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Using Behavioral Realism to Estimate Presence:

A Study of the Utility of Postural Responses to Motion Stimuli

Abstract

We recently reported that direct subjective ratings of the sense of presence are potentially unstable and can be biased by previous judgments of the same stimuli (Freeman et al., 1999). Objective measures of the behavioral realism elicited by a display offer an alternative to subjective ratings. Behavioral measures and presence are linked by the premise that, when observers experience a mediated environment (VE or broadcast) that makes them feel present, they will respond to stimuli within the environment as they would to stimuli in the real world. The experiment presented here measured postural responses to a video sequence filmed from the hood of a car traversing a rally track, using stereoscopic and monoscopic presentation. Results demonstrated a positive effect of stereoscopic presentation on the magnitude of postural responses elicited. Posttest subjective ratings of presence, vection, and involvement were also higher for stereoscopically presented stimuli. The postural and subjective measures were not significantly correlated, indicating that nonproprioceptive postural responses are unlikely to provide accurate estimates of presence. Such postural responses may prove useful for the evaluation of displays for specific applications and in the corroboration of group subjective ratings of presence, but cannot be taken in place of subjective ratings.

1 Introduction

Recent technological advances have enabled the development of new displays and communication devices with increased bandwidth (Slamin, 1998), and these devices have the potential to reproduce (or simulate, in the case of virtual reality) environments with greater fidelity than was previously possible. Specifically, by using enhanced resolution and digital transmission, new broadcast media can provide information through additional sensory channels (such as by displaying stereoscopic pictures), and an increased proportion of the sensory field can be stimulated through increased display sizes and new formats (such as HMDs). Similar developments have also occurred in sound transmission, and future developments may see these advances incorporated into interactive broadcast systems in which the display will adapt to changes in the position of the observer.

One outcome of these developments has been to increase the extent to which the observer feels part of the displayed environment. While assessments

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of televisual displays could previously be obtained using simple measures (such as picture quality), the development of these new devices has created a need for a global measure of the experience that assesses the overall impact of the display system on the observer. One commonly used construct is that of presence, a participant's ''sense of being there in a remote environment'' (Slater, Usoh, & Steed, 1994). Lombard and Ditton (1997) elegantly defined presence as the ''perceptual illusion of non-mediation,'' a definition that is consistent with that of Slater et al. By either definition, presence can be viewed as the extent to which an observer feels that he or she is witnessing, or experiencing, displayed events directly (as part of his / her environment), rather than observing the depiction of the events remotely through a display medium.

Methods of measuring presence thus far reported in the literature have primarily been subjective, relying on post-test ratings (such as Hendrix & Barfield, 1996; Slater & Usoh, 1994; Slater, Usoh, & Steed, 1994; Welch, et al., 1996; Kim & Biocca, 1997) or continuous assessment (such as Freeman et al., 1999; IJsselsteijn et al., 1998). Both posttest and continuous subjective assessments of presence require non-expert participants to rate the strength of their subjective sensation of presence for a given stimulus. An important distinction is that post-test measures can estimate presence from a number of scale ratings or a questionnaire, whereas continuous assessment must involve direct ratings of presence which must be periodically updated. To accomplish this reliably, participants need to understand the concept that they are rating.

However, in a recent series of studies, Freeman et al. (1999) reported that direct, on-line presence ratings can be biased by prior experience. Native participants rated a three-minute video sequence for one of three qualities: presence, interest, or ''3D-ness'' using continuous assessment. The sequence contained monoscopic and stereoscopic segments. Participants in all three groups were then required to provide continuous ratings of presence for a second test sequence. The mean ratings provided by the groups that were trained at rating 3D-ness were more sensitive to viewing condition (monoscopic versus stereoscopic) than were the other two groups. We concluded that dimensions such as interest and 3D-ness contributed to presence, and that their weightings could be influenced by prior experience.

By its nature, presence appears to be difficult to assess by subjective ratings. The problems result from the unusual nature of presence, which differs from commonly experienced sensations such as perceived temperature. First, in the normal waking state, we are continually aware of our place in the surrounding environment. Direct sensory information confirming our location is always available and is continually updated. Thus, under normal circumstances, one's current location is a universal feature of awareness, rather than a quality that varies continuously over time. The subjective evaluation of presence requires graded ratings of a sensation that is typically invariant, and observers' lack of experience of rating presence is one possible explanation of the difficulty in providing stable ratings (Freeman et al., 1999). Relatedly, non-expert participants are currently unlikely to be familiar with the sensation of presence in mediated environments. For comparison, consider perceived temperature. In everyday life, one experiences a range of temperatures, and evaluating one's current temperature can be viewed as comparing one's current state with memories of previous states. A second, related issue is that there are no verbal descriptors of degrees of presence, because to date there has been no need to communicate such feelings.

A third concern is that asking subjects to rate presence involves a conflict between sensation and knowledge. Observers know that they are currently in the test situation, and can remember how they got there. Yet the investigator asks them to what extent they feel that they are situated elsewhere. While this problem may be ameliorated by good questionnaire design, this conflict between sensation and knowledge is inherent in the measurement of presence.

A final issue with the assessment of presence, of relevance to all methodologies, is that the notion of presence is inextricably bound up with attentional factors (Barfield & Weghorst, 1993; Witmer & Singer, 1998). The extent to which an observer feels part of an environment may depend not only on the quality and extent of sensory information, but on the interest evoked by the displayed scene. This poses a challenge to the problem of evaluating displays, in which the researcher wishes to address the effect of display parameters in a content-free manner.

1.1 Behavioral Realism

None of these considerations provide reason for discarding subjective measurements of presence; rather, they suggest that such measures be treated with caution, and that other approaches should be investigated as adjuncts to subjective measures. We advocate an alternative approach that can be used to assess the impact of displays: *behavioral realism*. Variants of the idea have been proposed several times in the literature (for example, Sheridan, 1992; Held & Durlach, 1992; Slater & Usoh, 1994; Slater, Usoh, & Stead, 1994; Slater & Wilbur, 1997; Prothero, 1998; Hendrix & Barfield, 1996; Ohmi, 1998). The basic principle is that the more similar a display becomes to the environment it mimics, the more the observer will respond to the display in the same way that he / she would respond to the environment itself. In the extreme case, if the display is fully immersive and faithfully reproduces the sensory input on all channels, then it will be perceptually indistinguishable from the real environment, and responses to the display should therefore be equivalent to those to the environment itself.

