Measuring Vection in a Large Screen Virtual Environment*

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Abstract

This paper describes the use of a large screen virtual environment to induce the perception of translational and rotational self-motion. We explore two aspects of this problem. Our first study investigates how the level of visual immersion (seeing a reference frame) affects subjective measures of vection. For visual patterns consistent with translation, self-reported subjective measures of self-motion were increased when the floor and ceiling were visible outside of the projection area. When the visual patterns indicated rotation, the strength of the subjective experience of circular vection was unaffected by whether or not the floor and ceiling were visible. We also found that circular vection induced by the large screen display was reported subjectively more compelling than translational vection. The second study we present describes a novel way in which to measure the effects of displays intended to produce a sense of vection. It is known that people unintentionally drift forward if asked to run in place while blindfolded and that adaptations involving perceived linear self-motion can change the rate of drift. We showed for the first time that there is a lateral drift following perceived rotational self-motion and we added to the empirical data associated with the drift effect for translational self-motion by exploring the condition in which the only self-motion cues are visual.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality H.5.1 [Information Systems]: Multimedia Information Systems—Artificial, augmented, and virtual realities

Keywords: virtual environments, locomotion, self-motion perception, vection

1 Introduction

Figure 1: Wheelchair setup in front a large projection screen with a 3-dimensional model of a 280 meter street in Virtual Tübingen

Vection refers to the sensation of self-motion elicited by a moving visual stimulus [Fischer and Kornmüller 1930]. Vection percepts are commonly divided into *circular vection*, associated with rotational motion around a vertical axis centered on the viewer, and *translational vection*, involving straight-line movement. A frequently discussed occurrence of linear vection occurs when a person sitting in a stationary vehicle views another vehicle in motion and incorrectly perceives themselves to be moving. The majority of the perceptual studies of vection have dealt only with rotation, typically generating the visual stimulus utilizing a rotating optokinetic drum marked with a textured pattern, often consisting of black and white vertical stripes [Brandt et al. 1973; Dichgans and Brandt 1978; Howard and Howard 1994; Rieser et al. 1995]. Fewer studies address perception of linear vection [Lepecq et al. 1993; Harris et al. 2000]. These investigations have typically used textured visual stimuli such as random dot patterns. Recently, circular vection has successfully been induced and studied in virtual environments (VEs) using more realistic stimuli [Hettinger 2002; van der Steen and Brockhoff 2000; Riecke et al. 2005a; Riecke et al. 2005b; Schulte-Pelkum et al. 2004].

This paper reports on investigations of both linear and circular vection induced by viewing a large virtual reality projection screen. We focus on the situation in which the intent is to produce a sense of self motion in a physically stationary observer. While real walking seems to produce a greater sense of presence than does passively presented visual motion [Usoh et al. 1999], it is often the case that a sense of immersion in virtual environments needs to be produced with out physical movement of the user. We consider the question of whether or not the level of immersion (seeing a visible reference frame) makes a difference in the experience of vection. We also introduce a measure of vection involving blindfolded running-in-place after viewing a moving visual stimulus and suggest that this might complement more subjective measures.

Most virtual environments aim to be *visually immersive*, with no visual cues available to users about the display device itself or the

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real physical space in which the user is actually present. Visual immersion is thought to increase the cognitive sense of *presence* in the virtual world by removing visual stimuli not consistent with that virtual world. Visual immersion is also intended to increase the degree to which perception reflects the virtual world, since real world perceptual cues are reduced or eliminated. There are practical limits, however, to the degree of visual immersion that can be obtained with image displays. This is particularly true of projection-screen based systems, except for the special case of totally enveloping displays such as CAVEs. The importance of complete visual immersion in inducing vection is not clear. Visually apparent screen boundaries or other aspects of the stationary physical world might serve as a frame of reference indicating that the viewer is not moving. However, perception of real self-motion is not hindered by viewing one's own body or the vehicle in which one is traveling, both of which are stationary with respect to the viewer. It might be the case that the perceptual system treats the "real" parts of a virtual environment in the same manner. Screen boundaries might serve to introduce a perceputal depth ordering that facilitates vection based on the displayed image [Ohmi et al. 1987; Howard and Heckmann 1989]. Finally, it is possible that screen boundaries and the like provide a low-level frame of reference for optic flow, enhancing the perception of the speed of self-motion based on flow.

