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Motion Sickness and Postural Sway in Console Video Games

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Objective: We tested the hypotheses that (a) participants might develop motion sickness while playing "off-the-shelf" console video games and (b) postural motion would differ between sick and well participants, prior to the onset of motion sickness. **Background:** There have been many anecdotal reports of motion sickness among people who play console video games (e.g., Xbox, PlayStation). **Method:** Participants (40 undergraduate students) played a game continuously for up to 50 min while standing or sitting. We varied the distance to the display screen (and, consequently, the visual angle of the display). **Results:** Across conditions, the incidence of motion sickness ranged from 42% to 56%; incidence did not differ across conditions. During game play, head and torso motion differed between sick and well participants prior to the onset of subjective symptoms of motion sickness. **Conclusion:** The results indicate that console video games carry a significant risk of motion sickness. **Application:** Potential applications of this research include changes in the design of console video games and recommendations for how such systems should be used.

INTRODUCTION

Motion sickness is common in flight and driving simulators, afflicting up to 80% of users (e.g., Stanney et al., 1998). Anecdotal reports of motion sickness have also become common among players of console video games (e.g., Strohm, 2007). Game publishers have issued warnings and guidelines relating to motion sickness (e.g., GameZone, 2005). Each year since 2001, more than 200 million computer and video game units have been sold in the United States (Entertainment Software Association, 2006). If these games induce motion sickness in even a small proportion of users, then the number of affected individuals could be in the millions. These considerations motivate research on ways to predict and prevent motion sickness among players of computer and video games.

Console Video Games

One popular type of game system consists of console video games, such as PlayStation, Xbox, and Wii. There have been few controlled studies using these game systems. Previous research has focused on game-like virtual environments that were developed for laboratory use (e.g., Stanney, Hale, Nahmens, & Kennedy, 2003; Stanney, Kennedy, Drexler, & Harm, 1999). These studies cannot directly assess the nauseogenic properties of commercial console video games. Commercial console video games tend to have greater realism, faster update rates, and more content-related decisions and interactions; these and other factors may influence the incidence and severity of motion sickness.

Merhi, Faugloire, Flanagan, and Stoffregen (2007) examined relations between motion sickness and commercially available console video games. Participants played one of two games on a standard Xbox system. Game play was continuous in a single session that lasted up to 50 min. Participants wore a head-mounted display unit, and the games were presented through this unit. More than 90% of standing participants reported becoming motion sick, whereas only 59% of seated participants reported motion sickness.

Head-mounted displays can be nauseogenic (e.g., Draper, Viirre, Gawron, & Furness, 2001; Patterson, Winterbottom, & Pierce, 2006). Thus, it is

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unlikely that the incidence of motion sickness reported by Merhi et al. (2007) represents typical game play situations. To estimate the general incidence of motion sickness among players of console video games, in the present study we presented the games on a video monitor. To understand how motion sickness incidence is influenced by parameters of the game situation, we varied participants' distance from the video monitor and their posture (standing vs. sitting).

Motion Sickness and Movement

Because body movement may be relevant to the etiology of motion sickness, we evaluated relations between motion sickness and body movement during game play. Theories of motion sickness etiology typically have been based on the concept of sensory conflict (e.g., Duh, Parker, Philips, & Furness, 2004; Reason, 1978), the idea that motion sickness situations are characterized by patterns of perceptual stimulation that differ from patterns expected on the basis of past experience. Differences between current and expected patterns of perceptual stimulation are interpreted as sensory conflict, which is alleged to produce motion sickness.

In some variants of the theory, it is claimed that conflict is defined not in terms of a comparison between past and present sensory inputs but, rather, in terms of a comparison of different current sensory inputs, such as visual and vestibular stimulation (e.g., Benson, 1984; Patterson et al., 2006; Reason, 1978). Despite the intuitive appeal of the sensory conflict concept, theories based on sensory conflict have low predictive validity (Draper et al., 2001) and may not be scientifically falsifiable (e.g., Ebenholtz, Cohen, & Linder, 1994). We evaluated an alternative theory of motion sickness etiology.

