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Interpersonal Distance in Immersive Virtual Environments

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Digital immersive virtual environment technology (IVET) enables behavioral scientists to conduct ecologically realistic experiments with near-perfect experimental control. The authors employed IVET to study the interpersonal distance maintained between participants and virtual humans. In Study 1, participants traversed a three-dimensional virtual room in which a virtual human stood. In Study 2, a virtual human approached participants. In both studies, participant gender, virtual human gender, virtual human gaze behavior, and whether virtual humans were allegedly controlled by humans (i.e., avatars) or computers (i.e., agents) were varied. Results indicated that participants maintained greater distance from virtual humans when approaching their fronts compared to their backs. In addition, participants gave more personal space to virtual agents who engaged them in mutual gaze. Moreover, when virtual humans invaded their personal space, participants moved farthest from virtual human agents. The advantages and disadvantages of IVET for the study of human behavior are discussed.

Keywords: *human representation; proxemics; nonverbal behavior; computer-mediated communication; virtual reality*

In *Neuromancer*, William Gibson (1984) described virtual reality as a "consensual hallucination," a place where one intentionally uses technology to replace sensory input from the physical world, hoodwinking the five senses with synthetic stimuli. In Gibson's work, digital virtual humans were largely indistinguishable from physical (i.e., flesh and blood) humans. Although Gibson wrote more than a decade ago about immersive virtual environments as science fiction, today, social psychologists and others have begun to examine social interaction involving virtual humans (i.e., three-dimensional digital human representations that look and act in many ways like people) scientifically.

We began our own such work by examining proxemics, the study of interpersonal distance. As we enter a new millennium, digital technology has raised opportunities as well as new issues for proxemics research. Digital representations of human beings are becoming common in communication media and entertainment, particularly in immersive virtual environments (IVEs). Digital IVEs are now utilized for communication (Biocca & Levy, 1995; Guye-Vuillieme, Capin, Pandzic, Thalmann, & Thalmann, 1999; Slater, Sadagic, Usoh, & Schroeder, 2000), particularly in the business world (DeFanti, 2000). Psychologists have begun to use IVET, incorporating digital representations of humans as a tool to study human behavior to maximize ecological realism without sacrificing experimental control (Blascovich et al., in press).

IVET provides a unique and valuable tool for proxemics researchers. Past proxemics studies have typically employed observational methods with little or no experimental control, confederates who may behave inconsistently, and projective measurement techniques. In contrast, IVET allows investigators to maintain complete control over virtual human representations' appearance, behavior, and environment while ensuring a high degree of ecological validity or mundane realism (Blascovich, 2001; Loomis, Blascovich, & Beall, 1999). In

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addition, because specification of the exact location and orientation of the participant is a key and necessary technological aspect of IVET, proxemic behavior can be measured accurately online, continuously and covertly. Furthermore, using IVET, researchers can ensure that participants' eye height is matched with eye height of others in the IVEs, improving the salience of gaze manipulations and controlling for status differences due to height. Consequently, researchers have begun to use virtual environments as a tool to investigate personal space (Bailenson, Beall, Blascovich, Weisbuch, & Raimmundo, 2001; Bailenson, Blascovich, Beall, & Loomis, 2001; Krikorian, Lee, Chock, & Harms, 2000; Reeves & Nass, 1996; Sommer, 2002).

In a previous study (Bailenson, Blascovich, et al., 2001), we demonstrated nonverbal compensation effects (Argyle & Dean, 1965; Burgoon, Stern, & Dillman, 1995; Patterson & Webb, 2002) in an experiment in which participants interacted with virtual humans. Compensation in nonverbal behavior typically occurs when people use different types of gestures to maintain and regulate an appropriate level of interpersonal immediacy (Mehrabian, 1967). For example, people increase their interpersonal distance from interactants who engage them in mutual gaze.

In our previous study, participants walked up to virtual humans ostensibly to memorize certain features of their clothes. We manipulated the degree of mutual gaze exhibited by the virtual humans and continuously measured the distance between participants and the virtual humans. Our results demonstrated that, proxemically, in some ways, participants treated virtual agents as if they were actual humans. Participants rarely violated a personal space bubble of 40 cm and, furthermore, approached more closely to the back compared to the front of virtual people. Moreover, we demonstrated compensation effects in IVEs—participants maintained a greater distance from virtual humans that maintained constant mutual gaze than from virtual humans that did not. However, this first study left some crucial questions unanswered because only virtual humans that were actually and perceived to be computer controlled served as the interactants.

Blascovich and colleagues' threshold model of social influence within virtual environments (Blascovich, 2001, in press; Blascovich et al., in press) specifies the behavioral impact of two types of virtual humans, embodied agents and avatars. Preset computer algorithms completely control the former and another human being controls the latter online. According to Blascovich et al.'s model, at any given level of realism (conglomeration of social, behavioral, anthropometric, and photographic realism), a lower social influence threshold exists for avatars than for agents on deliberate, high-level (e.g., conscious or controlled) responses but relatively equal social influence exists on automatic, low-level (e.g., unconscious, uncontrolled) responses (see Figure 1). In other words, holding all sensory information constant, knowledge that a human controls a representation (i.e., avatar) will result in greater social influence than a comparable representation controlled by a computer program (i.e., agent) for high-level but not low-level responses. Hence, for high-level responses (e.g., meaningful conversations), the slope of the social influence threshold is relatively steep, but for low-level responses (e.g., reflexes, less consciously controlled processes), the slope of the threshold is relatively shallow (see Figure 1). It can be argued that proxemics involves a fairly automatic, low-level form of social influence, such that it is regulated without regard to conscious beliefs about the agency of a virtual person (Gifford, 1996).

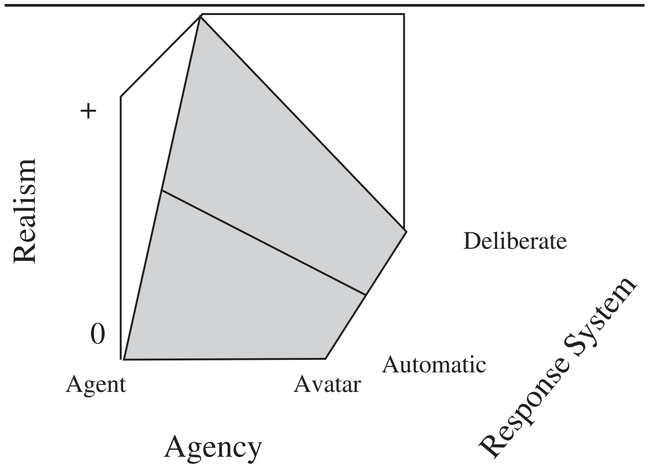

Figure 1 Specification of the Blascovich et al. (in press) model of social influence.
NOTE: The surface in the graph depicts the threshold of social influence. Values above the surface indicate social influence. High values on the Y-axis indicate high realism.

