# Towards an Objective Corroborative Measure of Presence: Postural Responses to Moving Video

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## 1. Introduction

The current pace of technological development in networks, computing power and displays, as well as improvements in human-system interfaces, enable the creation of services that are capable 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 non-interactive media, and applications in areas such as training and education, telecommunications, medicine, and 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 remote or 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, robust and valid methodology for measuring presence.

### 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 (Freeman, 1999; IJsselsteijn, de Ridder, Freeman & Avons, 2000). The majority of presence studies use questionnaires and rating scales to assess the presence experience. These subjective methods have the advantage that they do not disrupt the media experience, are easy to administer, and seem to have face validity. However, they are not without drawbacks. Subjective measures are known to be potentially unstable, with inconsistencies across different raters and rating situations. In addition, subjective presence ratings can also be biased by previous experience, e.g. through rating a different attribute in a previous session (Freeman, Avons, Pearson & IJsselsteijn, 1999).

One solution to the problem of instable subjective, post-test ratings is to use well-designed and detailed questionnaires which have been piloted on a wide variety of media, content, and individuals. This approach has been adopted by a number of research groups (Lessiter, Freeman, Keogh & Davidoff, 2000; Lombard, Ditton, Crane, Davis, Gil-Egui, Horvath & Rossman, 2000; Schubert, Friedmann and Regenbrecht, 1999; Witmer and Singer, 1998).

An alternative approach is to circumvent subjective assessment altogether by measuring those user responses that are produced automatically and without conscious deliberation, but 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 *behavioural* *realism* approach was proposed, which 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 (Freeman, Avons, Pearson, Meddis & IJsselsteijn, 2000). Based on this principle, a variety of objective corroborative measures can be formulated (see IJsselsteijn *et al*., 2000, for a discussion of several potential presence measures). Using such an objective corroborative measure of presence has the advantage of diminishing the likelihood that the subject 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 subjective report of presence (Freeman *et al.*, 2000).

It is important to note that potential behavioural measures of presence, such as postural response, skin conductance response or heart rate may also be sensitive to manipulations that do not affect subjective presence. Conversely, none of the objective corroborative measures that have been used or proposed to date will be sensitive to *all* possible medium or content manipulations that may affect the user's subjective sense of presence. Thus, it is highly unlikely that we will arrive at one *overall* objective corroborative measure. Rather, the objective measure that is being used as a presence measure should be selected for particular applications, according to their function. They should also be highly correlated to a well-established subjective measure of presence to ensure validity of the objective measure taken. Thus, we arrive at an *aggregate* measurement of presence that can reasonably be expected to be reliable, robust and valid (IJsselsteijn *et al*., 2000).

## 1.2 Postural responses

There are a number of different sources of information which may be used to control balance and posture. These include information from the receptors in feet and ankle joints, information from the vestibular organ, 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 do not only occur as proprioceptive responses but also in 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 to the behavioural realism paradigm.

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 postural responses occurred in the same direction as the centrifugal acceleration presented on the display. 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 these display manipulations have been shown to have an effect on presence (Prothero & Hoffman, 1995; Hendrix & Barfield, 1996; IJsselsteijn, de Ridder, Hamberg, Bouwhuis & Freeman, 1998; Freeman *et al*., 1999), no explicit subjective presence measure was reported in these postural response studies to enable a firm conclusion.

Following the behavioural realism paradigm, Freeman *et al*. (2000) recently reported a study on the utility of postural responses as a measure of presence. They found a positive effect of stereoscopic presentation on the magnitude of the postural responses, as well as on a subjective measure of presence, although the two measures were not significantly correlated per subject. The current study can be regarded as a replication and follow-up of the Freeman *et al.* (2000) study. Since FOV has previously been shown to affect postural responses (Hoshino *et al*., 1997) as well as presence ratings (Prothero & Hoffman, 1995), we wanted to perform a study using a display with a larger FOV than the one used in Freeman *et al*., which covered a horizontal visual angle of 28 degrees. We hypothesised that by using a larger display we should be able to replicate our earlier findings and, preferably, obtain clearer and more significant results in the expected direction, i.e. increased presence ratings as well as more pronounced postural responses to stimuli containing motion and to stereoscopically presented stimuli.

