What to Expect from Immersive Virtual Environment Exposure: Influences of Gender, Body Mass Index, and Past Experience

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For those interested in using head-coupled PC-based immersive virtual environment (VE) technology to train, entertain, or inform, it is essential to understand the effects this technology has on its users. This study investigated potential adverse effects, including the sickness associated with exposure and extreme responses (emesis, flashbacks). Participants were exposed to a VE for 15 to 60 min, with either complete or streamlined navigational control and simple or complex scenes, after which time measures of sickness were obtained. More than 80% of participants experienced nausea, oculomotor disturbances, and/or disorientation, with disorientation potentially lasting >24 hr. Of the participants, 12.9% prematurely ended their exposure because of adverse effects; of these, 9.2% experienced an emetic response, whereas only 1.2% of all participants experienced emesis. The results indicate that designers may be able to reduce these rates by limiting exposure duration and reducing the degrees of freedom of the user's navigational control. Results from gender, body mass, and past experience comparisons indicated it may be possible to identify those who will experience adverse effects attributable to exposure and warn such individuals. Applications for this research include military, entertainment, and any other interactive systems for which designers seek to avoid adverse effects associated with exposure.

INTRODUCTION

Virtual environments (VEs) are available for countless applications in fields as diverse as medicine, training, and entertainment and other leisure-time activities (Stone, 2002). Formerly reserved for the military and scientific endeavors, this surge of new applications has caused a large number of people to be exposed to this technology, including children and civilian adults, who may not be aware of the potential adverse effects of VE exposure. With increased use of VE systems by the general public has come a rise in the number of users experiencing negative side effects (Greenfield, 1994). This situation is building the ground for potential social (Calvert, 2002), legal (Kennedy, Kennedy, & Bartlett, 2002), and economic (Swann & Stone, 2002) repercussions. Thus there is a great need to research and understand the causes and factors that induce such negative effects in order to establish safe parameters for VE exposure (Stanney et al., 1998).

Some of the most common adverse effects associated with VE exposure are dizziness, drowsiness, headache, nausea, fatigue, and general malaise (Kennedy, Lane, Berbaum, & Lilienthal, 1993). Collectively, these symptoms are often referred to as *cybersickness* (McCauley & Sharkey, 1992). In addition to these problems experienced during exposure, aftereffects often linger, including disturbed proprioception (Lampton et al., 1994; Rolland, Biocca, Barlow, & Kancherla, 1995; Stanney, Kennedy, Drexler, & Harm, 1999) and postural instability (DiZio & Lackner, 2002; Kennedy & Stanney, 1996).

Why are VE systems associated with such adverse effects? Although there is no exact science of cybersickness (also known as *motion sickness*), a few theories exist. The most widely

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accepted theory is the sensory conflict theory put forth by Reason (1978) and Reason and Brand (1975). This theory suggests that conflicts between sensory inputs – either immediately present to an observer (e.g., visual motion without concordant vestibular stimulation) or between current patterns of input and those anticipated based on experience (e.g., when a visual scene updates later than expected because of lag) – lead to conflict in the neural mechanisms responsible for interpreting and responding to orientation and self-motion (Money, 1990). According to Treisman (1977), such conflict triggers defense mechanisms that respond to minimal physiological disturbances, such as would be produced by an absorbed toxin (i.e., the poison theory). Thus motion sickness is seen as a reflex (i.e., nausea, vomiting) provoked by a response to an artificial stimulus (i.e., sensory rearrangements).

Based on the sensory conflict and poison theories, VE system designers should strive to reduce intersensory conflicts (i.e., those arising from missing or mismatched modalities) as well as those associated with sensory expectations established through experience (e.g., depth and distance distortions, form and size distortions, delays of sensory feedback; Welch, 2002). Although the sensory conflict and poison theories provide a conceptual framework within which to characterize motion sickness, both theories lack predictive power to indicate when sickness will occur and how severe it will be, and neither can account for individual susceptibility differences.

An alternative theory is the ecological theory of motion sickness (Riccio & Stoffregen, 1991). This theory suggests that motion sickness is caused by postural instability associated with environmental situations (i.e., low-frequency vibration, weightlessness, perturbed gravitoinertial force vectors, altered specificity) that destabilize the postural control system. Virtual environments are suggested to destabilize postural control through altered specificity (i.e., visually specified accelerations and rotations that lack correlated bodily forces). According to this theory, those who interact with a VE system should probably be seated or provided with a support bar to assist with maintaining postural control. Although the postural stability theory can account for individual susceptibility (i.e., those who can maintain postural control should avoid sickness), it too fails to have predictive power to indicate which VE systems will lead to postural instability.

From a theoretical perspective, because it is not currently possible to predict which VE systems will be the most disturbing (and thereby to remedy the cause), it may prove effective to predict those who are most susceptible to cybersickness and the conditions under which adverse effects are the most severe. Past research has indicated that individual susceptibility to motion sickness is influenced by gender, motion sickness history, prior experience, and overall state of health, among other factors (Kolasinski, 1995; McFarland, 1953; Mirabile, 1990; Reason & Brand, 1975; Kingdon, Stanney, & Kennedy, 2001; Stanney et al., 1998). In addition, recent research suggests that streamlining navigational control may reduce, by nearly half, the level of adverse effects associated with complete navigational control (Stanney & Hash, 1998): 20% or more of the variance in simulator sickness is governed by the kinematics of the visual scene (i.e., scene complexity), and an additional 20% or more of the variance may be determined by exposure duration (Kennedy, Berbaum, Dunlap, & Smith, 1995; Kennedy, Stanney, & Dunlap, 2000). Influences of other factors should also be considered, including technical system factors such as optical distortion, field of view, flicker, motion platforms, refresh rate, resolution, transport delays, and update rate; these have been reviewed elsewhere (Biocca, 1992; Kolasinski, 1995; Pausch, Crea, & Conway, 1992).

System Design and Usage Factors

Navigational control. Stanney and Hash (1998) presented empirical evidence indicating that the extent of motion sickness experienced by VE users will be directly related to the level of navigational (i.e., movement) control provided to users. Further, Hettinger and Riccio (1992) suggested that an examination of motion sickness would be incomplete without considering operator control behavior and the opportunity for self-initiated user interaction. These relations can be likened to a common experience – namely, that the driver of an automobile rarely if ever experiences motion sickness, whereas passengers

often are afflicted (Casali, 1986). Several other studies (Held, 1965; Stott, 1990) have provided evidence suggesting that active and voluntary movements made when users have control over their own motion may provide the key to efficiently adapting to sensory rearrangements, such as those found in virtual environments. Further study is needed to determine the types of symptoms that different levels of navigational control cause, whether or not there are benefits to streamlining user control, and whether or not those exposed for long durations adapt to high levels of control, thus becoming less ill over time.

