Assessing Negative Side Effects in Virtual Environments

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(ABSTRACT)

Virtual environment (VE) systems have been touted as exciting new technologies with many varied applications. Today VEs are used in telerobotics, training, simulation, medicine, architecture, and entertainment. The future use of VEs seems limited only by the creativity of its designers. However, as with any developing technology, some difficulties need to be overcome. Certain users of VEs experience negative side effects from being immersed into the graphically rendered virtual worlds. Some side effects that have been observed include: disorientation, headaches, and difficulties with vision. These negative side effects threaten the safety and effectiveness of VE systems.

Negative side effects have been found to develop in a variety of environments. The research focus on VE side effects thus far has been on the symptoms and not the causes. The main goals of this research is fourfold: 1) to compare a new measure for side effects with established ones; 2) begin analyzing the causes of side effects with an analysis of head-tracking; 3) to examine any adaptation that may occur within a session and between days of a session; and, 4) to examine possible predictors for users who may experience side effects.

An experiment was conducted using two different VEs with either head-tracking on or head-tracking off over four days. A questionnaire, a balance test, a vision test, and magnitude estimations of side effects were used to assess the incidence and severity of sickness experienced in the VEs. Other assessments, including a mental rotation test, perceptual style, and a questionnaire on pre-existing susceptibility to motion sickness were administered. All factors were analyzed to determine what their relationships were with the incidence and severity of negative side effects that result from immersion into the VEs.

Results showed that head-tracking induces more negative side effects than no head-tracking. The maze task environment induces more negative side effects than the office task environment. Adaptation did not occur from day to day throughout the four testing sessions. The incidence and severity of negative side effects increased at a constant rate throughout the 30 minute immersive VE sessions, but did not show any significant changes from day to day. No evidence was found for a predictor that would foretell who might be susceptible to motion sickness in VEs.

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

INTRODUCTION

Users of virtual environments (VEs) are no longer limited to researchers in closed laboratories. The general public is using VE systems in ever expanding numbers, and along with this increased use is the growing numbers of users experiencing motion sick-like side effects (Greenfield, 1994; Van, 1995). Researchers are in the earliest stages of understanding VE side effects and their underlying mechanisms. Thus far investigations have been limited to cursory examinations on the general occurrence of side effects. The need to conduct more detailed research on the topic is self evident (Biocca, 1992; Dizio and Lackner, 1992; Kennedy and Lilienthal, 1994; Singer and Witmer, 1995). Measuring, predicting, and determining the exact causes of side effects are key areas of needed research. The training effectiveness, entertainment value, and very safety of VEs relies on systems that are free of negative side effects.

While anecdotal evidence for negative side effects is highest in immersive VEs, many other factors than simply having a visual scene in an HMD appear to contribute to the experience of negative side effects in VEs (Regan, 1995). The occurrence of motion sickness-like symptoms in VEs is a complex phenomenon that will require much research to understand completely. Not only are there numerous factors suspected of causing side effects in VEs, there are many symptoms that have been observed as well. Headaches, dizziness, vertigo, nausea, eyestrain, sweating, and in rare cases, vomiting can occur. It is the complex nature of both the causes and effects of motion sickness in VEs that creates problems for the researcher attempting to study the issue.

Attempts to measure VE side effects have been limited to questionnaire based subjective reports. These assessments are satisfactory for showing what systems induce side effects, but are highly limited in their ability to provide empirical evidence. A method for predicting which users may be susceptible to side effects in VEs would be invaluable, but may prove to be an elusive goal. Efforts to find suitable predictors have thus far met with little success. Determining what factors, and the extent that they cause side effects in VEs will be of great benefit to designers and users of VEs. Formal experiments need to be conducted to definitively determine the level of involvement various factors have in inducing sickness like symptoms in VEs. At this time there is little more than anecdotal evidence and “insight” into the true causes of side effects.

The research described here hopes to advance the efforts in understanding the occurrence of negative VE side effects in several ways: 1) by developing and validating a new measure for the incidence and severity of negative side effects experienced in immersive VEs; 2) analyzing the impact of head-tracking on the incidence and severity of negative side effects from immersion into VEs; and 3) assessing the effectiveness of potential predictors on the incidence of negative side effects in users. Secondary analyses will examine any change in side effects over time (both within and between sessions) and possible changes in performance due to side effects experienced. Additionally, the two VEs used in the experiment will be compared for levels of negative side effects induced.

