Brett Stevens
brett.stevens@port.ac.uk
Department of Information Systems
University of Portsmouth
Burnaby Terrace, 1-8 Burnaby Road
Portsmouth, Hampshire, UK
PO1 3AE
www.tech.port.ac.uk/~stevensb/

Jennifer Jerrams-Smith
jenny.jerrams-smith@port.ac.uk
Department of Information Systems
University of Portsmouth

David Heathcote
dheathco@bournemouth.ac.uk
School of Design, Engineering & Computing
Bournemouth University
Bournemouth, Dorset, UK
BH12 5BB

David Callear
david.callear@port.ac.uk
Department of Information Systems
University of Portsmouth

Putting the Virtual into Reality: Assessing Object-Presence with Projection-Augmented Models

Abstract

A projection-augmented model is a type of nonimmersive, coincident haptic and visual display that uses a physical model as a three-dimensional screen for projected visual information. Supporting all physiological depth cues and two sensory modalities should create a strong sense of the object's existence. However, conventional measures of presence have been defined only for displays that surround and isolate a user from the real world. The idea of object-presence is thus suggested to measure "the subjective experience that a particular object exists in a user's environment, even when that object does not" (Stevens & Jerrams-Smith, 2000). A correlation study was conducted to demonstrate the reliability and validity of object-presence as a construct. The results of a modified Singer and Witmer Presence Questionnaire suggest the existence of a reliable construct that exhibits face validity. However, the Presence Questionnaire did not correlate significantly with a user's tendency to become immersed in traditional media, which would support the assertion that this construct was object-presence. Considering previous work, the results of the current correlation study exhibited a pattern evident in previous studies of presence suggesting that object-presence and presence could be gender biased by the task to be completed or by the presence measure.

1 Introduction

Projection-table displays are localized in space, and serve as "functional alters" (Underkoffler, 1997) for information. The term projection-table is defined here as a generic environment fixed display device that projects visual information onto a screen arranged in a table, desk or workbench configuration. This definition precludes vertical displays such as conventional projector screens. However, it includes systems such as the ImmersaDesk that use a rear-projected screen angled at forty-five degrees, in a drafting-table format (Czernuszenko et al., 1997). A more typical setup, however, would project visual information onto a horizontal screen. The first of this type of nonimmersive virtual reality display was the Responsive Workbench, which was designed to allow a user to focus attention onto a task rather than attempting to simulate the user's working environment within the computer (Krueger & Froehlich 1994).

Projection-table displays have the potential to present dynamic three-dimensional objects, although they have a number of disadvantages. To support most physiological depth cues, such as stereopsis and motion parallax, a user's

Presence, *Vol. 11, No. 1, February 2002, 79–92*

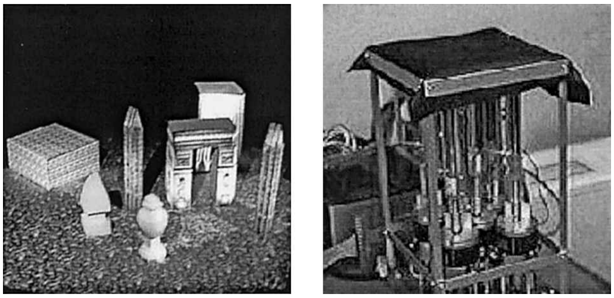

Figure 1. *Table-Top Spatially Augmented Reality (Raskar, Welch, & Chen, 1999) and The HapticScreen (Iwata, 1998).*

point of view needs to be established with some form of tracking device. This information is used to create and present an appropriate image for each eye, although, because two images are presented, special glasses are needed to filter out the incorrect image (Krueger & Froehlich, 1994). To present the correct perspective information to each simultaneous user requires multiple sets of these devices, which can prove costly in terms of equipment, processing power, and time (Agrawala et al., 1997).

A novel display paradigm is suggested to solve some of the problems associated with conventional nonimmersive displays. Referred to hereafter as a *projection-augmented model,* this display uses a simplified physical model as a three-dimensional screen for graphical information projected onto its surface. This definition does not restrict the size, shape, or orientation of a display, although the focus of this paper is limited to devices arranged in a projection-table format.

Two examples have been proposed (figure 1). *Table-Top Spatially Augmented Reality* uses static wooden or cardboard blocks as surrogate objects (Raskar, Welch, & Chen, 1999), whereas *The HapticScreen* is a dynamic version whose rubber screen can deform to approximate the shape of a required object (Iwata, 1998). Both static and dynamic displays use relatively low-resolution models, although the projected image provides a more realistic visual representation of the object's surface. The visual image can also be altered easily, like a conventional display, but, because it is presented on the surface of an object, all physiological depth cues are supported for multiple users. The physical object can also be touched, which provides coincident haptic and visual information. If a projection-augmented model supports multiple visual cues or two sensory modalities consistently, it should create a strong sense of palpability (Hinckley, 1996) or awareness that the object exists. It is important to note that, in this context, the awareness that an object exists relates to the combination of physical object and visual information, not the existence of the physical object alone.

One of virtual reality's key benefits is its ability to induce a sense of *presence*. Presence forms an important subjective measure of a user's virtual experience, although it is useful only in relation to performance (Ellis, 1996). It is assumed that the more natural the display feels, the greater its usefulness (Lombard & Ditton, 1997). This naturalness may better enable a user to utilize real-world skills in a virtual environment, and it may help to transfer learning from the virtual environment back into the real world (Slater, Linakis, Usoh, & Kooper, 1996). Research has concentrated on immersive virtual environments because nonimmersive displays, including projection-tables and projection-augmented models, may create a lower sense of presence. However, this lower sense of presence is based on a definition of presence that requires a user to feel as if they are in a different environment from the real world.

This paper suggests an alternative definition for presence that is more appropriate for nonimmersive displays. This definition assesses the sense that an object exists, although some of the factors that affect presence in an immersive environment are also applicable and will thus be reviewed first.

