Lane Phillips
Victoria Interrante*
Michael Kaeding
Brian Ries
Department of Computer Science
University of Minnesota
Minneapolis, MN 55455

Lee Anderson
Department of Architecture
University of Minnesota
Minneapolis, MN 55455

Correlations Between Physiological Response, Gait, Personality, and Presence in Immersive Virtual Environments

Abstract

In previous work, we have found significant differences in the accuracy with which people make initial spatial judgments in different types of head-mounted, display-based immersive virtual environments (IVEs; Phillips, Interrante, Kaeding, Ries, & Anderson, 2010). In particular, we have found that people tend to less severely underestimate egocentric distances in a virtual environment that is a photorealistic replica of a real place that they have recently visited than when the virtual environment is either a photorealistic replica of an unfamiliar place, or a nonphotorealistically (NPR) portrayed version of a familiar space. We have also noted significant differences in the effect of environment type on distance perception accuracy between individual participants. In this paper, we report the results of two experiments that seek further insight into these phenomena, focusing on factors related to depth of presence in the virtual environment. In our reported first experiment, we immersed users (between-subjects) in one of the three different types of IVEs and asked them to perform a series of well-defined tasks along a delimited path, first in a control version of the environment, and then in a stressful variant in which the floor around the marked path was cut away to reveal a 20-ft drop. We assessed participants' sense of presence during each trial using a diverse set of measures, including: questionnaires, recordings of heart rate and galvanic skin response, and gait metrics derived from tracking data. We computed the differences in each of these measures between the stressful and nonstressful versions of each environment, and then compared the changes due to stress between the different virtual environment conditions. Pooling the data over all participants in each group, we found significant physiological indications of stress after the appearance of the pit in all three environments, but we did not find significant differences in the magnitude of the stress response between the different virtual environment locales. We also did not find any significant difference in the level of subjective presence reported in each environment. However, we did find significant differences in gait: participants in the photorealistic replica room showed a significantly greater reduction in stride speed and stride length between the control and pit version of the room than did participants in either the photorealistically rendered nonreplica environment or the NPR replica environment conditions. Our second experiment, conducted with a new set of participants, sought to more directly investigate potential correlations between distance estimation accuracy and personality, stress response, and reported sense of presence, compara-

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*Correspondence to interran@cs.umn.edu.

This paper is an extension of our award-winning JVRC'10 conference presentation, "A Further Assessment of Factors Correlating with Presence in Immersive Virtual Environments" (Phillips, Interrante, Kaeding, Ries, & Anderson, 2010).

tively across different immersive virtual environment conditions. We used pretest questionnaires to assess a variety of personality measures, and then randomly immersed participants (between-subjects) in either the photorealistic replica or photorealistic non-replica environment and assessed the accuracy of their egocentric distance judgments in that IVE, followed by control trials in a neutral, real-world location. We then had participants go through the same set of tasks as in our first experiment while we collected physiological measures of their stress level and tracked their gait, and we compared the changes in these measures between the neutral and pit-enhanced versions of the environment. Finally, we had people fill out a brief presence questionnaire. Analyzing all of these data, we found that participants made significantly greater distance estimation errors in the unfamiliar room environment than in the replica room environment, but no other differences between the two environments were significant. We found significant positive correlation between several of the personality measures, but we did not find any notable significant correlations between personality and presence, or between either personality or presence and gait changes or distance estimation accuracy. These results suggest to us that the relationship between personality, presence, and performance in IVEs is complicated and not easily captured by existing measures.

1 Introduction

Virtual environment (VE) technology has tremendous potential to facilitate the process of architectural design by enabling architects and their clients to experience a designed space before it is built. The usefulness of this preview capability critically depends, however, on the ability of viewers to make judgments about what they see in the virtual environment that are equivalent to the judgments they would have made in the corresponding real environment.

Unfortunately, repeated studies of spatial perception in immersive virtual environments (IVEs) have shown that, under most common conditions, people act as if they do not perceive space in the same way in an IVE as they do in the real world. For the past several years, we have been working to understand the factors responsible for these differences, in order to gain insight into the most promising strategies for overcoming them.

In this paper, we report the results of two studies that seek insight into the potential of a relationship between distance perception accuracy and presence in an IVE. In the first of these studies, initially reported in Phillips, Interrante, Kaeding, Ries, and Anderson (2010), we use a variety of measures to qualitatively and quantitatively assess the extent to which participants might be experiencing different depths of presence in three different virtual environments in which different amounts of distance perception accuracy had been previously observed. In the second study, we integrate tests of distance perception accuracy with gait measurements and personality and presence questionnaires in an attempt to more directly investigate the extent to which people's propensity to make accurate action-based judgments of spatial perception in an IVE might be predicted by cognitive factors related to their sense of presence in that IVE.

2 Previous and Related Work

Numerous studies over the years have found that people tend to significantly underestimate egocentric distances in head-mounted, display-based (HMD) immersive virtual environments, and the factors that underlie this phenomenon remain poorly understood. Investigations of the physical limitations of the virtual reality equipment have not indicated any single factor as the root cause of this large, observed inaccuracy (Loomis & Knapp, 2003), although Willemsen, Colton, Creem-Regehr, and Thompson (2009) have determined that a small portion (~5%) of the underestimation can be robustly accounted for by the ergonomics of wearing an HMD system. Various solutions to the distance-underestimation problem have been proposed, including: introducing a deliberate mismatch between the visual or display field of view and the geometric field of view used for rendering (essentially, minifying the virtual environment in the view presented by the HMD; Kuhl, Thompson, & Creem-Regehr, 2006; Steinicke et al., 2011), providing feedback to facilitate adaptation to the misperception of egocentric distances (Richardson &

Waller, 2005; Mohler, Creem-Regehr, & Thompson, 2006), and giving people a self-avatar in the virtual environment (Ries, Interrante, Kaeding, & Anderson, 2008; Mohler, Creem-Regehr, Thompson, & Bülthoff, 2010). Interestingly, it has been discovered that people tend *not* to severely underestimate egocentric distances where they are immersed in a highly photorealistic virtual replica environment—a virtual model that is an exact visual match to the same real environment that they know themselves to be concurrently occupying (Interrante, Ries, & Anderson, 2006), although they do underestimate distances when the virtual replica environment is portrayed in a nonphotorealistic (NPR) line-drawing style (Phillips, Ries, Interrante, Kaeding, & Anderson, 2009).

NPR renderings can be useful for conveying the preliminary nature of a design and inviting modification. The question of distance perception in NPR virtual environments was first investigated by Gooch and Willemsen (2002) and Thompson et al. (2004), who found no effect of graphics quality on users' accuracy, although Kunz, Wouters, Smith, Thompson, and Creem-Regehr (2009) find different results when verbal report rather than an action-based measure of distance perception is used. Slater, Khanna, Mortensen, and Yu (2009) found that adding more quality to the computer graphics, using real-time ray tracing to create realistic light and shadows, increased users' subjective presence and their stress response when faced with a virtual precipice.

These and other related findings (e.g., Interrante, Ries, Lindquist, Kaeding, & Anderson, 2008), have led us to wonder if the problem of distance underestimation in HMD-based IVEs may be rooted less principally in the low-level visual cues provided by the visual stimulus and, more directly, higher-level factors related to how people interpret what they see. In particular, we hypothesize that if users lack a sense of presence in an IVE, they may be hesitant to act on what they see through the HMD in the same way as they would act on the equivalent visual stimulus obtained in the real world.

To explore this possibility, we seek to (1) determine reliable methods for assessing the extent of a participant's sense of presence in an immersive virtual environment, (2) compare these measures of presence across the variety of environmental conditions in which we have previously found systematic differences in peoples' distance estimation accuracy, and (3) correlate these measures of presence with responses on personality questionnaires and performance on tests of distance-estimation accuracy in different virtual environments.

Previous researchers have investigated many different measures of presence in virtual environments. The Slater-Usoh-Steed (SUS) and Witmer-Singer (PQ) questionnaires were popular early methods for assessing users' subjective sense of presence in immersive virtual environments (Slater, Usoh, & Steed, 1994; Witmer & Singer, 1998), along with the ITC-Sense of Presence Inventory (Lessiter, Freeman, Keogh, & Davidoff, 2001), which was developed to accommodate desktop VR and other nonimmersive systems. However, more recent research has raised concerns about the general applicability and robustness of using questionnaires to obtain absolute measures of presence that can be reliably compared between subjects (Slater, 2004). Meehan, Razzaque, Insko, Whitton, and Brooks (2005) looked at physiological measures in conjunction with survey responses and found a correlation between users' reported sense of presence (using the SUS) and the change in their skin conductance and heart rate after looking down from a virtual precipice. Guger et al. (2004) explored using heart rate variability and event-related electrocardiography to assess presence. Brogni, Vinayagamoorthy, Steed, and Slater (2006) and B. K. Wiederhold, Jang, Kim, and M. D. Wiederhold (2002) also found correlations between physiological measures and presence in virtual environments. Behavioral measures of presence were additionally used by Slater, Usoh, and Steed (1995) and carefully investigated by Freeman, Avons, Meddis, Pearson, and IJsselsteijn (2000), and others. Insko (2003) gives a comprehensive survey of the many ways in which presence has been measured. Slater and Garau (2007, p. 455) argue that presence is best understood as "the extent to which participants respond to virtual sensory data as if it were real" and advocate considering a variety of disparate measures in conjunction to assess presence. This is the approach we attempt to follow here.

Gait analysis is another measure that has been used in studying virtual environments. Mohler, Campos, Weyel, and Bülthoff (2007) found that users walk with shorter strides during free walking in an HMD-mediated virtual environment than they do in the real world. Phillips et al. (2010) introduced the use of gait analysis in conjunction with the appearance of a pit as a measure of behavioral change in a stressful virtual environment (VE).