Agency beliefs should have a noticeable effect on the use of more conscious, high-level nonverbal compensation. In certain situations, people compensate for inappropriate increases in intimacy or immediacy (Burgoon et al., 1995). In other words, if Person A uses signals such as interpersonal distance, gaze, gait, or facial expression to indicate an increase in immediacy toward Person B, then person B should compensate by decreasing immediacy using a similar type of signal. On the other hand, if the increase in immediacy is appropriate, then reciprocity could occur, such that Person B will mimic Person A's increase in immediacy. Usually this reciprocation of immediacy occurs when Person B wants to confirm closeness in a relationship (Manusov, 1995). However, previous research on immediacy and gesture has demonstrated mixed results, sometimes finding compensation,

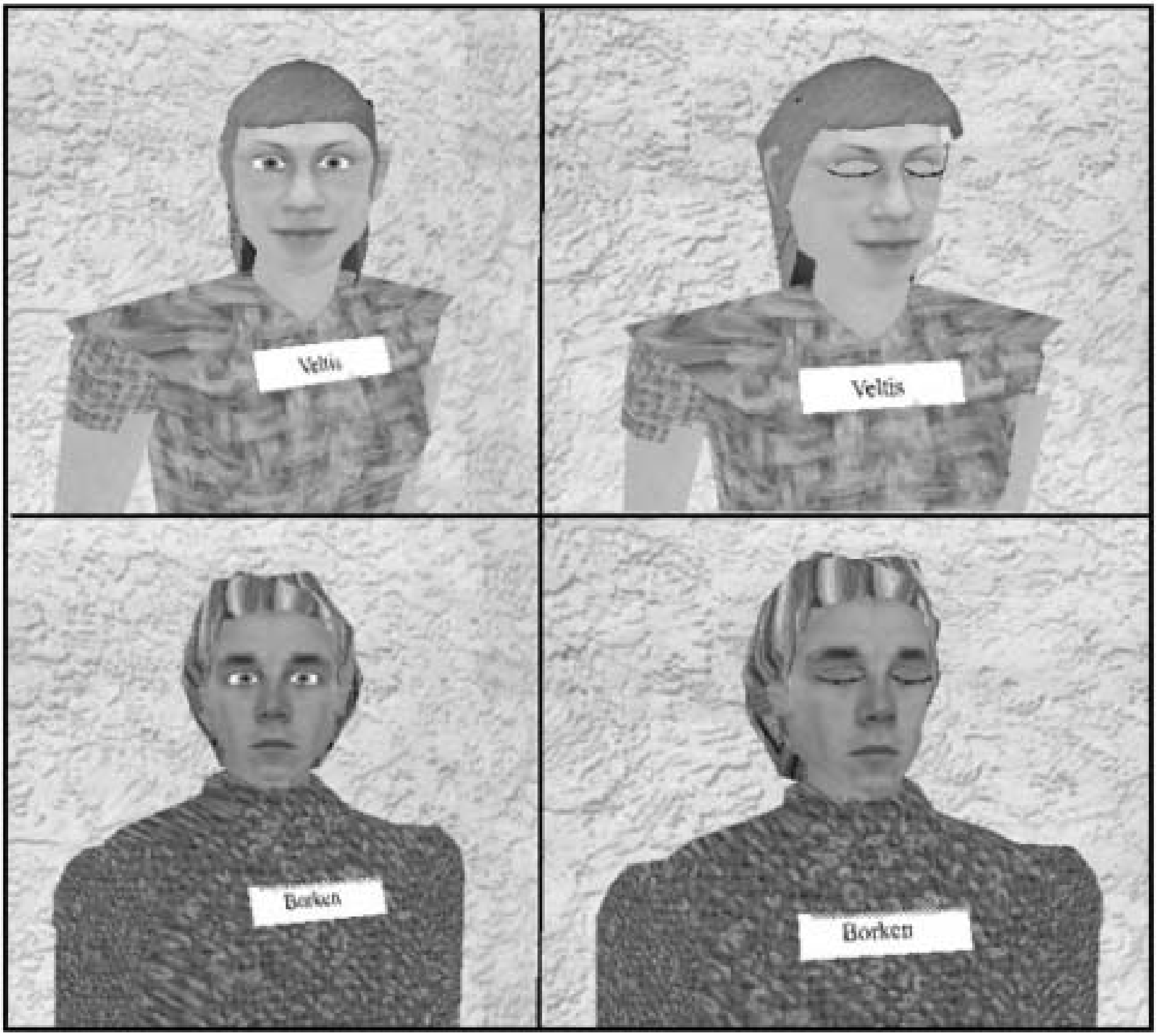

Figure 2 Pictures of the male and female virtual humans.
NOTE: Pictures on the left depict the high-gaze condition and pictures on the right depict the low-gaze condition.

other times finding reciprocity (Andersen, Guerrero, Buller, & Jorgensen, 1998; Hale & Burgoon, 1984). In the current set of studies, we expected to find more reciprocity with avatars than with agents because it is doubtful that participants would seek to form close relationships (i.e., increase immediacy) with an embodied computer algorithm.

Our previous study utilized only male agents. In that study, we found an interaction between the gender of participants and the agents' gaze behavior such that female participants regulated their personal space as a function of the agents' gaze behavior more than did male participants. In the current studies, we utilized both male and female virtual humans to further investigate that gender difference.

Overview of Experiments

We immersed participants in a single virtual environment containing a virtual human. In both studies reported in this article, we varied the same virtual human characteristics: gender, agency (agent vs. avatar; i.e., whether they were apparently controlled by a computer or by another human), and gaze behavior (mutual gaze or not). We measured participants' behaviors, including interpersonal distance, memory, and self-reported social presence and affect ratings.

In Experiment 1, participants were asked to memorize labels on virtual humans' shirts. As participants walked about the virtual environment, we tracked their position and orientation unobtrusively and automatically. Our hypotheses stem from research on compensation effects discussed above as well as our theoretical model (Blascovich, 2001, in press; Blascovich et al., in press). We hypothesized that participants would leave a larger personal space bubble around virtual humans who maintained eye gaze with the participants than around virtual humans who did not. In addition, in line with Blascovich et al.'s arguments regarding social influence, we predicted that participants would maintain more space around agents who engaged them in mutual gaze than agents who did not but less difference in space around avatars in the two gaze conditions. Across our manipulations, we predicted that the shape of the personal space bubble maintained around virtual humans would be similar to that maintained around actual humans in past studies (see Sommer, 2002, for a review). We also hypothesized that participants would maintain more space in front of than behind virtual humans based on our previous findings (Bailenson, Blascovich, et al., 2001) as well as other literature (Burgoon et al., 1995).

In Experiment 2, participants stood while a walking virtual human approached them and invaded participants' personal and body space. We measured participants' movements and posture changes as the virtual human invaded their space and elicited social presence and affect ratings from the participants. We made no a priori predictions for Experiment 2.

EXPERIMENT 1

Method

DESIGN

We manipulated one within-subject factor, virtual human gender, and three between-subject factors: gaze behavior, participant gender, and agency. There were two levels of gaze behavior (high vs. low). In the high level, the virtual human blinked his or her eyes at a natural rate and turned his or her head to gaze at participants' faces as they traversed the IVE. In this condition, the virtual humans' heads turned up to 85 degrees in either direction. In the low level, the virtual humans' eyes were closed and the head did not turn. Figure 2 illustrates male and female virtual humans with their eyes opened and closed. Finally, there were also two levels of agency (agent and avatar). Even though the actual behavior of the virtual humans was identical in both levels, we led participants to believe that the virtual human was either an agent or an avatar.

