ABSTRACT

MA, RUIQI. Telepresence and Performance in an Immersive Virtual Environment and Sporting Task. (Under the direction of David B. Kaber).

The purpose of this research was to assess the relationship between telepresence and performance in a synthetic environment. Telepresence is believed to be a mental construct and to enhance task performance in teleoperations and virtual environments. Consequently, it has been identified as a design ideal for synthetic environments. However, there is a limited understanding of telepresence and its relation to task performance. This research involved examination of a range of synthetic environment design features (e.g., viewpoint and auditory cue type) that were suspected to influence telepresence and compared differences in telepresence and task performance caused by manipulations of these factors and task difficulty.

A simulated basketball free-throw task was used in which subjects controlled the motions of a virtual basketball player. In addition to the basketball task performance (baskets/goals), subjects were required to report camera flashes in the virtual environment (stadium) and to simultaneously detect strobe light flashes in a real research laboratory. These tasks were designed as secondary-monitoring tasks and were intended to assess subject attention allocation to the virtual and real environments as an indicator of telepresence. Each subject was exposed to a single viewpoint condition including either an egocentric view, an exocentric view from behind the player, an exocentric view from the sideline of the court, or a selectable viewpoint. They were also exposed to four virtual sound conditions including task-relevant sounds, task-irrelevant sounds, a combination of sounds and no sound, as well as two visual display fidelity conditions including a low fidelity stadium composed of rendered walls surrounding the basketball court and a high

fidelity stadium that displayed a texture of a crowd watching the game. Finally, the subjects experienced two task difficulty conditions including 2-point and 3-point shots. The order of presentation of the sound, fidelity and difficulty conditions was randomized. Subjective ratings and the objective, attention-based measure of telepresence were recorded during the experiment, along with task performance and workload.

The results of the study provided evidence that the features of a simplistic synthetic environment, which include immersiveness (viewpoint) and auditory cue type significantly influence the sense of subjective telepresence. However, the objective, attention-based measure of telepresence did not prove to be sensitive to the experimental manipulations. Virtual task performance was significantly affected by task difficultly. This study also revealed significant effects of viewpoint and audio cue type on subjective workload. An analysis of trends on changes in telepresence and performance across settings of various virtual reality features provided compelling evidence that telepresence is a predictable experience unique from performance. However, the results of this analysis cannot be considered conclusive in terms of describing a causal relationship between telepresence and performance, in part, because of mixed findings across predictors. Beyond the relationship of telepresence and performance, this study provided further evidence of significant positive relations between telepresence and workload. There were no significant interaction effects among the virtual reality factors mentioned above in terms of performance, telepresence and workload. Although counter to expectation, and some previous research hypotheses on cross-modality interactions in virtual reality experiences, this finding was consistent with the findings of other prior empirical work. The lack of interaction effects on the response measures suggests that virtual reality design using multiple sensory channels could be relatively simple. However, this study did not examine all types of sensory cues including tactile and haptic. Furthermore, it is possible that more complex virtual environments for real-world applications might cause telepresence experiences more sensitive to, for example, cue conflicts.

TELEPRESENCE AND PERFORMANCE IN AN IMMERSIVE VIRTUAL ENVIRONMENT AND SPORTING TASK

by
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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

INDUSTRIAL ENGINEERING

Raleigh

2002

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BIOGRAPHY

Ruiqi Ma was born in Sichuan province in China in 1971. He was raised in Xuanhan city, Sichuan, where he completed his elementary and secondary education, graduating from Xuanhan First High School in 1989.

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List of Abbreviations

ANOVA	Analysis of Variance
DOF	Degree of Freedom
FOB	Flock of Birds
HMD	Head-Mounted Display
IT	Information Technology
ITQ	Immersive Tendencies Questionnaire
MCH	Modified Cooper-Harper
PQ	Presence Questionnaire
RW	Real World
SA	Situation Awareness
SE	Synthetic Environment
SSQ	Simulator Sickness Questionnaire
VAS	Visual Analog Scale
VR	Virtual Reality

1 Introduction

Telepresence, the perception of presence within a physically remote or simulated space, has been identified as a design ideal for synthetic environments (SEs) (Draper, Kaber, and Usher, 1998). A synthetic environment provides computer-mediated human interaction with an environment that is physically separate from the user in order to allow human perceptual, cognitive, and psychomotor capabilities to be projected into normally inaccessible, hostile, or simulated environments (Draper, Kaber, and Usher, 1999). Heeter (1992) identified three different types of presence including environment, social and personal presence. Draper et al. (1998) also identified three types of telepresence extant in the literature including simple telepresence, cybernetic telepresence, and experiential telepresence. These categories of telepresence differentiate the sensation or phenomenon in terms of task circumstances and types of SE users. However, telepresence is often preferred as a general term to describe the sense of presence within a SE. This thesis does not discriminate among types of telepresence or the terminology presence and telepresence, in general.

1.1 Origin of Telepresence in Teleoperations

Originally, the concept of telepresence emerged in the teleoperation arena. Teleoperation is defined as a human operator using a remote-control robotic system that consists of an operator interface and a remote machine to act on a remote environment (Schloerb, 1995). Teleoperators are commonly used in applications that are dangerous or hostile to humans, or in task environments that humans are not able to occupy at the current time, for example, outer space and deep-sea environments. Since current technologies do not allow for the development of a robot that has all the abilities of a human being (less the human's physical and psychological limitations), human operators must be involved in the operation of robots at a remote site through computers or other advanced technologies for perceptual and cognitive tasks.

Teleoperators have been identified as a subdivision of SEs along with virtual reality (VR) and telecommunication systems (Draper et al., 1999). Many newly developing technologies in the area of teleoperation and VR have increased the human's ability to complete tasks remotely (e.g., Riley, 2001). However, industry and research still seek to limit the possibility of error in teleoperator control loops, improve overall system reliability and ultimately enhance performance results.

The study of the robotics is multi-disciplinary in nature. It is difficult to achieve great progress in contemporary robotics research without a corresponding advance in understanding of human intelligence and the simulation of intelligence in machine systems. Although some researchers would like to create a "robotic human" that could function autonomously with great reliability, current technology has not provided robots with the capability to act independently and intelligently in complex and unstructured environments. There is an inevitable need for the human to act as a controller or supervisor in unstructured operations. This reality has caused a change in the direction of teleoperation research from the design of anthropomorphic robots to a focus on human-computer (machine) interface design that provides high-fidelity displays including rich visual, auditory and touch information on a remote site, in order to facilitate human operator perception and a sense of telepresence at the remote site (Riley, 2001). This major change in research direction was based on the belief that the sense of telepresence will improve overall teleoperation (human in-the-loop) task performance. A review of studies on human aspects of information technology (IT) undertaken by Salvendy and his colleagues over the past two decades also reveals this trend in research; that is, a shift from studying ergonomics in robotics system design to studies of human-computer interaction and usability testing for human operator information processing (Fang and Salvendy, 2001).

1.2 Factors Influencing Telepresence

It is important to identify and understand factors potentially contributing to the sense of telepresence in a SE in order to better describe telepresence and any relation of the phenomenon to teleoperation or virtual task performance. Nash, Edwards, Thompson and Barfield (2000) reviewed this problem by considering the global elements that are involved in typical usage of a SE or VR simulation, as shown in Figure 1. The computer system and VR, the communication mediums, individual differences, and the task and its external environment are all hypothesized to influence the sense of telepresence. The task (outside of the diagram) can also affect the entire operating environment. Different tasks will probably dictate differences in how other components relate to one another. The arrows in the diagram show the information that is transacted with the human through the interaction devices and display devices.

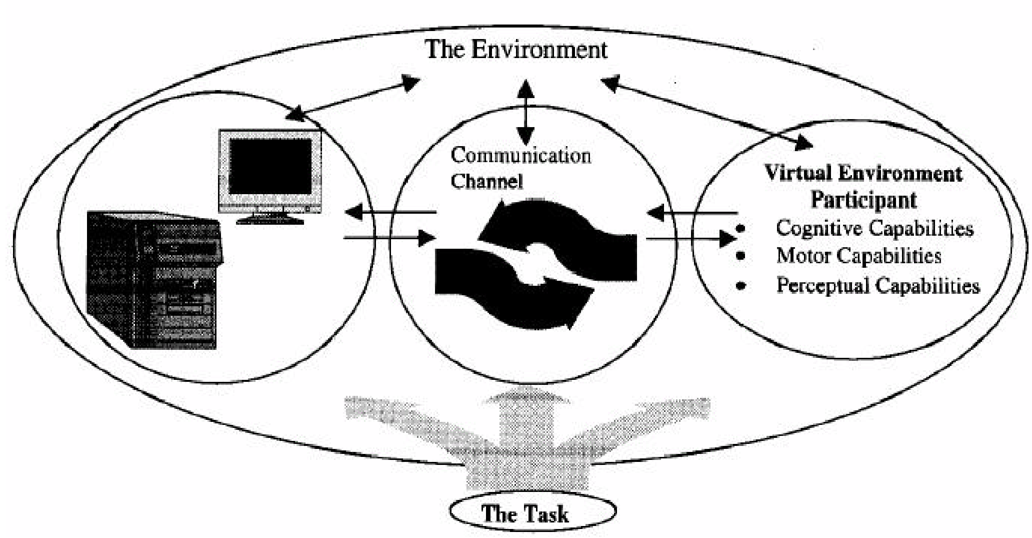

Figure 1: General framework of factors that affect virtual presence (Nash et al., 2000)

Sadowski and Stanney (2002) think both individual and system variables influence the level of telepresence experienced in VR. Some specific variables they identified include: (1) ease of interaction; (2) user-initiated control; (3) pictorial realism; (4) length of exposure; (5) social factors; and (6) system factors.

Sheridan (1992) identified five variables that supposedly contribute to inducing a sense of telepresence. Three of them are technological including: the extent of sensory information, control of sensors relative to the environment, and the ability to modify the physical environment. The other two are task, or context based including: task difficulty, and degree of automation.

All of these researchers state that a wide range of factors may influence the sense of telepresence, from the vividness of a VR (similarity to the real world) to the interactivity of a SE. These studies provide abstract information that could be used as a basis for designing an experiment, including specifying independent variables, in order to investigate controlled manipulations of the sense of telepresence. However, they do not provide information on operational methods that could be used to control the sense of telepresence in applications (e.g., teleoperation).

It is important to identify ways in which the factors hypothesized to influence the sense of telepresence can be manipulated in an experiment in order to develop more conclusive evidence on the root causes of the phenomenon. If telepresence is to be investigated using VR, Pretlove (1998) states that the basic requirements for humans to operate efficiently in a SE must be met including sufficient visual information for interpreting the synthetic scene. In a teleoperation scenario, basic requirements for performance may extend beyond visual stimulation to include auditory, and tactile feedback from the remote site in order to facilitate a valid and reliable operation. All of these basic features of SEs may influence the sense of telepresence. Unfortunately, it can be very difficult to create high fidelity, multi-modal VRs for use in experiments aimed at manipulating the sense of telepresence.

Some researchers believe VRs for research and application purposes should have basic characteristics including 3-D representation of a virtual environment and 3-D presentation of the VR. In addition, immersion is often identified as a requirement for VR system design (Psotka and Davison, 1993). This means that depth cues should be provided in the display or interface to the VR and that the users senses should be immersed in stimuli as part of the VR. The intent is to facilitate users' perception of the VR in a manner similar to their perception of reality. It has been speculated that such a setup will allow for the most accurate assessment of telepresence possible.

Among the basic characteristics of VR identified by Psotka and Davison (1993), immersion in a VR may be dictated in part by the viewpoint on the environment provided to a user, and viewpoint may also have a significant influence on telepresence. An egocentric viewpoint, perceived from the perspective of the user, is typically expected to provide a greater sense of self (Slater, Linakis, Usoh and Kooper, 1996) in a synthetic task environment and awareness of objects in the environment as compared to an exocentric viewpoint, which provides a "third" person perspective. With respect to the visual information of a SE and the vividness of visual displays, different levels of rendering and texturing are also believed to influence telepresence. A study by Barfield, Hendrix and Bjorneseth (1995) found that the greater the level of visual realism, the greater the sense of telepresence, in general. However, increasing levels of visual detail can be computationally expensive and possibly delay VR system responsiveness; thus, increasing the level of visual detail may ultimately reduce a person's sense of telepresence. In a study by Dinh, Walker, Song, Kobayashi, and Hodges (1999), no significant influence of different levels of visual fidelity on the sense of telepresence was observed. Given this contradictory evidence, research is still needed to assess the affect of the level of visual detail in a VR on telepresence and ultimately the affect on task performance.

Beyond visual stimuli, Dinh et al. (1999) also examined the role of other perceptual modalities in telepresence experiences in VR. They found significant main effects of auditory cues and tactile cues on telepresence. Tactile (touch) cues are one of the less studied factors in the field of human factors, which may influence the sense of telepresence. Tactile research has recently attracted a lot of attention (Biggs and Srinivasan, 2002). When the sense of touch is integrated with movement (motor behavior), the overall sensation is referred to as a haptic sense. Haptic devices and research in VR have also recently received substantial attention. One reason for this is that, when immersed in a VR through the use of a head-mounted display (HMD), if subjects are provided with realistic sensations of touch in interacting with virtual objects, the force feedback has been found to significantly increase the sense of telepresence (Sallnas, Rassmus-Grohn and Sjostrom, 2000). Although this research will not specifically examine the effects of haptics on telepresence experiences in VR, it is important to be aware of, and have a general understanding of, all VR system, task and user characteristics potentially influencing telepresence.

In general, it is possible that information from the haptic sense and other senses may be important to telepresence in SEs simply because contemporary VR technologies are limited in their capability to completely represent physical environments via the dominate senses (vision, audition). Often times, users must be able to use crude visual cues to manipulate objects and reach goals in an environment. Because of incomplete visual and auditory information in a VR, it is possible that information from one sensory channel is used to augment and help disambiguate information from another sensory channel (Biocca, Kim and Choi, 2001). Biocca et al. found that the process of intermodal integration might produce perceptual illusions that enhance the perception of information in one sensory channel (i.e., cross-modal enhancement) or arouse reports of sensations in senses that have not been stimulated by the interface (i.e., cross-modal illusions or synesthesia). It is possible that telepresence experiences may also derive from the process of multi-modal integration and; therefore, may be associated with other illusions, such as cross-modal transfers resulting from an internal process of creating a coherent mental model of the environment (Biocca et al., 2001).

On the basis of the research on potential factors in telepresence, it can be concluded that VR design should incorporate as many sensory cues as possible in order to motivate the sense of telepresence in investigating its importance to performance in SEs. Although main effects of various types of sensory stimulation on telepresence have been observed, Dinh et al. (1999) showed no significant interaction effect among visual, auditory, tactile, and olfactory cues on telepresence in VR. This suggests that it may be possible to effectively manipulate the sense of telepresence through changing types and various settings of cues independently, for example, visual stimuli. However, since VR is intentionally designed to be rich representation of real environments, a lack of interaction among VR features in affecting telepresence experience does not seem intuitive. For example, cue conflicts can occur (e.g., audio does not match visual information) in VRs just like reality and would be expected to impact or degrade telepresence and performance. When all of the above discussed factors are considered in VR design and are manipulated to provide subjects with different levels of telepresence in a SE, any relationship between telepresence and task performance can be further investigated.

Unfortunately, one obvious limitation of manipulating the factors mentioned above is that there is no standard detailed division of levels of, for example, sensory cues. However, it is possible to differentiate cue settings based on the nature of the task and experimenter' judgment. In addition, different levels of cue salience, relevance or fidelity can be defined using a binary approach (e.g., "on" or "off") and incorporated into the design of an experiment. These approaches were expected to allow for manipulation of the sense of telepresence and study of its relation to performance in this research.

1.3 Telepresence Measure

Although there has been wide expectation of potential performance benefits of telepresence (Riley, 2001), currently there exist few valid subjective or objective measures of the phenomenon that can be used to describe any structural or causal relationship with performance. As discussed above, the sense of telepresence is determined by many system, task and environmental factors; therefore, it is a complex research challenge to develop valid and reliable measures of telepresence, and there is likely no single index that will adequately assess the experience of telepresence (Stanney, Mourant and Kennedy, 1998). Both subjective and objective measures have been developed and used over the past decade.

At present, subjective questionnaires and rating scales are the most commonly used telepresence measurement techniques (Nash et al., 2000). However, in almost all scientific studies, objective measures are preferred for quantification of phenomena over subjective measures. Unfortunately, it is very difficult to define and implement an objective measure of telepresence in VR or a teleoperation scenario. Among several proposed subjective measures of telepresence, the Presence Questionnaire (PQ) developed by Witmer and Singer (1994, 1998), which includes many items, has been validated as a reliable technique. Some researchers have also successfully used a few simple questions to measure the sense of telepresence subjectively; for example, Draper and Blair (1996) used two subjective questions in order to measure telepresence in a teleoperation task.

With respect to objective measurements of telepresence, physiological responses (e.g., heart rate, pupil dilation, blink response, and muscle tension) have been proposed

(Nash et al., 2000). Telepresence has also been hypothesized to be related to situation awareness (SA), attentional resource allocation (Draper et al., 1998), and secondary task measures (Riley, 2001), which provide metrics of the amount of residual attentional resources available for information processing beyond resources dedicated to primary task performance. Measures of these cognitive constructs and secondary task measures of attention may represent potential objective measures of telepresence. Draper et al. (1998) also detailed a structured attentional resource model of telepresence including mathematical expressions for quantifying telepresence, workload and performance in terms of attention. Kaber and his colleagues (2000a, 2001) have conducted a series of studies to investigate the relationship between telepresence and attention to VR. They found a significant correlation between visual attention allocation to VR displays and ratings of telepresence; thus supporting the use of attention allocation as an objective measure of telepresence. Riley and Kaber (2001) provided preliminary results on the utility of measures of attention and SA for explaining telepresence. One limitation of a secondary task measure of telepresence is that the measurement technique itself may be obtrusive to virtual task performance and compromise the sense of telepresence (cause distraction of a VR user) and degrade primary task performance in some cases.

1.4 Telepresence and Performance

Telepresence is believed to be a mental construct and to enhance task performance in teleoperations and VRs (Nash et al., 2000). Consequently, it has been identified as a design ideal for SEs for many years (Draper et al., 1998). One of the most interesting and challenging tasks in telepresence research is investigation of the exact relationship between telepresence and task performance. It is critical to establish states of telepresence that may enhance teleoperation system performance or performance in VRs. It is also important to establish the relation between telepresence and performance in order to develop a model of telepresence for prescribing effective teleoperator designs that may ultimately improve remote task performance (Kaber, 1998).