## 2. Method

### 2.1 Subjects

Twenty-four students of the University of Essex (13 female, 11 male, average age 23.5 years, age range 18-30) participated in the experiment for which they were paid 2 GBP. Only subjects with a height of under 1.85 m were invited to participate in the experiment. All had normal or corrected to normal vision and a stereo-acuity of 30 sec-arc or better (as tested on the RANDOT random dot stereotest, Stereo Optical Co., Inc., Illinois, USA).

### 2.2 Apparatus

Observers viewed the stimulus films on a large curved stereoscopic projection display, with an image size of 50 degrees visual angle horizontally. Two synchronised Panasonic M2 (A750-B) video players provided the video input for the two projectors. These projectors had differently polarised filters placed in front of each, so that left and right eye images could be separated by wearing polarised spectacles. A Flock of Birds (FOB) magnetic position tracker (Ascension Technology Corporation, Burlington, VT, USA) was positioned at the base of the observers' necks, and was used to collect the observers' x, y, z positions for each measured period. The FOB was connected to a standard PC running custom software that controlled both the video players and sampled the x, y, z positions at 12.5 Hz. (see figure 1).

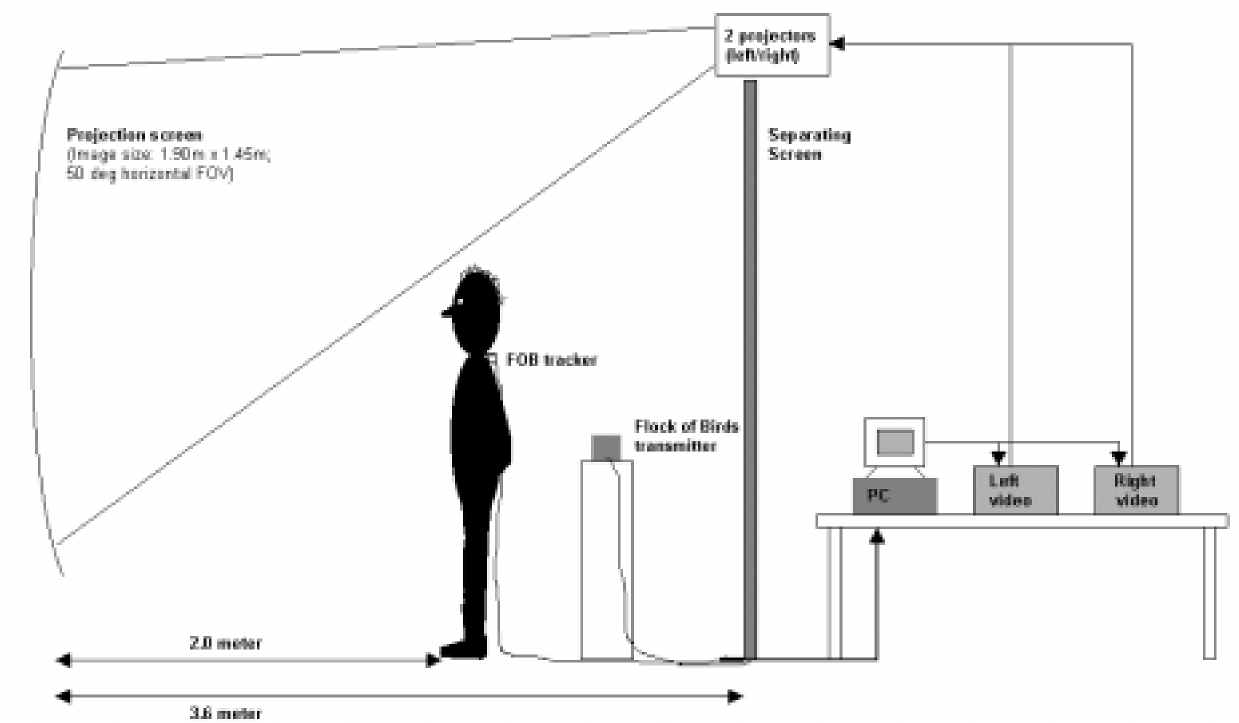


**Figure 1.** Schematic diagram of the laboratory set-up illustrating the observer's position in relation to the display. The observer's area of the laboratory was completely blacked out during the experimental sessions, with the only illumination coming from the projection display.

