

# Personal Space in Virtual Reality

LAURIE M. WILCOX, ROBERT S. ALLISON, SAMUEL ELFASSY, and CYNTHIA GRELIK  
York University

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Improving the sense of “presence” is a common goal of three-dimensional (3D) display technology for film, television, and virtual reality. However, there are instances in which 3D presentations may elicit unanticipated negative responses. For example, it is well established that violations of interpersonal space cause discomfort in real-world situations. Here we ask if people respond similarly when viewing life-sized stereoscopic images. Observers rated their level of comfort in response to animate and inanimate objects in live and virtual (stereoscopic projection) viewing conditions. Electrodermal activity was also recorded to monitor their physiological response to these stimuli. Observers exhibited significant negative reactions to violations of interpersonal space in stereoscopic 3D displays, which were equivalent to those experienced in the natural environment. These data have important implications for the creation of 3D media and the use of virtual reality systems.

Categories and Subject Descriptors: H.1.2 [Information Systems]: Models and Principles—*User/machine systems, human factors*; J.4 [Computer Applications]: Social and Behavioural Sciences—*Psychology*

General Terms: Human Factors, Experimentation

Additional Key Words and Phrases: Stereoscopic projection, personal space, and virtual reality

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## 1. INTRODUCTION

Stereoscopic 3D display technology has been employed in a wide variety of applications including IMAX theatres, immersive virtual reality systems, such as the CAVE, endoscopic surgery [Yao et al. 2002] and therapeutic intervention [Garcia-Palacios et al. 2002]. To ensure that such technologies are exploited fully by the intended users, it stands to reason that the technology be easy to use and create little or no discomfort in the user/audience. The majority of early and ongoing empirical evaluations of 3D display technology and virtual environments have been directed toward obvious physiological effects such as fatigue, eyestrain, and nausea [Hill and Howarth 2000]. Less obvious, but equally important, sources of discomfort in the real world are psychological reactions to social phenomena. For instance, a strong sense of social presence<sup>1</sup> is an important design goal of many shared virtual environments, where

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<sup>1</sup>Social presence is a term originating in the telecommunications literature that refers to a communicator’s sense of awareness of the presence of an interaction partner. Presence is a nebulous term widely used in the study of virtual environments. It can be defined as the “illusion of being present in a virtual environment” [Blade and Padgett 2002]. A related, but different, concept is that of copresence, which is simply the feeling of being present with others.

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This research was supported by Natural Sciences and Engineering Council of Canada grants to L.W. and R.A.

Authors’ address: Laurie M. Wilcox, Samuel Elfassy, and Cynthia Grelik, Centre for Research, Department of Psychology, York University, Toronto, Canada, M3J 1P3. Robert S. Allison, Centre for Research, Department of Computer Science and Engineering, York University, Toronto, Canada; email: lwilcox@yorku.ca or allison@cs.yorku.ca.

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ACM Transactions on Applied Perception, Vol. 3, No. 4, October 2006, Pages 412–428.

individuals interact within the virtual setting to achieve specific aims. There are a number of social factors that could influence the success or failure of such copresence efforts. A well-known example is the typical adverse reaction to invasion of one's interpersonal space, the region surrounding our bodies that is considered private, and not generally entered casually by others. In the popular sit-com, *Seinfeld*, a character known as the "close talker" played on this fact for comic effect. In this paper, we ask if this phenomenon is robust enough to influence observers of life-sized, stereoscopic photographs of people. To provide a meaningful evaluation of the strength of the response to virtual stimuli, in experiment 2 we evaluate the response to proximity of (identical) people and objects in *both* virtual and live test conditions.

In an influential paper, Hall [1963] categorized interpersonal space into four zones. The two of most interest here are the *intimate distance* zone (0–1 ft), in which smell, touch, and sight are potentially exchanged, and the *personal distance* zone (1–4 ft), in which eye contact is avoided with strangers, and smell, touch, and body heat are usually not exchanged. The latter is thought to be the transition zone between intimate contact and formal, public interactions. It has been well documented in the proxemics literature that (at least in Western cultures) invasions of the intimate distance zone elicit strong behavioral and physiological reactions. For example, in a study conducted by Felipe and Sommer [1966], university students were approached in a library by a confederate who sat in a chair a few inches away. The targeted students demonstrated blocking actions, such as rigidity, placing elbows outward in a defensive position, and eye aversion. In addition to flight and other such nonverbal reactions, there are studies that indicate physiological arousal in response to the physical proximity of another person. For instance, McBride et al. [1965] measured increased galvanic skin response (a measure of conductivity that increases with increased arousal) when participants were approached by a stranger who stood at a distance of 1 ft compared with 3 and 9 ft. Similarly, Bergman [1971] found that increased proximity of others in a discussion group, caused increased palmar sweat and reports of more anxiety. Importantly, Barash [1973] showed that the animate nature of the intruding stimulus is an important component of the observer's negative reaction; the severity of the response to invasion of personal space is more strongly correlated with the presence of another person than to a neutral object.

Since the turn of the last century, the development and improvement of audiovisual technology has made mediated interactions, those between humans and representations of humans via visual media, increasingly common. Early studies of mediated interactions reported similarities between how participants react to real stimuli and those represented in two-dimensional (2D) media, such as television [see Kaufman 1974; Reeves et al. 1985; Reeves and Nass 2000]. These experiments have generally supported Horton and Wohl's [1956] assertion that individuals develop parasocial relationships with people on-screen, which depend on the perceived interpersonal distances between the viewer and mediated people. Given that humans are familiar with many forms of audiovisual technology, and have no difficulty distinguishing these representations from real life, this response to mediated stimuli may seem surprising. However, if we consider this issue from an evolutionary perspective [Lombard 1995], the human experience with mediated stimuli has been limited, permitting little adaptation to mediated input. According to his argument, this lack of experience has prevented observers from developing coping strategies that would allow them to fully discount mediated stimuli as mere symbols or representations.

In the past decade, digital imaging and display technology have resulted in a dramatic increase in the quality and use of mediated stimuli (particularly images of people). The list of uses for such 3D displays is long and diverse and includes surgery (particularly investigative or exploratory efforts), entertainment (e.g., IMAX 3D film and video games), pilot training (3D flight simulators), and even psychotherapy (e.g., for the treatment of phobias). Not only are digital representations of humans (often referred to as avatars) increasingly life-like, but also the use of stereoscopic displays provides

an additional 3D quality that dramatically improves the participant's sense of immersion<sup>2</sup> [Holbrook 1998] A strong sense of presence is a common goal of stereoscopic display and virtual reality developers [Blade and Padgett 2002]. For instance, a quote from the official IMAX website promoting their 3D film boasts

...projection systems that enable images to leap from the giant flat screen and into the seats.  
(<http://www.imax.com/body.html?p=theatres/imax-3d.html&s=no>) July 14, 2004.