A number of studies have reported objective performance measures as metrics of *behavioral presence* (Slater & Wilbur, 1997) or suggested using task-performance measures as measures of presence (e.g., Schloerb, 1995; Ellis, 1996; Kalawsky, Bee, & Nee, 1998; Slater, Usoh, & Chrysanthou, 1995). Although measures based on task performance may be useful for the assessment of training in simulated environments, they are not necessarily related to presence. For example, Ellis (1996) reported that removing redundant information from air traffic control displays elevated performance, whereas this manipulation would also tend to decrease presence. In evaluating Ellis' argument, however, it is important to note that while realism is likely to be a component of presence, the two are not equivalent. Consistent with Ellis' example, reducing realism can improve performance. It does not, however, follow that this reduction in realism reduces presence. While reducing realism would tend to decrease presence, other proposed determinants of presence might be enhanced. For example, the removal of excess, redundant information might reduce realism, but also enable participants to better select a useful viewpoint (Sheridan's (1992) ''ability to control sensors'') or to more easily manipulate an environment (Sheridan's (1992) ''ability to modify an environment.'') Using Ellis' idea of iso-presence equivalence classes, while reducing realism would generally tend to reduce presence, there are some contexts in which this would not be the case.

1.2 Postural Responses

One promising measure for the assessment of behavioral realism consists of postural responses to displayed stimuli. Such measures are potentially useful for two reasons. First, observers are not normally aware of their postural responses. Therefore, the responses will not be mediated by high-level cognitive processing and, by a related argument, they are unlikely to affect concurrent subjective evaluations (Heeter, 1992). Second, postural measures have the capacity to produce differential levels of response. As postural measures do not generate simply binary results (for example, an observer either responding or not), it is likely to be easier to relate them to graded subjective presence ratings.

1.3 Visual Proprioception

Evidence of the importance of visual information for the control of stance has long been available. Observers exhibit more postural sway in the dark, or when blindfolded, than in the light, or when they have visual field impoverishment (van Asten, Gielen, & Denier van der Gon, 1988a, 1998b; Paulus et al., 1989; Edwards, 1946; Witkin and Wapner, 1950). More conclusive evidence in support of visual proprioception was provided by Lee and Lishman (1975) using a swinging room. Observers were placed 0.3 m from, and facing, a textured cylinder attached to the end wall of the swinging room. The room was then moved sinusoidally through a distance of 6 mm (peak to peak), with a period of 4 sec. Lee and Lishman showed that that the swinging room generated a significant amount of in-phase anteroposterior postural sway, and they concluded that the optic flow field produced by the oscillating surface controlled the stance of the observers. The observers themselves were unaware of either the room movement or their own movement.

Since the publication of Lee and Lishman's work, a substantial body of research has accumulated concerning visual proprioception. Parameters that have been studied include the field of view (FOV) presented to observers and stereoscopic depth cues. Increasing the FOV to which a moving stimulus is presented increases the proprioceptive response it generates (Stoffregen, 1985, 1986). The contribution of stereopsis to visual proprioception is less clear, but to date it has not been ruled out (Lee & Lishman, 1975; Paulus et al., 1989; Ojima & Yano, 1997; Uwa, Kaneko, & Kanatsugu, 1997). Both increasing FOV and the use of stereoscopic presentation enhance presence ratings (Hendrix & Barfield, 1996; Freeman et al., 1999). Thus, visual proprioception might be a suitable reflexive behavior to use in the evaluation of displays using the behavioral-realism approach. Our investigations of this issue will be reported elsewhere.

1.4 Postural Responses to Apparent Observer Motion

Postural responses also occur in response to observer motion through an environment. Importantly, these responses also occur under the illusion of observer motion. The illusion that the observer is moving when presented with a moving display is known as *vection*. This illusion also commonly occurs in the real world, for example, when, from a stationary train, we watch an adjacent train pulling out of a station and feel as though our train is moving. Prothero (1998) and Ohmi (1998) both propose that measures of vection and presence should be related, basing their arguments on the premise that it is likely that an observer will feel present in an environment that causes him / her to experience vection. Behaviors associated with movements through real environments may therefore be elicited by the illusion of motion. This provides another framework for evaluating displays through the behavioral-realism approach.

The enhancement of presence observed with stereoscopic stimuli may be related to increases in vection that have been reported with stereoscopic stimuli. Palmisano (1996) reported that stereoscopic presentation of moving-dot stimuli reduces the latency of vection onset and also increases the percentage of time for which observers report the sensation, relative to monoscopic presentation of the same stimuli. Palmisano's stimuli consisted of fields of randomly positioned dots which expanded outwards, simulating movement at a constant rate towards the observer, while the viewing position and projection plane remained fixed. Stereoscopic presentation enhanced vection relative to monoscopic presentation (both in terms of reducing latency of onset and increasing the duration of the sensation). This finding was robust as FOV and the density of the display were varied.

Previc and Mullen (1991) studied the relationship between vection and postural adjustments, using roll-vection stimuli. They found that vection latencies were much greater than the latencies for postural adjustments but that the two measures were highly correlated. Previc and Mullen concluded that the postural responses were not caused by vection, although the high correlation between the measures suggested that they were controlled by the same visual parameters. The relation between vection and postural adjustments for other types of motion remains an empirical question.

A number of recent studies have measured postural responses to real-world video stimuli with the goal of evaluating the presence elicited by various displays. Hoshino et al., (1997) measured postural responses elicited by realistic video sequences of a rolling boat. They reported larger postural responses with increased FOV and with stereoscopic presentation. On the basis of this and other studies, Ohmi (1998) proposed that postural responses to moving video might provide a useful means of assessing presence. Ohmi reported that stereoscopic presentation of a video stimulus—taken from a car driving at speed on a curving mountain road—enhanced presence relative to monoscopic presentation, but did not enhance vection, in contrast to Palmisano's (1996) results. Using a different stimulus, Ohmi reported that postural responses were related to centrifugal acceleration in the display, but did not report the relation of either variable to presence measures. In order to establish whether postural responses are a useful means of assessing presence, it is necessary to study the relation between them directly. In this paper, we report an experiment comparing the effects of monoscopic and stereoscopic video presentation on participants' postural responses and subjective ratings to moving and still video sequences.

Our work differs from that of Hoshino et al. (1997) in that they investigated roll vection, whereas our stimuli displayed left and right turns in rapid forward motion. Our moving stimulus consisted of continuous video shot from the hood of a rally car traversing a bending track at speed. The postural responses measured were lateral movements that Ohmi (1998) reported were related to the centrifugal acceleration. Post-test subjective ratings of presence, involvement, sensation of self-motion, and sickness[1] were also taken, to examine their relationship with postural responses.

