Effects of Stereoscopic Presentation, Image Motion, and Screen Size on Subjective and Objective Corroborative Measures of Presence

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Abstract

Recently, we reported that group subjective measures of presence as well as observers' postural responses are sensitive to increasing the realism of a display with motion content, by the addition of stereoscopic information, using a 20-inch stereoscopic screen with an effective horizontal field of view of 28 deg. (Freeman, Avons, Meddis, Pearson, & IJsselsteijn, 2000). The experiment presented here employed a large projection display with a 50 deg. horizontal field of view showing a rally car traversing a curved track at speed. The independent variables included image motion and stereoscopic presentation as within-subjects factors and screen size as a between-subjects factor. Dependent variables included subjective measures of presence, vection, involvement, and sickness, as well as observers' lateral postural responses, which served as a candidate objective corroborative measure of presence. Results demonstrated a noisy yet positive effect of stereoscopic presentation on the lateral postural responses. Post-test subjective ratings revealed a significant effect of stereoscopic presentation on the subjective judgments of presence, but not on those of vection, involvement, or sickness. Image motion had a large and significant effect on the subjective judgments of presence, vection, and involvement. The effect of image motion was considerably larger than that of stereoscopic viewing. By comparing results between experiments, a large effect of screen size on subjective presence ratings could be demonstrated, but only for the video stimulus that contained motion. The postural response measure did not differentiate between screen sizes, thus limiting its utility as an objective corroborative measure of presence, although further research is required to be able to be more firm in our conclusion regarding this issue.

1 Introduction

The current pace of technological development in networks, computing power, and displays, as well as improvements in human-system interfaces, enables the creation of services that are able to elicit a sense of presence in the user. The concept of presence has relevance and implications for the design and evaluation of a broad range of interactive and noninteractive media, and applications in areas such as training and education, telecommunications, telemedicine, VR psychotherapy, and various forms of entertainment.

Scientific research into presence is still at a relatively early stage of development. From the early 1990s onwards, the subjective sensation of "being there" in a mediated environment has been studied in relation to various media, most notably virtual environments (VEs). Although substantial progress has been made in presence research, there still exists a clear need for a reliable, valid, and robust methodology for measuring presence (Barfield, Zeltzer, Sheridan, & Slater, 1995; Stanney & Salvendy, 1998; IJsselsteijn, de Ridder, Freeman, & Avons, 2000).

1.1 Measuring Presence

The different approaches taken to measuring presence to date can be divided into two general categories of presence measures: subjective measures and objective corroborative measures. Subjective measures are measures whereby the participant is asked for a conscious judgment, either online or post-test, of his/her psychological state/response in relation to the mediated environment. The majority of presence studies to date use questionnaires and rating scales to assess the presence experience. These methods have the advantages that they generally do not disrupt the media experience, are easy to administer, and have face validity. However, they do have some limitations. The most important one is potentially poor reliability. Simple, subjective post-test measures are known to be potentially unstable, with inconsistencies across different raters and rating situations (Freeman, Avons, Pearson, & IJsselsteijn, 1999). A reason for this could be unfamiliarity with the concept of presence for naïve participants, which may in turn increase their potential sensitivity to demand characteristics of the experiment (that is, the hints and cues in a research situation that influence participants' perceptions of what is expected from them).

Researchers are exploring two approaches to overcome this reliability problem and create more-stable presence measures. One is to refine the measurement procedure (such as through better instructions and avoiding cues that may hint to the hypotheses being tested) as well as the subjective measures themselves. Subjective measures are being improved through better questionnaire design and careful piloting on a wide variety of media, content, and individuals (Witmer & Singer, 1998; Schubert, Friedmann, & Regenbrecht, 1999; Lessiter, Freeman, Keogh, & Davidoff, 2000; Lombard, Ditton, Crane, Davis, Gil-Egui, Horvath, & Rossman, 2000).

An alternative approach is to measure user responses that are produced automatically and without conscious deliberation, but that are still sensibly correlated with measurable properties of the medium and/or the content. In an attempt to develop such a measure of presence, the behavioral realism approach was proposed (Freeman, Avons, Meddis, Pearson, & IJsselsteijn, 2000). The approach is based on the premise that as a display better approximates the environment it represents, an observer's responses to stimuli within the display will tend to approximate those which he/she would exhibit in response to the environment itself. Based on this principle, a variety of objective corroborative measures can be formulated. (See IJsselsteijn et al. (2000) for a discussion of several actual and potential presence measures.) Using such an objective corroborative measure of presence has the advantage of diminishing the likelihood that the participant is responding to the demand characteristics of the experiment. In addition, it circumvents the conflict between sensation ("I am in a VE") versus knowledge ("I am in a psychology lab wearing an HMD"), that seems intrinsic to the subjective report of presence (Freeman et al., 2000).

It is important to note that candidate behavioral measures of presence such as postural responses, skin conductance, or heart rate may also be sensitive to manipulations that do not affect subjective presence. This signals a potential problem with the validity of the objective corroborative measure. To ensure validity of the selected objective measure, it should be combined with a subjective measure of presence, and results from both measures should correlate. Thus, a sensible research goal is an aggregate measurement of presence that can reasonably be expected to be reliable and valid (IJsselsteijn et al., 2000). Most objective corroborative measures used or proposed to date have limited robustness; that is, they will not be sensitive to all possible media (form and/or content) manipulations that may affect the user's subjective sense of presence. It seems unlikely that we will arrive at a single, overall objective corroborative measure of presence. Rather, the objective measure that is being used as a presence measure should be selected for particular applications, according to their function. For example, postural responses, as reported in this paper, can be used to assess displays aimed at providing a sense of movement; skin conductance response and heart rate can be used to assess emotionally involving experiences, and so on.

