Exp Brain Res (2012) 217:299–309
DOI 10.1007/s00221-011-2993-4

RESEARCH ARTICLE

Postural activity and motion sickness during video game play in children and adults

Chih-Hui Chang · Wu-Wen Pan · Li-Ya Tseng · Thomas A. Stoffregen

Received: 11 October 2011 / Accepted: 20 December 2011 / Published online: 1 January 2012

Abstract Research has confirmed that console video games give rise to motion sickness in many adults. During exposure to console video games, there are differences in postural activity (movement of the head and torso) between participants who later experience motion sickness and those who do not, confirming a prediction of the postural instability theory of motion sickness. Previous research has not addressed relations between video games, movement and motion sickness in children. We evaluated the nauseogenic properties of a commercially available console video game in both adults and 10-year-old children. Individuals played the game for up to 50 min and were instructed to discontinue immediately if they experienced any symptoms of motion sickness, however mild. During game play, we monitored movement of the head and torso. Motion sickness was reported by 67% of adults and by 56% of children; these rates did not differ. As a group, children moved more than adults. Across age groups, the positional variability of the head and torso increased over time during game play. In addition, we found differences in movement between participants who later reported motion sickness and those who did not. Some of these differences were general across age groups but we also found significant differences between the movement of adults and children who later reported motion sickness. The results confirm that console video games can induce motion sickness in children and demonstrate that changes in postural activity precede the onset of subjective symptoms of motion sickness in children.

Keywords Postural sway · Video games · Children · Motion sickness

Introduction

Children are among the main users of video games. In the United States, 89% of children aged 8–11 reported playing video games at least once per month, and 26% of individuals in that age group reported playing every day (Gentile 2009). In Singapore, 83% of children and adolescents aged 8–15 reported playing video games at least occasionally, and the average amount of playing time was 21.3 h per week (Gentile et al. 2011). Moreover, the numbers of children and adolescents playing video games have increased dramatically. In Germany, ownership of gaming consoles among adolescents ages 12–19 increased from 23 to 45% from 1998 to 2008 (Rehbein et al. 2010). Thus, any adverse effects of video game use could affect large numbers of children. One side effect that has been widely reported is motion sickness. There are many anecdotal reports about motion sickness among children who play video games but there has been no experimental investigation. In the present study, we investigated motion sickness among children and adults who played a console video game. A console video game is one featuring at least three components; a handheld gamepad, a monitor on which the game is displayed, and a console that holds game software and uses inputs from the gamepad to update the onscreen display. Examples include Xbox, Play Station, and Wii.

Among adults, the nauseogenic properties of console video games have been confirmed through laboratory

---

C.-H. Chang · W.-W. Pan · L.-Y. Tseng
Department of Physical Education,
National Kaohsiung Normal University, Kaohsiung, Taiwan

T. A. Stoffregen (✉)
School of Kinesiology, University of Minnesota,
224 Cooke Hall, 1900 University Ave SE,
Minneapolis, MN 55455, USA
e-mail: tas@umn.edu

experiments. Adults have been exposed to commercially available console video games while seated or standing, as active players or passive viewers, and with the games presented on video monitors or through head-mounted displays (Dong et al. 2011; Merhi et al. 2007; Pan and Chang 2011; Stoffregen et al. 2008). In each case, some participants have reported motion sickness; across studies and conditions, incidence has ranged from 15 to 100%. These studies confirm, under controlled laboratory conditions, that in adults, contemporary console video games can give rise to motion sickness in a wide range of conditions.

If video games were used solely for entertainment, then motion sickness among players might be considered to be relatively inconsequential. However, console video games are used in many non-entertainment settings. Video games are widely used as in the training of pilots, soldiers, and surgeons. Training with virtual reality simulations improves the performance of surgeons (Ali et al. 2004; Rosser et al. 2007), while performance on video games predicts the quality of laparoscopic surgical performance (Rosenberg et al. 2005). The use of video games for education and training is not limited to adults. Increasingly, video games are used as teaching tools in primary and secondary education (Barab et al. 2010), and in college and universities (e.g., Mayo 2007).

The use of video games in education and training in both adults and children is threatened by the risk of motion sickness among users. Hence, motion sickness research with video games can have implications for the design and use of game systems that extend beyond the entertainment industry, and for the design and use of simulator and virtual environment systems, in general. Such research can also have implications for general theories of the etiology of motion sickness.

Existing research relating motion sickness to console video games has focused on adults (Dong et al. 2011; Merhi et al. 2007; Pan and Chang 2011; Stoffregen et al. 2008). There has been no experimental investigation of the incidence of motion sickness among children who play video games. In the present study, one of our goals was to evaluate the nauseogenic properties of commercially available console video games among children.

Motion sickness and postural instability

In previous research, participants were exposed to video games for up to 50 min and were instructed to discontinue participation immediately if they experienced any subjective symptoms of motion sickness, however mild (Dong et al. 2011; Merhi et al. 2007; Pan and Chang 2011; Stoffregen et al. 2008). Data were collected on body movement during exposure to console video games but prior to the onset of any subjective symptoms of motion sickness. In each study, there were significant differences in parameters of body movement between participants who later reported motion sickness and those who did not. Across studies, differences existed in movement of the head, the torso, and the center of pressure. During exposure to video games, the evolution of movement over time differs between participants who later report motion sickness and those who do not (Dong et al. 2011; Merhi et al. 2007; Pan and Chang 2011; Stoffregen et al. 2008).

Theories of motion sickness etiology typically have been based on the concept of sensory conflict, the idea that motion sickness situations are characterized by patterns of perceptual stimulation that differ from patterns expected on the basis of past experience (e.g., Reason 1978). Differences between current and expected patterns of perceptual stimulation are interpreted as sensory conflict, which is alleged to produce motion sickness. Theories based on the concept of sensory conflict cannot readily explain the finding, in research on console video games, that the subjective experience of motion sickness has been preceded by changes in postural activity. By contrast, the postural instability theory of motion sickness (Riccio and Stoffregen 1991) predicts that motion sickness should be preceded by changes in movement of the body (the entire body or its segments), such that there are differences in movement between persons who later experience motion sickness and those who do not.