Many studies have explored the relationship between personality traits and presence in immersive virtual environments. Slater et al. (1994) were inspired by work in neuro-linguistic programming to investigate the relationship between participants' intrinsic propensity toward visual, auditory, or kinesthetic representation and the extent to which they report feeling present in an IVE. In their studies, subjective ratings of presence were positively correlated with increasing visual dominance and negatively correlated with increasing auditory dominance. For subjects with high kinesthetic scores, they found that presence was positively associated with the fidelity of their virtual self-representation. Witmer and Singer (1998) developed the Immersive Tendencies Questionnaire (ITQ) to predict the propensity of individuals to become involved or psychologically immersed in a virtual environment. The ITQ primarily focuses on queries intended to measure people's typical depth of involvement in common activities, along with their alertness and ability to focus. Witmer and Singer found a significant correlation between ITQ and PQ scores in two of four different experiments using both of these measures. Baños et al. (1999) also looked at how specific personality variables affect various aspects of the VR experience using an HMD-based IVE scenario. Their investigations focused on absorption (the ability to become completely involved in the task at hand) and dissociation (a measure of the extent of disruption of the normal integration of thoughts, feelings, and experiences into consciousness and memory). They measured absorption using a six-item Tellegen Absorption Scale (TAS; Tellegen & Atkinson, 1974) and dissociation using both the 26-item Dissociative Experiences Questionnaire (QED) (Riley, 1988) and the 28-item Dissociative Experiences Scale (DES; Bernstein & Putnam, 1986). They used a self-developed questionnaire to obtain measures on 15 different items related to participants' subjective experiences in the virtual environment, one of which was sense of presence. They found a significant correlation between sense of presence and absorption, and between sense of presence and dissociation as measured by the QED but not by the DES. Further analysis using *t*-tests found a significant relationship between sense of presence and higher than median scores in absorption, and a tendency (though not statistically significant) toward a relationship between sense of presence and higher than median scores in dissociation. Murray, Fox, and Pettifer (2007) tested for correlations between a person's experience of presence during a search task in an immersive cityscape environment (measured using a six-item SUS presence questionnaire; Usoh, Catena, Arman, & Slater, 2000) and the psychological variables of absorption (measured using the 34-item TAS; Tellegen & Atkinson, 1974), dissociation (measured using the 28-item DES; Bernstein & Putnam, 1986), immersive tendencies (measured using a 17-item version of the ITQ; Witmer & Singer, 1998), and locus of control (measured using a 29-item survey developed by Rotter, 1966). They found a significant positive correlation between presence and dissociation, and between presence and an external locus of control, but did not find a significant correlation between presence and immersive tendencies or between presence and absorption. Wallach, Safir, and Samana (2010) immersed participants in an HMD-mediated virtual experience simulating a short airplane flight and examined the correlation of presence (measured using Witmer and Singer's PQ) with five personality traits: empathy (measured using the fantasy subscale of the Interpersonal Reactivity Index; Davis, 1980), imagination (measured using a shortened form of the Betts' Questionnaire upon Mental Imagery, Sheehan, 1967), immersive tendencies (measured using the 18-question version of the ITQ), dissociation (measured using the DES; Bernstein & Putnam, 1986), and locus of control (LoCQ; Rotter). For the subset of their participants who visually engaged with the environment, they found a significant positive correlation between empathy and presence, and between immersive tendencies and presence, and signs of a possible predictive relationship between presence and an internal locus of control. Alsina-Jurnet and Gutiérrez-Maldonado (2010) investigated the relationship between presence (assessed using the Igroup Presence

Questionnaire; Schubert, Friedmann, & Regenbrecht, 2001) and a range of personality characteristics, including test anxiety and spatial and verbal intelligence. They found that among participants who were classified as having high test anxiety, there was a significant positive correlation between presence (defined by the total IPQ score) and spatial intelligence (assessed using a solid-figures rotation test; Yela, 1968), and a significant negative correlation between presence and extroversion (measured using the short revised version of the Eysenck Personality Questionnaire; S. B. G. Eysenck, H. J. Eysenck, & Barrett, 1985), but not between presence and verbal intelligence (assed using the vocabulary subtest of the Wechsler Adult Intelligence Scale, WAIS-III; Wechsler, 1958) or between presence and neuroticism, psychoticism, or computer experience.

3 Experiment 1

We designed a between-subjects experiment to assess the potential differences in presence evoked by the three different immersive virtual environment conditions in which we had previously noted differences in distance-perception accuracy.

3.1 Apparatus

The three different virtual environment models we used were: a photorealistic replica of our lab (PR room); a nonphotorealistic replica of our lab (NPR room); and a photorealistic model of a different, nonreplica room that was similar in dimensions to the lab space (PR hall). The photorealistic replica and nonreplica models were created by texture-mapping photographs of a real environment onto the surfaces of the models. The nonphotorealistic replica model was created by replacing the photographic textures used for the photorealistic replica environment with line drawings, obtained by hand-tracing thick, black lines at the locations of the most salient edges in the photographs, and superimposing a wide grid pattern on the floor. The virtual environments were modeled in Google SketchUp and Autodesk Maya and rendered on a custom-built PC with an nVidia Quadro FX 5800 card, using our VE software built on the OGRE gaming engine.

Figure 1. *A photograph of the physical environment.*

Each VE contained a path, marked in masking tape on the floor, traversing the long dimension of the space. A chair stood at the far end of the path, and a pair of wooden blocks lay alongside the path, extending toward the open space in the room. These elements were present in the real environment as well, to provide passive haptic cues and enhance presence. In each VE, a red cube sat on the chair, and a virtual target marked with a number sat out in the open space of the floor. A stressful version of each virtual environment was created by removing the floor in the area unbounded by the path and replicating the environment two more times below to reveal a two-story drop, leaving the marked path as a bridge to be traversed. The dimensions and location of the bridge, and the depth of the drop, were identical in all three environments, and the sizes of the gaps in the floor were as closely matched between the environments as possible. Additional furniture, consisting of tables and chairs modeled after the tables and chairs in the real lab space, was placed on the lowest level along with a numbered target, to provide cues to the height of the path over the floor below. Figure 1 shows a photograph of the real lab, and Figures 2 and 3 show images of the virtual models, taken from a similar vantage point.

We used EKG-Flex/Pro and SC-Flex/Pro sensors from Thought Technology, along with Biograph Infiniti

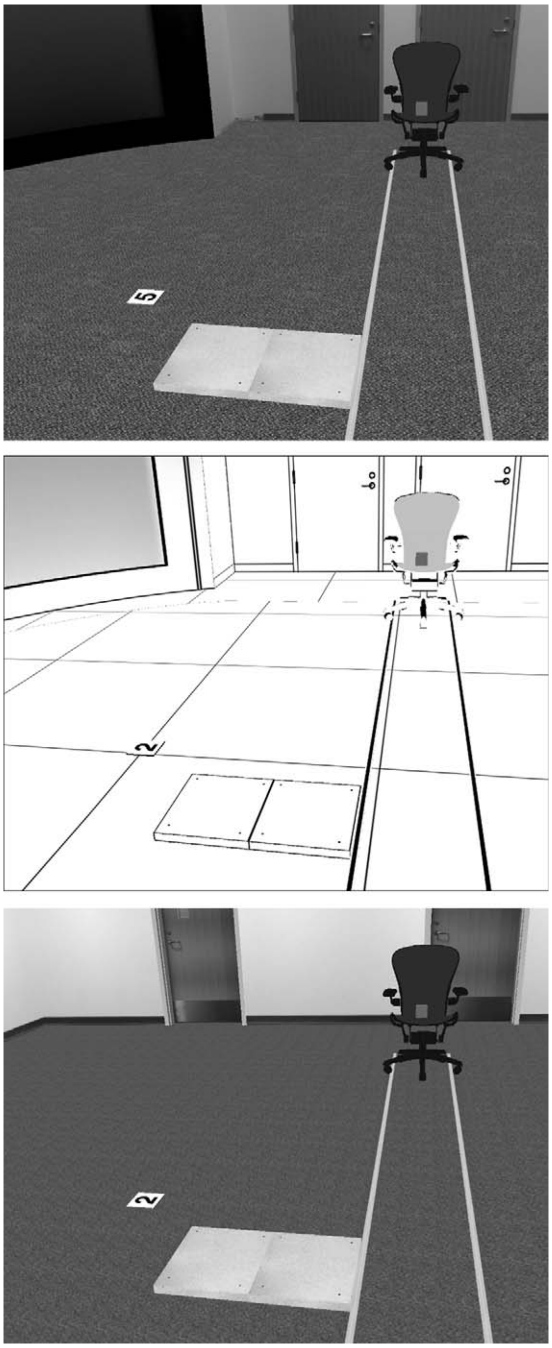

Figure 2. *The three different control environments. From top to bottom: PR room, NPR room, PR hall.*