Studies reviewed by Stanney, Salvendy, et al. (1998) showed a positive correlation between telepresence and performance on tasks such as tracking, searching, and training of time-constrained sensorimotor tasks. However, these tasks were abstract in nature and the results may not generalize to real-world teleoperation tasks. The studies by Kaber and his colleagues (2000a, 2000b, 2001), in which experiments were run on simulated robotic operations, also revealed a significant positive relationship between subjective telepresence and performance.

Although the results of previous experiments show a positive correlation between subjective and objective measures of the constructs of telepresence and performance, there is no direct evidence of a causal relationship. The question of whether the sense of telepresence in VR is causally related to task performance essentially remains unanswered (Welch, 1999). According to Nash, et al. (2000), telepresence is a construct and performance is a measured variable, so research designed to examine telepresence and performance relationships is often based on correlation analyses. Correlational designs have limits in the study of telepresence and performance relation findings because there is a wide variety of possible factors that may affect telepresence and performance. If not experimentally controlled, any of the previously discussed factors may influence telepresence and performance relations as “third variables”. This makes causation difficult to infer. Furthermore, the causal direction of any found relation may be impossible to infer (Nash et. al., 2000).

The uncertainty of the relationship of telepresence and performance is further complicated by the lack of reliable validated objective measures of telepresence. Although Kaber and his colleagues have provided preliminary results on the utility of measures of attention and SA for explaining telepresence objectively (e.g., Riley and Kaber, 2001), further work is needed to verify the validity and reliability of these measures for practice.

The study and debate regarding the relationship between telepresence and virtual task performance is critical. The importance of telepresence is dependent on its impact (if any) on task performance. Thus, if there is a relationship (causal or just correlational) between them, then there is a need to establish telepresence-based design guidelines for teleopertion and complex human-machine systems. If it is demonstrated that there is no relationship between the two, then the design, or modification, of systems with the goal of increasing the sense of telepresence may not be worthwhile (Riley, 2001).

In any case, it seems that some minimum amount of attentional resources will have to be devoted to any VR or teleoperation task, resulting in some minimum sense of telepresence and an associated level of performance (Nash et al., 2000). It is possible that the influence of telepresence on task performance is nonlinear, or the influence is different under varying operating scenarios. More work is needed to determine whether telepresence is a consideration that should continue to be addressed to provide optimal performance in teleoperator and VR applications.

1.5 Telepresence in Applications

Teleoperators and VR have a broad range of applications in outer space and deep-sea exploration, remote surgical operations, remote education and training, teleconferencing, and entertainment. For example, Konesky (2001) proposed exploration of the Hudson submarine canyon using a telepresence system. Freysinger, Gunkel, Thumfart and Truppe (2001) implemented telepresence design considerations in intraoperative orientation of a surgeon during video-endoscopic endonasal procedures. Unfortunately, without a clear understanding of the relationship between telepresence and task performance, continuing research investments may not be made into applications like this, which focus on the goal of increasing the sense of telepresence. Furthermore, we cannot predict telepresence-based design of a complex human-machine system or a VR that optimizes overall performance. In the projects mentioned above, the researchers were only able to provide the minimum, or necessary, telepresence for the remote observation and control tasks.

1.6 Summary

Telepresence has been identified as a design ideal for SEs. Research has had great expectation for a benefit of telepresence to overall human-machine system performance. Some studies have been conducted to investigate the origin of telepresence, measurement of telepresence, its underlying factors, and its utility as it relates to performance. However, we still do not have a complete and accurate understanding of telepresence. As Sheridan (1988) said, "(telepresence) is not even well formulated as a research problem". On the basis of this literature review, more work is needed to study factors that may affect or comprise the sense of telepresence, and how telepresence is related to task performance.

2 Problem Statement

There remains a limited understanding of the concept of telepresence even though many researchers have devised and executed studies in attempts to further knowledge regarding the origin of telepresence, measures of telepresence, its underlying factors, and its relation to performance. Without complete knowledge of the phenomenon, a model of telepresence cannot be developed for prescribing teleoperator designs that may improve remote task performance, and telepresence cannot be used as a predictor of human-machine system performance.

Most researchers believe that teleoperation task performance will improve with increasing telepresence. The potential benefit of telepresence on performance has motivated a lot of research to focus on studies of correlational relationships between telepresence and performance. However, few studies have demonstrated evidence of a direct, causal link between them. Welch (1999) failed to reveal a significant correlation, or causal link, between telepresence and performance in a visual-motor task. The author stated that the differences in subjective telepresence ratings for two VR designs incorporating either sounds relevant to the virtual task or no sounds were relatively small. Therefore, the utility of the study for assessing the relation of telepresence and performance across a broad range of levels of telepresence may have been limited. The studies by Kaber and his colleagues (2000a, 2000b, 2001) revealed significant positive relationships between subjective measures of telepresence and performance. The various manipulations of interface design conditions, teleoperation system network parameters, and task parameters they conducted caused significant differences in telepresence ratings.

In the previous studies, performance has usually been measured objectively and telepresence has been measured subjectively using rating techniques. Unfortunately, there have been no correlation studies of objective telepresence and objective measurements of performance. Ultimately, without this type of research, we cannot say whether telepresence is a unique mental construct or if the phenomenon is simply an element of performance.

In the present study, the relationship between objective and subjective measures of telepresence (based on operator attention allocation strategies) and task performance is evaluated in order to establish whether telepresence is a concept unique from performance and possibly related to task outcomes under certain circumstances. Beyond this, unlike previous experiments, the study examines experimental conditions, in which levels of telepresence are held "fixed" and performance is manipulated or vice versa. As mentioned above, any study of this nature needs to control for all potentially influential variables in order to avoid an influence on the relation of telepresence and task performance by "third variables". For this reason, many features of VR were controlled in this research including visual cues, auditory cues and virtual task characteristics.

It is believed that SE user access to a broader range of sensory cues promotes a greater sense of telepresence in remote or virtual task performance. Dinh, et al. (1999) created a multi-modal VR to provide users with visual, auditory, tactile and olfactory cues for investigating effects on the sense of telepresence and memory of spatial layout and object location in the VR. It was found that both telepresence and memory performance of object location increased significantly when tactile cues and auditory cues were added to the VR. However, this study did not focus on the relationship between telepresence and task performance. Furthermore, the simple task of memorizing objects within a VR may not be generalizable to real world tasks.

In the present study, the experimental task was a virtual basketball free-throw task. This task is perceptuo-motor in nature and was varied slightly across test trials with each research participant. We introduced auditory cues in order to facilitate different levels of telepresence. Sound conditions included relevant, irrelevant, both relevant and irrelevant, and no sounds. Sounds were expected to yield different senses of telepresence, but performance was expected to change in a different way because of feedback and distraction of sounds. Although Dinh et al. (1999) failed to find an effect of varying visual cues (showing different resolution texture maps and different illumination) on the perceived sense of telepresence in their experiment; multiple studies have not been conducted to conclusively demonstrate a lack of effect. We were also interested in the role of visual cues in telepresence and explored two settings of visual background in the present study (rendered or textured). It was expected that visual cues would generate differences in the sense of telepresence, but performance would remain constant. In addition to the auditory cues and the low and high background fidelity, we manipulated levels of telepresence within the VR through changes in viewpoint including egocentric and exocentric while subjects performed the virtual task. Although egocentric views are typically used in VR and telepresence systems, depending upon the nature of the synthetic task posed to users, exocentric views have been shown to be beneficial to performance (e.g., scientific data visualization; McCormick, Wickens, Banks and Yeh, 1998). Viewpoint was expected to yield different senses of telepresence, but performance was expected to change in a different way. More details on the specific hypotheses for the experiment are provided in the Methodology section. We also varied the level of difficulty of the task, which was not expected to influence the sense of telepresence, but was expected to impact virtual task performance.

The aforementioned experimental variables were expected to affect telepresence and performance in different ways, if indeed the two constructs are unique. The independent variable settings were also expected to allow for assessment of any relationship between telepresence and performance across a range of levels of each measure. Using a basketball task was expected to allow for a sensitive evaluation of a potential relation between telepresence and performance. That is, most people are familiar with basketball and the potential for telepresence experiences in the VR was expected to be greater than in a unique teleoperation scenario that many subjects may not be familiar with. If a relationship between telepresence and performance measures cannot be established in such a basic virtual task, then it may be less likely that a relation would be observed in a complex SE. In other words, the results obtained using the basic VR (virtual basketball) were expected to provide further insight into the potential relationship between telepresence and teleoperation performance. If there is evidence of an actual linkage between telepresence and performance in the simplistic VR, then applied research should be conducted using a real teleoperator.

3 Methodology

3.1 Objective

The basic objective of this experiment was to study the relationship between telepresence and performance in the SE. The results of previous experiments have shown a positive correlation between subjective and objective measures of these constructs, but there is no direct evidence of a causal relationship (or correlations of objective measures of telepresence and performance). The relationship between telepresence and performance was evaluated by manipulating levels of telepresence within the VR simulation of the basketball free-throw task through changes in viewpoint, background fidelity, auditory cues, and the position of a user's self-representation (virtual player) in the VR relative to the virtual basket/goal.

3.2 Tasks and Equipment

The task was a high fidelity, three-dimensional (3-D) simulation of a basketball free-throw presented in a VR. The simulation was programmed using Sense8's WorldUp VR development package. It was presented to users through a HMD integrated with a SGI workstation. User control inputs occurred via an Ascension Technologies 6 degree-of-freedom (DOF) mouse. The HMD was used to isolate subjects' vision to the VR and to simulate 3-D viewing of the VR (see Figure 2). Subjects were asked to shoot virtual basketballs and to attempt to make as many baskets/goals as possible in a set amount of time (2-minute periods). Subjects controlled the virtual player in shooting the ball, in particular how much force was used in order to send the ball to the goal. In this study, the subject controlled the shooting motion of the basketball in the VR through hand movements recorded by the Flock-of Birds (FOB) motion tracker (see Figure 3). The point of release of the basketball was defined by the computer system at the outset of the experiment. Based on the anthropometry of each subject, when the mouse was held in the hand and the upper arm was held in a horizontal position, the basketball was released by the virtual player when the lower arm achieved a right angle with the upper arm. No mouse click was needed to shoot a ball. Subjects could not control the dribble of the basketball. Initially the virtual basketball player stood in one position. Subjects were not permitted to change this position. After the experimenter calibrated the arm position of the subjects, subjects repeatedly attempted a specific shot in order to score as many goals as possible. In general, the computer recorded task performance automatically. Performance was defined as the number of baskets and the percentage of shots made. Telepresence was measured both objectively and subjectively using secondary task measures and subjective ratings.

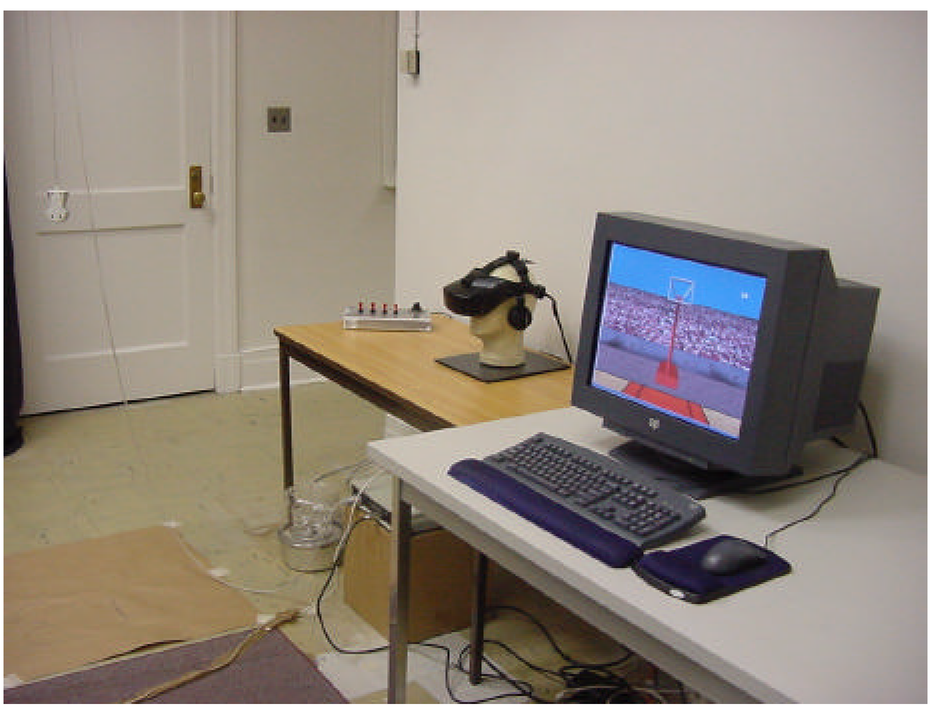

Figure 2: Equipment setup of the experiment

Figure 3: User immersed in virtual basketball task

In addition to shooting basketballs, the subjects were required to attend to two secondary tasks during test trials, which involved the detection of random visual cues both in the simulation and outside the VR (in the real world (RW)). The random cues were modeled as photoflashes in the stands of the virtual basketball stadium and real strobe light flashes in the actual research laboratory. Subjects were required to say “flash” or “light” when they detected either of the random cues. Sequences of the camera and strobe light flashes were controlled using a software algorithm and programmable logic controller. They were randomized for each subject and the same sequences were used across subject groups corresponding to the viewpoint settings. The secondary tasks were expected to provide information on the distribution of subject attentional resources across the VR and RW.

3.3 VR Simulation

The simulation presented a basketball stadium in which a player makes free-throw and 3-point shots. The basketball court had all of the conventional lines painted on it, and the goal had a backboard with a rim. There were two different backgrounds available in the simulation. One included gray walls, and the other showed a stadium with a crowd watching the player. One view was rendered and the other was textured. The stadium also had a scoreboard.

The proportions of object sizes in the simulation were representative of the proportions that would be expected in a real basketball game (i.e., the size of the court and the player were scaled realistically based on measurements of an actual college basketball court). Different models of the basketball player were presented as part of the simulation to ensure compatibility with the handedness of research participants.

3.4 Participants

Forty subjects were recruited from the North Carolina State University graduate and undergraduate student populations for voluntary participation in the study. Eight of these subjects were used in a pilot study in order to determine the necessary overall sample size for the experiment to ensure sensitive tests of the research hypotheses. The subjects were exposed to a special test condition not involving performance of either of the secondary tasks. The remaining 32 subjects participated in the actual experiment. No prior knowledge was needed for use of the simulation. All subjects were required to have 20/20 or corrected to normal visual acuity. All volunteers were compensated at a rate of $7.5 per hour.

3.5 Variables

3.5.1 Independent

Viewpoints: Each subject experienced one of four viewpoint conditions including an egocentric view (Figure 4), an exocentric view from behind the player (Figure 5), and an exocentric view from the sideline of the court (Figure 6). The fourth viewpoint condition allowed subjects to chose from the other three viewpoints. When using the egocentric viewpoint, subjects were able to see virtual representations of his/her arms when making a shot.