In the postural control literature, loss of stability generally is associated with a frank loss of control, such as falling. This is not the type of instability that was hypothesized by Riccio and Stoffregen (1991) to be related to motion sickness. They defined postural stability as the state in which uncontrolled movements of the perception and action systems are minimized. Postural instability, then, need not entail frank loss of control; stability may be degraded rather than lost outright. There can be variation in the magnitude of instability, and instability can persist over long periods of time without necessarily leading to loss of control. Riccio and Stoffregen claimed that postural instability is both necessary and sufficient for the occurrence of motion sickness. Consistent with the postural instability theory, changes in body sway have been found to precede motion sickness in a wide variety of contexts. These include the video game studies cited above, as well as laboratory devices (e.g., Bonnet et al. 2006; Stoffregen and Smart 1998), virtual environments (Villard et al. 2008), and military flight simulators (Stoffregen et al. 2000). In each case, 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. It is important to note that the postural instability theory of motion sickness does not equate “unstable movement” with “more movement”. The theory does not predict that persons at risk for motion sickness will necessarily move more than persons who do not become sick.

Motion sickness in children

Children are widely believed to have greater susceptibility to motion sickness than adults. This belief stems, in large part, from effects associated with vehicular travel. Research has shown that among passengers in vehicles, children tend to be more susceptible to motion sickness than adults (Bos et al. 2007; Turner and Griffin 1999). Interestingly, age-related trends are different in the context of motion sickness induced by one's own movement. Takahashi et al. (1994) asked 90 participants to walk while wearing reversing prism spectacles. They found that the youngest children (age 4 years) reported little or no motion sickness (though they did report that the spectacles gave them a headache). Motion sickness tended to increase with age, and by age 10 children did not differ from adults. Video games differ from vehicular travel in that players typically control the motion stimulus. Video games differ from both vehicular travel and self-controlled locomotion in that motion is virtual rather than physical. For these reasons, existing research with physical vehicles and locomotion may not generalize to the case of video games. Conversely, video games may provide a new method for the study of motion sickness in children and as a function of age, in general.

The present study

We sought to estimate the incidence of motion sickness while children played console video games. Because body movement may be relevant to the etiology of motion sickness, we evaluated relations between motion sickness and body movement during game play. In a cross-sectional design, adults and children played an "off the shelf" console video game. We evaluated the incidence and severity of motion sickness as a function of age. In addition, we collected data on movement of the head and torso during game play. We used these data to evaluate the hypothesis that differences in movement would exist between participants who later reported motion sickness and those who did not.

The postural instability theory makes predictions about differences in postural activity between persons who become motion sick and those who do not (Riccio and Stoffregen 1991). To evaluate these predictions, it is necessary to identify individual participants as being either sick or well. It is for this reason that participants in our studies make forced-choice, yes/no statements about their motion sickness status. This aspect of our method contrasts to the more common practice of assessing motion sickness in terms of the mean, across all participants, of some measure of the intensity of motion sickness symptoms, such as the SSQ (e.g., Duh et al. 2004). Because this method does not classify individuals as being either sick or well, it cannot be used to evaluate predictions made by the postural instability theory (e.g., Akiduki et al. 2005). One problem with using mean symptom severity as an operational definition of motion sickness incidence is that many of the symptoms of motion sickness can occur in the absence of motion sickness. For example, headache and eyestrain, which are assessed in the SSQ, often occur among persons who are not motion sick. This can be a problem with technologies that are associated with motion sickness but also with headache and eyestrain in the absence of motion sickness, such as head-mounted displays (e.g., Draper et al. 2001; Merhi et al. 2007).

Method

Participants

Twenty-four undergraduates (12 men and 12 women, age range = 18–27 years, mean age = 22.63 years, SD = 2.15 years; mean height = 164.38 cm, SD = 9.36 cm; mean weight = 61.12 kg, SD = 11.51 kg) and 25 elementary school students (12 boys and 13 girls, age range = 9.8–11.7 years, mean age = 10.60, SD = 0.49 years.; mean height = 140.92 cm, SD = 6.49 cm; mean weight = 35.20 kg, SD = 6.65 kg) were recruited as participants. All participants had normal to corrected normal vision, and no self- or parent-reported history of disease or malfunction of the vestibular apparatus, recurrent dizziness, or falls. Informed consent was obtained from the adult participants and from children's parents or guardians. The experimental procedure was approved by the Institute of Review Board of National Kaohsiung Normal University.

Apparatus

We used a standard Xbox system (Xbox 360 pro system, 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.

The video and audio portions of the game were presented using a CRT monitor (model SWT-268v, SOWA Inc., Taiwan) that measured 66 cm diagonally. Movement data were collected using a magnetic tracking system (Flock of Birds model 6DFOB, Ascension Technologies, Inc., Burlington, 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. The transmitter was located behind each participant's head, on a stand 50 cm from the participant's heels. Six degrees of freedom position data were collected from each receiver at 40 Hz and stored for later analysis.

Procedure

We assessed symptom severity using the Simulator Sickness Questionnaire, or *SSQ*, (Kennedy et al. 1993). The SSQ includes 16 items with a 4-point scale. The questions were translated into Chinese. In the children's version, the questions were in wording appropriate to the children's frame of reference. We used the Total Severity Score, which was computed in the recommended manner. We administered the SSQ twice, once before and once after exposure to the game.

After completing the informed consent procedure, participants filled out the pre-exposure SSQ. They were given a brief introduction to the Xbox system and to the game and were then permitted to explore the game (driving the simulated vehicle for 1 min or less) until they felt that they understood the rules and the use of the game pad. Participants played *Pure*, a cross-country four-wheeled motorcycle racing game. They played the game using the game pad. Positive acceleration (speeding up) was achieved with a button controlled using the right index finger, while negative acceleration (braking) was achieved via a button controlled using the left index finger. The left thumb operated a directional button that was used to control the right or left direction of the motorcycle. Participants drove the "race rental" motorcycle. Participants chose "single event" and then "sprint" from the course list. The course included 5 laps, and each lap included one right turn, one down hill, and one left turn. The course was an unpaved mountain road. The camera/viewpoint was set behind the motorcycle such that the player appeared to be following immediately behind the vehicle. The camera moved in three degrees of translation and three degrees of rotation. Participants were instructed to finish the designated course as fast as possible.