The postural instability theory of motion sickness (Riccio & Stoffregen, 1991) predicts that motion sickness should be preceded by instabilities in the control of bodily orientation. In research on stance, instability is often assumed to imply an increase in movement (e.g., Woollacott & Shumway-Cook, 2002), but we do not accept this implication. We define postural stability and instability in relation to the goals of postural control, which can include the facilitation of suprapostural activities (Riccio & Stoffregen, 1988, 1991). Riccio and Stoffregen (1991) offered a list of potential operational definitions of postural instability, many of which were not compatible with an equation between instability and the magnitude of postural activity. In the present study, we used several of these operational definitions in testing the prediction that motion sickness would be preceded by postural instability.

The postural instability theory claims that postural instability is both necessary and sufficient for the occurrence of motion sickness. The theory does not attempt to explain why the symptoms of motion sickness are what they are (e.g., nausea, vomiting). We do, however, claim that the symptoms of motion sickness do not arise from sensory conflict. Consistent with the postural instability theory, changes in body sway have been found to precede motion sickness in several contexts (e.g., Bonnet, Faugloire, Riley, Bardy, & Stoffregen, in press; Faugloire, Bonnet, Riley, Bardy, & Stoffregen, 2007; Stoffregen, Hettinger, Haas, Roe, & Smart, 2000; Stoffregen & Smart, 1998). Participants who eventually became motion sick exhibited changes in movement of the head and/or center of pressure, relative to participants who did not report motion sickness.

Similar results were obtained by Merhi et al. (2007), who measured movement of the head and torso while participants played commercially available console video games. Prior to the onset of subjective symptoms of motion sickness, the variability of head movement differed between participants who later became sick and those who did not.

If motion sickness is preceded by changes in body sway, then relations between body movement and motion sickness may have practical value in predicting motion sickness susceptibility. We return to this issue in the Discussion section.

The Present Study

Merhi et al. (2007) showed that motion sickness could occur when commercially available console video games were played using a head-mounted display but, as noted previously, it is likely that motion sickness incidence in their study was influenced by the use of a head-mounted display. Our primary motivation was to obtain a more realistic estimate of the incidence and severity of motion sickness that may occur among game players outside the laboratory. We sought to maximize the naturalism of the experimental situation. To this end, participants were asked to play a console video game presented on a video monitor. They played continuously for up to 50 min, and there were no experimental manipulations of any aspect of the game.

Merhi et al. (2007) found a significant reduction in the incidence of motion sickness when participants played console video games while seated, as opposed to standing. We expected a similar effect. We also varied the distance between participants and the game display. One of the distances we used (45 cm) equated the visual angle of the display with the visual angle of the head-mounted display used by Merhi et al. (2007). This distance provided the appropriate visual angle but seemed to place players unnaturally close to the display.

As noted, our primary motivation in this study was to estimate motion sickness incidence in conditions representative of nonlaboratory game play. For this reason, we also used a condition in which the distance from the player to the display was 85 cm (yielding a correspondingly smaller visual angle of the display). The 85-cm distance was comparable to the user-display distance employed in consumer play test research at Microsoft Game Studios (R. Pagulayan, personal communication, April 2007).

We measured motion of the head and torso while participants played the console video games. We tested the hypothesis that prior to the onset of subjective symptoms of motion sickness, movement would differ between participants who eventually became motion sick and those who did not. Following previous studies, we predicted that prior to the onset of subjective symptoms of motion sickness there would be differences in movement of the head and/or torso between participants who eventually became motion sick and those who did not.

We collected data on participants' prior experience with console video games. These data, together with analyses relating sex and motion sickness to body movement, are reported elsewhere (Flanagan, Faugloire, & Stoffregen, 2008).

METHOD

There were three experimental conditions. We positioned participants so that the visual angle of the CRT display was equal to the visual angle of the head-mounted display used by Merhi et al. (2007; 60° horizontal by 48° vertical). Using this visual angle, participants played the video game in two conditions: standing and sitting. To increase representativeness, we also included a third condition, in which participants sat at a more comfortable distance from the display; the increase in viewing distance reduced the visual angle of the display.

Participants

There were 40 participants. Participants were undergraduate students at the University of Minnesota who participated on a voluntary basis or received course credit for their participation. Each person participated in only one condition. See Table 1 for descriptive characteristics. The procedure used in this study was approved by the Institutional Review Board of the University of Minnesota.