However, as argued by Slater [2002], it is important to recognize that a compelling sense of presence could promote a positive emotional response, a negative emotional response, or no emotional arousal at all (e.g., in intentionally neutral or boring environments). Many producers of virtual environments do not concern themselves with the nature of the participant's response and, instead, focus solely on the realism achieved. There is some evidence that this approach may not be appropriate and that the intended emotional reaction should be considered prior to selection of display media.

Presence in a mediated environment takes on additional dimensions when the environment contains agents simulating humans or avatars representing other human beings. In telecommunications, the term social presence has been used to refer to the ability of a medium to support social interactions between users [Short et al. 1976]. Telephones, videoconferencing, Internet chat rooms, online gaming, etc., all support social presence to some degree. In virtual environments and multiuser online gaming (MMORPG), groups of users exhibit many of the characteristics of social interaction in physically colocated groups, such as collaboration, socially conditioned responses, such as embarrassment, respect for another's avatar, and the development of leadership behavior [Tromp et al. 1998; Slater et al. 2000]. In his ongoing survey of MMORPG users' attitudes toward online gaming, Yee has consistently found that players will form social bonds and react in socially appropriate ways to their mediated counterparts. In fact, according to self-reports, close to two-thirds of players behave the same in these contexts as they do in real interactions; the majority of the remaining one-third report heightened prosocial behavior [Yee 2005].

In shared virtual environments, as in the real world, one can potentially feel simultaneously physically and socially present with others. This experience of being "present with others" or "togetherness" in a virtual environment has been termed copresence, which is facilitated by close interpersonal interactions, such as touch-based interactions between persons [McLaughlin et al. 2003]. The phenomenon of copresence suggests that social phenomenon related to physical interactions or proximity may be important in shared virtual environments and related immersive media [Durlach and Slater 2000].

In a recent set of experiments, Bailenson et al. [2001] found that participants tended to maintain a greater distance from an embodied agent<sup>3</sup> than a similar-sized cylinder as they explored a 3D immersive virtual environment. In their follow-up study, Bailenson et al. [2003] examined other psychological components of this behavior. They included conditions in which the character approached the observer and either stopped at a given distance or passed through the observer. Bailenson et al. [2003] also manipulated the "agency" of the character; the invading character was either controlled by an external human (agent) or by software (avatar). In many respects, the approaching computerized characters resulted in avoidance responses similar to those reported in live situations (although the corresponding live condition was not assessed directly). Further, one interesting departure from the expected pattern of results was reported when the avatar approached and passed through a stationary observer. In this

<sup>2</sup>An immersive environment is the extent to which computer displays are capable of delivering an inclusive, extensive, surrounding, and vivid illusion of reality" [Slater and Wilbur 1997].

<sup>3</sup>Embodied agents are defined by Bailenson et al. [2001] as representations of humans that are controlled by the computer. Avatars, on the other hand, are agents that are under another human's control. This is an important distinction, for in their subsequent study, they find different patterns of avoidance for the two types of stimuli.

case, it appears that observers were made conscious of the virtual nature of the avatar and, instead of stepping out of the way, the subjects simply leaned to the left or right. An important component of the response to avatars and agents in Bailenson et al's [2003] study was the direction of gaze. As found in the human proxemics literature, eye contact with a stranger can provoke strong negative reactions [Argyle and Dean 1965]. The effect of gaze in Bailenson et al's experiment was contingent on the gender of the participant; women exhibited more avoidance in mutual gaze conditions than did men.

In general, the results described above are consistent with the hypothesis that personal space is maintained in virtual environments. However, the observed avoidance of the avatar could also be attributed to the fact that it did not appear lifelike and, in fact, may have been somewhat frightening. It is, therefore, important to bear in mind that although the measured behavioral response (avoidance) is consistent with existing self-report and physiological arousal in the proxemics literature, without a direct comparison this connection must be inferred. In our first experiment, we used 3D images of real people and objects positioned at various distances and asked observers to rate their comfort level. In the second experiment, we directly compared reactions to violations of personal space in comparable live and virtual settings. In this last study, both psychophysical and physiological measures of discomfort were used to assess the impact of the stimuli.

## 2. EXPERIMENT 1

### 2.1 Introduction

Reactions to the proximity of another human being vary directly and reliably with the distance of the intruder [Hall 1963] and whether the intruding stimulus is animate (i.e., human) or inanimate [Barash 1973]. Reported reactions include heightened anxiety, defensive postures, reports of discomfort, and even avoidance behaviors. As noted above, there is some evidence that virtual representations of humans can promote similar avoidance responses [Bailenson et al. 2001, 2003]. In this experiment, we use a self-report technique to assess the level of observer discomfort in response to stereoscopic photographs of animate (humans) and inanimate (objects) stimuli captured at three viewing distances that span the intimate and personal zone as defined by Hall [1963].

### 2.2 Methods

**2.2.1 Subjects.** Participants in experiment 1 ( $n = 22$ ) were volunteers ranging in age from 18 to 25 years. All participants had normal stereopsis as assessed using the RandDot Stereotest and wore their prescribed optical correction. All participants were recruited via Introductory Psychology courses and received partial course credit for their participation.

**2.2.2 Apparatus and Stimuli.** High-resolution stereoscopic images of the eight stimuli were taken using two Olympus Camedia C-2500L digital cameras, fixed at a separation of 6.5 cm. The cameras were calibrated and the images rectified using the Camera Calibration Toolbox for Matlab ([www.vision.caltech.edu/bouguetj/calib.doc/index.html](http://www.vision.caltech.edu/bouguetj/calib.doc/index.html)). The stimuli consisted of equal numbers of animate (people) and inanimate (objects) images, which had roughly the same height as a human head. All eight stimuli were photographed at three distances, 0.5, 1.0, and 2 m (see Figure 1A, B) for a total of 24 test conditions.