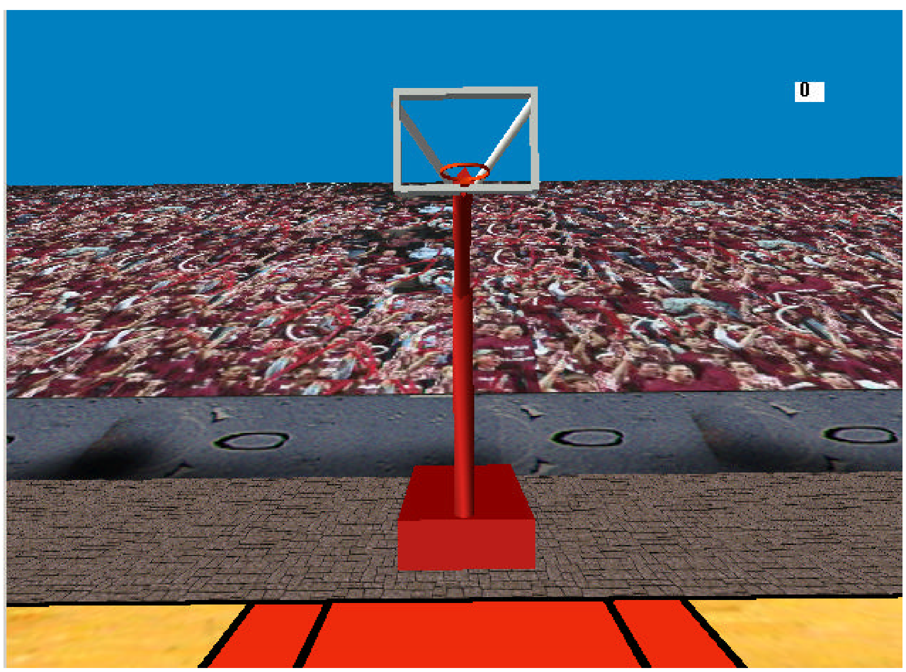

Figure 4: Simulation with egocentric viewpoint

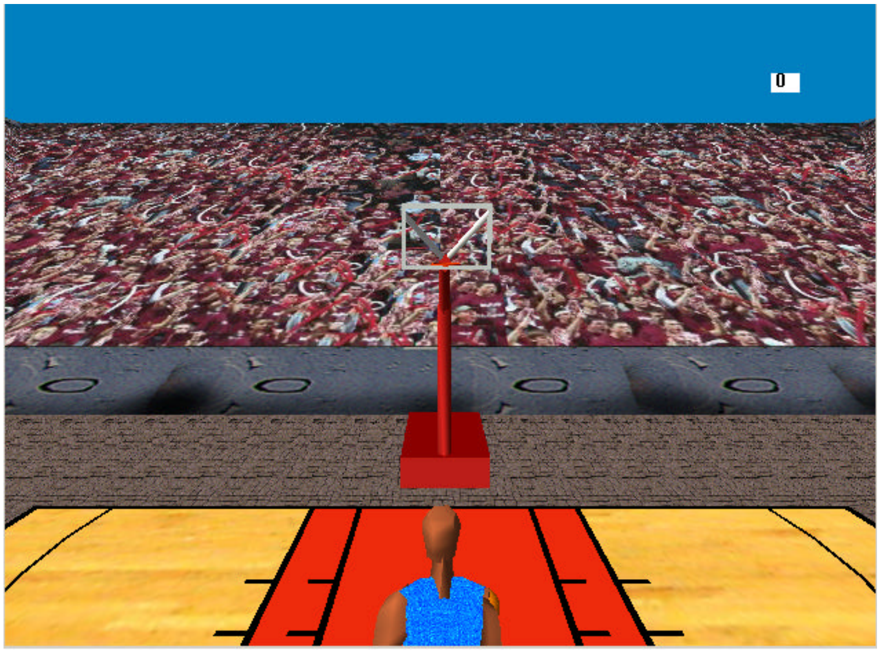

Figure 5: Simulation with exocentric (behind player) viewpoint

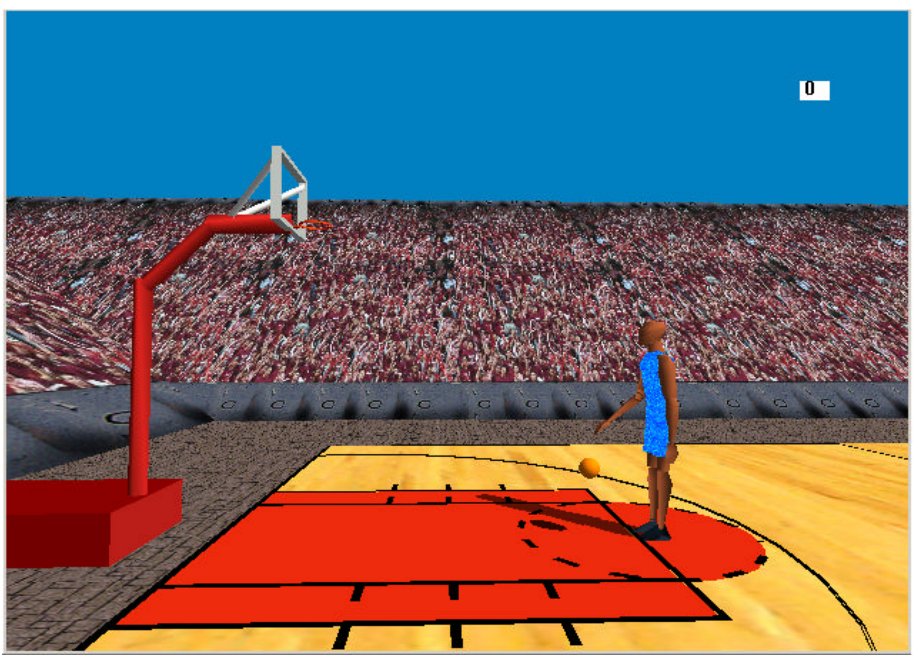

Figure 6: Simulation with exocentric (sideline) viewpoint

Sounds: Each subject was exposed to four levels of sound including task-relevant sounds, task-irrelevant sounds, a combination of task relevant and irrelevant sounds, and no sound. The relevant sounds included the sounds of the ball bouncing on the floor, bouncing off of the backboard or off of the rim, and cheering. There was also a sound to indicate the success of a shot ("swish"). The irrelevant sounds included sounds of crowd noise, sounds of a shot clock, and arena music. Table 1 presents a list of the specific sounds included in each of the identified categories along with descriptions.

Table 1: Categories of sounds

	Name of sound	Description of sound
Relevant sound (1)	"Board"	Basketball hits the backboard or rim
	"Swish"	Basketball goes through the net
	"Dribble"	Basketball bounces
	"Cheer"	Crowd makes noises symbolizing enthusiasm
Irrelevant sound (2)	"Miss"	Crowd makes noises symbolizing disappointment
	"Organ"	Organ plays crowd motivating music
	"PA squeal"	The sound on the speaker squealing
	"Shot-clock"	Shot clock sounds to signal time is up
	"Clap"	Crowd claps
	"Whistle"	The sound of a whistle
Both (3)	Relevant and irrelevant sounds	
None (4)	No sound	

Background: Each subject experienced two background conditions including a low fidelity stadium, as shown in Figure 7, and high fidelity stadium, as shown in Figure 8. The "poor" background was composed of rendered, plain gray, walls surrounding the basketball court. The "good" background displayed a texture of a crowd watching the game.

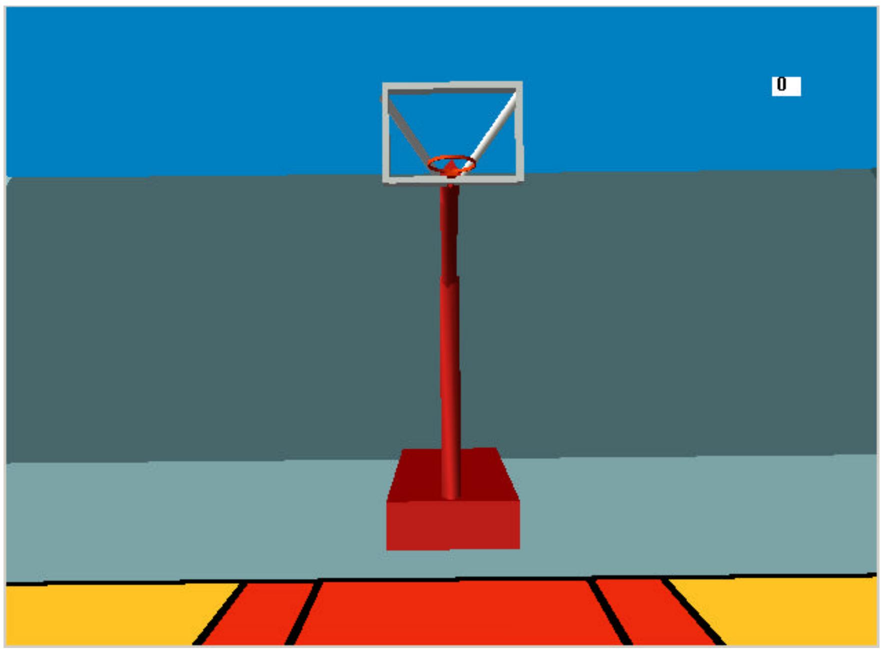

Figure 7: Simulation with low-fidelity background

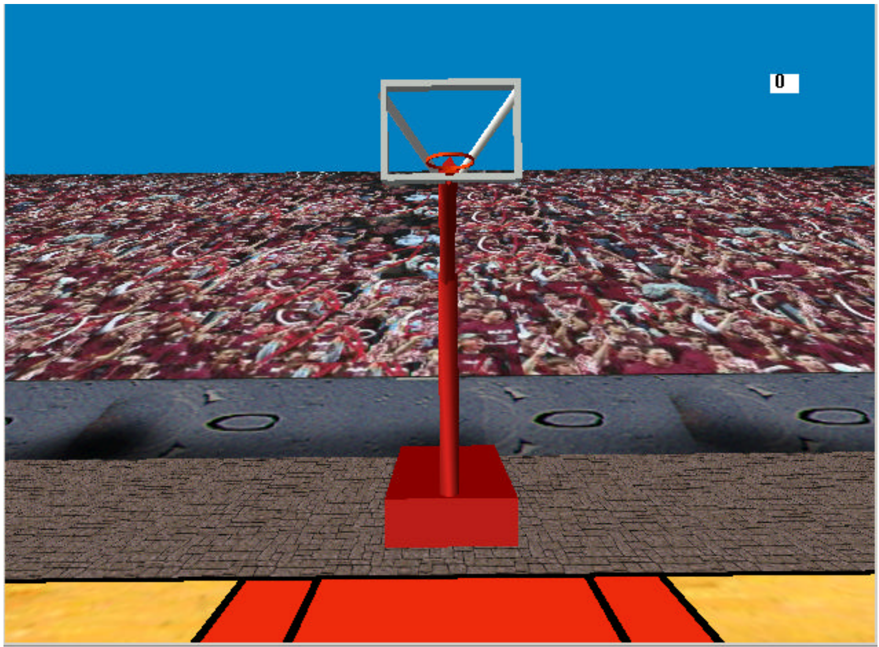

Figure 8: Simulation with high-fidelity background

Distance: Each subject experienced four different shot positions during the course of the experiment. There were two levels of distance to the goal as mentioned above. The distance varied randomly for each sound and background condition. There were 2-point and 3-point positions directly in front of the basket/goal (Figure 9 and 10) and 2-point and 3-point positions on the right side of the court at an angle to the basket/goal (Figure 11 and 12).

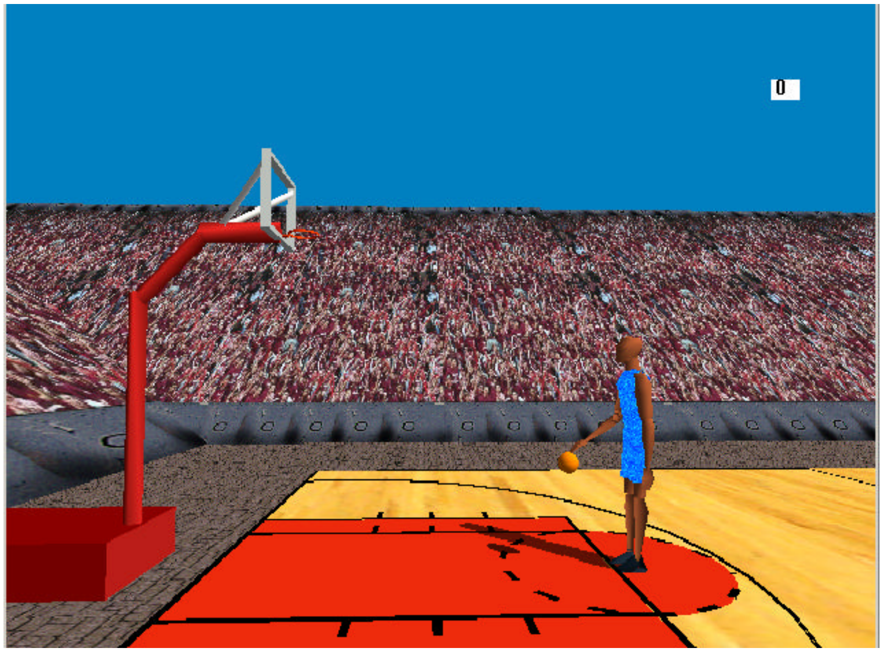

Figure 9: Simulation scene for direct 2-point shot

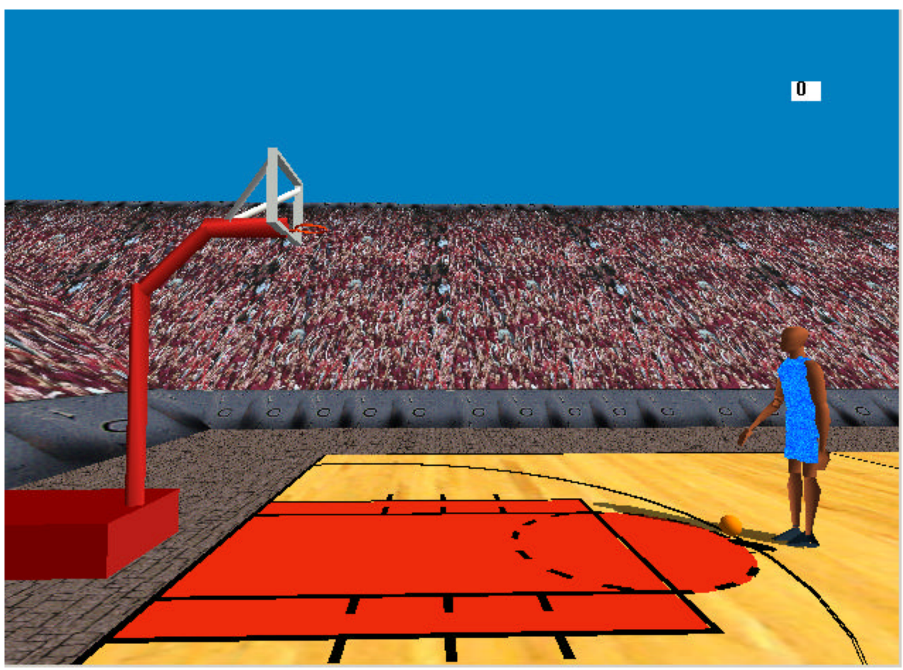

Figure 10: Simulation scene for direct 3-point shot

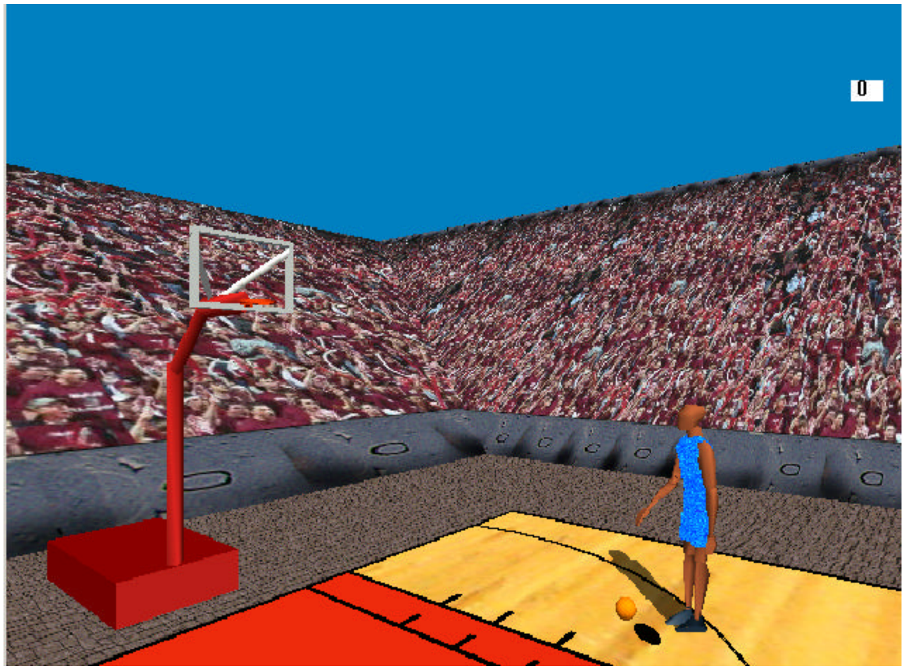

Figure 11: Simulation scene for 2-point shot at an angle

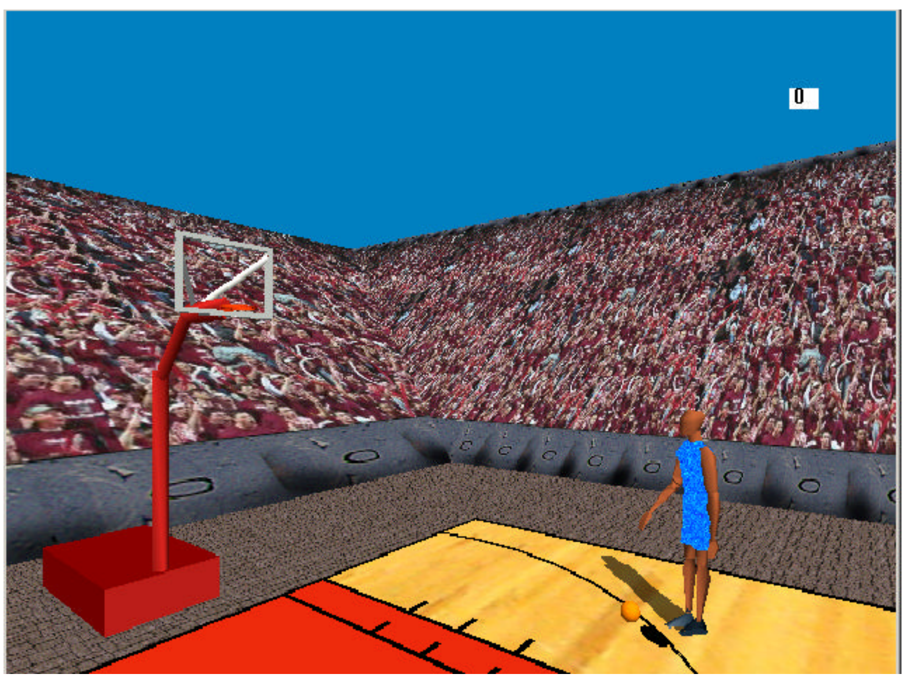

Figure 12: Simulation scene for 3-point shot at an angle

3.5.2 Dependent

Performance: Virtual basketball performance was measured as the number of successful shots made in a 2-minute period and as the percentage of successful shots to total shots attempted.

Telepresence: Telepresence was measured subjectively using a 2-question telepresence questionnaire developed by Draper and Blair (1996), administered after every trial (see Appendix F). Telepresence was also objectively measured in terms of secondary-monitoring task performance (signal detection rate) during the trials. It has been hypothesized that increases in allocation of attentional resources to remote task information may cause increases in telepresence. Significant correlations have been revealed between telepresence and SA, telepresence and attention to a VR by studies of Kaber and his colleagues (Riley and Kaber, 2001), supporting the use of SA and attention allocation as objective measures of telepresence. In this experiment, the secondary tasks randomly presented visual cues irrelevant to the primary task (camera flashes in the stands of the basketball stadium and strobe light flashes in the research lab). Telepresence was quantified as the ratio of performance in the camera flash detection and strobe light detection. This measure is similar to the attention allocation measure used by Riley and Kaber (2001). A high ratio will be considered indicative of increased attention allocation to the VR and a greater potential for telepresence.

Workload: Mental workload was measured after every trial by asking subjects to mark on a Visual Analog Scale (VAS) the level of mental demand experienced during the trial (see Appendix F). The scale was 5 inch in length and included “low” and “high” anchors at opposite ends. Subjects were asked to mark an "X" on the scale at the position they felt best represented the level of task load experienced during a test trial.

3.6 Design

A mixed design was used for this experiment. An equal number of subjects were randomly assigned to groups according to the levels of the viewpoint condition (egocentric, exocentric from behind the player, exocentric from the sideline, subject-preferred viewpoint), as shown in Table 2. The subjects in the same columns of this table followed the same trial orders, which were generated randomly. The auditory cues and background of the VR were controlled as within subjects' variables. Each subject completed 2 trials under each of 8 experimental conditions, totaling 16 trials (4 sound levels x 2 backgrounds x 2 trials). The four settings of shot position were balanced across the test trials for two subjects allowing for all combinations of position, sound and background fidelity to be investigated. Each subject experienced half of the test trials at the 2-point distance and half at the 3-point distance. Similarly each subject completed 8 trials with a direct shot to the basket and 8 trials shooting baskets from the right side of the court. This study focused on the shot distance as a task difficulty factor. The entire data collection table for the experiment is presented in Table 3, which included the viewpoint, visual background fidelity, sound and shot distance variables.