Three questions were addressed by the experiment reported here:

(1) Does presentation of monoscopic video of a real-world scene containing both forward and lateral motion generate a lateral-postural response from observers?
(2) Does stereoscopic presentation of the moving video result in more-pronounced lateral-postural responses from observers than monoscopic presentation of the same stimulus?
(3) Is the lateral-postural response reliably related to subjective ratings of presence, involvement or vection?

1. In piloting this experiment, a number of participants reported experiencing motion sickness when they were exposed to the moving stimulus for several minutes. We took care in the experiment to minimize the likelihood of participants experiencing motion sickness by presenting the stimuli for only relatively short durations. The sickness measure was included in the rating scales to check that this precaution had its desired effect, not to investigate the relationship between ratings of sickness and presence.

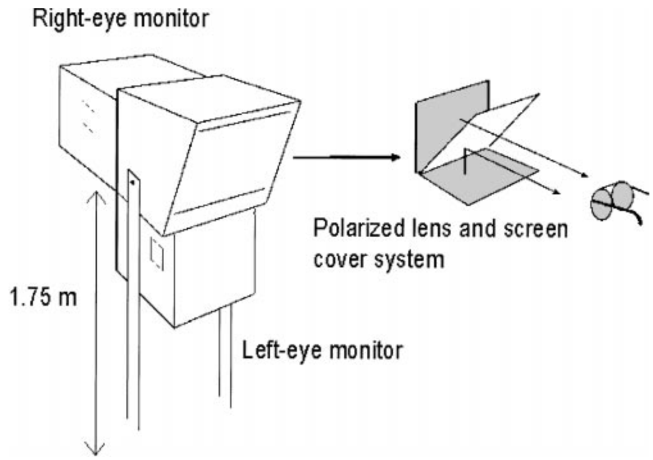


Figure 1. *Schematic diagram of the AEA Technology 20 in. stereoscopic display. Right- and left-eye views are presented at the same time (that is, time parallel) and polarization is used to separate the views.*

2 Method

2.1 Observers

Twenty-four students of the University of Essex (12 men, 12 women, average age 25 years, average height 1.75 m) volunteered to participate in the experiment for which they were paid £2. All had normal or corrected-to-normal vision and a stereoacuity of 30 sec-arc or better (as tested on the RANDOT random-dot stereotest).

2.2 Apparatus

Observers viewed the stimulus films on an AEA Technology 20 in. stereoscopic display consisting of two BARCO CPM 2053 color monitors (50 Hz PAL) with polarized filters in front of each. (See Figure 1). Observers viewed the display wearing polarized spectacles. Two synchronized Panasonic M2 (A750-B) video players provided the video input for the display.

A Flock of Birds magnetic position tracker was used to collect observers' *x*, *y*, and *z* positions for each measured period. A small receiver was attached to a 1 m circular length of cord that was placed around the observers' necks. The receiver was positioned firmly below the observers' collar line at the base of the neck. Several small metallic disks were placed at the front of the cord as a counterweight to keep the receiver firmly in position for the duration of each stimulus presentation. The tracker was connected to a standard PC running custom software that controlled both the video players and sampled x, y, z position data from the tracker at a frequency of 12.5 Hz.

2.3 Materials

2.3.1 Moving Video Stimulus. The moving video sequence was a 100 sec. excerpt from rushes taken from the filming of a rally car sequence used in the ACTS MIRAGE stereoscopic documentary film *Eye to Eye* (1997). The stimulus was a continuous piece of footage shot by cameras positioned on the hood of a rally car traveling at speed around an offroad rally track. The video was selected because it contained large amounts of motion parallax from the speed the car was travelling. It is important to note that there were no edits at all in the stimulus in order to avoid discontinuities in the stimulus and any resultant discontinuities in observers' postural responses while viewing. The predominant movement in the sequence was of the car rushing forward along the track, but within the stimulus were a number of sharp turns that caused the car to skid and / or change direction rapidly. To give the reader an idea of the magnitude of motion present in the sequence, a passenger present in the car at the time of filming would have experienced strong centrifugal forces as the car traveled around the corners and bends in the track. A frame from the moving video stimulus is shown in Figure 2(a).

Figure 2a. *Sample frame from the moving-video stimulus.*

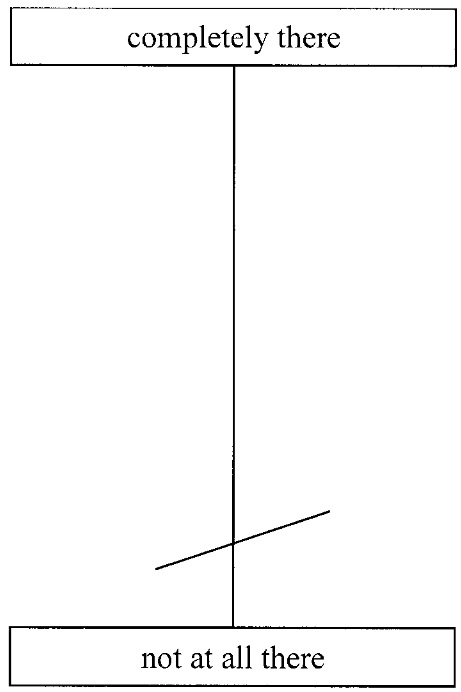
Figure 2b. *Sample frame from the still-video stimulus.*

2.3.2 Still-Video Stimulus. The still-video sequence was a still frame from the ACTS MIRAGE stereoscopic documentary *Eye to Eye* (1997), where a camera is situated by the side of the rally track awaiting a drive-by of the rally car. There was no motion or action for the duration of the stimulus presentation. Although the image was different to that of the moving stimulus at all times, objects were positioned at similar distances from the cameras in both stimuli. No observers reported being aware that one frame was repeated for 100 sec. or that it appeared unnatural in any way. A frame similar to that used for the still stimulus is shown in Figure 2(b).

2.3.3 Audio Stimuli. A mono, therefore nondirectional, synchronized soundtrack was presented with the moving video stimulus. The soundtrack consisted of the car's engine, gear changes, and clattering, as stones from the track hit the underside of the car. The audio track was identical for both monoscopic and stereoscopic presentations of the stimulus. The same audio track as used for the moving stimulus was overlaid on the still stimulus at a lower volume. The effect generated by the combination of the still video and the lower-volume au-

Presence Rating Scale

To what extent did you feel present in the displayed sequence - as though you were "really there"?



After viewing each stimulus, observers were required to complete a short series of rating scales. Each scale was presented on its own page in a pre-prepared booklet. Each scale was presented in the form shown on the left. For brevity, only the presence scale is shown here as it was presented. Questions and rating scale end-points for the Involvement, Self-Motion and Sickness scales are shown in the table below. Observers were required to mark a line across the scale to indicate their rating. The example shown on the left demonstrates a fairly "low" presence rating.

