

Motion Sickness, Virtual Reality and Postural Stability

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Dedication

قُلْ إِنَّ صَلَاتِي وَنُسُكِي وَمَحْيَايَ وَمَمَاتِي لِلَّهِ رَبِّ الْعَالَمِينَ

“Say: Surely my prayer and my sacrifice and my life and my death are (all) God, the Lord of the worlds. (The Cattle 6.162)

This work is dedicated as a sign of gratitude to my endlessly loving and compassionate mother and father whose presence inspired and motivated me to complete this work, as an inspiration to my highly energetic children Abdullah and Suhaila, and as a commitment to my loving and supportive wife Efdal.

Abstract

Motion sickness has been anecdotally reported to occur in the video game community. No confirmation of these reports has been documented by research studies in a laboratory setting. The present investigation was motivated, in part, by the lack of scientific documentation of motion sickness occurrence among video game users. Although some published work (Cobb, 1999; Cobb and Nichols, 1998) showed that users of video game tend to develop some symptoms of motion sickness, there was no clear indication whether these subjects in fact experienced motion sickness. In this work, I argue that this uncertainty can be answered by simply asking the subjects whether they experience motion sickness throughout their virtual reality exposure, instead of only measuring the variation in terms of sickness symptoms score. It is also important to stress that the published studies on motion sickness and video games mainly use simplified laboratory developed video games, rather than using the commercially available console video games. In addition, motion sickness is studied in laboratory settings rather than in more realistic conditions. Therefore, this work is intended to document the existence of motion sickness, in a realistic environment. I varied the game that participants played, their posture during game play (standing vs. sitting), and the technology through which games were presented (video monitor vs. head-mounted display). In addition, I sought to evaluate the postural instability theory of motion sickness in the context of video game use. I measured body motion during game play, and showed that motion sickness was preceded by changes in both the magnitude and dynamics of body movement. In this work, participants played standard

console video games using an Xbox game system. The series of experiments conducted were published in two peer review articles. The first paper “Motion Sickness, Console Video Games, and Head-Mounted Displays” evaluated the nauseogenic properties of commercial console video games when presented through a head-mounted display. The work published in this paper was aimed at 1) determining whether commercial console video games might be associated with motion sickness, 2) understanding some of the factors that may influence the incidence of motion sickness when commercial console video games are presented via an Head Mounted Display as well as conventional video monitor, and 3) documenting participants’ body movement during game play and to use these data to evaluate a prediction of the postural instability theory of motion sickness (Riccio & Stoffregen, 1991). Participants played standard console video games using Xbox game system. The game type (two Xbox games) and postural configuration (standing vs. sitting) were varied. Subjects played for up to 50 minutes and were asked to discontinue if they experience any symptoms of motion sickness. The results showed that sickness occurred in all conditions, but it was more common during standing. There was statistically significant difference in head motion between sick and well participants before the onset of motion sickness during seated play. The findings indicate that commercial console video game systems can be linked to motion sickness occurrence when presented via a head-mounted display and support the hypothesis that motion sickness is preceded by instability in the control of seated posture. Although the results point at a relationship between motion sickness and video game when the game is played using an HMD, additional work was needed to test this relationship in a more realistic circumstances. In the second paper, “Motion Sickness and Postural Sway in

Console Video Games”, the work was aimed at testing the hypothesis that 1) participants might develop motion sickness while playing “off-the-shelf” console video games and 2) postural motion would differ between sick and well participants, prior to the onset and motion sickness. Participants in this sequence of experiments played a game continuously for up to 50 minutes while standing or sitting. The distance to the display screen was varied. As result, motion sickness was observed across conditions. It ranged from 42% to 56%. During game play, head and torso motion differed between sick and well participants prior to the onset of subjective of motion sickness. The results from this work indicated that console video game carry significant risk of motion sickness, even when displayed on conventional video monitor. In conclusion, the present work has successfully documented the anecdotal relationship between motion sickness and video games. Sickness occurred in all conditions. The results indicate that commercial console video game systems can induce motion sickness when presented via a head-mounted display, and via conventional video monitor. The results support the hypothesis that motion sickness is preceded by instability in the control of seated posture.

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Chapter 1

Introduction

1 The Problem of motion sickness

Motion sickness is a serious problem in transportation and Virtual Reality technology (VR). Numerous studies have investigated this problem. However, so far, there is no acceptable solution. Traditionally, motion sickness is known to affect travelers whether land, sea or air ways of transportation is used. Motion sickness is one of the most common illnesses affecting the traveler, and it is estimated that about 50% of the normal population has experienced it (Baratta, 2005). People can become motion sick in cars, airplanes, trains, amusement park rides, or on boats or ships. Motion sickness is sometimes called airsickness or seasickness. Nevertheless, human continuous interaction with a variety of technological devices involving different sensory inputs, such as Virtual Reality (VR) technologies, provides evidence that motion sickness is not only limited to traveling. The occurrence of motion sickness is a critical issue for the future and the implementation of VR technology (Hettinger & Riccio, 1992). Video games, flight simulators, and looking through a microscope also can cause motion sickness (Laviola, 2000).

While recent improvements in vehicle design have made sickness rare in most transportation systems, the occurrence of motion sickness, for the past three decades, in VR technologies renewed the interest in the prediction and prevention of motion sickness. This might be due to widespread reports of motion sickness among users of simulation technology. There has been an ongoing debate within the scientific

community on whether sickness is caused by the poor quality and design of VR technologies or by its high fidelity (i.e., more real). The occurrence of motion sickness could be problematic for the future development and applications of virtual environments (Biocca, 1992; Hettinger, and Riccio, 1992; Laviola, 2000; Stanney et al., 1999). In the next section, I will address the two main categories of motion sickness and the background for its classification.

2 *Forms of Motion Sickness*

Motion Sickness vs. Simulator Sickness. Despite the fact that improvements in vehicle and roads design have made sickness rare in transportation, there is renewed interest in the cause and the prevention of motion sickness. This is due to frequent reports of motion sickness among users of simulation technology. Virtual technology-induced symptoms are also labeled as simulator sickness (Kennedy, Hettinger, & Lilienthal, 1990; Kennedy, Lane, Lilienthal, Berbaum & Hettinger, 1992). Simulator sickness was first discussed in 1957 (Kennedy and Folkes, 1990; Kennedy et al., 1992) while seasickness or motion sickness was first reported at least 2400 years ago (DiZio & Lackner, 1992).

Environment Specific Sickness. For practical reasons, motion sickness has been classified by researchers into three main categories; 1) vehicular or terrestrial, 2) space sickness (i.e., orbital flight), and 3) cybersickness (i.e., sickness produced by simulation/virtual technologies). Another reason for this categorization is the etiology of motion sickness and the underlying assumptions about stimuli evoking and processing. Perhaps, one of the major means of differentiations between modes of motion sickness is the large array of symptoms arising from different situations and

encounters. For this reason, some researchers argue that cybersickness and motion sickness are distinct because of the difference in occurrence rate and intensity across conditions and circumstances (Kennedy & Fowlkes, 1992; Kennedy, et al. 1992; Kennedy & Stanney, 1996). Furthermore, Stanney, Kennedy and Drexler (1997) indicated that there is a difference between the sickness generated by virtual environments (VE) and that provoked by exposure to simulators.

The names differ and the sickness is one? It has also been documented that the aftereffects of cybersickness (e.g., flashbacks, ataxia, and general disorientation) carry on long after the exiting from sickness provoking environment (Kennedy & Stanney, 1996; Stanney & Kennedy, 1997). Kennedy and his colleagues (1990) argued that because fixed-base simulators do not produce physical motion, motion sickness cannot be used as a global description of the type of sickness induced by them. Therefore, sickness induced by simulators should rather be named simulator sickness. Recently there has been an emerging tendency to make a distinction between the sickness caused by simulators and virtual environments, and the traditional motion sickness (Howarth & Costello, 1996; Laviola, 2000; Stanney et al., 1999). Howarth & Costello (1996) argue that such a difference between the visually induced sickness and traditional motion sickness can be attributed to the immersive nature of VE relative to traditional stimulations. On a similar note, sickness in VE systems and traditional simulators differences have been attributed to the difference in the complexity of the stimuli, and because the stimulus complexity generated by VE technology (Cobb & Nichols, 1998; Stanney, et al., 1997). These explanations fall short when it comes to providing clear and objective definitions to the terms *immersive* and *complexity*. Studying and

explaining motion sickness should be based on strong theoretical motives enabling the validation of predictions made in *a priori* fashion. In the next sections, I will discuss the history of motion sickness followed by a discussion of current theories of motion sickness.

3 History of Motion sickness

Ancient Phenomenon. Written accounts of motion sickness date back as far as the ancient Greeks (Reason & Brand, 1975). Nevertheless, this malady is still poorly understood. This might be caused by the poor predictability that is available to us, on who will get sick, in what situation, and why? The universal susceptibility, and the large number of common causes, can easily lead to a variety of speculations about the cause of motion sickness. The complexity of the phenomenon of motion sickness also extends the range of suggested cures from the use of drugs to the hanging of electrically conductive materials in cars, from homeopathy and acupuncture to biofeedback and “viewing the horizon” (Griffin, 1990; Reason & Brand, 1975).

Origins of Modern Theories. Although it is near impossible to trace back the exact date when motion sickness was first experienced, it is almost sure when the first theory of motion sickness has been documented. In 1881, Irwin stated that there appears to be a discord between the immediate or true visual impressions and a certain visual habit or visual sense of the fitness and order of things which passes into consciousness as a distressing feeling of uncertainty, dizziness and nausea. This statement became the central premise of the most popular theory of motion sickness: the sensory conflict theory. This theory is only one amongst many other theories addressing the etiology of

motions sickness (Reason & Brand, 1975). Another and more recent theory is the Postural Instability theory of motion sickness (Riccio & Stoffregen, 1991).

3.1 Symptomology versus Etiology

Theories of motion sickness often do not address all aspects of the phenomenon. Instead, they tend to focus upon limited facets of the problem. Currently, they can be classified into two categories, those that center upon symptomology and those that concentrate upon etiology. In this study I will be focusing on causal aspects of motion sickness rather than symptomology. Generally, situations that are likely to produce motion sickness often involve unusual perceptual stimulation, and an etiological theory must be able to account for this fact. Motion sickness also can involve disruption in the perception-action cycle of behavior. A satisfying theory should be able to account for these changes as well. Perceiving and acting can be viewed as complementary processes that enable an organism to interact successfully with its environment (Gibson, 1979). Therefore a viable etiological theory should not only address perception and action, but should also address the relation between them (Stoffregen & Riccio, 1991), and should also account for changes in the relations between perception, action, and the environment. These theories should address the issue of adaptation, i.e., how do organisms regain functional correspondences with provocative environments. Theories that can address these factors may be able to make specific suggestions regarding the prediction and prevention of motion sickness.

3.2 Theories of Motion Sickness Etiology

Motion sickness theories can be many, spread between superstition and speculation to theories that are motivated by observation. Early accounts of motion sickness etiology were often theories that attributed motion sickness to the disturbance of blood/fluid or the function of certain organs by certain types of motion. Irwin (1881, as cited in Reason & Brand, 1975) and de Champeaux (1881, as cited in Reason & Brand, 1975) first posited that vestibular systems might be involved. This has led to a more recent hypothesis that overstimulation of the vestibular system caused by a unique pattern of movements (e.g., sea travel) can induce motion sickness (Reason & Brand, 1975). It was sufficient to show that subjects can become motion sickness when stationary (i.e., VIMS) to disprove this hypothesis. Presently, there are two major theories that attempt to explain the phenomenon of motion sickness on the etiological level; these are the Sensory Conflict theory and Postural Instability theory. Typically, theories of motion sickness etiology have been based on the concept of sensory conflict (e.g., Duh, Parker, Philips & Furness, 2004; Reason, 1978). The central idea of this approach is that motion sickness situations are characterized by patterns of perceptual stimulation that differ from patterns expected on the basis of past experience. These differences are interpreted as sensory conflict, which is alleged to produce motion sickness. Theories based on this concept have low predictive validity (i.e., who will be come sick and in what situation?) (Draper, Viirre, Gawron, & Furness, 2001), and some researchers have argued that such theories may not be scientifically falsifiable (e.g., Ebenholtz, Cohen, & Linder, 1994). Although I will be discussing the central claims of the sensory conflict theory, in this

work I aim at evaluating an alternative theory of motion sickness etiology, the postural instability theory of motion sickness (Riccio & Stoffregen, 1991).