Participants completed two blocks of trials—one block with female virtual humans and one block with male virtual humans. There were five trials in each block, and order of blocks was counterbalanced across participants.

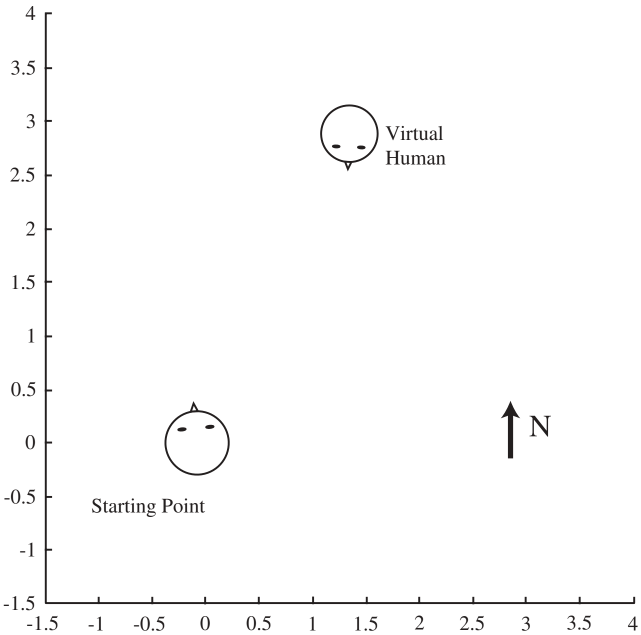

Figure 3 A diagram depicting the relative locations of the virtual human and participants' starting point in the virtual room. The scale is in meters.

MATERIALS AND APPARATUS

The virtual room was modeled as 7.2 m × 6.4 m × 4.5 m high, approximately 75% of the space of the physical room in which the experiment was conducted. This design ensured that participants did not walk into any physical walls during the study. Figure 3 depicts the location of the virtual human and the starting point of the participant. The virtual humans' eye height was approximately 1.7 m. Labels on the front of their shirts depicted names and labels on the back of their shirts depicted numbers. Participants themselves were not rendered. Hence, although participants could move about the IVE and see the virtual human in the room, they did not see any animated representation of themselves or any parts of their own bodies. We set the eye height of all participants at 1.7 m, the same height as the virtual humans' eyes. In doing so, we controlled for height differences as well as maximized the probability that participants noticed gaze behavior on the part of the virtual humans.

The technology used to render the IVEs is described in detail in Bailenson, Blascovich, et al. (2001). Figure 4 shows a participant wearing the equipment. Participants wore a head-mounted display (HMD) that includes a display monitor over each eye. The system redraws the virtual scene separately for each eye (to provide stereoscopic depth) approximately 30 times a second. Using our position and orientation tracking systems, it is possible for participants to experience realistically dynamic

Figure 4 A depiction of our virtual environment system.
NOTE: The components are (a) position tracking cameras, (b) head-mounted display (HMD) and orientation tracking sensor, and (c) image generator.

and stereoscopic visual input. In other words, the specific view drawn in the HMD depends on where the participant is standing in the physical room and which way he or she is looking. Users often describe the experience like "being inside a movie." There was no collision detection. In other words, a participant could walk through the virtual human or through a virtual wall without receiving any haptic cues.[1] While wearing the HMD, participants could not see any part of the physical world.

PARTICIPANTS

We recruited students from an introductory psychology class to serve as participants for pay or for experimental credit. There were 10 participants in each of the eight between-subjects conditions resulting from crossing participant gender, agency, and gaze behavior for a total of 80 participants in the study. Participants' age ranged from 18 to 30, with a mean of 19.61 (SD = 1.92).

PROCEDURE

Avatar condition. The experimenter introduced the participant to two other "participants" (actually confederates), one man and one woman. The experimenter then assigned experimental roles to the three people via a bogus chance device, drawing coins from a bag. The participant always was assigned the role of "walking person," whereas the confederates were the "stationary people."

Participants received instructions that they would be performing a memory test. They read the following paragraph:

> In the following experiment, you will be walking around in a series of virtual rooms. In the rooms with you will be a stationary person. The stationary person is wearing a white patch on the front of his or her shirt. A name is written on that patch. There is a similar patch on the

back of the shirt. On the back patch, a number is written. Your job is to walk over to the person in the room and to read the name and number on the patches. First, read the back patch and then read the front patch. Later on, we will be asking you questions about the names and numbers of the person in each room. We will also be asking you about their clothing, hair color, and eye color.

The participant and the confederates then viewed pictures of how they would look to each other in the virtual world (all pictures of the participants' avatars matched the participants in terms of hair color and gender). The experimenter told them that the confederates would be (i.e., would control the behavior of) the other stationary people in the virtual environment. The participant and confederates then put on the HMDs.

Agent condition. In the agent condition, the experimenter introduced each participant to two experimental assistants. The assistants remained in the room to keep the number of real people in the actual room constant across conditions. We then told participants that the computer was controlling the behavior of the stationary people in the virtual environment and showed participants pictures of the stationary agents.[2] Next, the participant put on an HMD.

Common procedures. To become accustomed to the equipment and traversing the virtual environment traversal, participants first explored an empty virtual room while wearing the HMD for approximately 1 min. After the practice exploration, we inserted the representation of the stationary virtual human into the virtual room and participants began the first block of trials. Figure 2 shows the relative size of the labels on front of the virtual human's shirt and Figure 3 shows the spatial relationship between the virtual human and the actual human. The virtual human faced virtual south and the participant began facing virtual north. Next, the participant walked from the starting point to the back of the virtual human. She or he read the number on the virtual human's back and then walked to the virtual human's front. After reading the front patch, the participant returned to the starting point and waited for the next trial. The labels on the virtual humans' shirts were large enough to read from approximately 0.75 m away, and the front and back labels were identical in size and shape.

For each of the five trials in a block, the specific virtual human differed via different colored shirts, different colored hair, and different names and numbers. Across participants, names, numbers, and other features appeared in each serial trial position an equal number of instances. Blocks lasted between 5 and 15 min, depending on the participant's walking speed. Participants had an opportunity to rest without wearing the HMD between blocks. The two blocks featured either male or female virtual humans. In the avatar condition, while the participant rested, we switched which confederate wore the HMD, such that the confederate of appropriate gender was matched with the appropriate experimental condition. Confederates and experimental assistants remained in the corner of the room during the experiment.

After participants completed the two blocks, they removed the HMDs and were given a pen-and-paper recall test. For the recall test, participants were instructed to "recall all the names and numbers on the patches." After the recall test, participants received a matching test in which all the names and numbers were listed. Their task was to draw lines that connected the name of the virtual human on a specific trial to the number of that virtual human on the same trial. We instructed participants to draw all 10 lines, guessing when they were unsure if a name went with a number.

Finally, after the recall test, participants wore the HMD for two more trials to complete a social presence questionnaire, one for a female virtual human and one for a male virtual human. For the questionnaire, a Likert-type scale (from –3 to +3) hung in space over the virtual human's head. Participants looked at the virtual human and the scale while the experimenter verbally administered the five-item social presence questionnaire designed to measure how much participants perceived the virtual human in the room to be like an actual person. The questions appear in Appendix A. In addition, participants rated their affect, or "how much they liked the virtual humans," on a similar scale, with higher numbers corresponding to positive affect.