TABLE 1: Descriptive Data for the Three Experimental Conditions

	Experimental Condition					
	Standing		Sitting-45		Sitting-85	
Measure	MS	Move	MS	Move	MS	Move
N						
Total	16	7	12	11	12	10
Women	12	5	4	4	6	4
Men	4	2	8	7	6	6
Sick	9	4	6	5	5	4
Well	7	3	6	6	7	6
Means						
Age (years)	21	23	21	21	21	21
Height (cm)	170	169	175	175	175	176
Weight (kg)	68	70	71	70	78	79

Note. MS: The number of participants included in analyses of motion sickness incidence and severity. Move: The number of participants included in analyses of movement data.

Apparatus

We used a standard Xbox system (Xbox 2, Microsoft Corp.), including the game unit, which contained graphics and control software, and the game pad, a handheld device that participants used to play the game. Participants played Whacked, a commercially available game that was developed for the Xbox system. In Whacked, the player moves through a virtual world, controlling multiaxis linear and angular motion. The video and audio portions of the game were presented using a CRT video monitor (Philips) that measured 68.6 cm diagonally.

Movement data were collected using a magnetic tracking system (Fastrak, Polhemus, Inc., Colchester, VT). One receiver was attached to a bicycle helmet and another to the skin at the level of the 7th cervical vertebra, using cloth medical tape. A third receiver was secured to the game pad. The transmitter was located behind the participant's head, on a stand. Six-degree-of-freedom position data were collected from each receiver at 40 Hz and stored for later analysis.

Motion Sickness Assessment

We assessed motion sickness incidence by asking participants to make direct, yes/no statements about whether they were motion sick. Participants were divided into sick and well groups based on these explicit verbal statements. Participants were instructed to discontinue when they began to experience motion sickness; however, they could discontinue at any time, for any reason. Thus, there was no motivation for them to give false reports of motion sickness as a means to discontinue participation. For this reason, when participants stated that they were motion sick, we accepted these statements as veridical. Verbal reports of motion sickness were unambiguous (e.g., "I feel nauseous, my stomach is queasy"; "I was going to throw up").

We assessed the severity of motion sickness using the Simulator Sickness Questionnaire, or SSQ (Kennedy, Lane, Berbaum, & Lilienthal, 1993). The SSQ was designed to assess the severity of a variety of symptoms that are often associated with motion sickness, such as fatigue, eyestrain, vertigo, and nausea. It was not designed to indicate, on a yes/no basis, whether any individual was or was not motion sick (R. S. Kennedy, personal communication, September 2007). We administered the SSQ at the beginning of the experiment and again at the end, either when the participant discontinued game play or at the end of the experimental session, whichever came first (Bonnet, Faugloire, Riley, Bardy, & Stoffregen, 2006; Stoffregen & Smart, 1998).

Procedure

After completing the informed consent procedure, participants filled out the SSQ. They were reminded that they could discontinue at any time, for any reason, and were asked to discontinue immediately if they felt any symptoms of motion sickness, however slight. Participants were given a brief introduction to the Xbox system and to Whacked. Participants were permitted to explore the game until they felt that they understood the rules and the use of the game pad.

Participants then played the game continuously for up to 50 min, restarting the game if necessary (i.e., if the game ended). Participants played in stocking feet and were instructed not to move their feet during the 50-min game session. At the end of 50 min (or at the time of discontinuation) participants were asked to state, yes or no, whether they were motion sick, after which they filled out the SSQ a second time.

As in Experiment 1 of Merhi et al. (2007), participants played Whacked. In the *standing condition* (16 participants), participants stood with their toes on a line on the floor; the line was 45 cm from the screen. They were asked to stand comfortably but not to move their feet. In the *sitting-45 condition* (12 participants), participants sat on a stool (58 cm high) that did not support the torso. They were permitted to rest their feet on the floor or on a rail near the bottom of the stool but were asked not to change foot position during the session. The stool had four feet; the front two feet were placed on the line on the floor. For both groups the visual angle of the screen was approximately 60° horizontal by 48° vertical. In the *sitting-85 condition* (12 participants), the front two feet of the stool were 85 cm from the monitor, which had a visual angle of approximately 35° horizontal by 26° vertical.