3.3 The sensory conflict theory

Sensory conflict theory has enjoyed widespread influence as an explanation of motion sickness. The conflict explanation has intuitive appeal and appears to be able to account for the occurrence under most conditions. In addition, conflict theory has provided a useful theoretical framework for researches to build upon through its classification of the situations that produce sickness and the sensory systems involved (Griffin, 1990; Watt, 1983).

Conflict theory modalities. The sensory conflict theory (Reason & Brand, 1975) is also known as sensory rearrangement theory (Reason & Brand, 1975), neural mismatch (Oman, 1982), and cue conflict (McCauley & Sharkey, 1992). The central idea of this approach is that motion sickness situations are characterized by patterns of perceptual stimulation that differ from patterns expected on the basis of past experience (i.e., memory or mental models). These differences are interpreted as sensory conflict, which is alleged to produce motion sickness. The early form of the sensory conflict theory was put forward by Irwin (1881) that sickness results from differences between the actual input and what the person's habitual sense of what is normal. Originally, motion sickness was believed to be the outcome of situations that led to combinations of sensory activities to which the person is unfamiliar. To sum up, the occurrence of incompatible types of motion brings about conflict through non-equalities in sensory input.

Types of sensory conflict. The sensory conflict theory was reshaped by Reason and Brand (1975) who classified sensory conflict into two categories; 1) inter-modal when conflict is the result of incongruity between visual and vestibular inputs, and 2) intra-modal conflict which refers to incongruity within a particular sense, for instance between the canals and otoliths of the vestibular system. Other types of conflict are also thought to take place within these categories. Type I conflict is produced by two (or more) sensory systems simultaneously presenting contradictory or uncorrelated information. A representative circumstance of type I conflict is when a person is looking at the 'stable' horizon from a heaving and pitching ship, moving while wearing any types of optically distorting apparatus, and space sickness. Type II conflict involves the receipt of motion cues from one system without the expected input from other systems (e.g., visual information in the absence of vestibular information or vice versa). Fixed based simulators, video games, and reading while in a moving vehicle are typical circumstances where type II conflict is believed to take place and potentially to cause motion sickness (Benson, 1984; Griffin, 1990; Reason & Brand, 1975).

Sensory rearrangement. The concept of *sensory rearrangement* suggests that sickness may arise from conflict between "the present evidence of our spatial senses and that held in store from our previous experience" (Reason & Brand, 1975, p. 134). That is, contrasting sensory information may produce sickness through expectancy violation. This concept of sensory rearrangement is a response to the inability of conflict theory to explain how conflict is resolved given that the stimulation that produced it is still present (Reason & Brand, 1975). In 1982, Oman suggested that conflicts between current sensory inputs and internal representations will cause in motion sickness. He

postulated that there is ongoing comparison of present and expected sensory inputs.

Oman postulated that motion sickness is produced when internal representations and current sensory inputs conflict with one another. Oman was faced with the challenging question on why some conflicts seem to induce motion sickness and others don't. Oman (1982) asserted that some in event of low magnitude (below a certain threshold) conflicts, motion sickness does not seem to occur.

Limitations of the sensory conflict theory. Being the most plausible available theory for motion sickness, the sensory conflict theory has gained a wide acceptance within the scientific community. However, like any other theory, the sensory conflict theory does not come without any flaws. Despite the ability to provide a probable explanation for motion sickness, this sensory-based explanation does lack the ability to provide quantitative explanation of the conflict. In other words, the conflict theory fails to account for the time-course and the magnitude of sensory conflict. Most importantly, the conflict is not powered to predict what type of conflict will take place and when it will occur. Its explanation of conflicts is conveniently available in an ad hoc manner. One of the central premises of the conflict theory suggests that motion sickness is the result of conflict between actual and expected inputs. However, the theory falls short from explaining how and where this conflict between, or comparison, of sensory inputs takes place. Furthermore, this sensory based theory does not make any claims regarding the role of behavior or the environment in the conflict. Active behaviors such as, postural instability/adjustment, are only thought of as a consequence of conflict and a byproduct of motion sickness, not as a causal factor (Griffin, 1990; Kennedy & Stanney, 1996; Reason & Brand, 1975; Stoffregen & Riccio, 1991). The absence of the

role of behavioral and environmental aspects restricts the theory from making prediction using empirical data. For instance, the conflict theory is ill equipped to provide explanation of situations where sickness occurs in laboratory settings using imposed motion frequencies of 0.08-0.4 Hz (Guignard & McCauley, 1990). The conflict theory gained a wide appeal mainly because of the absence of viable alternative explanations of motion sickness. However, the problems associated with this theory prevent it from providing solutions to the problem of motion sickness.

Implications. Despite its limitations, the sensory conflict continues to be the most widely accepted explanation of motion sickness in real and virtual environments. The proponents of this theory subscribe to the widely held belief that motion sickness is the result of errors in perceptual processing. It is not important to this theory how the discrepancy between actual and expected sensory signals. What seems to be important is that such discrepancy exists. One of the predominant limitations of this theory is that it difficult to empirically quantify the magnitude of conflicts and the timing of their occurrence because the theory does not provide testable predictions. Hence, researchers are forced to use physiological, motion sickness questionnaire, and other subjective data of symptomology.

These limitations motivated the emergence of alternative theories. The Postural Instability theory (Riccio & Stoffregen, 1991) is one of the theories that provide different perspective on motion sickness and offer predictions that are based on not perceptions alone, nor action alone, but on the relationship between the two.

3.4 Postural Instability Theory

The postural instability theory seems to be the most explicitly stated alternative known theory to the sensory conflict. Motivated by the Ecological Approach to Perception and Action, Riccio and Stoffregen (1991) put forward the ecological theory of motion sickness and postural instability, as a rival theory to the sensory conflict theory. The difference between these two theories lies in the central claims of each of them. While the sensory conflict theory rests its claim in a perceptual and the sensory level, the postural instability theory focuses on the interaction among perception, action and the environment. While Riccio and Stoffregen (1991) agree that sensory factors are important, they emphasize that strictly sensory/perceptual explanations of motion sickness are insufficient. Addressing their critiques to the sensory conflict theory, Stoffregen and Riccio (1991, p.160) suggested that “any satisfying theory of motion sickness must make assumptions about perception, about action, and about relations between the two”. The postural instability theory asserts that behavior (action) is a causal factor in motion sickness rather than being only a consequence. The conflict theory claims that the brain expects redundant information and that when this does not happen, the sensory systems work in an antagonistic manner producing the conflict that is believed to cause sickness. While Stoffregen and Riccio (1991) disagree with this claim, because redundant stimulation is both common and informative, they agree with the conflict theorists that situation that produce motions sickness are characterized by unfamiliarity. They, however, add that unfamiliarity does not necessitate the postulation of conflict between the current and stored inputs.

Alternative explanation? The central hypothesis of ecological theory of motion sickness is that motion sickness results from prolonged instability in the control of posture. Thus, sickness occurs in situations in which the individual does not possess or has not yet learned strategies for maintaining functionally effective postural control (Riccio & Stoffregen, 1991). These claims are based on abundance of critical observations and on the available empirical data in literature suggesting that there is a crucial role of the animal's action and postural configuration in the occurrence of motion sickness. That is, the actions of the animal in response to the stimulations of various environments (environmental property) are responsible for the outcome. Furthermore, Riccio and Stoffregen (1991) put forward a directly testable hypothesis that gave their theory a greater etiological power than its precedents. They postulate that motion sickness is caused by a prolonged postural instability. Thus, in order for this hypothesis to be tested, it is sufficient to monitor the individual's postural activity during exposure to provocative stimuli. Stoffregen and Smart (1998) exposed subjects to a visual stimulus that simulates human's postural spontaneous sway. Subjects who became sick in this experiment were found to exhibit dynamical changes in their postural activity that were different to those found in subjects who did not report being sick.

3.4.1. Postural instability and Motion sickness

Cobb and Nichols (1998) examined the postural performance of forty subjects before and after playing 20 minutes of a popular video game, with restricted movement. Their goal was studying how virtual reality can contribute to the deterioration of the user's postural performance. They found that balance disturbances were strongly correlated

with simulator sickness. Hamilton, Kantor and Magee (1989) also found that postural disequilibrium to be affected by exposure to VR simulator. Dizio and Lackner (1997) found a five-fold increase in sway amplitude after 15 min of VE exposure relative to pre-exposure using a Kistler force platform and the standard Romberg posture. Other studies (Stoffregen & Smart, 1998; Stoffregen, Hettinger, Haas, Roe, & Smart, 2000) reported that head instability was significantly greater for subjects who subsequently became motion sick than for those who did not become sick. The latter studies were clear about reporting motion sickness incidences and reversed the causal relationship between motion sickness and postural instability.

What comes first? According to Stoffregen and Smart (1998) and Stoffregen et al. (2000), motion sickness, when reported, was preceded by postural instability while in the other studies, motion sickness was thought of as a side or after effect of motion postural instability. This disparity in explaining findings turns out to be theoretically driven. While Stoffregen and his colleagues base their work within the postural instability theory of motion sickness (Riccio and Stoffregen, 1991), the other authors are motivated by the theory of sensory conflict (Reason, 1978).

The answer lies in the methodology. Whether induced by visual stimuli (Lishman & Lee, 1973; Stoffregen, 1985; Smart et al., 2002; Stoffregen & Smart, 1998), or by inertial ones (Griffin, 1990; Griffin & Mills, 2002; Lawther & Griffin, 1987; 1988), motion sickness has been reported to affect postural motion. It is well established, in the motions sickness literature, that instability is exhibited following the onset of motion sickness. It is worth to note here that postural instability has been treated as a side effect. This is evidenced by the studies that have specifically utilized postural measures

but have done so in a pre/post manner (Anderson, Reschke, Homick & Werness, 1986; Cobb, 1999; Cobb & Nichols, 1998; Hamilton, Kantor, & Magee, 1989; Kennedy & Stanney, 1996; Kenyon & Young, 1986). While these studies have attempted to examine the assumed relation between posture and motion sickness (i.e., that postural disturbances are a side-effect), success has been limited. The standard tests employed (various static and/or dynamic balance tests) were found to be very limited in their ability to detect the postural disruptions involved with motion sickness (Hamilton et al. 1989). This has very strong implications on how the relationship between postural instability and motion sickness is approached. While postural disturbances are considered as consequences of motion sickness (Cobb, 1999; Cobb & Nichols, 1998; Kennedy & Stanney, 1996; Kenyon & Young, 1986), Riccio and Stoffregen (1991) suggest that postural instability should precede motion sickness. This hypothesis has been empirically confirmed by Stoffregen and Smart (1998) who found significant changes in the postural activity between what they classified “sick” subjects and “well” subjects. Similar findings were obtained by Stoffregen et al. (2000) while exposing subjects to visual stimuli in a fixed based simulator. A fundamental difference in the methodology used by Stoffregen and his colleagues (2000) compared to other studies resides in the fact that postural activity was monitored from beginning to end of the exposure to the provocative stimuli. Another major methodological difference is that in the studies motivated by the postural instability theory, subjects are asked to answer yes or no, whether they are motion sick as they exit the simulator or the moving room. This classification of tested participants is important to facilitate the comparison of postural patterns between of the “sick” and “well” groups through the exposure period.

4 Postural Instability, Motion Sickness and Video Games

More recently, Merhi, Faugloire, Flanagan and Stoffregen (2007), tested the postural instability hypothesis by presenting a video game to players via a head-mounted display. In this experiment, participants were asked to indicate the feeling of any motion sickness symptoms during the play time. Participants filled out a Simulator Sickness Questionnaire (SSQ) and were asked to discontinue immediately if they felt any symptoms of motion sickness, however slight. Participant then played game continuously for up to 50 minutes. At the end of the 50 minutes 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. In two experiments, Merhi et al. (2007) asked participants to play a commercially available console video game that was presented through an HMD. They varied participants' posture (standing vs. seated) and the game that they played (Whacked vs. Halo, Microsoft Corp.). In each experiment, a minimum of 59% of participants reported motion sickness. In Experiment I, the incidence of sickness was greater when participants played while standing rather than while sitting. Across experiments, symptoms of motion sickness (i.e., SSQ scores) were higher after playing the game than before. When comparing postural motion of sick and well groups, the results revealed significant differences in motion of the head between groups, prior to the onset of motion sickness.

Participants stood with their toes on a line on the floor; the line was 45 cm from the video monitor. 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. Subjects 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. For both groups the visual angle of the screen was approximately 60 degrees horizontal by 48 degrees vertical. In the sitting results showed that players who experienced motion sickness exhibited instability in the control of seated posture. In a follow-up experiment, Stoffregen, Faugloire, Yoshida, Flanagan and Merhi (2008) had 40 participants play a game continuously for up to 50 minutes while standing or sitting. They varied the distance to the display screen, and consequently, the visual angle of the display. Across conditions, Stoffregen et al (2008), showed that 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. The results indicated that motion sickness was preceded by motion sickness.