2 Presence and Object-Presence

2.1 Presence in Immersive Virtual Environments

Presence can be generally defined as the "subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer & Singer, 1998, p. 225). A number of factors are thought to contribute to a sense of presence, and these can be organized into various classification schemes. A technologically orientated classification proposed by Sheridan (1992, 1996) suggests that presence determinates are the fidelity of sensory information, the ability to modify sensor orientation, and an ability to modify the environment. However, Heeter's user-oriented viewpoint (1992) suggests a higher-level organization scheme based on "personal presence" (the perception of self at a given location), "social presence" (the existence and reaction of other characters), and "environmental presence" (the contextually appropriate reaction of the environment to the user's existence). These two schemes are indicative of the differing focuses in presence research, although they contain some similar elements. This paper focuses on the user-oriented viewpoint, although it also considers the task to be attempted as Sheridan (1992) suggests that it may also be a determinate of presence.

2.1.1 Personal Presence. A user's ability to believe that they inhabit a virtual environment remote from the real world in which their physical self exists is based on a number of exogenous and endogenous factors (Slater & Usoh, 1993).

Visual realism may be the objective of some virtual reality systems but "there is more to presence than reality" (Heeter, 1992, p. 269). It has been shown that a sense of presence is correlated to scene depth (Nichols, Haldane, & Wilson, 2000) and thus requires the addition of sensory cues such as motion parallax and depth of focus to "activate the major space-related psychological responses and physiological reflexes" (Ellis, 1996, p. 299). Presence is the "perceptual illusion of nonmediation" (Lombard & Ditton, 1997) so elements that remind users that they are not viewing an environment directly should be eliminated because "presence occurs when the sensory data supports only the interpretation of being somewhere other than where the sense organs are located" (Loomis, 1992, p. 117). This could be achieved with a high-resolution, large field-of-view display that creates an unnoticeable sensation of being worn (Held & Durlach, 1992).

The presentation of information across multiple sensory modalities can create a strong sense of presence, although the information channels need to be consistent with each other and with previous experience (Held & Durlach, 1992; Ellis, 1996). Indeed, Zeltzer (1992) defines presence as a "lumped measure of the number and fidelity of available sensory input and output channels" (p. 128). Sensory modalities such as audition and haptics should be treated in a similar manner to vision. It should be possible for a user to reposition all sensors with respect to the environment (Sheridan, 1992, 1996) in order to perceive high-resolution, high dynamic range, and high-bandwidth information with low latency (Ellis, 1996).

For most people, the distinction between self and non-self occurs at the boundary of the body (Loomis, 1992). Creating a virtual form, or avatar, for a user should create a stronger sense of presence (Heeter, 1992). However, this only occurs given a sufficiently high correlation between efference and afference, whereby the user's actions correspond to movements of the avatar and movements of the avatar can be perceived by the user (Held & Durlach, 1992). A representation that resembles the user's real appearance may also increase presence, although Heeter (1992) refers to Lanier's surprise at how quickly users adapted to being represented by a nonhuman form, such as a lobster.

A number of factors responsible for presence may be beyond the control of virtual environment designers. A user is generally aware that the virtual environment is a technological construction, so the experience of presence in a virtual environment can be achieved only through a suspension of disbelief (Bates, 1992; Slater & Usoh, 1993). Presence is thus dependent on the user's willingness and ability to become involved, a psychological state that can be destroyed by distracting emotions and events that result from outside of the virtual environment (Witmer & Singer, 1998).

Conversely, presence can be enhanced if the virtual environment creates an emotional response such as danger (Slater & Usoh, 1993) or enjoyment (Barfield & Weghorst, 1993). These responses are dependent on the predisposition of the user to particular emotions, psychological states, or other personality characteristics (Lombard & Ditton, 1997). Interestingly, negative side effects that reduce presence—such as dizziness (Barfield

& Weghorst, 1993) or nausea (Singer & Witmer, 1996)—seem to be more prevalent in immersive virtual reality systems that isolate a user from the real world in order to remove external distractions, than it is in nonimmersive displays. Repeated exposure to a virtual environment can reduce the symptoms of some side effects over time, which should then increase presence. Experience can also affect presence more directly, particularly if the connection between actions and events is complex and needs to be learned (Held & Durlach, 1992). A sense of having "been there before" may increase the chances of going "there" again (Heeter, 1992, p. 265).

2.1.2 Social Presence. The reaction, to a user, of other entities in a virtual environment can provide evidence for a user's existence and hence increase presence (Heeter, 1992). Bates (1992) suggests taking lessons from traditional media, in which characters portrayed with "intelligence and emotion . . . let the viewer see the world as a place of life, purpose and feeling" (p. 133). Although a correlation between presence and copresence has been demonstrated in a follow-up study (Tromp et al., 1998), the association was not significant, and a more realistic avatar reportedly scared a user because its appearance conflicted with its unrealistic movement. These studies concentrated on interaction among groups of users in a virtual environment but artificially intelligent agents can also be used (Bates, 1992).

2.1.3 Environment Presence. The extent to which an environment automatically reacts to a user can "provide evidence that [a user] exist[s]" in a similar manner to social presence (Heeter, 1992, p. 265). However, one of the key determinates of presence, and a more important factor from an environment design perspective, is a user's ability to manually modify the environment (Sheridan, 1992, 1996). The methods for changing an environment should be simple or easy to learn (Loomis, 1992), and there should be a high correlation between a user's actions and the virtual environment's responses (Held & Durlach, 1992). A sense of presence thus seems to be ultimately dependent on an environment's content, geometry, and dynamics (Ellis, 1996). However, presentation style (Bates, 1992) and long-term dramatic structure (Slater & Wilbur, 1997) have also been proposed, although the latter is difficult for nonlinear "stories" (Bates, 1992). Presentation style includes techniques such as shot length, the distance of objects and entities from the user, and rapid point-of-view movement (Lombard & Ditton, 1997).

2.1.4 Task Factors. Virtual reality is used for a wide range of tasks from the practical to the emotional (Waterworth, 1999), so the task to be completed will also affect a user's sense of presence (Sheridan, 1992). Zeltzer (1992) suggests that presence can be determined only by asking where and for what purpose a user should be present and then finding the minimum set of factors to create presence for that task. Even though presence forms an important subjective measure of a user's virtual experience, the conventional definition of presence suggests that nonimmersive displays are inadequate, even for tasks that do not require the user to be immersed in a virtual environment.

A new measure is needed to assess presence for nonimmersive displays that will more closely consider task requirements and how naturally a display supports a user. "It is here" is the idea that a display medium brings an object or person to the user (Lombard & Ditton, 1997). This idea has been investigated for conventional television programs (Millerson, cited in Lombard & Ditton, 1997), where it assesses the belief that the actual object being displayed exists within the television set. However, this concept also provides a useful measure for nonimmersive displays where the object appears to be in the user's physical environment, instead of inside the display.