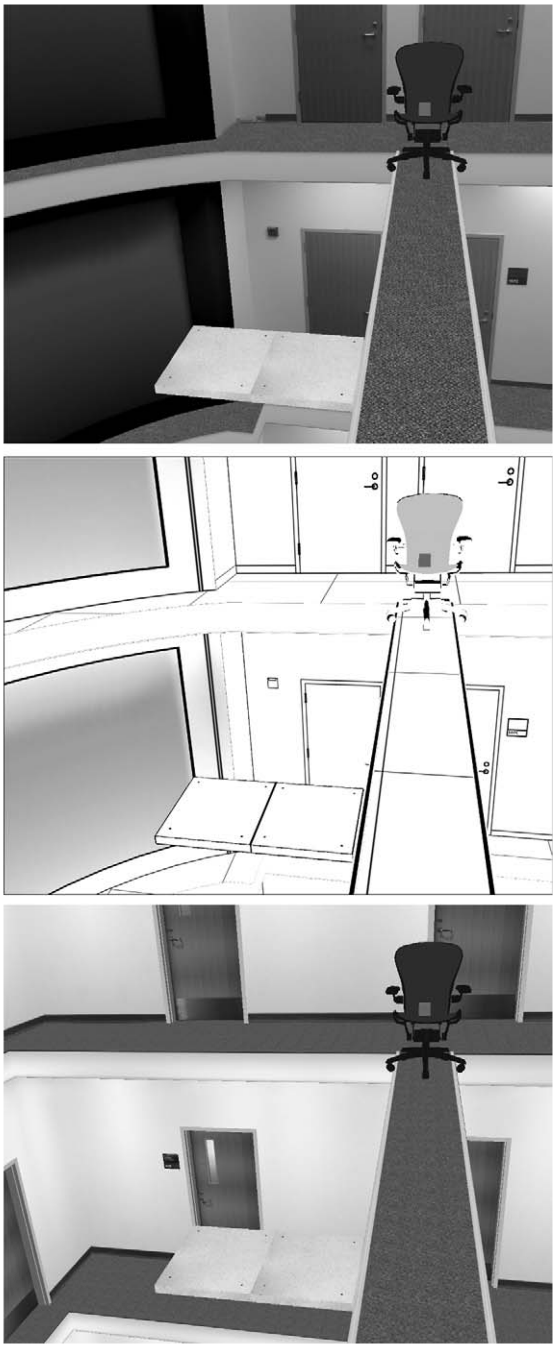

Figure 3. *The three different corresponding pit environments.*

software, to sample electrocardiograms at 256 Hz and skin conductance at 32 Hz. The sensors were attached to a small control box that participants wore at the waist. We used a Windows event hook in the Biograph Infiniti software to enable a key combination typed in Infiniti to be simultaneously received and interpreted by the VE software that was recording the locations of all of the tracked objects at 60 Hz. The synchronized key-press events were time-stamped and included in the data streams output by each program, allowing us to time-synchronize the data streams from these disparate sources.

The entire experiment was conducted in our laboratory, which is approximately 30-ft long and 16–25-ft wide. Participants viewed the virtual environment using an nVisor SX HMD, which has two screens offering a 1280 × 1024 resolution image over a manufacturer-specified 60° diagonal field of view with 100% stereo overlap. Tracking was provided by a Vicon motion-capture system consisting of 12 MX 40+ cameras and the Vicon IQ software. Since we did not intend to provide participants with a full-body avatar in this study, we did not ask them to wear a motion-capture bodysuit. Instead, we used retro-reflective markers attached to a pair of shin guards and a glove to track the movements of the participants' lower legs and right hand only. Additional tracking markers attached to the HMD allowed interactive control of the viewpoint. Figure 4 shows all of our hardware as it was used.

3.2 Procedure

Participants were first tested for stereo vision capability, and then arbitrarily assigned to experience one of the three different virtual environments. For the stereo test, we presented three different random dot stereograms on the HMD and asked participants to identify the shapes shown. A total of three prospective participants failed the stereo test, and were excused from further participation in the study. Participants were next asked to sign a consent form, and to read written instructions describing the experimental protocol. They were then provided with instructions about how to attach the ECG electrodes, and directed to a small office within the lab where, for reasons of privacy, they were allowed to prepare their skin and attach the electrodes by themselves. When ready, they reentered the main lab space, took off their shoes, and put on the shin guards and glove. At that point, the experimenter attached the skin conductance sensor and checked for signals from the Infiniti software, then assisted the participant to put on the HMD and adjust it for the correct view. One experimenter sat at the keyboard to control the virtual environment while another managed the HMD cables as the participant walked through the task.

Figure 4. *A photograph of our equipment in use.*

The experiment consisted of three trials. On each trial, the participants' task was to: walk along the marked path from the predefined home base to the chair; pick up the virtual red cube by reaching their hand out toward it; turn and walk back to the wooden platform; step out to the edge of the platform, feeling the end with their toes; report the number on the target and drop the cube onto it by shaking their hand; then return to the path, go back to the home base, and come to a stop while facing the wall. After two trials in the control condition, the floor was virtually dropped out while the participants' back was turned, and a third trial was performed with the identical protocol. The first trial was treated as practice, and used to collect baseline heart rate and GSR data. We also used that opportunity to verify that the participant understood the task, and to correct any errors. The differences in participants' physiological measures and gait metrics between the second and third trials were our primary measures of interest.

After completing the third trial, participants removed the HMD and the tracking and sensing equipment, and sat down at a desk to fill out a 12-question PQ based on the SUS survey (Slater et al., 1994).

3.3 Participants

We recruited a total of 40 participants (35 male, five female), ranging in age from 18 to 38 (average age = 21.58 ± 4.09) from our university community, through announcements in classes and via a sign placed on the door of our laboratory. Each participant was compensated with a $10 gift card. Data from nine participants had to be excluded from all analysis for varying reasons, including: critical loss of tracking (1), failure to follow the protocol (1), and breaks in presence that occurred due to experimenter error (2), or to the participant becoming snagged in the cables (4), or stopping and talking to the experimenters midway through a trial (1). Data from two additional participants had to be excluded from the gait analysis (only) because of a partial loss of tracking information, or because they stopped to look down at the pit midway along the path, and data from nine other participants had to be excluded from the physiological portion of the data analysis due to technical problems with getting a clean and uninterrupted signal from the ECG and/or skin conductance sensors. Table 1 lists the total number of participants with usable data in each condition.

Table 1. *Numbers of Participants with Usable Data*

	Gait	GSR	ECG	Survey
PR room	11	12	9	12
NPR room	10	9	7	10
PR hall	10	10	8	11
Total	31	31	24	33

3.4 Results

We defined a standard period of time over which to analyze the physiological data for each participant. This was defined as the portion of each trial between the first time one of the participant's legs came within 1 m of the wooden blocks while walking out toward the chair to pick up the cube, and the time their second leg passed this same point on the way back, after dropping the cube onto the target. In an ANOVA analysis of the physiological data, we found a significantly greater rate of increase in GSR over the course of the trials in the pit environment compared to that in the control environment, for participants in each of the three virtual environment conditions, PR room: $F(1, 22) = 6.90$, $p = .015$; NPR room: $F(1, 16) = 6.91$, $p = .018$; PR hall: $F(1, 18) = 7.41$, $p = .014$. An average GSR was recorded once per second, and the rate of increase was computed as the difference between the average GSR measured at the start and at the end of each trial, divided by the amount of time elapsed. We chose this measure in order to control for the fact that GSR tends to rise over time, by default. Our results suggest that each of the virtual environments was capable of inducing a significant stress response in most participants. However, we did not find any significant differences in the relative amount of the increase in GSR, after exposure to the pit, between the three different virtual environments. Figure 5 plots the average GSR for each participant in each environment, showing the magnitude of the individual differences observed; the error bars in these charts indicate the standard deviations about the means.

We also computed the average heart rate at 1-s intervals over the course of each trial, within the period described above, based on heartbeat counts derived from the ECG data using the QRS detection algorithm described by Köhler, Henning, and Orglmeister (2003), and correcting any mislabeled heartbeats by hand. Figure 6 plots the average heart rate for each participant in each environment; the error bars indicate the standard deviations about the means.

A statistical analysis did not find any significant difference between virtual environment locales, in the average heart rate change upon exposure to the pit, computed as $\Delta HR = (\text{meanPit} - \text{meanControl})/\text{meanControl}$. Furthermore, we did not find a significant difference in the

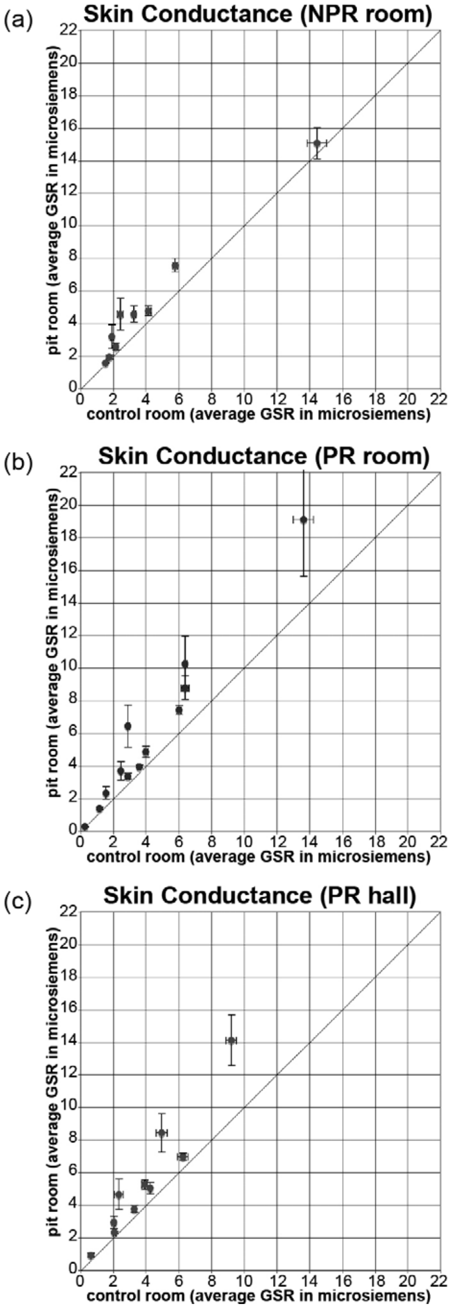

Figure 5. *Average galvanic skin response (GSR) in the control and pit conditions for each participant in each virtual environment. (a) NPR room. (b) PR room. (c) PR hall.*