Participants played the game continuously for up to 50 min, restarting the game if necessary (i.e., if the game ended). They stood with their toes even with a line that was 43.3 cm away from the monitor so that the visual angle of the screen was approximately 60° horizontal by 48° vertical, matching previous studies (Merhi et al. 2007; Stoffregen et al. 2008). They were instructed not to move their feet during the 50-min game session. An experimenter recorded the participants' game performances during their sessions, which included how many times participants finished a course and the number of errors they made during each course. Errors occurred in several situations: when the motorcycle hit a wall too hard, when the motorcycle fell off a cliff, or when the motorcycle moved in the wrong direction for too long. When an error occurred, the screen showed a PURE sign, after which the motorcycle was automatically returned to the course and the game continued. We recorded the number of PURE signs on the screen as the number of errors. At the end of 50 min (or at the time of discontinuation, whichever came first), participants were asked to state, yes or no, whether they were motion sick, after which they filled out the post-exposure SSQ.

Before beginning game play, participants were instructed that if they felt any symptoms of motion sickness, no matter how slight, they should stop playing immediately. 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. When participants stated that they were motion sick, we accepted these statements as veridical.

Data analysis

We included all participants in our analyses of motion sickness incidence, symptom severity, and game performance. We used χ^2 statistics to analyze the data of motion sickness incidence. As recommended by Kennedy et al. (1993), SSQ data were evaluated using the Mann–Whitney test and the Wilcoxon signed ranks test. Laps per minute and errors per minute were used to represent the participants' speed and accuracy, respectively. The Mann–Whitney test was used to analyze these performance data.

We evaluated the magnitude of movement, which we operationalized as the standard deviation of position of the head and torso. We separately analyzed movement in the anterior-posterior (AP) and mediolateral (ML) 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, and values of partial $\eta^2 > .06$ indicate a medium effect.

Results

Data for game performance are summarized in Fig. 1. Among well participants, speed (laps per minute) differed between the adult and child groups, $U = 11.00$, $P = .005$, with children completing more laps than adults (Fig. 1a). There were no other significant effects on lap completion. Errors per minute did not differ between the sick and the well adults, $U = 49.00$, $P > .05$, or between the sick and well children, $U = 45.00$, $P > .05$. Among participants who reported motion sickness, there were more errors per minute for children than for adults, $U = 59.00$, $P = .028$ (Fig. 1b). Among participants who did not report motion sickness, errors per minute did not differ between adults and children, $U = 38.00$, $P > .05$.

Subjective data

Motion sickness was reported by 30 of 49 participants (61%), including 16 of 24 adults (66.67%) and by 14 of 25

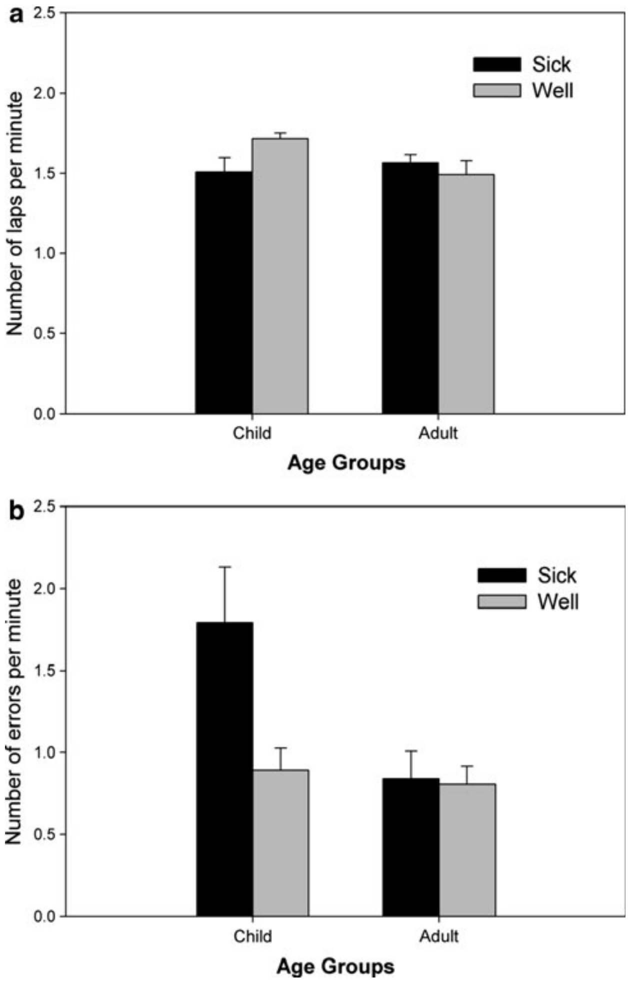

Fig. 1 Data on game performance. **a** Number of laps per minute. **b** Number of errors per minute. *Error bars* depict SE of the mean

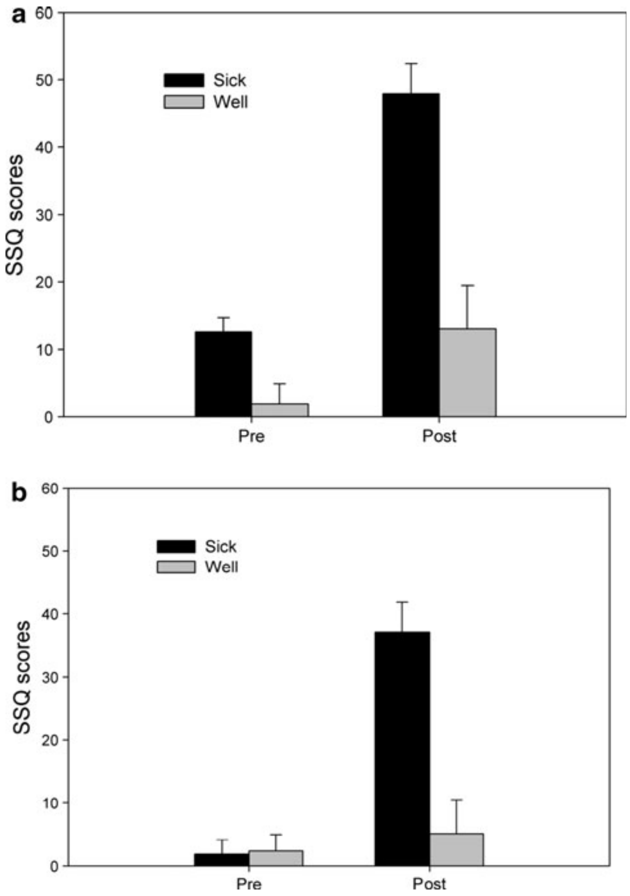

Fig. 2 Mean pre-exposure (pre) and post-exposure (post) total severity scores on the Simulator Sickness Questionnaire (SSQ). **a** Adults. **b** Children. *Error bars* depict SE of the mean