5 Visually induced motion sickness (VIMS)

Sickness that occurs from being exposed to visually displayed pattern of motion trajectories without the person being at physical motion is known as “visually induced motion sickness” (VIMS). VIMS is common in systems that depict motion of the user, such as flight and driving simulators, and many virtual environment systems (Stanney et al., 1998; Stoffregen et al., 2000). The effectiveness of simulation and virtual environment systems, and their acceptance by users, can be severely limited if they produce motion sickness (Biocca, 1992; Stanney et al., 1998). This provides a strong practical motivation for understanding this malady. Since most virtual environments consist of visual simulations (Hettinger & Riccio, 1992), VIMS is known to widely occur in laboratory devices, such as a moving room (Lishman & Lee, 1973; Stoffregen,

1985; Smart, Stoffregen & Bardy, 2002; Stoffregen & Smart, 1998), in fixed base flight simulators (Stoffregen et al., 2000), and in head-mounted displays (*HMD*)'s (Cobb, 1999; Cobb & Nichols, 1998; Draper, Viirre, Gawron, & Furness, 2001; Laviola, 2000). In general, there is a positive correlation between the technical sophistication of visual simulation and the incidence of motion sickness among users (Crowley, 1987; Kennedy & Fowlkes, 1992; Miller & Goodson, 1960; Nickerson, 1992). Generally, the better the system looks, the more likely it is to induce motion sickness. This correlation highlights the importance of behavioral research on motion sickness in simulator systems: Technological development, *per se*, will not solve this problem. By itself, technological development is making the problem of motion sickness worse, not better. What is needed is behavioral science research in order to understand the underlying human-technology relationship; that is to study how people interact with simulator systems. A successful approach is likely to depend upon research in which the unit of analysis is the human-machine system (e.g., Flach, Hancock, Caird, & Vicente, 1995; Vicente & Rasmussen, 1990). Whether in actual travel or in laboratory settings, whether it is called motion sickness or simulator sickness, the symptoms experienced are fundamentally the same. Throughout this work I will refer to this sickness as motion sickness despite the variety of nomenclatures that exist in the literature such as, simulator sickness, cybersickness, and airsickness, etc.

5.1 Visual displays

Concerns have been raised about the potential effects of virtual reality use (Biocca, 1992). Researches into the effects of simulated visual environment show that people exposed to VR risk developing motion sickness. VR users tend to exhibit

decreasing motor skills and performance as a result of VR exposure (Cobb & Nichols, 1998). Anecdotally, it has been reported that users of Console Video Games (CVGs) suffer of symptoms of motion sickness. However, no scientific research has examined those claims. The young population in the World, in general, and in the USA specifically, is becoming more exposed to VR via Computer and CVGs (e.g., Xbox, Xbox 360, Play Station II, Gamecube, etc.).

Most video game players (gamers) interact with game environments through either computer screen displays or regular video monitors. Using a keyboard and mouse or a controller pad (known also as game pad), gamers try to act on the game environment by moving avatars around and by pressing on buttons or manipulating joysticks. Recently, the increasing number of gamers inspired game producers to promote more exciting and more appealing games to compete for the monopoly of the market, by presenting new sophisticated, more intellectual, and more compelling types of games. Producers often rely on the sophistication of their virtual environment by improving the video graphic quality, introducing new avatars with more realistic looks (i.e., avatars that look much like a regular human being or a famous sports/movie star). The hardware manufacturers, whose main consumers are the army and the industries, find in gamers populations a lucrative target for their VR products. They are recently chasing gamers by advertising their virtual reality products like Head-Mounted Displays (HMD), sometimes with gyroscopes, as exciting visual displays that could bring about more compelling and immersive experiences to gamers. Therefore, the use of HMD's is starting to take place in the market, where advertisers promise the consumers a "True Stereoscopic 3D" vision.

5.1.1. Head-Mounted Display (HMD)

A Head-mounted display (HMD) is a set of goggles or a helmet with tiny monitors in front of each eye to generate images seen by the wearer as three-dimensional. Often the HMD is combined with a head tracker so that the images displayed in the HMD change as the head moves. In addition to mobility, HMD for visual environments facilitates an immersive experience that seems more real than an experience provided by a desk-top monitor (Ruddle, Payne & Jones, 1999). HMD use stems from military tasks, to medical and reaches the entertainment arena especially video games. There is an increasing optimism that HMD will soon replace the traditional computer monitors or the Cathode Ray Tube displays (CRT) in many of the fields, yet available data show no advantages for HMD over other visual displays. Morpew, Shively and Casey (2004) found no advantage for one display over the other when comparing the effect of using HMD versus a conventional video monitor in an Unmanned Aerial Vehicle sensor operator target search task. However, subjects showed a greater performance in placing the cursor over a target of interest when using a video monitor. In addition, a significant disadvantage was found for the HMD with respect to self-reported nausea, disorientation, and oculomotor strain. These findings positively correlate with findings by Cobb (1999) and Cobb and Nichols (1998) who reported that immersion in Virtual Environment (VE) for up to 20 minutes using an HMD produces a mild postural instability. Although Cobb (1999) and Cobb and Nichols (1998) suggest no association between self-reported symptoms and performance measures of postural instability, they however suggest that people exposed to VR risk developing motion sickness and decreasing motor skills and postural performance.

5.1.1.1. HMD and Vection

The suspicion that HMD may produce higher rates of sickness symptoms could be associated to their capacity of providing a higher self-motion sensation; known as “vection” (Hettinger & Riccio, 1992). Vection has long been associated with motion sickness. Several experiments have measured vection and motion sickness and found that the condition that produces the greatest vection also produces the greatest motion sickness (Ebenholz, Cohen & Linder, 1994; Hettinger & Riccio, 1992). However, Webb and Griffin (2003) showed that subjects wearing an HMD showed no difference in sickness symptoms while tracking a moving single dot stimulus (central vision stimulus) which does not induce vection, versus tracking a full screen of moving dots (peripheral vision stimulus) which is known to induce self-motion sensation. Furthermore, Webb and Griffin (2003) added that motion sickness and vection can vary independently, which implies that vection may not be playing a central role in generating higher sickness symptoms rates as it was thought (Hettinger & Riccio, 1992).

5.1.2. Video Monitors

Cathode Ray Tubes (CRT's) and Liquid Crystal Displays (LCD's) are the engineering names of what is known as video or computer desktop monitors. Thereinafter, these displays will be referred to as video monitors. Video monitors are often described as non-immersive systems or least immersive implementation of VR techniques (Viola et al., 2000). Because of the low rate of immersion and presence they provide, video monitors are not as subject to studies as HMD and other virtual reality visual displays are. It has been reported that symptoms of motion sickness and postural disturbances to

be higher in simulators employing space-stabilized head mounted displays (i.e. immersive virtual reality systems) than in simulators with dome-based projection systems or fixed video displays (Kennedy, Lanham, Massey, Drexler, & Lilienthal, 1995). Using the desktop system, the virtual environment is viewed through a portal or window by utilizing a standard high-resolution monitor. Such technology of “non-immersive” systems has advantages as it does not require the highest level of graphics performance and does not need any special hardware. This means that these systems can be regarded as the lowest cost VR solution that can be used for many applications. However, this low cost means that these systems will always be outperformed by more sophisticated implementations, since they provide almost no sense of immersion and are limited to a certain extent by current 2D interaction devices.

Commercial Video Games are mostly viewed on video monitors. Despite the documented low immersion rate that video monitors provide, there are many reports about motion sickness being experienced by users of video games. There are hundreds of comments on message board about motion sickness incidents due to extended hours of gaming, such as playing “HALO”, “DOOM”, “King Kong” and many other new games. The growing number of these opinions on technology forums could be a major concern for major producers of Video Games which risk driving their sales numbers in undesired direction.

6 Virtual Reality Technology, Video Games and Motion Sickness

Virtual reality (VR) and/or virtual environment (VE) technologies have undergone a tremendous rate of improvement for over three decades. They have constituted lately a ‘hot’ research area inspiring an unlimited creativity in research and development field.

The application of these technologies proved to be ubiquitous. Although the military is the first to encourage intensive research in these fields, VE and VR applications now seem to be found in clinical treatment, training, education, manufacturing, etc. Virtual Reality was seen as a way of exposing people to immersive 3D environments that afforded natural and intuitive coupling of sensory and psychomotor functions at a fraction of the cost of conventional simulators. Simulation and immersive virtual technologies play also a crucial role in the advance of training strategies and techniques of a seemingly growing number of fields like transportation, teleoperation, entertainment and others. For instance, teaching a pilot the skills of flight does not depend anymore on the use of an airplane as much as it used to be prior to the invention of flight simulators. Thanks to the technological improvements, aviation skills can be developed in a ground-based cockpit that the pilot can then transfer to a real-world mission. Efficiency of operating and teleoperating devices in different fields (e.g., telesurgery, astronomy, geology, etc.) also depends on the improvement of simulation and virtual technology (Yamanouchi & Yamazaki, 1999). While benefits of such technology seem unlimited, yet many people are affected adversely by exposure to the synthetic environments and the high definition displays. It is now well known that interacting with virtual technology could have many disadvantages, or negative effects (Stanney et al., 1998; McCauley and Sharkey, 1992).

Use of video games is increasing, so is the risk of motion sickness. One area of rapid technological improvement that is representative of all VR applications, is console video games, such as *Play Station*, and *Xbox*, in which players use a handheld controller (known as a *game pad*) to interact with a visually presented virtual world. Computer-

based video games in general and console video games (CVG) in specific also have wider significance. Games play a large role in driving research and development in areas that previously had been confined to the engineering and computer science communities (Pagulayan, Keeker, Wixon, Romero, & Fuller, 2003). Games act as showcases for cutting-edge developments in both software and interactive hardware systems. Thus, the appearance of motion sickness among users of console video games is an ominous sign not only for the console game industry, but also for designers and users of virtual environments, in general. Some previous studies have reported that playing console video games can increase the severity of symptoms associated with motion sickness (e.g., Murata, 2004). However, CVG's have not been the focus of previous research. In particular, previous studies have not attempted to determine the parameters of game use that may influence their propensity to induce sickness. In addition, previous studies have not differentiated the incidence of sickness from the severity of symptoms. This can be a problem because many symptoms that are associated with motion sickness are not unique to motion sickness. In particular, some symptoms of motion sickness, such as blurred vision, eyestrain, headache, and difficulty focusing are also associated with the use of desktop computer systems when motion sickness is absent (Lawson, Graeber, Mead, & Muth, 2002).

What do other studies miss about motion sickness? Among designers there is great competitive pressure to maximize the subjective persuasion or involvement of players. These systems have exhibited rapid improvement in both software and hardware, with resulting improvement in the realism of player movement, game scenarios, and environments. These improvements raise the question on whether console video games

may give rise to visually induced motion sickness. It has been anecdotally reported that motion sickness among players is common, but rarely investigated in the proper settings. Yet, it is a widely discussed concern, but not well documented. Studying motion sickness among gamers should address the problem within the correct context. That is, the relationship between subject and virtual environment should be representative to the actual gaming setup as realistically as possible (Stoffregen et al., 2008). Many studies addressed the relationship between motion sickness and virtual environment using video game as their testing platform. Although these studies reported that participants experienced symptoms of motion sickness, they failed to confirm any incidence of motion sickness (Cobb, 1999; Cobb and Nichols, 1998).

7 The present work

This study fits in the theory of postural instability framework. It is intended at first to document the increased reports on motion sickness incidents in the video gaming community. Another goal of this study is to test the central hypothesis of the postural instability theory that motion sickness is induced by postural instability.

Previous research has provided preliminary confirmation of key hypotheses of the postural instability theory (Stoffregen et al., 2000; Stoffregen & Smart, 1998). Another study has examined the ability of this theory to predict motion sickness by monitoring the postural activity during exposure to provocative stimuli (Smart et al., 2002). The setting of the previous studies was fundamentally simple. Participants in previous studies did not have any assigned task, except simply staring at an un-axial visual stimulus (e.g., moving room, computer graphic, map attached to the front wall of a moving room). The importance of the previous studies resides in their empirical

verification of the postural instability theory central hypothesis, that postural instability precedes motion sickness. However, in real life situations where motion sickness takes place, individuals usually are engaged in a variety of activities (i.e., reading a newspaper on a train, looking through a vehicle side window, controlling a flight simulator, playing a video game, etc.). Therefore, reducing the subject's task to only looking at a visual display is not representative of the real situation where people experience motion sickness. Such studies could suffer a lack of external validity. There is a need to study motion sickness in more realistic settings that possess a high representativeness of real life situations (Stoffregen et al., 2008). There have been few attempts to study motion sickness in real life situations, like traveling on a boat, airplane, or racing yachts (Turner & Griffin, 1995; Turner, Griffin, & Holland, 2000). These studies were based on subjective data (i.e., questionnaire) of a large number of participants, and on the motion of the airplane/yacht, but made no reference to the passengers' postural activity. Other research has studied the aftereffect of the use of head-mounted display using a joystick (Cobb, 1999; Cobb & Nichols, 1998) but only assessed the postural activity in a pre/post design, with added restriction on the subject action.