1.2 Postural Responses

A number of different sources of information may be used to control balance and posture. These include information from the receptors in feet and ankle joints, information from the vestibular organs, and information received through the eyes. The importance of vision as a source of information was demonstrated conclusively by Lee and his colleagues (Lee & Aronson, 1974; Lee & Lishman, 1975) in an experimental set-up known as the "swinging room." Postural adjustments occur as a proprioceptive response, and in addition as a response to real or illusory observer motion through an environment. It is this illusory perception of self-motion, known as *vection,* and the related postural responses that are of particular relevance within the behavioral realism approach. Palmisano (1996) reported a study in which observers viewed an array of dots expanding outwards on the display at an accelerating rate thus suggesting movement towards the observer at a constant rate. The results showed that stereoscopic presentation of moving dots reduced the latency of vection onset and also increased the percentage of time for which observers reported the feeling of self-motion, relative to the monoscopic presentation of the same stimuli. Previc and Mullen (1991) studied the relationship between vection and postural adjustments, using roll-vection stimuli, and found that vection latencies (as measured by self-report) were much greater than were latencies for observed postural adjustments. They concluded that the postural adjustments were not caused by vection; however, the high correlation between the two measures suggested that they were controlled by the same visual parameters.

Postural responses can serve as potential objective corroborative measures of presence, because they (i) occur automatically without conscious reflection and are thus unlikely to influence concurrent subjective evaluations, and (ii) they have the capacity to produce differential levels of response, making it easier to relate them to subjective ratings of presence (Freeman et al., 2000). Both Ohmi (1998) and Prothero (1998) proposed that measures of vection and presence should be related, based on the argument that an environment that causes an increase in vection will likely induce an increased sense of presence as well. Recent research on postural responses to real-world video stimuli showed that postural responses may indeed be sensitive to various display manipulations. Ohmi (1998) reported that the observers' postural responses were related to the centrifugal acceleration presented on the display. Unlike Palmisano's (1996) moving-dot study, however, Ohmi (1998) did not find an enhancement of vection when comparing stereoscopic with monoscopic moving video. Hoshino, Takashi, Oyamada, Ohmi, and Yoshizawa (1997) measured larger postural responses to a rolling-boat sequence with increased field of view (FOV) and with stereoscopic presentation. Although their display manipulations have also been shown to affect the subjective sense of presence (Prothero & Hoffman, 1995; Hendrix & Barfield, 1996; IJsselsteijn, de Ridder, Hamberg, Bouwhuis, & Freeman, 1998; Freeman et al., 1999), no specific subjective presence measure was reported in Hoshino et al.'s postural response studies to enable a firm conclusion regarding the utility of their objective measures.

Following the behavioral realism approach, Freeman et al. (2000) recently reported a study on the utility of postural responses as a measure of presence. In this paper, we reported a positive effect of stereoscopic presentation on the magnitude of observers' lateral postural responses, as well as on a subjective measure of presence, although the two measures were not significantly correlated per participant. The current study can be regarded as a replication and extension of the Freeman et al. (2000) study. Because FOV has previously been shown to affect postural responses (Hoshino et al., 1997) as well as presence ratings (Prothero & Hoffman, 1995), it was of interest to perform a study using a display with a larger FOV than the one used in Freeman et al. (2000), which covered a horizontal visual angle of 28 deg. Thus, by comparing the results from this study with the results from Freeman et al. (2000), we are able to investigate the effects of screen size, as a between-subjects factor, on both subjective and objective corroborative measures of presence.

With regard to postural responses, it was predicted that more movement would be detected with the moving stimulus than with the still stimulus. It is important to note that it was expected that observers would move in synchrony with lateral motion of the car. A passenger seated in a rally car would experience centrifugal forces in an opposite direction to the motion of the car, and to counter the forces would move in the same direction as the car. For example, if the car turned rapidly to the right, the passenger would experience centrifugal forces sending him/her left, and would lean right to counter the forces. Hence, when confronted with a display of a car traversing a curved rally track, the observer's reaction would result in their moving in the same direction as the car, in line with results found earlier (Freeman et al., 2000). Following the behavioral realism approach, it was predicted that the increased realism of the stereoscopic presentation would result in a stronger postural response. Therefore, it was predicted that the extent of postural adjustment to the moving stimulus would be enhanced under stereoscopic presentation. It was also predicted that a larger FOV would enhance postural responses. With regard to subjective presence ratings, it was predicted that higher ratings would be obtained for the stimuli containing image motion, for stereoscopic stimuli, and for stimuli presented with a larger FOV.

2 Method

2.1 Participants

Twenty-four students of the University of Essex (13 women, 11 men, average age 23.5 years, age range 18–30) participated in the experiment for which they were paid £2. Only participants with a height of under 1.85 m were invited to participate in the experiment. This restriction had to be imposed to prevent the top of the participant's head from obscuring part of the projection. (See figure 1.) 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 a large curved stereoscopic projection display, with an image size of 50 deg. visual angle horizontally. Two synchronized Panasonic M2 (A750-B) video players provided the video input for the two projectors. These projectors had differently polarized filters placed in front of each, so that left and right eye images could be separated by wearing polarized spectacles. A Flock of Birds (FOB) magnetic position tracker was used to collect the observers' x, y, and z positions for each measured period. The small FOB receiver was attached to a 1 m circular length of cord that was placed around the observers' neck, with several small metallic disks serving as counterweights to keep the tracker firmly in place. The FOB was connected to a standard PC running custom software that controlled both the video players and sampled the x, y, and z positions at 12.5 Hz. (See figure 1.)

2.3 Design

Three factors were studied via this experiment. Two factors—stereoscopic presentation and image motion—were manipulated as within-subjects (repeated measures) factors in this experiment, whereas the third factor, screen size, was studied as a between-subjects factor by comparing the results of the current experiment with recently published results (Freeman et al., 2000). To enable a comparison between the two data sets, all other experimental factors were kept equal as much as possible. Thus, the current experiment employs the same experimental design, instructions, stimuli, and measurement methods as Freeman et al. (2000).