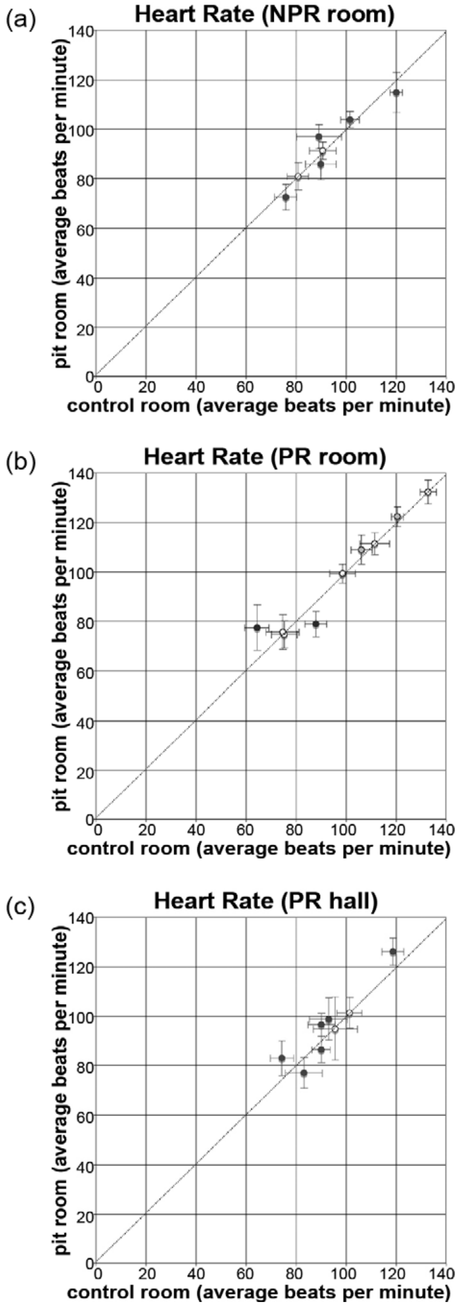

Figure 6. *Average heart rate in the control and pit conditions for each participant in each virtual environment. (a) NPR room. (b) PR room. (c) PR hall.*

average heart rate between the control and pit environments in any of the virtual environment conditions. These findings were disappointing, and inconsistent with the results of the earlier study by Meehan et al. (2005), which found a small but statistically significant increase in participants' average heart rate during trials in the pit versus in the control environment. We can only note that our results are similar in this respect to those of B. K.

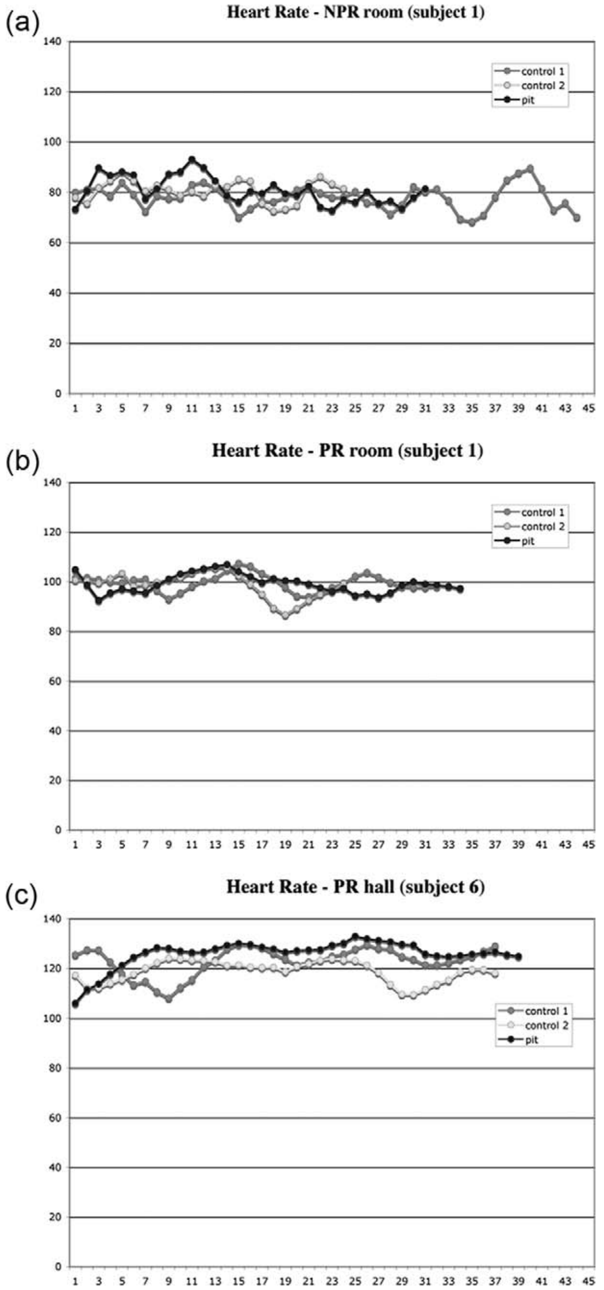

Figure 7. *Average heart rate, computed at 1-s intervals over each trial, shown for one representative participant in each condition. (a) NPR room, subject 1. (b) PR room, subject 1. (c) PR hall, subject 6.*

Wiederhold et al. (2002), who also did not find a significant difference between phobic and nonphobic participants, in average heart rate during a virtual flying scenario versus during a control phase. For a more detailed look at our heart rate data, Figure 7 shows the average heart rate for the participant with the median amount of relative change in heart rate between the pit and control conditions in each type of virtual environment, computed at 1-s intervals over the periods considered in our analysis.

Inspired by reports that heart-rate variability (Rowe, Sibert, & Irwin, 1998) might be a more promising measure of a participant's emotional state in a VE (Jang et al., 2002), we performed a follow-up analysis of the heart-rate data from our first experiment, in which we computed four different measures of heart-rate variability: the standard deviation of inter-beat intervals (SDNN); the square root of the mean squared difference of successive inter-beat intervals (RMSSD); the number of successive inter-beat intervals that differ by more than 50 ms (NN50); and the proportion of successive inter-beat intervals that differ by more than 50 ms (pNN50; Malik, 1996). We computed all of these measures over the same intervals as before, defined by the time between when participants passed a point on the path located 1 m before the wooden blocks while walking out, and the time they passed that same point on their way back. We found the four measures of heart-rate variability to be highly correlated with each other, but we did not find any significant differences in any of these measures between the control and pit versions of any of our three environments, nor between any of our three different VE locales.

For the gait analysis, we identified participants' footsteps by recording the position of the shin guards at the points where the speed reached a local minimum. We computed these minima by smoothing the position data with a linear, low-pass filter and then computing the speed. Due to intermittent occlusion, the tracking system would occasionally lose track of one of the shin guards; but fortunately, this mostly happened on the swinging foot, so we could still robustly identify the position of the standing foot. We computed stride length, stride width, and stride speed for the first four strides at the start of each trial, after the participant stepped out of the home base. We chose to restrict our focus to this portion of the data, illustrated for a representative participant in Figure 8, because we felt that this allowed the best consistent measure of active gait over all

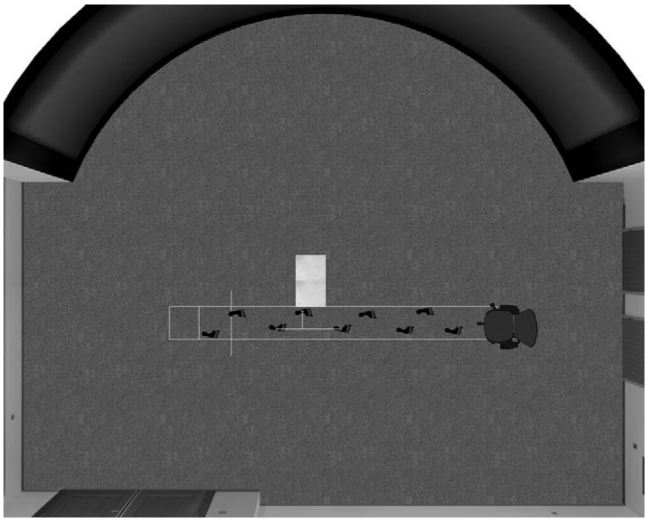

Figure 8. *An illustration of the footfall locations of a representative participant, with annotations denoting one stride length and one stride width. Gait parameters were computed, across all participants, based on the first four full strides recorded after the location indicated by the vertical line.*

participants, uncorrupted by startup and slowdown effects due to stopping at the chair or at the wooden blocks. We define stride length as the distance between successive steps with the same foot, and stride width as the perpendicular distance between adjacent strides (Figure 8).

Figures 9–11 plot the average stride length, stride speed, and stride width for each participant in each environment, and the error bars indicate the standard deviations about the means. Again using ANOVA, we found significant differences in the amount of change in both stride speed, $F(2, 28) = 4.98$, $p = .014$, and stride length, $F(2, 28) = 4.30$, $p = .024$, between the control and pit conditions between the different virtual environments, but no significant differences in stride width, possibly due to the implicit constraints on foot position imposed by the path.