Results

Participants neither reported nor appeared to have any difficulty navigating the virtual space. After the study, none of the participants reported suspicion of the confederates or guessed that proxemic behaviors were under scrutiny. All reported that they believed we were studying memory.

PERSONAL SPACE

The computer system sampled participants' positions at 18 Hz. Figure 5 depicts the paths that a typical participant traversed over the 10 trials. Each sample indicates the participant's position in the virtual room at any given sampled point in time, allowing us to compute the distance between the participant and the center point of the virtual human's head for each point in time during each trial.

We indexed personal space as the minimum or shortest distance that participants assumed between themselves and the virtual human across trials within a condition.[3] We chose minimum distance instead of average

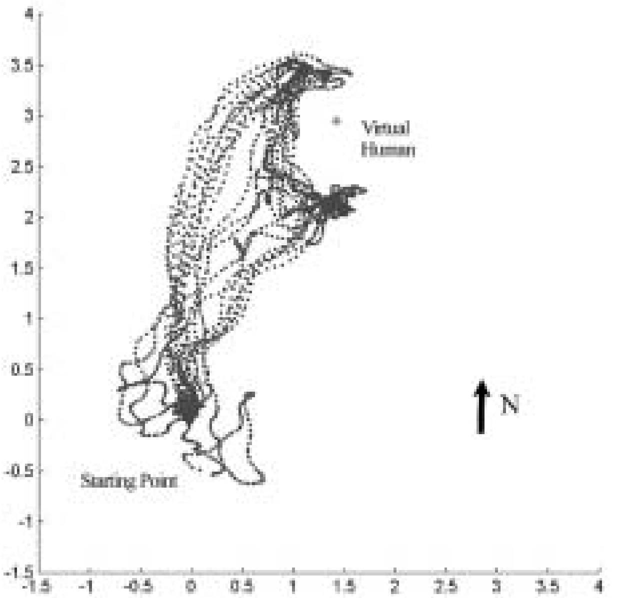

Figure 5 An example of the 10 paths from a typical participant as she walks from the starting point around the back of the virtual human, then in front of the virtual human, and then back to the starting point.

NOTE: Ticks on the axes represent meters and each point represents a location sample of the participant taken at 18 Hz.

distance for two reasons. First, minimum distance is a traditional measure used by proxemics researchers (Hayduk, 1983). Second, because participants were instructed to read the labels, they spent more time at the optimal reading distance (which is a function of the optimal resolution) than other distances. Consequently, given the nature of the task, average distance does not accurately reflect participants' attention to nonverbal gaze behavior. Our previous study on proxemics in IVEs (Bailenson, Blascovich, et al., 2001) also utilized this measure.

First, we compared front minimum distance (i.e., while the participant was in front of the midpoint of the agent's head) to back minimum distance (i.e., the minimum distance while the participant was in back of the midpoint of the agent's head). The mean front minimum distance was 0.51 m (SD = .17). The mean back minimum distance was 0.45 m (SD = .17). The difference between mean front and back minimum distances was significant, $t(79) = 5.01$, $p < .001$, and the two measures correlated with each other significantly, $r = .81$, $p < .01$. The mean minimum distance here is similar in size to non-IVE-based proxemic studies that have employed this measure (e.g., Rogers, 1972, found a minimum distance of approximately 0.40 m). Table 1 shows the mean minimum distance (across front/back) by our between-subject manipulations.[4]

We ran a four-way ANOVA with three between-subjects factors and one within-subjects factor (participant gender, gaze behavior, agency, and virtual human gender) and absolute minimum distance for each participant as the dependent variable. There was a main effect of virtual human gender, such that participants maintained greater distance from the female virtual human (M = .54, SD = .17) than the male virtual human (M = .46, SD = .16), $F(1, 72) = 26.19$, $p < .001$. None of the other main effects approached significance.

TABLE 1: Mean and Standard Deviation of Minimum Distance (in meters) Across Participant Gender, Gaze Behavior, and Agency

	Female Participants	*Male Participants*
No mutual gaze		
Agent	.34 (.14)	.38 (.20)
Avatar	.48 (.12)	.47 (.13)
Mutual gaze		
Agent	.43 (.16)	.54 (.18)
Avatar	.49 (.14)	.34 (.12)

There were two significant interactions. The first was between agency and gaze, $F(1, 72) = 4.74$, $p < .05$. As Table 1 indicates, participants maintained a greater distance from agents who engaged them in mutual gaze than from agents who did not. This difference in response to mutual gaze did not occur with avatars. Follow-up tests of simple effects indicated that the difference between the mutual gaze condition (M = .48) and the no gaze condition (M = .36) was significant in the agent condition, $t(39) = 2.31$, $p < .05$, but not in the avatar condition, $t(39) = 1.37$.

The second interaction was between participant gender and agency, $F(1, 72) = 4.00$, $p < .05$. As Table 1 shows, female participants stayed farther away from avatars than from agents. Male participants did not show this difference. Follow-up tests of simple effects demonstrated that the difference between the avatar condition (M = .48) and the agent condition (M = .39) was significant for female participants, $t(39) = 2.12$, $p < .05$, but not for male participants, $t(39) = .95$.

SOCIAL PRESENCE RATINGS

For social presence ratings, we summed the five responses on our questionnaire to provide an overall social presence score (Cronbach's α = .80). A positive social presence score indicates that the participant perceived the virtual human as conscious and aware, whereas a negative score indicates that the participant perceived the virtual human as unconscious and unaware. According to the model depicted in Figure 1, participants should report a higher level of presence from gazing virtual humans than from static ones. The mean social presence rating was –3.83 (SD = 12.21), the minimum was –28, and the maximum was 22.

We ran a four-way ANOVA with the same factors as the personal space analysis, this time with social presence ratings as the dependent variable. There was a main effect of mutual gaze, $F(1, 72) = 35.69$, $p < .001$. Participants reported a greater sense of social presence with virtual humans that demonstrated mutual gaze ($M = 3.00$, $SD = 9.25$) than with ones that did not ($M = -10.65$, $SD = 10.99$). Furthermore, the correlation between social presence ratings and minimum distance was nil, $r = .02$.

AFFECT RATINGS

Next, we examined affect ratings. Positive numbers indicated that participants liked the virtual human; negative numbers indicated dislike. The grand mean for affect was 1.25 ($SD = 1.50$). We then ran the four-way ANOVA with affect ratings as the dependent variable. There was a significant main effect of virtual human gender, such that participants liked the female virtual human ($M = 0.80$, $SD = 1.35$) less than the male virtual human ($M = 1.25$, $SD = 1.37$), $F(1, 72) = 8.83$, $p < .005$. No other effects were significant.

MEMORY

We ran the four-way ANOVA with the total number of names and numbers recalled as the dependent variable. The only significant effect was a main effect of agency, $F(1, 72) = 5.50$, $p < .05$. Participants' recall was higher for the names and numbers on the avatars ($M = 5.98$, $SD = 2.14$) than on the agents ($M = 4.88$, $SD = 1.99$). In other words, participants recalled the information more effectively when the virtual human was associated with an actual human being.