The two within-subjects factors that were manipulated in this experiment both had two levels: (i) viewing condition: monoscopic or stereoscopic; and (ii) image motion: still or moving. The four resulting trials (mono-still, mono-moving, stereo-still, stereo-moving) were fully counterbalanced with the only constraint on presentation order being that no participant could see two moving or

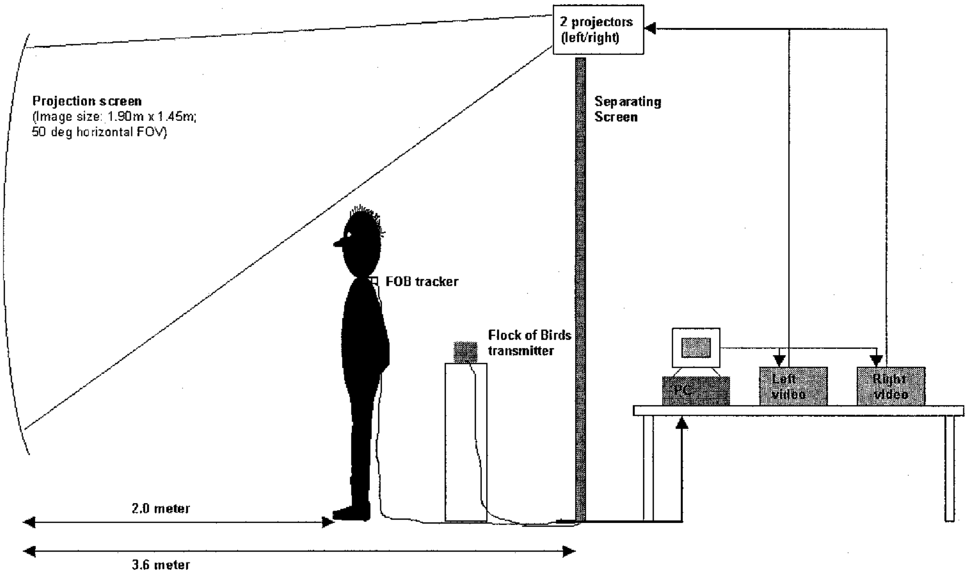


Figure 1. *Schematic diagram of the laboratory set-up illustrating the observer's position in relation to the display. The observer's area of the laboratory was completely blacked out during the experimental sessions, with the only illumination coming from the projection display.*

two still stimuli consecutively. This was done to minimize the possibility of motion sickness with the moving stimuli.

2.4 Stimuli

The moving video consisted of a 100 sec. excerpt from a rally car sequence, which was filmed for the ACTS MIRAGE stereoscopic documentary *Eye to Eye* (1997). The stimulus was a continuous piece of footage (without edits) shot by a small stereoscopic camera positioned on the hood of a rally car traveling at speed around an offroad rally track. (See figure 2.)

This video was selected because it included large amounts of motion parallax from the speed the car was traveling. Although the predominant movement was in the forward direction, there were a number of sharp left and right turns at which substantial lateral movement was present. The stimulus is thus capable of evoking lateral postural responses based on the direction of the centrifugal acceleration. The still video stimulus consisted of a still frame from the *Eye to Eye* footage, where the camera is situated by the side of the rally track awaiting the rally car to drive by. This stimulus had the advantage that it could still make sense from an ecological validity point of view. One could imagine actually standing at the side of the track, looking out over it. For stereoscopic presentation of the stimuli, both right- and left-eye video streams were played, whereas, for monoscopic presentation, the left-eye video stream was presented to both eyes. Participants were required to wear polarized spectacles for all stimulus conditions.

For all conditions, the video was accompanied by a synchronized, nondirectional audio track. For the moving video stimulus, this track consisted of sounds from the car's engine, gear changes, and clattering from stones hitting the underside of the car. The same audio track was used at a slightly lower sound intensity for the still video stimulus, thus giving the impression of a rally car driving somewhere in the distance. The lower sound intensity was chosen for the still video stimulus because playing it at the same volume as for the moving video stimulus resulted in a very unnatural perception, with no clear link between audio and video.

Figure 2 top. *Lightweight stereoscopic camera used to shoot the rally car sequence, mounted on the windshield (reprinted with permission of Independent Television Commission).*
Figure 2 bottom. *Sample frame from the moving video stimulus.*

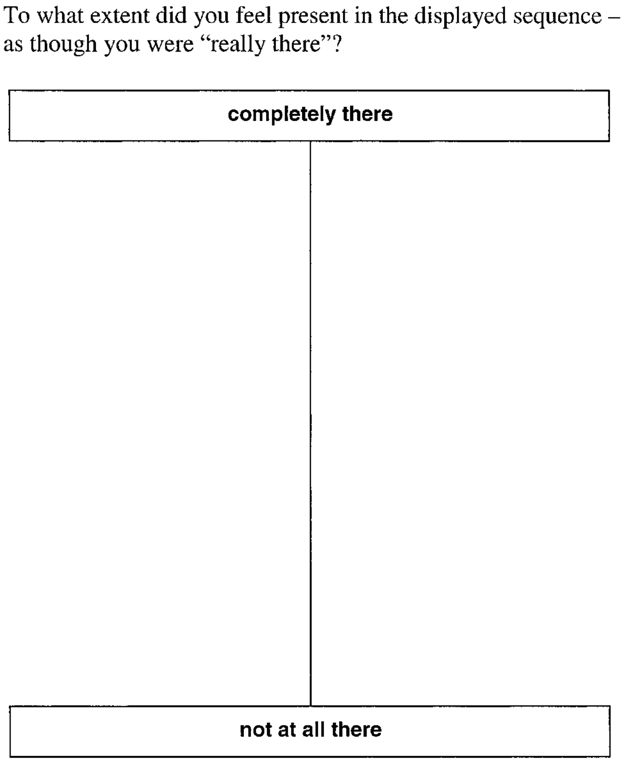


Figure 3. *The presence rating scale as it was used in the experiment. Participants were asked to place a mark on the rating scale according to how they felt, relative to the two extremes.*

