ... 7 Completely

27. How completely were your senses engaged in this experience?
1 Not engaged ... 4 Mildly engaged ... 7 Completely engaged

28. To what extent did events occurring outside the virtual environment distract from your experience in the virtual environment?
1 Not at all ... 4 Moderately ... 7 Very much

29. Overall, how much did you focus on using the display and control devices instead of the virtual experience and experimental tasks?
1 Not at all ... 4 Somewhat ... 7 Very much

30. Were you involved in the experimental task to the extent that you lost track of time?
1 Not at all ... 4 Somewhat ... 7 Completely

31. How easy was it to identify objects through physical interaction; like touching an object, walking over a surface, or bumping into a wall or objects?
1 Impossible ... 4 Moderately difficult ... 7 Very easy

32. Were there moments during the virtual environment experience when you felt completely focused on the task or environment?
1 None ... 4 Occasionally ... 7 Frequently

33. How easily did you adjust to the control devices used to interact with the virtual environment?
1 Not at all ... 4 Moderately ... 7 Very easily

34. Was the information provided through different senses in the virtual environment (e.g., vision, hearing, tough) consistent?
1 Not consistent ... 4 Moderately consistent ... 7 Very consistent

Appendix B

Witmer & Singer's Immersive Tendencies Questionnaire

1. Do you easily become deeply involved in movies or TV dramas?
   1 Never ... 4 Occasionally ... 7 Often

2. Do you ever become so involved in a TV program or a book that people have problems getting your attention?
   1 Never ... 4 Occasionally ... 7 Often

3. How mentally alert do you feel at the present time?
   1 Not alert ... 4 Moderately ... 7 Fully alert

4. Do you ever become so involved in a movie that you are not aware of things happening around you?
   1 Never ... 4 Occasionally ... 7 Often

5. How frequently do you find yourself closely identifying with characters in a story line?
   1 Never ... 4 Occasionally ... 7 Often

6. Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?
   1 Never ... 4 Occasionally ... 7 Often

7. What kind of books do you read most frequently? (Select one item only)
   Spy novels, Fantasies, Science fiction
   Adventure novels, Romance novels, Historical novels

Westerns, Mysteries, Other fiction
Biographies, Autobiographies, Other non-fiction

8. How physically fit do you feel today?
   1 Not fit ... 4 Moderately fit ... 7 Extremely fit

9. How good are you at blocking external distractions when you are involved in something?
   1 Not very good ... 4 Somethat good ... 7 Very good

10. When watching sports, do you ever become so involved in the game that you react as if you were one of the players?
    1 Never ... 4 Occasionally ... 7 Often

11. Do you ever become so involved in a daydream that you are not aware of things happening around you?
    1 Never ... 4 Occasionally ... 7 Often

12. Do you ever have dreams that are so real that you feel disoriented when you awake?
    1 Never ... 4 Occasionally ... 7 Often

13. When playing sports, do you become so involved in the game that you lose track of time?
    1 Never ... 4 Occasionally ... 7 Often

14. How well do you concentrate on enjoyable activities?
    1 Not at all ... 4 Moderately well ... 7 Very well

15. How often do you play arcade or video games? (often should be taken to mean every day or every two days on average)
    1 Never ... 4 Occasionally ... 7 Often

16. Have you ever gotten excited during a chase or fight scene on TV or in the movies?
    1 Never ... 4 Occasionally ... 7 Often

17. Have you ever gotten scared by something happening on a TV show or in a movie?
    1 Never ... 4 Occasionally ... 7 Often

18. Have you ever remained apprehensive or fearful long after watching a scary movie?
    1 Never ... 4 Occasionally ... 7 Often

19. Do you ever become so involved in doing something that you lose all track of time?
    1 Never ... 4 Occasionally ... 7 Often

Appendix C

Slater's Presence Questionnaire

1. Please rate your sense of "being there" in the virtual environment, on the following scale from 1 to 7, where 7 represents your normal experience of being in a place.
   1 Not at all ... 4 Somewhat ... 7 Completely

