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Equilibrium Theory Revisited: Mutual Gaze and Personal Space in Virtual Environments

Abstract

During the last half of the twentieth century, psychologists and anthropologists have studied proxemics, or spacing behavior, among people in many contexts. As we enter the twenty-first century, immersive virtual environment technology promises new experimental venues in which researchers can study proxemics. Immersive virtual environments provide realistic and compelling experimental settings without sacrificing experimental control. The experiment reported here tested Argyle and Dean's (1965) equilibrium theory's specification of an inverse relationship between mutual gaze, a nonverbal cue signaling intimacy, and interpersonal distance. Participants were immersed in a three-dimensional virtual room in which a virtual human representation (that is, an embodied agent) stood. Under the guise of a memory task, participants walked towards and around the agent. Distance between the participant and agent was tracked automatically via our immersive virtual environment system. All participants maintained more space around agents than they did around similarly sized and shaped but nonhuman-like objects. Female participants maintained more interpersonal distance between themselves and agents who engaged them in eye contact (that is, mutual gaze behavior) than between themselves and agents who did not engage them in eye contact, whereas male participants did not. Implications are discussed for the study of proxemics via immersive virtual environment technology, as well as the design of virtual environments and virtual humans.

1 Equilibrium Theory Revisited: Mutual Gaze and Personal Space in Virtual Environments

Proxemics, the study of personal space and interpersonal distance, began more than four decades ago. Hall (1959) and Sommer (1959) demonstrated that people maintain personal or buffer space around themselves and each other. Although the size of the buffer space remains remarkably stable across individuals, certain conditions—for example nonverbal expressions of intimacy (such as mutual gaze)—foster its expansion or contraction. Argyle and Dean (1965) describe the interaction between mutual gaze and proxemic behaviors. According to their intimacy equilibrium model, the two behaviors are inversely related to each other. Mutual gaze nonverbally promotes intimacy which, if inappropriate to the relationship between interactants, is decreased by increases in personal space (which nonverbally promotes less intimacy).

Immersive virtual environments (IVEs) raise at least two intriguing issues for proxemics research. One involves the validity of using IVE technology (IVET)

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to study proxemics experimentally. If IVET is methodologically valid for this purpose, then it provides a powerful research tool. Investigators can study proxemics with complete control over virtual human representations while at the same time maintaining a relatively high degree of ecological validity and mundane realism (Aronson & Carlsmith, 1969). A second issue concerns IVEs as a new type of space that may itself affect nonverbal and proxemic behaviors within them.

1.1 Nonverbal Communication

Patterson (1995) defines nonverbal communication as the "transmission of information and influence by an individual's physical and behavioral cues" (p. 424). Nonverbal communication has been studied extensively in psychology (for a review, see Argyle (1988)), anthropology (Hall, 1966; Watson, 1970), and computer science (Badler, Chi, & Chopra, 1999; Isbister & Nass, 2000). Nonverbal signals can be expressed through many channels, ranging from subtle ones such as voice intonation, to more obvious ones involving hand gestures. Moreover, these behaviors are often subconscious and unintentional (Zajonc, 1980).

1.2 Proxemics

Personal space, the distance between two or more human beings, has primarily been studied experimentally in one of four ways: chair selection, in which participants choose seats that vary in distance from a target person; stop distance, in which participants indicate when a real person such as an experimenter or confederate should stop approaching them; projective studies, in which participants manipulate dolls and figures; and natural observational studies. (See Hayduk (1983) for a review.) Researchers have identified several other factors that moderate personal space, including culture (Hall, 1966; Watson, 1970), race (Rosegrant & McCroskey, 1975), physiology (McBride, King, & James, 1965), age (Willis, 1966), and interpersonal relationships (Evans & Howard, 1973; Little, 1965).

Some researchers have argued that proxemic behaviors differ for men and women. Specifically, they claim that personal space between men is the largest, between women is the smallest, and between men and women is midlevel. Several experiments have demonstrated that, compared to men, women maintain less space between themselves and other people (Adler & Iverson, 1974; Aiello, 1977), have bodies that take up smaller amounts of physical space (Mehrabian, 1972; Jenni & Jenni, 1976), and are more likely than men to withdraw when their space is invaded (Henley, 1977). However, the evidence for these effects is mixed. In a survey of the proxemics literature, Hayduk (1983) determined that 27 studies found sex differences in the size of personal space, 54 studies found mixed evidence, and 29 studies found no effects.

IVEs may offer an experimental media that can help investigators examine gender differences in proxemic behaviors more reliably. Virtual environments offer a unique space for examining interactions because experimenters can maximize realism as in a field study without sacrificing the experimental control of a laboratory (Loomis, Blascovich, & Beall, 1999). Many proxemics studies have relied on naturalistic observation (where experimental control is at a minimum), confederates (whose behavior is necessarily variable), or projective techniques (which are largely unrealistic) to answer questions concerning personal space. Perhaps questions of personal space can be investigated more scientifically using IVEs. Research measuring the proxemic behavior of icons on two-dimensional desktop environments (Krikorian, Lee, Chock, & Harms, 2000) suggests that people do attempt to monitor their personal space in virtual environments. However, whether they do reliably in immersive three-dimensional virtual environments with realistic humanoid representations remains to be seen.

1.3 Mutual Gaze

Mutual gaze occurs when two people are looking at each other's eyes. Linguistically, mutual gaze helps people organize interactions by regulating conversational sequencing (Argyle, 1988). However, mutual gaze transmits information above and beyond linguistic regulation. Research demonstrates that people who exhibit high levels of mutual gaze are perceived as intimate (Scherer & Schiff, 1973), attentive (Breed, Christiansen, & Larson, 1972), competent (Sodikoff, Firestone, & Kaplan, 1974), and powerful (Argyle, Lefebvre, & Cook, 1974). In addition, people can be influenced by mutual gaze without necessarily being aware of it (Zajonc, 1980). Women tend to exhibit more mutual gaze in dyadic interactions than do men (Argyle & Cook, 1976; Chapman, 1975). In addition, women tend to tolerate and more favorably react to gaze than do men (Valentine & Ehrlichman, 1979). Furthermore, in a recent study on pedestrians' gaze avoidance, Patterson & Webb (in press) demonstrated that men gaze more often at women than at other men, but that women tend to gaze at men and other women equally as often. Similarly, numerous studies show that women are more adept than men are at transmitting and receiving nonverbal information. (See Hall (1984) for a review.)