The present work constitutes a necessary addition to the video game, virtual reality and motion sickness literature.

8 *Implications*

Gaming industry set a record in sales in 2006 by reaching \$12.5 billions (Snider, 2008).

This is the fastest growing industry across all sectors, and not only entertainment

industry. Revenue from computer games now exceeds that from the Hollywood box office. Competition for market share is cutthroat and the consumer demands ever more complexity and lifelike graphics and animation (digital dreamer website). Today, more than 50% of US households play computer and video games. Each year hundreds of software titles are published by some of the biggest names in the computer and electronics industry. In 2007, the video game sales reached another record of \$17.9 billion, which is 43% higher than the previous year (Snider, 2008). Although, video game sales don't seem to be affected by reports on motion sickness occurrence among gamers, motion sickness remains a topic to be addressed. Recent increasing reports of motion sickness, in video game players' population, may be a cause for concerns to parents, individual players, and corporations that dedicate their time, money, and resources developing these games. Virtual Reality manufacturers may face litigations because of the serious consequences of motion sickness that their products are reported to cause. Thus, research work that takes into account the real life scenario of the video game is needed to investigate and document the alleged occurrence of motion sickness among video game users. This will benefit both retailers, by launching safer products to the market, and consumers, by reducing the risk of falling motion sick as a result of video game use.

In order to address the motion sickness question in virtual reality environment, I conducted a series of experiments using console video game as platform and a variety of independent variables ranging between postural configurations to display technologies. The current work has resulted in two publications in peer review journal (Merhi et al., 2007; Stoffregen et al., 2008). The following sections include summaries

of these two publications. A more detailed account of the published work is documented in chapters 2 and 3 which include detailed descriptions of the series of experiments.

9 Summary of Chapter 2

This chapter consists of a publication of a series of experiments that tested the occurrence of motion sickness in a sample of subjects that played console video game using a Head Mounted Display as a medium to view a commercially available video game (Merhi et al., 2007).

Methods. Participants played standard console video games using an Xbox game system. Two independent variables were used in this study; 1) participants' postural configuration (standing vs. sitting) and 2) the game types (two Xbox games). Data on three dependent variables were collected: 1) postural movement (Head and Torso), 2) Simulator Sickness Questionnaires (before and after playing the game) and 3) Yes/No answer to the whether participants feel motion sickness as they exit the game.

Participants played for up to 50 min and were asked to discontinue if they experienced any symptoms of motion sickness (Merhi et al., 2007).

Predictions. The work published in this paper was aimed at 1) determining whether commercial console video games might be associated with motion sickness, 2) understanding some of the factors that may influence the incidence of motion sickness when commercial console video games are presented via an Head Mounted Display as well as conventional video monitor, and 3) documenting participants' body movement during game play and to use these data to evaluate a prediction of the postural instability theory of motion sickness (Riccio & Stoffregen, 1991). I predicted that 1) console video game systems can induce motion sickness when presented via a head-

mounted display 2) “sick” and “well” participants will display different postural patterns, and most importantly 3) postural instability will precede motion sickness.

Results. The results showed that sickness occurred in all conditions, but it was more common during standing. There was statistically significant difference in head motion between sick and well participants before the onset of motion sickness during seated play. The findings indicate that commercial console video game systems can be linked to motion sickness occurrence when presented via a head-mounted display and support the hypothesis that motion sickness is preceded by instability in the control of seated posture. Although the results point at a relationship between motion sickness and video game when the game is played using an HMD, additional work was needed to test this relationship in more realistic circumstances.

Conclusion. The results indicate that commercial console video game systems can induce motion sickness when presented via a head-mounted display and support the hypothesis that motion sickness is preceded by instability in the control of seated posture.

10 Summary of Chapter 3

This chapter consists of a publication that addressed the hypotheses that participants might develop motion sickness while playing "off-the-shelf" console video games.

Participants (40 undergraduate students) played a game continuously for up to 50 min (Stoffregen et al., 2008)

Methods. Two independent variables were used in this study; 1) participants' posture (standing vs. sitting) and 2) the distance to the display screen (near and far). Data on three dependent variables were collected: 1) postural movement (Head and Torso), 2)

Simulator Sickness Questionnaires (before and after playing the game) and 3) Yes/No answer to the whether participants feel motion sickness as they exit the game.

Participants in this sequence of experiments played a game continuously for up to 50 minutes while standing or sitting.

Predictions. I expected to observe 1) motion sickness occurrence across conditions, 2) postural instability prior to the onset of motion sickness, and 3) postural behavior difference between sick and well participants.

Participants (40 undergraduate students) played a game continuously for up to 50 min while standing or sitting. The distance to the display screen (and, consequently, the visual angle of the display) was another variable in this study (Stoffregen et al., 2008).

Results. The incidence of motion sickness ranged from 42% to 56%, across conditions; 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. The results indicate that commercial console video game systems can induce motion sickness when presented via a head-mounted display, and via conventional video monitor.

Conclusion. The results support the hypothesis that motion sickness is preceded by instability in the control of seated posture. Potential applications of this research include changes in the design of console video games and recommendations for how such systems should be used.

Chapter 2

This chapter consists of one of two publications used in this thesis (Merhi, Faugloire, Flanagan, and Stoffregen; 2007). Please note that the text and format of published article have been modified to abide by the University of Minnesota publishing guidelines.

This series of experiments had three main purposes. The first was to determine whether commercial console video games might be associated with motion sickness. Due to the limited previous research on commercial console video games, there was no clear basis for predicting the percentage of users who might become motion sick while playing a console video game. For this reason, I sought to maximize the chance that users would experience motion sickness. I did this by presenting the video games through a head-mounted display (HMD); HMDs are known to be nauseogenic (e.g. Cobb, 1999; Cobb & Nichols, 1998; Draper et al., 2001; Patterson et al., 2006).

The second main purpose was to understand some of the factors that may influence the incidence of motion sickness when commercial console video games are presented via an HMD. The use of commercial games meant that I did not have experimental control over parameters of game play. Manufacturers of game systems have declined to provide access to these data, or control over them. I exercised limited control over content by varying the game that was played, across experiments. In addition, I exercised experimental control over participants' posture during game play. In Experiment 1, separate groups of participants played the games while sitting and standing. Posture is known to influence motion sickness susceptibility in ships and

other vehicles (Baumgarten, Vogel, & Kass, 1981; Manning & Stewart, 1949; Money, 1970).

Console video games are rarely played using head-mounted display systems, and in this sense this study is unrepresentative of typical play situations. As a result, my presentation of the games through an HMD means that my data on motion sickness incidence and severity cannot be taken as being representative of the incidence or severity of motion sickness that might occur when people play console video games that are presented on cathode-ray tube monitors, on projection video systems, and so on. Aside from this factor, I sought to maximize the naturalism of the experimental situation. Participants were asked to play a console video game continuously for up to 50 minutes. There were no experimental manipulations of any aspect of the game. I warned participants that they might become ill, and asked them to discontinue play immediately if they experienced any symptoms of motion sickness. I collected data on the time of discontinuation, self-reports of the existence of motion sickness, and ratings of the intensity of motion sickness symptoms.

The third main purpose was to document participants' body movements during game play, and to use these data to evaluate a prediction of the postural instability theory of motion sickness (Riccio & Stoffregen, 1991). I measured motion of the head and torso while participants played the console video games. I terminated the collection of movement data immediately when participants reported the onset of motion sickness symptoms. Following previous studies, I 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, relative to those who did not.

Data analysis

Some participants were deleted from my analyses. Two *a priori* issues guided the selection of participants for analysis. First, to enable rigorous assignment of participants to the Sick and Well groups, I sought to ensure comparable exposure to the console video games for all participants. As expected, participants discontinued during the 50-minute session, stating that they were motion sick. However, some participants discontinued for other reasons, that is, without being motion sick. A consequence was that some participants in the Well group received a relatively brief exposure to the video games, whereas some participants in the Sick group received a longer exposure. A person who discontinued due to boredom, fatigue or discomfort with the HMD might have become motion sick, if he or she had continued in the experiment. The reverse is also true: A person who became motion sick after a given exposure duration might not have done so with a shorter duration. For these reasons I included only Well participants who completed at least 30 minutes of game play, and Sick participants who discontinued before the 30th minute. One consequence of my selection criteria is that the incidence of motion sickness observed in my experiments may not be representative of the general incidence of motion sickness related to console video games presented via an HMD.

The second issue guiding my selection of participants for analysis concerned the analysis of movement data. My analysis of movement data included a procedure that permitted us to examine the evolution of sway over time during play (Bonnet et al.,

2006; Faugloire et al., 2007). I aimed to analyse postural sway before the occurrence of sickness symptoms. For this reason, I excluded the final two minutes of postural data because participants might have been conservative in reporting the onset of sickness; that is, they might not have followed my instructions to discontinue participation immediately at the onset of symptoms. The remaining data were divided into 2-minute windows. Any excess data (i.e., the remainder when the total duration was divided by 2 minutes) was deleted from the beginning of the trial. The first, middle, and last windows were analyzed. For example, for a participant who discontinued after 13.3 minutes, the first window was from 1.3 to 3.3 min, the middle window was 5.3 to 7.3 min and the last window was 9.3 to 11.3 min. For Well participants, the windows were defined on the basis of the mean exposure duration (for each experiment) completed by the Sick group. The last window selected for Well participants corresponded to the average position (time) of the final window from the Sick group. This window selection ensured that the average exposure duration would be similar for the Sick and Well groups.

For data on body movement, the dependent variables were the standard deviation of position, and the velocity of motion, each examined separately in the anterior-posterior, medial-lateral, and vertical axes. Each variable was analyzed separately for motion of the head and torso. For each significant main effect and interaction in the ANOVAs, I estimated the effect size using the partial η^2 statistic.

Experiment

In Experiment 1, participants played *Whacked*, a game that has been anecdotally associated with motion sickness (Randy Pagulayan, personal communication, June, 2004). *Whacked* was released in 2002. In the game, an avatar moves through a simulated environment, trying to gain points by acquiring resources and destroying threats.

The independent variable was participants' posture. In some studies, participants have stood while wearing a head-mounted display (e.g., Cobb, 1999; Cobb & Nichols, 1998; Murata, 2004; Owen, Leadbetter, & Yardley, 1998), whereas in other studies they have sat (e.g., Draper et al., 2001; Stanney et al. (1999, 2003).

Method

Participants

Thirty-three persons were screened for the study. Of these, twenty-four met my selection criteria of comparable exposure times to the console video game (see above, under *Data analysis*), and were retained as experimental participants. The participants, eleven women and thirteen men, ranged in age between 17 and 35 years old (mean = 22 years), in height between 160 and 187 cm (mean = 173 cm), and in weight from 54.4 to 90.7 kg (mean = 70.1 kg). All participants had normal or corrected to normal vision and reported no history of recurrent dizziness, recurrent falls, or vestibular (inner ear) dysfunction. All participants stated that they were in good health and were not pregnant. As part of the informed consent procedure, participants were informed that they could discontinue their participation at any time, for any reason, and that they would receive full credit for experimental participation regardless of whether they completed the

experiment; there was, thus, no motivation for falsely stating that they were motion sick.

Apparatus

I used a standard Xbox system (Xbox 2, Microsoft Corp.), including the game unit and game pad. Participants played *Whacked*, in which players control their own motion through a virtual world. Accordingly, the game is characterized by frequent displays of optic flow simulating complex patterns of self motion.

The game was presented on an HMD (VisettePro, Cybermind, Inc., The Netherlands). The VisettePro is a bi-ocular VGA system with a field of view of 60 (horizontal) by 48 degrees for each eye, and 300,000 pixels (Figure 1). The display unit weighs 0.68 kg. The display screens and housing make the head-mounted display “front heavy.” The display is secured to the head using an adjustable clamp on the rear of the unit. Participants donned the unit by themselves and were asked to adjust the tightness of the clamp so that the unit was snug.