Virtual Environment Systems

Before discussing the phenomenon of side effects in VEs, it is necessary to define what exactly is meant when using the expression VEs. There are different meanings depending on the technologies that compose the VE systems. There are three general types of VEs: desktop, augmented, and immersive.

Desktop VEs usually involve three dimensional imaging by a display, often through the use of special glasses. Augmented VEs involve altering a real environment with overlayed graphics or displays produced by a VE rendering system. The third category, immersive VEs, entails artificially created three-dimensional environments through the use of graphics software that

engulfs the users sensory systems. This should not be confused with teleoperation which some researchers label immersive virtual reality (Held and Durlach, 1992; Sheridan, 1992). The reality in teleoperation consists of real remote locations being transmitted visually to a head-mounted or other display. The environments presented to the subjects in this research were completely artificially made by a graphics software package.

At this time, all practical applications of immersive VEs are limited to the vision and touch senses, with tactile information generally being conveyed through a standard 3D input device. The VE system used in this research consisted of a user in a helmet-mounted display (HMD) with inputs to the system motivated through a 3D space mouse input device. Figure 1 shows the HMD used in this study. Figure 2 shows the 3D space mouse.

Figure 1. The Virtual Research Systems, Inc. VR4 HMD.

Figure 2. The Logitech Magellan 3D space mouse.

Motion Sickness Theory

Side effects from immersion into VEs closely resemble those of pure motion sickness. A review of the basic principles of motion sickness must be completed before looking at VEs specifically. Side effects experienced in VEs is so new that only a few articles directly addressing the subject can be found. Despite this paucity of research, an effort was made to keep the focus of the literature review on VE based sources; however, basic motion sickness principles and the contribution of simulator sickness research is briefly covered to provide background information.

Motion sickness has likely been around as long as people have been in motion. Sea sickness, air sickness, car sickness, space sickness, and simulator sickness are all forms of motion sickness that have been well documented. The VE version of motion sickness is only the latest incarnation of this old nemesis. Several theories on the basic physiological bases for motion sickness have been presented to the scientific community. Among these the concept of sensory conflict stands above the rest as the "accepted" theory of motion sickness. Sensory conflict, however, remains far from an accepted absolute truth. A review of various theories on the causes of motion sickness is presented below.

The nature of the phenomenon of motion sickness is defined by Reason and Brand (1975) as a condition characterized by pallor, sweating, nausea and vomiting that results from the perception of real or apparent motion. Early theorists tried to attribute these symptoms to internal bodily mechanisms being disrupted by motion. Reason and Brand (1975) label these the blood and guts theories. Without any solid evidence to support the blood and guts ideas, these conjectures were quickly replaced by more reasonable vestibular theories in the late 1800's.

Scientists even then pondered on the possibility of conflict involving the vestibular system causing sickness, but these ideas were not refined until after W.W.II. A possible "sensory" conflict remained just part of the basis of vestibular theories. The experience of W.W.II combat fighter pilots provided solid evidence for a vestibular cause of motion sickness. Convinced that disruption of the vestibular system was at least a part of the cause for motion sickness, the debate on the specifics ensued. The two main theories that developed were the overstimulation theory and the sensory conflict theory.

Overstimulation.

The overstimulation theory states that sickness is caused by overstimulation of the vestibular system from the environment. Specifically, overstimulation of either the otoliths or the semi-circular canals are responsible for motion sickness (Reason and Brand, 1975; Regan, 1995). However, supporting evidence for this theory is controversial at best. Scientists have not pinpointed either the otoliths or the semi-circular canals as the primary causative factor in motion sickness.

The main problem with the overstimulation theory is explaining the occurrence of motion sickness symptoms in cases where the motion is purely perceptual, or when symptoms are experienced upon returning to a stationary position after motion has ceased. The after-motion sickness effect is explained away by residual effects occurring as a result of overstimulating the vestibular system. As for perceptual motion sickness, proponents for the overstimulation theory try to separate actual motion sickness and perceptual motion sickness into two distinct phenomena. However, as many have shown, the symptoms for the two are nearly identical. A new theory evolved which integrated the visual component of spatial orientation with the vestibular ideas, called sensory conflict theory.

Sensory Conflict.

The sensory conflict theory (sensory rearrangement, sensory mismatch, perceptual conflict, cue conflict, or stimulus rearrangement) has developed as the main theory for motion sickness accepted by most scientists today (Regan, 1995; Biocca, 1992; Dizio and Lackner, 1992; Pausch, 1992). The most detailed review of the sensory conflict theory was conducted by Reason and Brand (1975).