According to Argyle and Dean's (1965) research on the equilibrium theory, mutual gaze (a nonverbal cue signaling intimacy) moderates interpersonal distance. Several studies support this hypothesis. Rosenfeld, Breck, Smith, and Kehoe (1984) explored various conditions in which confederates violated participants' personal space by recording the number of times that the participants gazed at the confederates' eyes. These researchers demonstrated a dramatic reduction in gaze in response to invasion of personal space. Similarly, Patterson (1976, 1982) and Hayduk (1981) demonstrated that participants increase personal space between themselves and confederates who increased mutual gaze. Moreover, participants will move closer when facing the confederates' backs than their fronts (Aono, 1981; Ashton & Shaw, 1980; Hayduk, 1981).

Although there has been much research on mutual gaze, little of that research has involved controlled representations of people. Just as with proxemics, IVEs can improve the methods used to study mutual gaze. Gaze behavior of virtual humans can be regulated to be less susceptible to error than the scripted gaze behavior of confederates. Furthermore, using IVEs, we can guarantee that participants' eye height is exactly the same as the eye height of the virtual human, thus improving the probability that the manipulations of gaze will be noticed (as well as eliminating potential status differences due to height).

Virtual humans, when rendered stereoscopically in three-dimensional virtual environments, can prove to be surprisingly compelling representations of living humans. Recent conceptual and technological breakthroughs allow us to create virtual human representations that are behaviorally realistic (Badler et al., 1999; Massaro, 1998; Cassel & Thorisson, 1998). In real humans, different nonverbal behaviors are often highly correlated with each other (Argyle, 1988; Dittmann & Llewellyn, 1969). Hence, it is likely that past studies that claimed to manipulate one behavior actually manipulated many. For example, it would be difficult for a confederate to maintain eye gaze with a participant without moving his or her hands, or slightly changing facial expressions or breathing patterns. Controlling these behaviors in virtual humans allows us to maintain complete independence among these behaviors.

Previously, we defined the representation of some entity in a virtual environment as a virtual human. We can distinguish an embodied agent from an avatar.[1] An embodied agent is a virtual representation that is controlled entirely by a computer program, whereas an avatar is a virtual representation that is controlled at least partially by a human being. In the current study, we explore behavior with participants who are immersed with only agents.

2 The Experiment

2.1 Overview

We immersed experimental participants in a virtual room in which a virtual male agent stood. We instructed them to remember certain features and labels on the front and back of the agent's shirt. Unbeknownst to the participants, we recorded their absolute position and orientation with a precision tracking system as they walked about the virtual room.

1. This distinction is equivalent, respectively, to "agent-avatar" and "human-avatar," the distinction raised by Blascovich et al. (in press).

2.2 Hypotheses

We drew our hypotheses from Argyle and Dean's (1965) equilibrium model. By varying the degree of mutual gaze between the agent and the participant, we were able to test the inverse relationship of mutual gaze with personal space. We hypothesized that, when the agent constantly maintained eye gaze with the participant, the participant would leave the agent a larger bubble of personal space, compared to when the agent had his eyes closed. In addition, we varied the photographic realism of the agent's face: the agent either had a texture-mapped and photographically realistic face or one created from a series of flatly shaded polygons. Nowak (2000) also explores a similar difference in photographic realism and calls it the degree of anthropomorphism. In line with Blascovich et al.'s (in press) arguments regarding the relative importance of behavioral realism such as mutual gaze over photographic realism, we predicted larger effects on proxemic behavior due to mutual gaze than to photographic realism.

Furthermore, we predicted that the size and shape of the footprint of the personal space bubble maintained around agents would be similar to that maintained around real humans. We hypothesized that participants would maintain more space in front of the agent than they would behind it. We did not make predictions concerning gender differences in distance behavior, as the literature is unclear in this regard. (Hayduk, 1983). However, because the literature on mutual gaze more clearly indicates that women notice mutual gaze more than men do, we hypothesized that women would respond more strongly to our manipulations of gaze behavior than would men.

2.3 Methods

2.3.1 Design. We manipulated one within-participant variable (model of the agent's face) and two between-participant variables (gaze behavior of the agent and gender of the participant). There were two levels of face: flat shaded and photograph textured. Flat-shaded faces were "chiseled," that is, constructed as a three-dimensional model that had noticeably sharp facial topography. Photograph-textured faces had an image of an actual human face fitted to the three-dimensional model, loosely borrowing a technique developed by Sannier and Thalmann (1998). Figure 1 gives examples of the two conditions.

