Wider Stance Reduces Body Sway and Motion Sickness

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Abstract. Imposed visual oscillation in the body's anterior-posterior (AP) axis can induce changes in standing posture in both the AP and mediolateral (ML) axes. These changes tend to precede motion sickness. In unperturbed stance, ML body sway is strongly influenced by the distance between the feet during side-by-side stance. With the feet closer together ML sway is greater than when the feet are farther apart. Based on these findings, we reasoned that stance width might correlate negatively with the incidence of visually induced motion sickness. We varied the width of side-by-side stance (during exposure to AP visual oscillations). In a moving room, participants stood with their feet pressed together (0 cm), heel midlines 17 cm apart, or 30 cm apart. Room motion was a sum of sines between 0.1 and 0.4 Hz, with maximum amplitude of 1.8 cm. The magnitude of sway in the ML axis was reduced in the 30 cm condition, relative to the 17 cm and 0 cm conditions. The incidence of motion sickness was reduced in the 30 cm condition, relative to the 0 cm condition. Prior to the onset of motion sickness, head and torso movement differed between the Sick and Well groups. The results support the idea that posture is linked to motion sickness, and support the hypothesis that motion sickness incidence can be influenced by variations in stance width.

Introduction

Despite being a normal response to the perception of motion, the malaise of motion sickness incites physiological distress in as much as one third of the population (Murray, 1997). Ships, trains, aircraft, and automobiles are well-known culprits, inducing motion sickness in gravitoinertial force environments. Motion sickness has also been reported by users of virtual environments (e.g. fixed base flight simulators) and entertainment systems (e.g. wide-screen films and video games). It is this *visually induced motion sickness* that occurs with motion relative to the illuminated environment. For those individuals utilizing this technology, pilots for example, the occurrence of motion sickness can be particularly detrimental to training exercises and performance outcomes. Given the widespread use of such technology, there lies merit of the investigation into the etiology of visually induced motion sickness. Understanding its causal mechanisms will aid in developing approaches to predict and preclude its occurrence.

Multiple theories have attempted to explain the etiology of motion sickness, most of which are based on the concept of intersensory conflict. The notion of a discrepancy based on expected patterns of sensory stimulation and the current pattern of perceptual stimulation in the development of motion sickness has intuitive appeal. One failing of this theory is that it is virtually impossible for a scientist to know an individual’s history of sensory stimulation and predict such a conflict based on the current stimulation, leaving this theory unable to be tested.

The postural instability theory of motion sickness put forth by Riccio and Stoffregen (1991) states that motion environments could lead to instabilities in the control of movement, in general, and of bodily posture and orientation, in particular. This theory proposes that the development of such instabilities in postural control would precede motion sickness, and that motion sickness would occur only among persons who exhibited such postural instability. In several previous studies we have identified differences in postural activity (prior to the onset of subjective symptoms of motion sickness), between participants who later became motion sick and those that did not (e.g., Bonnet, Faugloire, Riley, Bardy & Stoffregen, 2006; Smart, Stoffregen & Bardy, 2002; Stoffregen & Smart, 1998).

Pertinent to the current study is the relationship of stance width (the distance between the feet in side-by-side stance) to parameters of normal body sway in unperturbed stance. Stance width is known to influence the magnitude of postural sway in the body’s mediolateral (ML) axis, such that widening the distance between the feet tends to decrease the magnitude of ML sway (e.g., Day, Steiger, Thompson, & Marsen, 1993; Kirby, Price, & MacLeod, 1987; Tarantola, Nardone, Tacchini, & Schieppati, 1997).

Of interest are previous findings that AP optical oscillation has led to significant increases in sway in the body’s ML axis, among participants who later became motion sick (e.g., Bonnet et al., 2006; Smart Stoffregen & Bardy, 2002; Stoffregen & Smart, 1998). Perturbed stance may differ from unperturbed stance, particularly in situations that may be associated with challenges to stance. Thus, manipulations that tend to reduce ML sway might reduce the incidence of motion sickness.

Would the effect of stance width on ML body sway occur in the context of imposed optical oscillations in the body’s AP axis? If so, would stance width be related to the incidence of motion sickness? Our study was designed to answer these questions. We also sought to determine whether motion sickness would be preceded by changes in body sway.

Method

Participants. Fifty-six students from the University of Minnesota participated in the study in exchange for course credit. There were 22 males and 34 females with a mean age of 20 years, ranging from 18 to 32 years. The mean height and weights were 170 cm and 68 kg; ranging from 150 cm to 189 cm and 43 kg to 98 kg, respectively. In addition to having corrected to normal or near normal vision, all participants stated they were in good health and free from a history of dizziness, falling or vestibular disorders. In preparation for the study, participants followed instructions to not eat four hours prior to their participation.