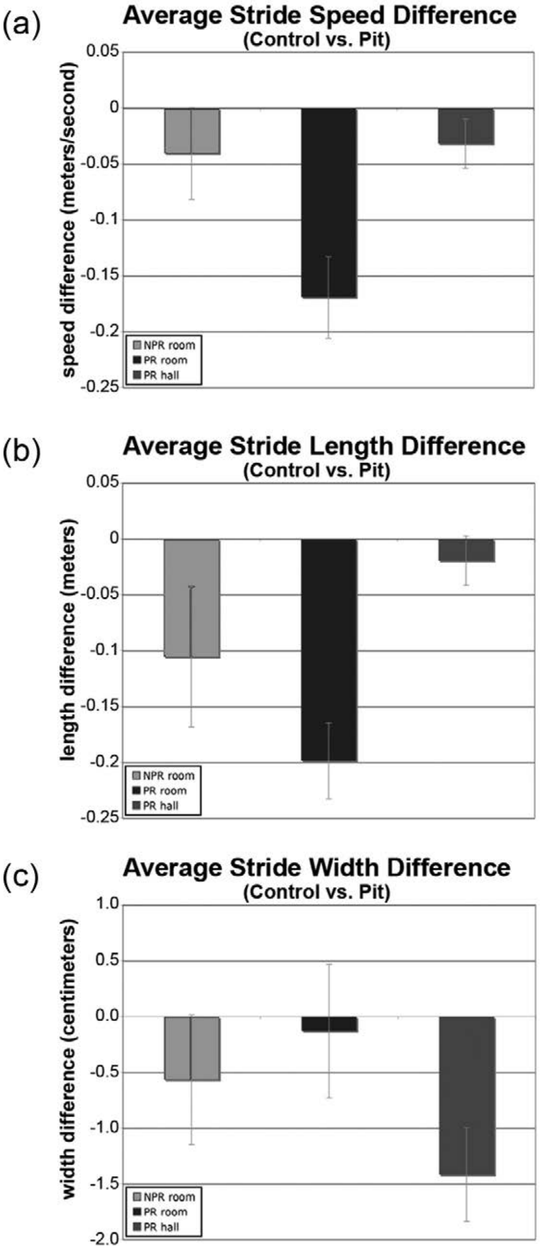

Figure 9. *Relative differences in the (a) average stride speed, (b) stride length, and (c) stride width, computed over all participants, between the control and pit conditions in each virtual environment.*

Overall, we found that participants walked significantly more slowly after exposure to the pit in the photorealistic room than in the photorealistic hall, $F(1, 19) = 9.52$, $p = .006$, or in the nonphotorealistic room, $F(1, 19) = 5.33$, $p = .032$. Figure 10 shows the average stride speed for each participant in each environment, and Figure 9(a) shows the average relative change in stride speed between the control and pit conditions in each environment.

Similarly, we found that participants took significantly shorter steps after exposure to the pit in the PR room than in the PR hall, $F(1, 19) = 17.93$, $p < .001$. How-

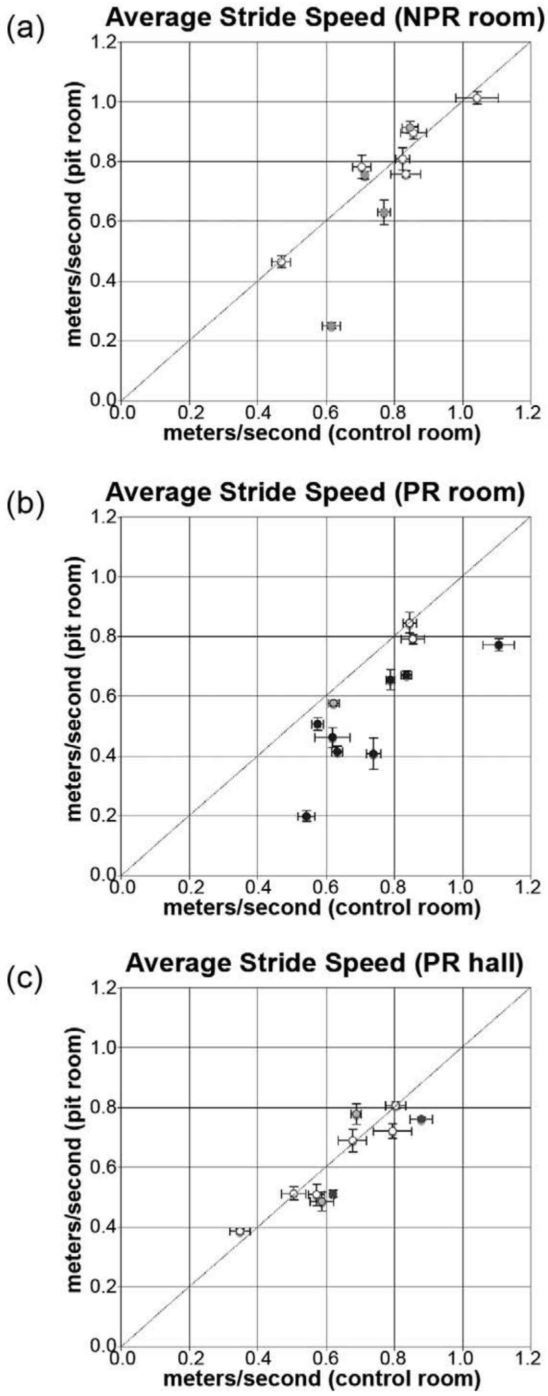

Figure 10. *Average stride speed in the control and pit conditions for each participant in each virtual environment. (a) NPR room. (b) PR room. (c) PR hall.*

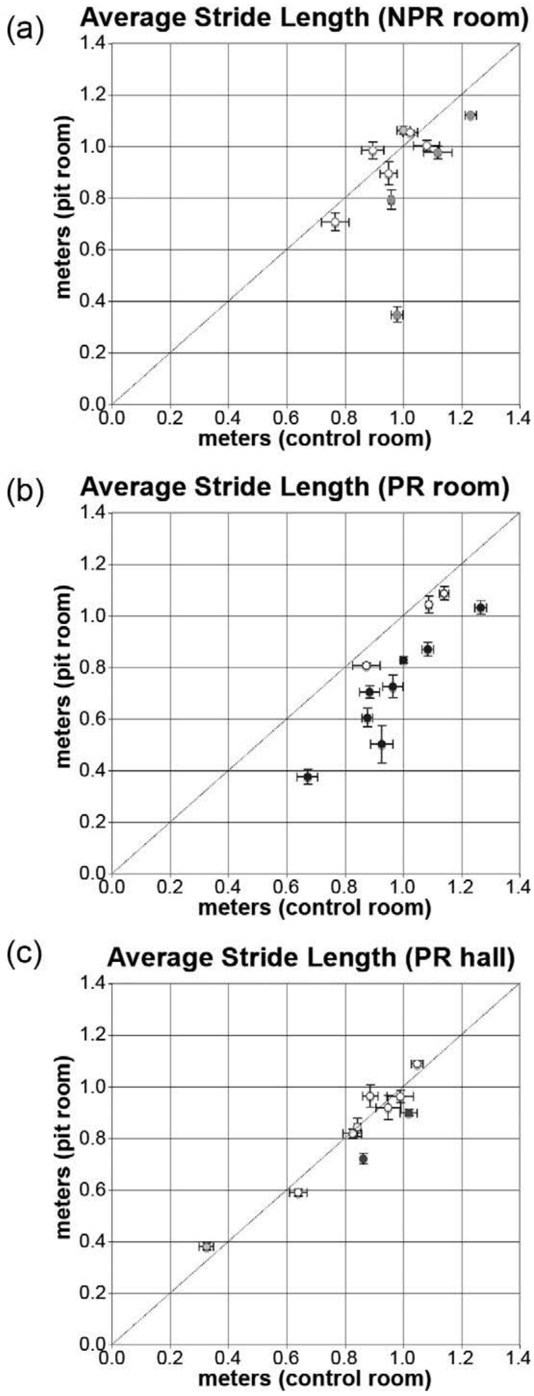

Figure 11. *Average stride length in the control and pit conditions for each participant in each virtual environment. (a) NPR room. (b) PR room. (c) PR hall.*

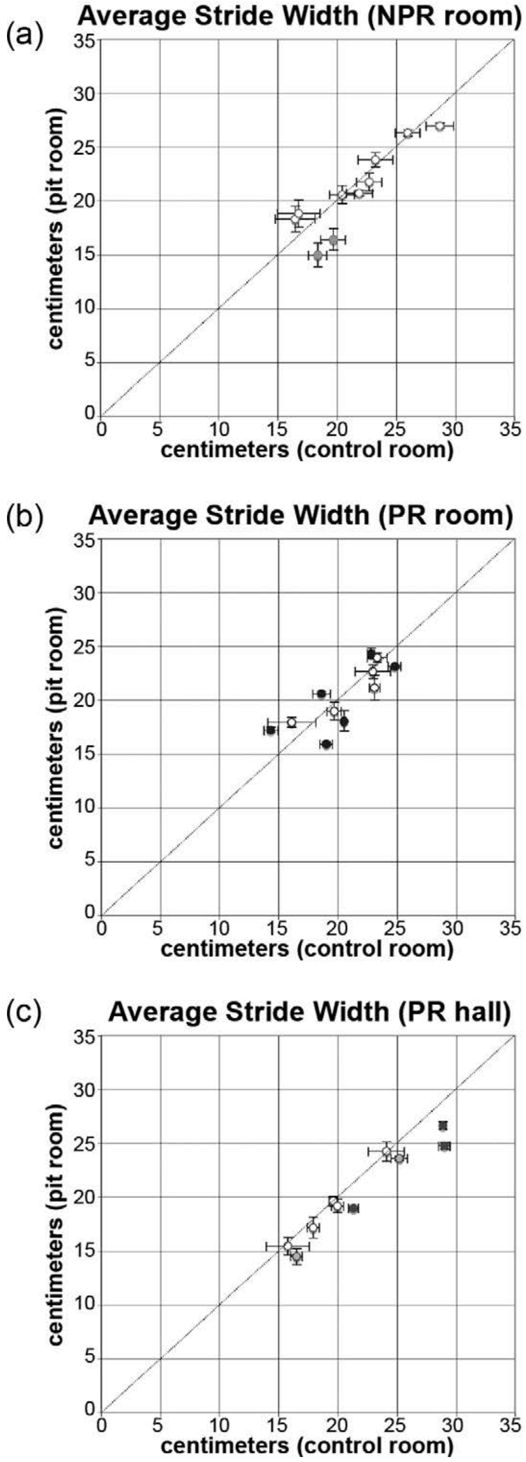

Figure 12. *Average stride width in the control and pit conditions for each participant in each virtual environment. (a) NPR room. (b) PR room. (c) PR hall.*

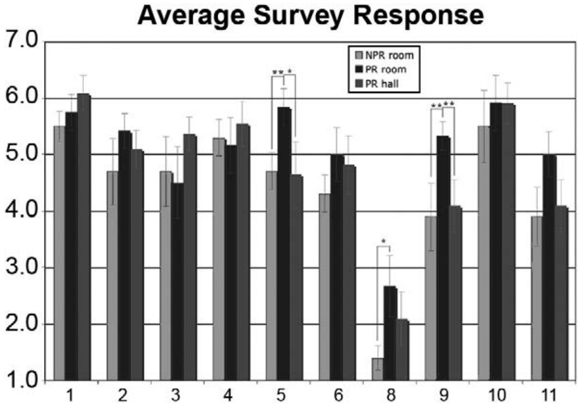

Figure 13. *Average responses to survey questions.*

ever, the variance in stride length between participants in the NPR room environment was relatively high, and the differences between the PR room and NPR room were not significant, $F(1, 19) = 1.71$, $p = .206$. Figure 11 shows the average stride lengths for each participant in each environment, revealing the nature of the variance in each condition, and Figure 9(b) shows the average relative change in stride length between the control and pit conditions in each environment.