Scoring:	**0**	**100**
Involvement	How involved were you in the displayed sequence? *(not at all involved)*	*(completely involved)*
Self Motion	To what extent did you feel that you were moving along the track, as though you were travelling with the car? *(no sense of motion)*	*(strong sense of motion)*
Sickness	To what extent did watching the sequence make you feel sick? *(not at all sick)*	*(very sick)*

Figure 3. *Subjective ratings: Questions and scales.*

dio track was one of waiting by the side of a rally track with a rally car driving somewhere in the distance. The audio track was played at a lower volume with the still stimulus because playing it at the same volume for the still as for the moving-video stimulus resulted in a very unnatural perception, with no clear link between the audio and video stimuli. Furthermore, the main question of interest in the experiment was whether stereoscopic presentation enhanced the postural response generated by the moving-video stimulus, and this was not confounded by the different audio levels accompanying the moving and still stimuli.

2.4 Rating Scales

After each stimulus was shown to observers, they were requested to fill in a short series of visual analogue rating scales. The rating scales were arranged in a booklet and were in the same order for each stimulus and observer. The booklet contained four visual analogue scales, each 10 cm long and presented vertically. (An example of the rating scales used is shown in Figure 3, along with the four questions asked and the scale endpoints.) Ratings were scored by measuring the distance in millimeters from the bottom end of scales to the point at which the observers' rating line crossed the scale (for example, a line at the bottom end of the presence scale, ''not at all there,'' resulted in a presence score of 0) and each therefore had a minimum possible score of 0 and a maximum of 100.[2]

3 Procedure

On arrival at the laboratory, observers were informed that in the experiment they would be required to watch a series of short videos and that their responses would be monitored. Observers were run singly. They were first dark-adapted by sitting in a darkened area of the laboratory where the display was located. They were then asked to stand upright in a relaxed and comfortable position, with feet slightly apart and separated by a marker line on the floor, in front of the stereoscopic display, looking straight ahead. The marker was aligned with the center of the display and with the anteroposterior (AP) axis of the FOB transmitter. (See Figure 4.) This was done to simplify the data collection, as all left-right movement by the observers was captured on one axis.

Before each measurement period, the experimenter checked that the observer was ready and in the correct position. Between each 100 sec. sequence, the screen cut to black and the experimenter switched on a small desk lamp that dimly illuminated the area in which observers were positioned. Observers were then instructed to sit down and fill in the rating scales relating to the stimulus they had just watched, by marking each analog scale with a line. Once the rating scales for a stimulus were completed, observers were asked to sit in the dark for a minute to partially dark-adapt them again before proceeding to the next display. At the end of the experiment, the experimenter tested each observer's stereoacuity.

All observers saw the moving and still stimuli both monoscopically (both eyes receiving the left-eye view) and stereoscopically (each eye receiving its appropriate view). The order of stimulus presentation was fully counterbalanced across observers, with a constraint on presentation order that no observer could see two moving stimuli or two still stimuli consecutively. This was in order to minimize the possibility of motion sickness, as the moving-video sequence contained movement that was quite violent.

Finally, observers were told that, if at any point they felt ill or unstable to the extent that they wanted the experiment to cease, all they had to do was ring a bell positioned directly in front of them.

4 Results

The results of the experiment are reported in three sections. In the first section, we report on observers' postural responses to the video; in the second, we report

2. A review of an earlier draft of this paper suggested that a single rating scale of presence might not constitute a robust measure. A number of authors have used a series of questions to measure presence (Slater & Usoh, 1994; Slater, Usob, & Steed, 1994; Hendrix, & Barfield, 1996), and recently questionnaires to measure presence have emerged (Witmer & Singer, 1998). The questionnaires thus far published concentrate largely on interactive elements of VEs, and we decided that these were unsuitable for use here because interactivity is a variable that we have not investigated. Prothero (1998) reported similar responses across five questions he used to measure presence, and because of the similarities across the responses, used only one question as a measure of presence. We are currently working on the development of a general questionnaire to measure presence (for interactive and noninteractive systems), but this was not available when the work reported here was completed.

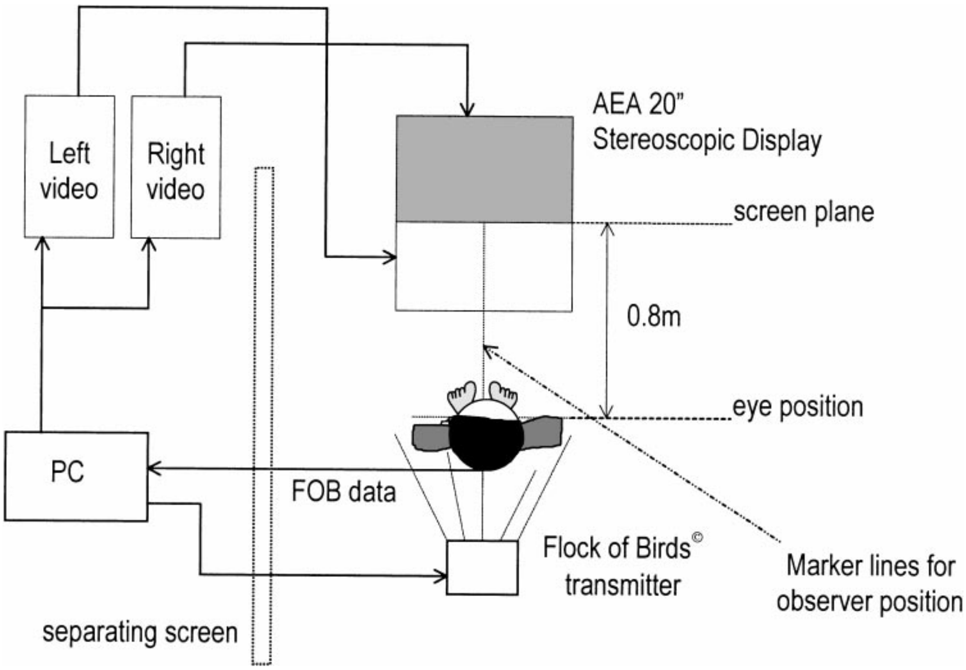


Figure 4. *Schematic diagram of the laboratory set-up illustrating the observer's position relative to the display. When the video was not displayed, no light source was present in the observer's area.*

on the subjective rating scale results; and, in the third, we examine the relations between the postural and subjective measures.