children (56.00%). The incidence for adults and children did not differ, $\chi^2(1) = 0.587$, $P > .05$. Among adults, the incidence of motion sickness did not differ between men (66.67%) and women (66.67%). Among children, motion sickness incidence was greater among girls (76.92%) than among boys (33.33%), $\chi^2(1) = 4.812$, $P = .028$. Fourteen participants discontinued (three adults and 11 children), with mean latency to discontinuation of 31.91 ± 9.61 min for adults and 31.24 ± 8.40 min for children. Each participant who discontinued stated that they were motion sick.

Data on symptom severity are summarized in Fig. 2. In adults (Fig. 2a), pre-exposure SSQ scores differed between the sick and well groups, $U = 23.50$, $P = .011$, with higher scores among adults who later reported motion sickness. Post-exposure, SSQ scores differed between the sick and well groups, $U = 10.50$, $P < .001$. For adults who reported motion sickness, post-exposure scores were higher than pre-exposure scores, $Z = -3.52$, $P < .001$. However, post-exposure scores were also higher than pre-exposure scores for adults who did not report motion sickness, $Z = -2.38$, $P = .018$. In children (Fig. 2b), pre-exposure SSQ scores did not differ between children who later reported motion sickness and those who did not, $U = 69.00$, $P > .05$. At post-exposure, SSQ scores were higher for children who reported motion sickness than for those who did not, $U = 3.50$, $P < .001$. For children who reported motion sickness, post-exposure scores were higher than pre-exposure scores, $Z = -3.30$, $P = .001$. For children who did not report motion sickness, post-exposure scores did not differ from pre-exposure scores, $Z = -1.28$, $P > .05$.

Among participants who reported motion sickness, pre-exposure SSQ scores were higher for adults than for children, $U = 40.50$, $P = .002$. At post-exposure scores did not differ between sick adults and sick children, $U = 79.50$, $P > .05$. Among participants who did not report motion sickness, pre-exposure SSQ scores did not differ between adults and children, $U = 33.00$, $P > .05$. At post-exposure, SSQ scores were higher for well adults than for well children, $U = 14.00$, $P = .012$.

Movement data

We analyzed the movement data using a windowing procedure that permitted us to examine the evolution of movement over time during exposure to the console video game (Dong et al. 2011; Merhi et al. 2007; Stoffregen et al. 2008). We examined three non-overlapping time windows (each 2 min in duration) selected from the beginning, middle, and end of the exposure. For this reason, we could include in our analysis only participants who were exposed to the game for 6 min or more. We also excluded two outliers (>2.5 standard deviations from the mean), one participant for whom a tracking system receiver became disconnected during game play, and six participants whose movement data were corrupted by intermittent metallic interference. Accordingly, analysis of movement data was conducted on 23 adults (11 men, 12 women), and 17 children (8 boy, 9 girls). The Sick group comprised 15 adults (7 male, 8 female) and nine children (3 male, 6 female). Among participants in the Sick group, the mean exposure duration was 47.82 ± 7.25 min for adults and 35.10 ± 13.14 min for children.

For the Sick group, we choose the first, the middle, and the final 2 min for each participant. Due to discontinuation, participants in the Sick and Well groups did not have the same duration of exposure to the game. We judged it to be important to ensure that the windows for the Sick and Well groups represented similar exposure durations. To ensure this, we tied the selection of windows for the Well group to the mean exposure duration of the Sick group. Accordingly, the 1st, 2nd, and 3rd time windows extended from 0 to 2 min, 22.91–24.91 min, and 45.82–47.82 min, respectively, for the Well Adult group, and 0–2 min, 16.55–18.55 min, and 33.10–35.10 min, respectively, for the Well Child group. This selection ensured that the average exposure duration was similar for the Sick and Well groups.

The head and torso movements in AP and ML axes were analyzed using Age (adult, child) × Sickness Group (sick, well) × Windows (first, W1; middle, W2; and last, W3) 3-way ANOVAs with the last factor as the repeated measure. The standard deviation of position, which represented movement variability, was the dependent variable. When the sphericity assumption was violated, the Huynh–Feldt method (Howell 1997) was used. The Huynh–Feldt method yields fractional degrees of freedom, which we report where appropriate.

Head movement

For movement in the AP axis, the main effect of Age was significant, $F(1, 36) = 18.93$, $P < .001$, partial $\eta^2 = .345$, revealing that positional variability was greater for children than for adults (Fig. 3a). The main effect of Time Windows was also significant, $F(1.22, 44.07) = 9.65$, $P = .002$, partial $\eta^2 = .211$, revealing that movement tended to increase over time (Fig. 4a). In addition, the main effect of Sickness Group was significant, $F(1, 36) = 5.31$, $P = .027$, partial $\eta^2 = .128$, with AP positional variability being greater for the Sick group than for the Well group (Fig. 5a). Finally, the Age × Time Windows × Sickness Group interaction was significant, $F(1.22, 44.07) = 5.46$, $P = 0.18$, partial $\eta^2 = .132$ (Fig. 6). For children in the sick group, the effect of the time Windows was significant, $F(1.03, 8.25) = 5.55$, $P = .045$, partial $\eta^2 = .410$. For sick children, positional variability was greater in W3 than in W1 or W2. For the sick group, the age effect was significant at W1, $F(1, 22) = 5.86$, $P = .024$, partial $\eta^2 = .210$ and at W3, $F(1, 22) = 12.59$, $P = .002$, partial $\eta^2 = .364$. In each case, positional variability was greater for children than for adults.