I used magnetic tracking system to collect movement data (Fastrak, Polhemus, Inc., Colchester, VT). One receiver was attached to the HMD, and another was attached to the skin at the level of the 7th cervical vertebra (i.e., between the shoulder blades), using cloth medical tape. The transmitter was located behind the subject’s head, on a stand. Six degree-of-freedom position data were collected from each receiver at 40 Hz, and stored on disk for later analysis.

Figure 1

Figure 1: The head-mounted display unit. The photo is reproduced with the permission of Cybermind Interactive Nederland.

Motion sickness assessment

I assessed the incidence of motion sickness by asking participants to make yes/no statements about whether they were motion sick. Participants were divided into Sick and Well groups based on either their explicit verbal statements or, if they reported that they were not motion sick at the end of the session, from written comments from take-home forms returned after 24 hours. Because participants could discontinue at any time for any reason, there was no motivation for participants to give false reports of motion sickness as a mean to discontinue participation. For this reason, I accepted participants' statements that they were motion sick. Verbal reports of motion sickness were unambiguous (e.g., "I feel nauseous, my stomach is queasy", "I was going to throw up").

I quantified motion sickness symptoms using the Simulator Sickness Questionnaire, or SSQ (Kennedy, Lane, Berbaum, & Lilienthal, 1993). I administered the SSQ at the beginning of the experiment and again at the end (e.g., Bonnet et al., 2006; Stoffregen et al., 2000; Stoffregen & Smart, 1998). The initial administration ensured that participants were familiar with the symptoms of motion sickness, and

provided a baseline level of symptoms against which scores from the post-exposure administration could be compared.

Procedure

After completing the informed consent procedure, participants filled out the SSQ, and were asked to remove their shoes. Participants were told that they might experience motion sickness, and that they should immediately report any subjective symptoms of motion sickness, however mild. They were also reminded that they could discontinue at any time, for any reason. The participant was given a brief introduction to the Xbox system and to *Whacked*. The user controlled movement of an avatar in a virtual world by way of the game pad, which controlled three linear degrees of freedom (fore-aft, left-right, up-down) and one angular degree of freedom (left-right rotation). Participants were permitted to explore the game until they felt that they understood the rules and the use of the game pad. In the experimental session, participants played the game for up to 50 minutes. If the game ended (e.g., if the avatar were killed a certain number of times), participants were asked to restart the game immediately and continue play. At the end of 50 minutes (or if they discontinued) participants filled out the SSQ a second time. The experiment was immediately stopped when any participant reported the onset of symptoms. Participants reporting symptoms were asked to remain in the lab until the symptoms dissipated. Participants who completed the 50 minute session without developing symptoms were given a take-home packet that included a printed copy of the SSQ, as well as a yes/no question: “Did you become motion sick?” They were asked to fill it out if they developed symptoms during the following 24 hours (Bonnet et al., 2006; Stoffregen & Smart, 1998). Symptom onset is sometimes delayed

up to several hours following termination of exposure to visual simulations of self motion (e.g., Kennedy & Lilienthal, 1994; Smart et al., 2002; Stanney et al., 1999, 2003; Stoffregen & Smart, 1998).

There were two experimental conditions; Standing and Sitting. In the Standing condition, participants played *Whacked* while standing comfortably, in stocking feet. They were instructed not to move their feet. In the Sitting condition, participants played *Whacked* while seated on a stool (i.e., there was no passive support of 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 was 58 cm high. Seven participants (two women, five men) participated in the Standing condition, whereas seventeen (nine women, eight men) participated in the Sitting condition. Each person participated in only one condition.

Power

I conducted a power analysis for the planned analyses of movement data, assuming the use of ANOVA with 24 participants, and a criterion alpha of .05. To conduct the power analysis I used G*Power 2.0 (Faul & Erdfelder, 1992). I found that the experimental design had 90% chance of identifying an effect size of 0.70 (Cohen's *f*; Cohen, 1988) as being significant. In this study, an effect size of 0.70 would correspond to a difference between means of 0.77 cm if the within standard deviation of the groups was 0.5 cm, or to a difference between means of 1.54 cm if the within standard deviation of the groups was 1.0 cm. Based on previous experiments on postural sway (e.g., Bonnet et al., 2006; Faugloire et al., 2007; Stoffregen & Smart,

1998) and this present design (participants playing a console video game), I concluded that this level of power was adequate.

Results and Discussion

I conducted separate analyses on subjective reports (motion sickness incidence and severity) and on movement data (head and torso).

Subjective reports

Motion sickness incidence

The Standing group. Each of the seven participants in the standing condition reported motion sickness while playing the game, and discontinued participation. The mean latency to discontinuation for these participants was 17 minutes, with 100% incidence of motion sickness.

The Sitting group. Of the seventeen seated participants, ten (three male, seven female) reported motion sickness while playing the game (59%). For these participants, the mean latency to discontinuation was 14 minutes. Two other participants discontinued, stating that they were not motion sick. The times of discontinuation for these two participants were 36 and 37 minutes. These two participants reported that they discontinued due to the weight and tightness of the head-mounted display, stating that they experienced pain in the back of the neck, or pain on the front of the head and around the eyes (the experimenter observed red marks around the eyes of some participants after removal of the head-mounted display). The experimenter questioned these individuals closely concerning motion sickness; each of them insisted that they were not motion sick. The other five participants completed the 50-minute exposure

period and did not report motion sickness. Accordingly, the Sick group consisted of ten participants, with seven in the Well group.

Standing versus Sitting. I compared the incidence of motion sickness between the standing and sitting conditions. The difference in sickness incidence was significant, Chi square (1) = 6.75, $p < .05$. The difference in motion sickness incidence between standing and sitting participation indicates a significant effect of posture on susceptibility to motion sickness among users of console video games.

Symptom Severity

The SSQ data are summarized in Table 1. SSQ data were analyzed using non-parametric statistics, because SSQ scores are not normally distributed (Kennedy et al., 1993). I computed Total Severity Scores in the recommended manner (Kennedy et al., 1993). The total severity score reflects the overall extent of symptom severity. SSQ scores were treated as a repeated-measures variable (before versus after exposure to the game).

Table 1

	N	PRE		POST	
		Mean	SD	Mean	SD
All Standing	7	29.4	47.0	63.6	49.8
Sick	7	29.4	47.0	63.6	49.8
Well	0	n/a	n/a	n/a	n/a
All Sitting	17	8.8	8.9	58.1	45.8
Sick	10	11.2	8.6	75.5	51.3
Well	7	5.3	8.6	33.1	20.6

Table 1: Mean (and standard deviation) total severity scores for the Simulator Sickness

Experiment 1

Questionnaire

The Standing group. The pre-post difference was significant (Wilcoxon Signed Rank Test, $Z = -2.37, p < .05$), indicating that the severity of symptoms increased following game play. Given that there was not a Well group in this condition (each member of the standing group reported motion sickness), I could not test for differences in symptom severity within this group as a function of motion sickness status.

The Sitting group. For the sitting participants in the Sick group, the mean pre- and post-exposure SSQ scores differed, $Z = -2.80, p < .05$, revealing that symptom severity was significantly greater following game play. This was true also for the Well group, $Z = -2.37, p < .05$. There were no significant differences between Sick and Well groups either pre- (Mann-Whitney $U = 33, ns$) or post-exposure ($U = 29.5, ns$).

Standing versus Sitting. The mean pre-exposure scores for the standing and sitting groups did not differ, Mann-Whitney $U = 47.5, ns$). The mean post-exposure score for the Sick group in the sitting condition did not differ from the mean post-exposure score for the Sick group in the standing condition ($Z = -0.538, ns$). Thus, sitting down brought a reduction in the incidence of sickness, but not in the severity of symptoms. As the standing condition did not include any Well participants, I could not test for differences in symptoms between the postural groups as a function of motion sickness status.

Movement data

I conducted Group (Sick vs. Well) \times Condition (Standing vs. Sitting) \times Window (beginning, middle and end of exposure) ANOVAs, with repeated measures upon the last factor, conducted for each dependent variable. Given that there was not a Well group in the standing condition, I could not test for interactions involving both Group and Condition (i.e., Group \times Condition and Group \times Condition \times Window interactions). Twenty-three of the twenty-four participants completed sufficient exposure duration to “fill” the three windows without overlap and were therefore included in subsequent analyses of postural data.

Overall movement

There was a main effect of Group (Sick vs. Well) on variability of head movements in the vertical axis, $F(1, 20) = 5.32$, $p < .05$, partial $\eta^2 = .21$. Sick participants (mean = 1.20 cm, sd = 0.56 cm) moved more in the vertical axis than Well participants (mean = 0.58 cm, sd = 0.55 cm). The main effects of Condition (Standing vs. Sitting) were significant for velocity of head and torso motion in both the antero-posterior and medio-lateral axes, each $F(1, 20) > 6.46$, $p < .05$, partial $\eta^2 > .24$. The main effect of Condition was also significant for variability of torso movements in the medio-lateral axis, $F(1, 20) = 5.13$, $p < .05$, partial $\eta^2 = .20$. In each case, movement was greater in the Standing condition than in the Sitting condition (Figure 2).

Figure 2

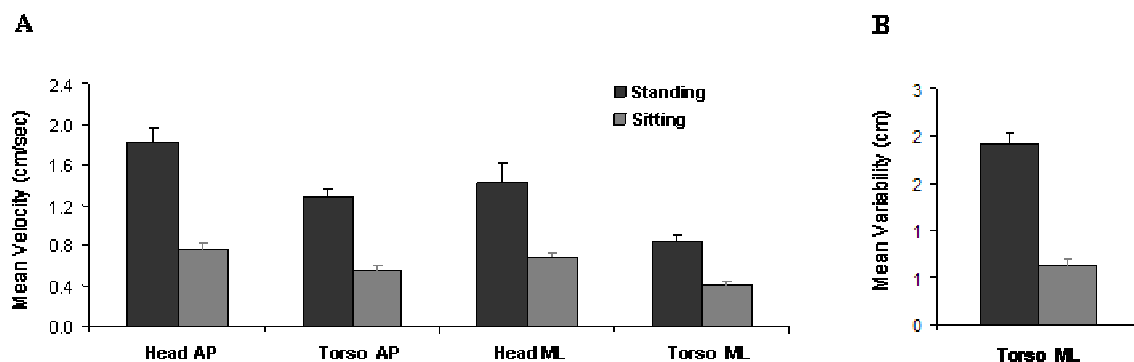


Figure 2: Significant main effects of Condition, Experiment 1. AP: anterior-posterior axis. ML: medial-lateral axis. A. Velocity. B. Variability. Error bars represent standard error.

The difference in the variability of vertical head movements between Sick and Well participants in the seated condition is consistent with a central hypothesis of the postural instability theory of motion sickness. Riccio and Stoffregen (1991) predicted that measurable instabilities in the control of posture should exist before the onset of subjective symptoms of motion sickness. In previous studies, I have found that motion sickness is preceded by changes in movement of the head, torso, or center of pressure (e.g., Bonnet et al., 2006; Stoffregen et al., 2000; Stoffregen & Smart, 1998). Stoffregen et al. (2000) found changes in motion of the head prior to the onset of motion sickness among participants seated in a flight simulator. My present results confirm that postural instability precedes motion sickness, and extends this finding to the seated use of a head-mounted display.

Stoffregen et al. (2000) found differences in head movement of Sick and Well participants prior to the onset of motion sickness. They did not collect data on torso motion (participants were restrained in the flight simulator cockpit using shoulder

straps). Thus, it is not possible to know whether the absence of group differences in torso movements in the present study is general. It is possible that in seated posture, instabilities in postural control are limited to head motion; however, I know of no theory that would predict this. An alternative view, which I prefer, is that the absence of group effects on torso motion may be related to the weight (Draper et al., 2001) and novelty (Lackner & DiZio, 1998) of the head-mounted display headset. It would be interesting to measure motion of the head, torso, and legs when seated and standing participants wore a head-mounted display that was inactive, or which showed a static scene. Such a study would permit us to understand changes in multisegment postural control that are related to the physical characteristics of the head-mounted display.

Evolution of movement during game play

The ANOVAs revealed main effects of Window on velocity in each axis (antero-posterior, medio-lateral, and vertical) for both head and torso movements, $F_s(2, 40) > 5.47, p < .05$, partial $\eta^2 > .21$. The velocity of head and torso movement increased over time in each axis (Figure 3 A and B). The main effect of Window was also significant for variability of torso movement in the vertical axis, $F(2, 40) = 5.85, p < .05$, partial $\eta^2 = .23$. Variability tended to increase over time (Figure 4 C).