4.1 Postural Responses to the Video

The position recordings included a high-frequency noise component which arose by induction from the video apparatus. To remove this, a moving-average filter was applied to individual observers' position traces for each stimulus. The window size of this averaging operation was 1.04 sec.; so, for each smoothed position, thirteen data points were averaged together. Group mean position traces were obtained by averaging together individual observers' position traces by condition. Figures 5(a) and (b) show the group means of observers' left-right positions (cm) split by condition and stimulus. As can be seen from Figure 5(a), there was a strong correlation between the movement exhibited by observers for the stereoscopic and monoscopic moving video conditions. Marked on Figure 5(a) are the points in the moving stimulus that the car traveled around bends in the rally track. As predicted, observers in the experiment moved in the same directions as the car. When the car moved to the right to go around a bend, observers moved right, and vice versa. The similarity between the two traces demonstrates that observers were moving in response to the movement of the video stimulus and in synchrony with one another. For the still-video conditions (Figure 5(b)), there is no such correlation, indicating—as expected—that observers moved out of synchrony with each other.

The total distance that observers moved in each condition was calculated by summing all lateral movement across each 100 sec. measurement period for each observer. Figure 6 illustrates the enhancement, by the moving stimulus, of group mean lateral distance traveled by observers for monoscopic and stereoscopic presentation. Observers exhibited more lateral movement when the video was moving than when it was stationary, with both monoscopic ($t = 2.846$, $df = 23$, $p < 0.01$, two-tailed), and stereoscopic presentation ($t = 3.122$, $df = 23$,

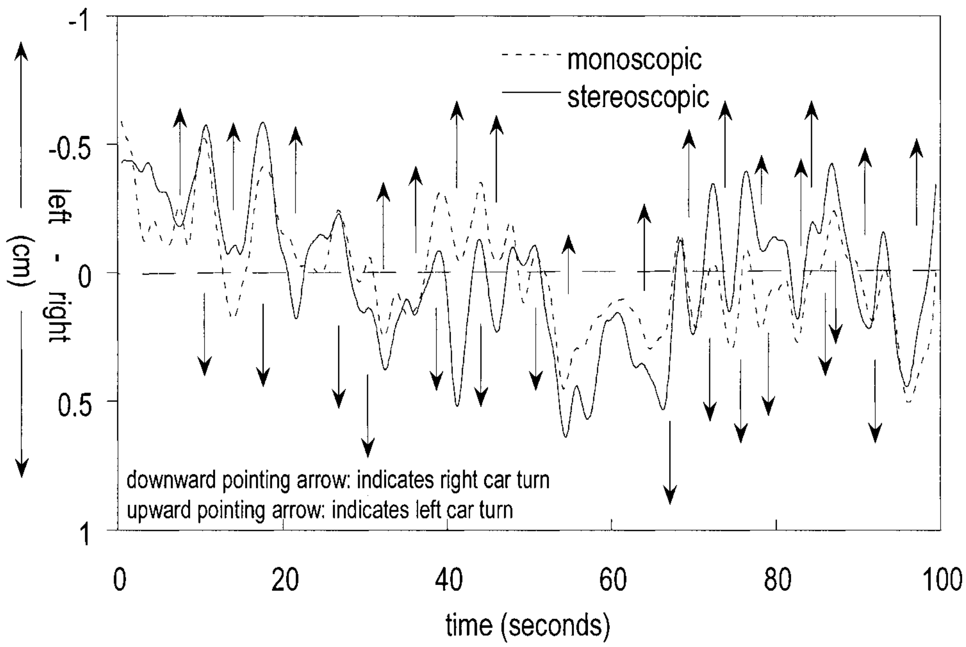


Figure 5a. *Effects of viewing condition on group mean left–right position, for the moving-video stimulus.*

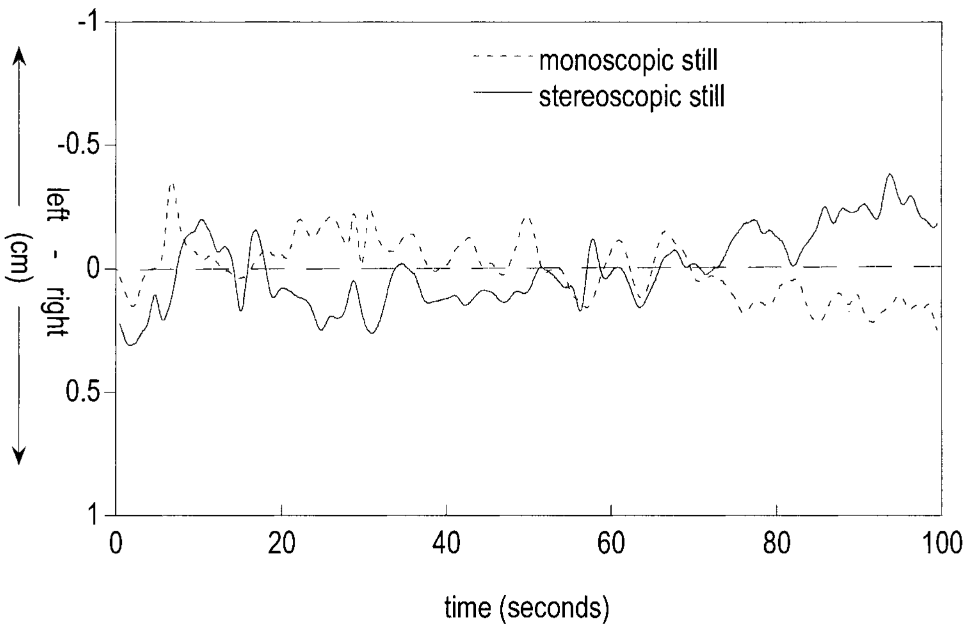


Figure 5b. *Effects of viewing condition on group mean left–right position, for the still-video stimulus.*

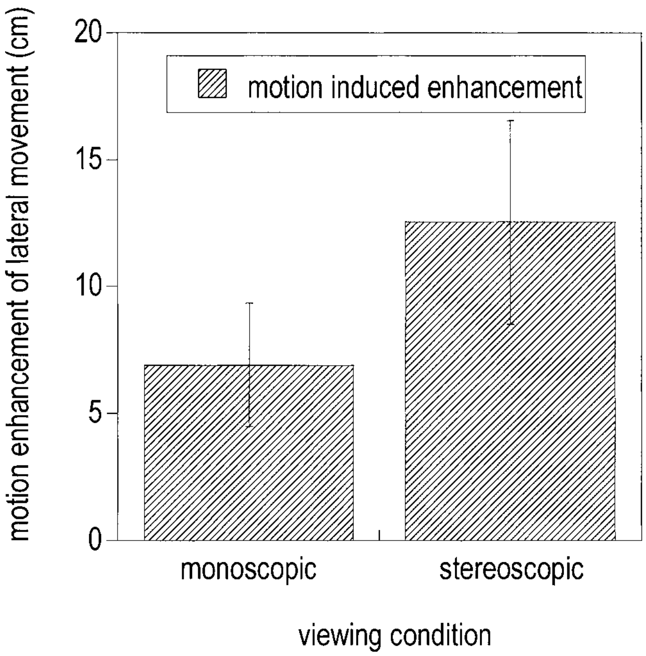


Figure 6. *Effects of viewing condition on enhancement of lateral movement induced by moving-video stimulus over still stimulus. Bars indicate standard errors.*

$p < 0.005$, two-tailed). As predicted, the motion-induced increase in lateral movement was greater for stereoscopic than monoscopic viewing and just failed to reach significance on a one-tailed test ($t = 1.589$, $df = 23$, $p = 0.063$).