2.2 Object-Presence

Witmer and Singer (1998) state that presence in a virtual environment is dependent on immersion and involvement. Although Slater and Wilbur (1997) suggest that one of the key components of immersion is the extent to which a virtual environment surrounds the user. However, a virtual environment is constructed from objects, which permits the Witmer and Singer definition of presence to be rewritten as "the subjective experience of being *co-located with a set of objects*, even when one is physically *not in such a situation*". If this definition is used, the implication that the user should be surrounded, inherent in the concept of environment, is replaced with the idea that a user should have a sense of being "with" an object.

Consider the other component of immersion as suggested by Slater and Wilber (1997). The quality of a display ("vivid"), the range of sensory modalities ("extensive"), and the correspondence between the user's actions and displayed information ("matching") are all aspects of how naturally a display supports a user. These components are not unique requirements for immersive displays. Indeed, the only other factor unique to immersion—apart from the ability to surround a user—is the extent to which a user is removed from reality ("inclusion"). Thus, the difference in presence between immersive and nonimmersive displays results from a display surrounding and isolating a user. However, some tasks do not require the user to be surrounded or isolated.

Following the style used by Witmer and Singer (1998), "the subjective experience that a particular object exists in a user's environment, even when that object does not" will be termed *object-presence* (Stevens & Jerrams-Smith, 2001, p. 196). It should be noted that this definition does not distinguish between real or virtual objects or environments. Thus, object-presence applies to immersive virtual reality; although, in this case, object-presence and presence would be different views of the same concept. More interesting, though, is the subjective experience that an object exists in the real world. This can be thought of as a special case of virtual reality, in which the user is colocated with a virtual environment (figure 2), a situation that can be facilitated by both nonimmersive and augmented reality displays.

Presence and object-presence have a close relationship. Both can be conceptualized as types of transportation (Lombard & Ditton, 1997) wherein either the user is transported to the virtual environment or the virtual environment is transported to the user. Given the close relationship between these two concepts, the classification scheme proposed by Heeter (1992) will also be used to investigate factors that may affect object-presence.

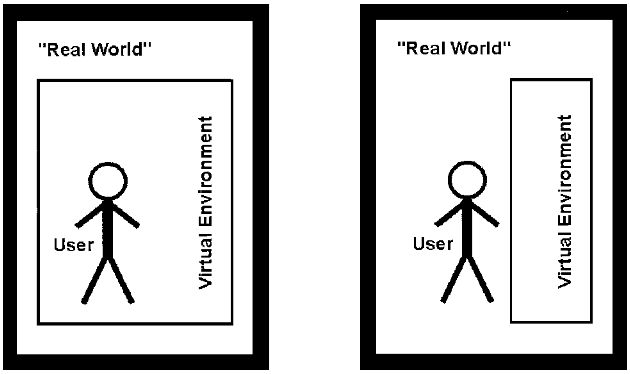

Figure 2. *Presence and object-presence.*

2.2.1 Personal Presence. In a similar manner to presentation in an immersive virtual environment, object-presence is thought to be linked to scene depth and thus requires the display to support physiological depth cues such as stereopsis, motion parallax, accommodation, and convergence. These depth cues will be expected for close object viewing because they operate most effectively within two meters (Rokita, 1996) and are thus probably more important for nonimmersive object displays than for immersive virtual environments. A high-resolution display would be needed to support a suitable depth range, and devices to simulate depth cues or to track users should be as unobtrusive as possible. Having an object occluded by the display's edges would also reduce object-presence. Therefore, a display with a wide field of view would be desirable for this problem to be confined to a user's peripheral vision. However, even though this would reduce distraction, it may not eliminate it.

The presentation of consistent information using audition as well as vision ought to provide corroboration that what is seen actually exists. However, the existence of an object in the real world is most strongly confirmed by being able to touch it, and the addition of haptic information should give a strong sense of object-presence. Again, the user should be able to view the object from any angle and "by moving the hand to a new configuration or pattern of contact" (Sheridan, 1996, p. 243) to touch any surface and hence perceive an object's shape and ideally its texture.

Perceiving the existence of an object in the real world is a natural task that most people accomplish every day. Therefore, the suspension of disbelief (Bates, 1992; Slater & Usoh, 1993) that is required for object-presence is thought to be less challenging when compared to that required to feel presence in an environment that a user knows does not exist. No attempt is made to isolate a user, so it is unnecessary to provide an avatar for a user to identify with. Also, the ability to become "involved", so easily destroyed by events that result from outside of an immersive virtual environment, ought not to be as volatile for object-presence. This is due to the object and distracting event existing in the same reality. The user is not trying to supplant one existence with another, but only perceive a minor distortion in it. This perception will be affected only if a confounding event occurs in the display volume, such as passing a real object through a virtual object. This type of event could be eliminated once a user has learned how to interact with an object-display. Object-presence should thus depend on past experience with the display, although experience with the object under investigation will also be a factor.

2.2.2 Social Presence. Object-presence could also benefit from social presence because "if the story makes sense and doesn't depend only on coincidence, if the characters act in consistent and understandable ways, if the actors skillfully and convincingly create their personae, [then] the experience is more likely to ring true" (Lombard & Ditton, 1997) Although this principally applies to interaction with a virtual human, the character could be any non-object entity.

For example, if a virtual mouse scurries in from one side of a display to sniff a virtual object, then the addition of another entity interacting with it may increase the user's sense of object-presence. This is a similar concept to the virtual creature designed to increase presence in an immersive virtual reality application by noticing a user and demanding to be picked up and thrown (Delany, cited in Heeter, 1992). However, Heeter suggests that the characteristics and interactions supported by an entity may affect presence. This may also be true for object-presence and, given the previous example, a user's attitude to mice may be a strong positive or negative influence. This effect may be most strongly felt if the user has a phobia, as it has been shown that strong emotions such as fear can affect presence (Slater & Usoh, 1993).