Data Analysis

Subjective reports. We included all participants in our analysis of the incidence and severity of motion sickness. SSQ data were evaluated using the Mann-Whitney test and the Wilcoxon signed ranks test.

Movement data. In analyzing the movement data, we excluded members of the well group who discontinued because of boredom, fatigue, or discomfort. We also excluded several participants for technical reasons: Because of intermittent metallic interference with the magnetic tracking system, some of the data files could not be analyzed. Postural data were analyzed based on a windowing procedure that permitted us to examine the evolution of sway over time during exposure to console video games. We examined three nonoverlapping windows (each 2 min in duration) selected from the beginning, middle, and end of the exposure. For well participants, the windows were defined on the basis of the mean exposure duration completed by the sick group (for each experiment). The last window selected for well participants corresponded to the average time of the final window from the sick group. This window selection ensured that the average exposure duration was similar for the sick and well groups.

We analyzed movement of the head, torso, and game pad in terms of the standard deviation of position, the velocity, and the range of motion, with separate analyses in the anteroposterior, mediolateral, and vertical axes. In our ANOVAs, we estimated the effect size using the partial η^2 statistic. According to Cohen (1988), values of partial $\eta^2 > .14$ indicate a large effect.

RESULTS

Motion Sickness Incidence and Discontinuation

Standing condition. The sick group comprised 9 participants (56%) who reported motion sickness while playing the game and discontinued (mean latency to discontinuation = 20.2 min). The remaining 7 participants stated that they were not motion sick and constituted the well group. Three well participants discontinued, with discontinuation times of 1.8, 38.3, and 46.4 min. Reasons for discontinuation included headache without motion sickness and boredom. The 56% motion sickness incidence was less than the 100% incidence observed with standing participants by Merhi et al. (2007), $\chi^2(1) = 4.40$, $p < .05$.

Sitting-45 condition. The sick group comprised 6 participants (50%) who reported motion sickness while playing the game and discontinued (mean latency to discontinuation = 22.7 min). The other 6 participants stated that they were not motion sick and constituted the well group. None of the well participants discontinued. Incidence did not differ between the sitting and standing conditions at the 45-cm distance, $\chi^2(1) = 0.11$, $p > .05$, nor did this incidence differ significantly from the 59% found playing the same game within the sitting condition of Merhi et al. (2007), $\chi^2(1) = 0.22$, $p > .05$.

Sitting-85 condition. Five participants (42%) stated that they were motion sick and discontinued (mean latency = 24.5 min). The remaining 7 participants stated that they were not motion sick and constituted the well group. One well participant discontinued after 2 min, citing boredom. The incidence of sickness did not differ between the two seated conditions, $\chi^2(1) = 0.17$, $p > .05$.

Symptom Severity

Standing condition. The data are summarized in Figure 1a. At preexposure, SSQ scores did not differ between the sick and well groups ($U = 15.5$, $p > .71$). At postexposure, SSQ scores differed ($U = 3.0$, $p < .02$), with scores for the sick group being higher. The preexposure-postexposure change in scores was significant for the sick group ($Z = –2.67$, $p < .01$) but not for the well group ($Z = –1.83$, $p > .07$).

Sitting-45 condition. The data are summarized in Figure 1b. At preexposure, the sick and well participants did not differ in terms of total severity scores ($U = 14.0$, $p > .59$). At postexposure, the total severity score for the sick participants was greater than that of the well participants ($U = 4.0$, $p < .03$). Postexposure scores were greater than those at preexposure for the sick group ($Z = –2.20$, $p < .03$) and for the well group ($Z = –2.20$, $p < .03$).

Sitting-85 condition. The data are summarized in Figure 1c. The sick and well groups did not differ at preexposure ($U = 10.5$, $p > .05$) or at postexposure ($U = 13.0$, $p > .05$). Postexposure scores were greater than preexposure scores for the sick group ($Z = –2.04$, $p < .04$) and for the well group ($Z = –2.21$, $p < .03$).

We conducted post hoc tests comparing postexposure scores across conditions separately for the sick and well groups. Across conditions, there were no differences in the postexposure scores for the well groups (Kruskal-Wallis test, $p > .05$). For the sick groups, postexposure SSQ scores also did not differ across conditions ($p > .05$).