Table 2: Subject groupings

Viewpoint	Subject#							
Egocentric (1)	1	2	3	4	17	18	19	20
Exocentric From Behind Player (2)	5	6	7	8	21	22	23	24
Exocentric From Sideline (3)	9	10	11	12	25	26	27	28
Selectable (4)	13	14	15	16	29	30	31	32

Table 3: Experiment design - complete data collection table

<table>
<tr><th colspan="6" rowspan="3">Within-Subjects Variables</th><th colspan="4">Between-Subjects Variable</th></tr>
<tr><th colspan="4">Viewpoint</th></tr>
<tr><th>Egocentric (1)</th><th>Exocentric From Behind Player (2)</th><th>Exocentric From Sideline (3)</th><th>Selectable (4)</th></tr>
<tr><td rowspan="16">Background Fidelity</td><td rowspan="8">Low (1)</td><td rowspan="16">Shot Distance</td><td rowspan="4">2-point (1)</td><td rowspan="16">Sound</td><td>Relevant (1)</td><td rowspan="16">Subject Number: 1, 2, 3, 4, 17, 18, 19, 20</td><td rowspan="16">Subject Number: 5, 6, 7, 8, 21, 22, 23, 24</td><td rowspan="16">Subject Number: 9, 10, 11, 12, 25, 26, 27, 28</td><td rowspan="16">Subject Number: 13, 14, 15, 16, 29, 30, 31, 32</td></tr>
<tr><td>Irrelevant (2)</td></tr>
<tr><td>Relevant + Irrelevant (3)</td></tr>
<tr><td>None (4)</td></tr>
<tr><td rowspan="4">3-point (2)</td><td>Relevant (1)</td></tr>
<tr><td>Irrelevant (2)</td></tr>
<tr><td>Relevant + Irrelevant (3)</td></tr>
<tr><td>None (4)</td></tr>
<tr><td rowspan="8">High (2)</td><td rowspan="4">2-point (1)</td><td>Relevant (1)</td></tr>
<tr><td>Irrelevant (2)</td></tr>
<tr><td>Relevant + Irrelevant (3)</td></tr>
<tr><td>None (4)</td></tr>
<tr><td rowspan="4">3-point (2)</td><td>Relevant (1)</td></tr>
<tr><td>Irrelevant (2)</td></tr>
<tr><td>Relevant + Irrelevant (3)</td></tr>
<tr><td>None (4)</td></tr>
</table>

Consequently, the design yielded 2 replicates for each fidelity, sound and position condition, 4 replicates for each fidelity, sound, and distance combination, and 8 replicates under each fidelity and sound combination per pair of subjects. The experimental condition setup was the same for all four viewpoints.

3.7 Training

Before subjects began the experiment, they were provided with a dedicated training session, including learning to control the simulated basketball player and making a shot within the VR by using the Ascension Technologies 6-DOF mouse. Subjects were familiarized with the secondary tasks. In order to not introduce a bias from the training session into the full experiment, the training simulation was a simplistic version of the experimental task, which was repeated for all training trials. The differences between the training and full experiment setups are summarized in Table 4 and an image of the training simulation is shown in Figure 13.

Each subject was provided four 2-minute trials to practice the task. Figure 14 shows the average performance trends (learning curves) for all subjects across the four training trials. In general, it can be observed from the plot that subjects achieved the highest average task performance by the third trial, and then their learning of the task (shooting performance) appeared to plateau at the fourth trial. This graphical analysis served as a basis for establishing that subjects understood the task procedure.

Table 4: Comparison of training and experiment conditions

	Training	Full experiment
Viewpoint	Same for training and full experiment	Same
Sound	Relevant (excluding cheering)	All of the sound conditions (relevant, irrelevant, both, none)
Shot position	From an angle at the left side of the court. One distance was used between the 2 and 3 point shot distances.	Four positions including 2 and 3 point shots directly in front of the basket and from an angle at the right side of the court.
Fidelity	Textured image of stadium benches (as a background).	Rendered and fully textured background.
Camera flash and strobe light	NO	YES
Use of Flock of Birds	YES	YES
Use of head-mounted display	YES	YES

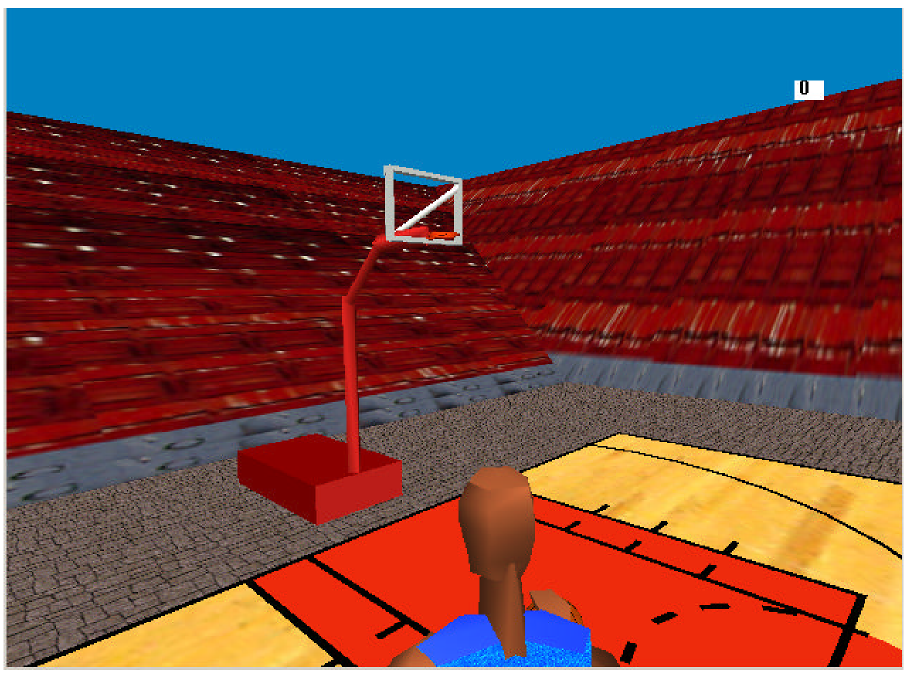

Figure 13: Simulation for training participants (exocentric (behind player) view of medium fidelity background)

Figure 14: Average baskets across four training trials

3.8 Hypotheses

If telepresence and performance are unique phenomenon, manipulations of each of the independent variables were expected to affect the response measures in different ways. Table 5 summarizes the overall expected levels of telepresence and performance for each condition. The table essentially presents hypotheses on performance behavior and telepresence experiences and suggests the expected relationship of the specific measures under the various experimental conditions. It should be noted that the distance variable served to increase the level of task difficulty for the subject and was expected to primarily influence performance. Changes in the distance condition ensured that repeated exposure to specific combinations of fidelity and sound remained novel for subjects.

Table 5: Summary of expected telepresence and performance results

Variable	Telepresence	Performance
SOUND		
No sound	Minimum	Poor to worst
Irrelevant sound	Low	Poor to worst (distracting?)
Relevant sound	High	Good to best (provides feedback as basis for adjusting actions)
Irrelevant + relevant sound	Maximum	Good to best (but irrelevant sounds may be distracting)
BACKGROUND		
Low fidelity	Low	No difference in effect, unless too much visual clutter leads to distraction under high fidelity.
High fidelity	High	
VIEWPOINT		
Egocentric	High to maximum	Poor
Exocentric-behind player	Low	Worst (cannot see ball at beginning of shot)
Exocentric-sidelines	Minimum	Good to best (better view of z-axis depth)
Selectable	High to maximum	Good to best
POSITION		
2-point on straight line	No difference in effect expected	Best
3-point on straight line		Poor to good
2-point on off angle line		Poor to good
3-point on off angle line		Worst

In general, it was hypothesized that telepresence is different from performance. It was expected that increases or decreases in performance might occur in conjunction with increases or decreases in telepresence. The specific hypotheses for the experiment included the following:

(1) In regard to auditory cue effects on telepresence, it was expected that the addition of either task relevant or irrelevant stimuli would contribute to the sense of telepresence in the VR. More specifically, it was hypothesized that task relevant information would prove to be more important to telepresence ratings than task irrelevant information. This is because with task relevant cues, the user actions in the simulation

would be perceived as having an impact on the auditory characteristics of the VR. Providing both types of sound was expected to elicit the highest telepresence ratings. The subject would receive the most cues that related to the surrounding environment and to their activities. Telepresence was also expected to be higher under the irrelevant sound condition than no sound whatsoever because the user would receive more cues on what was occurring in the environment.

(2) In regard to the effect of auditory cues on performance, we expected that task irrelevant sound might compromise performance in comparison to both no sound whatsoever and task relevant sound because of possible distraction from the latter setting. It was also expected that task relevant sounds would improve performance as a result of feedback on subject actions in the simulation. It was expected that presentation of relevant auditory cues and both relevant and irrelevant sounds would produce similar performance results, as they provided the same level of assistance in completing the task. The user received feedback from the relevant sounds in order to adjust his/her actions in future shots.

(3) With respect to visual cues, it was predicted that there would be no difference in performance between the high and low fidelity backgrounds. There were no cues provided in either background that directly aided in the completion of the basketball-shooting task. However, telepresence was expected to be greater in the high fidelity simulation because the user had a more realistic view of the environment. Similar to the sound settings, there might be distractions associated with a more complex background; therefore, having a high-fidelity background might actually decrease performance.

(4) With respect to viewpoint, the egocentric view was expected to yield the highest telepresence ratings because it provided subjects with the greatest degree of immersion in the environment and performance of the task. Telepresence differences among these conditions might also be attributable to the nature of the task, as dictated by the viewpoint. In regard to performance, the egocentric condition was not expected to produce the highest scores because the user did not have as good of a sense of the distance to the backboard as with the exocentric view from the sidelines. The sideline exocentric view allowed subjects to see the axis that they were working in (*z*-axis or depth) and enabled them to better visualize the distance between the player and the goal. The selectable viewpoint was expected to provide high performance and telepresence ratings because the subject could exploit the advantages of each viewpoint. It was also hypothesized that the selectable (or dynamic) viewpoint might provide higher telepresence than the egocentric view because it encouraged a subject's sense of control.

(5) With respect to the interaction of the auditory cues and VR background, it was expected that cue correspondence (interaction) might be important to subjects. That is, the impact of presenting task irrelevant sounds (e.g., fans cheering a "miss") on telepresence may be moderated by whether a user was provided with visuals of the objects that produce such sounds (a cheering crowd). Therefore, telepresence ratings under the irrelevant auditory cueing condition were expected to be greater with a high-fidelity background presenting texture maps of a cheering crowd, etc.

3.9 Procedures

Table 6 presents a list of all the steps in the experimental procedure for each subject along with time estimates.

Table 6: Overview of experimental procedure and rough time

Step in procedure	Time (minutes)
1. An Introduction to the experiment, including informed consent (see Appendix B).	5-10
2. Collection of anthropometric survey data (see Appendix C).	5
3. Familiarization with HMD and the Ascension Technologies 6-DOF mouse	5
4. Administration of Immersive Tendencies Questionnaire (ITQ) (see Appendix E) to gauge susceptibility of subjects to telepresence experiences.	10-15
5. Familiarization with experimental conditions (sounds, background, etc.).	20
6. Administering a sim-sickness questionnaire (SSQ) (see Appendix G).	5
7. Familiarization with the telepresence survey and mental workload rating scale (see Appendix F).	5
8. Completion of 4 training trials.	15-20
9. A 5-minute break including SSQ.	5
10. Familiarization with the secondary tasks.	5-10
11. Completion of 8 trials, each of which were followed by the telepresence survey and the workload rating.	25
12. A 5-minute break including SSQ.	5
13. Completion of a second set of 8 trials (total of 16 trials), each of which will be followed by the telepresence survey and the workload rating	25
14. Sim-sickness questionnaires (SSQ) completed after test trial 16.	5

The total experiment time for each subject was approximately 2 hours and 30 minutes.

The testing protocol was used to expose each subject to a single viewpoint condition. The type of sound and the level of background fidelity were varied across trials. Each subject completed 16 trials under 8 experimental conditions. He/she completed 2 trials (replications) under the 4 sound and 2 backgrounds conditions. One trial was at the 2-point shot distance, and one was at the 3-point shot distance, which was determined randomly. Each trial lasted two minutes. After each trial, subjects completed the telepresence questionnaire and the workload rating. After half the test trials had been completed and at the close of the experiment, the sim-sickness questionnaire was administered (see Appendix A for complete instructions to participants delivered during the experiment).

4 Data Analysis

All statistical analyses were performed using SAS (Statistical Analysis Software). They included multi-way analyses of variance (ANOVA) applied to the dependent variables to investigate the influence of viewpoint, fidelity (level of detail of the VR background), sound, and task difficulty (shot distance) on the sense of telepresence and task performance. The full ANOVA model for the experiment can be written as follows:

$$Y_{ijklmn} = \mu + VP_i + F_j + S_k + D_l + SUB(VP)_{m(i)} + VP*F_{ij} + VP*S_{ik} + VP*D_{il} + F*S_{jk} + F*D_{jl} + F*SUB(VP)_{jm(i)} + S*D_{kl} + S*SUB(VP)_{km(i)} + D*SUB(VP)_{lm(i)} + VP*F*S_{ijk} + VP*F*D_{ijl} + VP*S*D_{ikl} + F*S*D_{jkl} + F*S*SUB(VP)_{jkm(i)} + F*D*SUB(VP)_{jlm(i)} + S*D*SUB(VP)_{klm(i)} + VP*F*S*D_{ijkl} + F*S*D*SUB(VP)_{jklm(i)} + \varepsilon_{n(ijklm)}$$

where,

Y_{ijklmn} = the response variable (e.g., total number of baskets, workload rating)

VP_i = Viewpoint

F_j = Background fidelity

S_k = Sound

D_l = Distance

$SUB(VP)m_{(i)}$ = Subject (nested in VP)

$\varepsilon_{n(ijklm)}$ = Experimental error

i = 1, 2, 3, 4

j = 1, 2

k = 1, 2, 3, 4

$l = 1, 2$

$m = 1, 2, 3, 4$

$n = 1, 2$

Although the distance manipulation was expected to have the potential to reveal interesting information about the relationship of telepresence to task performance, task difficulty had not been identified as an underlying factor in telepresence as frequently as the other sensory variables controlled in this study. Consequently, if distance did not appear to be significant in the full statistical model, the reduced model presented below was analyzed:

$$Y_{ijklm} = \mu + VP_i + F_j + S_k + SUB(VP)_{l(i)} + VP*F_{ij} + VP*S_{ik} + F*S_{jk} + F*SUB(VP)_{jl(i)} + S*SUB(VP)_{kl(i)} + VP*F*S_{ijk} + F*S*SUB(VP)_{jkl(i)} + \varepsilon_{m(ijkl)}$$

where,

Y_{ijklm} = the response variable (e.g., total number of baskets, workload rating)

VP_i = Viewpoint

F_j = Background fidelity

S_k = Sound

$SUB(VP)_{l(i)}$ = Subject (nested in VP)

$\varepsilon_{m(ijkl)}$ = Experimental error

$i = 1, 2, 3, 4$

$j = 1, 2$

$k = 1, 2, 3, 4$

$l = 1, 2, 3, 4$

$m = 1, 2$

An alpha level of 0.05 was used to identify any significant main effects of VP, F, or S and the presence of any significant interactions. Further investigation of significant predictors was conducted using post-hoc tests, specifically Tukey's Honestly Significant Difference tests with an alpha criterion of 0.05.

Correlation analyses were conducted to identify any potential relationships among the various response measures to be recorded during the experiment, including: (1) primary task performance measures and the subjective and objective (secondary task performance) measures of telepresence; (2) primary task performance measures and the subjective measure of workload; (3) subjective ratings of telepresence and the objective measure of telepresence (ratio of secondary task performance); and (4) subjective workload measures and the sense of telepresence. Pearson Product-Moment coefficients were calculated to establish the strength of any positive or negative linear associations of the responses. The SAS PROC CORR procedure was used to establish the statistical significance of the correlations of interest to the study.

5 Results

5.1 Subjects

Twenty-three males and 9 females participated in the actual experiment. The average age of the subjects was 23.7 years. All persons had 20/20, or corrected to normal, vision. As part of the anthropometric data survey, subjects were asked to rate their prior experience with VR applications, in playing video games, or simply using a PC. They were also asked about any experience playing basketball. With respect to VR experience, the average response (on a scale from 1 = "none" to 5 = "frequent") was low (1.7). With respect to playing video games, on average subjects indicated moderate experience (3.2). With respect to PC experience, the average subject rating indicated a high frequency of use (4.7). Finally, in regard to playing basketball, on average subjects reported relatively infrequent experiences (2.7).

5.2 Performance Measures

The results on an ANOVA on the full statistical model revealed a significant effect due to the task difficulty (shot distance) in terms of total baskets ($F(1,127) = 17.62$, $p<0.0001$) and the ratio of total baskets to total shots ($F(1,127) = 11.26$, $p<0.001$). There was a significantly greater number of baskets/goals at the 2-point distance than at the 3-point distance. Figure 15 presents the means for total baskets across the levels of task difficulty (shot distances). In general, the total number of baskets was a more sensitive measure of performance in this analysis than the number of baskets per shots attempted.

There were no significant interaction effects among the independent variables in terms of performance.