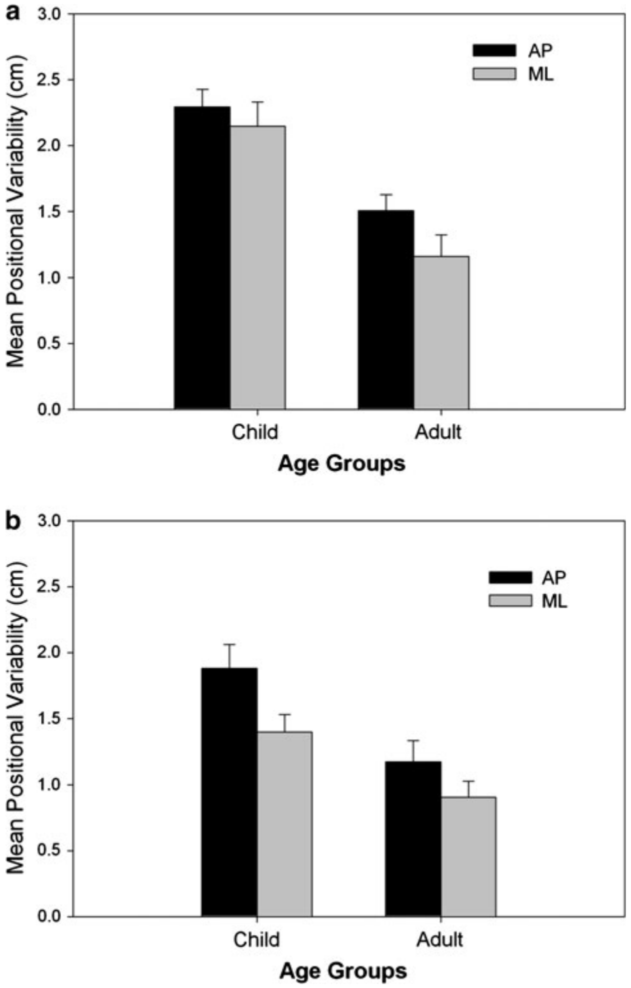

Fig. 3 Positional variability the head and torso for adults and children. **a** Head. **b** Torso. *Error bars* depict SE of the mean

For movement in the ML axis, the main effect of Age was significant, $F(1,36) = 16.39$, $P < .001$, partial $\eta^2 = .313$, revealing that positional variability was greater

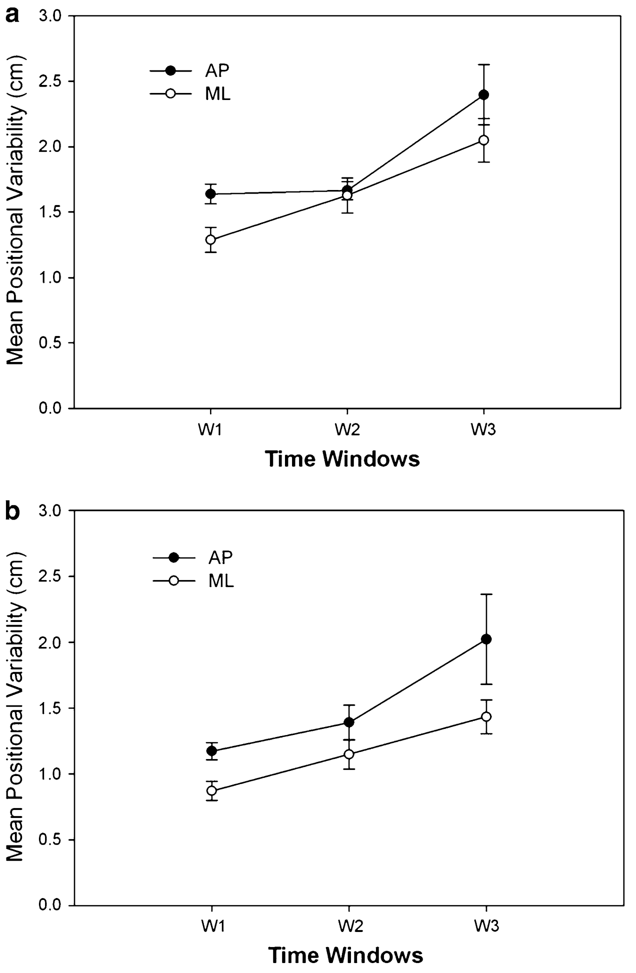

Fig. 4 Positional variability for the three time windows. **a** Head. **b** Torso. *W1* the first time window, *W2* the second time window, *W3* the final time window. *Error bars* represent SE of the mean

for children than for adults (Fig. 3a). The main effect of Time Windows was also significant, F(2,72) = 28.88, $P = .000$, partial $\eta^2 = .445$ (Fig. 4a).

Torso movement

For movement in the AP axis, the main effect of Age was significant, $F(1, 36) = 8.64$, $P = .006$, partial $\eta^2 = .194$, with children moving more than adults (Fig. 3b). The main effect of Time Windows was also significant, $F(1.27, 45.76) = 4.08$, $P = .040$, partial $\eta^2 = .102$, with positional variability increasing over time (Fig. 4b). Finally, the main effect of Sickness Group was significant, $F(1, 36) = 4.82$, $P = .035$, partial $\eta^2 = .118$. Positional variability was greater for the Sick group than for the Well group (Fig. 5b).

For movement in the ML axis, the main effect of Age was significant, $F(1, 36) = 7.36$, $P = .010$, partial $\eta^2 = .170$, with children moving more than adults (Fig. 3b). The main effect of Time Windows was also significant, $F(2, 72) = 16.85$, $P = .000$, partial $\eta^2 = .319$, with positional variability increasing over time (Fig. 4b).