Figure 12 shows the average stride widths for each participant in each environment, and Figure 9(c) shows the average relative change in stride width between the control and pit conditions in each environment. Note that in Figure 11 the variance in width, where it occurs, tends to be higher in the control than in the pit environments, indicating that participants were likely motivated to take particular care to keep their feet safely within the confines of the path when the area outside of the path was portrayed to be vacant. As this incentive to decrease stride width to stay on the path is at odds with the expected tendency for participants to increase their stride width to better maintain their balance under vertigo-inducing conditions, it appears, in hindsight, that the usefulness of the stride-width metric in our pit/path scenario may be somewhat limited.

Figure 13 shows the average responses to each of the survey questions, by question number. The first six questions asked participants to compare their experience in the virtual world with their usual experience in the real world. The next four questions attempted to probe the intensity of participants' reaction to the appearance of the pit. Significant differences were found between participants in the PR condition and participants in one or more of the other conditions, in the responses to two questions (Q5 and Q9), and marginally significant differences were found in the response to a third (Q8).

Question 5 probed the depth of participants' place illusion, reading: "*Consider your memory of being in the virtual room. How similar in terms of the structure of this memory is this to the structure of the memory of other places you have been today? By 'structure of the memory' consider things like the extent to which you have a visual memory of the virtual world, whether that memory is in color, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other structural elements.*" Participants were asked to indicate their response on a 7-point scale, under the heading "*I think of the virtual world as a place in a way similar to other places that I've been today. 1 = not at all, 7 = very much so.*" Unfortunately, Q5 contains the assumption that the VE would represent a different place than any other the participant would have visited that day. Participants in our study could have misunderstood this question as asking them to compare the VE to somewhere they had visited earlier. In that case, the PR room would be expected to score highly, since it was a faithful replica of the real environment that the participants were in while completing the survey. Although by similar logic, the same effect might also have been expected to apply to the NPR replica room, it clearly did not.

Question 9 asked: "*How disturbed by the environment were you during the third task?*" Participants were asked to indicate their response on a 7-point scale, under the heading "*During the third task, I was… 1 = not at all uncomfortable, 7 = very uncomfortable.*" Participants in the realistic replica room indicated a significantly higher level of discomfort than those who experienced either of the other two virtual environments.

Question 8 was meant to establish a baseline for Q9. It asked: "*How disturbed by the environment were you during the second task?*" and participants were asked to indicate their responses in the same way as above. The levels of discomfort indicated in response to question 8 were significantly lower, for all environments, than those given in response to question 9; but somewhat surprisingly, we find that participants who were immersed in the photorealistic replica room again indicated a higher level of discomfort than participants in the other environments, and significantly more than participants in the nonphotorealistic replica room. It is possible that participants in the photorealistic replica room condition were preferentially biased to use the real room environment as an implicit baseline, in which context experiencing the virtual replica could be interpreted as feeling somewhat uncomfortable. However, it is also possible that some participants got confused by the phrasing of the question, for example, interpreting the second task as dropping the block and the third task as returning to home base. This is suggested by the fact that one participant in the PR room condition reported the maximum discomfort level of 7 during task 2, followed by only a moderate discomfort level of 4 during task 3. In hindsight, we realized that we should have used more explicit terms to differentiate the control and pit environments; to address this shortcoming, we rephrased these questions in our follow-up experiment.

3.5 Discussion

The goal of our first experiment was to investigate the extent to which participants might be experiencing different levels of presence in each of our three different immersive virtual environment conditions, in order to gain insight into the extent to which differences in presence might explain the differences in distance perception accuracy that we had previously noted between these conditions. Some of our results appear to be consistent with the hypothesis that participants who were immersed in the photorealistic replica room experienced a greater sense of presence in that environment than the participants who were immersed in the nonreplica virtual hall environment or in the nonphotorealistic replica room. Specifically, the gait data and the survey data seem to support this interpretation fairly well. Yet others of our results, specifically the physiological data analysis, do not support this hypothesis at all, so the overall picture remains far from clear. Because of the between-subjects design, the possibility of unbalanced individual differences in immersive tendencies also cannot be ruled out, which further complicates the interpretation.

4 Experiment 2

In our second experiment, we sought to better control for the potential effects of individual differences in immersability and to more directly investigate the possibility of a link between the extent to which participants feel present in a virtual environment and the accuracy with which they will judge egocentric distances in that environment. To do this, we reran our first experiment with a new set of participants after augmenting our protocol to include a suite of personality questionnaires and distance-estimation testing. Specifically, we conducted a new between-subjects experiment that consisted of three phases: personality testing; distance-estimation testing; and physiological response and gait monitoring, followed by the administration of a subjective presence questionnaire.

4.1 Participants

We recruited 24 (10 female, 14 male) new participants for this study, ranging in age from 18 to 35 ($\mu = 21.3 \pm 3.8$). None of the participants had previously been involved with any virtual reality studies in our lab. Half of the participants were respondents to a sign placed on the door of our lab and the other half were students in a journalism class who participated for extra credit. All participants were given a $10 gift certificate at the conclusion of the study for their efforts.

4.2 Procedure and Apparatus

After entering our lab and signing the requisite consent forms, participants were first screened for stereoscopic vision ability, using a simple test in which they were asked to put on the HMD and identify the shapes of simple geometric figures depicted in three subsequently presented random dot stereograms. They were then directed to a small private office, adjoining the larger lab space, where they were asked to complete three different personality questionnaires: the 34-item TAS (Tellegen & Atkinson, 1974), the 28-item DES (Bernstein & Putnam, 1986), and the original 28-item ITQ (Witmer & Singer, 1998). Participants were asked to indicate their responses to each questionnaire on a discrete 4-option Likert scale. Although the TAS questionnaire was originally designed on a 2-point scale (True/False), while the ITQ was originally designed on a 7-point scale, we felt that using a consistent, intermediate option for all of these instruments would be preferable under our circumstances. We scored each test by taking the sum of the responses over all of the questions. We chose these three instruments based on various previous reports of the potential correlation of these three personality measures—absorption, dissociation, and immersive tendencies—with assorted measures of presence in immersive virtual environments (Baños et al., 1999; Murray et al., 2007; Wallach et al., 2010).

After filling out the personality questionnaires, participants were asked to read the written instructions for the distance estimation task (phase 2 of the experiment). They were then brought back into the main lab, where they strapped an MP3 player to their arm and put on a set of ear buds to hear a background audio track of white noise, intended to mask any ambient sounds from the laboratory environment that might provide auditory cues to their location in the room. Following this, they put on the HMD and adjusted it for comfort, secure fit, and clear viewing. We used the same HMD as described in Experiment 1 (Section 3.1). For tracking in this phase of Experiment 2, we used a HiBall 3100 tracker which provided high accuracy coverage throughout the entire room. Half of the participants were randomly assigned to experience the realistic co-located replica room environment (PR room), and the others were immersed in the realistic but unfamiliar virtual environment (PR hall). Both environment models were the same control environments that we used in Experiment 1 (Figure 3), but were rendered for this phase of the experiment using the G3D game engine. We did not use the NPR replica room environment in Experiment 2.

Due to an unfortunate oversight in our software setup process, which we realized only partway through testing, the first 12 of our participants (equal numbers in each condition) experienced the G3D-rendered virtual environments with a stereo convergence setting that was closer than optimal, resulting in stereo pairs that might have been difficult for some participants to fuse. We corrected this setting for the subsequent 12 participants, and treated the stereo setting as a blocking factor in our analysis.

We collected 20 independent measures of distance-estimation accuracy from each participant, through 20 trials of blind walking in their assigned environment. Participants began each trial at an arbitrary location near the edge of the room, facing inward toward the open space. At the start of each trial, the display was turned on and a virtual target appeared on the floor at a calculated distance directly in front of the participant. Distances were selected from randomized blocks of five possibilities: 8 ft, 10 ft, 12 ft, 14 ft, or 16 ft, so that each participant made four judgments at each distance, and the distances that were presented varied randomly between each successive judgment. The participants indicated their understanding of the distance to the target by closing their eyes, saying “start,” walking to where they thought the target was located, and saying “done.” At the start signal, an experimenter used a key press to record the starting position and blank the display (to prevent any inadvertent peeking); upon hearing “done” the experimenter used a second key press to record the ending position while leaving the display turned off. The experimenter then gripped the participant’s shoulders and directed him or her to a new, randomly selected starting position. There the display was turned back on and the participant was allowed to view the next target.