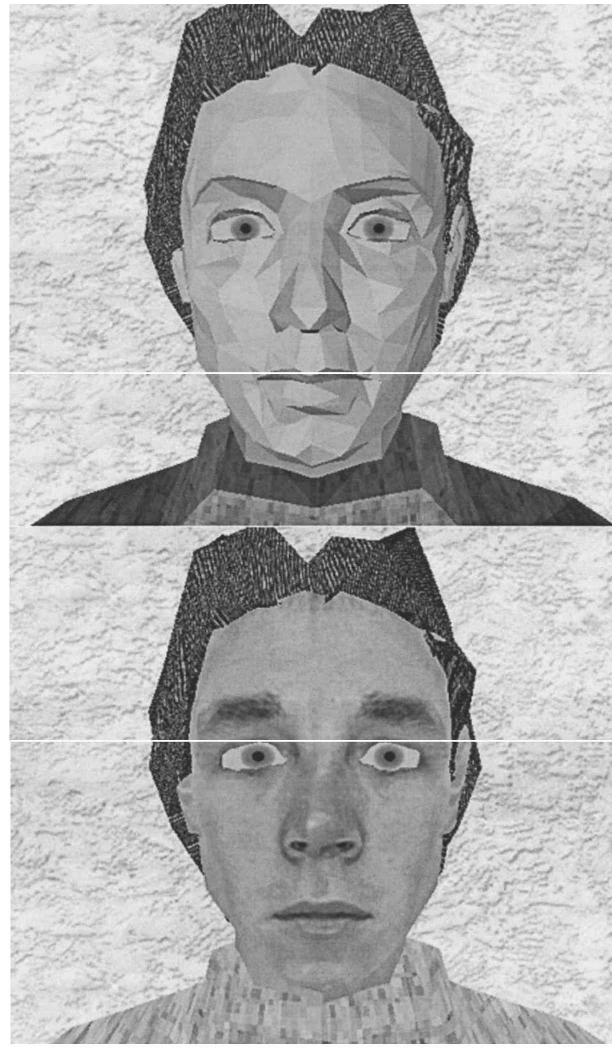

Figure 1. *Pictures of the two face conditions. The flat shaded-face is on top, the photographic texture is on the bottom.*

We manipulated five levels of increasingly realistic gaze behavior. In the lowest, level 1, the agent's eyes were closed. In level 2, his eyes were open. In level 3, the agent's eyes were open and he blinked. In level 4, in addition to blinking his eyes, the agent turned his head so that he constantly gazed at the participant's face as he

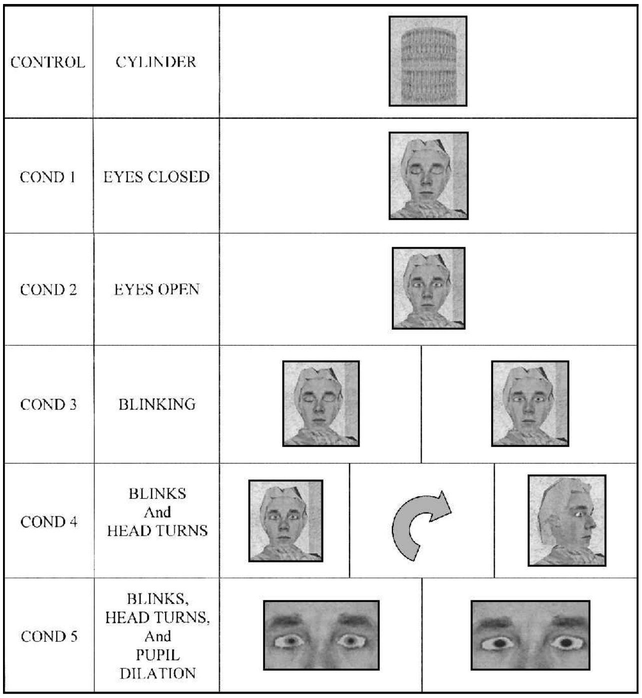

Figure 2. *Pictures of the different gaze-behavior levels.*

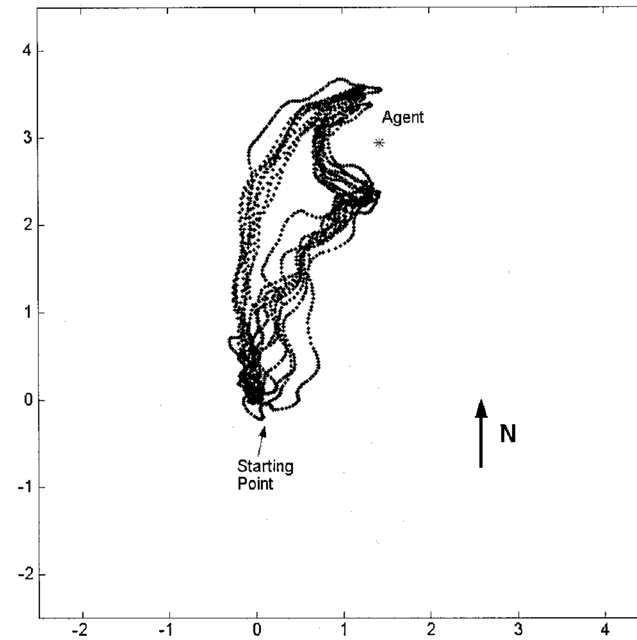

Figure 3. *An example of the ten paths from a participant in realism condition 4. The ticks on the axes represent meters.*

or she traversed the environment. The agent's head turned 85 deg. in either direction. Level 5 of gaze behavior was the same as level 4; however, the agent's pupils dilated by 50% when the participant stepped within 0.75 m of the agent. Figure 2 illustrates the differences among these levels. In levels 4 and 5, the agent does not necessarily demonstrate completely realistic gaze behavior, because he does not ever glance away from the participant. We realize that normal gaze behavior includes random glances away from the target, but, to maintain experimental control, we did not include sporadic movements such as glancing away. Along the same lines, we chose to separate these gaze behaviors in a systematic way, as opposed to integrating them all at once. In this fashion, we could attempt to gauge the unique contribution of each behavior.

Each participant "interacted" with agents in a single level of gaze behavior. We presented participants two blocks of trials: one block with flat polygon-shaded faces and one with photograph-textured faces. Each block had five trials, and the order of blocks was counterbalanced across participants. In addition, we ran a control condition on a separate group of participants that was identical to the other conditions except that, instead of a humanoid representation in the room, there was an object representation (a pylon) that was the same width and height as the agent. The task in this control condition was exactly the same as the other conditions.