2.2.3 Environment Presence. One of the key elements of object-presence is the ability to interact with an object. The methods for exploring or manipulating an object should involve natural gestures with a high correlation between a user's actions and the display's response. Presence in an immersive virtual reality requires a long-term structure (plot) that can be enhanced by isolating a user from the real world (Slater & Wilbur, 1997). Isolation allows a virtual environment to be presented with no distractions, although in one study users who incorporated external distractions into the virtual environment reported the highest sense of presence (Slater & Wilbur, 1997). This suggests that presence is more dependent on coherence rather than immersion, although immersion isolates a user from distractions and hence maintains coherence. Thus, object-presence can be enhanced either by isolating a user from reality, or, more interestingly, by providing a display that accommodates external events, rules, and objects into a structure coherent with the object being presented. A blurring of the boundaries between a virtual environment and the real world will ultimately maintain coherence because all events will take place in the same reality.

2.2.4 Task Factors. Object displays can be used to view the components of an atom or the formation of the universe. Although it is possible to present an atom and a planet at the same size, the change in scale may affect object-presence. This effect may be particularly noticeable for familiar objects presented at the wrong scale. Indeed, familiarity with an object, as with the display itself (Lombard & Ditton, 1997), may have additional effects. If a user has never experienced an object's existence, it may have less meaning and hence less object-presence (Hoffman, Prothero, Wells, & Groen, 1998). Conversely, a user familiar with a real-world object may notice inaccuracies in its virtual representation with a similar result. Naturally, tasks that try to create the sense that an object exists in the real world should not require the user to be surrounded by a virtual environment, but consistency between a task and the display's surroundings may increase object-presence.

3 Correlation Study

3.1 Aims

This study is an initial investigation to determine if object-presence is a reliable and valid construct that can be measured for projection-augmented models. Object-presence, defined as the subjective sensation that an object exists in the user's environment, has a close relationship with presence in an immersive virtual environment (Lombard & Ditton, 1997). Hence, if object-presence is a reliable and valid construct, the same measures should be applicable. Objective measures such as eliciting a "startle response" (Held & Durlach, 1992), the awareness of real-world distractions (Nichols et al., 2000), or distinguishing between a virtual environment and a real-world scene (Schloerb, 1995; Sheridan, 1996) have been proposed. However, presence is a mental state, and, as such, it has been suggested that its fundamental measure is subjective response (Sheridan, 1992).

This study therefore attempts to ascertain whether a reliable and valid construct can be measured from a user's subjective responses to existing presence measures. Object-presence for this study pertains to *the combination of physical object and visual information,* not the existence of the physical object alone. As a subjective response, object-presence is likely to be influenced by user variation. Thus, a valid measure of object-presence should also correlate with a user's predisposition to become involved and immersed in other media.

3.2 Measures

A number of subjective presence measures have been developed, ranging from simple post-test ratings that directly ask for the participants' sense of "being there" (Slater & Usoh, 1993; Hendrix & Barfield, 1995) to full-scale questionnaires (Lessiter, Freeman, Keogh, & Davidoff, 2000; Lombard et al., 2000). The Singer and Witmer (1996) Presence Questionnaire (PQ) was chosen because it has been shown to be statistically reliable and valid in a number of studies (Witmer & Singer, 1998; Nichols et al., 2000; Sallnäs, 1999). In addition, unlike simple post-test ratings, it does not require a participant to understand the concept of presence in order to complete it.

However, the PQ is not without criticism. In one study, no significant difference was found between the presence rating for a task completed in a real office or a virtual simulation of it (Usoh, Catena, Arman, & Slater, 2000). A simple post-test rating scale, which more directly asked for the participants' sense of presence, produced similar although marginally significant results. This inability to distinguish between a real or virtual environment may be attributed to the apparent irrelevance of PQ questions to a real-life scenario, such as: "*Overall, how much did you focus on using the display and control devices instead of the virtual experience and experimental tasks?*" It has been shown, in a separate study, that presence scores are affected when participants fail to understand the relationship between a question and experience, and hence generate a score based on a personal interpretation of the question (Freeman, Avons, Pearson, & IJsselsteijn, 1999). This effect was noted during the pilot study, and, consequently, the language used for the PQ questions was altered to better match the experimental scenario. The PQ has been shown to measure a subjective construct (Witmer & Singer, 1998), not simply a score for specific questions; thus, by preserving the focus of the questions themselves, it is assumed that the conceptual construct is unaffected by minor language changes.

The Presence Questionnaire includes three subscales previously identified by cluster analysis based on the results provided by 152 participants (Witmer & Singer, 1998). The Involvement-Control subscale measures the extent to which participants become absorbed in the experience as well as application's responsiveness. The Natural subscale measures its consistency with reality, and the Interface Quality subscale measures a participant's ability to concentrate on a task. In addition, Witmer and Singer, suggested three other subscales, although these did not result from the cluster analysis.

The Resolution subscale measures the extent to which an object can be closely studied and looked at from multiple directions, the Auditory subscale measures sound in a virtual environment, and the Haptic subscale measures the ability to touch and move an object. The experimental scenario did not include any sound; therefore, the results obtained for the auditory subscale are not included in the total score.

The Immersive Tendencies Questionnaire (ITQ) is a companion questionnaire to the PQ, designed to measure the participants' propensity for immersion in traditional media or environmental situations (Singer & Witmer, 1996). The ITQ has been shown to be statistically reliable and valid and to correlate with the PQ score for a number of studies (Witmer & Singer, 1998). It has three subscale clusters: the Focus subscale is a measure of mental alertness, the Involvement subscale measures a participant's propensity to become engrossed in a media, and the Game subscale measures the frequency and extent of a participant's experience with video games. In addition to the questionnaire data, the participant's age, sex, vision status, task completion time, design type, and competency with the apparatus were also noted. These factors are used to determine if a selection variable systematically affected the ITQ and PQ scores for this study.

3.3 Participants

Sixteen participants took part in the study (eight men and eight women). The mean age for the men was 27 years (range 22–35), and the mean age for the women was 31 years (range 26–39). The combined mean age was 29. All participants were computer literate, although not all of them had used a drawing application before.

3.4 Apparatus/Materials

A 3M MP8725 LCD projector was used to project Microsoft Paint at a resolution of 800×600 with a total image area of 52 cm by 38 cm onto an A1 sheet of white paper that was secured to a conventional office desk. The physical model consisted of a white, plaster-covered polystyrene representation of a mobile telephone. To reduce image blurring, the model's height was kept within the projector's depth of focus. The model measured 26 cm by 9.5 cm by 3.5 cm, which covered an area approximately four times the size of a conventional mobile phone (figure 3). The drawing application was run on a personal computer with a 166 MHz Pentium processor with 40 MB of RAM. A mouse was used as the input device.