The most commonly used measure for circular vection are introspective reports using a joystick, such as the moment when vection first occurs (*onset time*) or saturates, the perceived self-motion velocity, the intensity and convincingness of the illusion and the vection aftereffect. For excellent overviews see [Brandt et al. 1973; Dichgans and Brandt 1978; Hettinger 2002; Warren and Wertheim 1990]. Pointing tasks have also been used to investigate if perceived self-motion also results in a shift in the egocentric location of previously seen targets [Lepecq et al. 1993].

Introspective measures of vection suffer from problems with variability and cognitive bias that are often associated with verbal reports of perceptual phenomena. With the pointing task, it is difficult to develop a pointing paradigm that can distinguish between perceived self-motion or world-motion. Riecke et al. [Riecke et al. 2004] showed that visual information of a naturalistic, well-known scene was enough to induce rapid spatial updating, but they made no claims about whether or not this is due to the experience of vection. In fact, a control experiment suggested that spatial updating can happen even in the complete absence of any motion cues [Riecke et al. 2005c]. Lepecq used a pointing task to claim that linear vection was in fact occurring, but his experimental paradigm was not able to distinguish between self-motion and world motion [Lepecq et al. 1993].

2 Introspective Measures of Vection

Our first experiment investigated linear and circular vection by providing visual stimuli for both forward/backward translational self-motion and rotational self-motion. Visual stimuli were presented on a large, curved projection screen. On some trials, participants had a view of the screen that included portions of the floor and ceiling of the room. On other trials, field of view was limited to an area just within the boundaries of the screen. The effects of different rates of visual acceleration and deceleration were also evaluated.

2.1 Methods

16 naive participants completed the experiment, with ages ranging from 17 to 42 years (mean: 25.6). Participants were paid for their participation in the experiment and each experimental session was 90 minutes in length.

Figure 2: Full vertical FOV and restricted FOV setup in wheelchair

2.1.1 Stimuli and apparatus

For this experiment participants were seated in a wheelchair that had black cloth blocking the light from all sides but the front (Figures 1–2). The wheelchair was used only to constrain viewing conditions and was not used to move the participant. The fixed viewing position eliminated the need for active head tracking. Participants viewed the stimulus monocularly. River sounds played through noise canceling head phones were used during all four sessions to mask auditory localization cues. Attached to the wheelchair was a chin-rest and a removable field of view (FOV) limiter that allowed us to easily change from a full vertical FOV that excluded only the ability to see the wheelchair and ones feet to a limited vertical FOV that allowed only the viewing of the screens. The large screen provided a possible 220° horizontal FOV by 50° vertical FOV from the viewing location. The visual display was based on Virtual Tübingen, a high fidelity model of the central village of Tübingen, Germany. To investigate translational motion, participants were presented with a view consistent with motion down a 280m long straight street (Figure 1). For rotational motion, participants viewed a scene consistent with rotation in place at a location near the center of the marketplace square.

2.1.2 General procedure

Participants started with an initial training phase to familiarize them with the nature of the experiment. The experiment itself involved four sessions for each participant. The first two sessions utilized the translational display, the second two used the rotational display. In each pair of sessions (translation/rotation), one session was done with the vertical field of view restriction and the other where the floor and ceiling of the room was visible. The ordering of the field of view manipulation was balanced over the participants. Horizontal FOV remained unchanged in all conditions. The acceleration phase of each movement took either 0.5 seconds or 10 seconds to reach full velocity. The maximum linear velocity was 8 m/s and the maximum angular velocity was 30°/second. These acceleration and velocity rates were chosen based on subjective experience of vection prior to conducting the experiment. In all conditions, participants were asked to look at the entire screen and not to fixate at any given point on the screen.