Discussion

The first experiment replicated and extended our previous results (Bailenson, Blascovich, et al., 2001). Regarding interpersonal distance, participants in this study clearly treated virtual humans in a manner similar to actual humans. The average minimum distance was close to a half-meter away, indicating that participants avoided intimate interpersonal distance between themselves and the virtual humans. In addition, the size and shape of the personal space bubble around the virtual humans closely resembled the shape of the bubble that people typically leave around real, nonintimate humans, with the front distance being larger than the back distance (Argyle, 1988). Furthermore, replicating our previous study, the personal space bubble changed as a function of realism and agency manipulations.

In line with our threshold model of social influence (Figure 1), when the virtual human was believed to be an avatar, driven by an actual human, less behavioral realism (e.g., mutual gaze behavior) was necessary for participants to maintain appropriate interpersonal distance. In other words, a belief that a virtual human was an avatar (i.e., an online representation of another person) deterred invasions of personal space. However, when the virtual human was believed to be an agent (i.e., driven by the computer), increased behavioral realism was necessary for participants to maintain appropriate interpersonal distance. This interaction between gaze and agency replicates the results from our previous work (Bailenson, Blascovich, et al., 2001). Furthermore, the finding that interpersonal distance changes as a function of participants' high-level beliefs about the virtual humans suggests that this type of social influence is not completely or always automatic but can be susceptible to explicit and conscious regulation.

We also found an interaction between agency and participant gender. Women maintained more space around avatars than agents, whereas men did not show this distinction. This gender pattern replicates our previous findings (Bailenson, Blascovich, et al., 2001): Women appear more sensitive than men to the characteristics of virtual humans in terms of interpersonal distance. This effect is consistent with data that women are more adept than are men at transmitting and receiving nonverbal information (see Hall, 1984, for a review). Finally, social presence ratings did not predict interpersonal distance. This may have occurred because of the difficulty of accurately capturing the notion of social presence ratings using questionnaires exclusively (Bailenson, Blascovich, et al., 2001). Participants may not be able to accurately self-report the degree to which they "attribute sentience" to a three-dimensional model. Consequently, behavioral measures such as interpersonal distance may be a better way to measure social influence within immersive virtual environments than self-report measures.

EXPERIMENT 2

In Experiment 1, participants approached stationary virtual humans, and we examined the degree of interpersonal distance that participants maintained between themselves and virtual humans standing still. In Experiment 2, we examined what happens when virtual humans walk and violate the personal space of participants. Again, we immersed participants in a room with virtual humans. As in the first study, participants examined the virtual humans and provided social presence and affect ratings. After participants finished the ratings task, we programmed the virtual humans to walk toward and "through" participants. In other words, the virtual humans invaded the personal and body space of the participants. We then measured how far participants moved away from the virtual humans as well as participants' verbal reactions to having their personal space invaded.

In Experiment 1, we found that participants' proxemic behavior was moderated by their agency beliefs concerning the virtual humans and the gaze

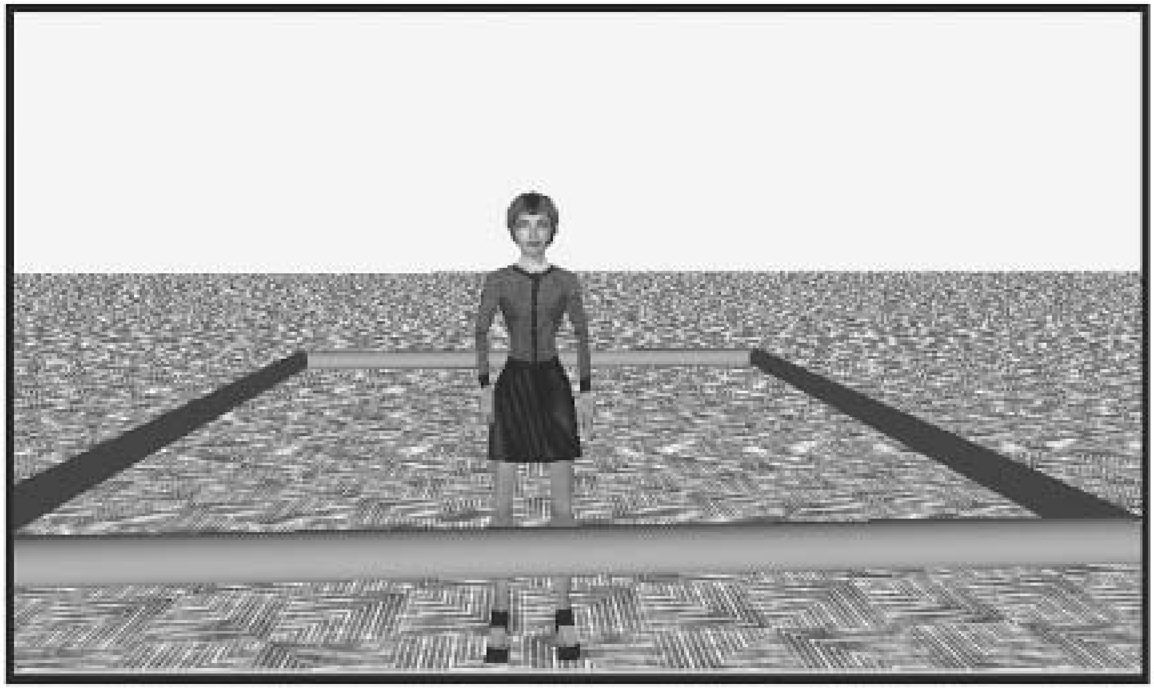

Figure 6 The view of the immersive virtual environment (IVE) that participants saw in Experiment 2.
NOTE: This is an example of a female virtual human before she began to walk toward and through the participant. The floating bars were inserted to indicate the location of the physical walls of the room.

behavior of the virtual humans. In that study, participants had the opportunity to control their spacing behavior. However, in our second study, the virtual humans walked toward and then through participants' bodily space without any warning. Consequently, we expected that whatever participant response occurred might be a more "automatic" reaction, that is, a response less susceptible to control.

There were a number of other differences between this study and the first study. First, the three-dimensional models we used to embody the agents were different. Because the virtual humans needed to walk, it was necessary to create more complexly animated models. Consequently, the virtual humans had different heads and faces in Experiment 2 than in Experiment 1. Second, the study took place in a smaller physical room than the first study because we did not require our participants to walk all the way around the virtual human.

Method

DESIGN

We manipulated the same independent variables as the first study: virtual human gender, gaze behavior, participant gender, and agency. As in the first study, we presented participants two separate trials—one with a female virtual human and one with a male virtual human. Order of trials was counterbalanced across participants.

MATERIALS AND APPARATUS

The physical room in which Experiment 2 took place was approximately 3 m × 2.4 m × 3 m high. The virtual environment had no walls or ceiling but we placed virtual ropes in the environment to square off a section to ensure that participants did not collide with the physical walls. Figure 6 shows a first-person view of the virtual human in the virtual room. The participants started inside of the virtual ropes, looking at the virtual human. As in the previous study, the virtual humans' eye height was approximately 1.7 m. Again, participants themselves were not rendered, and we set the eye height of participants to be the same height as the virtual humans' eyes.

PARTICIPANTS

There were 10 participants in each of the eight between-subjects conditions resulting from crossing participant gender, agency, and gaze behavior, resulting in 80 total participants in the study.[5] Participants' age ranged from 18 to 25. Participants received experimental credit in an introductory psychology class for participation.