2.5 Measurement

The dependent measures included subjective ratings of presence, vection, and involvement. Also, a subjective rating of (motion) sickness was included for control purposes, to be able to identify those participants that were sensitive to motion sickness, because this could potentially influence their subjective experience as well as their postural stability. All subjective ratings were performed by placing a rating line somewhere along a visual analog rating scale, which was converted to a number from 0 to 100 after the experiment. The verbatim instructions were "Place a mark across the rating scale according to how you feel. The mark should indicate how you feel relative to the two extremes." Figure 3 shows the presence rating scale as it was used in the experiment. Similar rating scales were used for involvement, vection, and sickness, each with different questions and rating scale endpoints. These were (i) for involvement: "How involved were you in the displayed sequence?" (Not at all involved–Completely involved); (ii) for vection: "To what extent did you feel that you were moving along the track, as though you were traveling with the car?" (No sense of motion–Strong sense of motion); and (iii) for sickness: "To what extent did watching the sequence make you feel sick?" (Not at all sick–Very sick).

In addition to the subjective measures, postural responses were measured as a potential objective corroborative measure of presence, using the FOB magnetic position tracker. Because our moving stimuli displayed left and right turns in rapid forward motion, the postural response that was of primary interest to us was in the lateral direction; that is, the lateral movements that Ohmi (1998) reported were related to the perception of centrifugal acceleration.

2.6 Procedure

On arrival at the laboratory, participants received instructions that they were required to watch a number of short videos and that their responses would be monitored. They were asked to stand still in a relaxed, upright position with their feet placed within marker lines on the floor, indicating a distance of 2 m to the stereoscopic projection display. After each 100 sec. sequence, the screen cut to black and a small light was switched on to allow the participants to fill out the rating scales relating to the stimulus they had just watched. After the four sequences were completed, the experimenter tested the participant's stereoacuity. This was done after the experiment in order not to prime participants on stereoscopic or 3-D material, because this may act as a demand characteristic and influence subsequent presence ratings (Freeman et al., 1999).

3 Results

3.1 Subjective Ratings

Figure 4 presents the group mean ratings for presence, vection, involvement, and sickness, for each of the four experimental conditions. Error bars reflect standard error of the mean. A two-way ANOVA (that is, with viewing condition and motion as factors, each with two levels) was carried out on the raw subjective ratings to test the main effects and interactions for statistical significance. The results revealed a significant effect of stereoscopic presentation on presence ratings ($F(1,23) = 6.811$, $p < 0.05$), but not on ratings of vection, involvement, or sickness. Motion had a large and significant effect on the subjective judgments of presence ($F(1,23) = 84.725$, $p < 0.001$), vection ($F(1,23) = 155,80$, $p < 0.001$) and involvement ($F(1,23) = 68.723$, $p < 0.001$). The effect size of motion was considerably larger than that of stereoscopic viewing. There was a small, nonsignificant effect of motion on reported sickness ($F(1,23) = 3.318$, $p = 0.082$), with overall levels of reported sickness being low. No significant interaction between viewing condition and motion was found for any of the subjective ratings.

3.2 Postural Responses

In analyzing the postural responses, we first had to remove a high-frequency noise component from the recordings, which was due to induction from the video apparatus. It was removed by applying a moving-average filter to the individual position data. The window size of this averaging procedure was 1.04 sec., so, for each smoothed position, thirteen data points were averaged together. The total distance moved in each condition was then calculated across each 100 sec. measurement period per observer. We found that a number of observers produced unreliable postural responses, in that they showed large, sudden peaks in the lateral direction, which indicated the participant had taken a (small) step to the left or right. This was potentially a compensating movement to keep balance. Although such a break in postural stability may be caused by the visual stimulus (comparable to participants falling off the beam in the Lee and Lishman (1975) study), we were unable to identify a pattern in the frequency or size of these peak responses in relation to the presented stimuli. Given the extraordinary impact of these peaks on the analysis of the data set, however, we decided to exclude from further analyses those participants that showed, in one or more conditions, a lateral movement larger than plus or minus 10 cm. Using this criterion, the data of sixteen participants were further analyzed.

The top of figure 5 illustrates the effects of motion and viewing condition on the group mean lateral postural responses using the large screen size (50 deg. horizontal FOV). To allow a comparison, the bottom of figure 5 illustrates the postural response data from Freeman et al. (2000), for the smaller screen size (28 deg. horizontal FOV). The comparison between the two data sets will be discussed in more detail in section 3.3. The effects of motion and viewing condition were in the