Scene complexity. Although Pausch et al. (1992) suggested that scene complexity has minimal effects on motion sickness, several researchers (Hettinger, 2002; Kennedy & Fowlkes, 1992; McCauley & Sharkley, 1992) have suggested that the rate of visual flow (i.e., visual scene complexity) influences the incidence – and, more so, the severity – of motion sickness experienced by an individual, possibly because of positional data latencies of head-tracking hardware (DiZio & Lackner, 1997). This is probably attributable to the relationship between vection (i.e., illusory self-motion) and the spatial and temporal frequency of optical patterns (i.e., scene complexity; Hettinger, 2002). Vection, which is often associated with heightened motion sickness, generally increases with increased scene detail. More specifically, Howard (1986) indicated that vection is related to the optical texture density of a scene. Owen, Wolpert, and Warren (1983) further suggested that "edge rate" is more influential than global optical flow. Thus scenes with greater texture and more edges, such as might be found with high ceilings, as opposed to low ceilings, may produce high levels of vection and, in turn, sickness. Hettinger (2002) further suggested that the size of the visual field and the presence of movement in the background (i.e., periphery), as opposed to motion stimulation in the foreground, influence vection. It is important to further investigate such influences of scene complexity on VE sickness to determine if there are benefits to visually simplifying scenes.

Exposure duration. Exposure duration and number of repeat exposures have been shown to affect the level of motion sickness experienced. Kennedy et al. (2000) demonstrated that exposure duration is positively related and that repetition is negatively related to total sickness across a wide variety of simulators. Similarly, Fowlkes, Kennedy, and Lilienthal (1987) found that the intensity and duration of postural instability associated with exposure to a simulator increased with prolonged exposure. Because of these issues, the U.S. Army Research Institute (Knerr et al., 1998) has suggested that VE exposures should be limited to 15 min, a period that may be too short for some training, educational, or analysis-based applications. Means of extending exposure duration while minimizing adverse effects are required. It may be, for example, that if navigational control is streamlined and visual scenes are simplified, exposure duration can be extended without adverse effects. These interrelationships between system design and usage factors need to be further examined.

Individual Factors

Gender. It is generally suggested that females experience greater motion sickness than do males (Kennedy, Lanham, Drexler, & Lilienthal, 1995). Biocca (1992) reported that this difference may be attributable to males being reticent to report sickness, as he suggested that males and females do not differ in their sensory response to motion stimuli. Kennedy and Frank (1985), however, found that females may have larger fields of view than males do, and thus their sensory experience may indeed be different from that of males. Dobie, May, McBride, and Dobie (2001) found that females experience significantly more motion sickness than do males on devices in which the groups had similar exposure history, regardless of age and level of physical activity, with no support for a lack of reporting from males. Further gender studies, specifically in VE systems, are required to clarify these differences.

Motion sickness histories. The incidence of motion sickness varies greatly among individuals; some appear immune, whereas others are highly susceptible (Kennedy, Hettinger, & Lilienthal, 1990). These differences are suggested to be attributable to individual factors, such as unstable binocular vision, individual variations in interpupillary distance, susceptibility to photic seizures and migraines, drug and/or alcohol consumption, health status, and ability to adapt

to novel sensory environments (Stanney et al., 1998), as well as sensitivity to vection (i.e., illusory self-motion), optokinetic motion perception, transformations in optical flow patterns, monocular movement in depth, and other visual functions (Kennedy et al., 1990).

The Motion History Questionnaire (MHQ), which was developed 30 years ago to study airsickness and disorientation attributable to Coriolis stimulation, is often used to assess susceptibility differences based on past occurrences of sickness in inertial environments (Kennedy & Graybiel, 1965). Scores on the MHQ are generally predictive of an individual's susceptibility to motion sickness in physically moving environments. In a VE study (Kennedy, Stanney, Dunlap, & Jones, 1996), however, MHQ scores were not significantly correlated with preexposure, immediate postexposure, or 30-min postexposure sickness reports. However, recent reports (Graeber, 2001a; Kennedy, Lane, Grizzard, et al., 2001; Kennedy, Lane, Stanney, Kingdon, & Lanham, 2001) have shown promise with a new method of scoring the MHQ that can account for approximately 20% of the variance in susceptibility to VE sickness. These techniques also predict, prior to VE exposure, a substantial percentage of subsequent quits. Further study is required to determine if such techniques can accurately predict susceptibility to VE sickness. If so, such tools could provide screening measures.

Prior experience. Previous exposure to provocative environments (e.g., simulator, aircraft, roller coaster, merry-go-round, carnival rides) influences susceptibility to motion sickness. Over repeated, intermittent, short exposures to such environments, habituation may occur in which symptomatology decreases (McCauley & Sharkey, 1992; Welch, 1978). Kolasinski (1995) suggested that individuals who repeatedly experience these environments may build a tolerance to sickness-inducing stimuli and thus learn adaptive behaviors that minimize adverse effects. It is important to determine if this holds true for VE systems, as prior experience may provide a means of increasing tolerance to VE systems.

Overall state of health. Body mass index (BMI), which is a measure that takes into account a person's weight and height to gauge total body fat, is a guideline used to define one's overall nutritional and health status (Dembert, Jekel, & Mooney, 1984; National Heart, Lung, and Blood Institute [NHLBI], 1998; Pierson & Eagle, 1969). BMI is significantly correlated with total body fat content and can be used to assess overweight and obesity (NHLBI, 1998). BMI may also be indicative of susceptibility to motion sickness. High BMI (i.e., adiposity) has been reported to put underwater divers at risk for developing decompression sickness (Dembert et al., 1984). However, adiposity can be associated with higher levels of ACTH and epinephrine, which have been shown to provide some level of resistance to motion sickness, probably because elevated levels diminish activity of the gastrointestinal system (Kohl, 1985, 1990; Thornton, Linder, Moore, & Pool, 1987). Based on these conflicting data, it is not clear whether higher BMI should contribute to or provide resistance against the adverse effects of VE exposure.

This study examined each of these system design, usage, and individual factors and their relation to VE sickness symptoms. The goal was to characterize the types of adverse effects commonly associated with VE exposure as well as to identify both individual and system-related characteristics that may be predictive of these adverse effects. Although several studies have examined VE sickness (Kolasinski, 1995; Lawson, Graeber, Mead, & Muth, 2002; So, Lo, & Ko, 2001; Stanney et al., 1998), few have identified means of designing and using these systems in a manner that minimizes adverse effects or of predicting the individuals who are most susceptible. By examining the interrelationships among system design, usage, and individual factors, in the current study we seek to achieve both of these objectives. This knowledge should assist in developing VE systems that are more amenable to their users.