## 2.3 Design

Two factors were manipulated in this experiment: viewing condition (monoscopic or stereoscopic) and motion (still or moving), both as within-subjects factors (repeated measures design). 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 subject could see two moving or two still stimuli consecutively. This was done in order to minimise the possibility of motion sickness with the moving stimuli. In addition to the postural response measurement, the dependent measures included subjective ratings of presence, vection and involvement. Also, a subjective rating of (motion) sickness was included for control purposes. 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.

## 2.4 Stimuli

The moving video consisted of a 100 second 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 camera positioned on the bonnet of a rally car travelling at speed around an off-road rally track. This video was selected because it included large amounts of motion parallax from the speed the car was travelling. Although the predominant movement was in the forward direction, there were a number of sharp turns at which significant lateral movement was present. The still video stimulus consisted of a still frame from the earlier mentioned ‘Eye to eye’ footage, where the camera is situated by the side of the rally track awaiting a drive-by by the rally car. 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. Subjects were required to wear the polarised spectacles for all stimulus conditions.

## 2.5 Procedure

On arrival at the laboratory, subjects 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 upright in a relaxed and comfortable position with their feet within the marker lines on the floor, indicating a distance of 2 meters to the stereoscopic projection display. After each 100 second sequence the screen cut to black and a small light was switched on to allow the subjects to fill out the rating scales relating to the stimulus they had just watched. After the four sequences were completed, the experimenter tested the subject’s stereo-acuity. This was done after the experiment in order not to prime subjects on stereoscopic or 3D material, since this may influence subsequent presence ratings (Freeman *et al*, 1999).

## 3. Results and Discussion

### 3.1 Subjective Ratings

Figure 2 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. We carried out a 2x2 ANOVA to test the main effects and interactions for statistical significance. The results of these ANOVAs are summarised in table 1.