The ITQ and the modified PQ questions were scored on a seven-point scale using the semantic differentiation principle. Both questionnaires were completed on a separate desk from the experimental system so that participants could not see (and therefore be distracted by) the display.

3.5 Procedure

Participants were first presented with an outline of the whole experiment during which the four main tasks were explained. After this, the Immersive Tendencies Questionnaire was completed, and the participant's age, sex, and vision status were recorded. Participants then turned to the desk behind them, the room lights were turned off, and a 3 min. practice task was completed using the drawing package projected onto a flat white surface. The system was reset, and a physical model of a mobile telephone was placed in the projection area. Participants then designed a color scheme, for a University of Portsmouth branded mobile telephone case, directly on the model's surface. A maximum time limit of 15 min. was allocated for this task, although participants were allowed to finish earlier if they wanted to. The task completion time was recorded along with the participants' competency with the drawing application and whether the participant's design considered salient physical features on the model. After the design tasks, the room lights were turned back on, and the participants were moved back to the original desk to complete the Presence Questionnaire. Both questionnaires were presented on paper and transcribed by hand into SPSS v9.0 for analysis. All results were checked after input.

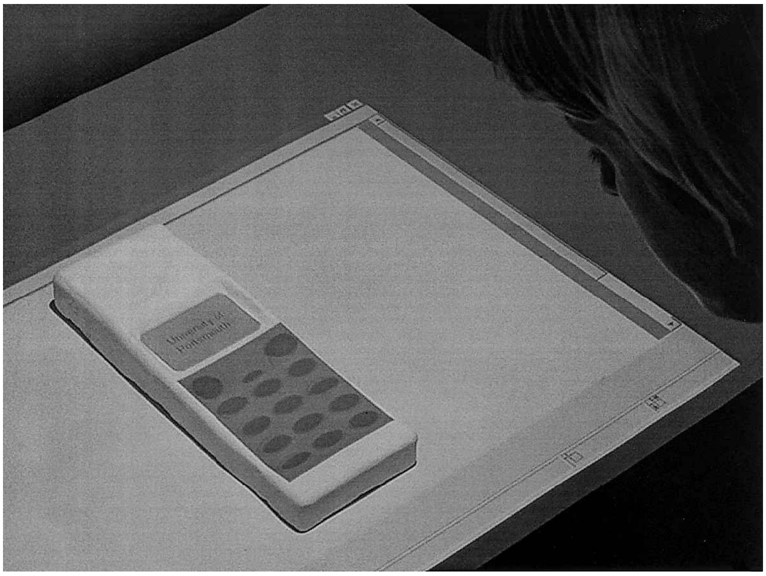

Figure 3. *Pilot-study participant starting to add visual detail to the projection-augmented model.*

3.6 Results

Assessing the Presence Questionnaire's scale for reliability, with a Cronbach's alpha test for internal consistency, gave a result of 0.84 ($N = 16$).

A Pearson correlation was calculated between the total score for the Presence Questionnaire without the questions that related to audition (mean = 135.94, s.d. = 18.40) and the score for each of the subscale clusters identified during previous studies (Witmer & Singer, 1998). A significant correlation was found for the Involvement-Control subscale ($r(16) = 0.88, p < 0.01$), the Natural subscale ($r(16) = 0.70, p < 0.01$) and the Interface Quality subscale ($r(16) = 0.63, p < 0.01$). The Resolution subscale did show a significant correlation ($r(16) = 0.60, p < 0.05$), although the Haptic subscale did not ($r(16) = 0.38, p = 0.15$). Significant correlations were also found between the Involvement-Control and Natural subscales ($r(16) = 0.75, p < 0.01$).

A reliability analysis and subscale analysis was conducted on the Immersive Tendencies Questionnaire. The Cronbach's alpha test generated a score of 0.86 ($N = 16$). A Pearson correlation was calculated between the total score for the Immersive Tendencies Questionnaire (mean = 138.69, s.d. = 21.48) and the score for each of its subscale clusters. A significant correlation was found for the Focus subscale ($r(16) = 0.85, p < 0.01$), the Involvement subscale ($r(16) = 0.57, p < 0.05$), and the Game subscale ($r(16) = 0.62, p < 0.01$).

There was a nonsignificant, almost zero, Pearson correlation between the Immersive Tendencies Questionnaire score and the Presence Questionnaire score ($r(16) = -0.10, p = 0.72$). When divided by sex (figure 4), scores for men exhibited a nonsignificant positive trend ($r(8) = 0.60, p < 0.12$), whereas women exhibited a nonsignificant negative trend ($r(8) = -0.49, p < 0.22$).

Pearson correlations conducted between the questionnaires' subscales showed no significant results. However, when divided by sex, the situation changed. For men, the ITQ's Focus subscale significantly correlated with the PQ's total ($r(8) = 0.92, p < 0.01$), Involvement-Control subscale ($r(8) = 0.77, p < 0.05$), and Natural subscale ($r(16) = 0.75, p < 0.05$). The PQ's Involvement-Control subscale also significantly correlated with the ITQ's Involvement subscale ($r(8) = 0.73, p < 0.05$) and total ($r(8) = 0.71, p < 0.05$). However, for women, a significant negative correlation was found between the PQ's Involvement-Control subscale and the ITQ's Involvement subscale ($r(8) = -0.75$, $p < 0.05$). In addition, the PQ's Natural subscale negatively correlated with the ITQ total ($r(8) = -0.85$, $p < 0.01$) and Game subscales ($r(8) = -0.80$, $p < 0.05$).

Other participant factors may have influenced the results, so, for the PQ and ITQ, including their subscales, Pearson correlations were computed with age, drawing application competency, design type, and task completion time. Only the ITQ's Game subscale negatively correlated to the subject's age ($r(16) = -0.57$, $p < 0.05$) and sex ($r(16) = -0.63$, $p < 0.01$), whereas task completion time was negatively correlated to the participants' competency with the drawing application ($r(16) = -0.58$, $p < 0.05$).