METHOD

Participants

The participants were 1102 (632 males, 467 females, 3 gender unrecorded) students from the University of Central Florida, mostly from the Colleges of Engineering and Psychology. The age range of participants was 15 to 53 years (mean = 21.03, *SD* = 4.43). In order for participants to

accurately see the three-dimensionality of the VE, it was essential that they have depth perception. Thus all participants were verified to have depth perception using the Wirt Circles from the Titmus Stereotest (Fricke, 1997) and reported that they were not prone to seizures. The experimental protocol was approved in advance by the University of Central Florida Institutional Review Board. Participants who volunteered to participate in the experiment were rewarded either by extra credit or monetary compensation.

Tasks

During interaction, participants traversed throughout a VE, performing several different tasks along the way. The battery of tasks used included locomotion, object manipulation, tracking, reaction time, and recognition tasks, which are based on the Virtual Environment Performance Assessment Battery (VEPAB) (Lampton et al., 1994). These tasks were performed in a VE shaped like a maze consisting of 29 rooms and 3 long corridors.

Locomotion tasks. Virtual environment applications often require participants to traverse through the virtual world while attending to target tasks. In this VE there were straightaway, elevator, turning, and doorways (room-to-room) locomotion tasks. For the straightaway task, participants were required to move as quickly as possible down a long, straight corridor. The elevator task involved elevated doors, so that vertical as well as horizontal movements were required. Rooms were designed such that the entrance and exit doors were of varying heights. Participants had to use the middle button on the control device to "drag up" off the ground and exit through elevated doors. For the turning task, participants navigated horizontally through a series of 20 90° turns. For the doorways (room-to-room) task, participants were required to move through a series of empty rooms connected by doorways that were offset so that a curved course had to be followed.

Manipulation tasks. For object manipulation tasks, participants used the mouse cursor to interact with and move objects throughout the virtual environment. When the cursor was located over an object, participants would pick up or grasp the object by pushing the right mouse button. They could then drag the object to a desired location and release the button to release the object. One set of object manipulation tasks required participants to grasp a slider bar and move it to a marked location. Another involved clicking on a basketball and dragging it upward to place it in a basketball net. Some sliders were horizontal relative to the participant and others were vertical. There were also two sets of object insertion tasks, which occurred in either two or three axes of movement.

Choice reaction time task. For this task participants entered a room containing a black rotating cube. Selecting the cube made it stop rotating and change to a specific color. Participants then had to turn around, look at the wall opposite the cube, and select the cube color from a panel of colors on the wall. Once participants had selected the correct color from the panel, the cube again turned black and began to rotate. Participants performed this sequence three times before they were allowed to go on to the next room.

Apparatus

A 200-MHz Pentium MMX computer with 64 MB of RAM and an Elsa Winner Pro 2000/X with an 8 MB RAM graphics board were used to generate the virtual environments. RenderWare software was used to develop the virtual environments. A Logitech Cordless Mouseman Pro was used as the input device. A Virtual Research V6 helmet-mounted display (HMD), equipped with a Virtual iO! Tracker, was used to generate the graphics and track users' movements. The V6 has dual active-matrix LCDs, 640 × 80 resolution per eye (60 Hz update rate), 48° horizontal × 36° vertical field of view (60° diagonal), and pixel size of 4.21 arcmin/pixel; it weighed 29 ounces (0.82 kg) and was used in stereo mode. Users adjusted the lens interpupil distance (available range 52–74 mm) and the distance from their eyes to the screens (available range 10–30 mm) individually to obtain a perceived clear view. The HMD was equipped with Sennheiser HD25 high-performance headphones, through which music was played.

A Summagraphics SummaSketch FX digitizing tablet with a cordless stylus was used to measure proprioceptive aftereffects (i.e., eye-hand coordination) from VE exposure (see details about this measurement approach in Stanney

et al., 1999). Video equipment was used to assess postural stability (i.e., ataxia) before and after VE exposure (see details about this measurement approach in Kennedy & Stanney, 1996).

The MHQ (Kennedy & Graybiel, 1965) was used to assess susceptibility based on past occurrences of sickness in inertial environments. Of the 960 participants who completed the VE exposure, 405 were categorized as susceptible and 555 as nonsusceptible, based on the revised MHQ scoring technique developed in Graeber (2001a). The scoring was 0 = *low susceptibility,* 1 = *high susceptibility.*

The Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) was used to assess subjective aftereffects. The SSQ consists of a checklist of 26 symptoms, each of which is related in terms of degree of severity (*none* = 0, *slight* = 1, *moderate* = 2, *severe* = 3). A weighted scoring procedure is used to obtain a global score reflecting the overall discomfort level, known as the *total severity* (TS) score. The SSQ also provides scores on three subscales representing separable but somewhat correlated dimensions of simulator sickness: nausea (N), oculomotor disturbances (O), and disorientation (D).

Procedure

Prior to the experimental session, all participants filled out informed consent and demographics forms as well as the MHQ. Then participants were tested for stereoscopic depth perception. Participants had to score 6 or higher out of 9 on the Titmus Stereotest to have their data included in the data analysis. Information from the demographics form allowed calculation of participants' BMI, which was derived from the formula BMI = (weight)/(height^2) (Pierson & Eagle, 1969). Based on the NHLBI's (1998) BMI guidelines, those participants who reported their weight and height (15 of the total 1102 went unreported) were classified as underweight (BMI ≤ 18.5; n = 91, M = 17.12, SD = 1.18), healthy weight (18.6 ≤ BMI ≥ 24.9; n = 710; M = 21.67; SD = 1.69), overweight (25 ≤ BMI ≥ 29.9; n = 215; M = 26.92; SD = 1.43), or obese (BMI ≥ 30; n = 71; M = 34.05; SD = 3.88).

Prior to participants' exposure to the VE, baseline measures of the SSQ, eye-hand coordination, and postural stability were obtained. In order for participants to proceed with the experiment, their preexposure SSQ score had to fall at or below 7.48, which qualified them to be in good health for the experiment.