PROCEDURE

The experimenter introduced participants in the avatar condition to two confederates, one man and one woman, and implemented the same rigged game of chance as in Experiment 1 to assign the three people to experimental roles. The participant always ended up in the same room, whereas the confederates went to one of two other rooms, depending on which virtual human gender condition the participant was assigned to first. The agent condition was similar to the avatar condition. Instead of sitting participants down with two confederates, we sat them down next to two experimental assistants. The assistants remained in the room for the duration of the study. We instructed participants that they would be "examining a virtual person and answering questions about him or her."

We then showed participants pictures of other virtual humans and told them that either a computer or the other people in the experiment (i.e., confederates) would be controlling the behavior of the virtual people depending on the participant's agency condition. Furthermore, we showed participants a picture of how they would look in the IVE. The experimenter showed them one of four pictures to match their gender and hair color. Participants then donned the HMD and were placed in an empty virtual room.

After 1 min of practice exploration, we inserted the representation of the virtual person into the virtual room and the participant began the trial. The participant first walked to the left side of the virtual human, then across the front of the virtual human, and then to the right side of the virtual human. Finally, we instructed them to walk to the front of the virtual human to ensure that they could read a Likert-type scale that we inserted over the virtual human's head. We then administered the same social presence and affect questions from Experiment 1.

After they answered the questions, we led participants back to the starting point and told them to stand comfortably. When they were comfortable, we pressed a key that prompted the virtual human to walk directly toward and then through the participant. After the virtual human walked through the participants, the trial was over.

Each trial took between 5 and 10 min, depending on the participant's walking speed. As in the previous study, participants had an opportunity to rest between trials. The two trials featured either a male or female virtual human. In the avatar condition, while the participant rested, we switched which confederate wore the HMD, such that the confederate of appropriate gender was matched with the appropriate experimental condition.

After the two trials, participants filled out an emotional reaction questionnaire that gauged how angry, scared, and startled they were when the virtual human walked through them. The questions appear in Appendix B, and participants indicated their agreement on a 7-point Likert-type scale.

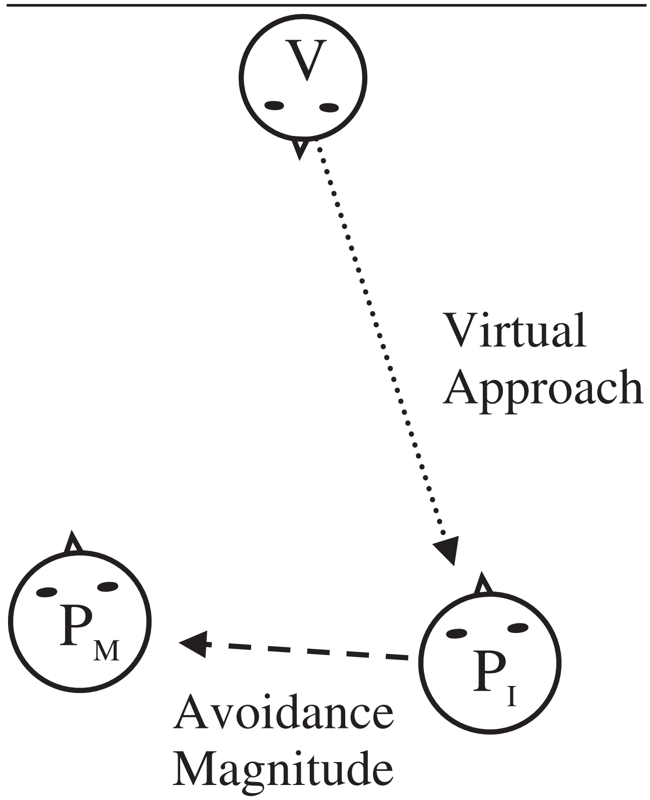

Figure 7 The orientation of the virtual human and the participant in Experiment 2.
NOTE: The dependent variable of interest was avoidance magnitude, the amount that participants moved away from the approaching virtual human. V = where the virtual human stood initially, P_M = the farthest point from P_I to which the participant moved, P_I = where a given participant stood initially.

Results

As in the first study, participants neither reported nor were observed to have difficulties adjusting to the IVE, and none of them guessed we were studying their proxemic behavior.

DISTANCING BEHAVIOR

We examined the degree to which participants moved away from the virtual human when he or she invaded their space. As in the first study, the computer system sampled the participants' position at a rate of approximately 18 Hz. Figure 7 depicts where a given participant stood initially (Point P_I) and where the virtual human stood initially (Point V). When the virtual human began to walk and approach the participant, we measured how far away participants moved from Point P_I. In other words, as the virtual human invaded their personal space, participants could move out of the way. Point P_M is the farthest point from P_I to which the participant

TABLE 2: Mean and Standard Deviation of Avoidance Magnitude (in cm) Across Participant Gender, Avatar Gender, Gaze Behavior, and Agency

	Male Virtual Humans	
	Female Participants	*Male Participants*
No mutual gaze		
Agent	5.60 (8.10)	5.65 (4.55)
Avatar	3.13 (2.09)	3.38 (2.56)
Mutual gaze		
Agent	6.39 (0.10)	4.23 (4.03)
Avatar	4.66 (6.51)	4.69 (3.93)
	Female Virtual Humans	
	Female Participants	*Male Participants*
No mutual gaze		
Agent	6.19 (6.43)	4.49 (4.79)
Avatar	1.92 (1.17)	2.32 (2.03)
Mutual gaze		
Agent	4.70 (6.46)	3.62 (1.98)
Avatar	3.06 (1.78)	1.92 (1.17)

moved. We measured the distance between point P_I and point P_M. We refer to this measure as avoidance magnitude, the extent to which a participant moved away from the approaching virtual human. The virtual human walked at one-half m per second. The walk from the virtual human to the participant took approximately 1.5 s.

The mean avoidance magnitude was 5.41 cm (SD = 6.27), the minimum was 0.78 and the maximum was 36.26. Table 2 reports the avoidance magnitude by condition. We ran an ANOVA using the four factors discussed above (participant gender, gaze behavior, agency, and virtual human gender) and avoidance magnitude as the dependent variable. There was a main effect of agency such that participants moved farther away from the approaching embodied agent (M = 6.89, SD = 7.76) than the approaching avatar (M = 3.36, SD = 1.93), $F(1, 70) = 7.87$, $p < .01$. None of the other main effects approached significance.

Figure 8 shows participants' mean absolute avoidance magnitude over time as the virtual human approached for both avatars and for agents. The figure suggests that participants tended to move most after the virtual human made contact with them in the IVE. We added another within-subjects variable, contact time (before contact or after contact), to the four-way ANOVA reported above and found a reliable main effect of contact time, with the maximum avoidance magnitude before contact (M =3.39, SD = 3.57) being smaller than the maximum avoidance magnitude after contact (M = 4.66, SD = 6.88), $F(1, 69) = 9.99$, $p < .01$. This suggests that the movement was a consequence of the virtual humans invading the participants' body space.