Movement Data

Standing condition. We analyzed movement

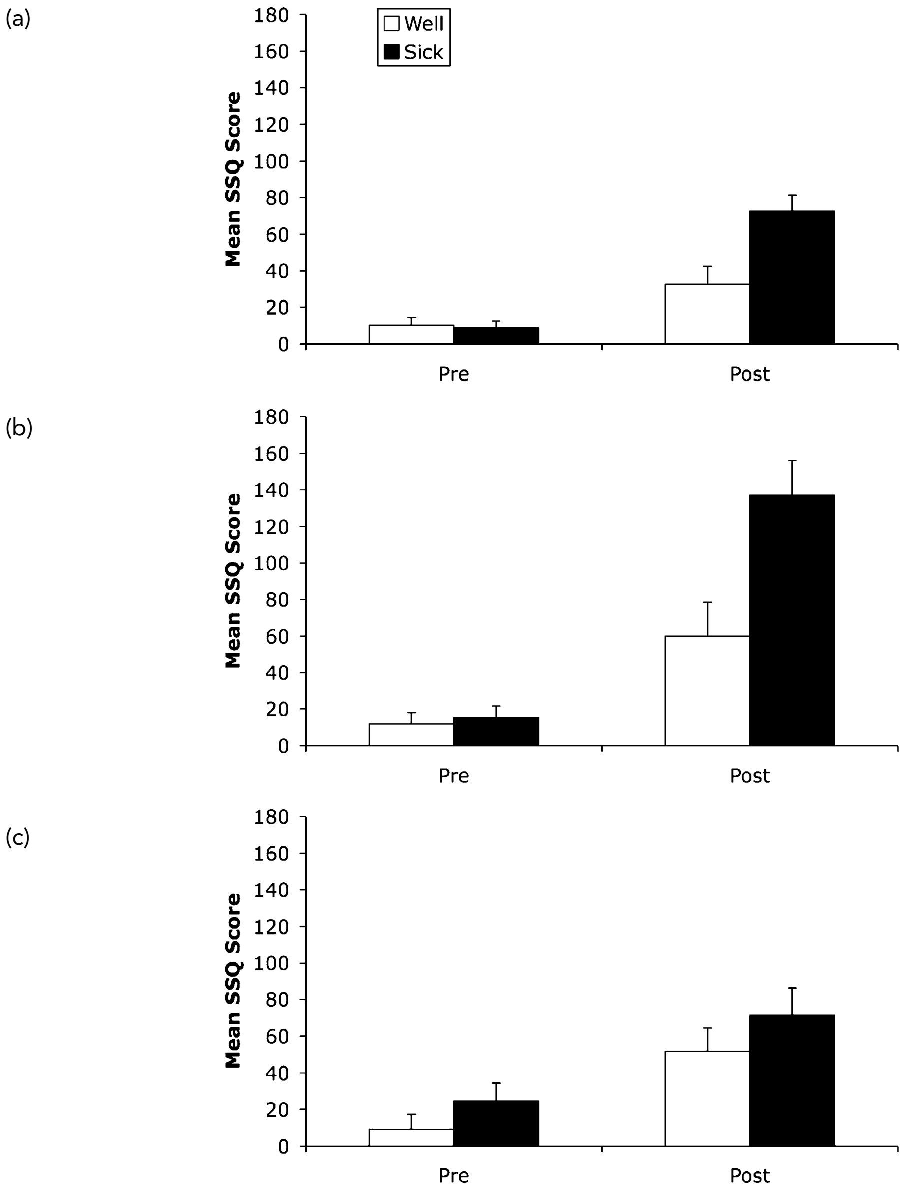

Figure 1. Mean preexposure (pre) and postexposure (post) scores on the Simulator Sickness Questionnaire (SSQ): (a) standing condition, (b) sitting-45 condition, (c) sitting-85 condition. The error bars represent standard error.