Apparatus. Large-field visual motion was generated by a moving room (e.g. Lishman & Lee, 1975). This was a three-sided square room (2.4 m on a side) with access provided through the non-constructed open wall in the rear of the room. The room, mounted on wheels, was moved by a computer-driven motor in one axis along rails (Figure 1a). The experimental optical stimulus oscillated the room with a sum-of-sines function comprised of ten sine waves ranging from 0.02-0.31 Hz (e.g. Bonnet et al., 2006). The maximum peak-to-peak amplitude of the room movement was 1.8 cm (Figure 1b.).

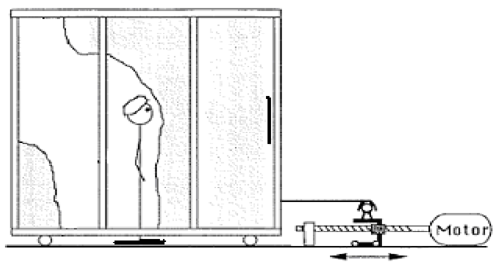

Figure 1a. Moving room.

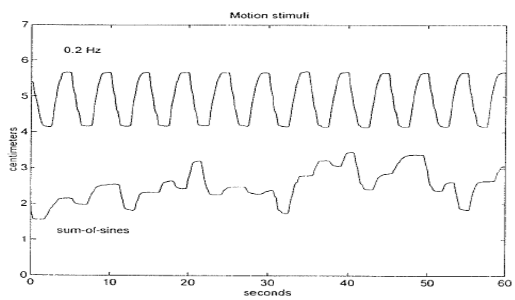

Figure 1b. Motion stimulus.

Procedure. All participants completed a simulator sickness questionnaire or SSQ (Kennedy, Lane, Berbaum, & Lilienthal, 1993) for several purposes. First, the pre-SSQ was utilized to assess an initial level of sickness symptoms prior to exposure to the optical stimulus. Second, it sidestepped false reports of sickness by ensuring familiarity with motion sickness symptomatology. Finally, the pre-exposure SSQ was used to compare against post-SSQ data collected at the conclusion of the experiment.

With the initial SSQ completed, participants were asked to stand with their eyes open on one foot for 30 seconds as a simple test of balance skills. Participants were randomly assigned to one of three stance conditions; heels pressed together (0 cm), heel midlines 17 cm apart, or 30 cm apart. The feet were rotated outward at an angle of 10˚ in each condition. Participants entered the moving room and were instructed to stand on one of three sets of lines marked on the surface of a force platform, each corresponding to one of the three experimental conditions.

The experiment consisted of up to eight trials. The description of the trials is presented in Table 1. During each trial, participants were instructed to stand comfortably with their hands at their sides, avoiding any unnecessary movement, and to keep their gaze within the confines of the map on the wall 1.5 meters in front of them. The instructions provided to the participants were to discontinue the experiment immediately upon experiencing any motion sickness symptoms. Upon completion of all the trials, participants completed a second SSQ (post-exposure). If a participant discontinued the experiment before completing all trials, they were given a second SSQ and asked to complete it upon experiencing symptoms after leaving the laboratory or at the end of 24 hours. Stoffregen (1985) noted that symptom onset was sometimes delayed up to an hour after exposure to the moving room. Additionally, Kennedy et al. (1993) found that symptoms of dizziness, disorientation and vertigo were sometimes experienced up to twelve hours after leaving a simulator. Finally, participants were encouraged to remain in the lab until they appeared free of symptoms and ataxia.

Table 1. The sequence of trials. A randomly generated sequence of the three stance conditions were used for the first three trials.

Trial	Condition
1	60 s, eyes open, no imposed motion
2	60 s, eyes open, no imposed motion
3	60 s, eyes open, no imposed motion
3 - 7	10 min, room motion of 0.1-0.4 Hz sum-of-sines, 1.8 cm amplitude, random stance assignment
8 - 10	repeat of trials 1-3

Results

Motion sickness incidence. Motion sickness incidence was 63% in the 0 cm condition (12 of 19 participants), 45% in the 17 cm condition (9 of 20) and 24% in the 30 cm condition (4 of 17). Incidence in the 0 cm condition (63%) did not differ significantly from the 17 cm condition

(45%). By contrast, the 24% incidence in the 30 cm condition was significantly less than that of the 0 cm condition, chi-square = 0.017, $p < 0.05$, indicating a relationship between stance width and motion sickness incidence.