2.3.2 Materials and Apparatus. The virtual room was modeled to be 7.2 m by 6.4 m by 4.5 m high (approximately 75% of the space of the physical room) to ensure that participants did not walk into any physical walls while they traversed the virtual room. Figure 3 shows the location of the agent in the virtual room as well as the participants' starting point. The agent was represented as a Caucasian male, three-dimensional, polygon-based model. His height was 1.85 m, and his body was always facing south in the room. He wore a label on both the front and back of his shirt. The front label listed his name, and the back label listed a num-

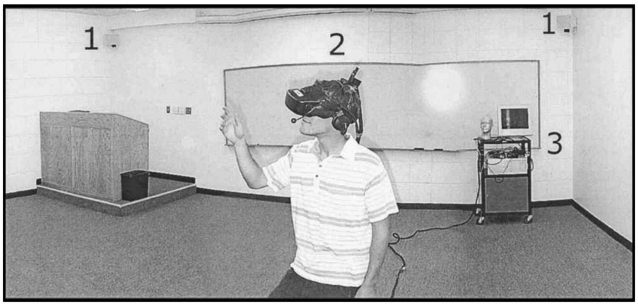

Figure 4. *A depiction of our virtual environment system. The components are (1) position tracking cameras, (2) HMD and orientation tracking sensor, and (3) image generator.*

ber.[2] The size of the text on each label was chosen so that, at a viewing distance of 1 m, the task of reading the word or number was perceptually easy with only a few quick fixations.

Participants themselves were not rendered. Hence, although participants could walk about the virtual environment and see the agent or the pylon in the room, they did not see any animated representation of themselves. Consequently, if a participant looked down while walking, he or she would not see his or her own legs and feet. We set the eye height to be exactly the same as the agent's eyes for all participants, and participants began the trial facing the agent (north in the room).

The technology used to render the IVEs is shown in figure 4. The head-mounted displays (HMD) was a Virtual Research V8 HMD (a stereoscopic display with dual 680 × 480 resolution LCD panels that refresh at 72 Hz). The optics of this display presented a visual stimulus subtending approximately 50 deg. horizontally by 38 deg. vertically. Perspectively correct stereoscopic images were rendered by a 450 MHz Pentium III dual-processor computer with an Evans & Sutherland Tornado 3000 dual-pipe graphics card, and these images were updated at an average frame rate of 36 Hz. The simulated viewpoint was continually updated by the participant's head movements. The orientation of the participant's head was tracked by a three-axis orientation sensing system (Intersense IS300, update rate of 150 Hz), and the location of the participant's head was tracked three-dimensionally by a passive optical position sensing system (developed in our lab and capable of measuring position with a resolution of 1 part in 30,000, or approximately 0.2 mm in a 5 m square workspace, 60 Hz). The system latency, or the amount of delay between a participant's head or body motion and the resulting concomitant update in the HMD's visual display was a maximum of 65 ms. Using this hybrid tracking system, it is possible for a participant to experience appropriate sensory input when she turns her head at the same time as she walks. There was no collision detection. In other words, a participant could walk through the agent or through a virtual wall without receiving any haptic or auditory cues.

2. The numbers were all prime and the names were all six letters, two syllables, and matched for frequency using Yahoo Web-based white-pages software. The names and numbers appear in appendix A. The text of the names and numbers were modeled to be approximately 1.5 in. high.

2.3.3 Participants. Participants were recruited on campus and were either paid or given experimental credit in an introductory psychology class for participation. Four men and four women participated in each of the five gaze-behavior conditions, and six men and four women participated in the control condition, resulting in fifty total participants in the study. Participants' age ranged from 18 to 31.

2.3.4 Procedure. One individual participated in each session. We instructed participants that they would be walking around a room and engaging in 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 see a person. The person is wearing a white patch on the front of his shirt. His name is written on that patch. He is also wearing a similar patch on the back of his 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 his 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. When you have read the patches and examined the person in each room, we will ask you to step back to the starting point in the room. The starting point is marked by a piece of wood on the floor.

Our ostensible experimental task of reading and memorizing the agent's name and number motivated the participant to move within a relatively close range (1 m or less) of the agent so as to easily read the textual material. We felt that, by design, this secondary task would unwittingly cause the subject to move close enough to the avatar as to intrude potentially upon the hypothesized personal space bubble of this entity. Subsequently, the participant's movements would result from a competition between their desire to maintain an appropriate level of personal space and their need to accurately read the patches.

When they understood the instructions, participants tried on the HMD. To become accustomed to the equipment and walking while immersed, participants were given a chance to walk around an empty virtual room while wearing the HMD. Participants freely explored the room for approximately 1 min. and then walked back to the starting point. None of the participants had any trouble finding the starting point.

After the practice exploration, participants began the first block. Figure 5 simulates a participant walking around the virtual room. For each trial, participants began facing the agent. They then stepped from the starting point and walked around to the back of the agent (or the pylon in the control condition). They read the number on the agent's back and then walked back around to his front. After reading the front patch, they returned back to the starting point and waited for the next trial. We chose the patch-reading task for two reasons. First, it ensured that our participants would be motivated to approach the agent relatively closely. Second, because nonverbal behavior tends to be implicit and often unintentional (Zajonc, 1980), we decided that measuring personal space while subjects were intentionally engaged in a distracting task would be the most effective manner to elicit these behaviors.

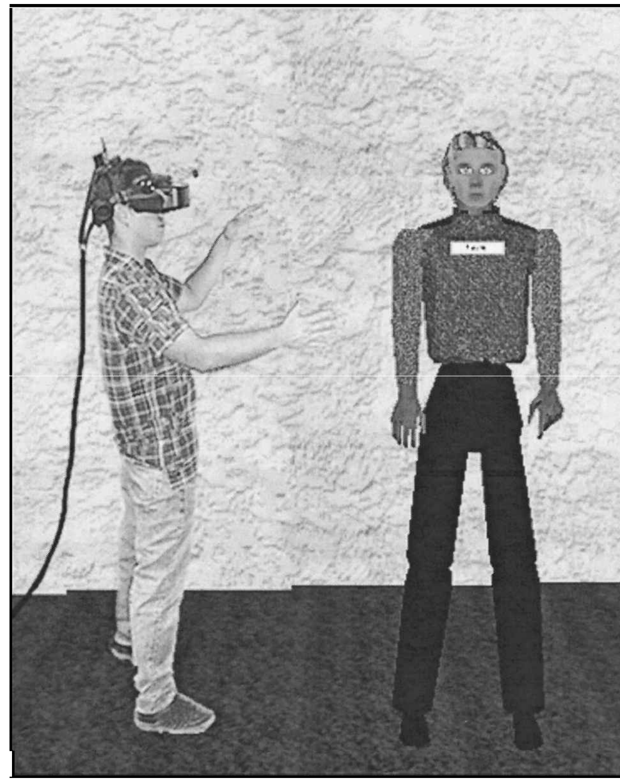

Figure 5. *The virtual environment as seen by the user. In this figure, we include a representation of the user wearing the HMD solely to indicate scale. However, participants could not see a representation of their own avatar.*