Each participant was randomly assigned to one of 48 treatment conditions. Experimental conditions were based on (a) amount of navigational control, in which complete control allowed six degrees of freedom (DOF) of user movement (roll, pitch, and yaw as well as x, y, and z translational movements) and streamlined control allowed three DOF: linear movement in the fore–aft (x) and up-down (z) directions, as well as pitch; (b) scene content, in which simple scenes were flat shaded with no textures and low ceilings, whereas complex scenes had textures and high ceilings; and (c) duration of exposure (15, 30, 45, or 60 min). During exposure, participants maintained a seated position while wearing the HMD and traversed through the maze completing the battery of tasks described earlier. Immediately following the exposure period, postexposure SSQ, eye-hand coordination, and postural stability measures were obtained. These measures were taken every 15 min up to 1 hr after exposure. During this time, some participants took part in readaptation exercises (peg-in-hole and rail-walking activities), depending on their assigned conditions. Participants were provided with an SSQ to take with them and to fill out 2 to 4 hr, more than 4 hr, and the next morning after VE exposure.

Experimental Design

The experiment was a 4 × 2 × 2 × 3 between-subjects design, with 20 participants randomly assigned to each condition. The independent variables were exposure duration (15, 30, 45, and 60 min), navigational control condition (complete and streamlined), scene complexity (simple and complex), and readaptation mechanism (none, peg in hole, rail walking). The readapation mechanisms are discussed in detail in Stanney, Champney, Hash, Kennedy, and Compton (2003). Dependent variables included the N, O, D, and TS scores from the SSQ. Demographic variables used in the analysis of sickness incidence included gender, BMI, motion sickness histories, and prior experience. In addition, dropout and emetic response rates were examined.

RESULTS

Of the 1102 participants who were exposed to the VE, 142 (12.9%) dropped out because of sickness. The following results were based on 960 (564 males, 396 females) participants who completed their assigned exposure time. The initial statistical analysis revealed that the data taken from the postexposure SSQ were of a nonnormal distribution. Therefore, nonparametric statistics were used for the analyses.

Overall, 81% of participants reported higher levels of symptoms on the SSQ immediately after VE exposure as compared with before VE exposure. The influences on the level of symptom severity experienced – based on the duration of exposure, level of navigational control, and scene complexity, as well as a number of individual variables – are reviewed in the following sections.

Duration

Spearman's correlation results indicated that exposure duration had a significant effect on SSQ-N ($r = .171$, $p < .0001$), SSQ-O ($r = .264$, $p < .0001$), SSQ-D ($r = .133$, $p < .0001$), and SSQ-TS ($r = .225$, $p < .0001$) scores (see Figure 1 and Table 1). All symptoms have a strong positive relationship with exposure duration: As exposure time increased, so too did symptom severity. The mean symptoms for all exposure durations followed a D > N > O profile. This is the common profile found for VE exposure, with greater disorientation and nausea and lesser oculomotor disturbances (Kennedy, Lane, Lilienthal, Berbaum, & Hettinger, 1992; Stanney, Kennedy, & Drexler, 1997; Stanney et al., 1998).

Differences among groups were determined by a Kruskal-Wallis nonparametric test. The Dunn nonparametric post hoc test was used to determine which durations were significantly different. Statistically significant ($\alpha = .05$) differences per SSQ symptom type (N, O, D, TS) among groups are summarized in the following sections.

Nausea. Kruskal-Wallis results revealed that the mean SSQ-N score significantly ($\chi^2 = 30.59$, $p < .0001$) differed with respect to VE duration. The 15-min group had significantly ($p < .01$) lower SSQ-N scores, on average, as compared with those who underwent 45 or 60 min of exposure.

Oculomotor. Results revealed that the mean SSQ-O score significantly ($\chi^2 = 68.85$, $p < .0001$) differed with respect to VE duration. Participants from the 15-min group had, on average, SSQ-O scores that were significantly lower ($p < .01$) than those of participants who were exposed for 45 or 60 min. The mean scores also differed significantly ($p < .01$) between the 30-min group and the 60-min group, with the 30-min group's scores being lower.

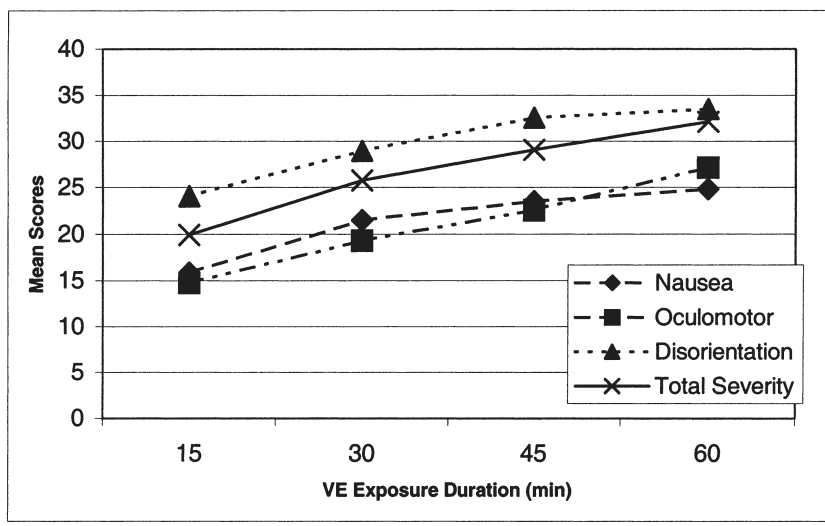

Figure 1. Mean SSQ scores by VE exposure duration.

TABLE 1: Descriptive Statistics of SSQ Symptoms by Exposure Duration

Exposure (min)	Symptom	Mean SSQ	*SD*
15	Total severity	19.96	25.92
	Nausea	15.86	23.94
	Oculomotor	14.75	20.19
	Disorientation	24.07	34.04
30	Total severity	25.73	25.73
	Nausea	21.50	24.85
	Oculomotor	19.30	19.32
	Disorientation	28.94	35.67
45	Total severity	29.08	26.63
	Nausea	23.49	26.50
	Oculomotor	22.55	20.18
	Disorientation	32.54	35.49
60	Total severity	32.10	26.56
	Nausea	24.80	25.04
	Oculomotor	27.13	21.86
	Disorientation	33.47	34.43

Note: n = 240 for each duration.

Disorientation. Results revealed that the mean SSQ-D score significantly ($\chi^2 = 18.33$, $p < .001$) differed with respect to VE duration. The 15-min group's mean SSQ-D score was significantly ($p < .05$) lower than that of the 45- and 60-min groups.

Total severity. Results revealed that the mean SSQ-TS score significantly ($\chi^2 = 51.00$, $p < .0001$) differed with respect to VE duration. The 15-min group had, on average, significantly ($p < .01$) lower SSQ-TS scores than did those who were exposed for 45 or 60 min.