Symptom severity. We analyzed the Total Severity Score (Kennedy et al., 1993). Within the Sick groups for each condition, the Wilcoxon Signed Ranks test revealed no significant difference between the pre-test and post-test SSQ scores in the 30 cm condition, but did reveal significant differences in the 0 cm and 17 cm conditions. In the 17 cm condition the post-test scores (Mean = 71.06) were significantly higher than the pre-tests scores (Mean = 14.96), $z = -2.668$, $p = 0.008$. Additionally, the post-test scores (Mean = 63.89) were significantly higher than pre-test scores (Mean = 13.40) in the 0 cm condition, $z = -2.987$, $p = 0.003$, indicating an increase in subjective reports of sickness symptoms.

Post-test SSQ scores differed significantly between Sick and Well Groups, $p < 0.05$, (Figure 2). For the post-test scores, the difference in rank between the Sick and Well groups was significant in each of the three conditions. Those participants that became sick reported a higher level of subjective sickness symptomatology than those that did not become sick. When participants stood with their heels 0 cm apart, the Mann-Whitney *U* test revealed higher scores for the Sick group (Mean Rank = 12.96) than the Well group (Mean Rank = 4.93), $U = 6.5$, $p = 0.003$. With the 17 cm condition, the Sick group post-test scores (Mean Rank = 15.22) were higher than Well group post-test scores (Mean Rank = 6.64), $U = 7$, $p = 0.001$. Finally, the Sick group post-test scores (Mean Rank = 15.25) in the 30 cm condition were again higher than the Well group post-test scores (Mean Rank = 7.08), $U = 1$, $p = 0.003$.

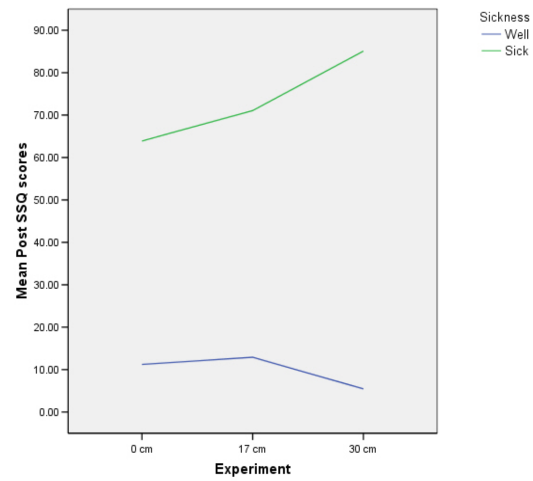

Figure 2. Mean Post SSQ scores of Sick and Well groups for stance condition.

Postural data

We analyzed postural motion during the sum-of-sines trials, comparing the three stance conditions. We expected that as stance width increased the variability of motion in the ML axis would decrease, and that a narrow stance width would result in increased variability of motion in the ML axis. We found a significant Condition × Axis interaction in the variability of torso movement, $F(2,49) = 4.175$, $p < .05$ (Figure 3). ML variability was reduced in the 30 cm condition, relative to the 17 cm and 0 cm conditions.

Figure 3. Variability in the velocity of torso movement.

We also compared movement in the Sick and Well groups. Using a procedure developed by Bonnet et al. (2006), we examined sway over time during exposure to room motion, evaluating the first two minutes, the middle two minutes, and the final two minutes of exposure. We found a significant Group × Time interaction on the velocity of torso motion, $F(2,98) = 3.436$, $p < .05$ (Figure 4).

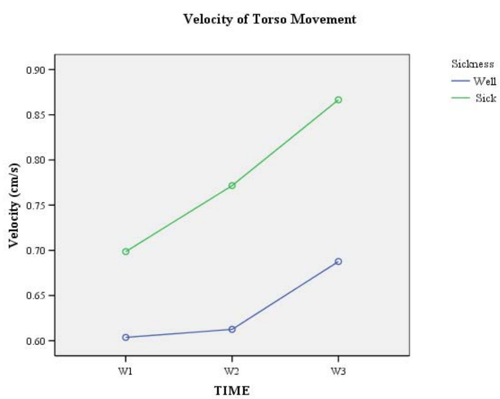

Figure 4. Velocity of torso movement.

Discussion

There were three important results. First, increasing stance width reduced the magnitude of postural sway in the ML axis, consistent with previous studies (Day et al., 1993; Kirby et al., 1987; Tarantola et al., 1997). Second, motion sickness was preceded by changes in postural activity, consistent with previous studies of visually induced motion sickness (Bonnet et al., 2006; Smart et al., 2002; Stoffregen & Smart, 1998), and consistent with the postural instability theory of motion sickness etiology (Riccio & Stoffregen, 1991). The third and most novel result was that the incidence of visually induced motion sickness was influenced by stance width. This result suggests that motion sickness incidence might be reduced by instructing users of (for example) video game systems to adopt a wider stance.

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