For each of the five trials in a block, the agent wore a different-colored shirt, had different-colored hair, and had a different name and number. In the control condition, the pylon was colored differently for each trial (the same colors as the agent's shirts in the other conditions). Across participants, the names, numbers, and other features appeared in each serial trial position an equal number of instances. Blocks took between 5 and 15 min., depending on the participant's walking rate. Participants had an opportunity to rest between blocks.

After participants completed the two blocks, they removed the HMD and were administered a pen-and-paper recall test. For the recall test, participants tried 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 agent on a specific trial to the number of that agent on the same trial. We instructed participants to draw all ten lines, guessing when they were unsure if a name went with a number.

Finally, after the recall test, participants put the HMD back on for two more trials in order to complete a social presence questionnaire: one with the photograph-textured face and one with the flat-shaded face. We never explicitly instructed our participants that the avatar was an agent controlled entirely by the computer. However, postexperimental interviews indicated that none of our participants suspected the avatar was controlled by another human being.

For the survey, a Likert-type scale (from -3 to $+3$) hung in space over the agent's head. Participants looked at the agent and the scale while the experimenter verbally administered the five-item social presence questionnaire. People feel high social presence if they are in a virtual environment and behave as if interacting with other veritable human beings. For a more detailed discussion of social presence in immersive virtual environments, see Blascovich et al. (in press). To capture the most realistic measure of social presence possible, we asked the ratings questions while participants were immersed. The questions appear in appendix B. Participants in the control condition did not answer the questionnaire.

2.4 Results

Participants had no problems walking through the virtual space, and none experienced any significant simulator sickness. After the experiment, none of the participants indicated that they had guessed that their proxemic behaviors were under scrutiny. All were under the impression that we were primarily studying memory.

The tracking system saved the participant's position at a rate of 18 Hz. Figure 3 depicts the paths that a typical participant traversed over the ten trials. Each position sample located the participant's position in the virtual room. For each participant, we recorded the minimum distance between the centerpoint of the participant's head and the centerpoint of the agent's head during each trial. There were no reliable differences between the two types of faces (photograph textured and flat shaded) in any of the analyses. Consequently, we collapsed across this variable in subsequent analyses.

2.4.1 Personal Space.

Our primary predictions concerned the distance between the participants and the agent. Figures 6 and 7 show the paths by participants' gender and experimental condition. Participants actually stepped through the agent on only two trials (by two different participants) out of 400. Interestingly, both of them were in the lowest level of gaze behavior (that is, the agent's eyes were closed). The other 38 participants did not "touch" the agent.

We used two objective measures of participants' invasion of the agent's personal space: minimum distance and invasion duration. Minimum distance was defined as the shortest distance that participants maintained between themselves and the agent. We chose minimum distance instead of average distance for two reasons: first, as Hayduk (1983) points out, many previous studies measuring proxemics relied on this measure, and, second, because some participants concentrated on reading the labels, they spent blocks of time at a specific reading distance. Consequently, given the nature of the task, average distance may not accurately reflect participants' attention to the nonverbal gaze behavior. On the other hand, minimum distance is a better measure of how close they were willing to go to the agent while examining his features and walking around him. The second measure, invasion duration, was defined as the amount of time that participants spent inside the agent's intimate space, which, based on work by Hall (1966), we define as the number of seconds spent within a range of 45 cm. The invasion duration data were almost identical to the minimum distance data, such that the two measures produced similar significant effects and also correlated highly with each other. Consequently, for the purposes of brevity and clarity, we present only the minimum-distance data. It is important to note here that our distance measure may result in larger distances than other measures (see Hayduk (1981)) because we measure distance between the centerpoint of the heads instead of the perimeter of the heads.