data from 7 participants ($n = 4$ sick, $n = 3$ well). The independent variables were windows (first, middle, and last) and group (sick vs. well). We found significant Group × Windows interactions for the velocity of vertical head movement, $F(2, 10) = 4.04$, $p < .05$, partial $\eta^2 = .45$, and for the variability, $F(2, 10) = 4.40$, $p < .05$, partial $\eta^2 = .47$, and range, $F(2, 10) = 4.51$, $p < .05$, partial $\eta^2 = .47$, of vertical torso movement. Across windows, movement tended to increase for the well group but not for the sick group (Figure 2). These effects are consistent with our hypothesis that movement should differ between the sick and well groups prior to the onset of motion sickness. The effects differ from those in previous studies (e.g., Bonnet et al., in press; Faugloire et al., 2007), in which movement for the sick group has tended to increase over time, whereas the well group remained steady over time.

Sitting-45 and sitting-85 conditions. We analyzed movement data from 21 participants (Table 1). The independent variables were viewing distance

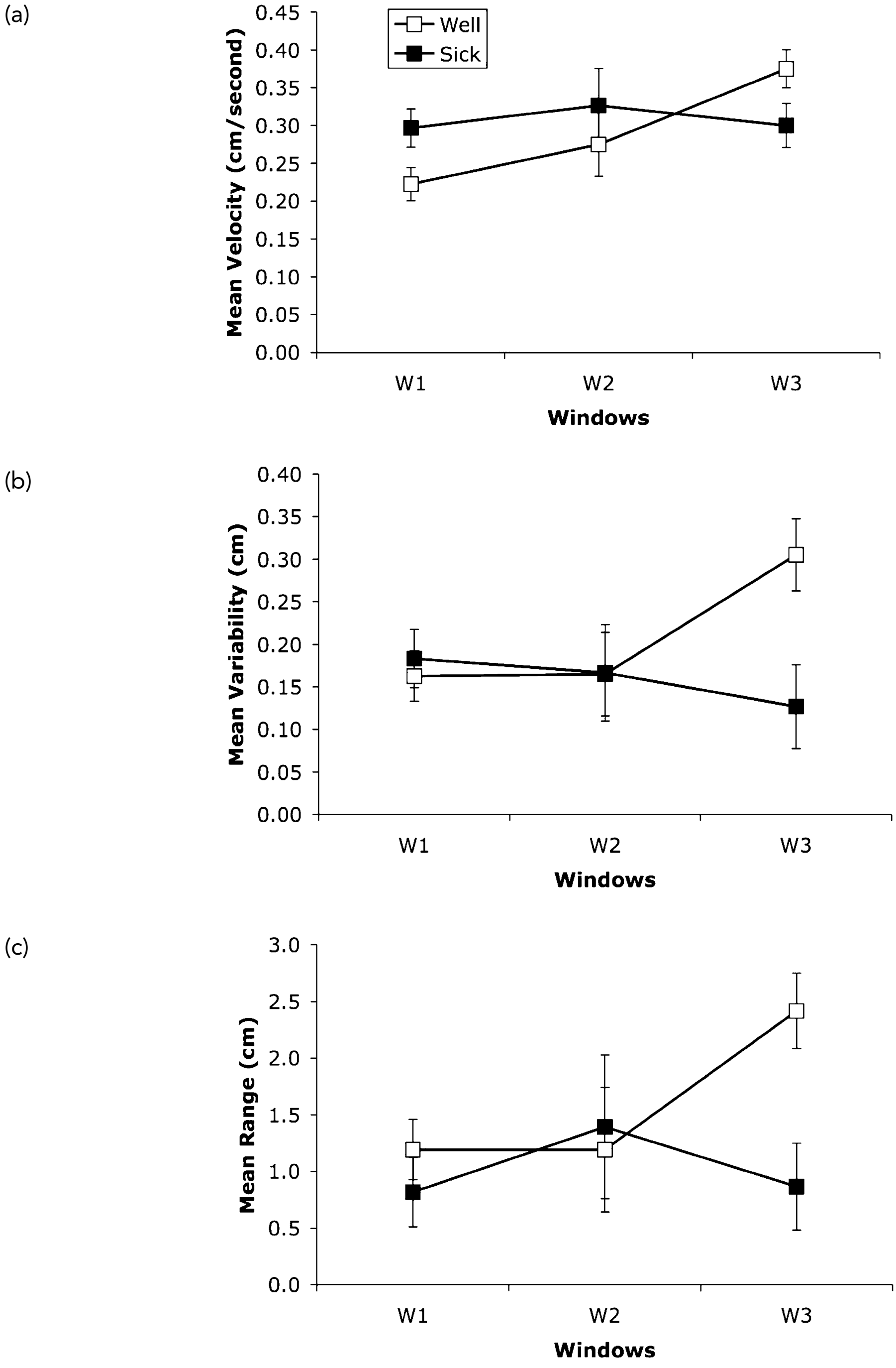

Figure 2. Vertical movement in the standing condition: (a) mean head velocity, (b) mean torso variability, (c) mean torso range. The error bars represent standard error. W1, W2, W3 = first, middle, and last windows

(45 vs. 85 cm), windows (first, middle, and last), and group (sick vs. well). We found significant Group × Condition interactions on the velocity of mediolateral torso movement, $F(1, 17) = 4.24$, $p < .05$, partial $\eta^2 = .20$, and on the range of mediolateral game pad movement, $F(1, 17) = 4.27$, $p < .05$, partial $\eta^2 = .20$. Figure 3 shows that in the sitting-45 condition movement tended to be greater for the sick group than for the well group, whereas in the sitting-85 condition this pattern was reversed.

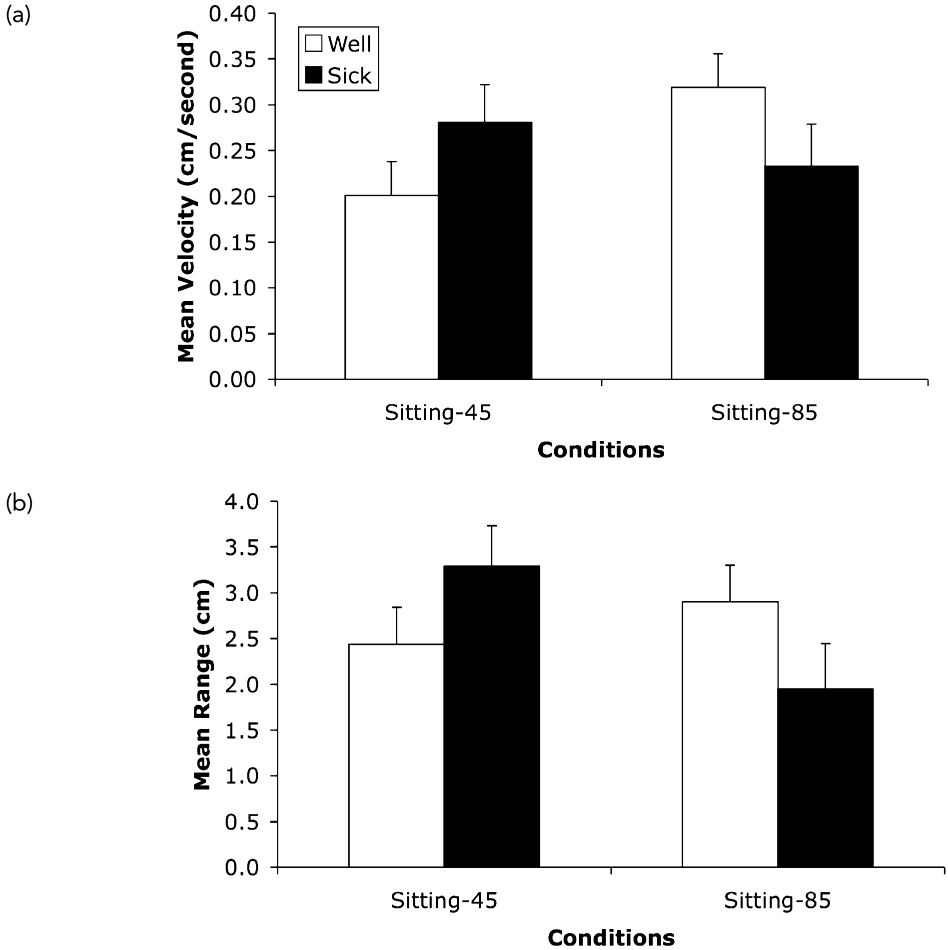

Figure 3. Mediolateral movement in the sitting conditions: (a) mean torso velocity, (b) mean game pad variability. The error bars represent standard error.