3.7 Discussion

This study set out to investigate whether object-presence is a reliable and valid construct that can be measured for a projection-augmented model using existing methods. The modified version of the Singer & Witmer (1996) Presence Questionnaire used to assess object-presence had a Cronbach's alpha of 0.84 ($N = 16$), which indicates that it does indeed form a reliable scale.

To determine whether the PQ is measuring a unified construct, the PQ's subscale scores were correlated with the total for the questionnaire. All of the subscales correlated with the total score (INV/C − $r(16) = 0.88$, $p < 0.01$; NAT − $r(16) = 0.70$, $p < 0.01$; QUL − $r(16) = 0.63$, $p < 0.01$; RES − $r(16) = 0.60$, $p < 0.05$) except the Haptics subscale ($r(16) = 0.38$, $p = 0.15$). Given that the display presents coincident visual and haptic information, this result seems surprising. However, observations during the experiment noted that participants did not touch the model because it was not explicitly required that they do so to complete the task. This is a flaw in the experiment's design as it has been suggested that haptic feedback increases presence (Hoffman et al., 1996; Sallnäs, 1999). More research is needed to investigate the difference in object-presence between haptic and nonhaptic interaction, and how this is affected by the task to be completed. However, the results of this study do still present a unified measure based on visual perception alone.

The reliability result and the correlations between the PQ total score and its subscales indicate that the questionnaire is measuring a unified construct. However, whether that construct is object-presence is a matter for debate. The correlation results for the PQ can be interpreted in three ways. First, the PQ could correlate with a construct not related to object-presence. The PQ questions used were adapted from a questionnaire based on factors derived from presence theory (Witmer & Singer, 1998), and it is assumed that the minor changes to the language of the questionnaire do not alter the measured construct significantly. This is supported by the reported existence of an underlying construct for different mediated experiences (Lessiter et al., 2000).

The second interpretation suggests that the PQ correlates with a construct related to object-presence. The nonadapted PQ measures a form of presence that requires a user to feel immersed and involved within a virtual environment. This has been likened to presence as transportation, "you are there" (Lombard & Ditton, 1997). Object-presence is similar, except that it is likened to transportation as "it is here" Thus, the adapted PQ could be constructing a measure of involvement with the display instead of object-presence. Indeed, it has been suggested that, as a measure of subjective feelings, Involvement-Control is the only PQ subscale related to presence (Regenbrecht, Schubert, & Friedmann, 1998). This view is supported by the strong correlation between the Involvement-Control subscale and the total score ($r(16) = 0.88$, $p < 0.01$). However, if the PQ is measuring the construct of involvement, then the PQ subscales that correlate with the PQ total should also correlate with the Involvement-Control subscale. The results show that only the Natural subscale is significantly correlated ($r(16) = 0.75$, $p < 0.01$), suggesting that the PQ total is more than just a construct of involvement. In addition, the PQ total correlates with the Natural, Interface Quality, and Resolution subscales; thus, the PQ total is dependent on the extent to which a display supports interaction, the "immersion" factor for immersive virtual environments, as well as involvement. These two factors were theoretical requirements for the initial questionnaire and support the assertion that the underlying construct has been preserved in the adapted PQ, a result that also adds further support to the rejection of the first interpretation.

The third interpretation of the results suggests that the PQ score correlates with object-presence itself although it does not necessarily measure the entire construct. It is believed that the empirical results do indeed support this view as each of the subscales (which are thought to contribute to a sense of presence and hence object-presence) are significantly correlated. However, the existence of a valid and reliable construct of object-presence, assessable with existing measures, would be more strongly supported if its score correlates with the participants' inherent propensity to become immersed in conventional media or situations, such as a film or sporting event.

This propensity should be reflected in a user's Immersive Tendencies Questionnaire score. A reliability analysis and subscale analysis was conducted on the ITQ to confirm that it is a valid tool for the experimental population used. The Cronbach's alpha level (0.86, $N = 16$) and the correlations between the subscales and the total ITQ score (FOC – $r(16) = 0.85$, $p < 0.01$; INV – $r(16) = 0.57$, $p < 0.05$; GAME – $r(16) = 0.62$, $p < 0.01$) suggest that this is indeed so.

The correlation between the ITQ and PQ total was nonsignificant ($r(16) = -0.10$, $p = 0.72$). This result is disappointing, though unsurprising. Witmer and Singer (1998) reported that, in the four experiments in which both questionnaires were used, only two showed a significant correlation; although there was a significant correlation when the results of all four studies were combined. A scatter plot of the results grouped by sex seems to indicate an interesting trend: results for men exhibit a positive trend, whereas results for women exhibit a negative trend (figure 4). This may be due to men finding projection-augmented models more natural than do women, a suggestion that is supported by the negative correlation, for female subjects, between the ITQ total and the PQ's Natural subscale ($r(8) = -0.85$, $p < 0.01$). Moreover, the PQ's Involvement-Control subscale positively correlated with the ITQ's Involvement subscale for men ($r(8) = 0.73$, $p < 0.05$) but negatively correlated for women ($r(8) = -0.75$, $p < 0.05$) suggesting that men could relate more to projection-augmented models. However, a Pearson correlation between the ITQ and the PQ total showed nonsignificant results for either men ($r(8) = 0.60$, $p < 0.12$) or women ($r(8) = -0.49$, $p < 0.22$).

Witmer (2000) reported similar, although statistically significant, results in two experiments. These trends were not evident in all studies, which led Witmer to conclude that this type of correlation was the result of sample bias. This could be the case for the present study because the sample size was small ($N = 16$). However, even though women sometimes exhibited a negative trend in other studies, men never did. Although inconclusive, the possibility of gender bias raises two important issues.

The first question that needs to be addressed is whether a measure is biased towards one particular gender. For example, the ITQ includes a question that assesses whether a participant has "ever gotten excited during a chase or fight scene on TV or in the movies?" Part of this question requires empathy with an aggressive emotional response, which may be considered a more masculine trait. Therefore, to reduce bias, a subjective measure should assess a more representative set of emotions such as the six fundamental emotional states of surprise, anger, sadness, disgust, fear, and happiness (Ekman & Friesen, 1971).