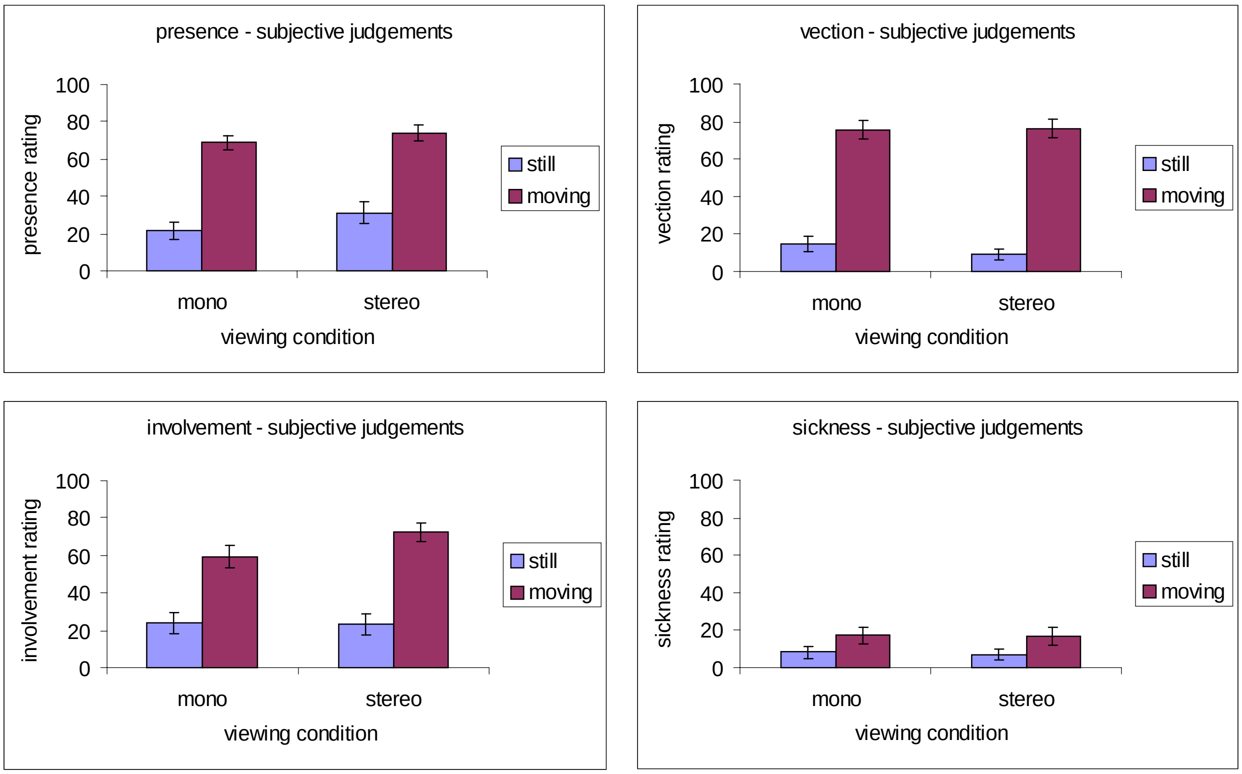


**Figure 2.** Effects of viewing condition and motion content on the group mean subjective ratings of presence, vection, involvement and sickness. Bars indicate standard errors.

As can be derived from figure 2, and is statistically supported by the analyses presented in table 1, motion has a large and significant effect on the subjective judgements of presence, vection and involvement. The effect size of motion is considerably larger than that of viewing condition. In fact, the effect of viewing condition only reaches significance for the presence ratings. There is a small, non-significant effect of motion on reported sickness, with overall level of reported sickness being low. There is no significant interaction between viewing condition and motion for any of the subjective ratings.

| | Viewing (stereo/mono) | Motion (still/moving) | Viewing x Motion |
|---|---|---|---|
| Presence | **F(1,23)=6.811, p<0.05** | **F(1,23)=84.725, p<0.001** | F(1,23)=0.644, n.s. |
| Vection | F(1,23)=0.937, n.s. | **F(1,23)=155,80, p<0.001** | F(1,23)=1.418, n.s. |
| Involvement | F(1,23)=2.358, n.s. | **F(1,23)=68.723, p<0.001** | F(1,23)=4.084, p=0.055 |
| Sickness | F(1,23)=0.39, n.s. | F(1,23)=3.318, p=0.082 | F(1,23)=0.063, n.s. |

**Table 1**. Statistical results (2x2 ANOVA) for the subjective ratings (n=24). Significant results are indicated in bold.

The significant effect of both viewing condition and motion on presence is consistent with results from earlier experiments showing independent effects of viewing condition and motion on subjective presence ratings (IJsselsteijn *et al*., 1998; Freeman *et al*., 1999), and with other studies (Hendrix and Barfield, 1996). When we compare these results to the results reported in Freeman *et al*. (2000), we notice that the effect of viewing condition in our current study is smaller (although still significant) and the effect of motion larger. This may be due to fact that, in the current study, stimuli were presented using a larger FOV (50 deg. horizontally versus 28 deg. horizontally), which emphasises the psychological impact of motion stimuli since a larger portion of peripheral vision is being stimulated. The peripheral retina is known to be especially sensitive to high velocity stimulus motion (Coren & Ward, 1989, p.381), as was the case in our experiment. When we compare the absolute levels of the mean presence ratings between experiments, we find higher ratings of presence for moving stimuli in the current experiment, irrespective of viewing condition, whereas the still stimuli receive very similar ratings in both experiments. This supports the suggestion that motion stimuli have a larger psychological impact with a larger FOV.

Vection ratings are clearly and significantly affected by the motion content of the stimulus, whereas stereoscopic presentation had no significant effect on vection. These results are in line with our earlier experimental results on vection (Freeman *et al*, 2000) and results reported by Ohmi (1998). They are in conflict however, with Palmisano (1996) who reported increased vection with stereoscopic presentation using moving dot stimuli.

Involvement ratings follow a pattern similar to that of presence, although whereas stereoscopic presentation significantly enhanced presence, it does 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 3-factor solution for the presence construct: 'spatial presence', 'involvement', and 'realness'. Recently, Lessiter *et al*. (2000) have 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.