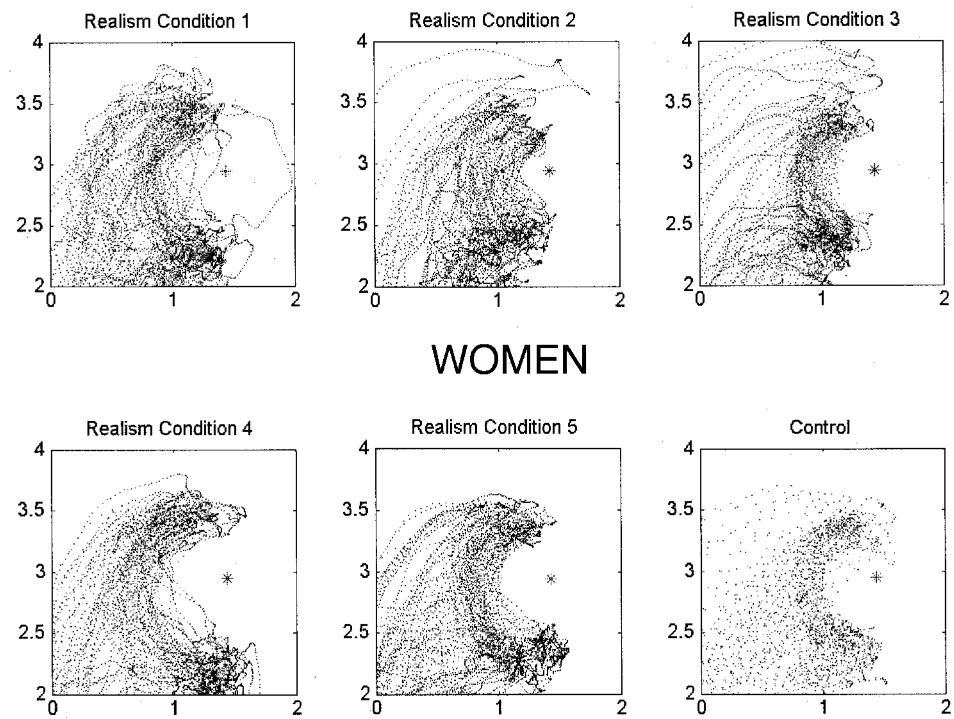

Figure 6. *A plot of the female participants' paths by condition. The graphs include only data that surrounds the agent. Each point on the figure represents a sample reading (taken at 20 Hz). Each figure depicts the samples from all of the subjects from that condition.*

Regarding personal space and gaze behavior, we predicted monotonic increases with increasing realism. We expected that participants would be most likely to respect an agent's personal space when he exhibited realistic gaze behaviors (Argyle & Dean, 1965). Consequently, we predicted that minimum distance should be longest in the high-gaze conditions (4 and 5) and shortest in the condition in which the agent's eyes were closed, and in the control condition in which there is a cylindrical pylon instead of a humanoid agent. (See hypotheses.)

We analyzed both back minimum distance (the minimum distance while the participant was behind the midpoint of the agent's head) and front minimum distance (the minimum distance while the participant was in front of the midpoint of the agent's head). The average back minimum distance (not including the control condition) was 0.37 m (s.d. = 0.15); the minimum was 0.06, and the maximum was 0.68. The average front minimum distance was 0.40 (s.d. = 0.15); the minimum was 0.04, and the maximum was 0.71. A one-way ANOVA indicated a marginal effect for the difference between front and back minimum distances: $F(1, 39) = 3.25$; $p < 0.08$, which is consistent with studies discussed previously (Hayduk, 1983) that find the footprint of the personal space bubble to be slightly larger in front than in back. The two measures correlated with each other significantly: $r = 0.78$.

Table 1 displays the average back minimum distance by condition. Participants approached more closely to the back of the cylinder (M = 0.24; s.d. = 0.06) than to the back of the agent (M = 0.37; s.d. = 0.13): $F(1, 48) = 10.27$; $p < 0.01$.

Table 1 suggests that female participants did in fact exhibit the predicted monotonic trend. To further explore that trend, we ran a nonparametric correlation

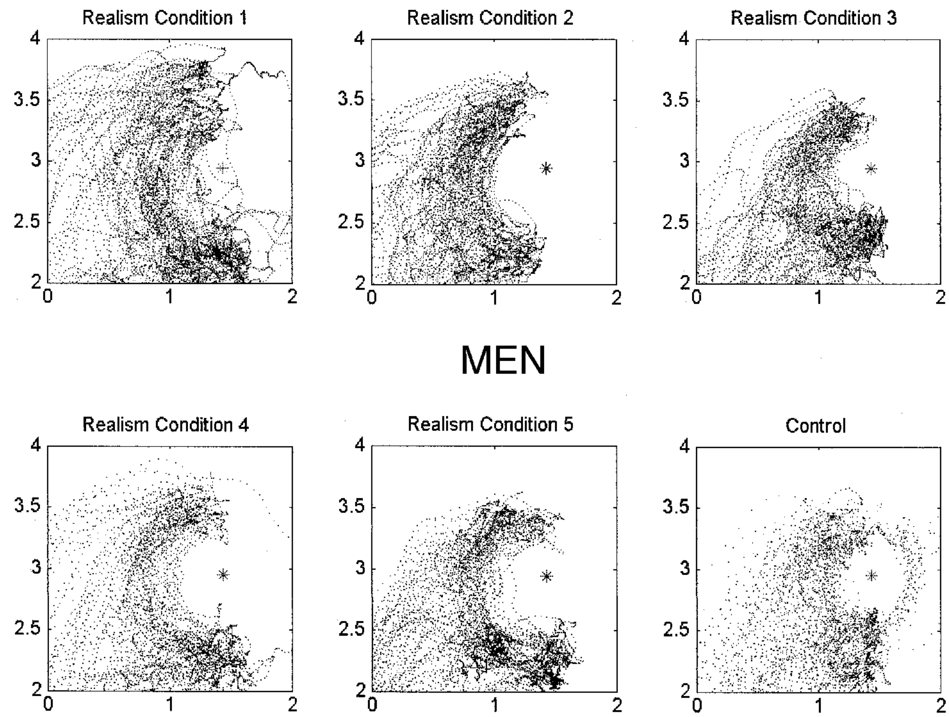

Figure 7. *A plot of the male participants' paths by condition. The graphs include only data that surrounds the agent. Each point on the figure represents a sample reading (taken at 18 Hz). Each figure depicts the samples from all of the subjects from that condition.*

test[3] between participants' back minimum distance and their gaze-behavior level. First, we examined female participants. With 24 observations (four female participants in each of the five levels plus the control), we find a significant Spearman's correlation: $r = 0.47$; $p < 0.01$. We also find a significant effect for male participants: $r = 0.43$; $p < 0.05$. As predicted, both men and women gave more personal space to agents who exhibited realistic gaze behavior than to agents who did not as well as to the control pylon.