4.2 Subjective Ratings

Figure 7 illustrates the group mean ratings across each of the scales. The statistical results reported below were derived from 2 × 2 ANOVAs for each scale (viewing condition × motion), except where indicated.

4.2.1 Presence. Figure 7(a) illustrates the group mean presence ratings for the four stimuli. Observers provided higher ratings of their sense of presence when the stimuli were presented stereoscopically than monoscopically ($F_{(1,23)} = 17.025$, $p < 0.001$) and for the moving stimulus compared to the still stimulus ($F_{(1,23)} = 29.041$, $p < 0.001$). In addition, there was no hint of an interaction between the two factors ($F_{(1,23)} < 1.0$, n.s.). This result is consistent with earlier experiments showing independent effects of viewing condition and motion on subjective presence ratings (Freeman et al., 1999; IJsselsteijn et al., 1998) and with other studies (Hendrix & Barfield, 1996).

4.2.2 Involvement. Figure 7(b) illustrates the group mean involvement ratings for the four stimuli. Observers provided higher ratings of their sense of involvement when the stimuli were presented stereoscopically than monoscopically ($F_{(1,23)} = 9.063$, $p < 0.001$) and for the moving stimulus compared to the still stimulus ($F_{(1,23)} = 46.099$, $p < 0.001$). As for the presence ratings, there was no hint of an interaction between the two factors ($F_{(1,23)} < 1.0$, n.s.). Observers' ratings of involvement therefore followed a very similar pattern to their ratings of presence.

4.2.3 Sensation of Self-Motion (Vection). Figure 7(c) illustrates the motion-induced enhancement in the group mean ratings of observers' sensation of self-motion for monoscopic and stereoscopic presentation. Observers provided higher ratings of their sensation of self-motion for the moving stimulus than for the still stimulus, both with monoscopic ($t = 8.418$, $df = 23$, $p < 0.001$, two-tailed) and stereoscopic presentation ($t = -8.422$, $df = 23$, $p < 0.001$, two-tailed). However, counter to our prediction, a paired-sample t-test revealed that the motion-induced enhancement of vection (comparing vection ratings for moving to vection ratings for still stimuli) was not higher for stereoscopic than monoscopic presentation ($t = 1.035$, $df = 23$, $p = 0.312$, two-tailed). This result is consistent with Ohmi's (1998) report but inconsistent with Palmisano's (1996) finding that stereoscopic presentation enhanced vection when observers were presented with optic flow patterns generated by moving dots. We discuss this issue below.

4.2.4 Sickness. Figure 7(d) illustrates the group mean ratings of the observers' sickness ratings. This question was included as the moving-video stimulus contained large amounts of motion, and, in piloting, several volunteers reported slight feelings of motion