The object under investigation or the task to be completed by the participants (Sheridan, 1992) could also be a biasing factor. A mobile telephone was used as the object during this investigation because it was seen as a gender-neutral device. However, it is possible that men found this object or even the projection-augmented model display itself as more relevant and therefore more involving. Considering task factors, a study in which Witmer (2000) reported a similar pattern of trends, the task involved spatial navigation, which women are reported to find more difficult than men do (Astur, Ortiz, & Sutherland, 1998). Therefore, it is suggested that a set of standard, gender-neutral tasks may be needed together with standardized measurements to assess object-

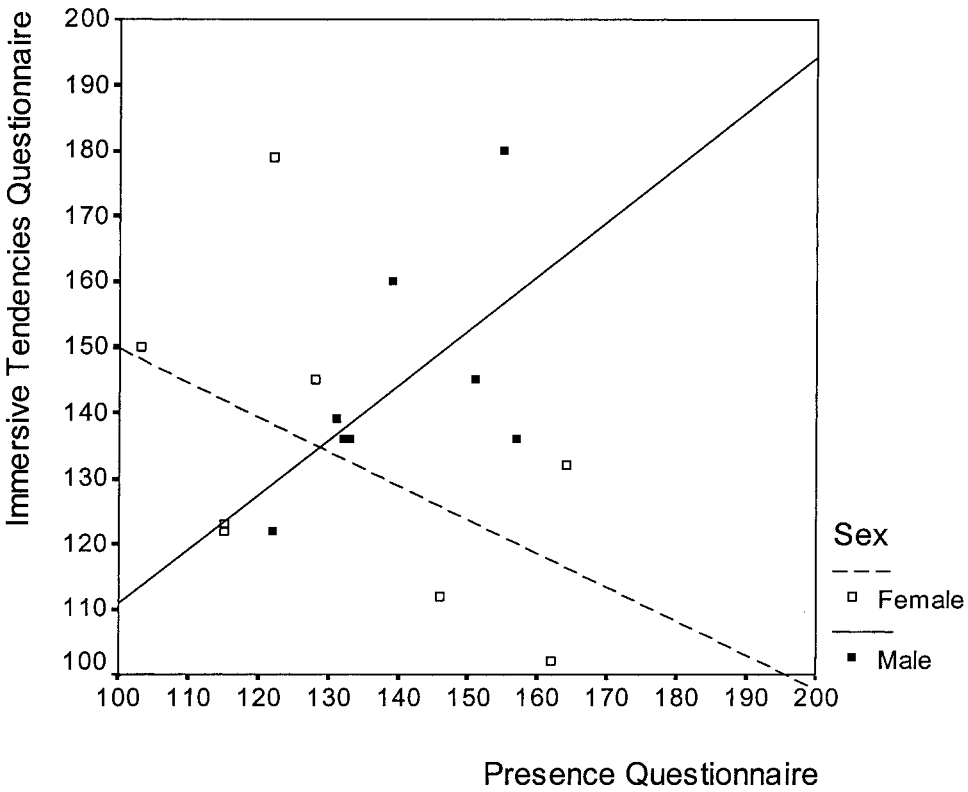

Figure 4. *Scatter plot of Immersive Tendencies Questionnaire scores against Presence Questionnaire scores divided by sex.*

presence or presence for comparisons between particular systems.

Instead of sex, some other participant characteristic could be influencing the results. Thus, the ITQ and PQ, along with all its subscales, were correlated with age, competency with the drawing application, the design type, and the task completion time. Only the ITQ's Game subscale negatively correlated to the subject's age ($r(16) = -0.57, p < 0.05$) and sex ($r(16) = -0.63$, $p < 0.01$), indicating that younger participants or men are more likely to play and become involved in video games. Unsurprisingly, the time to complete the task was negatively correlated to the participant's proficiency with the application ($r(16) = -0.58, p < 0.05$), demonstrating that more-experienced participants finished in less time. However, neither of these results consistently affects the scores for the ITQ or PQ.

4 Conclusions

Projection-augmented models offer a unique method for presenting visual and haptic information in the same spatial location. The visual information is projected onto a physical model that supports all physiological depth cues and the ability to touch the object under investigation, allowing a user to naturally access information.

One of the measures applied to a virtual reality display is the extent to which a user feels present. Linked to the idea of a display supporting the user in a "natural" way (Lombard & Ditton, 1997), object-presence may enhance a user's ability to utilize real-world skills for a virtual task and help to transfer learning from the virtual task back into the real world. The conventional definition of presence requires a user to be isolated from the real world and surrounded with a virtual environment. Although this definition is appropriate for some tasks, others do not require the creation of an entire environment.

Nonimmersive displays can provide a realistic natural stimulus to a user even though they have a limited field of view. The idea of object-presence is suggested as a measure of the extent to which information presented with a nonimmersive display seems natural to a user. This concept replaces the feeling of being surrounded by an environment with the sense of being colocated with a collection of objects. The results from the correlation study suggest the existence of a reliable construct that can be measured using subjective response. It is suggested that this construct is object-presence because the questionnaire exhibits face validity; however, the nonsignificant correlation with the user's immersive tendencies does not provide additional support for this assertion. The idea that an object exists in a user's environment is a measure that can be extended to all immersive, nonimmersive, and augmented reality displays, although standardized, gender-neutral tasks and measures may be needed if object-presence or presence is to be compared across different systems.

Acknowledgments

The authors would like to thank Miss Amanda Brightman for her continued patience and ideas throughout the writing of this paper, as well as Dr. Steve Hand for providing comments on earlier versions. Special thanks must also go to Bob Witmer for supplying extra information about his investigation results that used the PQ and ITQ.

References

Agrawala, M., Beers, A. C., Froehlich, B. Hanrahan, P., McDowall, I., & Bolas, M. (1997). The two-user responsive workbench: Support for collaboration through individual views of a shared space. *Proceedings of SIGGRAPH '97: Computer Graphics Proceedings, Annual Conference Series,* 327–332.

Astur, R. S., Ortiz, M. L., & Sutherland, R. J. (1998). A characterization of performance by men and women in a virtual Morris water task: A large and reliable sex difference. *Behavioral Brain Research, 93*(1-2), 185–190.

Barfield, W., & Weghorst, S. (1993). The sense of presence within virtual environments: A conceptual framework. *Proceedings of Fifth International Conference on Human Computer Interaction*, 699–704.

Bates, J. (1992). Virtual reality, art and entertainment. *Presence: Teleoperators and Virtual Environments, 1*(1), 133–138.