Stereoscopic images were presented using an Electrohome Model Marquee-8000 CRT projector and a  $2.35 \times 1.73$  m back-projection screen. All testing was performed in a dimly lit room; illumination and room temperature were held constant to avoid potential confounds [Adams and Zuckerman 1991]. The region of the screen surrounding the test images was filled with a black and white texture that served as a reference plane. The observers were seated in a chair 1 m from the screen with their heads positioned in a chin rest. The subjects wore Stereographics CrystalEyes 3D shutter glasses that switched in synchrony with the projector (at 120 Hz, giving 60 Hz per eye). This allowed presentation of

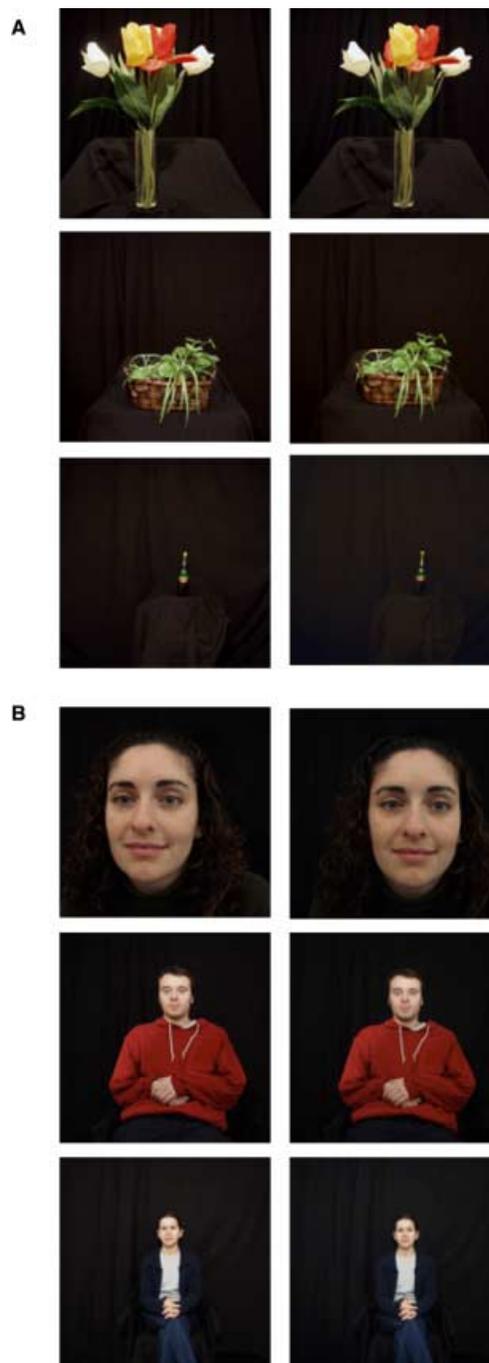


Fig. 1. Shown here are examples of the images of objects (upper set) and people (lower set) used in experiment 1. The images are provided as stereopairs; fusion of the left and right columns by crossing the eyes will produce stereoscopic depth. Within each set, the images were captured at 0.5, 1.0, and 2.0 (rows one through three). Note that the images have been rescaled and the resolution lowered for purposes of reproduction.

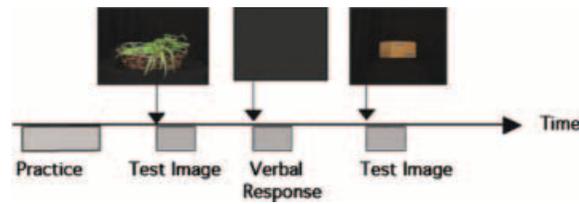


Fig. 2. The sequence of events in experiment 1. Following practice trials, subjects viewed a stereoscopic test image for 5 s. The test image was replaced by a blank screen and subjects were given 6 s to make their rating.

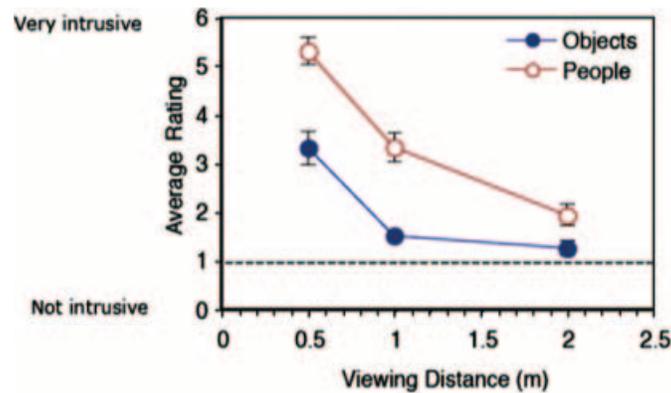


Fig. 3. Comfort ratings obtained in response to 3D images of people (open circles) and objects (closed circles) at each of three viewing distances. Ratings are averaged across 22 subjects and the error bars represent  $\pm 1$  SE of the mean.

the appropriate stereoscopic half-images to each eye separately. A Macintosh G3 computer and MATLAB software were used to present the stimuli and to record the verbal ratings made by the subjects (input by the experimenter).

**2.2.3 Procedure.** As outlined in Figure 2, participants viewed each image for 5 s once (to avoid familiarity effects) in quasirandom order. When the test interval was completed, the image was replaced by a blank screen and participants were asked to rate their level of comfort in response to the stimulus they had just viewed. For this purpose, a Likert scale, which ranged from 1 (comfortable, not intrusive) to 7 (very uncomfortable, very intrusive), was used. Prior to testing, all observers were familiarized with the rating scale and told to rate each test image according to “how comfortable they felt when viewing it” and to consider this with respect to “how intrusive the image was.” Thus, an image that resulted in no sense of intrusion and, therefore, was comfortable to view would be rated 1; a very intrusive image, which caused the observer to feel very uncomfortable, would be rated 7. The scale seemed to be well suited to this task, for none of the observers reported having difficulty applying it.

## 2.3 Results

Figure 3 shows the average rating data for stimuli presented at each of the three distances in Experiment 1, for objects (closed symbols) and people (open symbols).

A repeated-measures ANOVA showed main effects of both viewing distance ( $F(1.1, 23.3) = 132.35$ ,  $p < 0.05$ ) and stimulus type ( $F(1, 21) = 179.40$ ,  $p < 0.05$ ). The interaction between these two variables was also significant ( $F(1.29, 27.21) = 15.96$ ,  $p < 0.05$ ). Note that the assumption of sphericity was violated for the distance and interaction analyses so the Greenhouse–Geisser correction was

applied. From this analysis and Figure 3 it is clear that there is an increase in discomfort as 3D images are moved closer to the observer. Further, the reaction to these images is more intense when the images depict people rather than objects as demonstrated by a significant interaction between distance and object type.