## 3.2 Postural responses

In analysing 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 seconds, so for each smoothed position 13 data points were averaged together. The total distance moved in each condition was then calculated across each 100 second 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 subject had taken a (small) step to the left or right. This was potentially a compensating movement to keep balance, and unlikely to correlate in any predictable way to the presented stimuli. Indeed, we were unable to identify a significant pattern in the number or sizes of these peak responses. Given the extraordinary impact of these peaks on the analysis of the dataset however, we decided to exclude from further analyses those subjects that showed, in one or more conditions, a lateral movement larger than plus or minus 10cm. Using this criterion, the data of 16 subjects were further analysed.

Figure 3 illustrates the effects of motion and viewing condition on the group mean lateral postural responses. The effects of motion and viewing condition are in the expected direction, i.e. 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 vs. moving) almost reached statistical significance ($t=1.826$, $df=15$, $p=0.088$).

Although somewhat noisy, the postural results do provide support for the hypothesis that adding stereoscopic information may increase the postural responses to displayed motion. This provides weak support for the use of postural responses as a measure of behavioural realism, in particular for evaluating displays intended to provide a sense of movement. Although results from both the subjective ratings and the postural responses are in line with the results reported by Freeman *et al.* (2000), we were unable to obtain a clearer postural measure due to the instability of the subjects during the postural measurements. This may imply that for more immersive displays, postural response measures based on body sway could become problematic, since obscuring the ground reference plane may lead to considerable postural instability.

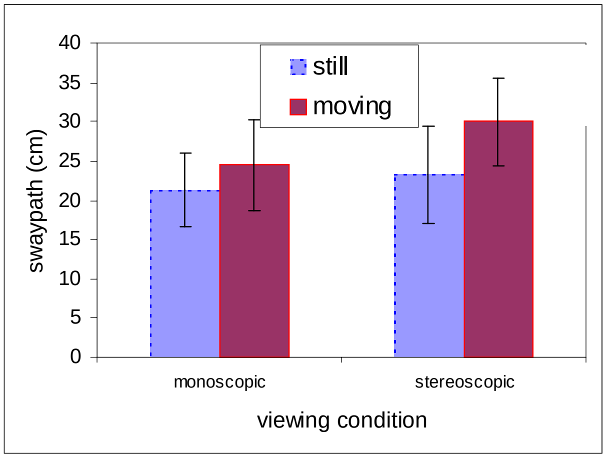


**Figure 3**. Effects of motion and viewing condition on the group mean lateral postural responses (n=16).

## 4. Acknowledgements

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## 5. References

ACTS MIRAGE project (1997) "Eye to eye" - stereoscopic film.
Online: http://www.itc.co.uk/mirage/MIR3D008.htm

Coren, S. & Ward, L.M. (1989). *Sensation and perception.* Harcourt Brace Jovanovich, Inc., San Diego.

Freeman, J. (1999). Subjective and objective approaches to the assessment of presence. PhD thesis, University of Essex, UK.

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 behavioural realism to estimate presence: A study of the utility of postural responses to motion stimuli. *Presence: Teleoperators and Virtual Environments*, in press.

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*, in press.
Online: http://www.ipo.tue.nl/homepages/wijssels/SPIE_HVEI_2000.pdf

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. To be presented at PRESENCE 2000 - 3rd International Workshop on Presence, Delft, The Netherlands, 27-28 March 2000.
Online: http://homepages.gold.ac.uk/immediate/P2000-lessiter.htm

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. To be presented at PRESENCE 2000 - 3rd International Workshop on Presence, Delft, The Netherlands, 27-28 March 2000.
Online: http://nimbus.temple.edu/~mlombard/P2000.htm

Ohmi, M. (1998). Sensation of self-motion induced by real-world stimuli. *Selection and Integration of Visual Information: Proceedings of the International Workshop on Advances in Research on Visual Cognition*, Tsukuba, Japan, December 8-11, 1997, 175-181.

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

Prothero, J.D. (1998). The role of rest frames in vection, presence and motion sickness. PhD thesis, University of Washington, USA.
Online: 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.
Online: 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 Worshop on Presence, University of Essex, Colchester, UK, 6-7 April 1999.
Online: http://www.uni-jena.de/~sth/vr/insights.html

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