Figure 3

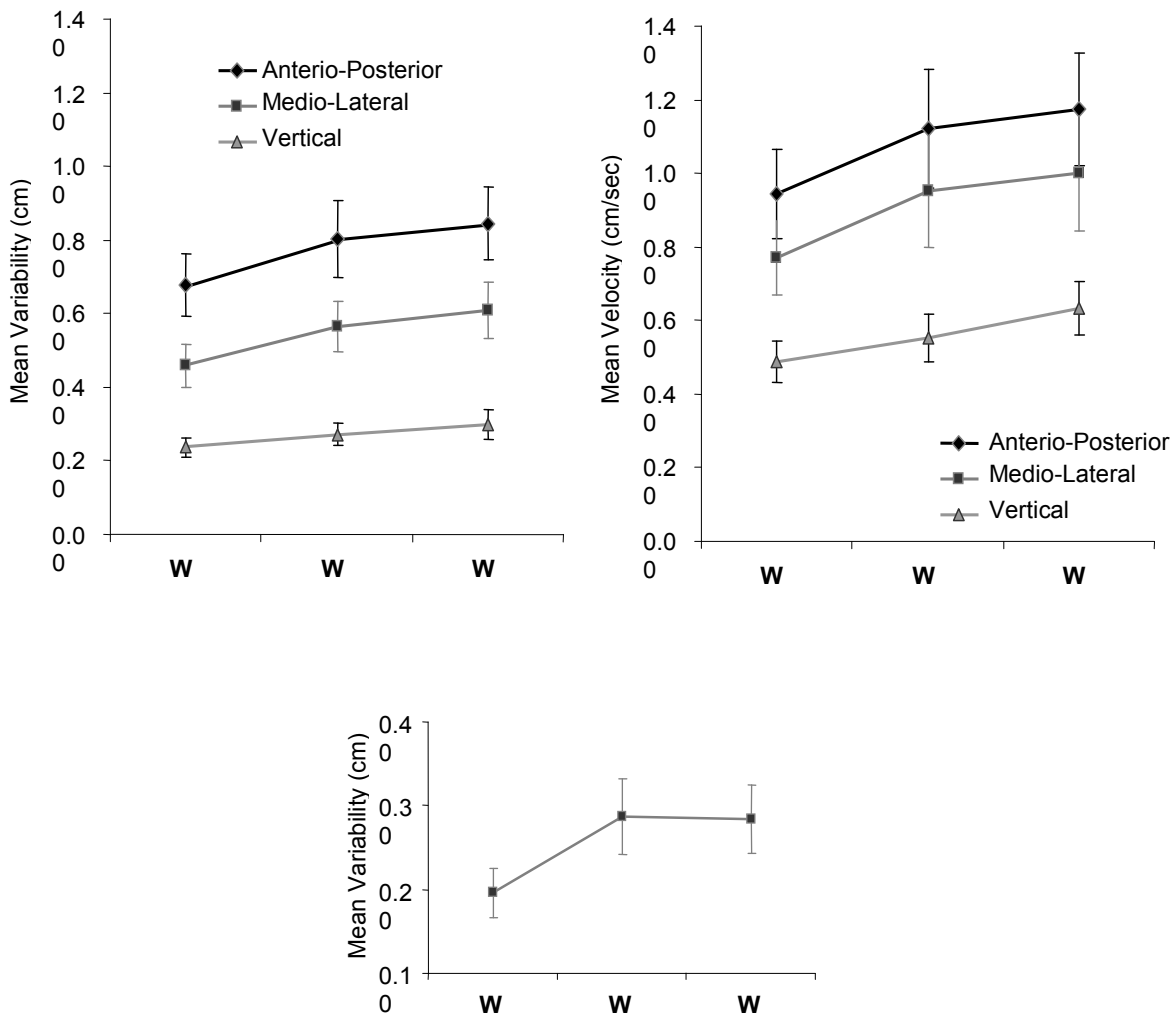
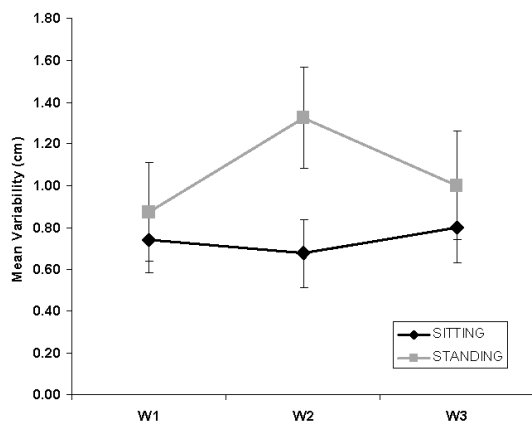


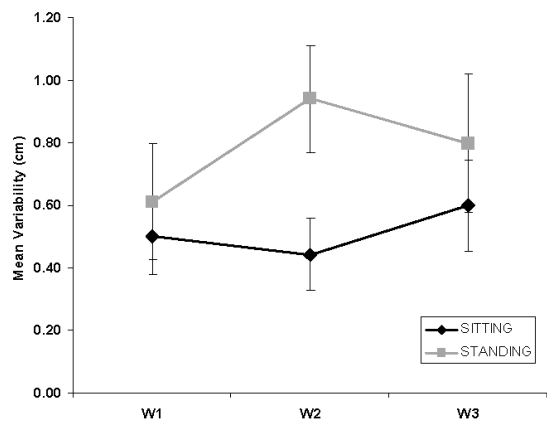
Figure 3: Significant main effects of Window, Experiment 1. A. Velocity of torso movement. B. Velocity of head movement. C. Variability of vertical torso movement. Error bars represent standard error.

Figure 4

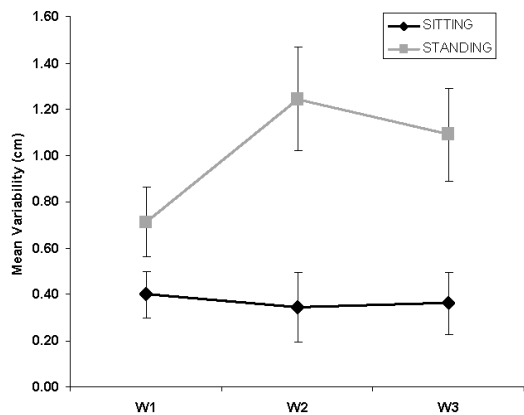
A



B



C



D

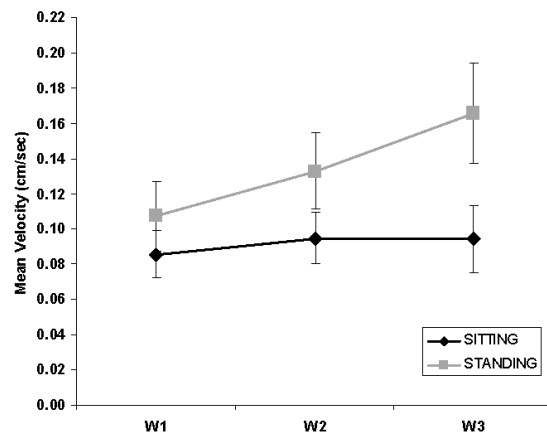


Figure 4 : Significant Window \times Condition interactions, Experiment 1. A. Variability of anterior-posterior head movement. B. Variability of anterior-posterior torso movement. C. Variability of medio-lateral head movement. D. Velocity of vertical torso movement.

The ANOVAs revealed significant Window \times Condition interactions for variability of head and torso motion in the antero-posterior axis, $F(2, 40) > 3.57, p < .05$, partial $\eta^2 > .15$. The Window \times Condition interaction was also significant for variability of head movements in the medio-lateral axis, $F(2, 40) = 3.38, p < .05$, partial $\eta^2 = .14$, and for torso velocity in the vertical axis, $F(2, 40) = 3.56, p < .05$, partial $\eta^2 = .15$. For the significant Window \times Condition interactions, movement of standing participants exhibited an inverted-U function or increased over time, whereas movement of seated participants tended to be stable over time (Figure 4).

I found no significant Window \times Group (Sick vs. Well) interactions in any of the dependent variables, for either the head or the torso.

I found a number of differences in head and torso movement between standing and sitting participants, in both overall movement and in the evolution of movement during game play. The main effects of Condition suggest that players moved more when they were standing than when seated. Such a result would be expected based on the different biomechanics of standing and sitting. When standing, I control body posture primarily through rotations around the hips and ankles (e.g., Bardy, Marin, Stoffregen, & Bootsma, 1999; Horak & MacPherson, 1996). When seated, I control body posture primarily through rotations around the hips. Thus, relative to sitting, stance is characterized by the control of more limbs and the coordination of rotation around more joints. These differences may explain the increases in movement observed in the overall data. However, the window analyses suggest more complex interpretations. Why would movement evolve differently over time for seated and standing players? One possibility is that seated and standing players may adapt

differently to the novel task of stabilizing the bulky head-mounted display unit.

Another possibility is that players may move differently in response to action within the game, depending on whether they are standing versus sitting. Additional research will be needed to address these and other possibilities. Very little is known about the control of seated posture; in particular, there are few studies in which the control of seated posture has been measured using modern quantitative methods (e.g., precise tracking systems).

Experiment 2

In Experiment 2, I sought to determine whether the nauseogenic properties of the experimental situation were unique to the particular game I was using, or could generalize to other games. Accordingly, Experiment 2 was identical to the sitting condition in Experiment 1 except that a different game was used.

Method

Participants. Of an initial sample of fifteen participants, nine met the selection criteria of comparable exposure times to the console video game, and were selected for subsequent analysis. These participants (two females and seven males), ranged in age between 19 and 22 years old (mean = 20 years), in height between 167 and 190 cm (mean = 174 cm), and in weight from 61.2 to 99.8 kg (mean = 79.0 kg). All participants had normal or corrected to normal vision and reported no history of recurrent dizziness, recurrent falls, or vestibular (inner ear) dysfunction. All participants stated that they were in good health and were not pregnant. As part of the informed consent procedure, participants were informed that they could discontinue their participation at any time, for any reason, and that they would receive full credit for experimental participation

regardless of whether they completed the experiment; there was, thus, no motivation for falsely stating that they were motion sick.

Procedure. Participants played *Halo*, a commercially available Xbox game. Like *Whacked*, *Halo* depicts self-controlled motion of the player through a virtual world. Participants played while seated on the stool that was used in Experiment 1.

Results and Discussion

Subjective reports

Motion Sickness Incidence

The Sick group comprised eight participants (6 male, 2 female), or 89% of my sample. Each of the sick participants discontinued during the game session, stating that they were motion sick, with a mean discontinuation latency of 16 minutes. The sole Well participant discontinued after 35 minutes, denying motion sickness and giving reasons similar to those reported in Experiment 1. The high incidence of sickness confirms that the phenomenon of motion sickness in console video games is not limited to *Whacked*, and confirms that players of console video games can experience motion sickness while seated.

The incidence of motion sickness of seated participants playing *Halo* (Experiment 2) did not differ from seated participants playing *Whacked* (Experiment 1, sitting condition), $\chi^2(1) = 2.50, ns$.

Symptom severity

The SSQ scores are summarized in Table 2. For the Sick group, the mean pre-exposure and post-exposure scores differed, $Z = -2.52, p < .05$. For the Well participant, the pre-exposure score was 3.74 and the post-exposure score was 93.50.

I compared the severity of motion sickness between the participants playing *Halo* to those playing *Whacked*. The difference in SSQ scores was not significant for either the Sick or the Well groups, either before or after game play (each $p > .05$).

Table 2

	N	PRE		POST	
		Mean	SD	Mean	SD
All	9	7.9	9.2	79.4	24.7
Sick	8	8.4	9.7	77.6	25.8
Well	1	3.7	0	93.5	0

Table 2. Mean (and standard deviation) total severity scores for the Simulator Sickness Questionnaire, Experiment 2.

Movement data

Given that there was not a Well group in Experiment 2, I could not test the prediction that movement would differ for Sick and Well groups, and I could not test interactions involving State (Sick vs. Well). I conducted repeated measures ANOVAS assessing effects of the Window factor (beginning, middle and end of exposure). No significant effect of Window was found in any of my dependent variables, for either head or torso.

Halo versus Whacked

I examined the possibility that *Halo* and *Whacked* may have evoked different patterns of movement. For each dependent variable, in each axis, I compared movement data from the participants in Experiment 2 (who played *Halo*) with the participants in the Sitting condition from Experiment 1 (who played *Whacked*). To that end, I conducted Game (*Halo* vs. *Whacked*) \times State (Sick vs. Well) \times Window (beginning, middle and end of exposure) ANOVAs on the Head and Torso dependent variables.