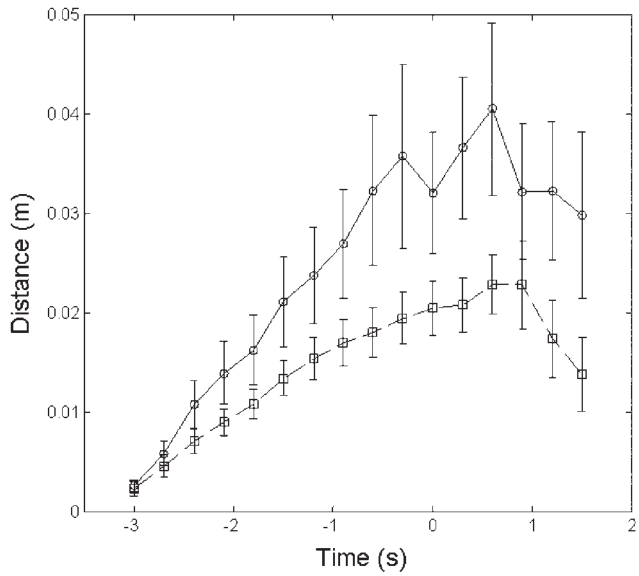

Figure 8 Mean absolute avoidance magnitude over time as the avatar approaches for both avatars (line with squares) and for agents (line with circles).

NOTE: The virtual human's head made contact with the participant at time 0. Error bars reflect ±1 standard error of the mean, and individual participants' data was averaged over 0.3-s windows for the plot.

SOCIAL PRESENCE RATINGS

On the social presence ratings task, we computed the same social presence score as in Experiment 1 for each virtual human gender (Cronbach's $\alpha = .82$). The average social presence rating score was –1.44 (SD = 10.91), the minimum was –28 and the maximum was 28. Thirty-three out of the 80 scores showed positive social presence.

We ran the four-way ANOVA with social presence ratings as the dependent variable. Table 3 depicts the social presence data by condition. As in Experiment 1, we found a significant main effect of mutual gaze, $F(1, 70) = 46.06$, $p < .001$. Participants reported a greater sense of social presence with virtual humans that demonstrated mutual gaze (M = 1.64, SD = 4.48) than with ones that did not (M = –3.93, SD = 4.31). We also found a main effect of agency, $F(1, 72) = 28.03$, $p < .001$. Not surprisingly, participants reported more social presence with avatars (M = 1.17, SD = 5.20) than with agents (M = –3.26, SD = 4.24). In addition, there was a main effect of virtual human gender, $F(1, 72) = 6.11$, $p < .05$. Participants experienced more social presence with the male virtual human (M = –.78, SD = 5.48) than with the female virtual human (M = –1.58, SD = 5.36).

There were also three significant interactions. First, there was a significant interaction between virtual human gender and agency, $F(1, 72) = 4.10$, $p < .05$. As

Table 3 illustrates, participants reported the greatest social presence with male avatars. Second, there was an interaction between participant gender and mutual gaze, $F(1, 72) = 5.62$, $p < .05$. As Table 3 depicts, male participants were more sensitive to mutual gaze in their ratings than female participants. This effect differs from our previous study, in which women were more observant in regard to gaze (Bailenson, Blascovich, et al., 2001). This discrepancy may be a result of using different models of virtual humans in the two studies. Finally, there was a three-way interaction between participant gender, virtual human gender, and agency, $F(1, 72) = 5.93$, $p < .05$. This effect was driven primarily by female participants reporting the highest social presence with male avatars.

TABLE 3: Mean and Standard Deviation of Social Presence Ratings Across Participant Gender, Avatar Gender, Gaze Behavior, and Agency

	Male Virtual Humans	
	Female Participants	*Male Participants*
No mutual gaze		
Agent	–5.00 (3.13)	–5.40 (4.72)
Avatar	1.00 (4.94)	–3.32 (4.49)
Mutual gaze		
Agent	–1.18 (3.87)	–1.00 (3.77)
Avatar	3.40 (3.03)	6.56 (4.69)
	Female Virtual Humans	
	Female Participants	*Male Participants*
No mutual gaze		
Agent	–5.58 (3.82)	–7.3 (3.27)
Avatar	–2.00 (4.61)	–3.22 (4.06)
Mutual gaze		
Agent	–0.09 (4.15)	–0.20 (3.55)
Avatar	1.00 (3.05)	6.00 (4.72)

AFFECT RATINGS

Participants reported "how much they liked the virtual humans." Positive numbers indicated that participants liked the virtual human; negative numbers indicated the opposite. The grand mean for affect was .84 ($SD = 3.69$). We then ran an ANOVA using the same four independent variables from the previous ones and affect ratings as the dependent variable. There were no significant effects or interactions.

EMOTIONAL REACTION QUESTIONNAIRE

The postexperiment emotional reaction questionnaire was designed to measure how angry, surprised, and vengeful the participants were after the virtual humans walked through them. The questions appear in Appendix B. We averaged responses to the five questions (Cronbach's $\alpha = .78$) and then correlated the emotion reaction score with avoidance magnitude. The positive correlation was significant, $r = .30$, $p < .007$, indicating that people who self-reported strong reactions tended to move away more from the virtual human.

Discussion

In Experiment 2, we measured participants' behavioral and self-reported emotional reactions as different types of virtual humans invaded their personal space bubble and body space. The mean avoidance magnitude, although reliable statistically, was only about 5 cm. Originally, we expected larger reactions. However, a majority of our participants did not actually step out of the way. Instead, most participants leaned away from the approaching virtual human. Consequently, a ceiling effect may have operated, precluding large differences as a function of our independent variables. Nonetheless, the fact that avoidance magnitude correlated reliably with emotion reaction ratings after the experiment indicates that participants' movements were in fact related to their beliefs about the virtual humans.

The largest effect in this study was that participants moved or leaned out of the virtual human's way most often when it was an embodied agent controlled by a computer. Our model of social influence did not predict this effect and our interpretation of these data is necessarily ad hoc. According to Blascovich et al.'s model, people are influenced more easily by an avatar than by an agent because they attribute human sentience and rationality to an avatar. People approach one another all the time in the real world. This explanation is consistent with the concept of reciprocity discussed above. Participants might have displayed some instances of reciprocity as the avatar approached them because an avatar represents a person with whom participants may eventually form a close relationship, whereas an agent does not. Consequently, people might trust that an avatar (i.e., another person) would not walk through them. In other words, as the virtual human approached, participants might have expected that representation to stop when a human being controlled it. Consequently, they did not move out of the avatar's way when it began to move into their space. On the other hand, participants would not expect a computer-driven agent to understand or be sensitive to the notion of personal space. In this regard, participants would get out of the way of an approaching agent because the probability of that virtual human actually colliding with them would be higher.[6]

GENERAL DISCUSSION

In both experiments, participants exhibited patterns of interpersonal distance behavior with respect to virtual humans similar to that which decades of research using actual humans have demonstrated. In Experiment 1, participants maintained personal space bubbles around virtual humans that were quite similar in both size and shape to bubbles typically maintained around actual humans. Furthermore, these results replicated those of our previous study examining proxemic behavior in IVEs (Bailenson, Blascovich, et al., 2001). However, participants behaved quite differently depending on whether the virtual human was an agent or an avatar. Specifically, in Experiment 1, the threshold for social influence regarding proxemics appeared to be higher for agents than for avatars. In other words, people gave an avatar more personal space than an agent even if the avatar did not behave realistically. However, an agent needed to display realistic gaze behavior to influence interpersonal distance behavior. This is in line with the predictions based on Blascovich et al.'s model (Blascovich, 2001, in press; Blascovich et al., in press). Furthermore, in Experiment 2, people reacted to approaching agents differently than they reacted to approaching avatars: They avoided the virtual human more when it was controlled by a computer than another veritable human being. Consequently, people may have low-level, negative reactions to an embodied agent that surface most clearly during automatic behaviors (i.e., getting out of the way).