During each translational or rotational visual movement participants were asked to report the intensity at which they felt they were

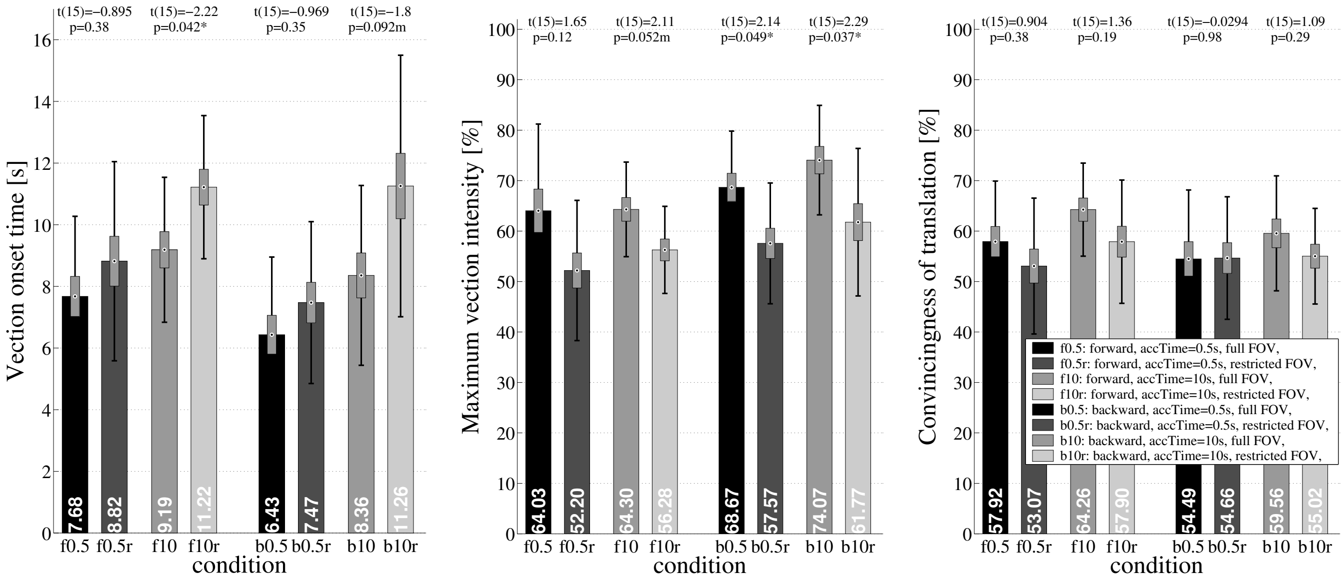

Figure 3: Linear Vection: Plotted are mean vection onset times, vection intensity and convincingness of vection for each of the experimental conditions investigating linear vection. Boxes and whiskers depict one standard error of the mean and one standard deviation, respectively. The experimental conditions are explained in the figure legend.

moving in space using a joystick. Once they completed viewing the visual motion they were asked to continue to report movement if they felt any aftereffect. Then when the experience of vection had faded the participants were asked to rate how convincing their own self-movement was. When the participant was ready they started the next trial.

Overall between-subject differences in vection responses were removed using the following normalization procedure: Each data point per participant was divided by the ratio between the mean performance of that participant across all conditions and the mean of all participants across all conditions. This normalization procedure was done for each of the plots for introspective measures.

2.2 Results and Discussion

Figures 3 and 4 show the subjective measures of vection for the cases in which the visual information indicated either translational or rotational self-motion. There was a decrease in vection onset time and an increase in maximum vection achieved for linear vection when participants could see the room as opposed to only the screens. For circular vection there was no significant difference between full vertical FOV and screen-only FOV, though there was a slight trend for the screen-only FOV to improve the subjective experience of circular vection. Linear vection was less convincing than circular vection (58% versus 68%), even though participants indicated a similar maximum vection intensity rating (61% and 66%, respectively). The faster visual acceleration resulted in a faster vection onset time for both linear and circular vection.

The results show that a visible floor and ceiling enhanced the sense of translational vection. Whether this is due to the room providing a frame of reference to spatial orientation or lower-level effects associated with contrast in optic flow remains an open question, though during debriefing several of the participants stated that seeing the room increased the sense of self-motion because they saw the room as moving with them. It is as yet unclear why a similar effect was not observed for rotational motion. The results also indicate that faster visual accelerations improve the feeling of both circular and linear vection and that circular vection is reported to be slightly more convincing than linear vection, at least for the display used in this experiment.