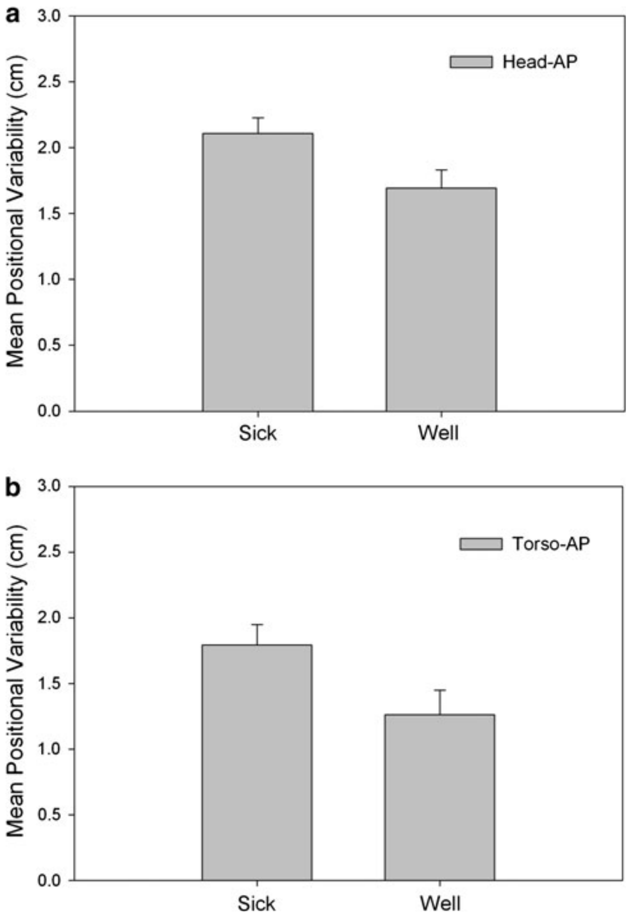

Fig. 5 Positional variability in the AP axis for Sick and Well. **a** Head. **b** Torso. *Error bars* depict SE of the mean

Discussion

Adults and pre-adolescent children played an "off the shelf" console video game. Motion sickness was reported by 61% of the participants; motion sickness incidence did not differ between adults and children. In general, children moved more than adults. During game play, movement tended to increase over time. In addition, movement differed between participants who later reported motion sickness and those who did not. These results are discussed below.

Motion sickness incidence and severity

Motion sickness incidence in adults was similar to previous studies in which adults have played console video games (Dong et al. 2011; Merhi et al. 2007; Stoffregen et al. 2008). Our data on motion sickness incidence in children

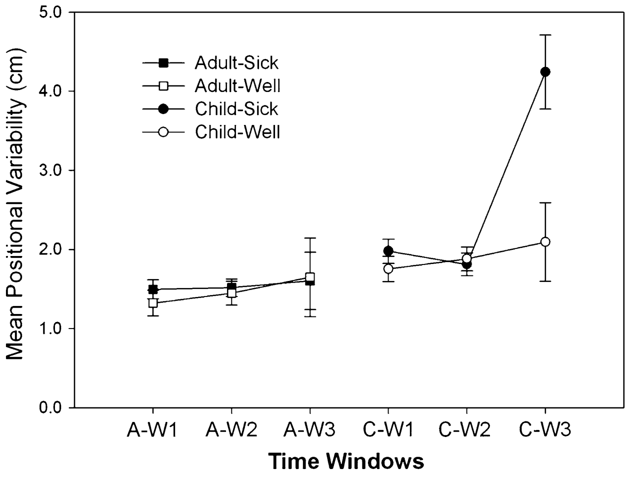

Fig. 6 Positional variability of the head in the AP axis. *C-W1* Children in the first time Window, *C-W2* Children in the second time Window, *C-W3* Children in the final time Window, *A-W1* Adults in the first time Window, *A-W2* Adults in the second time Window, *A-W3* Adults in the final time Window. *Error bars* depict SE of the mean

provide the first controlled confirmation that pre-adolescent children are susceptible to motion sickness arising from video game play. Our results suggest that the risk of motion sickness among players of console video games may be comparable in children and adults.

By age 10, children do not differ from adults in the severity of motion sickness symptoms induced by walking while wearing reversing prisms (Takahashi et al. 1994). In physical vehicles, children tend to be more susceptible to motion sickness than adults (Bos et al. 2007; Turner and Griffin 1999). By contrast, the present study revealed no difference in incidence between adults and children during exposure to a virtual vehicle. It is important to note, however, that in our study, participants controlled the virtual vehicle, whereas participants were passengers in the studies of Bos et al. and Turner and Griffin with physical vehicles. The difference in control is important because vehicle control is known to influence motion sickness susceptibility. In adults, the incidence of motion sickness is reduced among drivers (relative to passengers) in physical vehicles (Rolnick and Lubow 1991) as well as in virtual vehicles (Dong et al. 2011). Because they were walking, participants in the study of Takahashi et al. were in control of their own locomotion. Thus, the results of the current study are consistent with the hypothesis that 10-year-old children and adults do not differ in motion sickness susceptibility when they are in control of the motion stimulus.

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 addition, the distance of participants from the video monitor was small (43 cm): Outside the laboratory, it is likely that children typically adopt greater distances when playing video games. For these reasons, our data on motion sickness incidence and severity may not be representative of the incidence and severity of motion sickness associated with console video games outside the laboratory. However, existing research with adults may be relevant. Stoffregen et al. (2008) varied the distance of adult participants from a video monitor during video game play (either 45 cm or 85 cm). Motion sickness incidence did not differ between these two conditions. By contrast, Merhi et al. (2007) exposed adults to console video games and found that motion sickness was significantly greater when games were played while standing than when games were played while seated. Further research will be needed to determine the possible effects of these factors on motion sickness among children. However, the results of the present study (together with those of Dong et al. 2011; Merhi et al. 2007; Stoffregen et al. 2008) suggest that motion sickness incidence during video game play may be quite high among both adults and children.

Among participants who reported motion sickness the severity of subjective symptoms (as measured by the SSQ) increased from pre-exposure to post-exposure (Fig. 2). We also observed an increase (from pre-exposure to post-exposure) in symptom severity for adults who stated that they were not motion sick. The SSQ indexes symptoms, such as general discomfort, fatigue, eyestrain, and blurred vision, that characterize motion sickness but which also occur in the absence of motion sickness. Many of these symptoms are well-documented side effects of exposure to virtual environments and simulation technologies (e.g., Stanney et al. 1998). The SSQ is a reliable measure of the severity of subjective symptoms that are associated with motion sickness. However, our results, together with results of other studies of motion sickness in video games (e.g., Dong et al. 2011; Merhi et al. 2007; Stoffregen et al. 2008), suggest that the SSQ may not be sensitive to differences between motion sickness and other subjective aftereffects of exposure to virtual environments.