We then used a regression procedure to partial out the variance due to memory matching scores and social presence ratings (see subsection 2.4.2) from back minimum distance. Cohen and Cohen (1983) provide a formal description of this process. The purpose of this analysis was twofold: to statistically control for participants whose high motivation in the memory task prevented them from noticing the agent's gaze behavior, and to statistically control for participants who found

Table 1. *Average and Standard Deviation of Back Minimum in Meters by Condition*

Gaze Condition	Women	Men
Control	0.25 (0.04)	0.22 (0.05)
1	0.32 (0.26)	0.36 (0.18)
2	0.33 (0.06)	0.42 (0.16)
3	0.36 (0.01)	0.27 (0.06)
4	0.42 (0.05)	0.42 (0.08)
5	0.45 (0.15)	0.36 (0.10)

3. We used a nonparametric correlation for this analysis because the levels of the realism variable were ordinal. For this reason, we could not run a simultaneous analysis using presence, matching, and realism (as a linear variable).

Table 2. *Average Standardized Means of Covariate-Adjusted Back Minimums by Condition*

Gaze Condition	Women	Men
Control	−0.78	−1.85
1	−0.06	0.03
2	−0.14	0.64
3	0.02	−0.65
4	0.58	0.52
5	0.59	−0.44

Table 3. *Average and Standard Deviation of Front Minimum in Meters by Condition*

Gaze Condition	Women	Men
Control	0.37 (0.06)	0.27 (0.12)
1	0.34 (0.29)	0.37 (0.16)
2	0.39 (0.06)	0.48 (0.18)
3	0.39 (0.08)	0.30 (0.06)
4	0.50 (0.12)	0.35 (0.15)
5	0.46 (0.13)	0.41 (0.11)

the entire virtual reality experience to be either too intimidating or too unpersuasive to notice the agent's gaze behavior. In later sections, we discuss both memory scores and social presence ratings individually.

Table 2 shows the standardized means (adjusted for memory matching and social presence) of minimum back distance by condition. We again ran Spearman's correlation test, this time between the participants' standardized adjusted back distance mean and their gaze-behavior level. First, we examined female participants. With 24 observations,[4] we still find significant effects for both women ($r = 0.47$; $p < 0.01$) and men ($r = 0.36$; $p < 0.05$).

Table 3 shows the means of front minimum distance by condition. Participants approached the front of the cylinder more closely (M = 0.31; s.d. = 0.09) than the front of the agent (M = 0.40; s.d. = 0.15): $F(1, 48) = 3.74$; $p < 0.059$. We ran the same Spearman's correlation analysis between front minimum distance and gaze-behavior level that we did for back minimum distance. There were no significant effects for either female participants ($r = 0.33$) or for male participants ($r = 0.22$). However, again we adjusted the means for social presence and memory matching score. Table 4 shows the adjusted standardized means of minimum front distance by condition. The correlation between adjusted front distance and gaze-behavior level was significant for women ($r = 34$; $p < 0.055$), but not for men ($r = -0.13$). When taking into account social presence and memory task motivation, women gave more personal space to the front of agents who exhibited realistic gaze behavior.

Table 4. *Average Standardized Means of Covariate-Adjusted Front Minimums by Condition*

Gaze Condition	Women	Men
Control	−0.31	−1.21
1	−0.62	−0.36
2	−0.38	0.36
3	−0.08	−0.74
4	0.52	−0.48
5	0.46	−0.15

Interestingly, when controlling for social presence and matching, we found a marginal effect for social presence ratings across male and female subjects: $t(19) = 1.82$; $p < 0.09$. Further examination demonstrated a Pearson's correlation of 0.44, $p < 0.054$ between social presence ratings and front minimum distance for men.[5] In other words, male participants did not adjust their degree of front minimum distance ac-

4. We did not have presence ratings for the control condition, so we partialed out only the variance from matching score for those observations.

5. Using back minimum distance, the correlation between social presence ratings and minimum distance is in the same direction for men ($r = 0.38$), but this effect was not significant with only twenty observations.

cording to our gaze-behavior manipulations. Instead, they respected the space of agents to which they subjectively assigned sentience and gaze in their social presence ratings. This effect is consistent with data from Patterson and Webb (in press) that demonstrates that men do not maintain eye contact with other men, and consequently would not notice male gaze as much as women would. This evidence explains why table 2 does not show a clear linear trend for male participants.

Another interesting finding was the degree of individual differences by mutual gaze condition. As figures 6 and 7 demonstrate, more variance occurred in the low gaze than in the high-gaze behavior conditions. To test this hypothesis, we implemented Levene's test for homogeneity of variances using gaze as an independent variable. For the dependent variable, we included the distance between every point illustrated in figures 6 and 7 and the agent. With all six levels of gaze behavior, there was no significant effect. However, when we lumped the two conditions (four and five) in which the agent maintained constant mutual gaze, we see that there was significantly less intersubject variance in the high-gaze behavior conditions (0.73 cm) than in the low-gaze behavior conditions (1.83 cm): $F(1, 48) = 4.50$; $p < 0.05$. In other words, participants displayed large individual differences, showing high variance in regards to how far away they stand from the agent when the agent did not maintain eye contact with them. However, their proxemic behavior was more uniform (that is, less variant) in the high-gaze conditions.

In sum, women are more affected by the gaze behaviors of the agent and adjust their personal space more accordingly than do men. However, men do subjectively assign gaze behavior to the agent, and their proxemic behavior reflects this perception. Furthermore, both men and women demonstrate less variance in their proxemic behavior when the agent displays mutual gaze behavior than when the agent does not.

2.4.2 Social Presence Ratings. On the social presence ratings task, we summed the ten responses into a simple score. Cronbach's reliability alpha, a measure commonly used to assess reliability across the individual items of a scale (Cohen & Cohen, 1983), was 0.83 across the ten questions. A positive social presence score indicates that the participant believed the agent was conscious and was watching him or her, whereas a negative score indicates that the participant felt the agent was just a computerized image. The average social presence rating score was −5.18 (s.d. = 11.42); the minimum was −30 and the maximum was 16. Fifteen out of forty scores were positive, indicating that more than a third of the participants perceived the agent to be realistic and assigned some degree of sentience to him.