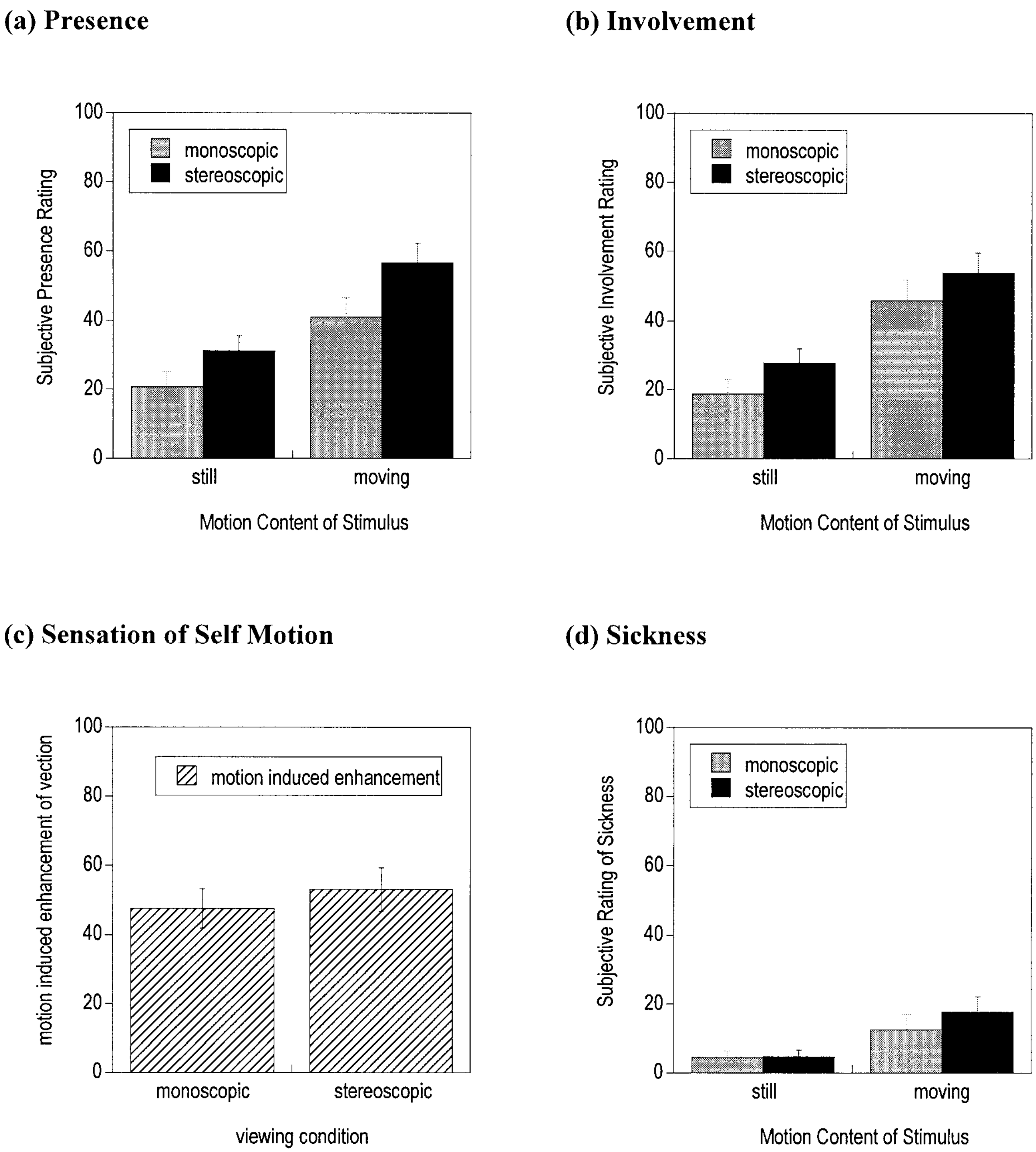


Figure 7. *Effects of viewing condition and motion content of stimulus on group mean subjective ratings of (a) Presence, (b) Involvement, (c) Vection (sensation of self-motion), and (d) Sickness. Figure 5(c) illustrates enhancement of vection ratings caused by the moving stimulus, over ratings obtained for the still stimulus. Bars indicate standard errors.*

sickness while watching it. Observers provided higher ratings of sickness for the moving stimuli compared to the still stimuli ($F_{(1,23)} = 6.248$, $p < 0.05$) and reported similar feelings of sickness when the stimuli were presented stereoscopically or monoscopically ($F_{(1,23)} = 2.283$, $p = 0.144$). There was no significant interaction between the two factors ($F_{(1,23)} = 1.868$, $p = 0.185$).

4.3 Relation Between Objective Postural Responses and Subjective Presence Ratings

Although the primary aim of the experiment reported here was to establish whether larger postural responses would be generated by stereoscopic than monoscopic stimulus presentation, another important question concerns the relationship between the behavioral and the subjective presence measures reported above.

A comparison of Figures 6 and 7(a) reveals that stereoscopic stimulus presentation resulted in both an increase in induced lateral movement and an increase in presence ratings. This suggests that, for data averaged across observers, the postural measure might provide a useful estimate of the presence elicited by the display. The relationship between the two measures was investigated by correlating the difference between the stereoscopic and monoscopic motion-induced increases in postural response against the difference between stereoscopic and monoscopic presence ratings for the moving stimulus. No relationship was found between these measures, Pearson's $r(22) = 0.025$. This demonstrated that, while on a group level similar effects of stereoscopic presentation were measured both through the subjective presence ratings and the postural measures, on an individual basis this was not the case. In effect, observers who exhibited larger postural responses to the moving stimulus with stereoscopic presentation did not necessarily provide the biggest differences in presence ratings between the monoscopic and stereoscopic images. This result might be attributable to noise in our measurements.

5 Discussion

As expected, postural responses were elicited by the moving-video stimulus. This was reflected in the increased lateral movement measured with the moving stimulus (compared to the stationary stimulus) and in the marked degree of synchrony of movements observed across the two viewing conditions. The postural responses to this moving stimulus therefore provide a potential measure to study the effectiveness of different kinds of display.

Using this measure, the results suggested that stereoscopic presentation enhanced the lateral movement elicited by the display, although this effect was relatively weak and just failed to reach significance. The increase in postural responses to a moving stimulus presented stereoscopically supports the findings reported by Hoshino et al. (1997). In both cases, it could be argued that enhancement of vection (through stereoscopic presentation) was responsible for the increased movement. However, this was not supported by subjective ratings of self-motion, discussed below.

Post-test subjective ratings of presence, involvement, and vection were found to vary across conditions. Presence ratings were enhanced by stereoscopic presentation and by scene motion independently, confirming earlier findings obtained using continuous assessment (Freeman et al., 1999; IJsselsteijn et al., 1998). Increased ratings of presence with stereoscopic presentation have also been reported by Ohmi (1998) (although, in his results, presence and visual fatigue were combined in one factor score) and also by Hendrix and Barfield (1996). Ratings of involvement were much more variable than those of presence, but these also showed an increase with stimulus motion and with stereoscopic presentation. We found no significant increase in reported vection with stereoscopic presentation, and our results therefore support Ohmi, but conflict with Palmisano (1996), who reported increased vection with stereoscopic viewing. However, Palmisano measured vection online, whereas we used post-test ratings. Any increase in the proportion of time experiencing vection may not be reflected in post-test measures (for example, Frederickson & Kahneman, 1993). In addition, there were large differences across these studies in the kinds of motion, stimuli, and displays used. The effect of stereoscopic viewing on vection, especially for real-world stimuli, seems worthy of more investigation.

Finally, we examined the relationship between presence ratings and postural response measures across conditions. No significant relationship was found between presence and postural responses. There are several possible reasons for this. The presence measure may have been contaminated by the novelty of the display or the arousing nature of the stimulus. It is also possible that there is a mismatch between online postural measures and post-test measures of presence (cf. Frederickson & Kahneman, 1993). Another possibility is that the postural response was driven by lateral motion in the display, and that presence ratings were affected more by the forward motion in the display. To further investigate these issues, more-extensive investigations using online measurements of posture, presence, and vection are required. In addition, in the experiment reported here, the display was relatively small (28 deg. visual angle, horizontally). Because increased FOV has previously been shown to affect presence ratings and postural responses, it is possible that clearer results and increased correlations between subjective and objective measures would be observed with larger displays. We have plans to repeat the experiment using a larger display in the near future.

Two important issues remain concerning the usefulness of postural responses in presence research. The first issue is the correspondence between the presence-generating components of a displayed or virtual environment and the response-generating components. It is clear from the discussions of presence in the literature (such as Slater & Wilbur, 1997; Witmer & Singer, 1998; Sheridan, 1992; Ellis, 1996) that presence may be enhanced by other factors such as how interesting the stimuli are, or the degree of interaction. Thus, presence has more facets than we have studied here. Because of this, we do not advocate the use of this kind of postural response as a general measure of presence, but we have shown that it is possible to obtain objective behavioral measures that can be used to gauge the extent to which different display parameters control responses in the viewer. This may be more closely related to (physical) immersion than to presence, but it is potentially useful in designing displays that optimize the effect of ecological factors. An advantage of this method is that the evaluation does not depend upon the content of the display (for example, whether it is interesting or aesthetically attractive), provided that the appropriate ecological properties are displayed. As one example of this approach, if the need were to create a display that would instill in the viewer an optimum sense of subjective motion, the behavioral-realism approach could be used to monitor the effectiveness of display parameters such as FOV (for example, Ohmi, 1998). However, by this account, the presence felt by viewers might be determined by content-related factors, such as how engaging, novel, or arousing the displays were. The second issue is whether there is likely to be any single response that can be used as a global measure of display effectiveness. This seems unlikely, because different responses are governed by different types of sensory input. For example, the display parameters that optimize a sense of rapid movement will not necessarily be the same as those that optimize precise spatial localization or those that elicit social responses to facial expressions. In their respective applications, these types of response may contribute to the sense of presence or may just indicate that the display effectively captures the ecological information governing the behavior. In either case, by creating displays that optimize these responses, the sense of presence may be enhanced.