The sensory conflict theory is based on our bodies ability to locate itself in space. Many sensory systems are capable of providing these cues. Vision is the most salient system, and arguably the most important. However, vision does not act alone. The hearing, kinesthetic, proprioceptive, and vestibular systems are all used to give information on the bodies location in space.

Sound localization can be used to provide relative positioning of the body to other objects in space. The kinesthetic sense provides information on the movements of the limbs through space. The proprioceptive senses provides information on where the various parts of the body are located in relation to each other. The kinesthetic receptors comprise a subsystem to the proprioceptive system that are concentrated in the joints of the limbs. They give information on the location and movement of the limbs. The vestibular system provides information on changing angular position and motion on the body, particularly the head. The sense of balance is determined by the vestibular system.

Ideally all these systems are sending congruent signals to the brain to determine the bodies position relative to other objects in space. The premise of the sensory conflict theory is that some subset of these sensory systems are not sending harmonious information to the brain. The resulting disharmony leads to a motion sickness response by the body. The senses focused on by most proponents of the sensory conflict theory are the vision and vestibular systems.

A look at what can happen to a pilot in air combat serves as an example of sensory conflict. A pilot in a real dog fight experiences a multitude of changing velocities and positions. Both the visual and vestibular signals sent to the brain are rapidly changing. In a simulated dogfight, the user experiences nearly all the visual information while experiencing none of the vestibular input. The body through experience, or just inherently, knows to expect vestibular stimulation when the visual scene is like that of a dogfight. Somewhere in the brain a conflict is realized and negative side effects resembling motion sickness begin to occur in the body.

The sensory conflict theory was the first to incorporate the visual sense into its explanation for motion sickness. It is the foremost theory for visually induced motion sickness in VEs and fixed base simulators where all motion is perceptual and not actual. However, other ideas about the cause of visually induced motion sickness exist. Predominant among these is the lag, or position-tracking error theory.

Tracking Error.

Hettinger and Riccio (1992) state that visually induced motion sickness can occur in two different situations. In the first, perceivable and excessive lags in the display's visual field from head motion in a HMD initiate visually induced motion sickness. They believe this problem will be eliminated as the speed of the VE controlling hardware and software improves. In the second situation, a representation of self-motion produces an experience of self-motion without the corresponding physical displacement. The second case highlights what was just described as a sensory conflict. The visual self-motion sensation is in conflict with the lack of corresponding vestibular information on body displacement. For this second case, in contrast to the first, negative side effects may actually increase in severity and frequency as the simulation of visual

motion in VEs improves. This would result from an even more distinct conflict between a more faithfully presented visual scene and a lack of vestibular cues.

While Hettinger and Riccio (1992) state that lag induced sickness will disappear with advances in VE technology, others expand on the lag, or tracking error theory believing it can still explain sickness like symptoms. Position-tracking is the ability of the VE system to update movement in the graphical world. There are three types of errors that can develop while position-tracking occurs: the first is conflicts between where body objects (hands, arms, head) are located graphically and where they are in actual space, the second is lags in scene update rate for graphic non-body object positions, and the third is jitter or oscillation of the visual scene (Biocca, 1992).

The first error type is another form of sensory conflict. In this case the conflict is between where the visual system perceives the body and the where the proprioceptive system indicates the actual position of the body parts. The third error type is one where advancements in VE technology should realistically eliminate any mitigation of negative side effects due to jitter or oscillation in the visual scene. The second error type is the one described by most scientists when discussing the lag theory.

Scene update rate, the basis of the second tracking error type, is the speed that computer systems can update the graphical image. The error is most obvious in older VE systems where users can watch the scene jump in discrete frames from a very slow system update rate. Prior to VE studies simulator research showed the same result, with visual lag problems contributing significantly to decreased operator performance and increased discomfort (Frank, Casali, and Wierwille, 1988). Visual lag was shown to contribute significantly more than motion lag in generating lower performance and greater discomfort in simulator use (Frank et al., 1988).

The scene update rate problem has lessened significantly in newer systems. Scene update in most VEs today is not perceived by users, the visual scene appears to have smooth continual movements. However, some advocates for the position-tracking theory continue to attribute causation to the inherent lag in all systems, no matter how technologically sophisticated VEs become.

The latest tangent states that users are suffering negative side effects from physically sensing scene updates without actually perceiving them. Some theorists argue that the scene update rate, even at very fast rates where the perceptual scene movement is completely smooth, are being captured by the visual sensory system and relayed to the inner brain (Bates, 1995). Somewhere in the brain this information triggers a motion sickness response in certain hyper-sensitive users. This is not a widely accepted hypothesis.