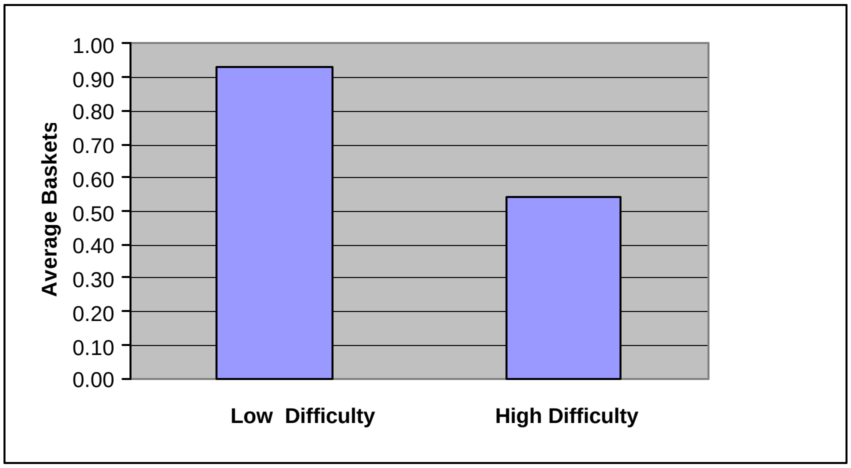

Figure 15: Average number of total baskets across levels of task difficulty (shot distances)

5.3 Telepresence Measures

The immersive tendencies of all subjects were recorded at the outset of the experiment using Witmer and Singer's (1994) ITQ measure. The questionnaire revealed a mean subject score of 60 (out of 126 possible rating points) with a standard deviation of 10.26. This measure is considered later in the results as part of a correlation analysis with telepresence ratings collected at the end of test trials. Initially, a 4 (viewpoint) x 2 (visual fidelity background) x 2 (shot distance, or task difficulty) x 4 (sound) ANOVA was conducted on the ratings on the two telepresence questions, which subjects completed using 7-point scales. Additional ANOVAs were also conducted on the sum of these ratings and the percentage of the maximum telepresence rating ((PQ1+PQ2) / 14 x 100). The ANOVAs on the full statistical model (including the task difficulty variable) revealed no significant effect of shot distance on the subjective sense of telepresence.

Consequently, this variable was dropped from the model, and the reduced model presented in the Data Analysis section was used to assess the influence of the other VR factors on telepresence ratings. The reduced model revealed significant main effects of auditory cue type, immersiveness (viewpoint) and individual differences on both telepresence ratings (PQ1 and PQ2) and the combined measures, including the sum of PQ1 and PQ2. The relevant F-test results and associated significance levels are presented for each independent variable and response measure in Table 7. There was no significant effect of background fidelity on any of the telepresence rating measures.

Table 7: F-test results on telepresence rating for various predictors

Predictor Variable	Response Measure			
	PQ1	PQ2	PQ1+PQ2	(PQ1+PQ2)/14x100
Sound*	F(3,63) = 15.26 P<0.0001	F(3,63) = 9.53 P<0.0001	F(3,63) = 13.44 P<0.0001	F(3,63) = 13.16 P<0.0001
Viewpoint*	F(3,63) = 4.77 P<0.01	F(3,63) = 6.03 P<0.01	F(3,63) = 4.82 P<0.01	F(3,63) = 4.74 P<0.01
Subject (viewpoint)*	F(4,63) = 6.09 P<0.0001	F(4,63) = 5.02 P<0.01	F(4,63) = 4.88 P<0.01	F(4,63) = 4.86 P<0.01

(Note: A asterisk (*) indicate a significant effect at p<0.01.)

As in evaluating the performance measures, the ANOVAs revealed no significant interaction effects on the PQ scores and integrated measures. Tukey's HSD tests on the individual telepresence ratings were conducted to further investigate the significant viewpoint and sound main effects. The post-hoc procedure on PQ1 revealed significantly higher (p<0.05) telepresence ratings under the sound condition including both relevant and irrelevant cues, the condition presenting only relevant sounds, and the irrelevant sound condition, as compared with the no sound condition. According to Tukey's tests, the egocentric viewpoint produced the greatest (p<0.05) sensations of telepresence in comparison to the exocentric view from the sideline, the selectable viewpoint, and the exocentric view from behind the player. The pattern of results on the PQ2 measure was basically identical with the combined relevant and irrelevant, relevant, and irrelevant sound conditions producing significantly higher ($p<0.05$) telepresence ratings than the no sound condition. This correspondence of results across the two telepresence questions was expected based on the original intention of Draper and Blair (1996) to make observations of the same construct through different phrasing of questions. Tukey's tests on the PQ2 response also revealed the egocentric viewpoint and selectable viewpoint to produce significantly higher ($p<0.05$) telepresence ratings than the exocentric view from the sideline, and the exocentric view from behind the player. This made sense as subjects also had access to the more immersive egocentric viewpoint under the selectable, or preferred, viewpoint condition. The pattern of results on the integrated telepresence measures were basically identical to the trends for the PQ1 and PQ2 responses, as the combined measures were merely additive and geometric transformations of the individual ratings. Therefore, the results of post-hoc procedures on these responses are not presented here. Figure 16 and 17 present the mean telepresence ratings across the levels of the sound condition and the viewpoint condition for the PQ1 and PQ2 measures, respectively. In general, subjective ratings of telepresence increased as a greater number of audio cues were presented in the VR and, in particular, as task relevant audio cues were added. With respect to the viewpoint conditions, it can be observed from the graph that the most immersive viewpoint and the viewing option that allowed subjects to select among all viewpoints produced higher perceived telepresence.

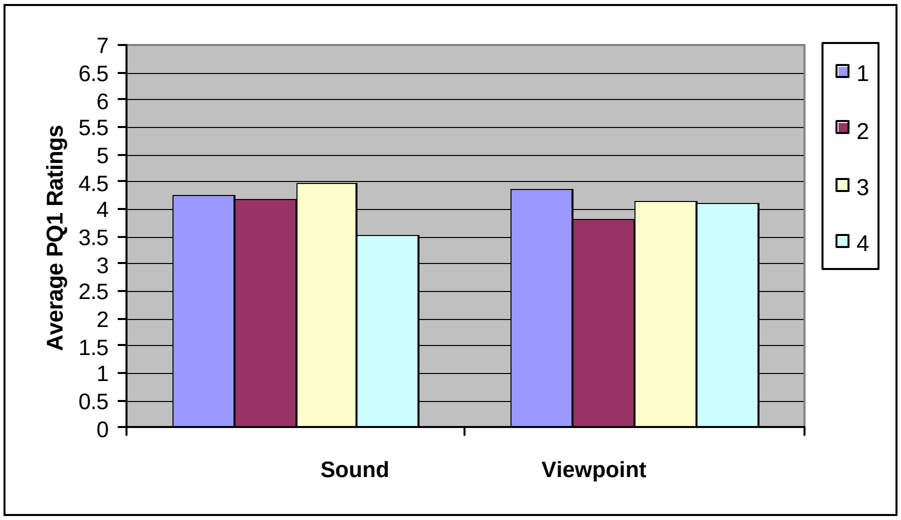

Figure 16: Average PQ1 ratings across sound and viewpoint conditions

(Note: For sound: 1 = Relevant; 2 = Irrelevant; 3 = Relevant and irrelevant; 4 = None. For viewpoint: 1 = Egocentric; 2 = Exocentric from behind player; 3 = Exocentric from sideline; 4 = Selectable.)

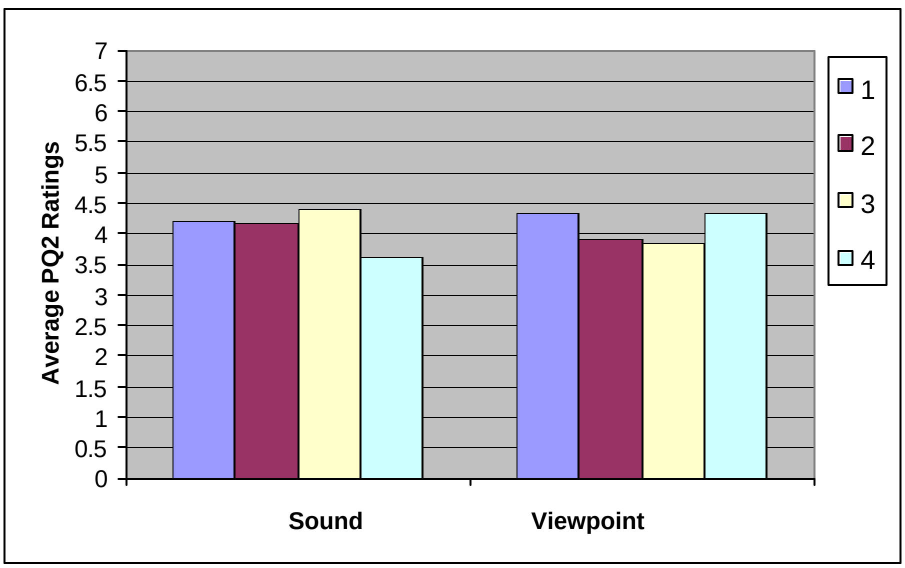

Figure 17: Average PQ2 ratings across sound and viewpoint conditions

(Note: For sound: 1 = Relevant; 2 = Irrelevant; 3 = Relevant and irrelevant; 4 = None. For viewpoint: 1 = Egocentric; 2 = Exocentric from behind player; 3 = Exocentric from sideline; 4 = Selectable.)

In general, it appeared that PQ1+PQ2 was the more sensitive of the two composite measures of telepresence evaluated in this study. Consequently, it was used along with the total number of baskets in additional analyses of the relationship between telepresence and task performance. The trends of normalized telepresence and performance scores are compared later in this section.

5.4 Objective Measure of Telepresence

An ANOVA on the full statistical model revealed no significant effect of shot distance (task difficulty) on secondary task performance or the ratio of performance in camera flash detection to performance in strobe light detection. Consequently, the reduced statistical model (not including the shot distance variable) was used to investigate the influence of the various VR features on the objective measure of telepresence. However, there appeared to be no significant effects of audio cue type, background fidelity or viewpoint on the objective sense of telepresence. There were also no significant interaction effects. In general, these results were unexpected based on Riley and Kaber's (2001) finding that a similar attention-based, objective measure of telepresence was significant in explaining variations in subjective ratings of telepresence (PQ scores using Witmer and Singer's (1994) measure). More will be said about this in the Discussion section.

Related to this analysis, the sensitivity of each secondary task measure for indicating changes in operator attention allocation strategies due to the VR feature manipulations was also assessed. The reduced statistical model was used to identify any significant effects of viewpoint, auditory cue, and background fidelity in signal detection in the VR and RW secondary tasks. An ANOVA on secondary task performance in VR revealed significant influences of background fidelity ($F(1,63) = 11.10$, $p<0.001$) and individual differences ($F(4,63) = 2.73$, $p<0.05$). Figure 18 presents a means plot on the hit-to-signal ratio in the camera flash detection indicating substantially better performance under the low fidelity condition. There was a significantly greater detection rate in the secondary task in VR at the low background fidelity than at the high background fidelity. The high background fidelity provided more visual demand or noise, and may have distracted subjects from the perception of the camera flashes in the VR.

The reduced statistical model also revealed significant main effects of viewpoint ($F(1,63) = 6.58$, $p<0.001$) and individual differences ($F(4,63) = 4.46$, $p<0.01$) on the detection rate in the secondary task in the RW (strobe light detection). Figure 19 presents a graph of the average hit-to-signal ratio in strobe light detection for the various viewpoint conditions. Tukey's HSD tests indicated there was a significantly lower ($p<0.05$) signal detection rate in the secondary task when the immersive viewpoint and exocentric view providing information on the distance between the player and the basket were used by subjects. There were no significant interaction effects of the various VR features on either of the secondary task measures.

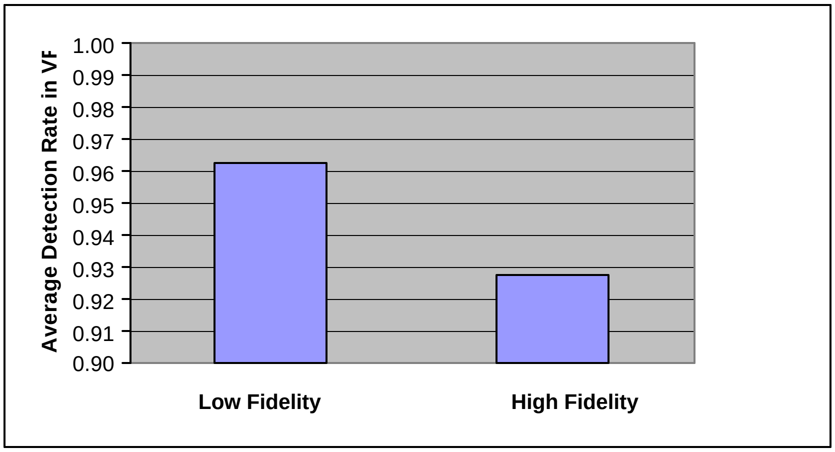

Figure 18: Average detection rate in secondary task in VR across background fidelity conditions

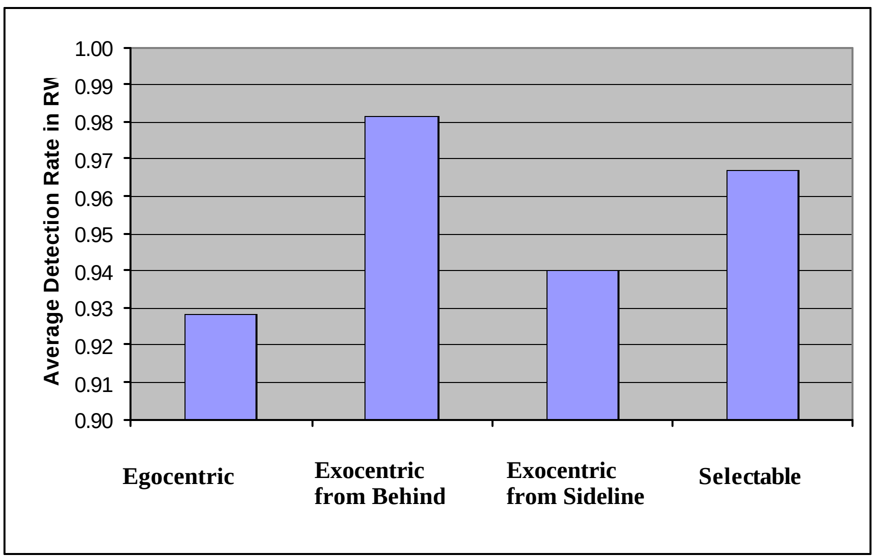

Figure 19: Average detection rate in secondary task in RW across viewpoint conditions

5.5 Workload Measures

An ANOVA on the full statistical model revealed significant effects of viewpoint ($F(3,127) = 16.23$, $p<0.0001$) and audio cue type ($F(3,127) = 3.28$, $p<0.05$) on subjective workload captured using the uni-dimensional rating scale. Individual differences within viewpoint condition were also significant ($F(4,127) = 4.65$, $p<0.01$) in effect on workload ratings. There were no significant interaction effects among VR features on workload.

Tukey's HSD test was used to further investigate the significant workload effects. Results indicated workload to be significantly greater ($p<0.05$) when subjects used the selectable (or preferred) viewpoint, exocentric view from the sideline and egocentric viewpoint as compared with the exocentric view from behind the player. That is, the lowest ratings ($p<0.05$) of workload were recorded under the exocentric view from behind the player. With respect to the audio cue type, significantly lower ($p<0.05$) ratings of workload were recorded under the no cue condition, as compared to the use of relevant, irrelevant, and both relevant and irrelevant sounds in the VR.

Figure 20 presents a plot of the mean workload ratings for each viewpoint condition. In general, it can be observed from the graph that the immersive viewpoint and the viewing option that allowed subjects to select among all viewpoints produced higher perceived workload. Figure 21 presents a plot of mean workload ratings for each audio cue type condition. In general, subjective ratings of workload increased as a greater number of audio cues were presented in the VR and as irrelevant cues were added.

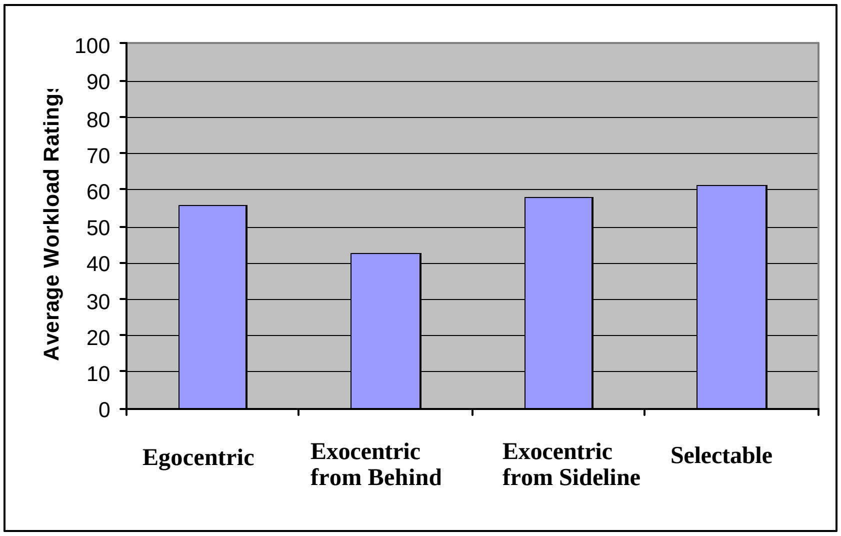

Figure 20: Average workload ratings across viewpoint conditions

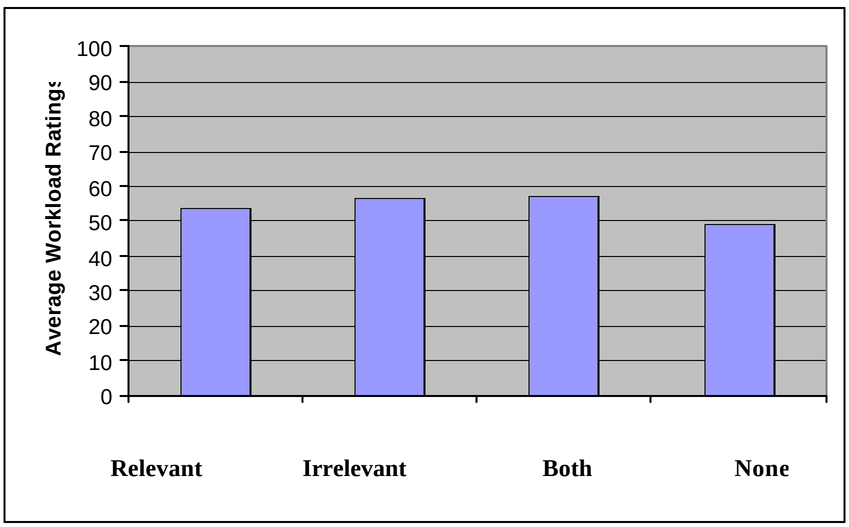

Figure 21: Average workload ratings across sound conditions

The independent analyses of each of the secondary task measures may also be considered as evaluations of objective workload in the overall dual-task scenario, as secondary tasks have been found to be valid and reliable indicators of workload (Wickens, 1992). Interestingly the results on the main effect of viewpoint on strobe light detection generally corresponded with the subjective ratings of workload collected using the VAS on mental demand. The exocentric view from behind the player reduced subjective perceptions of load and allowed for improvements in the hit-to-signal ratio in the secondary task. In addition, those viewpoints producing the lowest mean number of strobe detections, including the egocentric viewpoint and exocentric view from the sideline, also produced significantly higher ratings of workload.