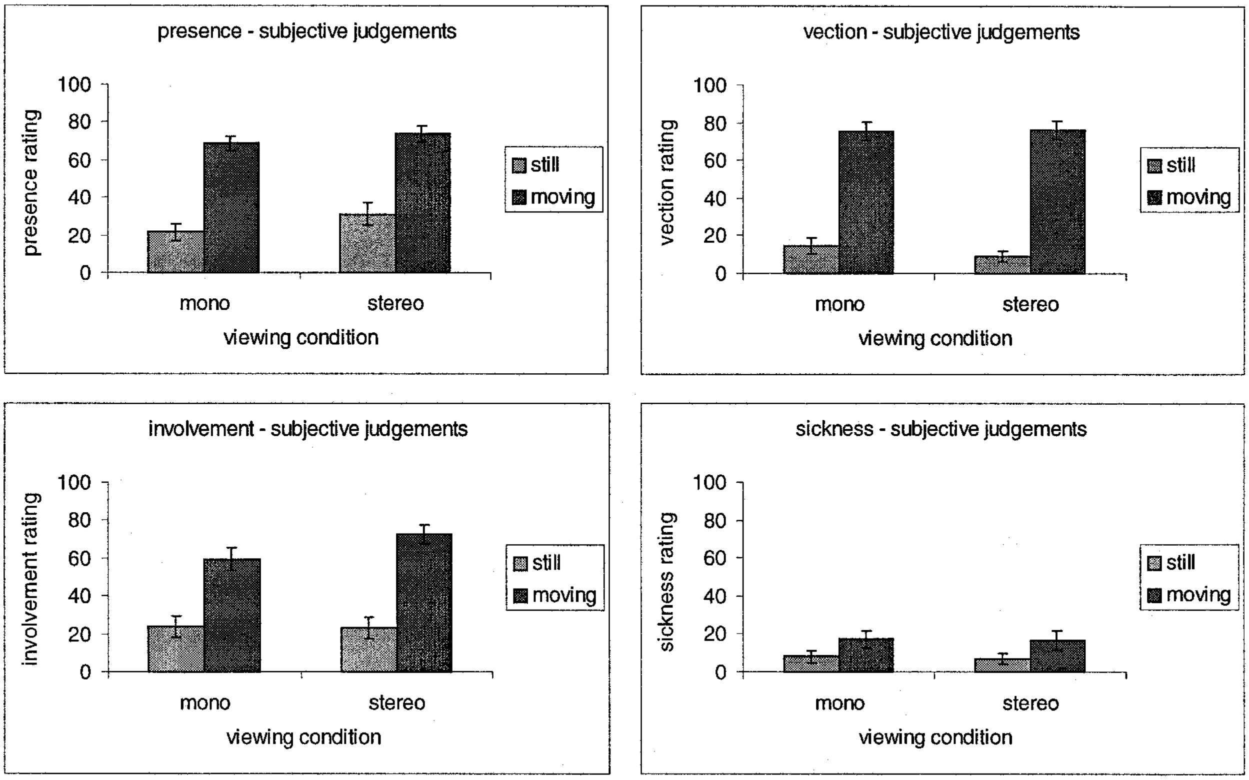
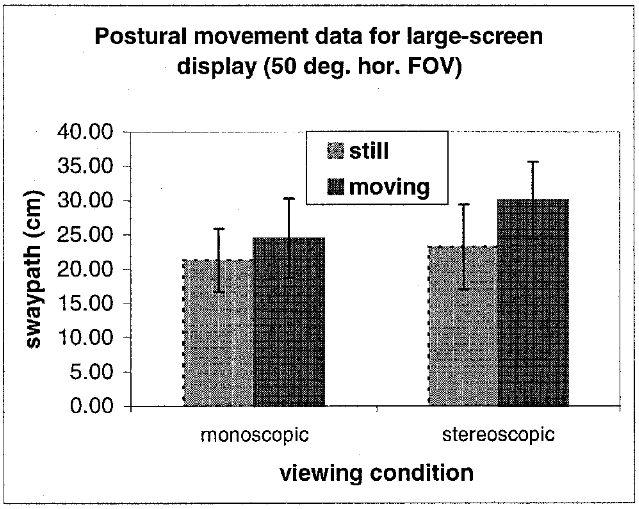


Figure 4. *Effects of viewing condition and image motion on the group mean subjective ratings of presence, vection, involvement, and sickness. Bars indicate standard errors.*

expected direction, that is, larger postural responses for moving than for still video and larger postural responses for stereoscopic than for monoscopic presentation. However, given the large error, these results failed to reach significance using a two-tailed, paired-samples t-test, although, for the stereoscopic condition, the motion-level comparison (still versus moving) approached significance ($t = 1.826$, $df = 15$, $p = 0.088$).

The prediction advanced in the introduction to this experiment stated that there would be larger lateral postural responses to lateral movement within the video. Analyzing postural responses across the full 100 sec. stimulus included a substantial proportion of the stimulus in which there was no lateral car movement, only forward movement of the car on the rally track. To enable a more sensitive analysis, the group mean postural responses were split for two different portions of the video stimulus: curved sections (that is, the + /− 1 sec. around each turn the rally car made), and noncurved sections (the remaining duration of the 100 sec. stimulus). A more accurate statement of the prediction advanced in the introduction is now possible; namely that stereoscopic presentation will enhance observers' lateral postural responses relative to monoscopic presentation for curved sections of the moving stimulus, but less so for the noncurved sections.

Figure 6 shows the group mean average swaypath in centimeters per second, to enable comparison between the "at bends" section, reflecting postural responses over a total of thirty curves (that is, sixty seconds) and the "at straights" section, reflecting postural responses over the remaining forty seconds. It can be seen from figure 6 that the overall postural responses across conditions are higher for the curved sections relative to the noncurved sections of the video stimulus. Figure 6 also illustrates that the motion enhancement—the difference



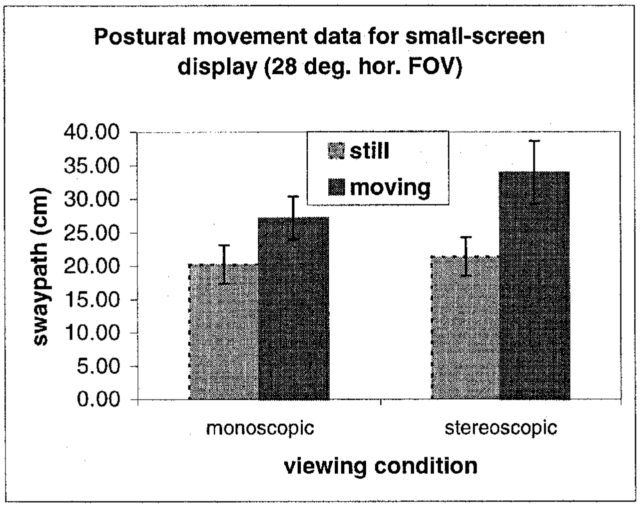


Figure 5 top. *Effects of image motion and viewing condition on the group mean lateral postural responses (n = 16).*

Figure 5 bottom. *Data from Freeman et al. (2000). Effects of image motion and viewing condition on the group mean lateral postural responses (n = 24).*

between moving and still video—is negligible for the monoscopic condition during the noncurved sections and most pronounced for the stereoscopic condition during the curved sections. The motion enhancement for stereoscopically presented noncurved sections is equal to the motion enhancement for monoscopically presented curved sections.