We realize that immediacy can be measured using a host of nonverbal gestures, such as gaze, gait, facial expressions, intonation, and other cues (Burgoon et al., 1995). In the current work, we examined only interpersonal distance. Although we realize that we may have missed many instances of compensation, we were limited in the types of gestures we measured in the current study by participants' faces being covered by the HMD. In future studies, we plan to track participants' facial expressions using eye trackers inside the HMD as well as tracking facial muscle movement. Nonetheless, it is particularly notable that using just two cues, we were able to demonstrate changes in interpersonal distance behavior to compensate for increases in mutual gaze.

In the current article, we examined two general questions: How can we use IVEs to learn more about human nonverbal behavior and how do people react to virtual humans? Immersive virtual environments have certain advantages over traditional physical environments in psychological research. As discussed above, IVEs allow us to create unique experimental manipulations. Furthermore, the technology provides us with extremely precise and unobtrusive measures: Participants had absolutely no idea we were measuring their personal space.

Regarding personal space, past research has found that greater interpersonal distance occurs between men and the smallest distance occurs between women (Brady & Walker, 1978). In the current studies, as in our previous studies (Bailenson, Blascovich, et al., 2001), we did not find this pattern. Previous findings of gender differences have attempted to explain the effect in terms of differences in body sizes (Ickes & Barnes, 1977). To more closely understand this notion, IVEs provide us an excellent tool to disentangle the normal confound of men having larger body sizes than women because in future studies we can design our virtual humans to have any range of shapes or sizes. A related reason why we did not find the traditional gender effects in IVEs might have to do with the nature of the technology. In virtual environments, there is no possibility of physical collisions; consequently, there is no threat of physical contact or violence. In an IVE, the traditional finding (that men stay farthest away from men) may not occur because the notions of physical harm from aggression are not as easily actualized in the digital world.

One limitation to the current research is the type of interactions in which participants engaged. The nature of the label-reading task is not a typical or particularly engaging interaction. However, it was chosen because it provided a good cover story for a walk around the virtual person without making the purpose of the studies in terms of measuring proxemics obvious. We have implemented studies in IVEs with more engaging interactions, such as a group of avatars working together to play a game of 20 questions (Bailenson, Beall, & Blascovich, in press), and also have observed the influence of typical mutual gaze behaviors in those more involved tasks. In future studies, we seek to have multiple interactants navigate within the same IVE and observe their interpersonal distance behaviors.

Living, breathing humans socially respond to virtual humans in IVEs in a naturalistic way regarding personal space, social presence, and affect. This is not surprising given past research that surprisingly demonstrates that people tend to treat computer hardware in a manner that seems exclusively appropriate for humans (Reeves & Nass, 1996). This conclusion has broad implications. For example, we now know that on some basic level, people do not dismiss virtual humans as mere animations. Consequently, it should not surprise us that individuals who spend long periods of time in immersive chat rooms or video games may be substantially socially impacted by virtual others (Williams, Cheung, & Choi, 2000).

Advantages and Disadvantages of IVET for Psychological Research

These studies shed light on the utility of using IVET for the purpose of studying human behavior, proxemics in particular. However, there are some disadvantages as well. First, as certain researchers point out (Hebl & Kleck, in press; Zebrowitz, in press), the technology may be so novel that data collected inside an IVE cannot generalize to the population at large. In other words, studies in an IVE will only shed light on humans as they interact with one another virtually. However, the data collected from the current study provide support for a rebuttal to such a criticism. In the current study, participants left a remarkably naturally sized and shaped personal space bubble around virtual people. Furthermore, in some instances, we observed traditional compensation effects, despite the fact that we were limited to looking at only two nonverbal cues (gaze and interpersonal distance).

One major problem with using IVET to study interpersonal distance is the lack of physical contact between virtual representations. On a conscious level, our participants knew that there was absolutely no way that an avatar or agent could physically touch them, bump into them, or harm them in any way. Because of this high-level belief, in certain aspects, interpersonal interactions in an IVE may be fundamentally different than everyday interaction in the physical world. However, because this belief can only operate at a rational, high-conscious level, we still observed the presence of many automatic responses. In other words, despite the fact that participants knew on some level that the agents and avatars could not be touched, they still gave the virtual humans a large bubble of personal space. In time, as haptic technology develops, virtual humans will be able to "be touched" just as easily as they are able to "be seen" today.

In conclusion, we believe that IVET provides a valuable tool to study everyday nonverbal behavior. Despite differences between virtual interactions and physical interactions, psychologists will be able to use IVEs to answer questions that cannot be easily addressed using traditional surveys, vignettes, or confederates. IVET is already proving to be a worthy tool to augment traditional methods of studying human interaction.

APPENDIX A
Questions From the Social Presence Survey

1. I perceive that I am in the presence of another person in the room with me.
2. I feel that the person is watching me and is aware of my presence.
3. The thought that the person is not a real person crosses my mind often.
4. The person appears to be sentient, conscious, and alive to me.
5. I perceive the person as being only a computerized image, not as a real person.

APPENDIX B
Questions From the Postexperiment Reaction

1. I felt angry when the virtual people walked through me.
2. I felt startled when the virtual people walked through me.
3. I felt scared when the virtual people walked through me.
4. I would be willing to delete the virtual people such that they no longer existed any longer.
5. After they walked right through me, I would like to get revenge against the virtual people.

NOTES

1. The realism of our environments was high enough to deter participants from attempting to collide with any objects. Only 2 of 80 actually collided with either the walls or the virtual human.

2. In both levels of the agency variable, we also told participants that there were no virtual mirrors and they would not be able to see how they themselves appeared in the virtual environment.

3. We eliminated the first trial of each block to allow participants to acquaint themselves with the procedure.

4. There was a slight confound in that the participant always walked to the back of the virtual human before the front to view the labels. However, the front/back difference occurs consistently over the five trials, suggesting that order effects are not responsible. Furthermore, our previous work on interpersonal distance in IVEs also demonstrated this difference (Bailenson, Blascovich, Beall, & Loomis, 2001).

5. Due to equipment failure, location and orientation data from two participants were lost: one in the male participant, high-realism, avatar condition and one in the male participant, low-realism, avatar condition.

6. In the current study, we did not include a nonhumanoid control condition. In other words, we did not include any condition in which an object that approached our participants did not look like a human. The purpose of such a control condition would be to compare our data to people's general tendency to avoid a looming object. When designing the study, we attempted to include such a condition. However, it proved very difficult to implement an approaching object that (a) did not look completely unnatural and foreign (such as an inanimate pole inexplicably moving toward our participants) or (b) did not bring other meaningful variables into the control condition (such as avoiding a moving vehicle or a dog).

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