## 2.4 Discussion

The results of experiment 1 provide convincing evidence that negative psychological reactions to invasion of personal space are experienced in response to stereoscopically projected images. Not only does the effect follow the predicted pattern of decay with increasing stimulus distance, but there is substantially higher discomfort reported in response to animate compared with inanimate stimuli. The size of the effects reported here are notable given that the observers were not moved toward the stimuli nor did the stimuli appear to move. Further, all animate stimuli were shown seated, with their gaze averted and maintaining a neutral expression. Given that observers' responses to proximity have been shown to vary with both gaze direction and expression, it is possible that the results of this study may have *underestimated* the negative reaction to invasion of personal space by stereoscopic images.

## 3. EXPERIMENT 2

### 3.1 Introduction

To date two broad classes of experiment have been performed to evaluate the consequences of invasion of personal space. In the social sciences, testing is typically performed with live stimuli (confederates or objects) or with 2D mediated stimuli, such as photographs or film. In the virtual environments literature, experiments have been performed with head-mounted displays and projection systems that have 3D capabilities. While it is possible to make general comparisons, it is not possible to directly compare the results of existing live and virtual experiments. Factors that make such a comparison difficult (if not impossible) include differences in the appearance, gender, and expression of the animate stimuli, as well as large differences in the test setting and participant population. The following study addresses this problem by measuring the degree of discomfort experienced in response to virtual stimuli and the same stimuli presented "live." All variables were carefully controlled to permit direct comparison of the degree of discomfort experienced in the two conditions. Another distinguishing feature of this experiment is that in addition to the Likert rating scale, we included for comparison purposes an objective physiological measure of arousal, i.e., electrodermal activity (EDA). Electrodermal activity results from the dense innervation of sweat glands by afferent neurons from the sympathetic axis of the autonomic nervous system. When an individual reacts to a salient stimulus, stimulation of the sweat glands alters the conductance of a low current applied to the skin. This modulation of conductance can be either sustained or transient in nature and it is the more rapid of the two that is often referred to as galvanic skin response or GSR, and has been widely used in psychological studies (e.g., McBride et al. 1965). Recent fMRI studies have provided support for the use of EDA responses as an index of arousal by finding that EDA is reliably associated with cortical activity and that the locus of activity in the brain is differentiated by the nature of the observer's arousal (for an overview, see Crichley 2002). In this study, we use conventional techniques for assessing transient changes in skin conductance. One important benefit of including this measure, is that it should be unaffected by the demand characteristics of the study (e.g., the desire to perform "well").

### 3.2 Methods

**3.2.1 Subjects.** Participants in experiment 2 ( $n = 16$ ) were volunteers, ranging in age from 20 to 35 years, none of whom participated in experiment 1. Because this experiment required repeat testing,

the participants consisted primarily of graduate and undergraduate students working in neighboring laboratories. All observers had normal stereopsis as assessed using the RandDot Stereotest and wore their prescribed optical correction. All observers were naïve as to the hypothesis being tested, but most had prior experience with psychophysical experiments.

**3.2.2 Apparatus and Stimuli.** The apparatus used to project and view the stereoscopic images in the virtual test conditions was identical to that described in experiment 1. A total of 10 test stimuli were used, again with equal numbers in the animate and inanimate categories. To ensure that the observers' view of the live stimuli was restricted to the specified interval, a mechanical shutter was mounted in front of the chin rest. The computer controlled the position of the shutter via a digital output from the computer. The shutter was used in both the live and virtual test sessions in case it influenced the observers' level of comfort. In the live test conditions, we presented the same set of stimuli used in the virtual sessions at distances of 0.5, 1.0, and 2 m. The textured background used in experiment 1 was not necessary here for the background of the image provided a strong reference frame. Animate stimuli were seated on a stool at the appropriate distance, while inanimate stimuli were mounted on wooden platforms and placed in position at eye level (see Figure 4). During testing, animate stimuli looked at a point 20° to the right of the observer's head and did not smile or speak at any time. The people stimuli also wore the identical clothing and hairstyles on the live test days as they did when their pictures were taken for virtual testing.

During the live test sessions it was necessary to have the individuals serving as stimuli present in the room during testing and ready to take their place as a stimulus when needed. As illustrated schematically in Figure 5, the testing area was surrounded by grey curtains (shown as a doubled line) that separated the observers from the rest of the room. The test stimuli (both people and objects) were positioned to one side of the curtain, as were the two experimenters, and the computer that controlled data acquisition. Thus, during the testing the observer could only see the curtained enclosure and the test stimulus.

Subject's EDA was monitored using a Beckman GSR Type R411 module in constant current mode. The output of the module was connected to the experimental computer via a National Instruments PCI-MIO-16XE-50 data acquisition card sampling at 20 Hz with 16-bit precision. The device was calibrated prior to each session using fixed-impedance calibration points so that voltages on the data acquisition card could be converted to skin conductance values. At the beginning of each experimental session, Ag/AgCl surface electrodes were connected to the medial phalanx of the index and middle finger of the participant's nondominant hand using an isotonic paste.

**3.2.3 Procedure.** Experiment 2 was conducted on two nonconsecutive days. Each day consisted of a live and a virtual test session and, to control for order effects, one-half of the subjects participated in the live condition first, virtual second, and vice versa. On the first day of testing, the equipment and task were explained to each observer at the beginning of the session. All questions regarding the equipment and, in particular, that used to record EDA, were addressed in advance so that the observers were as comfortable as possible. Testing proceeded according to the time-line shown in Figure 6. Following application of the recording electrodes, the interface was given time to stabilize and a baseline EDA reading was taken for 120 s. For each trial, continuous recordings of EDA data began 2 s prior to presentation of the stimulus and ended when the stimulus disappeared.