Czernuszenko, M., Pape, D., Sandin, D., DeFanti, T., Dawe, G. L., & Brown, M. D. (1997). The ImmersDesk and Infinity Wall projection-based virtual reality displays. *Computer Graphics, 31*(2), 46–49.

Ekman, P, & Friesen, W. V. (1971). Constants across cultures in the face and emotion. *Journal of personality and social psychology, 17*(2), 124–129.

Ellis, S. R. (1996). Presence of mind: A reaction to Thomas Sheridan's "Further musings on the psychophysics of presence." *Presence: Teleoperators and Virtual Environments, 5*(2), 247–259.

Freeman, J., Avons, S. E., Pearson, D. E., and IJsselsteijn, W. A. (1999). Effects of sensory information and prior experience on direct subjective ratings of presence. *Presence: Teleoperators and Virtual Environments, 8*(1), 1–13.

Heeter, C. (1992). Being there: The subjective experience of presence: *Presence: Teleoperators and Virtual Environments, 1*(2), 262–271.

Held, R. M., & Durlach, N. I. (1992). Telepresence. *Presence: Teleoperators and Virtual Environments, 1*(1), 109–112.

Hendrix, C., & Barfield, W. (1995). Presence in virtual environments as a function of visual and auditory cues. *Proceedings of IEEE Virtual Reality Annual International Symposium VRAIS '95,* 74–82.

Hinckley, K. (1996). *Haptic issues for virtual manipulation.* Unpublished doctoral dissertation, University of Virginia.

Hoffman, H., Groen, J., Rousseau, S., Hollander, A., Winn, W., Wells, M., & Furness, T. (1996). Tactile augmentation: Enhancing presence in virtual reality with tactile feedback from real objects. *Proceedings of American Psychological Society.*

Hoffman, H. G., Prothero, J. D., Wells, M. J., & Groen, J. (1998). Virtual chess: Meaning enhances users' sense of presence in virtual environments. *International Journal of Human Computer Interaction, 10*(2), 251–263.

Iwata, H. (1998). HapticScreen. *Proceedings of SIGGRAPH '98: Conference Abstracts and Applications,* 117.

Krueger, W., & Froehlich, B. (1994). The responsive workbench. *IEEE Computer Graphics and Applications, 14*(3), 12–15.

Lessiter, J., Freeman, J., Keogh, E., & Davidoff, J. (2000). Development of a cross-media presence questionnaire: The ITC-Sense of presence questionnaire. *Proceedings of Presence 2000: The Third International Workshop on Presence.*

Lombard, M., & Ditton, T. (1997). At the heart of it all: The concept of presence. *Journal of Computer-Mediated Communication, 3*(2), [online]. Available at: www.ascusc.org/jcmc/vol3/issue2/lombard.html. [Accessed 17 May 2000.]

Lombard, M., Ditton, T. B., Crane, D., Davies, B., Gil-Egui, G., Horvath, K., & Rossman, J. (2000). Measuring presence: A literature-based approach to the development of a standardized paper-and-pencil instrument.: *Proceedings of Presence 2000: The Third International Workshop on Presence.*

Loomis, J. M. (1992). Distal attribution and presence. *Presence: Teleoperators and Virtual Environments, 1*(1), 113–119.

Nichols, S., Haldane, C., & Wilson, J. R. (2000). Measurement of presence and its consequences in virtual environments. *International Journal of Human-Computer Studies, 52,* 471–491.

Raskar, R., Welch, G., & Chen, W.C. (1999). Table-top spatially-augmented reality: Bringing physical models to life with projected imagery. *Proceedings of International Workshop on Augmented Reality IWAR'99.*

Regenbrecht, H. T., Schubert, T. W., & Fredmann, F. (1998). Measuring the sense of presence and its relations to fear of heights in virtual environments. *International Journal of Human Computer Interaction, 10*(3), 233–249.

Rokita, P. (1996). Generating depth of field effects in virtual reality applications. *IEEE Computer Graphics and Applications, 16*(2), 18–21.

Sallnäs, E. L. (1999). Presence in multimodal interfaces. *Proceedings of the 2nd International Conference on Presence.*

Schloerb, D. W. (1995). A quantitative measure of telepresence, *Presence: Teleoperators and Virtual Environments, 4*(1), 64–80.

Sheridan, T. B. (1992). Musings on telepresence and virtual presence. *Presence: Teleoperators and Virtual Environments, 1*(1), 120–125.

———. (1996). Further musings on the psychophysics of presence. *Presence: Teleoperators and Virtual Environments, 5*(2), 241–246.

Singer, M. J., & Witmer, B. G. (1996). *Presence Measures for Virtual Environments: Background and Development.* (Draft ARI research note). U.S. Army Research Institute for the Behavioral and Social Sciences.

Slater, M., Linakis, V., Usoh, M., & Kooper, R. (1996). Immersion, presence and performance in virtual environments. *Proceedings of ACM Virtual Reality Software and Technology VRST '96,* Press, 163–172.

Slater, M., & Usoh, M. (1993). Presence in immersive virtual environments. *Proceedings of IEEE Virtual Reality Annual International Symposium VRAIS '93,* 90–96.

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and Virtual Environments, 6*(6), 603–616.

Stevens, B., & Jerrams-Smith, J. (2001). The sense of object-presence with projection-augmented models. In S. Brewster & R. Murray-Smith (Eds.), *LNCS 2058: The 1st international workshop on haptic human-computer interaction* (pp. 73–75). London: Springer-Verlag.

Tromp, J., Bullock, A., Steed, A., Sadagic, A., Slater, M., & Frécon, E. (1998). Small group behavior in the coven project. *IEEE Computer Graphics and Applications, 18*(6), 53–63.

Underkoffler, J. (1997). Antisedentary beigeless computing. *Personal Technologies, 1*(1), 28–40.

Usoh, M., Catena, E., Arman, S., & Slater M. (2000). Presence questionnaires in reality. *Presence: Teleoperators and Virtual Environments, 9*(5), 497–503.

Waterworth, J. A. (1999). The scope of presence. *Proceedings of the 2nd International Conference on Presence.*

Witmer, B. G. (August 18, 2000). Personal communication.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments, 7*(3), 225–240.

Zeltzer, D. (1992). Autonomy, interaction and presence. *Presence: Teleoperators and Virtual Environments, 1*(1), 127–132.