In summary, the present findings suggest that increasing the realism of a moving display by adding stereoscopic information increased both the postural responses to the display and subjective ratings of presence. This provides weak support for the use of behavioral measures in evaluating displays, particularly those intended to provide a sensation of movement. However, the correlation between the enhancement, due to stereoscopic presentation, of both postural responses and presence ratings was non-significant. The absence of this correlation (and issues concerning how general an indicator of presence such measures constitute) suggest that postural responses should not be taken as direct substitutes for subjective presence ratings, although they may still be useful in the evaluation of display characteristics.

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References

Barfield, W., & Weghorst, S. (1993). The sense of presence within virtual environments: A conceptual framework. In G. Salvendy & M. Smith (Eds.), Human Computer Interaction: Applications and Case Studies (pp. 699–704). Elsevier.

Edwards, A. S. (1946). Body sway and vision. *Journal of Experimental Psychology, 36,* 526–535.

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

Frederickson, B. L., & Kahneman, D. (1993). Duration neglect in retrospective evaluations of affective episodes. *Journal of Personality and Social Psychology, 65,* 45–55.

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

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

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

Hendrix, C., & Barfield, W. (1996). Presence within virtual environments as a function of visual display parameters. *Presence: Teleoperators and Virtual Environments, 5* (3), 274–289.

Hoshino, M., Takashi, M., Oyamada, K., Ohmi, M., & Yoshizawa, T. (1997). Body sway induced by 3D images. *Proceedings of Imaging Science & Technology/SPIE's 9th Annual Symposium, 3012,* 400–407.

IJsselsteijn, W., de Ridder, H., Hamberg, R., Bouwhuis, D., & Freeman, J. (1998). Perceived depth and the feeling of presence in 3DTV. *Displays, 18,* 207–214.

Kalawsky, R. S., Bee, S. T., & Nee, S. P. (1999). Human factors evaluation techniques to aid understanding of virtual interfaces. *BT Technology Journal, 17,* 128–141.

Kim, T., & Biocca, F. (1997). Telepresence via television: Two dimensions of telepresence may have different connections to memory and persuasion. *Journal of Computer Mediated Communication, 3* (2), (http: / / www.ascusc.org / jcmc / vol3 / issue2 / kim.html).

Lee, D. N., & Lishman, J. R. (1975). Visual proprioceptive control of stance. *Journal of Human Movement Studies, 1,* 87–95.

Lombard, M., & Ditton, T. (1997). At the heart of it all: The concept of presence. *Journal of Computer Mediated Communication, 3* (2). (http / / www.ascusc.org / jcmc / vol3 / issue2 / lombard.html).

Ohmi, M. (1998). Sensation of self-motion-induced by real-world stimuli. In *Proceedings of the International Workshop on Advances in Research on Visual Cognition: Selection and Integration of Visual Information* (pp. 175–181). Tsukuba, Ibaraki, Japan: Science and Technology Association & National Institute of Bioscience and Human-Technology.

Ojima, S., & Yano, S. (1997). Effect of depth sensation on body sway with binocular vision. *Electronics and Communications in Japan, Part 3, 80* (4), 83–95.

Palmisano, S. (1996). Perceiving self-motion in depth: The role of stereoscopic motion and changing-size cues. *Perception and Psychophysics, 58* (8), 1168–1176.

Paulus, W., Straube, A., Krafczyk, S., & Brandt, T. (1989). Differential effects of retinal target displacement, changing size and changing disparity in the control of anterior / posterior and lateral body sway. *Experimental Brain Research, 78,* 243–252.

Previc, F. H., & Mullen, T. J. (1991). A comparison of the latencies of visually induced postural change and self-motion perception. *Journal of Vestibular Research, 1,* 317–323.

Prothero, J. D. (1998). The role of rest frames in vection, presence and motion sickness. Unpublished doctoral dissertation, University of Washington. (Available online at http: / / www.hitl.washington.edu / publications / r-98-11.)

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

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

Slamin, B. (1998). Live and wide. *The Journal of the Royal Television Society*, January / February 1998, 21.

Slater, M., & Usoh, M. (1994). Representations systems, perceptual position, and presence in immersive virtual environments. *Presence: Teleoperators and Virtual Environments, 2* (3), 221–233.

Slater, M., Usoh, M., & Chrysanthou, Y. (1995). The influence of dynamic shadows on presence in immersive virtual environments. In M. Goebel (Ed.), Virtual Environments '95 (pp. 8–21). New York: Springer Wien, Springer Computer Science.

Slater, M., Usoh, M., & Steed, A. (1994). Depth of presence in virtual environments. *Presence: Teleoperators and Virtual Environments, 3* (2), 130–144.

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

Stoffregen, T. A. (1985). Flow structure versus retinal location in the optical control of stance. *Journal of Experimental Psychology: Human Perception and Performance, 11* (5), 554–565.

———. (1986). The role of optical velocity in the control of stance. *Perception and Psychophysics, 39* (5), 335–360.

Uwa, N., Kaneko, H., & Kanatsugu, Y. (1997). Motion in depth and body sway for stimuli with changing-disparity and changing-size. In *Proceedings of the International Workshop on Advances in Research on Visual Cognition: Selection and Integration of Visual Information* (pp. 259–263). Tsukuba, Ibaraki, Japan: Science and Technology Association & National Institute of Bioscience and Human-Technology.

van Asten, W. N. J. C., Gielen, C. C. A. M., & Denier van der Gon, J. J. (1988a). Postural movements induced by rotations of visual scenes. *Journal of the Optical Society of America, A 5*, 1781–1789.

———. (1988b). Postural adjustments induced by simulated motion of differently structured scenes. *Experimental Brain Research, 73*, 371–383.

Welch, R. B., Blackmon, T. T., Liu, A., Mellers, B. A., & Stark, L. W. (1996). The effects of pictorial realism, delay of visual feedback and observer interactivity on the subjective sense of presence. *Presence: Teleoperators and Virtual Environments, 5* (3), 263–273.

Witkin, H. A., & Wapner, S. (1950). Visual factors in the maintenance of upright posture. *American Journal of Psychology, 63* (1), 31–50.

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