As in experiment 1, participants viewed each of the live and virtual images once in quasirandom order. To ensure that all subjects did not view the stimuli in the same test order and to keep track of the particular sequence presented to each observer, six random test sequences were generated via computer. One of the experimenters used a printed version to place the stimuli for each subject, while the other experimenter controlled the data input and EDA acquisition. The exposure duration was increased to 12 s to permit adequate EDA sampling in both conditions, and to provide sufficient time

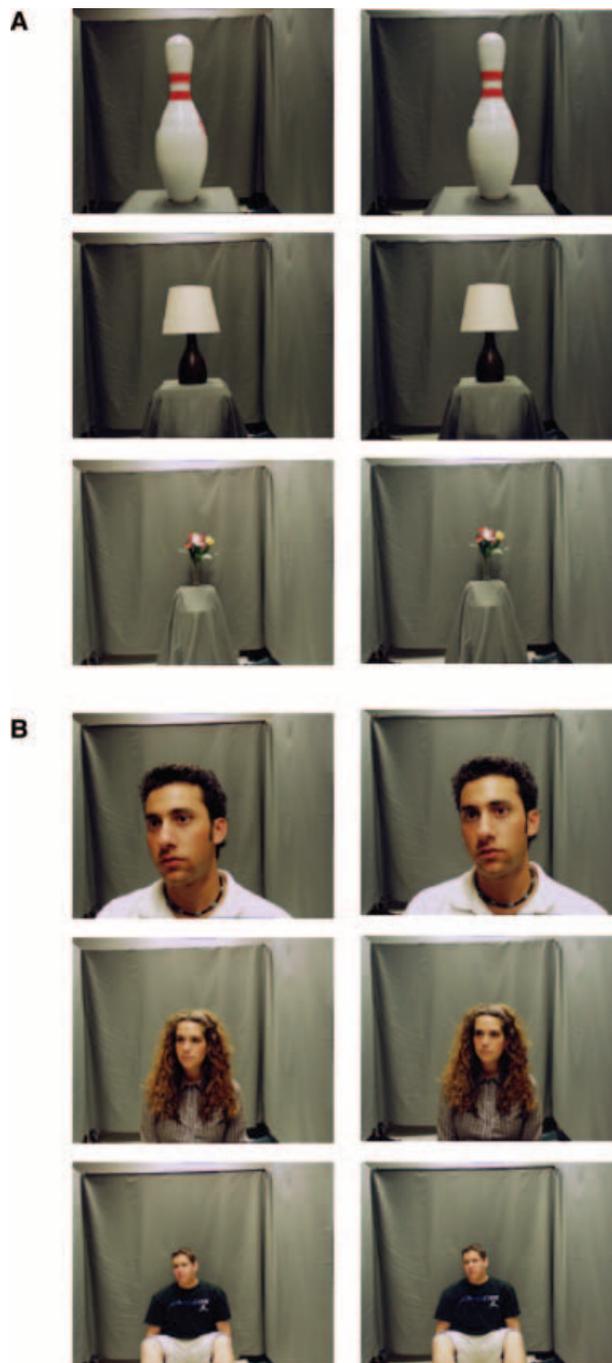


Fig. 4. Shown here are examples of the images of objects (upper set) and people (lower set) used in experiment 2. As in Figure 1, the images are provided as stereopairs, fusion of the left and right columns by crossing the eyes will produce stereoscopic depth. Within each set, the images were captured at 0.5, 1.0, and 2.0 (rows one–three, respectively). Note that the images have been rescaled and the resolution lowered for purposes of reproduction.

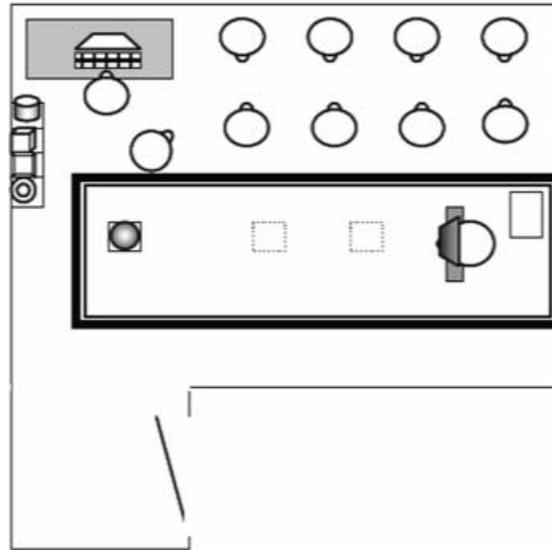


Fig. 5. Shown here is a schematic of the testing area during the live test session of experiment 2. The double-lined rectangle represents the curtained region where the subjects sat and viewed the stimuli through a shutter; they could not see anything outside this enclosure. An object is shown at 2 m; dotted squares show the 0.5- and 1-m locations. Two experimenters were present and are positioned at the computer and at the corner of the test region. The objects used as test stimuli are located along the left wall, mounted on wooden stands, and people used as test stimuli sat along the wall facing one another. The EDA equipment was positioned behind the observer.

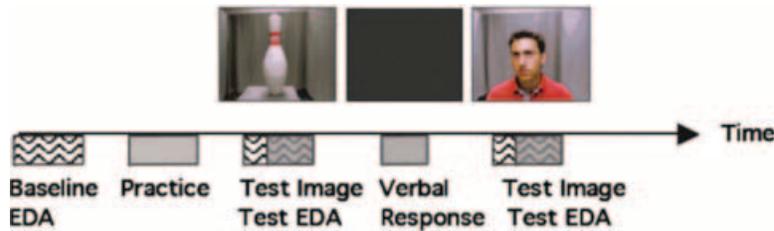


Fig. 6. The sequence of events in experiment 2. The patterned regions indicate EDA recording intervals, which occurred prior to the practice trials (baseline) and then before and during stimulus presentation. Following practice trials, subjects viewed a stereoscopic test image for 12 s. The test image was replaced by a blank screen and subjects were given 12 s to make their rating. During the 12 s intertrial interval, the test object/person was replaced with the next stimulus in the test sequence.

to manually exchange the stimuli in the live test condition. In all conditions, when the test stimulus was removed, participants were asked to rate their comfort level. The Likert scale used in the first experiment was used to assess the participant’s comfort level.

### 3.3 Results

3.3.1 *Rating Data.* Figure 7 depicts rating data from Experiment 2 for the virtual (A) and live (B) test conditions. Animate stimuli are represented by circles and inanimate stimuli by squares.