DISCUSSION

The results indicate that motion sickness can occur among players of console video games under a variety of conditions. In addition, we found significant differences in postural activity between sick and well participants prior to the onset of subjective symptoms of motion sickness. These are the two main results of the study.

Representative Incidence?

The incidence of sickness was high, even in our most representative condition (sitting-85). Motion sickness incidence might have been elevated artifactually, given that participants knew that the study was about motion sickness, were specifically warned that they might become motion sick, and completed the SSQ before engaging in game play. In the standing condition, incidence might also have been affected by participants' posture. We instructed participants not to move their feet during game play. This constraint contrasts with ordinary stance, in which people tend to move their feet every few seconds (e.g., Zatsiorsky & Duarte, 2000). In this sense, the standing condition may have been unrepresentative of ordinary game play situations. It is possible that the prevention of foot movement could have influenced overall postural stability, which in turn could have altered the incidence of motion sickness. However, it is unlikely that such an effect could account for the occurrence of motion sickness in the two sitting conditions.

Another factor possibly relevant to incidence was the requirement to play the game continuously for 50 min. Such an effect seems unlikely, however, given widespread anecdotal reports of play sessions lasting for 12 hr or more.

Further research will be needed to determine the percentage of persons who become motion sick while playing console video games outside the laboratory. However, the results of the present study (together with those of Merhi et al., 2007) suggest that motion sickness incidence may be quite high, whether players stand or sit.

The Role of Visual Display Technology

The incidence of motion sickness in the standing condition (56%) was less than when standing participants played the same game via a head-mounted display (100%; Merhi et al., 2007). By contrast, sickness incidence in the sitting conditions did not differ from the incidence reported by Merhi et al. (2007) during sitting. The only difference between the two studies in these conditions was that in Merhi et al. (2007) console video games were presented via a head-mounted display. These results suggest that the head-mounted display contributes to motion sickness only when users are standing.

Movement and Motion Sickness

In both the standing and sitting conditions, our prediction that movement would differ between the sick and well groups prior to the onset of subjective motion sickness symptoms was confirmed. In this sense, the results also are consistent with findings of Merhi et al. (2007) and other studies (e.g., Bonnet et al., 2006; Faugloire et al., 2007; Stoffregen et al., 2000; Stoffregen & Smart, 1998).

In the standing condition, the nature of differences between the sick and well groups was unusual. In three different parameters of head and torso motion, movement increased over time (i.e., across windows) for the well group but not for the sick group. This pattern of results differs from that in previous studies that have assessed motion sickness in a moving room. In those studies, movement tended to increase over time in the sick group but not the well group (Bonnet et al., 2006; Faugloire et al., 2007; Merhi et al., 2007). Both types of effects are consistent with our hypothesis that the postural activity of sick and well participants would differ prior to the onset of motion sickness. We do not know why the direction of the effect was different in the present study; this will be an important subject for future research.

As the present study shows (and as noted in the Introduction), the exact relationship between measures of postural instability and subsequent motion sickness is not yet certain, in part because there is not yet a widely accepted definition of stability and instability in human movement (see also Faugloire et al., 2007). Some studies have found differences between sick and well participants in parameters of body sway that are defined independent of the magnitude of movement (e.g., Bonnet et al., 2006; Villard, Flanagan, Albanese, & Stoffregen, 2008 [this issue]). Monitoring of players' movements is reliable and inexpensive; a popular example is the Wii system, which responds to players' movements. When the relationship between sway and subsequent motion sickness is better understood, changes in postural stability might be used to warn players who are at risk of developing motion sickness.

CONCLUSION

Motion sickness among users of console video games is real. The incidence is remarkably high, even under the most representative conditions (i.e., when games are viewed on a video monitor, from a comfortable distance, by seated players). Sickness was preceded by changes in movement of the head and torso, as predicted by the postural instability theory of motion sickness (Riccio & Stoffregen, 1991). These changes might be monitored and used to warn players who were at risk of developing motion sickness. We conclude that motion sickness is a serious operational issue for designers, manufacturers, and users of console video games.

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