Table 5. *Average Social Presence Score by Condition*

Gaze Condition	Women	Men
1	−13.25 (18.58)	−13.75 (7.14)
2	−1.75 (5.47)	−7.00 (12.33)
3	−3.00 (16.44)	−5.25 (9.56)
4	−2.75 (4.54)	1.00 (9.39)
5	2.5 (15.55)	−8.5 (6.45)

Just as with personal distance, there was absolutely no effect of the face variable or gender. Table 5 shows the average rating score by condition. We ran a nonparametric correlation between gaze behavior and rating score. Across gender, Spearman's *rho* was 0.30, $p < 0.03$, indicating that participants experienced higher social presence when the agent's gaze behavior was high. We then ran the same analysis by gender. The correlation was not significant for the 24 men ($r = 0.24$), but it was for the 24 women ($r = 0.42$; $p < 0.03$). The fact that women tailored their social presence ratings to the gaze manipulations is consistent with studies (Hall, 1984) that demonstrate that women are more likely to accurately decode nonverbal gestures than men are.

2.4.3 Memory. Participants' recall tended to be poor in general, so, for the remainder of the section, we discuss their memory score on the matching task (percentage of correct matches). Neither gaze behavior nor gender significantly affected matching score. However, when we compared the control condition to the other five levels of gaze behavior, we found that participants' memory was better for the control condition with the pylon in the room (M = 0.28; s.d. = 18) than for the trials with the agent in the room (M = 0.15; s.d. = 0.11): $F(1, 48) = 7.24$; $p < 0.01$. This result is consistent with previous work on social inhibition (Blascovich, Mendes, Hunter, & Salomon, 1999), in which the presence of another person impeded performance on novel or difficult tasks.[6]

2.5 Discussion

The focus of this research is on the subtle nonverbal exchanges that occur between a person and an embodied agent. Participants in our study clearly did not treat our agent as a mere animation. On the contrary, the results suggest that, in virtual environments, people were influenced by the three-dimensional model. Initially, participants overwhelmingly avoided direct contact with the agent, despite the fact that our system did not employ any type of display to indicate collisions. Moreover, participants respected personal space of the humanoid representation more than they did the cylinder in the control condition.

Furthermore, we found gender differences in response to nonverbal gestures that are consistent with findings from the nonvirtual environment literature. Female participants noted the gaze behavior of the agent more than male participants did, as indicated by the social presence ratings. Furthermore, not only did women respond more to the nonverbal behaviors in their ratings, but they were also more likely to respect the agent's personal space if he displayed realistic gaze behavior than were the males in our study. This confirmation of the equilibrium theory in virtual environments is particularly notable considering that the participants had absolutely no idea that we were measuring their personal space and that the gaze behavior condition was varied between subjects. Furthermore, these results occurred in a social situation that was completely nonverbal; in other words, our participants treated the agent in a manner similar to the manner in which they would treat humans, despite the fact that there were no actual verbal exchanges.

In addition to modulating our participants' proxemic behaviors, the agent affected their performance on the memory task. Participants who encoded the names and numbers while the humanoid agent was in the room had difficulty on the memory task (compared to the control condition). This social inhibition on memory lends additional support to the notion that the presence of virtual observers affected people in similar ways to real observers.

3 Implications and Future Research

Immersive virtual environments are becoming more commonplace in the fields of social psychological research (Slater, Sadagic, Usoh, & Schroeder, 2000; Loomis et al., 1999; Hoyt, 1999; Swinth, 2000), communication (Guye-Vuilleme, Capin, Pandzic, Thalmann, & Thalmann, 1999; Biocca & Levy, 1995), and business (DeFanti, 2000). It seems inevitable that, as we use these virtual environments more and more, interactions between avatars will become routine. Our data is similar to previous work (Reeves & Nass, 1996) that shows that people do assign some degree of sentience to a relatively simple virtual representation of a human being, especially when that representation exhibits realistic gaze behavior. Furthermore, as Blascovich et al. (in press) argue, realistic gaze behavior seems to be more crucial than photographic realism in establishing the social presence of an agent. This result has implications for the design of agents as well as for virtual environments in general.

The current study provides a starting point for an empirical exploration of nonverbal gestures of agents and avatars in IVEs. We have established that proxemics can be a valuable tool for measuring the behavioral realism of an agent or an avatar. People tend to perceive nonverbal gestures on an implicit level (Zajonc, 1980), and degree of personal space appears to be an accurate way to measure people's perception of social presence and realism in virtual environments. Other studies demonstrate that implicit behavioral measures such as body

6. We do acknowledge the possibility that this effect occurred because there was an extra feature to remember on the human figure (hair color) than on the pylon, and that this extra feature may have somehow distracted participants.

posture can be a reliable measure of the user's sense of presence in virtual environments (Freeman, Avons, Meddis, Pearson, & IJsselsteijn, 2000). Similarly, personal space may be a more reliable measure of social presence than a typical ratings survey in immersive virtual environments.

As discussed in the previous paragraphs, our data replicate a number of findings from the field of nonverbal gestures and personal space (Argyle, 1988). Consequently, our study suggests validation for the use of virtual environments as a medium to study human behavior. Moreover, virtual environment technology appears to deliver the exceptional balance of realism and experimental control it promised. Consequently, nonverbal behaviors that previously could be studied using only field observations (such as gaze and personal space) can now be rigorously explored in the laboratory.

One shortcoming of the current study is that the agent whom participants approached was always male. Especially because we found an effect of the participant's gender, it is crucial for future studies to examine people's spacing behavior towards both male and female agents. Along similar lines, future studies should address the distinction between agents and avatars in virtual environments. In the current study, we employed agents that were driven by the computer. However, participants' use of personal space might be vastly different when they approach an avatar that is directly controlled by a human being. We are currently testing this hypothesis.

Appendix A. *The Names and Numbers from the Agents' Labels*

Names	Numbers
Stader	37
Borken	29
Waller	19
Jotter	5
Mervis	73
Nerson	61
Veltis	23
Rudins	11
Debnar	3
Kipple	53

Appendix B. The 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.

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