3 Blindfolded running-in-place drift

To more completely understand the phenomenon of vection, it is desirable to complement subjective measures with measures that are less dependent on cognitive factors/instructions and can be more easily quantified and replicated [Lepecq et al. 1993]. Blindfolded running in place shows promise as one such measure. Normally, a person asked to run in place while blindfolded will in fact unknowingly drift forward an average distance of about 40cm in 15 seconds [Anstis 1995]. This rate of drift is subject to adaptation effects [Anstis 1995; Durgin et al. 2000; Proffitt et al. 2003; Durgin et al. in press]. For example, blindfolded walking/running on a treadmill increases the blindfolded running/walking in place drift. If people walk on a treadmill while viewing computer graphics consistent with forward motion, this drift is significantly reduced [Durgin et al. 2000]. Durgin et al. (in press) argues that the altering of the drift effect is due to a conflict between the biomechanical actions associated with self-motion and other perceptual indications of self-motion. This suggests that drift during blindfolded running-in-place might be affected by the degree to which a person experiences vection during a preceding adaptation phase. To our knowledge, the experiment described below is the first to investigate how the running-in-place drift effect is alerted when only visual information is consistent with self-motion. It is also the first study to explore how circular vection influences blindfolded running in place.

In this experiment, we measured running-in-place drift before and after viewing a visual display presented on the same display device as used in the first experiment, but without use of the wheelchair and with different viewing restrictors. Circular motions consistent with turning in place to the left and turning in place to the right were displayed, as well as translational motions consistent with moving

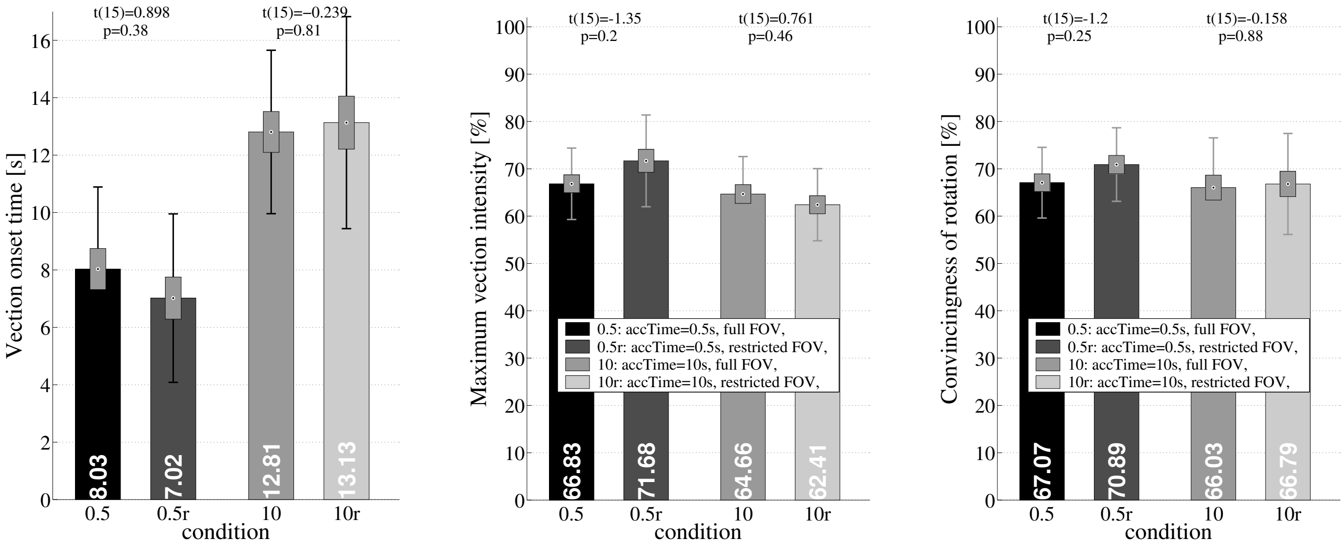

Figure 4: Circular Vection: Plotted are mean vection onset times, vection intensity and convincingness of vection for each of the 4 experimental conditions investigating circular vection. The data was pooled over left and right rotations. Boxes and whiskers depict one standard error of the mean and one standard deviation, respectively. The 4 experimental conditions are explained in the figure legend.