A statistical analysis of the results (three-way ANOVA with road type, motion, and viewing condition as factors) showed a significant main effect of road type ($F(1,15) = 10.457, p < 0.01$) and a significant interaction between road type and motion ($F(1,15) = 4.882$, $p < 0.05$). A two-tailed, paired-samples, t-test revealed a significant effect of motion in the stereoscopic presentation of the curved video section ($t = 2.260$, $df = 15$, $p < 0.05$).

As was argued in the introduction, a promising approach to measuring presence is the combination of both subjective and objective measures in order to arrive at an aggregate measurement that is both reliable and valid. Therefore, the relation between subjective and objective corroborative measures of presence is of interest. Although the subjective and objective measurement results averaged across observers suggest a positive relationship (compare figures 4 and 5a), the correlation between the two types of measurement across the four experimental conditions demonstrated no relationship (Pearson's $r = -0.015$). When analyzed at an individual level, five participants (of the sixteen analyzed) showed a significant correlation, four of which were positive and one of which was negative. A potential positive relationship between the subjective and objective corroborative measures may have been obscured by the noise in the results of the postural response measure.

3.3 Comparison with Freeman et al. (2000): Effects of Screen Size

When comparing the subjective results of the present study, employing the large screen (50 deg. FOV), with the results from our earlier experiment using a much smaller screen (28 deg. FOV), both experiments can be regarded as one experiment with 48 participants and in which screen size is a between-subjects factor and viewing condition and motion are within-subjects factors. In figures 7 and 8, subjective data from both experiments are plotted together for presence and for vection, respectively, which are the two dependent variables that are of most interest at this point. Figure 7 illustrates a large effect of screen size on the subjective sense of presence, but only for the moving video stimu-

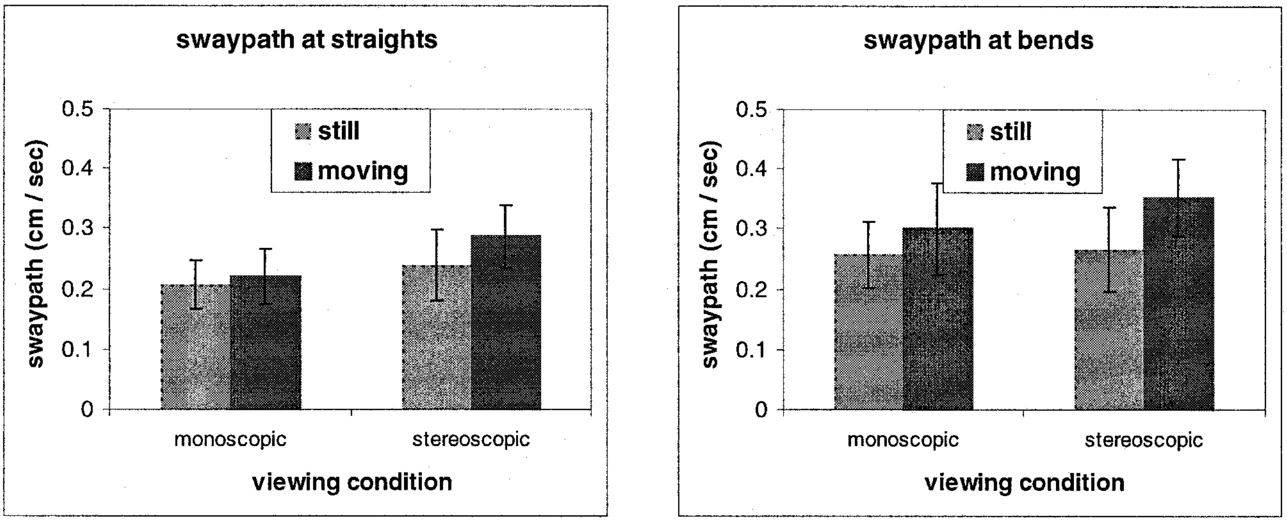


Figure 6. *Effects of image motion and viewing condition split for the noncurved and curved sections of the video stimulus, expressed in postural response per second.*

lus. For still video, both screen sizes give identical results. This result was supported by a repeated-measures ANOVA (two factors within-subjects: viewing condition and motion; one factor between-subjects: screen size) which revealed a significant effect of screen size on presence ($F(1,46) = 4.714, p < 0.05$) as well as a highly significant interaction between screen size and motion ($F(1,46) = 11.449, p = 0.001$). The effects of screen size on vection, illustrated in figure 8, were somewhat less pronounced. Statistically, the interaction between viewing condition and screen size was significant ($F(1,46) = 6.211, p < 0.05$) and the main effect of screen size almost reached significance ($F(1,46) = 3.185, p = 0.081$).

The group mean lateral postural responses showed similar trends in both studies (compare figures 5a and 5b). A Mann-Whitney *U* test, a nonparametric test for two independent samples, revealed no statistically significant differences between the two studies in terms of the postural responses; thus, comparing the studies failed to demonstrate an effect of screen size on the objective corroborative measure of presence.

4 Discussion

The significant effect of both stereoscopic presentation and image motion on presence is consistent with results from earlier experiments showing independent effects of stereo and motion on subjective presence ratings (Hendrix & Barfield, 1996; IJsselsteijn et al., 1998; Freeman et al., 1999). When comparing the current subjective presence results to the results reported in Freeman et al. (2000), we also found a significant between-subjects effect of screen size on subjective presence ratings, in line with earlier studies (Prothero & Hoffman, 1995). The effect of screen size was, in fact, only apparent for the motion conditions: for still video, there was no effect of screen size on subjective presence ratings. This may be explained by the fact that the screen size enhances the psychological impact of motion stimuli, because a larger portion of peripheral vision is being stimulated. The peripheral retina is known to be especially sensitive to high-velocity stimulus motion (Brown, 1972; Bhatia, 1975), as was the case with the stimuli used in our experiment.