The ANOVAs revealed main effects of Window on torso velocity in each axis, $F_s(2, 40) > 3.35$, $p < .05$, partial $\eta^2 > .14$. The main effect of Window was also significant for head variability in the vertical axis, $F(2, 40) = 3.25$, $p < .05$, partial $\eta^2 > .14$. In each case, velocity and movement tended to increase over time (Figure 5).

Figure 5

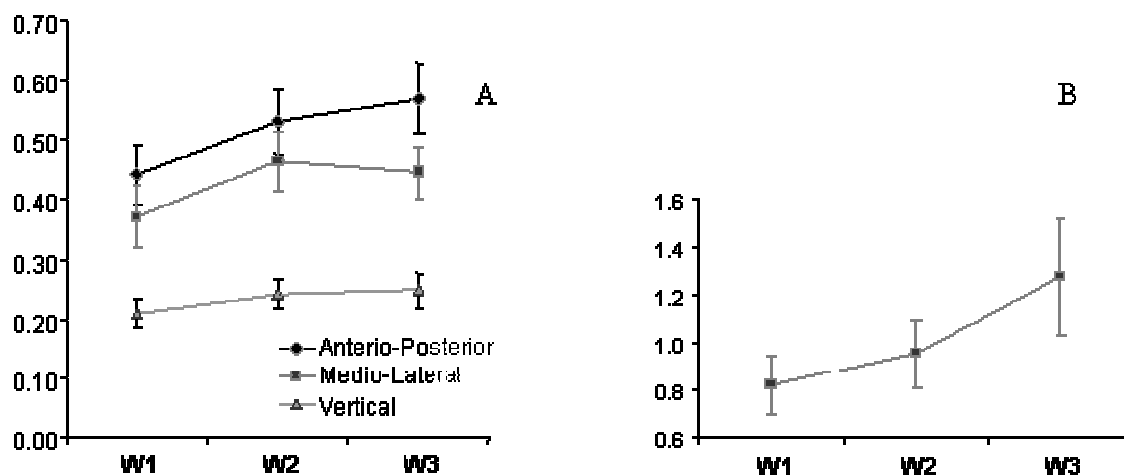


Figure 5: Significant main effects of Window, Experiment 2. A. Velocity of torso movement. B. Variability of vertical head movement. Error bars represent standard error

The ANOVAs revealed a main effect of Game for variability of head movement in the medio-lateral axis, with $F(1, 20) = 4.48$, $p < .05$, partial $\eta^2 = .18$. When playing *Halo*, participants who later became motion sick exhibited greater medio-lateral head movement (mean = 1.06 cm, SD = 0.32 cm) than participants playing *Whacked* who later became sick (mean = 0.36 cm, SD = 0.33 cm). There were no other significant effects. Because there was only one Well participant, I could not test possible interactions between games and motion sickness status.

General Discussion

In two experiments, I asked participants to play a commercially available console video game that was presented through a head mounted display. I varied participants' posture (standing versus seated), and I varied the game that they played (*Whacked* versus *Halo*). In each experiment, a minimum of 59% of participants reported motion sickness. In Experiment 1, the incidence of sickness was greater when participants played while standing, rather than sitting. Across experiments, symptoms of motion sickness (i.e., SSQ scores) were higher after playing the game than before. I was able to compare postural motion of Sick and Well groups only in the seated condition of Experiment 1. This comparison revealed significant differences in motion of the head between groups, prior to the onset of motion sickness.

Motion Sickness Incidence

I have confirmed that motion sickness can occur among users of commercially available console video games. The incidence of sickness was high during the standing condition, and was significantly lower when participants were seated. The difference in incidence as a function of posture may have implications for theories of motion sickness

etiology. For example, it is not clear whether this result could be predicted or explained by the sensory conflict theory of motion sickness (e.g., Reason, 1978). The reduction in motion sickness incidence during seated game play is compatible with the postural instability theory of motion sickness, if I assume that in seated posture the body tends to be more stable than during stance.

My use of the head-mounted display means that the present study cannot be taken as indicating the incidence of motion sickness that would be expected when commercially available console video games were played through more typical presentation systems, such as television monitors. Head-mounted displays are known to be associated with motion sickness (e.g., Draper et al., 2001). Thus, it seems likely that the incidence of sickness would be lower if commercially available console video games were not presented through head-mounted displays.

Postural instability and motion sickness

Riccio and Stoffregen (1991) predicted that instabilities in the control of posture would occur before the onset of subjective symptoms of motion sickness. That hypothesis has been confirmed for both standing and sitting persons, in studies that involved neither head-mounted displays nor video games (e.g., Bonnet et al., 2006; Stoffregen et al., 2000; Stoffregen & Smart, 1998). In the seated condition of Experiment 1, I found a difference in head motion between participants who did not report motion sickness and those who did. Postural motion was greater among participants who later became sick than among those who did not. This difference supports the postural instability theory of motion sickness.

In some studies, I have found that body movement evolves differently, during exposure to nauseogenic stimuli, for participants who become sick and those who do not (e.g., Faugloire et al., 2007), whereas in other studies this effect has not occurred (e.g., Bonnet et al., 2006). In the present study differences in body movement between Sick and Well participants did not evolve over time. This finding suggests that differences in body movement that were related to the incidence of motion sickness were present at the onset of game play. Future research will be needed to determine whether these early differences in movement were related to the use of the head-mounted display, or to the playing of commercially available console video games.

Conclusion

I have confirmed that motion sickness occurs among users of commercially available console video games. My findings are consistent with anecdotal reports from game users. Due to my use of a head-mounted display, it should not be assumed that the incidence of motion sickness among players of commercially available console video games is as high as it was in my experiments. Reliable data on the incidence of motion sickness among players of commercially available console video games could be obtained by using display systems that typically are used during game play outside the laboratory.

The popularity of console video games provides a motivation for research that may permit us to gain control of motion sickness among players; to predict it, and to prevent it. Prediction might be achieved through monitoring of players' movements during game play (Smart et al., 2002). Online analysis of movement data might make it

possible to identify individuals who were at-risk for motion sickness; such persons could be advised of the risk and encouraged to discontinue play.

Research on the etiology of motion sickness in commercially available console video games will require a wider range of experimental manipulations. It would be very helpful for experimenters to obtain data from the game software about the nature of movements (e.g., direction, axis, amplitude, frequency) in which users engage while playing the game. However, access to game data can be obtained only with permission of the manufacturers. It will also be important to determine the effects previous experience with console video games upon postural instability and motion sickness. I hope that rigorous documentation of the problem of motion sickness among users of console video games will spur cooperative research efforts between behavioral scientists and game developers.

Chapter 3

This chapter consists of one of two publications used in this thesis (Stoffregen et al.,; 2008). Please note that the text and format have been modified to abide by the University of Minnesota publishing guidelines.

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 U.S. (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 is console video games, such as *Play Station*, *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 et al., 2003; Stanney, Kennedy, Drexler, and 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.

The first set of experiments described in Chapter 2 (Merhi, Faugloire, Flanagan, & 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 minutes. 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, while 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 unlikely that the incidence of motion sickness reported by Merhi et al. represents typical game play situations. To estimate the general incidence of motion sickness among players of console video games, in the present study I presented the games on a video monitor. To understand how motion sickness incidence is influenced by parameters of the game situation I 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, I 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 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). I 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., Wollacott & Shumway-Cook, 2002), but I do not accept this implication. I define postural stability and instability in relation to the goals of postural control, which can include the facilitation of supra-postural activities (Riccio & Stoffregen, 1988, 1991). Riccio and Stoffregen 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, I 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). I 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, 2008; 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. I 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 above, it is likely in their study that motion sickness incidence was influenced by the use of a head-mounted display. My 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. I 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 minutes, 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 console video games were played while seated, as opposed to standing. I expected a similar effect. I also varied the distance between participants and the game display. One of the distances 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 above, my primary motivation in this study was to estimate motion sickness incidence in conditions representative of non-laboratory game play. For this reason, I 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 playtest research at Microsoft Game Studios (R. Pagulayan, personal communication, April 2007).

I measured motion of the head and torso while participants played the console video games. I 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, I 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, relative to those who did not.

Method

There were three experimental conditions. I 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. (60° horizontal by 48° vertical). Using this visual angle, participants played the video game in two conditions: standing and sitting. To increase representativeness, I 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 3 for descriptive characteristics. The procedure used in this study was approved by the Institutional Review Board of the University of Minnesota.

Table 3

B: SITTING 45			A: STANDING			C: SITTING 85		
MEASURE	MS	MOVE	MEASURE	MS	MOVE	MEASURE	MS	MOVE
N			N			N		
TOTAL	12	11	TOTAL	16	7	TOTAL	12	10
WOMEN	4	4	WOMEN	12	5	WOMEN	6	4
MEN	8	7	MEN	4	2	MEN	6	6
SICK	6	5	SICK	9	4	SICK	5	4
WELL	6	6	WELL	7	3	WELL	7	6
MEANS			MEANS			MEANS		
AGE	21	21	AGE	21	23	AGE	21	21
HEIGHT (cm)	175	175	HEIGHT (cm)	170	169	HEIGHT (cm)	175	176
WEIGHT (kg)	71	70	WEIGHT (kg)	68	70	WEIGHT (kg)	78	79

Table 3: Descriptive data for the three experimental conditions. 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

I 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 multi-axis linear and angular motion. The video and audio portions of the game were presented using a cathode ray tube 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

I 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, I 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”).

I 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). I 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 (cf., Bonnet et al., 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 minutes, 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-minute game session. At the end of 50 minutes (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. I included all participants in my 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, I excluded members of the Well group who discontinued because of boredom, fatigue, or discomfort. I also excluded several subjects for technical reasons: Due to 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. I examined three non-overlapping windows (each two minutes in duration) selected from the beginning, the middle and the 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.

I 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 anterior-posterior, mediolateral, and vertical axes. In the ANOVAs, I estimated the effect size using the partial η^2 statistic. According to Cohen (1988), values of partial $\eta^2 > 0.14$ indicate a large effect.

Results

Motion sickness incidence and discontinuation

Standing condition. The Sick group comprised nine participants (56%) who reported motion sickness while playing the game, and discontinued (mean latency to discontinuation = 20.2 minutes). The remaining seven 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 minutes. 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 six participants (50%) who reported motion sickness while playing the game and discontinued (mean latency to discontinuation = 22.7 minutes). The other six 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 minutes). The remaining seven participants stated that they were not motion sick, and constituted the Well group. One Well participant discontinued after 2 minutes, citing boredom. The incidence of sickness did not differ between the two seated conditions, $\chi^2 (1) = 0.17 p > .05$.

Severity Symptoms

Standing condition. The data are summarized in Figure 6A. At pre-exposure, SSQ scores did not differ for the Sick and Well groups ($U = 15.5, p > 0.71$). At post-exposure, SSQ scores differed ($U = 3.0, p < 0.02$), with scores for the Sick group being higher. The pre-post change in scores was significant for the Sick group ($Z = -2.67, p < 0.01$), but not for the Well group ($Z = -1.83, p > 0.07$).

Figure 6

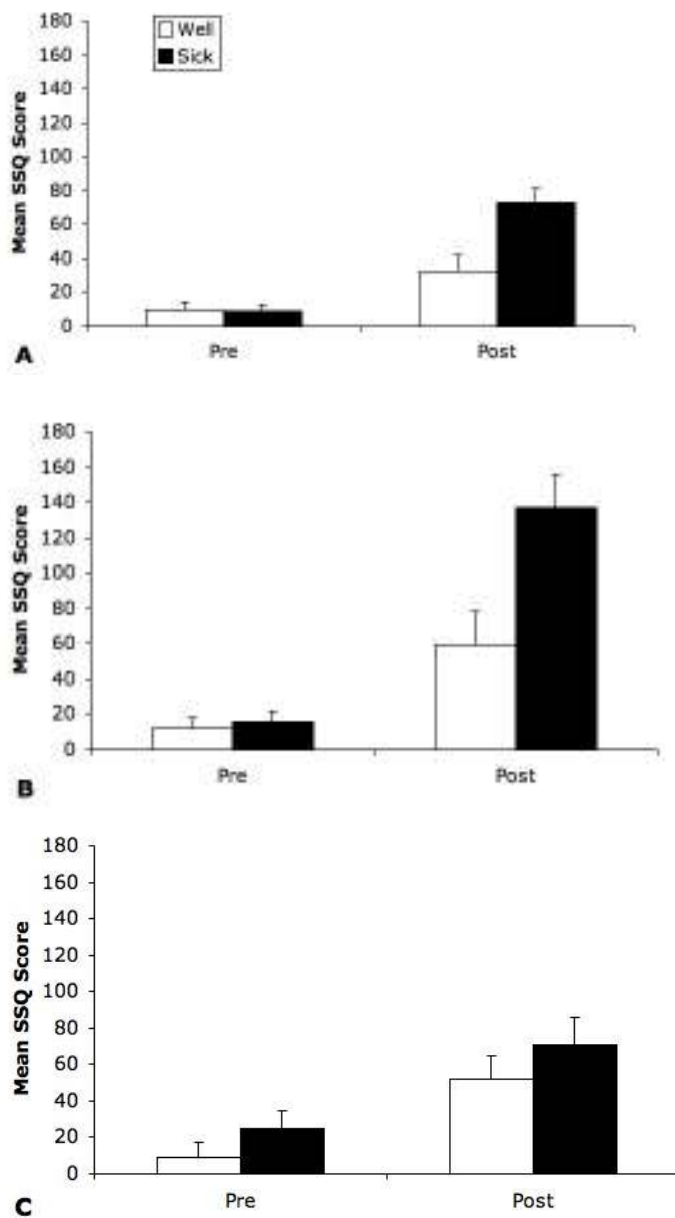


Figure 6: Mean pre-exposure and post-exposure scores on the Simulator Sickness Questionnaire (SSQ), (A) Standing condition, (B) Sitting-45 condition, (C) Sitting-85 condition. The error bars represent standard error.