Figure 5: Panoramic image used for rotational intervention for running-in-place drift

forward and moving backwards. We also ask participants to report the convincingness of their perceived self-motion for each trial. Two different visual stimuli were used for circular vection. The two patterns had the same overall optic flow but had been shown in another study to result in different subjective reports of vection (one lower than the other) [Riecke et al. 2005a].

3.1 Running-in-Place Methods

Six participants completed the experiment, with ages ranging from 22 to 35 years (mean: 26). Each experimental session was 60 minutes in length.

3.1.1 Stimuli and Apparatus

Participants stood in front of a large screen projection and viewed either a panoramic image of Tübingen marketplace (See Figure 5), the same panoramic image vertically sliced (See Figure 6), or a 280 meter street in Virtual Tübingen. Participants wore headphones to block out noise. Goggles were used to limit the vertical field of view (Figure 7). Head tracking using VICON system with three cameras was used to record the position and orientation of the participant while they were running in place.

3.1.2 General Procedure

Drift while blindfolded running-in-place was measured before and after an adaptation phase involving observation of a visual display shown on the same large curved screen as used in the previous experiment. The effect of adaptation to three different visual cues to self-motion were examined: translational motion through a rendering of the 280 meter street in Virtual Tübingen, rotational motion of a panoramic image of the Tübingen marketplace, and rotational motion of the same image vertically sliced so as to induce less subjective vection but a similar visual flow [Riecke et al. 2004]. The effects of translation were separately evaluated for forward and backward visual motion, both presented at a speed of 8 m/s for a duration of 30 seconds. The effects of rotation using both of the visual stimuli were separately evaluated for left and right motions, both presented with an angular velocity of 45°/second for a duration of 20 seconds. Acceleration and deceleration durations were 0.5 seconds in all cases.

In the pre-test, participants were blindfolded and asked to look

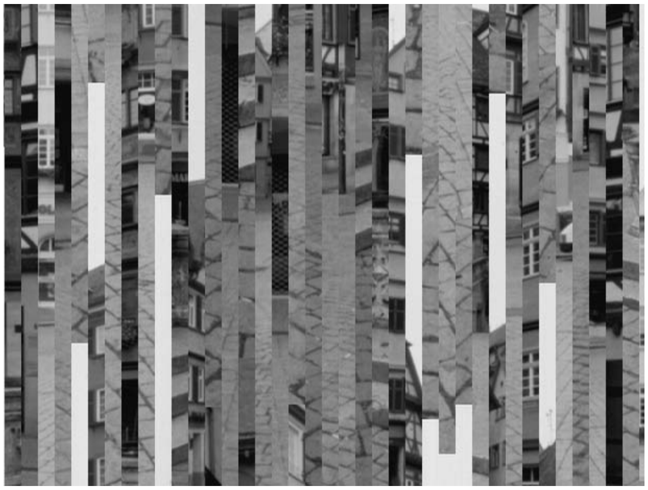

Figure 6: Vertically sliced panoramic image

Figure 7: The setup for our running-in-place experiment

straight ahead and attempt to run in place for 20 seconds. Then, in order to ensure that the participant did not receive feedback about their drift, they were guided in a circuitous path around the lab and back to the center of the room. After the intervention period participants were asked again to run in place. Each trial was separated by 3 minutes of rest, during which participants were asked to report the convincingness of the perceived self-motion in the previous trial. No other introspective measures were reported for this experiment.

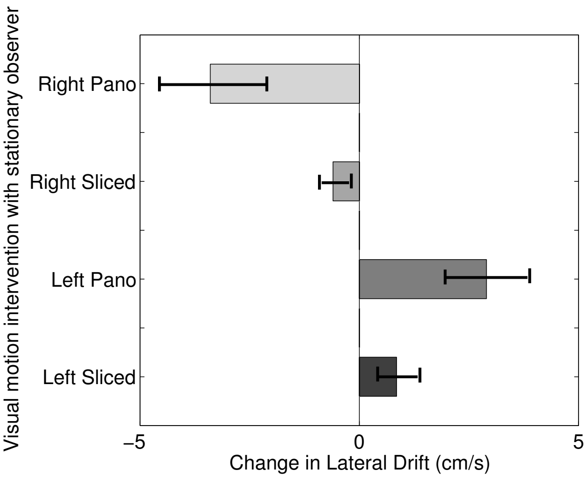

Figure 8: Average lateral drift for the rotating visual stimulus intervention. Note the larger increase in drift for the intact (unsliced) panorama image stimulus compared to the sliced stimulus. This parallels the convincingness ratings for vection, which were also larger for the intact stimulus.