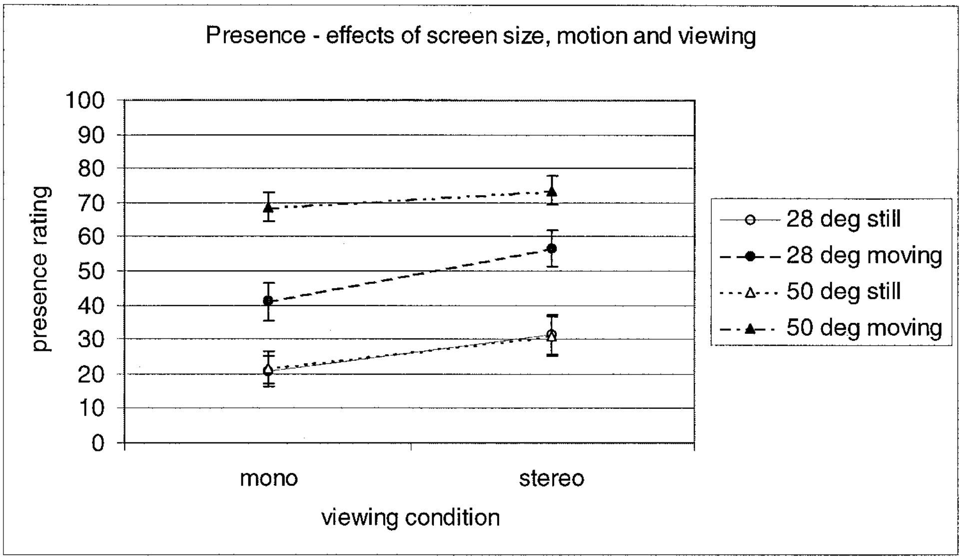


Figure 7. *Comparison of the group mean subjective presence ratings from Freeman et al. (2000) with the subjective presence ratings from the current study.*

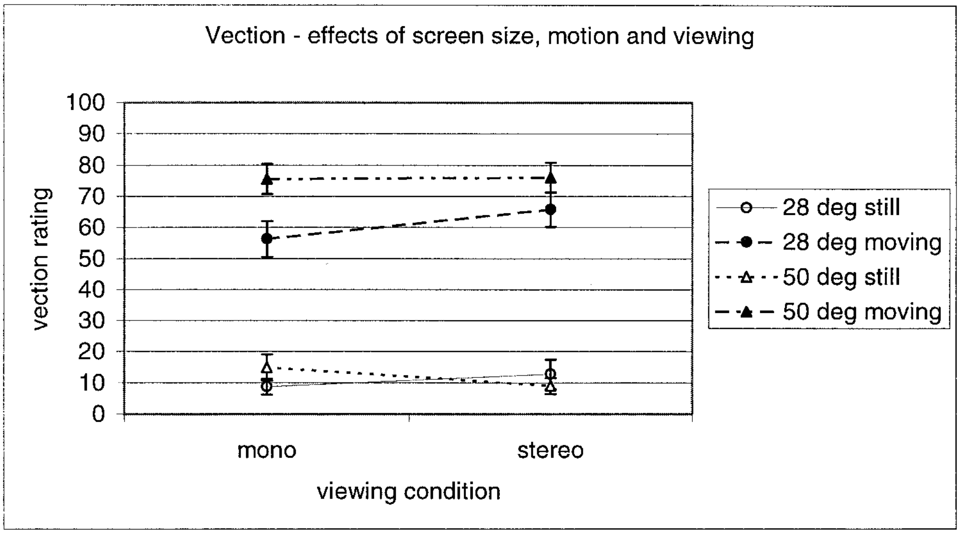


Figure 8. *Comparison of the group mean subjective vection ratings from Freeman et al. (2000) with the subjective presence ratings from the current study.*

Vection ratings were clearly and significantly affected by the image motion of the stimulus, whereas stereoscopic presentation had no significant effect on vection. These results are in line with previous experimental results on vection of our own (Freeman et al., 2000) and of Ohmi (1998). They are in conflict, however, with Palmisano (1996) who reported increased vection with stereoscopic presentation using moving-dot stimuli. Simple explanations for this discrepancy might be a dissociation between online and post-test measures, or between subjective judgments and reaction-time measures. For example, it is possible that a latency measure, as used by Palmisano, would reveal an effect of viewing condition on vection. Alternatively, however, the discrepancy in results between our studies and that of Palmisano (1996) may be an interesting consequence of using real-world visual stimuli. In our video stimuli, spatial layout is specified by many cues such as interposition, texture gradients, and perspective. Palmisano's moving-dot stimuli had none of these cues. His monoscopic display can be regarded as quite ambiguous with respect to the array of dots, which could have been perceived as expanding outwards at an accelerating rate in the display plane, or coming towards the observer. In Palmisano's stimuli, stereo fixed the position of each point source in space, emphasizing the movement of the dots towards the observer. It is thus possible that, in the absence of other sources of information signaling the direction of movement, stereoscopic information can drive vection, as shown by Palmisano (1996). In our studies, as in Ohmi (1998), many other sources of information were available that signaled movement towards the observer. It is possible that, as such cues were present, adding stereo had no discernible effect on vection. Taken together, our results and those of Ohmi and Palmisano support the idea that vection is controlled by the extent of information in a display conveying motion towards an observer.

Involvement ratings followed a pattern similar to that of presence, although whereas stereoscopic presentation significantly enhanced presence, it did not affect involvement significantly. Recent factor-analytic insights into the structure of presence suggest that involvement constitutes part of the presence experience. Schubert et al. (1999) arrived at a three-factor solution for the presence construct: "spatial presence," "involvement," and "realness." Lessiter et al. (2000) identified a very similar factor structure for presence: "physical space," "engagement," "naturalness," and "negative effects." It makes sense to assume that stereoscopic presentation has a more pronounced effect on the spatial presence/physical space component of presence relative to the involvement/engagement component.