Navigational Control

Spearman's correlation results revealed that navigational control condition was significantly linearly related to SSQ-N ($r = .207$, $p < .0001$), SSQ-D ($r = .080$, $p = .014$) and SSQ-TS ($r = .117$, $p < .001$) scores (see Table 2). Nausea (SSQ-N), disorientation (SSQ-D), and total severity (SSQ-TS) have a strong positive relationship with navigational control. As the amount of navigational control allowed to participants increased in terms of DOF, so too did the level of nausea, disorientation, and total severity experienced.

The Mann-Whitney nonparametric test for two independent means indicated that the SSQ-N, SSQ-D, and SSQ-TS scores significantly ($Z = 6.399$, $p < .001$; $Z = 2.467$, $p = .014$; and $Z = 3.63$, $p < .001$, respectively) differed among the navigational control conditions. The mean SSQ-N score under the complete control condition was 39.9% higher than that under the streamlined control condition, and the mean SSQ-D score was 15.8% higher under the complete condition. The mean SSQ-TS score under the complete condition was 20.4% higher as compared with the streamlined condition. The profile of symptoms also differed based on navigational control condition, with the complete control condition displaying a D > N > O profile and the streamlined condition displaying a D > O > N profile.

Scene Complexity

Spearman's correlation results revealed that the sickness level experienced by participants was not significantly linearly related to scene complexity. Mann-Whitney results indicated that the mean sickness scores did not differ across the complex and simple scenes (see Table 2). It may be that the scenes did not provide enough of a difference in vection (Hettinger, 2002) to differentiate between them. The current manipulation involved comparing textured with flat-shaded

TABLE 2: Descriptive Statistics of SSQ Symptoms by Control Condition and Scene Complexity (n = 480)

	Control				Scene Complexity			
	Complete		Streamlined		Complex		Simple	
SSQ Symptoms	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Total severity	29.76	28.07	23.67	24.60	27.01	27.11	26.72	26.56
Nausea	26.75	28.34	16.08	20.52	22.60	26.19	21.42	25.29
Oculomotor	21.48	20.97	20.39	20.79	20.70	21.02	20.93	20.88
Disorientation	32.31	36.36	27.20	33.54	29.52	35.95	29.75	35.05

surfaces as well as low versus high ceilings. It may be that the size of the visual field and the presence of background (periphery) – as opposed to foreground – motion stimulation (Hettinger, 2002) are more influential than the factors herein studied.

Additional study is needed that systematically measures scene complexity and its effects on sickness. This is no easy task. *Kinematics* (Hixon, Niven, & Correia, 1966) refers to those variations in scene content and user-system interactions that are affected by what the participant does during the simulation, such as turns, dives, and changes in altitude, which can be further complicated by position tracking errors. Although most would agree that the amount of such visual dynamics is likely to be a contributing factor to motion sickness in general, it is not always clear how this is graded when visual displays and dynamic user interaction (i.e., no set path to traverse) are involved. A suggested next step is to compare the factors that are thought to affect vection (see Hettinger, 2002) and to determine how they in turn affect sickness.

Gender

Spearman's correlation results revealed that the SSQ-O ($r = .133$, $p < .001$), SSQ-D ($r = .130$, $p < .001$), and SSQ-TS scores ($r = .091$, $p = .005$) were significantly linearly related to the participant's gender, with males experiencing less of these symptoms than females. Mann-Whitney test results indicated that the mean of the SSQ-O ($Z = –4.110$, $p < .001$), SSQ-D ($Z = –4.016$, $p < .001$), and SSQ-TS ($Z = –2.81$, $p = .005$) scores significantly differed between the gender groups. Female participants had 22.0% higher SSQ-O, 24.5% higher SSQ-D, and 15.0% higher SSQ-TS scores as compared with males (see Table 3). In addition, the symptom profiles differed between the gender groups, with males experiencing a D > N > O profile and females a D > O > N profile.

Body Mass Index

Spearman's correlation results revealed that the SSQ-O ($r = –.073$, $p = .025$) was significantly linearly related to participant's BMI, with oculomotor symptoms decreasing with increasing BMI (underweight $M = 22.28$, $SD = 20.78$; healthy weight $M = 21.65$, $SD = 21.45$; overweight $M = 19.62$, $SD = 19.44$; obese $M = 16.31$, $SD = 19.23$). The other SSQ symptoms (TS, N, D) did not correlate significantly with BMI. Kruskal-Wallis tests showed no significant differences in the mean SSQ symptom scores (TS, N, O, or D) among BMI groups.

Motion Sickness Histories

The MHQ was used to compare a participant's susceptibility to sickness with their post-VE exposure SSQ scores. Spearman's correlation results revealed that MHQ susceptibility scores (0 = *low,* 1 = *high*) were significantly positively related to SSQ-N ($r = .239$, $p < .001$), SSQ-O ($r = .211$, $p < .001$), SSQ-D ($r = .244$, $p < .001$), and SSQ-TS scores ($r = .258$, $p < .001$); as MHQ score increased, so too did SSQ scores. Mann-Whitney test results indicated that mean SSQ scores of the susceptibility groups differed significantly (SSQ-N: $Z = –7.137$, $p < .001$; SSQ-O: $Z = –6.491$, $p < .001$; SSQ-D: $Z = –7.548$, $p < .001$; SSQ-TS: $Z = –7.687$, $p < .001$), with the susceptible group experiencing 39.9% higher SSQ-TS scores, on average, as compared with the nonsusceptible group (see Table 3).

TABLE 3: Descriptive Statistics of SSQ Symptoms by Gender and Susceptibility

	Gender				Susceptibility			
	Male ($n = 564$)		Female ($n = 396$)		Nonsusceptible ($n = 555$)		Susceptible ($n = 405$)	
SSQ Symptoms	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Total severity	24.89	25.80	29.32	27.42	20.88	21.51	34.72	30.48
Nausea	21.92	25.88	20.69	24.46	16.26	20.84	28.48	28.93
Oculomotor	18.75	19.74	24.04	22.06	17.17	18.14	26.09	23.18
Disorientation	26.24	32.82	34.76	37.49	22.45	28.10	39.77	40.75

In addition, Spearman's correlation results revealed that gender was significantly ($r = .201$, $p < .001$) related to MHQ score. Mann-Whitney test results indicated that the mean MHQ scores significantly ($Z = -6.228$, $p < .001$) differed between genders, with females (mean = 2.87, $SD = 1.68$) having 22.0% higher MHQ scores, on average, as compared with males (mean = 2.24, $SD = 1.54$). Thus it may be increased susceptibility rather than gender that led to the higher levels of SSQ-O and SSQ-D experienced by females. In fact, Graeber (2001b) has convincing evidence that when susceptibility is controlled for, gender is no longer predictive of sickness symptoms.