As in experiment 1, animate stimuli are consistently rated higher (causing more discomfort) than inanimate stimuli and discomfort increases as the stimuli approach the observers. Results of the analysis of variance showed main effects of both viewing distance ( $F(1.4, 21.6) = 41.8, p < 0.01$ , with Greenhouse–Geisser applied), and stimulus type ( $F(1, 15) = 5.99p < 0.05$ ). There was no difference

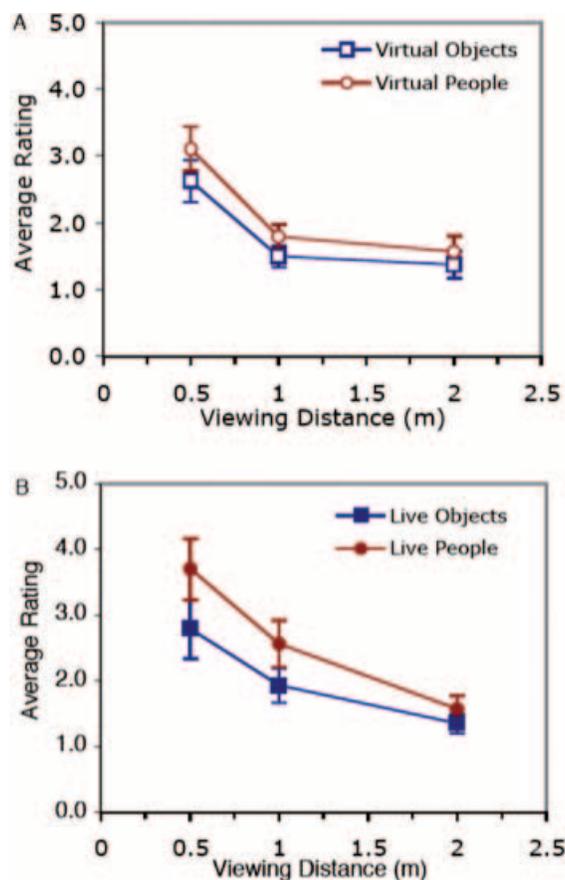


Fig. 7. Average rating data are shown here for objects (squares) and people (circles) in the virtual (A) and live (B) test conditions. Data are averaged across 16 subjects and the error bars represent  $\pm 1$  SE of the mean.

between the ratings made in the live and virtual test conditions ( $F(1, 15) = 2.9, p > 0.1$ ) and none of the remaining interaction terms were significant. We noted that the effects of proximity and stimulus type were not as large here as in experiment 1. Closer evaluation of these data revealed six subjects whose pattern of responses was inconsistent with that reported in experiment 1; that is, they did not show the classic proximity effect in the live test condition. That is, these subjects did not report any increased discomfort as a function of the nearness of animate objects. Given that these observers did not react negatively under the most provocative “live” exposure conditions, it would be unreasonable to expect them to do so in response to 3D photographs. In other words, since the observers did not exhibit the phenomenon of interest, we can not expect that the (nonexistent) reaction could be modulated by experimental manipulation. Indeed, the data from the remaining ten observers looks much more similar to the pattern of results shown in experiment 1, an observation confirmed by analysis of variance (Figure 8).

In addition to the main effects of proximity and stimulus type, which were also present in the analysis of the full data set, there was a tendency for higher ratings in the live conditions ( $F(1, 57.8) = 6.74, p < 0.05$ ). Furthermore, there was a significant stimulus by distance interaction ( $F(1.2, 10.8) = 15.8, p < 0.05$ ) that was not present in the original analysis. This interaction was investigated further using a post-hoc simple effects analysis. At the nearest distance, animate stimuli (whether live or virtual)

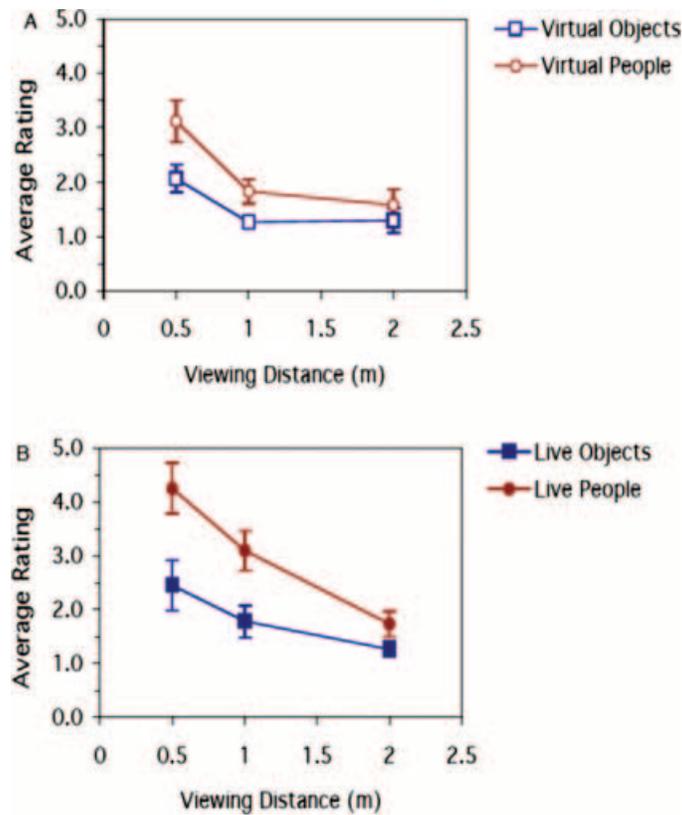


Fig. 8. Average rating data from subjects who exhibited the proximity effect under live test conditions are shown here for objects (squares) and people (circles) in the virtual (A) and live (B) test conditions. Data are averaged across 10 subjects, and the error bars represent  $\pm$  one standard error of the mean.

generated significantly higher discomfort ratings than inanimate objects ( $F(1, 10) = 6.324, p < 0.05$ ). In addition, live or virtual animate objects at the closest distance produced significantly more discomfort compared to animate objects at the farthest distance ( $F(1, 10) = 11.081, p < 0.01$ ) and to live or virtual inanimate objects both at the intermediate ( $F(1, 10) = 12.937, p < 0.01$ ) and at the farthest distance ( $F(1, 10) = 16.487, p < 0.01$ ). It is interesting to note that no significant differences were found between subject discomfort levels across the various presentation distances for live or virtual inanimate objects. Thus, this interaction is as a result of the tendency for ratings of animate stimuli to change (decrease) more as a function of viewing distance than did the ratings of inanimate stimuli. As noted below, removal of these subjects did not change the pattern of the EDA data.

**3.3.2 EDA Results.** EDA was quantified as the difference between the skin conductance prior to stimulus presentation and the peak reading on each trial. Recall that increased conductance is associated with higher physiological arousal [Critchley 2002]. Figure 9 shows the average reading for each image class at each distance for live (A) and virtual (B) conditions.