Movement of adults versus children

Children moved more than adults (Fig. 3). This effect was observed for both groups (sick and well), for both body segments (head and torso), and in both axes (AP, ML). This effect is consistent with previous studies comparing adults and children in stance (Godoi and Barela 2008; Olivier et al. 2008) and while seated (Hong et al. 2008). Group differences in movement were independent of motion sickness incidence, which did not differ between children and adults: The fact that children moved more than adults did not make children more susceptible than adults to motion sickness.

Generalized increases in movement during exposure

Positional variability increased over time, with a maximum at Window 3 (Fig. 4). This effect was observed for both groups (sick and well), for both body segments (head and torso), and in both axes (AP, ML). These changes were independent of motion sickness incidence, that is, they reflect changes in movement over time that were not related to subsequent reports of motion sickness. Similar changes in movement patterns over time have been found in previous studies of console video games (Dong et al. 2011; Merhi et al. 2007; Pan and Chang 2011; Stoffregen et al. 2008) and during exposure to virtual environments in general (e.g., Stanney et al. 1998). We conclude that movement tends to increase over time during exposure to virtual environments in children as well as in adults and that such effects can be independent of the incidence of motion sickness.

Movement of Sick versus Well

Movement differed between participants who later reported motion sickness and those who did not. We found main effects of Sickness Group for movement of the head and the torso (Fig. 5). Similar main effects of motion sickness incidence on postural activity have been observed (in adults) when motion sickness has been induced by laboratory devices (Bonnet et al. 2006; Stoffregen and Smart 1998; Stoffregen et al. 2010), in flight simulators (Stoffregen et al. 2000), and when console video games were presented via head-mounted displays (Merhi et al. 2007). Overall (i.e., across windows), both adults and children who later reported motion sickness moved more than those who did not. Consistent with the postural instability theory of motion sickness (Riccio and Stoffregen 1991), the subjective symptoms of motion sickness were preceded by changes in movement such that movement differed significantly between participants who later reported motion sickness and those who did not. The present study extends confirmation of this hypothesis to 10-year-old children, indicating that changes in movement precede motion sickness in 10-year olds as well as in adults.

We also found a significant interaction revealing that changes in movement over time differed as a function of age (adults vs. children) and as a function of motion sickness status (Sick vs. Well). Head movement increased dramatically in the final time window among children who later reported motion sickness (Fig. 6). It is important to note that the increase in movement at Window 3 for children who later reported motion sickness was not general; it did not occur in the ML axis of head movement, or in either axis of torso movement. An implication of these results is that the main effect of Sickness Group on torso movement (Fig. 5b) must be taken at face value (i.e., it cannot be attributed to any underlying interaction).

The 3-way interaction indicates that children and adults differed in the temporal development of postural activity that preceded motion sickness (Fig. 6). Among children who later reported motion sickness, there was a dramatic increase in head movement in the AP axis during the final 2 min of game play. It could be that our child participants were reluctant to report the onset of subjective symptoms of motion sickness; that is, it may be that movement in Window 3 occurred after children were already motion sick. However, due to the specificity of the effect—it occurred in only one axis of only one body segment—we are inclined to reject this interpretation. An alternative interpretation of the present results, which we prefer, is that motion sickness related changes in postural activity developed differently during exposure to the game for adults and 10-year-old children. Some authors have argued that the standing postural control of children is essentially “adult like” by age 10 (e.g., Assaiante and Amblard 1995). However, studies that have examined stance in the context of suprapostural visual tasks have reported that for some measures, postural control continues to develop after age 10 (e.g., Olivier et al. 2010). Moreover, relatively few studies have evaluated the developmental course of postural reponses to dynamic visual motion stimuli of the type used in the present study. Our results suggest that postural responses to complex, multi-axis visual motion stimuli may continue to develop beyond the age of 10 years.

Effects of sickness group were observed only in the AP axis. This axis-specific loss of stability replicates an earlier study of console video game virtual vehicles. In Dong et al. (2011), adults drove a virtual automobile around a paved track. Dong et al. found main effects of exposure duration (i.e., Time Windows) for movement of the head and torso in both the AP and ML axes. As in the present study, differences in movement between the Sick and Well groups were found only in the AP axis. By contrast, research with console video games that involve virtual ambulation (walking) has found movement differences between sick and well participants in multiple axes (Merhi et al. 2007; Stoffregen et al. 2008). Future research should investigate how postural instability and motion sickness may be related to differences between virtual vehicles and virtual ambulation. It will be especially interesting to evaluate this question in the context of children: Does movement evolve differently for vehicular and non-vehicular video games among children who later experience motion sickness?

Conclusion

Our results confirm that motion sickness can occur among 10-year-old children who play contemporary console video games. Motion sickness incidence did not differ between children and adults; thus, it is likely that many children experience motion sickness as a result of playing video games. This effect is significant for the general well-being of young players but, in addition, may threaten the use of console video games in education at all age levels.

One practical implication of the present study concerns the prediction of motion sickness in individuals. The fact that changes in movement precede the onset of subjective motion sickness symptoms suggests the possibility that susceptibility to motion sickness might be predicted on the basis of objective data about bodily movement. Smart et al. (2002) collected data on standing body sway while adults were exposed to potentially nauseogenic motion in a laboratory device. Discriminant analysis revealed that parameters of body sway could be used to predict the occurrence of motion sickness in individual participants. The accuracy of these predictions, in terms of the percent of variance accounted for, was greater than with traditional prediction methods that are based upon physiological or questionnaire data. Increasingly, console video game systems have the ability to detect the movement of players. Normally, these movement data are used to operate the game system; however, such data might be used (simultaneously) to assess the likelihood that players would develop motion sickness and to warn players that—if they continue—they may become ill.