5.6 Telepresence and Performance in the Virtual Basketball-Shooting Task

Since the ratio of secondary task performance calculated as part of this study did not appear to be a sensitive indicator of the phenomenon of telepresence, in order to provide further insight into the relationship of telepresence and human performance through SEs, in this section of the analysis, normalized values developed based on the summation of the PQ1 and PQ2 ratings, as well as the total number of baskets made in trials, are related to each other and trends in the data are examined across settings of the various independent variables found to be significant in influencing either of the original response measures. The normalized scores were determined by dividing each telepresence rating or basket score by the minimum rating or worst score under each cue type condition.

Recall that telepresence ratings were significantly influenced by the users viewpoint and the type of auditory cues presented in the VR; whereas, performance was only affected by the shot distance manipulation. Related to this, there was no expectation that the shot distance would have a direct and substantial impact on telepresence ratings (i.e., an indirect affect might have been possible as a result of task difficulty impacting subject perceptions of workload and, consequently, telepresence). Table 8 presents the means and normalized values for the combined telepresence measure (PQ1+PQ2) and total baskets across the various experimental conditions. The table also includes subjective categorizations of the ratings and scores identical to the categories used in Table 5 to summarize the research hypotheses under the various viewpoint, background fidelity, auditory and task difficulty conditions. The categorization of scores in Table 8 (based on relative comparisons of scores) for those independent variables that were significant in effect on telepresence and performance almost completely conforms to the hypotheses reflected through Table 5, save the trend of performance across the various sound conditions.

Table 8: Means and normalized values of telepresence and performance by cue types

Cue types		PQ1+PQ2			Total Baskets		
		Average Rating	Categories	Normalized value	Average Score	Categories	Normalized value
Viewpoint	Egocentric	8.73*	Maximum	1.13	0.65	Worst	1.00
	Exocentric Behind	7.70*	Minimum	1.00	0.79	Good	1.22
	Exocentric Beside	7.99*	Low	1.04	0.71	Poor	1.09
	Preferred	8.41*	High	1.09	0.80	Best	1.23
Fidelity	Low Fidelity	8.16	Low	1.00	0.81	Good	1.23
	High Fidelity	8.26	High	1.01	0.66	Poor	1.00
Distance	2-point	8.21	No difference	1.00	0.93*	Good	1.72
	3-point	8.20		1.00	0.54*	Poor	1.00
Sound	Relevant	8.47*	High	1.19	0.78	Good	1.18
	Irrelevant	8.34*	Low	1.17	0.83	Best	1.26
	Both: Relevant and Irrelevant	8.89*	Maximum	1.25	0.66	Worst	1.00
	None	7.13*	Minimum	1.00	0.68	Poor	1.03

(Note: A asterisk (*) indicates a significant effect at $p<0.01$.)

The different trends of the normalized results for telepresence and performance can be seen in Figure 22 through 25. Although the difference in the telepresence and performance responses may have resulted from "third variables" (as described by Nash et al., 2000), which were not accounted for in the statistical model, the graphs generally indicate that telepresence is a phenomenon unique from performance. However, caution must be taken interpreting the graphs, as they do not describe a causal link between telepresence and performance, but merely the association of changes in telepresence experiences and performance under various SE conditions. Furthermore, the trends depict the relative relationship of the response measures in the virtual basketball task. It is entirely possible that different trends might occur for other tasks, more or less complex.

Figure 22 shows that the immersive viewpoint contributed to an increase in telepresence, but served to degrade performance (possibly due to a lack of subject capability to visualize/see the position of the player relative to the basket) in comparison to all other conditions. As can be seen in the graph the exocentric viewpoint served to improve performance but telepresence decreased. Not surprisingly the selectable viewpoint condition produced performance improvements over all other conditions and promoted telepresence possibly because of subject capability to use the egocentric viewpoint under this condition in addition to the two exocentric viewpoints.

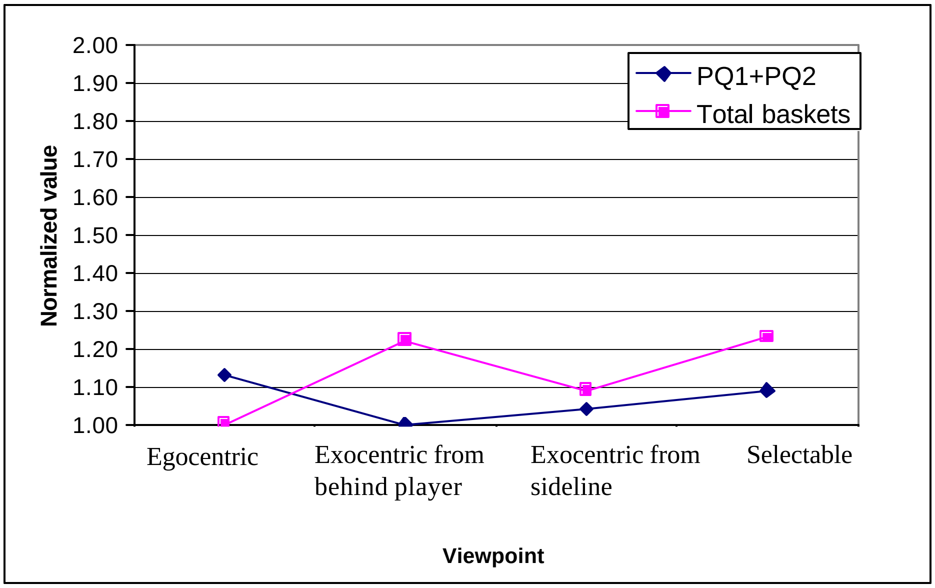

Figure 22: Normalized values of telepresence and performance across viewpoint conditions

The trends on differences in telepresence and performance across the background fidelity conditions are presented in Figure 23. As hypothesized, performance appeared to degrade as the complexity of the background and the levels of visual distractions increased. Somewhat unexpectedly, telepresence only increased slightly from the low to high fidelity conditions. Based on previous research (Barfield, et al., 1995), it was expected that the level of visual realism and richness of the VR would drive substantial changes in telepresence.

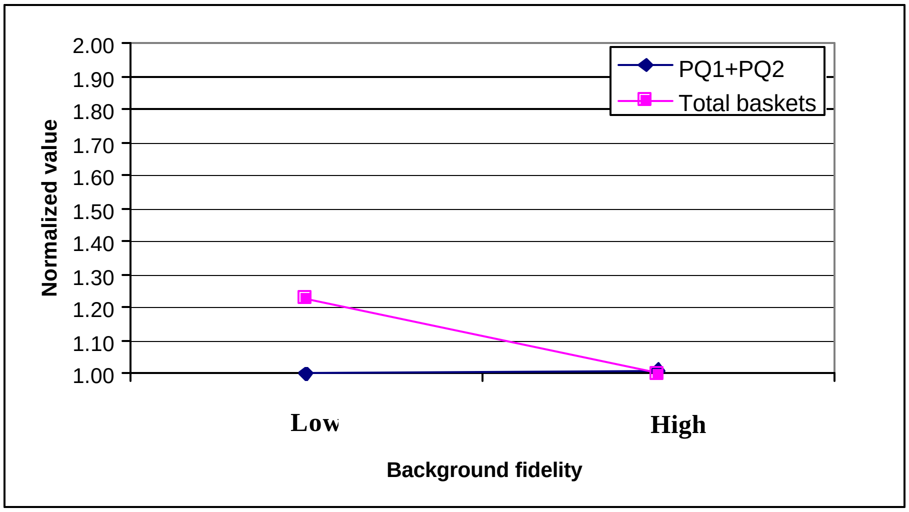

Figure 23: Normalized values of telepresence and performance across fidelity conditions

The trends on normalized telepresence and performance scores for the two settings of task difficulty are presented in Figure 24. As hypothesized, they indicated a substantial decrease in performance with increasing task difficulty without any corresponding change in telepresence.

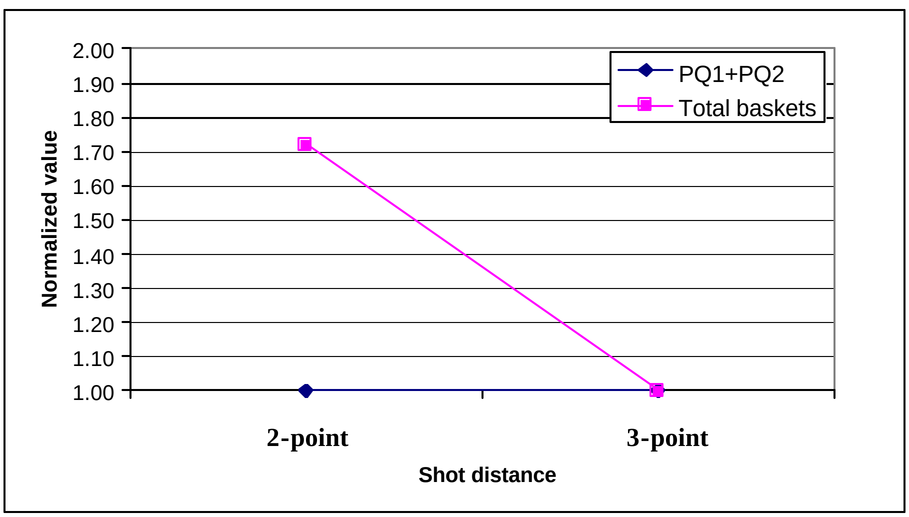

Figure 24: Normalized values of telepresence and performance on shot distance

Figure 25 presents the trends on differences in telepresence and performance across the various sound conditions. In general, the addition of task-relevant sounds to the VR increased telepresence ratings, but appeared to degrade performance. Both telepresence and performance decreased in the absence of auditory cues in comparison to the conditions presenting either relevant or irrelevant sounds.

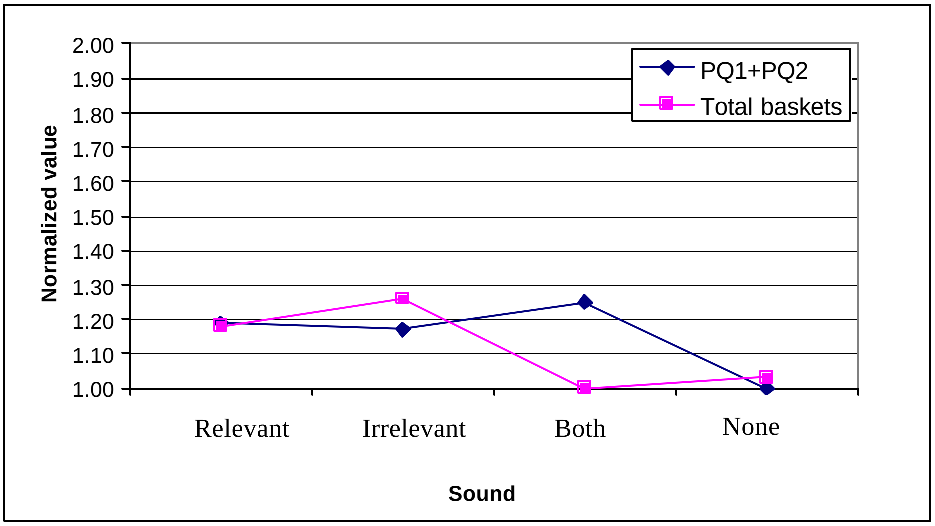

Figure 25: Normalized values of telepresence and performance across sound conditions

5.7 Correlation Analysis Results

Correlation analyses were conducted according to the Data Analysis plan in order to examine the relation of immersive tendencies to actual ratings of telepresence and the overall relation of telepresence to performance across the experimental conditions. In particular, this study was interested in correlation evidence that would corroborate the general findings based on the analysis of trends in normalized scores of telepresence and performance in the virtual basketball task. Correlation analyses were also conducted to establish the degree of agreement among observations on the subjective and objective measures of telepresence and to further assess agreement among the various workload measures, including subjective ratings and performance on each of the secondary tasks.

A Pearson-product moment coefficient revealed a significant positive linear association between immersive tendency scores captured using the ITQ and the subjective ratings of telepresence (PQ1+PQ2) ($r = 0.238$, $p<0.0001$), but not among ITQ scores and the objective measure of telepresence, which was based on secondary task performance (hit-to-signal ratio for the camera flash detection task / hit-to-signal ratio for the strobe light detection task) ($r = 0.0349$, $p<0.5$).

Correlation analyses of the telepresence ratings with performance and workload revealed only significant positive associations of subjective telepresence with workload ratings ($r = 0.3928$, $p<0.0001$), and the objective measure of telepresence (based on secondary task performance) and perceptions of workload ($r = 0.1476$, $p<0.01$). The objective measure of telepresence based on subjective attention allocation to the secondary tasks was also not significantly correlated with task performance ($r = -0.05146$, $p<0.5$).

Pearson correlation coefficients were also used to establish the relation of workload and performance in the study and the degree of correspondence of the workload ratings and secondary task performance. The mental workload ratings were significantly positively related to performance (total baskets) ($r = 0.1158$, $p<0.05$). Subjective workload was also significantly, negatively related to the hit-to-signal ratio for the strobe light detection task ($r = -0.2132$, $p<0.0001$), as might have been expected based on the ANOVA results across the two types of response measures.

6 Discussion

This section presents a discussion of the observed performance, telepresence and workload effects of the various VR feature manipulations and the correlations among the response measures. With respect to performance, the results of the distance manipulation were consistent with the hypotheses. There was significantly better performance at the 2-point than 3-point distance.

6.1 Telepresence in VR

In general, the results on the subjective sense of telepresence supported the hypotheses. The study revealed no significant effect of task difficulty (shot distance) on telepresence ratings. This finding differs from the results of the studies by Riley and Kaber (2001) and Riley (2001). They explored multiple levels of difficulty in simulated tasks, for example, requiring subjects to search for and detect mines in a VR using a robotic rover. In Riley and Kaber (2001), subjects exposed to a high difficulty condition reported significantly lower ($p<0.05$) telepresence than subjects in low or moderate groups, which were not significantly different. In general, very high level difficulty may frustrate subjects, causing higher workload and degrading telepresence. However, there may also be some minimum level of difficulty necessary to cause subject engagement in a virtual task and experiences of being part of the task environment. It is possible that the difficulty settings investigated in this study did not go significantly beyond the minimum challenge to subjects to cause telepresence. Consequently, changes in telepresence were not observed due to the shot distance manipulation.

With respect to the sound condition, the results were consistent with the findings of Dinh et al. (1999) that auditory cues (ambient sounds) increase the sense of telepresence. The current study expanded upon this work by demonstrating that both relevant and irrelevant sounds increase telepresence, and that relevant sounds are more effective for increasing the sense of telepresence than irrelevant sounds. The irrelevant sound condition also produced greater perceptions of workload for users.

There was a trend for increased telepresence with higher background fidelity most likely due to the simulation providing a more realistic view of the task environment. However, the results were not significant. This finding differs from the hypotheses of Barfield et al. (1995) that the level of visual realism and richness of a VR would drive substantial changes in telepresence. However, the result is consistent with the study by Dinh et al. (1999) in which they failed to find a significant influence of visual cue types on subjective telepresence. It may be that there is some minimum level of visual detail in a VR necessary to cause the sense of telepresence; however, beyond this level, there may be no significant changes in telepresence with further increases in visual detail.

The egocentric view yielded the highest telepresence ratings because it provided subjects with the greatest immersion in the environment and the greatest degree of self-reference in the task. The selectable and preferred viewpoint provided subjects with the capability to exploit the advantages of each viewpoint and possibly to match their preference of viewpoint. Consequently, it generated the next to best sense of telepresence. The exocentric view from behind player was expected to produce better telepresence than the exocentric view from the sideline; however, it generated the "minimum" telepresence in the study. The exocentric view from behind player should have provided subjects with greater self-reference in the SE than the sideline view, which was a “third” person perspective. This deviation of the results from the hypotheses probably arose from the specific characteristics of the behind player view. In the experiment, subjects exposed to this condition could see the player, but not the arms of the player or basketball while it was being dribbled prior to a shot. Subjects may have been frustrated by this view because it did not provide visual information consistent with their perceptions in a real basketball environment; thus, causing degradation in the involvement of self in the VR.

There appeared to be no significant effects of audio cue type, background fidelity or viewpoint on the objective sense of telepresence, which was defined by the ratio of attention allocation to the virtual and real world secondary-monitoring tasks. It is possible that the lack of agreement between the results on an attention-based measure of telepresence obtained in this study and those presented by Riley and Kaber (2001) may be attributed to differences in the subjective telepresence rating techniques used and the design of the secondary tasks across studies. Riley and Kaber (2001) used Witmer and Singer’s (1994) PQ, which is far more probing of different aspects of telepresence than Draper and Blair’s (1996) general questions on the degree of user association with a VR. Beyond this, Riley and Kaber’s secondary tasks were identical in design except the RW version was presented on a computer display other than that used to present their VR to subjects. In this study, the camera flashes were artificial and fundamentally different in terms of perceptual features from the real strobe light flashes that occurred in the lab.

6.2 Workload in VR

The results indicated that viewpoint, sound and individual differences were significant factors in subjective workload. The mental workload ratings were significantly positively related to performance. Mental workload was also significantly, positively correlated with subjective telepresence ($r = 0.39286$, $p<0.0001$). This is consistent with the study by Draper and Blair (1996), in which telepresence ratings were significantly correlated with composite workload scores ($r = 0.52$) during completion of a pipe-cutting task using a teleoperator. Other previous research (Riley and Kaber, 2001) has shown that telepresence may be significantly, negatively correlated with mental workload. In general, these results taken together appear to indicate that some minimum level of workload may be necessary to establish the sense of telepresence; however, when workload is high, it may degrade the sense of telepresence (e.g., Riley and Kaber, 2001). This is similar to the earlier inference on task difficulty.