Because of technical difficulties with the recording apparatus, EDA data from four of the subjects were not included ( $n = 12$ ). Analysis of variance (using the Greenhouse–Geisser correction) of the EDA results revealed a significant interaction between the type of stimulus and viewing distance

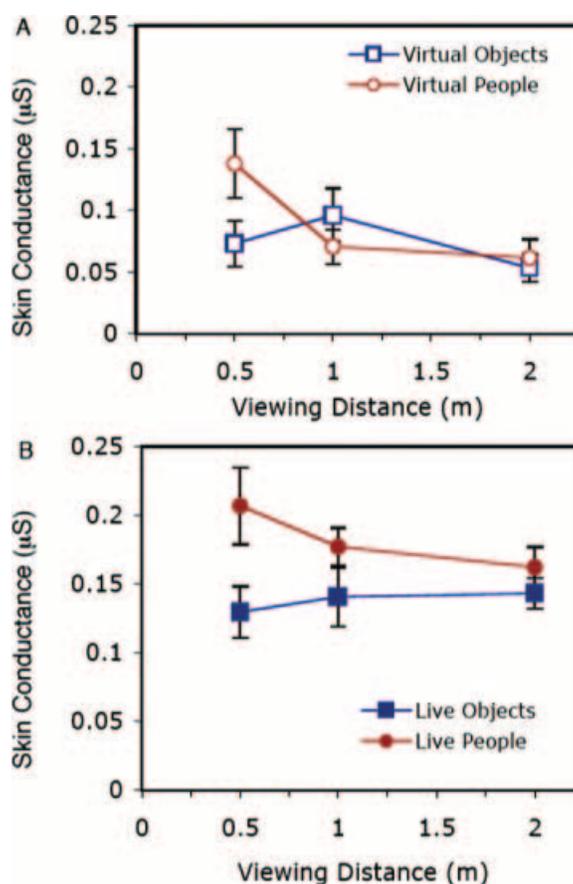


Fig. 9. A, B. Average EDA data are shown here for objects (squares) and people (circles) in the virtual (A) and live (B) test conditions. Data are averaged across 12 subjects and the error bars represent  $\pm 1$  SE of the mean.

( $F(1.53, 16.9) = 4.1, p < 0.05$ ). Post hoc simple effects analysis of this interaction confirmed that animate stimuli (whether live or virtual) generated significantly higher EDA responses than inanimate objects at the nearest distance ( $F(1, 16) = 6.456, p < 0.05$ ). In addition, live or virtual animate objects at the closest distance produced significantly more discomfort compared to animate objects at the farthest distance ( $F(1, 16) = 5.120, p < 0.05$ ), and to inanimate objects both at the intermediate ( $F(1, 16) = 5.192, p < 0.05$ ) and at the farthest distance ( $F(1, 16) = 5.215, p < 0.05$ ). There were no significant differences in the level of the subject's EDA response across the various presentation distances for inanimate objects. Thus, this interaction reflects the fact that skin conductance remained unchanged as a function of distance when objects were viewed, but increased when images of people were seen at 0.5 m. The identical pattern of results was obtained when those who did not experience the proximity effect in the live test conditions were omitted ( $n = 9$ ).

#### 4. DISCUSSION

The results of experiment 2 are consistent with those of experiment 1 and support the occurrence of a virtual counterpart of the social phenomenon of invasion of personal space. The response to invasion of one's personal space is not restricted to reported comfort levels, but are also evident in *objective* correlates

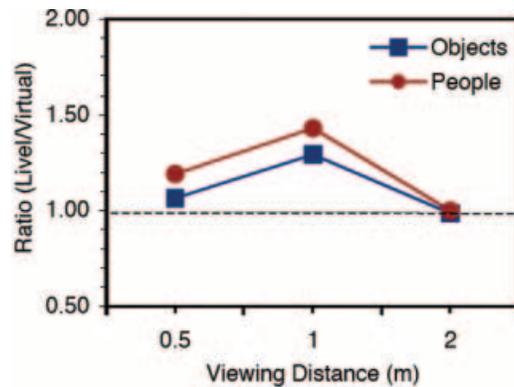


Fig. 10. The results of experiment 2 are depicted here as ratios (live/virtual). Animate and inanimate stimuli are shown as circles and squares, respectively. The dotted line indicates a ratio of one, that is, where ratings were equivalent.

of arousal via changes in skin conductance. One of the goals of experiment 2 was to permit a direct comparison of subject's reaction to live and virtual stimuli at different viewing distances. To this end, we calculated the ratio of ratings in the live and virtual test conditions for objects and people (see Figure 10).

The data depicted in Figure 10 show that at 0.5 and 2.0 m, ratings for virtual and live stimuli are very similar. However, at 1 m, the ratios are greater than one indicating that at this distance the ratings are slightly higher in live test conditions. This pattern may be related to the elimination of cue conflict at 1 m in the stereoscopic display. Recall that the stereoscopic images were taken at three viewing distances, however, the observers were always seated 1 m from the display. Therefore, in the 1 m condition, there was less conflict between vergence and accommodation. This proposal is supported by the fact that the pattern (across distance) is the same regardless of the type of stimulus (animate versus inanimate). However, the presence of cue conflict cannot account for the effect of proximity shown in experiments 1 and 2 for there is greater conflict at the proximity of 2 m, but comfort ratings are significantly lower in this condition compared to 0.5 m. Further, if cue conflict were the only factor in reported discomfort then we would expect to, but do not, see similar ratings in response to objects and people.

## 5. GENERAL DISCUSSION

We have shown that perceived intrusion into one's personal distance zone [Hall 1963] by stereoscopically projected stimuli can cause significant increases in viewer discomfort. As predicted, this proximity effect is greater for images of people than for images of objects, and decreases at viewing distances greater than 0.5 m. Experiment 2 demonstrated that the response to invasion of virtual personal space shows the same trend as the response to the same stimuli in a live setting. Further, physiological measures of arousal are consistent with the observers' ratings at 0.5 m.

It is evident that the difference in ratings between objects and people was greater in experiment 1 than in experiment 2. We believe that this is because of differences in the pool of observers used. That is, naïve students were recruited for experiment 1, most of whom had never been in an experimental setting before. Because subjects were required to participate in two sessions, we recruited subjects from neighboring vision laboratories for experiment 2. The latter group had no specific information regarding the experimental hypothesis, but most had previous experience with psychophysical experiments. As a result they were generally more comfortable and tended to make lower ratings. This difference is also a likely explanation for the fact that a number of subjects in experiment 2 failed to exhibit the classic proximity effect under live test conditions.