2. To what extent were there times during the experience when the virtual room became the "reality" for you, and you almost forgot about the "real world" of the laboratory?
   There were times during the experience when the virtual room became more real or present for me compared to the "real world"... 1 At no time ... 4 Sometimes ... 7 Almost all the time

3. When you think back about your experience, do you think of the virtual room more as images that you saw, or more as somewhere that you visited?
   The virtual room seems to me more like ... 1 Images that I saw ... 4 About 50/50 ... 7 Somewhere that I visited

4. During the course of the experience, which was stronger on the whole, your sense of being in the virtual room, or of being in the real world of the laboratory?
   I had a stronger sense of being in ... 1 The real world in the lab ... 4 About 50/50 ... 7 The virtual room

5. When you think about the virtual reality, to what extent is the way that you are thinking about this similar to the way that you are thinking about the various places that you have been today?
   I think of the virtual room as a place in a way similar to other places that I have been today... 1 Not at all ... 4 Somewhat ... 7 Very much so

Appendix D

Co-Presence Questionnaire

1. To what extent did you have a sense that the other members of the group were in the same place as you during the course of these events?
   I sensed that the others were in the same place as me... 1. Never ... 4. About 50/50 ... 7. All the time

2. To what extent did you have a sense that you where in the same place as the other group members during the course of the experience?
   I sensed that I was in the same place as the others... 1. Never ... 4. About 50/50 ... 7. All the time

3. To what extent did you have a sense of the emergence of a group/community during the course of these events?
   I sensed the emergence of a group... 1. Never ... 4. About 50/50 ... 7. All the time

4. To what extent did you did you have a feeling that you were collaborating with real people and not robots?
   I had a feeling that I was collaborating with real people... 1. Never ... 4. About 50/50 ... 7. All the time

5. When you think back about your last experience, do you remember this as more like talking to a computer or communicating with a group of people? *1.Talking to a computer ... 4. About 50/50 ... 7. Communicationg with a group*

6. To what extent did you have a sense of being "part of the group"?
   I had a sense of being "part of the group" ... 1. Never ... 4. Sometimes ... 7. All the time

Appendix E

Collaboration Questionnaire

1. What do you think was the overall team performance ?
   1 Not very good performance ... 4 Average performance ... 7 Very good performance
2. If you needed to perform another task, would you like to form the same group again ?
   1 Not at all ... 4 ... 7 Definitely yes
3. How well did you think you collaborated in the group ?
   1 Not very well ... 4 Somewhat well ... 7 Very well
4. How would you rate the overall group collaboration ?
   1 Very bad ... 4 Average ... 7 Very good
5. How would you rate [blue avatar]'s collaboration ?
   1 Very bad ... 4 Average ... 7 Very good
6. How would you rate [red avatar]'s collaboration ?
   1 Very bad ... 4 Average ... 7 Very well
7. How would you rate [green avatar]'s collaboration ?
   1 Very bad ... 4 Average ... 7 Very good
8. During the experince, how cooperative did you find the other group members ?
   1 Not very cooperative ... 4 Somewhat cooperative ... 7 Very cooperative
9. How would you rate your cooperativeness during the task ?
   1 Very poor ... 4 Average ... 7 Very good
10. During the experience, how talkative did you find the other group members ?
    1 Not very talkative ... 4 Somewhat talkative ... 7 Very talkative

11. How would you rate your talkativeness during the experience ? *1 Not very talkative ... 4 Somewhat talkative ... 7 Very talkative*

12. Would you like to meet the members of the group in person?
1 Not at all ... 4 50/50 ... 7 Very much

13. During the experience, how confortable where you with the other group members?
1 Not very confortable ... 4 Somewhat confortable ... 7 Very confortable

14. How would you rate your degree of enjoyment during the experience ?
1 Not very enjoyable ... 4 Somewhat enjoyable ... 7 Very enjoyable

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