After the 20 blind walking trials in the virtual environment, participants removed the HMD (but not the radio), and were taken out of the lab to a quiet hallway in the basement of the same building to perform 10 baseline trials of blind walking distance estimation in the real world. Instead of wearing the HMD, participants wore a blindfold. At the start of each trial, the experimenter placed a physical target (a paper disk) on the floor at a randomly preselected distance in front of the participant, while his or her eyes were closed. After the experimenter returned to a position behind the participant, the participant was allowed to raise the blindfold, look at the distant target, then replace the blindfold and walk to where he or she thought that the target was located. The participant then waited while the experimenter measured the distance between the two targets, and between the starting target and the participant’s ending location, using a tape measure. After the distances were recorded, the participant was walked forward a short distance and then turned around, and the targets were repositioned. We chose to use a neutral external environment, rather than our lab, for the baseline distance-estimation task in order to avoid any possible interaction between the real and virtual environments that might inadvertently offer a selective advantage to the participants in the PR or NPR room conditions, due to practice or familiarity. We scheduled the real-world, blind-walking trials after the virtual environment blind-walking trials in order to enforce a natural break from wearing the VR equipment between the second and third phases of the experiment.

After completing the real-world, distance-estimation trials, participants were brought back to the lab and given written instructions for the last phase of the experiment. The apparatus and procedure we used in this third phase were identical to that in Experiment 1, except that we did not use the physiological sensing equipment, since we had not found significant results from the physiological monitoring in that experiment. Participants put on a pair of tracked shinguards and gloves, were positioned at a predefined starting location (home base) in the lab, and then put on the HMD to find themselves immersed in the same virtual environment model in which they had previously made distance judgments. In each of three trials, they walked along a marked path to a chair at the opposite end of the room, picked up a virtual cube from the chair by reaching out to touch it with their tracked hand, walked back along the path to a set of wooden blocks located about halfway between the chair and the home base, stepped out onto the wooden blocks, looked down toward a target on the floor, stated the number they saw on the target, shook their hand to drop the virtual cube onto the target, then returned along the path to the home base. Before the third trial, while the participant was at home base and facing toward the wall, the floor was virtually dropped out in the center of the room to cause the marked path to appear to be a bridge over a two-story drop.

Upon completion of the last phase of the experiment, participants removed the HMD and tracking equipment, and were taken back into the small private office adjacent to the open space of the lab to complete the same SUS-based questionnaire as used in Experiment 1, with a few edits in the wording for clarity.

4.3 Results and Discussion

In previous studies, we had found that participants who were immersed in our photorealistic replica room environment made significantly fewer severe distance-underestimation errors than participants who were immersed in equally photorealistic but unfamiliar and non-co-located virtual environments. We observed this same trend in our present experiment. Overall, participants underestimated distances in the PR room by an average of 5.82%, which was not significantly different from their average underestimation error of 0.11% in the real world, $F(1, 22) = 1.27$, $p = .271$. In contrast, participants underestimated distances in the PR hall by an average of 17.72%, which was significantly different from their average underestimation error of 2.45% in the real world, $F(1, 22) = 13.89$, $p = .001$. There was no significant difference by t-tests in the pattern of errors between participants who completed the task with the optimal versus suboptimal stereo settings ($p = .902$); and when only the subgroup of participants who experienced the correct stereo settings were considered, the ANOVA again confirmed that the effect of the virtual environment was significant, $F(1, 21) = 4.8978$, $p = .0381$.

Although we had found a significant main effect of virtual environment (PR room vs. PR hall) on the magnitude of participants' gait changes after exposure to the pit in Experiment 1, we did not find this to be the case in Experiment 2. Rather, stride length and speed decreased significantly after the floor was dropped out both in the PR room length difference $= -17.8$ cm, $F(1, 11) = 11.900$, $p = .005$, speed difference $= -0.144$ m/s, $F(1, 11) = 7.688$, $p = .018$; and in the PR hall, length difference $= -13.2$ cm, $F(1, 11) = 12.768$, $p = .004$, speed difference $= -0.098$ m/s, $F(1, 11) = 7.342$, $p = .020$, and there was no significant main effect of the environment locale on the amount of change in stride length, $F(1, 21) = 0.622$, $p = .439$, or stride speed, $F(1, 21) = 0.585$, $p = .453$. Changes in stride width after exposure to the pit were not statistically significant in either environment, width difference in the PR room $= +1.97$ cm, $F(1, 11) = 1.025$, $p = .333$, and width difference in the PR hall $= +1.16$ cm, $F(1, 11) = 0.553$, $p = .473$); and there was also no significant effect of (or interaction with) the stereo setting that had been used during the earlier distance-estimation trials. Comparing the gait changes observed in Experiment 2 to the gait changes observed in Experiment 1, we observe a significantly more pronounced response to the appearance of the pit among participants in the PR hall environment in Experiment 2. In Experiment 1, the average stride length difference in the PR hall, after exposure to the pit, was only -1.94 cm, compared to -19.9 cm in the PR room. Likewise, the average stride speed difference in the PR hall was only -0.032 m/s, compared to -0.169 m/s in the PR room. Between Experiments 1 and 2, there was no significant difference in the amount of stride length and speed compression observed in the photorealistic replica environment, $F(1, 21) = 0.108$, $p = .746$ and $F(1, 21) = 0.145$, $p = .707$, but there *was* a significantly greater amount of stride-length compression observed in the photorealistic nonreplica environment, $F(1, 20) = 6.106$, $p = .023$, and the stride speed difference was three times greater in the PR hall in Experiment 2 than in Experiment 1, although this difference did not reach statistical significance, $F(1, 20) = 2.36$, $p = .139$. We believe that the discrepancy in the results between Experiment 1 and Experiment 2 is most likely due to the differences in methodology between these two experiments; in Experiment 2, participants had significant prior exposure to and experience in the photorealistic nonreplica environment, as a result of performing the distance-estimation trials there in Phase 2, before completing the block-dropping task in Phase 3. It is possible that this longer period of prior familiarization with the photorealistic hall environment engendered a stronger sense of presence in that environment when participants returned to it after completing the walking trials in the real world, causing them to then react more strongly to the appearance of the pit than did the participants in Experiment 1.

The main goal of our second experiment, however, was to explore the potential relationship between personality factors, measures of presence, and distance-estimation accuracy in our two different virtual environments. Pooling the data over all participants, we found an average score on the TAS of 91.0 on a scale of 34–136 (55.9%). This was slightly less than Murray et al.'s finding of an average score of 21.8 on a scale from 0–34 (64.1%; Murray et al., 2007), although the ability to make a direct comparison is somewhat compromised by the fact that we used a 4-point rather than a binary scale. Fortunately, the internal consistency of our participants' responses to this survey was fairly high (Cronbach's $\alpha = 0.906$), bolstering our confidence in the reliability of our data. Our participants' average score on the 28-item ITQ was 75.5 on a scale of 28–112 (56.5%), which is similar to, but slightly higher than, both the average of 68.23 (50.26%) found by Murray et al. using a 7-point Likert scale on the 17-item ITQ with a possible range of scores from 17–119 (Murray et al., 2007), and the average of 69.96 (51.9%) found by Wallach et al. (2010). The internal consistency of our participants' answers to the items in the ITQ was less strong than on the TAS, with Cronbach's $\alpha = 0.653$ on the full, 28-item survey. Considering just the 17-item subset identified as most reliable in previous testing by Witmer and Singer (1998), we computed an average ITQ score of 51.4 on a scale from 17–68 (67.4%). Using a similar winnowing process as described by Witmer and Singer, we identified a (different) subset of 12 items in the ITQ survey for which Cronbach's α reached a final value of 0.825. Our participants' average ITQ score on these 12 items was 32.2 on a scale from 12–48 (56.1%), consistent with their results on the full, 28-item survey. Our participants' average score on the DES was 22.1%, slightly higher than the 16.1% found by Wallach et al. (2010), but similar to the 23.5% found by Murray et al. (2007). The internal consistency of our participants' responses to the items on the DES was also reasonably high (Cronbach's $\alpha = 0.910$).

An analysis of the responses to our final survey showed that game-playing experience was well balanced between participants in each of our virtual environment groups. The majority of our participants were not avid game players; 8 of 12 (PR room) and 7 of 12 (PR hall) reported that they spent 0–4 hours/wk on average playing video games, and another 2 of 12 (PR room) and 4 of 12 (PR hall) spent a modest 5–9 hours/wk. Only one participant in each group reported spending either 15–19 or 20+ hours gaming. The average of the scores on the first six (presence-related) questions on our 10-item questionnaire was 34.5 ± 0.90 among participants who experienced the photorealistic room and 33.9 ± 0.89 among participants who experienced the photorealistic hall, on a scale from 6–42, a difference that was not statistically significant, $F(1, 21) = 0.0196$, $p = .8899$. There was also no significant effect of the virtual environment locale on the responses to any of the individual questions in the SUS survey. Internal consistency as measured by Cronbach's α was relatively weak for the SUS, with $\alpha = 0.364$ on the six presence-related questions—a result that is not entirely unexpected, as the SUS is intended to assess several different aspects of presence (such as place illusion and plausibility illusion) that are expected to be capable of varying independently.

We next sought to probe the relationship between personality scores, distance-estimation errors, gait changes, and subjective presence (as measured by the SUS). To test for normality in our data, we began by computing the skew and kurtosis of each distribution. None of our data had significant skew (absolute sample skew greater than 1) or significant kurtosis (absolute sample excess kurtosis greater than 2). The distance error difference and stride length data had some mild skew (0.725 and -0.692, respectively) but minimal kurtosis (less than 0.5), and the DES data had some mild kurtosis (-1.094) but negligible skew (less than 0.5). All of the other distributions had both absolute skew less than 0.5 and absolute kurtosis less than 1. We also used MATLAB to perform a Lillilifors test of normality on each of the data distributions, and this measure found that the TAS, ITQ, SUS, distance-error difference, stride-length difference, and stride-speed difference data were not significantly different from a normal distribution, while the DES data was nonnormally distributed, $p = .0412$. A visual inspection of various histograms of the DES data

Table 2. *Correlations Between Measures Across Both Virtual Environments*

	ITQ	DES	SUS	VR-RW distance error	Stride-length change	Stride-speed change
TAS	**0.649****	**0.463**$*$	−0.242	**−0.484**$*$	0.092	−0.037
ITQ		0.337	−0.243	−0.386	−0.172	−0.277
DES			0.125	−0.122	−0.001	0.047
SUS				0.279	0.110	0.120

NOTE. Pearson correlations between personality scores, distance-estimation errors, gait changes, and reported subjective presence, among all participants pooled between the two virtual environments. $*p < .05$, $^{**}p < .01$

Table 3. *Correlations Between Measures in the Photorealistic Replica Environment Only*

	VR-RW distance error	Stride-length change	Stride-speed change
TAS	−0.193	−0.097	−0.308
ITQ	−0.167	−0.191	−0.435
DES	0.208	−0.232	−0.422
SUS	0.518	0.122	0.092
Distance error		−0.109	−0.075

NOTE. Pearson correlations between personality scores, virtual world minus real-world distance-estimation errors, gait changes, and reported subjective presence, among participants who experienced the photorealistic replica room environment.