Our EDA results echo those of McBride et al. [1965]. Note that in their study, McBride et al. used live test stimuli and varied the viewing distance from 0.3 to 2.7 m, whereas we used live and virtual stimuli, and evaluated a smaller range of distances (0.5–2.0 m). They report that their strongest effects occurred at the shortest viewing distance and that at the longest distance the responses were significantly lowered. We have confirmed this overall pattern for animate stimuli presented live, using a stereoscopic projection system. Further, our comparison of the responses to animate and inanimate stimuli confirms that this physiological response is not simply because of the testing environment or stereoscopic display.

## 5.1 Virtual Proxemics

The experiments reported here are generally congruent with the results of Bailenson et al. [2001, 2003]. Recall that in their experiments Bailenson and colleagues reported that subjects tended to avoid representations of humans in immersive environments. That is, subjects kept a greater distance between themselves and an embodied agent than they did between themselves and a virtual barrel. Further, they showed avoidance behavior when the agent moved toward them, invading their personal space. To compare the two sets of experiments, it is necessary to assume that their avoidance response reflects a certain degree of discomfort. Both of these measures (avoidance and self-ratings) have been used in existing proxemics literature and the two tend to be complimentary. This is true of our studies, although there are a number of other differences between the experiments that are of interest.

For instance, our stimuli were images of real people, projected onto a screen that remained stationary throughout the study. A number of different images were also used, so the observers would not become familiar with the stimulus. In comparison, Bailenson et al. [2001, 2003] used computer-generated representations of humans that were of limited fidelity, so that the stimuli could be rendered in real time. It is well established that humans are extremely sensitive to distortion of facial features [Diamond and Carey 1986; Yin 1969] and it is possible that the avoidance of the agent was influenced by its disconcerting appearance. As discussed below, comparison of the observers' response to a live version of the stimuli would have provided a useful basis for evaluating the effect of the appearance of Bailenson et al.'s [2001, 2003] stimuli.

The experiments of Bailenson and colleagues are notable for their use of an immersive environment. It is likely that their subjects had a much stronger sense of presence in their experiments than in our virtual conditions and, as such, their results are indicative of how we react to representations of humans in such situations. Our observers were not in an immersive environment, however, it is important to note that even so, there was a significant degree of discomfort that varied with the apparent proximity of the stimuli (and the class of stimulus). Thus, taken together, the results of our experiments and those of Bailenson et al. [2001, 2003] highlight the point that humans are extremely sensitive to the apparent proximity of mediated representations of humans. In addition to keeping their distance from an embodied agent, observers experience emotional arousal (discomfort) as reflected in self-rating and increased skin conductance in response to more life-like, but stationary, 3D images.

**5.1.1 Implications.** As mentioned in the introduction to this paper, there is a large and expanding number of applications for stereoscopic displays and immersive environments. One application that is particularly relevant to our work is the use of immersive environments to treat individuals suffering from phobias. In such therapy programs, the patient can be exposed to virtual versions of terrifying stimuli or places in a controlled, and safe manner. It stands to reason that these techniques rely heavily on the patient's belief that the cause of their distress is physically present in the room. In a set of experiments that are germane to the results presented here, Pertaub et al. [2002] have assessed the impact of a virtual audience on people with public speaking phobias; they manipulated the type of audience reaction and the presentation media used. They found that a neutral or positive response

from the audience did not affect the participants' level of anxiety in response to a 5-min presentation, but the presence of a negative audience had a strong effect causing increased anxiety in all participants. Importantly, this increase in anxiety was higher when participants viewed the audience in a 3D virtual environment than when audience was presented on a 2D computer monitor. Pertraub et al. [2002] used a number of psychological scales to evaluate their observers' responses to their test conditions. Their data also show that observers' social/psychological responses to mediated 3D stimuli are governed by the same factors that influence real-world interactions. This occurs in spite of obvious indications that the mediated stimuli are not physically present but are, for example, projected on to a screen or are imperfect renderings of humans.

Lombard [1995] has proposed an evolutionary explanation for "parasocial" relationships, which involve humans interacting with audiovisual media. He argues that in evolutionary terms humans have not had sufficient exposure to virtual environments to allow them to adapt their social responses. Therefore, stimuli presented in immersive environments are not correctly processed as symbols and so elicit the same responses as in live interactions. The use of stereoscopic displays is an important component of this response, for 2D images of people do not elicit avoidance behavior [Argyle and Dean 1965] or social anxiety [Pertraub et al. 2002].

Reeves and Nass [2000] have studied human-computer interactions extensively using social psychology as a framework. They have reported many instances of reactions to mediated stimuli that mimic what would be expected in human interactions (e.g., gender stereotypes). They take the position that to humans, mediated stimuli are as real as the original stimuli, in terms of their unconscious responses to them. They also argue convincingly that this response is not the same as anthropomorphizing, but is an example of reflexively relying on existing social scripts or rules that guide social behavior toward the mediated stimulus that have evolved with our species. If true, one could argue that demonstrating reactions to invasion of personal space by mediated stimuli (of any type) are not surprising. However, at least two important issues are raised by results like ours. First, if Lombard [1995] is correct, then extended exposure to mediated stimuli might (over generations) alter the human response and such change must be documented to be fully understood. More importantly, we would argue that 3D display technology and immersive environments have or will have the capacity to create stimuli that are more disturbing than conventional social interactions. How will/do observers react in cases where social norms are violated in (potentially extreme) ways that cannot be achieved in the natural environment?

Thus, a critical aspect of this work is that while an improved sense of presence may often be a desirable result of the use of 3D display technology, this presence elicits both positive and negative aspects of interactions in the real world. In this, we echo the point made by Reeves and Nass [2000] that increased perceptual response to mediated stimuli is not always desirable or necessary. Therefore, the content and the intended audience impact should be jointly considered when choosing display media. For instance, if the goal is a positive, relaxed reaction to animate stimuli, then 3D displays should be used with a moderate range of depth values, respecting the viewer's personal space. However, this phenomenon can also be exploited to, say, evoke real audience discomfort when faced with a virtual "close talker."

#### ACKNOWLEDGMENTS

Many thanks to L. Harris, J. Kaiserman, J. Laurence, and J. Zacher for their valuable contributions to this project.

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Received January 2006; accepted February 2006