Prior Adverse Experience

Spearmen's correlation results indicated that prior adverse experience with roller coasters ($r = .183$, $p < .0001$), merry-go-rounds ($r = .184$, $p < .0001$), aircraft ($r = .195$, $p < .0001$), simulators ($r = .231$, $p < .0001$), long bus rides ($r = .239$, $p < .0001$), and carnival rides ($r = .248$, $p < .0001$) may be positively related to the level of VE sickness experienced; as the history of such adverse experiences increased, so too did VE sickness symptoms.

Dropout and Emetic Response Rates

Of the 1102 participants who were exposed to the VE, 142 (12.9%) dropped out because of sickness (68 males, 71 females, and 3 gender unrecorded). The dropout distribution was significantly related to exposure duration ($r = .198$, $p < .001$). The percentage of dropouts from each exposure duration was 6.3% for 15 min, 16.9% for 30 min, 31.0% for 45 min, and 45.8% for 60 min. Navigational control was also significantly related to the dropout distribution ($r = .184$, $p < .001$). Of the dropouts, 77.5% were from the complete control condition and 22.5% were from the streamlined condition. Scene complexity did not affect dropout rate, as approximately 50% of those who dropped out experienced each type of scene (see Table 4).

Of the approximately 13% of participants who could not complete their assigned VE exposure duration, 14 participants (9.2% of dropouts; 1.18% of all participants) experienced an emetic response: 6 males (8.8% of male dropouts), 7 females (9.9% of female dropouts), and 1 unrecorded. The number of emetic responses was significantly related to exposure duration ($r = .087$, $p = .004$). One participant

TABLE 4: Dropout and Emetic Response Rates by Exposure Duration, Scene Complexity, and Control Condition ($n = 1102$)

		Streamlined Control		Complete Control		
Exposure (min)		Simple Scenes	Complex Scenes	Simple Scenes	Complex Scenes	Total
15	SSQ-TS	18.10 (24.93)	19.32 (27.60)	22.32 (26.14)	21.92 (29.08)	20.44 (26.90)
	Dropouts	2	0	2	5	9
	Emetic	0	0	0	1	1
30	SSQ-TS	27.22 (27.11)	22.38 (24.65)	28.53 (28.57)	27.57 (25.41)	26.52 (26.45)
	Dropouts	5	1	7	11	24
	Emetic	0	0	0	1	1
45	SSQ-TS	28.40 (24.88)	24.19 (25.92)	38.38 (31.59)	34.48 (26.93)	31.96 (28.07)
	Dropouts	4	2	20	18	44
	Emetic	0	1	2	0	3
60	SSQ-TS	28.75 (25.72)	34.92 (28.48)	45.06 (33.09)	43.30 (33.64)	38.58 (31.21)
	Dropouts	7	11	27	20	65
	Emetic	0	4	2	3	9
Total	SSQ-TS	25.72 (25.90)	25.61 (27.30)	34.69 (31.40)	32.37 (29.95)	
	Dropouts	18	14	56	54	142
	Emetic	0	5	4	5	14

Note. Numbers in parentheses represent standard deviations.

each from the 15-min and 30-min durations vomited, whereas 3 from the 45-min and 9 from the 60-min durations vomited. The navigational control condition was not significantly related to emetic response rate (9 participants had complete control, and 5 participants had streamlined control). Scene complexity was also not significantly related to emetic response rate, although 71.4% of those who vomited were exposed to complex scenes, whereas 28.6% were exposed to simple scenes.

BMI was not significantly related to emetic response rate ($r = –.36$, $p = .239$). However, no participants who had a higher BMI (those classified as overweight or obese) had an emetic response, whereas 1 underweight participant and 11 healthy weight participants had an emetic response. It may be that adiposity is protective against emetic responses in a VE; in past studies, this is suggested to be attributable to diminished activity of the gastrointestinal system (Kohl, 1985, 1990; Thornton et al., 1987). Further study is needed to clarify this relationship.

Flashback and Drowsiness

Flashbacks and drowsiness are symptoms included in the SSQ checklist that do not factor into the N, O, D, and TS calculations. Flashbacks (i.e., visual illusion of movement or false sensations of movement when not in the VE; Baltzley, Kennedy, Berbaum, Lilienthal, & Gower, 1989) were experienced immediately after VE exposure by 144 (15.0%) participants at various levels of severity (12.2% slight, 2.5% moderate, and 0.3% severe). This is a high incidence level for what is thought to be a rare outcome from VE exposure (Kennedy et al., 1992).

Overall, drowsiness severity among participants increased significantly ($Z = –11.363$, $p < .0001$), from a mean of 0.56 ($SD = 0.73$) pre-VE exposure to a mean of 0.61 ($SD = 0.75$) immediately after exposure based on Wilcoxon's signed rank test. Of the 960 participants who completed their VE exposure, 420 (43.8%) experienced some level of drowsiness (33.0% slight, 9.0% moderate, and 1.8% severe) immediately after VE exposure (preexposure: 22.9% slight; 1.4% moderate, and 0.1% severe). Although severe drowsiness had the lowest occurrence on postexposure, it is interesting to note that 1 participant fell asleep during posttesting. Preexposure and immediate postexposure drowsiness scores were significantly ($r = .232$, $p < .001$) positively correlated: If participants had higher preexposure drowsiness, they were more likely to experience drowsiness after VE exposure.

In addition, drowsiness was positively correlated with VE duration ($r = .100$, $p = .002$): As exposure duration increased, so too did drowsiness. Kruskal-Wallis test results indicated that drowsiness significantly ($\chi^2 = 12.28$, $p = .006$) differed among the different VE durations, with the 60-min group experiencing 54% more severe drowsiness as compared with the 15-min group (based on a Dunn post hoc test, $p < .05$). Drowsiness and flashback scores were also found to be significantly ($r = .137$, $p < .001$; and $r = .078$, $p = .015$, respectively) related to gender, with females experiencing higher levels of drowsiness and flashbacks on average, compared with males. A significant positive relationship between flashbacks and drowsiness was also found ($r = .206$, $p < .001$): As participants experienced increased drowsiness, they also experienced greater severity of flashbacks. The high incidence of drowsiness supports researchers who have warned of the possibility for "sopite syndrome" (DiZio & Lackner, 1992; Graybiel & Knepton, 1976), which is characterized by lowered arousal (e.g., drowsiness, fatigue) or mood during or after VE exposure. Such compromised functioning could affect performance without being fully detected by the afflicted person (Kennedy, 1994; Lawson et al., 2002; Lawson & Mead, 1997).