Table 4. *Correlations Between Measures in the Photorealistic Non-replica Environment Only*

	VR-RW distance error	Stride-length change	Stride-speed change
TAS	**−0.755****	0.296	0.282
ITQ	**−0.711****	−0.173	−0.047
DES	−0.413	0.245	**0.579**$*$
SUS	−0.027	0.151	0.208
Distance error		0.076	0.227

NOTE. Pearson correlations between personality scores, virtual world minus real-world distance-estimation errors, gait changes, and reported subjective presence, among participants who experienced the photorealistic unfamiliar environment (PR hall). $*p < .05$, $^{**}p < .01$

revealed a subtle trend toward bi-modality at the finer granularities. Because of the predominately normal character of our data overall, however, we decided to proceed with computing Pearson's correlations between all of the distributions. We computed these measures using the pooled data for all participants (Table 2) and for participants grouped by virtual environment locale (Tables 3 and 4). For completeness, we also computed Spearman's rank correlations for the pooled data and found qualitatively similar results.

Among the personality measures, we found a significant positive correlation between absorption and immersive tendencies, and between absorption and dissociation. We found no significant correlation between any of the personality measures and subjective presence as assessed by the SUS questionnaire, nor between SUS score and distance estimation error (see Figure 14).

Among participants who experienced the PR room environment, none of the correlations we tested for were statistically significant. However, among participants who experienced the PR hall environment, we found a significant negative correlation between absorption and VR-RW distance error (see Figure 15) and between immersive tendencies and VR-RW distance error (see Figure 16), indicating that participants who scored higher for absorption and immersive tendencies tended to underestimate distances more severely in the PR hall virtual environment.

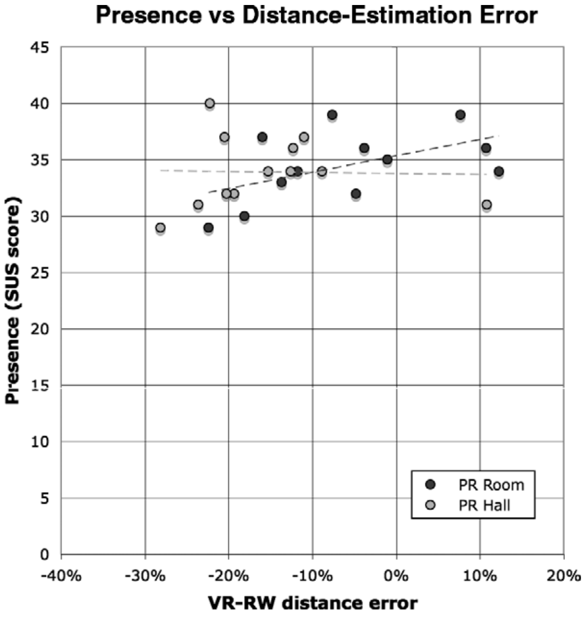

Figure 14. *A plot of the relationship between reported subjective presence and distance-estimation error.*

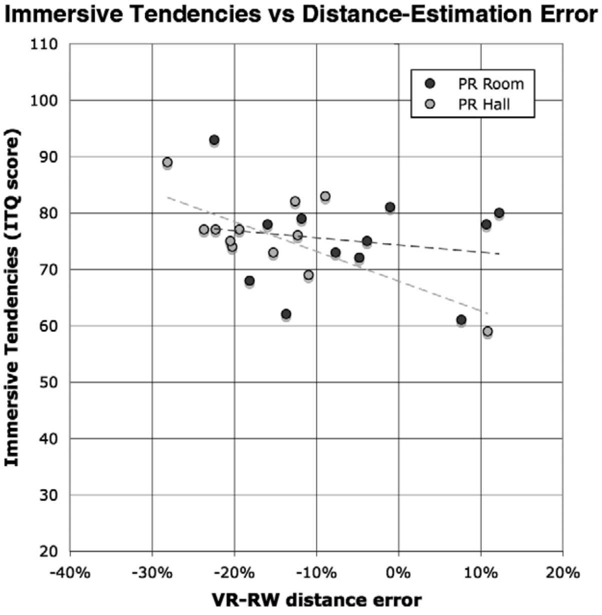

Figure 16. *A plot of the relationship between immersive tendencies and distance-estimation error.*

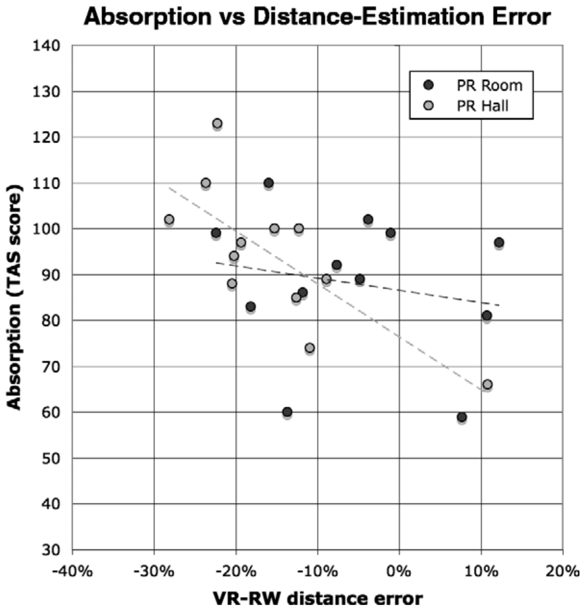

Figure 15. *A plot of the relationship between absorption and distance-estimation error.*

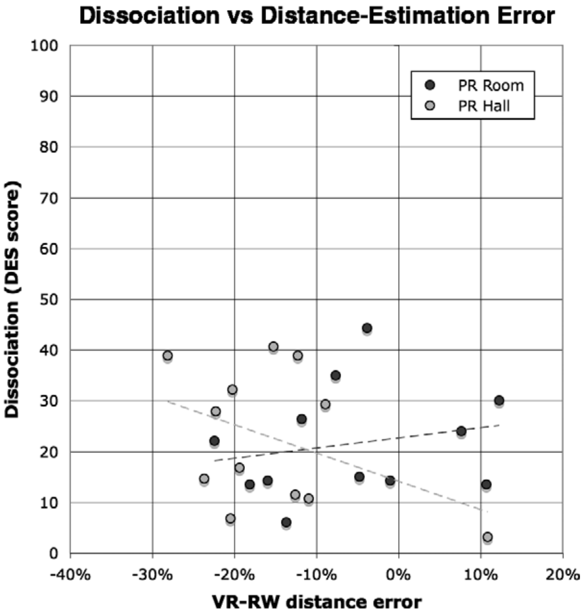

Figure 17. *A plot of the relationship between dissociation and distance-estimation error.*

Although we did not observe a significant correlation between VR-RW distance error and dissociation (Figure 17), we did observe a statistically significant positive correlation between dissociation and change in stride speed after exposure to the pit, indicating that participants who scored lower for dissociation tended to react with a more severe decrease in walking speed after exposure to the pit in this environment.

Although we did not observe any significant correlation between VR-RW distance error and any of the tested personality measures among participants who estimated distances in the PR room, the significance of the negative correlation between absorption and VR-RW distance error persisted in the pooled data for all participants across both environments (see Figure 17).

We also considered regression models of estimation error, gait changes, and SUS presence score, with absorption, immersive tendencies, dissociation, and the environment (PR room vs. PR hall) as parameters. We found that a model of the difference between participants' real-world and virtual-world egocentric distance-estimation errors that included the virtual environment locale (PR room vs. PR hall) and absorption (TAS score) as parameters was significant, $F(2, 21) = 5.674$, $p = .011$. Eighteen percent of the variance was explained by the locale and the TAS score explained another 17%. The other models that we tested were not significant.

5 Conclusions

In this paper, we have reported the results of two experiments intended to explore selected aspects of the relationship between personality, presence, and task performance in immersive virtual environments. Some of our results appear to offer marginal support for the hypothesis that participants tend to experience a greater sense of presence, at least initially, when immersed in a virtual environment that is a photorealistic replica of their concurrently occupied, real-world environment, than when immersed in a photorealistically rendered virtual environment that represents a different place that is unfamiliar to them, or when immersed in a virtual environment that is nonphotorealistically rendered, even when they are told that it represents an exact replica of the real environment that they are concurrently occupying. Specifically, the gait data and survey data from Experiment 1 and the distance-estimation data and some of the survey data from Experiment 2 seem consistent with this interpretation. However, others of our results—specifically, the physiological data from Experiment 1 and the gait and other survey data from Experiment 2, which are not significantly different between the tested virtual environment conditions—while not clearly contradicting this hypothesis, do little to support it, and the conclusions we can draw from the correlations, or lack thereof, between personality traits and presence or distance-estimation error are unclear. In future investigations, we hope to refine our investigations by, among other things, using larger sample sizes, examining other personality variables, and exploring additional methods for probing differences in behavior between real and virtual environments. As suggested by Slater (2009), it may be necessary to consider a more nuanced interpretation of what it means to be present in an IVE. Different types of presence may be evoked under different circumstances, and result in different response behavior to presented situations or stimuli.

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