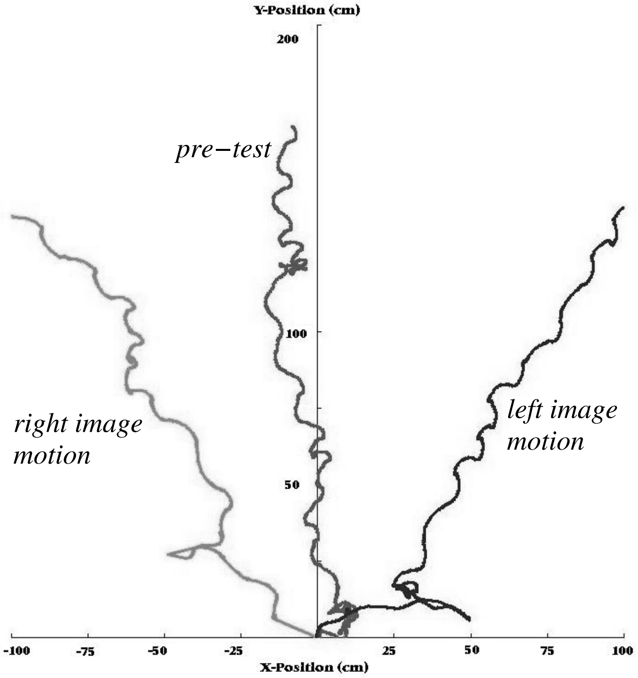

Figure 9: Running-in-place location for intact (unsliced) panorama rotation for Subject 1 for a duration of 20 seconds. Note the clear rightward and leftward shift corresponding to the leftward and rightward rotating vection stimulus respectively.

3.2 Results and Discussion

3.2.1 Rotational Interventions

As predicted by Riecke et al. [Riecke et al. 2005a], the intact (unsliced) stimulus yielded higher subjective convincingness ratings (60–70%) than the sliced stimulus (0–60%) for circular vection. Blindfolded running-in-place drift was also different for the two types of visual stimuli. The realistic rotating imagery produced a substantial lateral drift towards the direction of visually indicated self-rotation, averaging 2.9 cm/s for right rotation and 3.4 cm/s for left rotation. Little lateral drift occurred for the sliced panorama image, averaging 0.85 cm/s for right rotation and 0.6 cm/s for left rotation. Figure 8 shows a plot of the average lateral drift in either of these four cases. Figure 9 compares the pre-test trajectory of a representative subject to the post-test trajectories for left and right rotation of the realistic panorama image. Figure 10 shows the comparable plots for the sliced panorama image. Since the visual flow for the less compelling visual stimulus contained similar optic flow patterns (sliced) this argues that the perception of self-rotation (vec-

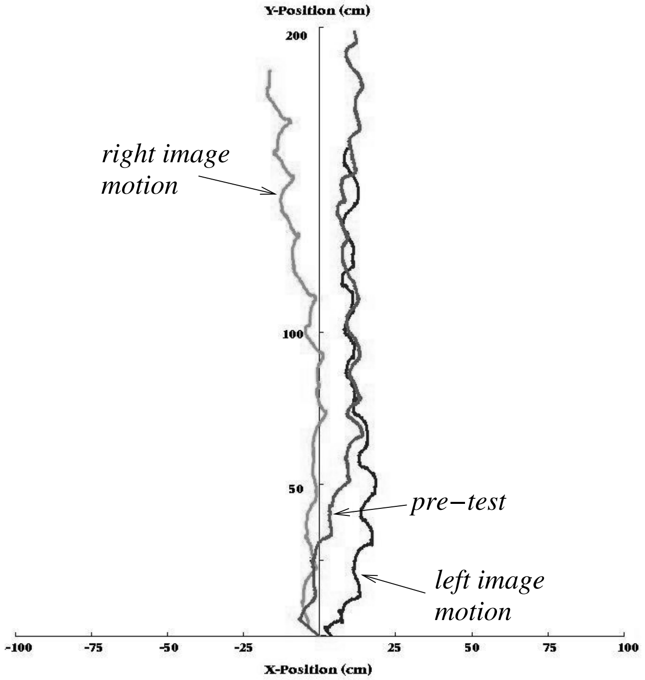

Figure 10: Running-in-place location for vertically sliced panorama rotation for Subject 1 for a duration of 20 seconds. The data show no effect of the rotation direction of the vection stimulus.