Sitting-45 condition. The data are summarized in Figure 6B. At pre-exposure, the Sick and Well participants did not differ in terms of total severity scores ($U = 14.0$, $p > 0.59$). At post-exposure, the total severity score for the Sick participants was greater than that of the Well participants ($U = 4.0$, $p < 0.03$). Post-exposure scores were greater than pre-exposure for the Sick group ($Z = -2.20$, $p < 0.03$), and for the Well group ($Z = -2.20$, $p < 0.03$).

Sitting-85 condition. The data are summarized in Figure 6C. The Sick and Well groups did not differ at pre-exposure ($U = 10.5$, $p > .05$), or at post-exposure ($U = 13.0$, $p > .05$). Post-exposure scores were greater than pre-exposure scores for the Sick group ($Z = -2.04$, $p < 0.04$), and for the Well group ($Z = -2.21$, $p < 0.03$).

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

Movement data

Standing condition. I analyzed movement data from seven participants (N = 4 Sick; N = 3 Well). The independent variables were Windows (first, middle, and last), and Group (Sick vs. Well). I found significant Group \times 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, while remaining steady for the Sick group (Figure 7).

These effects are consistent with my hypothesis that movement should differ between

the Sick and Well groups prior to the onset of motion sickness. The effects differ from previous studies (e.g., Bonnet et al., 2006; Faugloire, Bonnet, Riley, Bardy, & Stoffregen, 2007), in which movement has tended to increase over time for the Sick group, with the Well group remaining steady over time.

Figure 7

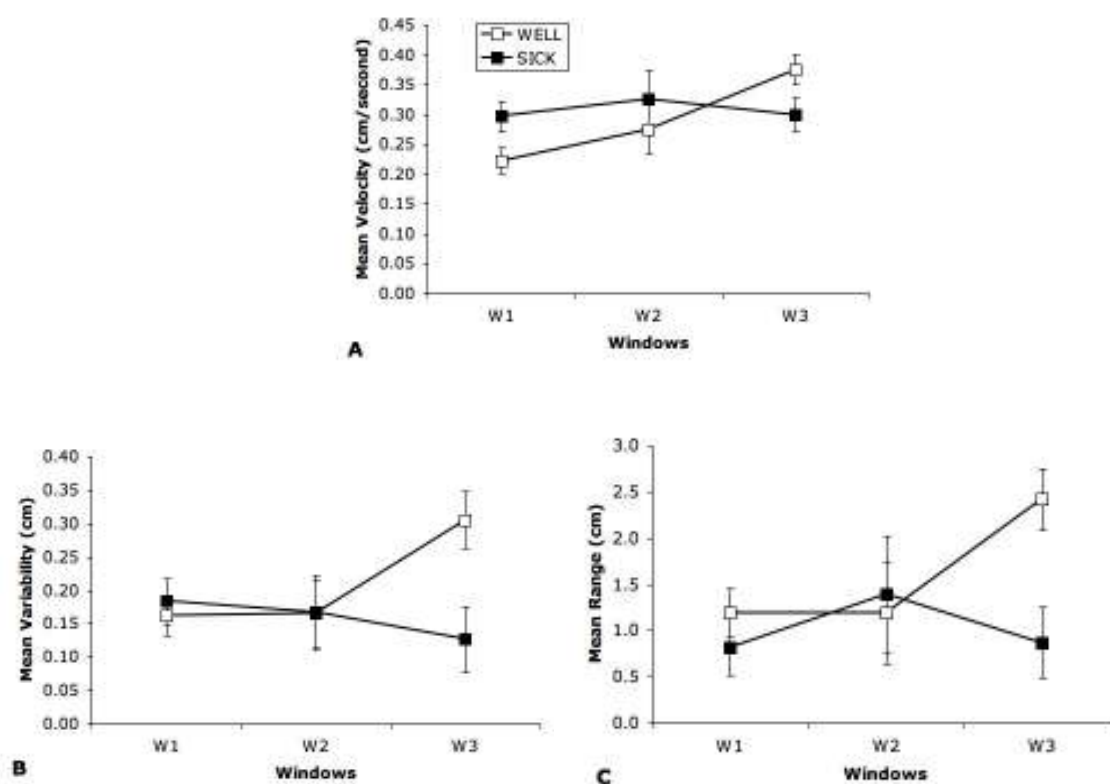


Figure 7: Vertical movement in the standing condition. (A) Mean head velocity, (B) mean torso variability, (C) mean torso range. The error bars represent standard error.

Sitting-45 and Sitting-85 conditions. I analyzed movement data from 21 participants (Table 1). The independent variables were viewing distance (45 cm vs. 85 cm), Windows (first, middle, and last), and Group (Sick vs. Well). I found significant Group \times Condition interactions on the velocity of mediolateral torso movement ($F(1, 17) = 4.24, p < .05, \text{partial } \eta^2 = .20$), and on the range of mediolateral gamepad

movement ($F(1, 17) = 4.27, p < .05, \text{partial } \eta^2 = .20$). Figure 8 shows that in the Sitting-45 condition movement tended to be greater for the Sick group than for the Well group, while in the Sitting-85 condition this pattern was reversed.

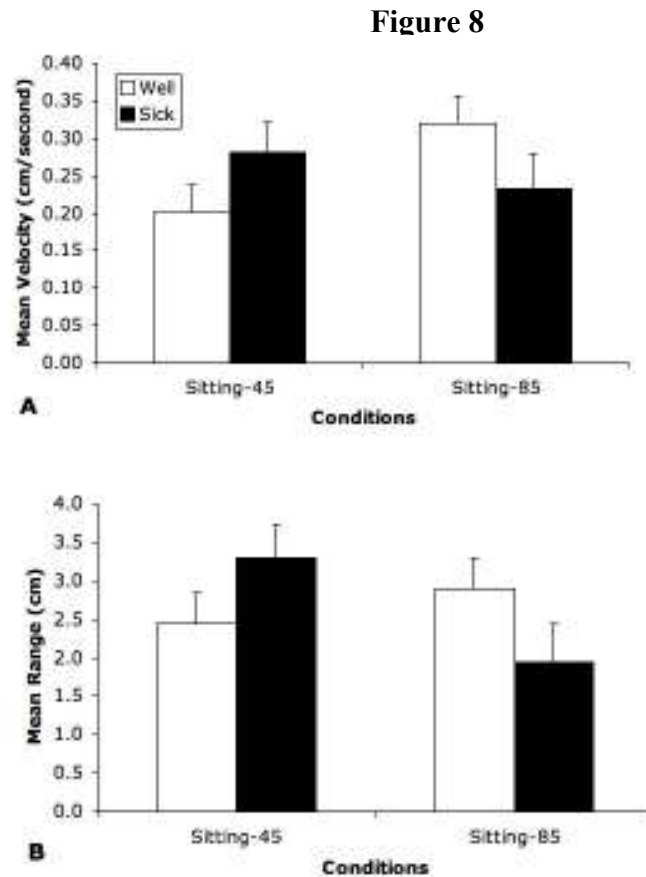


Figure 8: Mediolateral movement in the sitting conditions. (A) Mean torso velocity; (B) mean gamepad variability. The error bars represent standard error.

Discussion

The results indicate that motion sickness can occur among players of console video games under a variety of conditions. In addition, I 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 my 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. I 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 minutes. Such an effect seems unlikely, however, given widespread anecdotal reports of play sessions lasting for 12 hours, 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. during sitting. The only difference between the two studies in these conditions was that in Merhi et al. 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, my 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, while remaining steady over time for the Sick group. This pattern of results differs from previous studies that have assessed motion sickness in a moving room. In these studies, movement in the Sick group tended to increase over time, while remaining steady in the Well group (Bonnet et al., 2006; Faugloire et al., 2007; Merhi et al., 2007). Both types of effects are consistent with my hypothesis that the postural activity of Sick and Well participants would differ prior to the onset of motion sickness. I 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). 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. I conclude that motion sickness is a serious operational issue for designers, manufacturers, and users of console video games.

Chapter 4

4 Discussion

4.1 General Findings

The findings of the study confirm the predictions presented above. I predicted that 1) video games will induce motion sickness in gamers, 2) motion sickness will occur across conditions, 3) a significant difference in their postural activity between sick and well participants.

The results from of this study confirmed that motion sickness occurs among users of commercially available console video games. These findings are consistent with anecdotal reports from game users and are very well aligned with the predictions I made above. I predicted that motion sickness will occur in video game users independent of display technology or postural configuration of the users. Since the rate of motion sickness was unexpectedly high when gamers interacted with the gaming environment through HMD, as second set of experiments was conducted in a more day-to-day scenario to obtain more “realistic” data on the incidence of motion sickness. Gamers then interacted with commercially available console video games using a video monitor, a display system that is typically used during game play outside the laboratory. These results indicate that, whether HMD or video monitor was used, motion sickness can occur among players of console video games under a variety of conditions. In addition, there were significant differences in postural activity between the “sick” and the “well” participants prior to the onset of subjective symptoms of motion sickness. These are the two main results of the study.

4.2 Representative Incidence

The participants in all the experiments were specifically warned that they might become motion sick, and completed the SSQ before engaging in game play. The incidence of sickness was high, even in the most representative condition; that is when the player was sitting at 85 cm away from the video monitor (sitting-85). This could suggest that motion sickness incidence might have been elevated artifactually, given that participants knew that the study was about motion sickness. In the standing condition, incidence might also have been affected by participants' posture. Participants were instructed 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 both studies suggest that motion sickness incidence may be quite high, whether players stand or sit, near to or away from the video monitor.

The Role of Visual Display Technology Based on the postural instability theory of motion sickness, I predicted that there could be a causal relationship between postural configuration (sitting vs. standing) and the incidence of motion sickness. The results show that motion sickness occurrence in the standing condition (56%) was less than when standing participants played the same game using an HMD. By contrast, sickness incidence in the sitting conditions did not differ in both studies. The only difference between the two studies in these conditions was the visual display (HMD vs. video monitor). While these results suggest that the HMD contributes to motion sickness only when users are standing, it can be concluded that postural configuration is the key factor in inducing motion sickness, where the body, in the standing position, exhibits movements of greater amplitude around a distal axis of rotation (ankles) than movements around a more proximal axis of rotation (hips), observed in the sitting position.

4.3 Movement and Motion Sickness

In both the standing and sitting conditions, the 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 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 the hypothesis that the postural activity of sick and well participants would differ prior to the onset of motion sickness. It is unknown 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). 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.

5 Conclusion

The popularity of console video games provides a motivation for research that could allow one to gain control of motion sickness among players –to predict it and to prevent it. Prediction might be achieved through monitoring players' movements during game

play (Smart et al., 2002). Online/real time analysis of movement data might make it possible to identify individuals who are at risk for motion sickness; such individuals could be advised of the risk and encouraged to discontinue play. Research on the etiology of motion sickness with commercially available console video games will require a wider range of experimental manipulations. It would be very helpful for experimenters to obtain data from the game software publishers/developers about the nature of movements (e.g., direction, axis, amplitude, frequency) in which users engage while playing the game. However, access to game data can be obtained only with the permission of the manufacturers. It will also be important to determine the effects of previous experience with console video games on postural instability and motion sickness. Based on the findings of this study, I hope that rigorous documentation of the problem of motion sickness among users of console video games will spur cooperative research efforts between behavioral scientists and game developers.

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. As a conclusion, motion sickness seems to be a serious operational issue for designers, manufacturers, and users of console video games.

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