The postural results provided weak support for the hypothesis that adding stereoscopic information may increase the postural responses to displayed motion, in line with the subjective results and results from earlier experiments. The results from the curved/noncurved split seem to suggest that lateral motion in the image and stereoscopic presentation both have an independent effect on observers' lateral postural movements, and that they are summated linearly when combined.

The fact that the postural responses did not differentiate between different screen sizes does not bode well for the utility of postural responses as an objective corroborative measure of presence. This is especially relevant given the fact that the current results underline the importance of screen size for subjective presence ratings. However, we cannot be conclusive in either embracing or discarding postural responses as a potential measure of presence. First, the postural responses measured in the current study were quite noisy, leading us to discard eight out of twenty-four participants from further analysis. Perhaps a different measurement technique of postural responses, such as a balance platform or stabilometer, would provide a more stable measure in this regard. Another option would be to have participants sit down in a car seat that contains an array of pressure sensors to measure the change in weight distribution as the participant's body moves to compensate for the illusory centrifugal forces generated by the visual display. With the rally car material used in the current experiment, this measurement method would have the added advantage of being matched to the stimulus context, thereby increasing the ecological validity of the experiment.

Second, an additional issue of concern is that the larger display also illuminated more of the ambient field (the otherwise darkened laboratory) than did the smaller display, thus potentially providing orientation cues that may have compensated for an effect of screen size on postural responses. To investigate this possibility, an experiment will need to be performed using, for instance, a head-mounted display with the ability to completely exclude the physical world, so that a larger field of view does not result in greater illumination of the surrounding area.

In sum, the experiment presented in this paper has clearly shown effects of stereoscopic presentation, image motion, and screen size on subjective presence ratings. The effect of screen size was only apparent when motion stimuli were used, an effect attributed to the increased motion sensitivity of peripheral vision. Ratings of self-motion did not increase significantly with stereoscopic presentation, which can be explained by the visual richness of our video stimuli. With our stimuli, stereo could not provide much additional movement information, unlike the moving-dot stimuli Palmisano (1996) used. From the point of view of objective measurement of presence, the current results were somewhat disappointing. Although observers' postural responses appeared to be sensitive to stereoscopic presentation relative to monoscopic presentation, there was no between-subjects effect of screen size. Such an effect would clearly be expected, both from the literature as well as from our own subjective presence ratings. However, further experimentation is needed to be able to be more conclusive about the utility of postural responses as an objective corroborative measure of presence.

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References

ACTS MIRAGE project. (1997). *Eye to Eye* [Stereoscopic film]. [On-line]. Available: http://www.itc.co.uk/mirage/MIR3D008.htm

Barfield, W., Zeltzer, D., Sheridan, T., & Slater, M. (1995). Presence and performance within virtual environments. In W. Barfield & T. A. Furness, III (Eds.), *Virtual Environments and advanced interface design* (pp. 473–513). New York: Oxford University Press.

Bhatia, B. (1975). Minimum separable as function of speed of a moving object. *Vision Research, 15,* 23–33.

Brown, B. (1972). Resolution thresholds for moving targets at the fovea and in the peripheral retina. *Vision Research, 12,* 293–304.

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,* 1–13.

Freeman, J., Avons, S. E., Meddis, R., Pearson, D. E., & IJsselsteijn, W. A. (2000). Using behavioral realism to estimate presence: A study of the utility of postural responses to motion stimuli. *Presence: Teleoperators and Virtual Environments, 9,* 149–164.

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

Hoshino, M., Takashi, M., Oyamada, K., Ohmi, M., & Yoshizawa, T. (1997). Body sway induced by 3D images. *Proceedings of the SPIE, 3012,* 400–407.

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

IJsselsteijn, W. A., de Ridder, H., Freeman, J., & Avons, S. E. (2000). Presence: Concept, determinants and measurement. *Proceedings of the SPIE, 3959,* 520–529.

Lee, D. N., & Aronson, E. (1974). Visual proprioceptive control of standing in infants. *Perception and Psychophysics, 15,* 529–532.

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

Lessiter, J., Freeman, J., Keogh, E., & Davidoff, J. (2000). Development of a new cross-media presence questionnaire: The ITC-Sense of Presence Inventory. In W. A. IJsselsteijn, J. Freeman, & H. de Ridder (Eds.), *Proceedings of PRESENCE 2000—3rd International Workshop on Presence,* (CD-ROM), Delft, The Netherlands.

Lombard, M., Ditton, T., Crane, D., Davis, B., Gil-Egui, G., Horvath, K., & Rossman, J. (2000). Measuring presence: A literature-based approach to the development of a standardized paper-and-pencil instrument. In W. A. IJsselsteijn, J. Freeman, & H. de Ridder (Eds.), *Proceedings of PRES-*

ENCE 2000—3rd International Workshop on Presence (CD-ROM), Delft, The Netherlands.

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

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

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 [On-line]. Available: http://www.hitl.washington.edu/publications/r-98-11/.

Prothero, J. D., & Hoffman, H. (1995). *Widening the field-of-view increases the sense of presence in immersive virtual environments.* (HITLab Technical Report R-95-5). [On-line]. Available: http://www.hitl.washington.edu/publications/r-95-5/

Schubert, T., Friedman, F., & Regenbrecht, H. (1999). *Decomposing the sense of presence: Factor analytic insights.* Paper presented at the 2nd International Workshop on Presence, University of Essex, UK, April 1999 [On-line]. Available: http://www.uni-jena.de/~sth/vr/insights.html.

Stanney, K., & Salvendy, G. (1998). Aftereffects and sense of presence in virtual environments: Formulation of a research and development agenda. *International Journal of Human-Computer Interaction, 10,* 135–187.

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