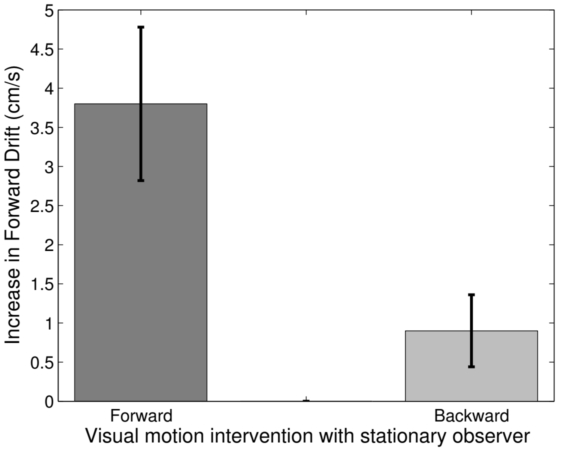

Figure 11: Average translational drift. Both visual interventions produced a clear increase in the forward drift. This effect was unexpectedly stronger for the forward stimulus.

tion) may be what altered the amount to which participants drifted to the right or the left of center.

3.2.2 Translational Intervention

Visual motion indicating forward translation through space significantly increased the forward drift during blindfolded walking in place compared to pre-adaptation results. Visual motion indicating backward translation through space also increased the forward drift during blindfolded walking in place compared to pre-adaptation results, but by a much smaller amount. For visual motion indicating forward travel, forward drift increased by 3.8 cm/s from pre- to post-test, while for visual motion indicating backward travel, forward drift increased by 0.85 cm/s from pre- to post-test (Figure 11). Convincingness for forward self-motion ranged from 70-80%. Convincingness for backward self-motion ranged from 0-50&.

3.2.3 Running-in-place drift as a measure of vection

Eyes open running over solid ground produces little change in drift during blindfolded walking [Durgin et al. in press]. Our data, however, shows that lateral drift increases when visual cues for circular vection are more compelling. Drift is also differentially affected by whether the visual cues for translational motion indicate forward or backward movement. At least for a stationary observer placed in an environment where the only cue to self-motion is visual, drift increases with the subjective sense of self-motion.

In our experiment participants had conflicting information about their own self-motion. Visual information indicated that participants were rotating or translating through space while all other information was consistent with standing in place. When participants experienced a convincing experience of visually-induced self-motion the amount of running-in-place drift increased. When participants were not convinced of their own self-motion the running-in-place drift did not increase or increased very little. More systematic measurements of both introspective measures and the running-in-place measurement would need to be completed to fully understand how closely this correlates. If a participant felt convinced of his own passive forward self-motion, Durgin's work suggests that the running-in-place drift should decrease [Durgin et al. in press]. However, our results involving visually-induced forward linear vection found that the drift increases. This argues that subjects may not be having a compelling experience of linear vection (though they report that they are by introspective measures). It could also be that the speed of the visual-motion affects the running-in-place drift by affecting the participants posture during the post-test. These issues need to be more thoroughly investigated before running-in-place drift can be used to measure vection.

4 Summary and Conclusion

This paper presents collected subjective data on the experience of linear and circular vection. It shows that allowing a person to see the portions of the room beyond the display screen decreases vection onset time and increases the maximum vection intensity for translation, but not for rotations. We also propose a new measure for evaluating one's experience of vection in a VE: the running-in-place drift effect. As scientists attempt to make VEs more efficient and more perceptually accurate for the experience of self-motion more measures will be needed to evaluate the effectiveness of these VEs for inducing the illusion of self-motion.

Fully understanding the components of a convincing experience of vection could have important implications for virtual environments. Large scale VEs are not easy to build and are expensive, especially if physical movement of the user is required. Being able to more easily induce the compelling illusion of self-motion would enable many more VE applications to be within a small laboratory setting.

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