Prolonged Aftereffects

It is essential to understand how long the adverse aftereffects of VE exposure persist. To assess prolonged effects, participants reported their symptoms via the SSQ immediately after VE exposure and then every 15 min postexposure up to 60 min. The results indicate that symptoms persisted during this interval, with SSQ-TS diminishing by only 30.7% compared with the immediate postexposure values (see Table 5). Friedman's nonparametric test showed a significant difference in SSQ-TS across time ($\chi^2 = 1232$, $p < .00001$). Post hoc measures revealed that all postexposure measures (0, 15, 30, 45, and 60 min) were significantly higher than preexposure SSQ-TS scores.

TABLE 5: Prolonged Aftereffects Associated with Head-Coupled PC-Based Immersive VE Systems

	N	O	D	TS
Preexposure (n = 960)	2.11	3.26	0.12	2.47
0 min (n = 960)	21.42	20.93	29.75	26.72
15 min (n = 960)	15.02	16.66	21.84	19.97
30 min (n = 960)	14.20	16.94	19.42	19.14
45 min (n = 960)	13.13	16.81	17.59	18.17
60 min (n = 960)	12.56	16.49	16.79	17.57
2–4 hr (n = 366)	16.81	14.50	12.89	17.21
> 4 hr (n = 366)	5.43	9.81	6.88	8.82
~ 24 hr (n = 366)	2.23	4.08	3.59	3.85

Note. Preexposure values for subset of n = 366, who returned the take-home questionnaires: N = 2.27, O = 3.15, D = 0.11, TS = 2.47.

To gauge how prolonged aftereffects may be, an analysis was conducted in which participants were asked to fill out an SSQ concerning symptoms they were experiencing 2 to 4 hr, more than 4 hr, and the next morning (approximately 24 hr) after VE exposure. Of the 960 participants who completed their VE exposure, 366 returned this questionnaire. Friedman's nonparametric test revealed a significant difference in SSQ-TS across time ($\chi^2 = 470$, $p < .001$; see Table 5). Post hoc tests revealed that sickness symptoms were significantly higher at 2 to 4 hr postexposure as compared with preexposure measures. At 2 to 4 hr postexposure, 73% of participants still had symptoms substantially higher than they had before VE exposure, with the SSQ-TS scores nearly seven times higher than preexposure levels (see Table 5). Examining the three subdimensions of symptoms indicated that 2 to 4 hr after exposure, SSQ-N was 7.4 times higher, SSQ-O was 4.6 times higher, and SSQ-D was 117.2 times higher than preexposure levels. The high disorientation is consistent with other studies that have indicated that VE systems engender high levels of dizziness and vertigo after exposure (Stanney & Kennedy, 1998); it is also reflective of very low preexposure SSQ-D scores.

More than 4 hr after VE exposure, 35% of participants still reported SSQ symptoms higher than preexposure exposure levels; however, on average sickness was no longer significantly different from that preexposure. By the next morning, 18% of participants reported higher levels of SSQ symptoms than those reported before VE exposure; however, again these differences were not significant.

Posture and Proprioceptive Aftereffects

These analyses are based on the evaluation of subjectively reported sickness symptoms. In addition to these data, postural stability and proprioceptive aftereffects were assessed. These analyses showed significantly greater postural instability and a shift in proprioception after VE exposure as compared with preexposure. These objective measures provide further support that the well-being of participants was compromised by VE exposure. These results, as well as those associated with the readaptation mechanisms, are reported in detail in Stanney et al. (2003).

DISCUSSION

Taken together, the results suggest that head-coupled PC-based immersive VE systems may engender significant levels of adverse effects. The current study used the Virtual iO! head-tracker coupled with a V6 HMD. Adverse effects associated with immersion in this system led approximately 13% of participants (68 males and 71 females) to terminate their VE exposure without completing their assigned duration; of these, 14 participants experienced an emetic response. As expected, the percentage of dropouts and emetic response rate increased with increasing exposure duration (see Table 4). The results of this research corroborate past studies (Lawson et al., 2002) that indicate that

an emetic response as a result of VE exposure is infrequent (1.14%) as compared with other symptoms. The results further indicate that dropout rates can be quite high (~50%) for prolonged exposure (1 hr) to head-coupled PC-based immersive systems. For those aspiring to utilize such VE systems for protracted exposures (e.g., training), this could prove problematic.

In correspondence with the suggestions by McCauley and Sharkey (1992) and Kennedy et al. (2000) that longer exposure results in increased incidence of sickness, the current study found that as VE exposure duration increased from 15 to 60 min, so too did the level of adverse effects (see Table 1). This could be taken as support for the ecological theory of motion sickness (Riccio & Stoffregen, 1991), because the longer one has to remain seated while wearing an HMD, the more difficult it may become to maintain postural control. It may be that people find it difficult to maintain postural control in such conditions for more than 15 min, as sickness increased appreciably for longer exposure durations. This premise should be further explored by measuring postural instability over various durations of exposure. The results from this study further suggest that at about 45 min of VE exposure, participants reach a plateau in the degree of nausea and disorientation they experience, whereas oculomotor symptoms continue to rise (see Table 1).

Results from the navigational control condition, which showed higher levels of nausea for complete control than for streamlined control, could also be taken as support for the ecological theory. It may have been more difficult to maintain postural control in the complete control condition because this condition would have allowed visually specified rotations (i.e., yaw and roll motion) that lacked correlated bodily forces, whereas such motions were not allowed in the streamlined condition. It is possible that this discordance could have led to greater levels of sensory conflict; thus these data could also be seen as consistent with the sensory conflict theory (Reason, 1978; Reason & Brand, 1975). Howarth and Finch (1999) found similar results with a video game (i.e., participants traversed a VE, shooting monsters for 20 min), when they compared a complete control condition and found it to be more nauseogenic than a hand control condition, in which participants' travel was limited to one direction (i.e., straight ahead).

The present study went further, by examining complete (six DOF) navigational control versus streamlined (three DOF) control for up to 60 min of exposure. The results indicated that participants in the complete control condition experienced 39.9% higher levels of nausea and 20.4% higher total severity of symptoms as compared with those in the streamlined condition (see Table 2). In addition, complete control led to 110 (77.5%) dropouts, as compared with 32 (22.5%) dropouts from the streamlined control condition. When streamlined control was coupled with a simple visual scene, the dropout rate dropped (18, or 13%), with no one in this condition experiencing an emetic response. Thus VE designers may be able to simplify visual scene imagery and streamline the DOF of navigational control to reduce both dropout and emetic response rates.