The subjective workload was also significantly, negatively related to the hit-to-signal ratio for the strobe light detection task. The decrease in the detection rate for the secondary task in the RW accompanied by a significant increase in workload ratings was expected.

6.3 Lack of Interaction Effects on Response Measures

There were no significant interaction effects among all the factors (background fidelity, sound, viewpoint, and task difficulty) in terms of performance, telepresence and workload. Although counter to expectation and the hypothesis that a cue conflict might occur as a result of auditory cue and background fidelity manipulations, this result is consistent with the findings by Dinh et al. (1999). However, Dinh et al. did not investigate workload in their study. In the present study, information from the different sensory channels (e.g., auditory and visual) did not interact to improve or decrease overall performance and telepresence in the VR, nor did the combination of cues influence the subjective perception of workload. These results do not support the intuitive hypotheses on cross-modal interaction by Biocca et al. (2001); however, the current study did not explore haptic cues. It is possible that there is some interaction between the visual and haptic modalities (i.e., Biocca et al., 2001).

The lack of interaction effects on the above response measures suggests that VR design using multiple sensory channels could be relatively simple in that a designer may only need to consider the main effect of each channel on performance, telepresence etc., in the VR development process. It is important to note that mental workload was generally low across all experimental conditions. It is possible that users may be more sensitive to VR feature manipulations and combinations of various viewpoint, auditory cue and fidelity settings under more demanding task circumstances.

6.4 Correlations among Telepresence and Performance

The study revealed a significant correlation between ITQ and the subjective ratings of telepresence, but not among ITQ scores and the objective measure of telepresence, based on secondary task performance (hit-to-signal ratio for the camera flash detection task / hit-to-signal ratio for the strobe light detection task. These results were not unexpected as the attention-based objective measure of telepresence did not appear to be a sensitive indicator of changes in telepresence due to the experimental manipulations of factors suspected to underlie telepresence experiences (which were revealed by the subjective ratings). The study revealed significant main effects of VR features including viewpoint and sound on subjective telepresence.

The telepresence measure summing PQ1 and PQ2 ratings was not correlated with virtual task performance, as might have been expected based on the primary ANOVA results of the study demonstrating task difficulty to be important to performance, but sound and viewpoint to dictate telepresence ratings. Although the shot distance significantly influenced task performance, it did not appear to influence telepresence ratings.

The study did not reveal a correlation of objective telepresence and performance. These results differ from the findings of previous research showing significant correlations of telepresence and performance (Riley and Kaber, 2001; Kaber et al., 2000a) and maybe attributed to the specific experimental manipulations. In this study, we selected independent factors and settings that created the potential for telepresence and performance to function in different ways in order to establish telepresence as a unique construct.

However, there was a significant correlation between the subjective and the objective measures of telepresence ($r = 0.1201$, $p<0.01$). This result suggests a contradiction with the findings that background fidelity, viewpoint and sound did not significantly influence objective telepresence; whereas, viewpoint and sound significantly influenced the subjective sense of telepresence. Considering the design of a measure of allocation of attention to VR as an indicator of the degree of telepresence, it is possible that the overall capacity of attention of the human being may have been exceeded in this study. When a subject is performing a primary task in a VR, he/she may have enough attentional capacity to observe a secondary task in VR, which requires divided attention. However, requiring performance in the primary task plus observation of two secondary tasks - one virtual and one real - may exceed attentional capacity. With this, and the results of the study, in mind, it maybe reasonable to only use RW secondary-task performance as an indicator of attentional allocation and the degree of telepresence in VR. In the current study, there was a significant, negative correlation between subjective telepresence and the detection rate for the secondary task in the RW (i.e., the correlation between PQ1+PQ2 and strobe light detections ($r = -0.18862$, $p<0.0001$)). Furthermore, the study revealed viewpoint and individual differences to be significant main effects in the detection rate for the strobe light. According to Tukey's tests, the egocentric viewpoint produced the worst ($p<0.05$) secondary task performance in comparison to the other viewpoint conditions. This was consistent with the result that egocentric viewpoint produced the highest subjective rating of telepresence in the study.

Since the experience of telepresence is determined by many system, task and environmental factors, the use of a hit-to-signal ratio for a visual or auditory stimulus-response may be sufficient to objectively reflect the experience of telepresence and would appear to be consistent with a subjective measure of telepresence. However, given the differences in the results from the current study and previous work by Riley and Kaber (2001), it may be possible that the best way to measure telepresence is to simply use a subjective or qualitative method (e.g., rating scales) since telepresence is essentially a subjective concept (Draper et al., 1999).

7 Conclusion

The goal of this study was to assess the relationship between telepresence and performance in a basic SE. The sub goals were to: (1) provide more information on features of VR that may influence telepresence experiences, and (2) provide additional insight into the relation of telepresence and task performance, in particular the correlation of an objective measure of telepresence (based on VR user attention allocation to virtual and real world secondary-monitoring tasks) and user success in a simplistic virtual basketball task. Previous studies have not investigated the potential relation between an objective measure of telepresence and performance.

The results of the study provided evidence that the features of a simplistic SE, which include immersiveness (viewpoint) and auditory cue type significantly influence the sense of subjective telepresence. In addition, level of task difficulty appears to be an important factor in performance in VR. Unfortunately, in this study the objective attention-based measure of telepresence did not prove to be sensitive to the experimental manipulations, like subjective ratings of telepresence. This differs from previous findings and may be attributable to the unique design of the secondary tasks as part of the measure used in this study.

The analysis of trends on absolute changes in telepresence and performance across settings of various VR features provided compelling evidence that telepresence is a predictable experience unique from performance. However, the results of this analysis cannot be considered conclusive in terms of describing a causal relationship between telepresence and performance, in part, because of the mixed findings across predictors. Although it is widely expected that telepresence is related to performance, the overall correlations of performance and both subjective and objective measures of telepresence were not significant in the study. This was most likely due to the conditions selected for the study. That is, several of the experimental manipulations were intended to cause an increase or decrease in performance without a corresponding change in telepresence or vice versa. It is also possible that the overall sense of telepresence in the basketball VR was relatively weak and the factor settings caused small changes in a user's experience of telepresence along with no significant change in performance. Similarly, it is also possible that the sense of telepresence has only a subtle influence on performance.

The findings above provide some basic insight into the potential telepresence implications of the design of VR. Although differences in telepresence due to the experiment manipulations were statistically significant, from a practical perspective (or absolute perspective) they may seem small. It is possible that, in a more complex VR application, involving rich sounds and visual information, telepresence experiences and fluctuations based on changes in system interface features may be greater and have more practical importance. For example, in the surgical operation environment implemented by Freysinger et al. (2001), highly detailed audio and visual information is provided to user to promote a higher sense of telepresence and to assist for operator performance. The absence of this information could be detrimental to a surgeon's perception of immersion/involvement in an actual surgical operation and ultimately the accuracy of performance. However, at this point in telepresence research, it is difficult to project the practical implications of the phenomenon because it has not been formally examined as a predictor variable in performance.

In order to conduct more robust analyses of telepresence, more technological and psychological factors that are suspected to significantly influence telepresence need to be investigated. This may allow for a wider range of telepresence experiences to be explored and provide for a more sensitive and complete assessment of any relationship between telepresence and performance. For example, haptic (touch) cues could be introduced into future experiments. A key question for such research is how much of a change in telepresence is necessary to cause a change in performance (i.e., how much of a change will allow for a sensitive examination of the relationship between telepresence and performance).

In future research on the relationship of telepresence and performance in SEs, it will also be important that fine and accurate measures of user success in virtual task performance be used. For example, in the virtual basketball task, it might have been helpful to count the number of shots that were close to the basket, as an ancillary performance measure. The motivation for using this type of measure is that there maybe different levels of telepresence and performance achievable in the SE and it maybe worthwhile to capture information on telepresence at slightly less than optimal levels of performance, etc.

Beyond the relationship of telepresence and performance, this study provided further evidence of significant positive relations between a subjective measure of telepresence and workload, as well as between an objective measure of telepresence (based on attention allocation) and perceptions of workload. These and other results of the study were consistent with previous research (Riley and Kaber, 2001).

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Appendix A: Instructions for Participants

I. Introduction

Thank you for volunteering to participate in this experiment. The goal of this study is to examine the relationship between presence in a virtual environment (VE) and virtual task performance. The experimental task will require you to use a head-mounted display, or HMD. You control inputs to the system via an Ascension Tech. 6-DOF mouse. The virtual task is a high-fidelity 3-dimensional simulation of a basketball free throw. You will be asked to shoot basketballs and make as many baskets as possible in a set amount of time. You will also be asked to report a photographer's flash in basketball stands and a strobe light flash in the room when you see them. During the experiment, you will complete an extensive training session and sixteen test trials.

Overview of Procedures

The procedures we will follow during the experiment will be executed in one session. You will first experience four training trials. A 5-minute break will follow training. You will then complete sixteen task trials. And there is a 5-minute break between trials 8 and 9.

An overview of the procedures for the session includes:

1. An Introduction to the experiment and the equipment.
2. Collecting survey data.
3. Familiarization with the equipment, including the HMD and the Ascension Tech. 6-DOF mouse.
4. Administering an Immersive Tendencies Questionnaire.
5. Familiarization with different types of sounds and background to be presented in the experiment.
6. Administering a sim-sickness questionnaire.
7. Familiarization with a presence survey and mental workload rating scale.
8. Familiarization with a secondary task.
9. A 5-minute break.
10. Completion of 8 trials, each of which will be followed by the presence survey and the workload rating.
11. A 5-minute break.

12. Completion of the next 8 trials (total 16 trials), each of which will be followed by the presence survey and the workload rating.
13. Sim-sickness questionnaires will be completed after the training session, and after test trials 8 and 16.

Informed Consent and Subject-Survey Sheet

[Give the subject the informed consent form. Summarize the informed consent for the subject and encourage them to read the form.]

This form summarizes the information that has been presented to you thus far and identifies the persons responsible for the study. The form also addresses University liability to the experiment. I encourage you to read the form. This form will not be associated with any of the other survey forms used in this experiment. In order to participate in this study you must have 20/20 or corrected vision, and you must not have a seizure disorder or use a pacemaker. You may experience sim-sickness (or "motion-sickness" like symptoms) from using the HMD, but precautionary measures will be taken to insure your well-being. Please sign and date this form.

[Present the subject with the Subject-Survey sheet.]

This form asks about your personal characteristics and will serve to verify your qualifications for the study. Please take a few moments to complete the survey. If you have any questions, I will be happy to address them. This form, like the informed consent form, will not be associated with any of the other survey forms used in this experiment.

[Have subjects complete all payment forms for participation. Be sure to record the time that the subject started participation.]

This is the payment form that will be used to calculate your compensation for participating in the experiment. Please fill-out the information. Your Social Security number must be included on this form for tax purposes; however, this form will not be associated with any of the other survey forms used in the study. The income you earn from this experiment is taxable and you should report it to the IRS.

II. Familiarization

I will present all instructions to you orally. If you do not understand certain instructions, you will be able to ask questions before completion of each step in the procedure. You may also ask questions about the experiment during the familiarization, training, and rest periods. Please follow all instructions carefully.

Equipment Familiarization

The equipment to be used in this experiment includes a high-performance graphics visualization workstation presenting the virtual environment and task. The system is integrated with the Ascension Tech. 6-DOF mouse. A HMD will be used to isolate your vision to the VE and to simulate 3-D viewing of the VE.

[Check to see if the subject has any questions about the equipment or setup.]

Simulation Familiarization and Training Session

Before we begin the training, you will complete an Immersive Tendencies Questionnaire that was referred to during the summary of the experimental procedures.

[Give subject Immersive Tendencies Questionnaire.]

This survey seeks to determine how well or easily you can immerse yourself in different environmental situations. It establishes the degree to which you are susceptible to feeling a part of a virtual environment. Please read the instructions at the top of the form regarding its completion.

[Allow time to complete survey.]

[Check to see if the subject has any questions.]

Simulator Sickness Information

It is possible that you may experience simulator sickness when using the immersive VE displays. Therefore, procedures will be employed to assure your safety and well-being. Please inform us at any point if you begin to experience motion sickness-like symptoms.

In order to determine the possible presence of simulator sickness symptoms, the Simulator Sickness Questionnaire (SSQ) will be administered to you at the beginning of experimental testing, after the training session, and after trials 8 and 16. If your pre-exposure scores on the SSQ indicate that you are not currently in good health, you will not be permitted to participate. If the post-exposure scores indicate that you may be suffering from sim-sickness, the questionnaire will be administered at 20-minute intervals after a trial for up to 1 hour. If scores do not return to pre-test levels within 1 hour after an experiment, you will be advised not to drive a motor vehicle for 24 hours, and a ride will be provided to you. It will also be recommended that you seek medical counsel for "motion sickness-like" symptoms. This first sim-sickness form will be used as a baseline to compare your post-trial scores. Please fill out this form carefully.

[Hand subject sim-sickness form and let them fill it out now. Calculate sim-sickness score using "HelperSheet" tab in SimSickAndErrorSheets.xls in Excel on the desktop of the computer. If scores exceed criteria, dismiss subject.]

[Read if subject scores exceed criteria.]

Thank you for coming today. This concludes your participation in the experiment. You will be compensated for the time you have spent here.)

[After the training session, and after trials 8 and 16, please ask subjects to fill the SSQ form again. Calculate sim-sickness score using "HelperSheet" tab in SimSickAndErrorSheets.xls in Excel on the desktop of the computer.]

III. Training

[Before start of experiment, paste the brown paper on the floor in the area around the subject's position.]

As discussed, you will now complete a dedicated training session. This training is provided to allow you to learn the control of the simulation of a basketball player making a free throw or 3-point shot within the virtual environment using the Ascension Tech. 6-DOF mouse.

[Only read one of the following four paragraphs to the subject who is randomly assigned to the related viewpoint.]

[Egocentric:] You will view the basketball court from the perspective of the player.

[Exocentric behind:] You will view the basketball court from a perspective behind the player.

[Exocentric beside:] You will view the basketball court from a perspective beside the player.

[Selectable viewpoints:] You will be able to select your preferred viewpoint from the egocentric, exocentric behind, and exocentric beside viewpoints. Egocentric views provide a view of the basketball court from the player. Exocentric views provide images from the perspective behind and beside the player, according to which viewpoint is given. I will now show you images that are representative of each of the viewpoints.

[Show slides of each of the viewpoints only to the subject for "selectable viewpoint".]

In addition to learning control of the simulation with the mouse, you will also be familiarized with different sounds and background levels.

[Play sounds and show the description of the sounds on the desktop of the computer, show background levels. The experimenter should not say anything to subjects regarding whether sounds are relevant or irrelevant!]

The goal of the task is to successfully make as many baskets as possible within the 2-min. trial period. Increasing the number of shoots you make will not necessarily result in an increase in the number of baskets made. That is, you need to take time to judge the distance from the player to the basket and to carefully think about the speed at which you move your arm in order to shoot the ball into the basket. You should attempt to refine your arm motion in order to make the greatest number of baskets.

[Slow-down the demonstration shots that you make as experimenters. Comment to subjects during the demonstration that on average, shooting about 20-25 shots per trial seems to produce the highest number of baskets.]

[Demonstrate making a shot, allow subject to try shot (before calibrating), and allow subject to observe experimenter (using simulation).]

I am now going to show you how to shoot a basket. When you are ready to attempt a shot, lift your hand and push upward to make a shot like this. First I am going to allow you to try making a shot and get comfortable with the simulation. Note that we have not calibrated the software for you yet, so don't be surprised if you are unable to make any shots. This is just for you to get comfortable with the HMD and to decide on a comfortable standing position.

[Show subject where and how to stand. Place the HMD on them. Allow them to try a few shots (allowing them to move a little if desired). Remove the HMD and ask the subject to choose a comfortable standing position over the brown paper on the ground.]

Now I am going to show you in detail how to make a shot [now the experimenter should put on the HMD and demonstrate making a shot – have the simulation calibrated for whoever is doing the demonstration.] Some hints for successful shooting are:

- Do not move your arm too quickly. The simulation does not register a shot if you move too quickly.
- Since the force of the basketball is determined by the velocity of your lower arm at the end of the shot, initiate the shot slowly and carefully control the speed of your lower arm at the end of the shot.

[Open WorldUp Player basketball training simulation. WorldUp Platform. Bball_left_train_HMD for left hand people or bball_right_train_HMD for right hand people on the desktop.]

[Please ask the subject stand on the paper and start calibrating the simulation for the subject. Record the position data of the arm of the subject. Then, draw the line around the feet on the paper. The subject will stand on the exactly same position for the next training and trials.]

[Make sure the subject standing on the marked position. Require them to put on HMD. Start the training.]

You will complete 4 training trials. Each trial will last for two minutes. Are there any questions?

[Open and start the simulation for the 4 training trials.]

[If the subject does not reach asymptote by the end of the training trials, then continue training trials until the subject does reach asymptote. Continue to present conditions in random order.]

[After the training session is done.]

[Hand subject sim-sickness form and let them fill it out again after the practice session. Calculate sim-sickness score using "HelperSheet" tab in SimSickAndErrorSheets.xls in Excel on the desktop of the computer.]

Telepresence Questionnaire

Now, I will provide you with a brief explanation of the Telepresence Questionnaire, which is intended to assess your association with the virtual task and environment during performance. The telepresence questionnaire will be completed after each trial. It is intended to capture the degree to which you felt a part of the basketball task and environment. I will show you the survey and please read the instructions on the survey so that you will know how to respond to the questions with a rating following the experimental trials. You drag the slide bar to the position you think is suitable and release it.

[Show the subject the Telepresence Questionnaire and read the statement at the top of a copy of the Telepresence Questionnaire.]

Workload

In order to assess the task workload that you experience during experimental testing, you will complete a workload subjective rating form. A description of mental workload is provided in the sheet. Please read it carefully.

At the end of each test trial, you will be required to complete subjective ratings of perceived workload. You will rate task workload using this form.   You will complete the workload form by indicating the level of demand you experienced during the task by dragging the slide bar along the scale and release it when it is position you want.

[Show the subject the Mental Workload Questionnaire and read the statement at the top of a copy of the Workload Questionnaire.]

Do you have any questions?

Demonstrate Secondary Task

[The experimenter demonstrating the camera flash and strobe flash.]