We evaluated relations between motion sickness and movement of the head and torso. Overall, 10-year-old children moved more than adults, consistent with previous research comparing postural activity in adults and children. We also identified differences in postural activity between participants who later reported motion sickness and those who did not, consistent with a prediction of the postural instability theory of motion sickness (Riccio and Stoffregen 1991). While the movement of children and adults was not identical, these results suggest that with respect to the etiology of motion sickness, there may be fundamental similarities between adults and children in relations between visual motion stimuli and the control of bodily movement (Stoffregen 2011).

Acknowledgments We thank Shotah Stoffregen for help with video game terminology.

References

Akiduki H, Nishiike S, Watanabe H, Matsuoka K, Kubo T, Takeda N (2005) Visual-vestibular conflict induced by virtual reality in humans. Neurosci Let 340:197–200

Ali MR, Mowery Y, Kaplan B, DeMaria EJ (2004) Training the novice in laparoscopy. Surg Endo 16:1732–1736

Assaiante C, Amblard B (1995) An ontogenic model for the sensorimotor organization of balance control in humans. Hum Mov Sci 14:13–43

Barab SA, Gresalfi M, Ingram-Goble A (2010) Transformational play: using games to position person, content, and context. Educ Res 39:525–536

Bonnet CT, Faugloire E, Riley MA, Bardy BG, Stoffregen TA (2006) Motion sickness preceded by unstable displacements of the center of pressure. Hum Move Sci 25(6):800–820

Bos JE, Damala D, Lewis C, Ganguly A, Turan O (2007) Susceptibility to seasickness. Ergon 50:890–901

Cohen J (1988) Statistical power analysis for the behavioral sciences, 2nd edn. Erlbaum, Hillsdale

Dong X, Yoshida K, Stoffregen TA (2011) Control of a virtual vehicle influences postural activity and motion sickness. J Exp Psych: Appl 17:128–138

Draper MH, Viirre ES, Gawron VJ, Furness TA (2001) The effects of image scale and system delay on simulator sickness within head-coupled virtual environments. Hum Factors 43:129–146

Duh H, Parker D, Philips J, Furness T (2004) "Conflicting" motion cues to the visual and vestibular self-motion systems around 0.06 Hz evoke simulator sickness. Hum Fact 46:142–153

Gentile D (2009) Pathological video-game use among youth ages 8 to 18: a national study. Psych Sci 20:594–602

Gentile D, Choo H, Liau A, Sim T, Li D, Fung D et al (2011) Pathological video game use among youths: a two-year longitudinal study. Pediat 127(2):e319–e329

Godoi D, Barela JA (2008) Body sway and sensory motor coupling adaptation in children: effects of distance manipulation. Dev Psych 50:77–87

Hong SL, James EG, Newell KM (2008) Age-related complexity and coupling of children's sitting posture. Dev Psych 50:502–510

Howell DC (1997) Statistical methods for psychology, 4th edn. Wadsworth Publishing Company, Belmont CA

Kennedy RS, Lane NE, Berbaum KS, Lilienthal MG (1993) Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness. Int J Avi Psych 3:203–220

Mayo MJ (2007) Games for science and engineering education. Comm ACM 50:30–35

Merhi O, Faugloire E, Flanagan M, Stoffregen TA (2007) Motion sickness, console video games, and head-mounted displays. Hum Factors 49:920–934

Olivier I, Palluel E, Nougier V (2008) Effects of attentional focus on postural sway in children and adults. Exp Brain Res 185:341–345

Olivier I, Cuisinier R, Vaugoyeau M, Nougier V, Assaiante C (2010) Age-related differences in cognitive and postural dual-task performance. Gait Pos 32:494–499

Pan W-W, Chang C-H (2011) Console video games induced postural sway and motion sickness. Sports Ex Res 13:232–240

Reason JT (1978) Motion sickness adaptation: a neural mismatch model. J Royal Soc Med 71:819–829

Rehbein F, Kleimann M, Mößle T (2010) Prevalence and risk factors of video game dependency in adolescence: results of a German nationwide survey. Cyberpsych Beh Social Network 13(3):269–277

Riccio GE, Stoffregen TA (1991) An ecological theory of motion sickness and postural instability. Eco Psych 3:195–240

Rolnick A, Lubow RE (1991) Why is the driver rarely motion sick? The role of controllability in motion sickness. Ergonomics 34:867–879

Rosenberg BH, Landsittel D, Averch TD (2005) Can video games be used to predict or improve laparoscopic skills? J Endour 19:372–376

Rosser JC, Lynch PJ, Cuddihy L, Gentile DA, Klonsky J (2007) The impact of video games on training surgeons in the 21st century. Arch Surg 142:181–186

Smart LJ, Stoffregen TA, Bardy BG (2002) Visually-induced motion sickness predicted by postural instability. Hum Factors 44:451–465

Stanney K, Salvendy G, Deisinger J, DiZio P, Ellis S, Ellison J et al (1998) Aftereffects and sense of presence in virtual environments: formulation of a research and development agenda. Int J Hum-Comp Interact 10(2):135–187

Stoffregen TA (2011) Motion sickness considered as a movement disorder. Science et Motricité 74:19–30

Stoffregen TA, Smart LJ (1998) Postural instability precedes motion sickness. Brain Res Bull 47:437–448

Stoffregen TA, Pagulayan RJ, Bardy BG, Hettinger LJ (2000) Modulating postural control to facilitate visual performance. Hum Move Sci 19:203–220

Stoffregen TA, Faugloire E, Yoshida K, Flanagan MB, Merhi O (2008) Motion sickness and postural sway in console video games. Hum Factors 50:322–331

Stoffregen TA, Yoshida K, Villard S, Scibora L, Bardy BG (2010) Stance width influences postural stability and motion sickness. Ecol Psychol 22:169–191

Takahashi M, Toriyabe I, Takei Y, Kanzaki J (1994) Study on experimental motion sickness in children. Acta Otolaryn 114:231–237

Turner M, Griffin MJ (1999) Motion sickness in public road transport: passenger behavior and susceptibility. Ergonomics 42:444–461

Villard SJ, Flanagan MB, Albanese GM, Stoffregen TA (2008) Postural instability and motion sickness in a virtual moving room. Hum Factors 50:332–345