Gender is another important factor related to sickness susceptibility (Money, 1970). Generally females report higher sickness levels than males do, and this trend was supported in the current study (see Table 3). However, we found that females do not experience more nausea than do males; in fact, their nausea symptoms were slightly less (not significant). Differences between the genders were attributable to females experiencing significantly higher levels of oculomotor and disorientation symptoms, as compared with the males.

These findings are important because past studies have pointed to a difference between the genders in the tendency to *report* symptoms, with females reporting greater susceptibility (Reason & Brand, 1975). We found that for one dimension of sickness (i.e., nausea), males and females reported about the same level of symptoms (even slightly less for females). This suggests that one should look to the underlying causes of oculomotor and disorientation symptoms, which the females experienced to a greater degree than did the males, to identify the root cause of these gender differences. It is unclear whether these differences are attributable to anatomical differences or an effect of hormones (Griffin, 1991). The MHQ scores indicated, based on their past experiences, that females were more susceptible to motion sickness than

were males. Furthermore, those who were rated as more susceptible experienced significantly more adverse symptoms after VE exposure. Thus it could be that susceptibility is a stronger predictor of VE sickness than is gender.

This study showed a strong relationship between SSQ sickness outcome and prior adverse experience with simulators, aircraft, roller coasters, merry-go-rounds, long bus rides, and carnival rides. If participants tended to experience motion sickness on any of those, they also were more likely to experience a high sickness level after VE exposure. Therefore, individuals who tend to get motion sickness should be warned that they may experience high levels of nausea and disorientation during or after VE exposure.

Although one cannot draw definitive conclusions from one experiment, the current study of a large population of users provides insights into a potential profile of adverse effects that may be associated with head-coupled PC-based immersive VE systems (see Table 6). Designers and administrators of such systems should understand these effects when designing their systems or developing usage protocols. Drawing on the results of this study, as well as the literature reviewed, we present (Table 7) a preliminary set of design and usage guidelines that may assist in minimizing adverse effects for head-coupled PC-based immersive VE systems.

The incorporation of the VEPAB (Lampton et al., 1994) into the current study should enhance the generalizability of the results, as this battery consists of a set of basic tasks thought to be relevant to most VE systems. It is important to note, however, that the generalizability of the results of this study are bound to head-coupled PC-based immersive VE systems that incorporate tasks similar to those used in this study. One may be inclined to attribute the maladies

TABLE 6: Profile of Potential Adverse Effects Associated with Exposure to Head-Coupled PC-Based Immersive VE Systems

As exposure time increases so too may adverse symptom severity.
With prolonged (> 45 min) exposure, adverse effects can be expected to level off.
Dropout rates may vary from about 10% to 50%, with higher levels associated with prolonged exposures (e.g., 60 min or more).
Complete user movement control (six DOF) can be expected to lead to more dropouts (in this study, 3.4 times more) and greater levels of nausea than streamlined control (three DOF).
Scene complexity does not appear to affect dropout rate; however, complex scenes may lead to 2.5 times more emetic responses.
Females exposed to VE systems can be expected to be more susceptible to motion sickness and to experience higher levels of oculomotor and disorientation symptoms as compared with males.
BMI does not appear to be strongly related to sickness symptoms; however, those with higher BMIs may be less prone to experience an emetic response.
Individuals susceptible to motion sickness can be expected to experience about twice the level of adverse effects as compared with nonsusceptible individuals.
Individuals who have experienced an emetic response associated with carnival rides and the like can be expected to experience about twice the level of adverse effects as compared with those who do not experience such emesis.
Individuals can be expected to experience lowered arousal (e.g., drowsiness, fatigue) after exposure.
Individuals with higher preexposure drowsiness may be more likely to experience drowsiness after exposure, and those exposed for long durations (e.g., 60 min or more) can be expected to experience about twice the level of drowsiness as compared with those exposed for a shorter duration.
Flashbacks (i.e., visual illusion of movement or false sensations of movement when not in the VE) can be expected to occur.
As drowsiness increases, one can expect a greater severity of flashbacks.
Watch out for the possibility of prolonged disorientation (e.g., dizziness and vertigo) after exposure, with symptoms potentially lasting more than 24 hr.

TABLE 7: Preliminary Design and Usage Guidelines for Head-Coupled PC-Based Immersive VE Systems

Initial exposure duration should be kept short (15 min), and expectations should be set for continued use (e.g., target exposure duration, intersession intervals). Provide a means of maintaining postural control, especially for exposures longer than 15 min.
Reduce DOF of user movement control, particularly during initial exposure and during severe movements (e.g., pitching, rolling, diving, quick turns). When using visually specified accelerations and rotations, provide correlated bodily forces, if possible.
Expect individuals to differ greatly in motion sickness susceptibility, and use the MHQ or another instrument to gauge susceptibility of the target user population; appropriately advise those who are particularly susceptible.
Expect females, those with past histories of motion sickness, and, potentially, those with lower BMIs to be the most susceptible to adverse effects.
Expect dropouts and emetic responses; develop interventions (e.g., warnings, instructions) for addressing these issues.
Warn users that prolonged aftereffects, flashbacks, and drowsiness may occur after exposure and encourage them to exercise appropriate caution.
Encourage users to be well rested and free from ailments before commencing exposure.
Warn users that adverse effects occur during exposure, and encourage users to withdraw from exposure if they become afflicted.

experienced in this study to the particular system used, but the data do not support this supposition. The system time delay for the current system was set not by the V6 HMD, which updates at 60 Hz, or the software, which updates at 20 Hz, but by the Virtual iO! Headtracker, which updates at about 10 Hz. This head tracker thus presented a system time delay of about 100 ms (i.e., the delay between movements made by the user and subsequent update of the visual scene).

Such system time delays have been hypothesized to lead to adverse effects (Kennedy et al., 1990), and in one study by DiZio and Lackner (1997), delays showed an effect at 100, 200, and 300 msec. However, DiZio and Lackner (1997) also found significant sickness at the lowest delay (67 msec) analyzed, and in several other studies that have empirically examined various time delays, a significant relation has not been found. Uliano, Kennedy, and Lambert (1986) examined delays between 125 and 215 ms and failed to find a significant effect between increasing time delay and simulator sickness. Draper, Viirre, Furness, and Gawron (2001) examined time delays of 125 and 250 ms using the same head tracker used in this study (i.e., Virtual iO!) and similarly failed to find a significant relation between sickness and time delay. Thus it is our view that compared with the technology, individual and usage factors, including those examined in this study (i.e., individual susceptibility, navigational control, and exposure duration), have a greater influence on adverse effects associated with head-coupled PC-based immersive VE systems.

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