During the test trials, you will be asked to report when you see two different flashes, one within the virtual environment and one outside of the simulation (in the real world). Please put on the HMD and I will demonstrate the two flashes.

(1) The flash in the simulation will look like this [show the flash in the simulation]. When you see a camera's-flash in the VE, you should **say "flash"**.

(2) The flash outside of the simulation will look like this [demonstrate the strobe flash]. When you see the strobe light flash, please **say "light".**

(3) If you see both of them at the same time, say both **"light"** and **"flash"** in any order.

You will now be provided with a 5-minute break.

IV. Experimental Testing

Now, you will complete 16 test trials in the virtual basketball task that you trained on. The experimental procedures are as follows:

(1) Shoot as many baskets as possible in a two-minute trial; remember to say "**flash"** or **"light"** when you see the camera flash and strobe light.

(2) Completion of the telepresence and workload questionnaire after each trial;

(3) Completion of the sim-sickness questionnaire (after trials 8 and 16)

This sequence will be repeated for all 16 trials.

[Check to see if the subject has any questions.]

Due to the nature of the experiment, keeping your attention focused on completing the task is important. I ask that you refrain from talking during the testing periods. If you have any difficulties, however, please do not hesitate to bring them to my attention and I will assist you.

You will now begin your first experimental trial. Your task is to shoot as many baskets as possible in two minutes.

[Open WorldUp Player basketball training simulation. WorldUp Platform. Bball_right_HMD.wup for the right hand people or bball_left_HMD.wup for the left hand people on the desktop.]

[Require them to put on HMD.]

When you are ready to start, please tell the experimenter and he will start the trial. Don't forget to call out the camera "flash" and strobe "light" when you see them.

[Open and start the simulation for the 16 testing trials. Run the subject through the trial conditions in random order, according to the condition form for the trial.]

[Set up the switches according to the condition form for the trial.]

[Make sure start the simulation and enable the strobe light at the same time.]

[Record the response of the subject for the camera's flash and the strobe light's flash on the specific form during the trial.]

[Have subject complete presence and workload questionnaire after each trial.]

[Also have subject complete SSQ (after trials 8 & 16). Calculate sim-sickness score using "HelperSheet" tab in SimSickAndErrorSheets.xls in Excel on the desktop of the computer.]

[Allow subject have 5-minute break between the trials 8 and 9.]

Experimental Procedure

[Run the telepresence_workload.exe and input the subject # .]

[Run the appropriate simulation.]

[Input the condition set-up in the dialogue according to the condition form.]

[Set up the switches according to the condition form for the trial.]

[Make sure the subject stand on the exactly same position and record the arm position correctly.]

[Help subject put on HMD and make sure it is adjusted correctly, but attempt to do this as quickly as possible.]

[Help subject hold on the 6-DOF mouse.]

[Remind subjects to report the “flash” and “light” before EVERY testing trial.]

When you are ready to start, please tell the experimenter and he will start the trial. Don’t forget to call out the camera “flash” and strobe “light” when you see them.

[Ask subject if they are ready to proceed.]

[Make sure start the simulation and enable the strobe light at the same time.]

[Record the response of the subject for the camera’s flash and the strobe light’s flash on the specific form during the trial.]

[When subject has completed each trial, help them take off HMD.]

[Ask the subject to finish the telepresence and workload questionnaire.]
I would now like you to complete the telepresence questionnaire that we discussed in covering the experimental procedures and instructions. This survey is intended to capture the degree to which you felt a part of the virtual environment. Please respond to each question with a rating.

[When the subject is filling in the telepresence-workload questionnaire, run the dialogue to set up the conditions for the next trials.]

1. **Calculate sim-sickness score after subject has completed the SSQ form (after trial 08 and trial 16).**
2. **If sim-sickness score <= pretest score, skip step 3.**
3. **If sim-sickness score is higher than pre-test score, have subject wait for 20 minutes.**
    a. **After 20 minutes, give sim-sickness test again.**
    b. **(This sequence may be repeated for an hour. If scores are not back to normal after an hour, dismiss subject.)**

([Read if subject sim sickness scores do not return to pretest levels.]

Thank you for coming today. This concludes your participation in the experiment. You will be compensated for the time you have spent here.
[Give subject instructions for obtaining payment. Calculate their total payment and instruct them to go to Riddick to collect their money.]

[Set up next trial.]

You will now complete your next experimental trial. The method of shooting the ball will be the same. The task will be the same. Following this trial, as in the previous test, you will complete the telepresence form and workload form (and Sim-sickness questionnaire at end of trials 8 and 16).

When you are ready to start, please tell the experimenter and he will start the trial. Don't forget to call out the camera "flash" and strobe "light" when you see them.

[Check to see if the subject has any questions. Overview experimental procedure.]

[When the experiment is done, please save the bball_sim_data.txt as bball_sim_data_(subject#).txt, and the bball_sim_train.txt as bball_sim_train_(subject#).txt under the C:/SimData directory. For example, it should be bball_sim_data_01.txt for the subject 01, and so on.]

[When the experiment is done, please save the tele_test.txt as tele_test_(subject#). txt under the C:/QueData directory. For example, it should be tele_test_01.txt for the subject 01, and so on.]

[When the experiment is done, please save the bball_sim_data_selectable.txt as bball_sim_data_selectable_(subject#). txt under the C:/SimData directory. For example, it should be bball_sim_data_selectable_01.txt for the subject 01, and so on.]

Appendix B: Informed Consent Form

Informed Consent Form
Department of Industrial Engineering
North Carolina State University

I hereby give my consent for voluntary participation in the research project titled, "Telepresence and Performance in Teleoperations." I understand that the person responsible for this project is Dr. David B. Kaber, who can be telephoned at (919) 515-3086. He or one of his authorized assistants has explained to me the objective of the study to investigate the relationship between telepresence and performance in a synthetic basketball task. Dr. Kaber or one of his authorized assistants have agreed to answer any inquiries I may have concerning the procedures of the research and have informed me of my right to refuse to answer any specific questions asked of me. He or one of his authorized assistants have also informed me that I may contact the North Carolina State University (NCSU), Institutional Review Board for the Protection of Human Subjects by writing them in care of Dr. Matt Zingraff, Chair of IRB, Research Administration, NCSU, 1 Leazar Hall, Box 7514, Raleigh, NC 27695, or by calling (919) 515-2444.

Information concerning compensation for my participation in this study has been explained to me as follows: (1) I will receive $7.50 per hour for each hour of my participation in the experiment. (2) In the event that I choose to terminate my participation in the experiment, I will be paid for only the time I have provided. (3) The researchers for the study have the right to terminate my participation if I am not cooperative or I experience discomfort or fatigue.

Dr. Kaber or one of his authorized assistants has explained to me the procedures to be followed in this study and the potential risks and discomforts. In summary the procedures include: (1) an equipment familiarization period; (2) a sim-sickness questionnaire; (3) an extensive training session to learn and practice the control commands required to perform the virtual basketball task; (4) familiarization with a subjective workload measurement technique; (5) 16 test trials in the basketball virtual environment using a head-mounted display (HMD); (6) and a debriefing on the study. All training and testing will be conducted during a single experimental session that will require approximately 2.5 hour of my time.

The risks have also been explained to me as follows: (1) a potential exists for visual strain and/or fatigue in viewing the virtual environment displays through immersive displays including the HMD and desktop VR display; (2) a potential exists for soreness of the hand and arm muscles from extensive use in controlling the simulated basketball task using a motion tracking hand control. These risks are not substantially different from those associated with my everyday PC use. In the event that I experience fatigue or discomfort, I will inform the experimenters immediately. In addition, I will be tested for motion sickness symptoms before and after the experiment. I understand that if the symptoms have not dissipated after 1 hour, I will be advised not to drive a car for 24 hours and a ride will be provided.

I understand that if this research project results in any physical or mental harm to me, treatment is not necessarily available at the NCSU, Student Health Services, nor is there necessarily any insurance carried by the University or its personnel applicable to cover any such injury. Financial compensation for any such injury must be provided through my own insurance program. Further information about these matters may be obtained from the Institutional Review Board at (919) 515-2444, 1 Leazar Hall, NCSU Campus.

I understand that I will not derive any therapeutic treatment from my participation in this study. I understand that I may discontinue my participation in this study at any time without prejudice. I understand that all data will be kept confidential and that my name will not be used in any reports, written or unwritten. I have received a copy of this consent form for my personal records.

Signature of Subject: **Date:**

______________________________ ______________________________

Signature of Authorized Representative: **Signature of Witness to Oral Presentation:**

______________________________ ______________________________

SUBJECT SURVEY

TELEPRESENCE AND PERFORMANCE IN TELEOPERATION

The intended purpose of this form is to establish a subject profile based on volunteered anthropometric data. Please complete the sheet to the best of your knowledge following the example formats indicated in the parentheses adjacent to each data field label.

Age (XX yr.): ____________ Gender (M/F): __________
Handedness (Left/Right): ____________

Corrected Visual Acuity: Left Eye (XX/XX): ___________
Right Eye (XX/XX): ____________

	1	2	3	4	5
Video Game Experience:	1 None	2	3 Occasional	4	5 Frequent
PC Experience:	1 None	2	3 Occasional	4	5 Frequent
VR Experience:	1 None	2	3 Occasional	4	5 Frequent
Basketball Experience:	1 None	2	3 Occasional	4	5 Frequent

DO NOT WRITE BELOW THIS LINE.

Subject #: ______ Viewpoint: 1 / 2 / 3 / 4

IMMERSIVE TENDENCIES QUESTIONNAIRE

TELEPRESENCE AND PERFORMANCE IN TELEOPERATIONS

Indicate your preferred answer by marking an "x" in the appropriate box of each seven-point scale. Please consider the entire scale when marking you responses, as intermediate levels may apply. For example, if your response is once or twice, the second box from the left should be marked. If your response is many times but not extremely often, then the sixth (or second box from the right) should be marked.

1. Do you easily become deeply involved in movies or TV dramas?

NEVER OCCASIONALLY OFTEN

2. Do you ever become so involved in a television program or book that people have problems getting your attention?

NEVER OCCASIONALLY OFTEN

3. How mentally alert do you feel at the present time?

NOT ALERT **MODERATELY** **FULLY ALERT**

4. Do you ever become so involved in a movie that you are not aware of things happening around you?

NEVER OCCASIONALLY OFTEN

5. How frequently do you find yourself closely identifying with the characters in a story line?

NEVER OCCASIONALLY 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?

NEVER OCCASIONALLY OFTEN

7. What kinds of books do you read most frequently? (CIRCLE 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?

|____|____|____|____|____|____|____|

NOT FIT — MODERATELY **FIT** — EXTREMELY **FIT**

9. How good are you at blocking out external distractions when you are involved in something?

|____|____|____|____|____|____|____|

NOT VERY **GOOD** — SOMEWHAT **GOOD** — 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?

|____|____|____|____|____|____|____|

NEVER — OCCASIONALLY — OFTEN

11. Do you ever become so involved in a daydream that you are not aware of things happening around you?

|____|____|____|____|____|____|____|

NEVER — OCCASIONALLY — OFTEN

12. Do you ever have dreams that are so real that you feel disoriented when you awake?

|____|____|____|____|____|____|____|

NEVER — OCCASIONALLY — OFTEN

13. When playing sports, do you become so involved in the game that you lose track of time?

|____|____|____|____|____|____|____|

NEVER — OCCASIONALLY — OFTEN

14. How well do you concentrate on enjoyable activities?

NOT AT ALL MODERATELY 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.)

NEVER OCCASIONALLY OFTEN

16. Have you ever gotten excited during a chase or fight scene on TV or in the movies?

NEVER OCCASIONALLY OFTEN

17. Have you ever gotten scared by something happening on a TV show or in a movie?

NEVER OCCASIONALLY OFTEN

18. Have you ever remained apprehensive or fearful long after watching a scary movie?

NEVER OCCASIONALLY OFTEN

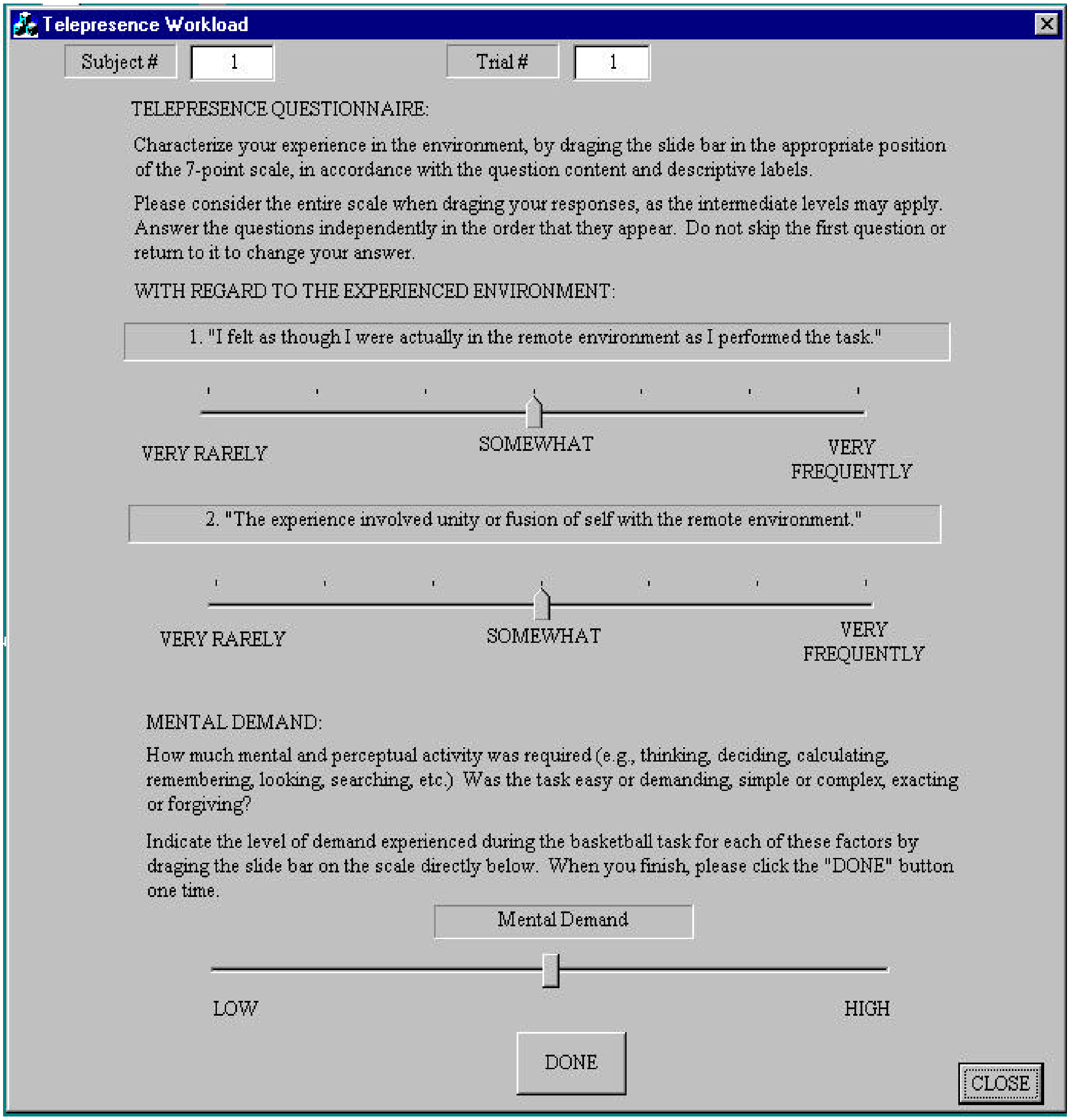
19. Do you ever become so involved in doing something that you lose all track of time?

NEVER **OCCASIONALLY** **OFTEN**

DO NOT WRITE BELOW THIS LINE.

Subject #: ______ Viewpoint: 1 / 2 / 3 / 4

Appendix E: Subjective Telepresence and Mental Workload Assessment



Telepresence Workload

Subject # 1

Trial # 1

TELEPRESENCE QUESTIONNAIRE:

Characterize your experience in the environment, by draging the slide bar in the appropriate position of the 7-point scale, in accordance with the question content and descriptive labels.

Please consider the entire scale when draging your responses, as the intermediate levels may apply. Answer the questions independently in the order that they appear. Do not skip the first question or return to it to change your answer.

WITH REGARD TO THE EXPERIENCED ENVIRONMENT:

1. "I felt as though I were actually in the remote environment as I performed the task."

VERY RARELY

SOMEWHAT

VERY FREQUENTLY

2. "The experience involved unity or fusion of self with the remote environment."

VERY RARELY

SOMEWHAT

VERY FREQUENTLY

MENTAL DEMAND:

How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.) Was the task easy or demanding, simple or complex, exacting or forgiving?

Indicate the level of demand experienced during the basketball task for each of these factors by draging the slide bar on the scale directly below. When you finish, please click the "DONE" button one time.

Mental Demand

LOW

HIGH

DONE

CLOSE

Appendix F: Simulator Sickness Questionnaire

SIMULATOR SICKNESS QUESTIONNAIRE

Department of Industrial Engineering
North Carolina State University
NSF Telepresence Project

Instructions: Circle the items that apply to you RIGHT NOW.

SYMPTOM	RATING			
General Discomfort	None	Slight	Moderate	Severe
Fatigue	None	Slight	Moderate	Severe
Headache	None	Slight	Moderate	Severe
Eye Strain	None	Slight	Moderate	Severe
Difficulty Focusing	None	Slight	Moderate	Severe
Increased Salivation	None	Slight	Moderate	Severe
Sweating	None	Slight	Moderate	Severe
Nausea	None	Slight	Moderate	Severe
Difficulty Concentrating	None	Slight	Moderate	Severe
"Fullness of the Head"	None	Slight	Moderate	Severe
Blurred Vision	None	Slight	Moderate	Severe
Dizzy (eyes open)	None	Slight	Moderate	Severe
Dizzy (eyes closed)	None	Slight	Moderate	Severe
Vertigo	None	Slight	Moderate	Severe
Stomach Awareness*	None	Slight	Moderate	Severe
Burping	None	Slight	Moderate	Severe
Other. Please describe.				

* "Stomach Awareness" is usually used to indicate a feeling of discomfort, which is just short of nausea

DO NOT WRITE BELOW THIS LINE.

Subject #: ______ Trial #: (At start / After training session / After trial 08 / After trial 16)