Some researchers go to the opposite extreme, postulating that as VE technology advances to a level where extremely fast scene update rates are possible, there will be no sickness in VEs whatsoever. Most scientists do no agree with this statement or that scene update rate is the sole cause for motion sickness in VEs. For most researchers, a rational middle ground is accepted. Scene update rate is viewed as one factor among many that contribute to the experience of side effects in immersive VEs, with much research and technological advances needed before definitive statements can be made.

Evolutionary

Each of the theories listed above describe the mechanisms behind why the body develops motion sickness; however, they all stop short in explaining why the brain initiates sickness as a response to the conflicting spatial information it receives. One theory attempts to tie in the sickness response through evolutionary changes in humans. Treisman (1977) suggested that motion sickness is a carryover from a body survival mechanism to the ingestion of poison. Visual and

vestibular systems may become in conflict with each other due to ingested poison, particularly one affecting the neurological functioning of the two systems. The body reacts by trying to expel the offending poison through vomiting. Other negative effects remind the individual not to ingest the item that contained the poison again. It is an interesting theory that provides some stimulating thinking on the topic, but remains little more than oft-cited speculation.

Whether a leftover evolutionary poison defense mechanism or not, clearly there is more to side effects experienced in VEs than can be explained by sensory conflict theory or any other single theory. The very nature of immersion into a 3D environment, the lack of bodily cues in the environment, the artificiality of the environments, and the equipment itself all contribute to the side effects experienced by VE users. The exact causes and reasons for the existence of motion sickness remain somewhat of a mystery. However, motion sickness and its corresponding theories do serve as a solid backbone of explanation for this complex phenomenon.

Measuring Side Effects in VEs

Before going into detail on the evidence for side effects specifically in VEs, some of the various measures that have been used to document their existence will be explained. There are many options for investigating the health conditions of participants before, during, and after an experience in a simulated environment. Casali and Frank (1988) reviewed a large contingent of measures used in simulator sickness research. This review will focus on measures that have been used to assess side effects in VEs, with some discussion of those taken from the simulator sickness field. The measures that have been used for VEs are based on subjective report, with a few attempts at measuring balance. The first subjective measure to be discussed will be a comprehensive questionnaire, the other is a simple 6-point rating scale. The present research endeavor will continue the effort to capture side effects with subjective report by utilizing the psychophysiological measurement method of magnitude estimation. That measurement process will also be introduced in this section.

There is substantial debate on the appropriateness of subjective measures for such a complex phenomenon. In addition to the subjective measures, more objective measurement methods will be discussed. Physiological measures often have been used in simulator sickness studies, but none so far have been tried in VE experiments. Other measures based on performance can provide insight into the bodies physical condition. One such measure is postural stability, which has proven in some studies to provide information on the condition of participants prior to and after experimental sessions. This particular performance measure will also be expanded on.

Simulator Sickness Questionnaire.

The most popular measure for both simulator sickness and side effects experienced in VEs is a questionnaire adapted from aircraft simulator research, the simulator sickness questionnaire (SSQ) (Kennedy, Lane, Berbaum, and Lilienthal, 1993b). This is a measure given pre- and post-session that provides an overview of the side effects experienced throughout the VE session. It contributes a good summary of information on the symptoms experienced and approximate severity levels. In addition, graphical profiles based on categories of symptoms can be created which allow relative comparisons to be made between systems.

The SSQ asks for ratings on three main cluster categories of side effects: oculomotor (eye strain, difficulty focusing, blurred vision, headache), disorientation (dizziness, vertigo), and nausea (nausea, stomach awareness, increased salivation, burping). A total severity sickness score is computed based on the three subscales (curiously most researchers do not report the total severity score). Research has shown the SSQ to be effective as a post-session analysis tool of simulator sickness symptoms. The SSQ has achieved similar success in measuring the symptoms of side effects experienced in VEs.

The typical result of an experiment using the SSQ is to develop a symptom profile graph which is used to "diagnose" the system in question. Figure 2 shows a symptom profile for four different environments evaluated by Kennedy, Jones, Lilienthal, and Harm (1993a). In Figure 2, the Pre-flight Adaptation Trainer by NASA (PAT NASA) is a VE based space simulator. The space sick category is actual space sickness. The spinning chair is a test used by NASA to pretest for motion sickness. The Navy fleet is a composite profile for several simulators used by the US Navy.

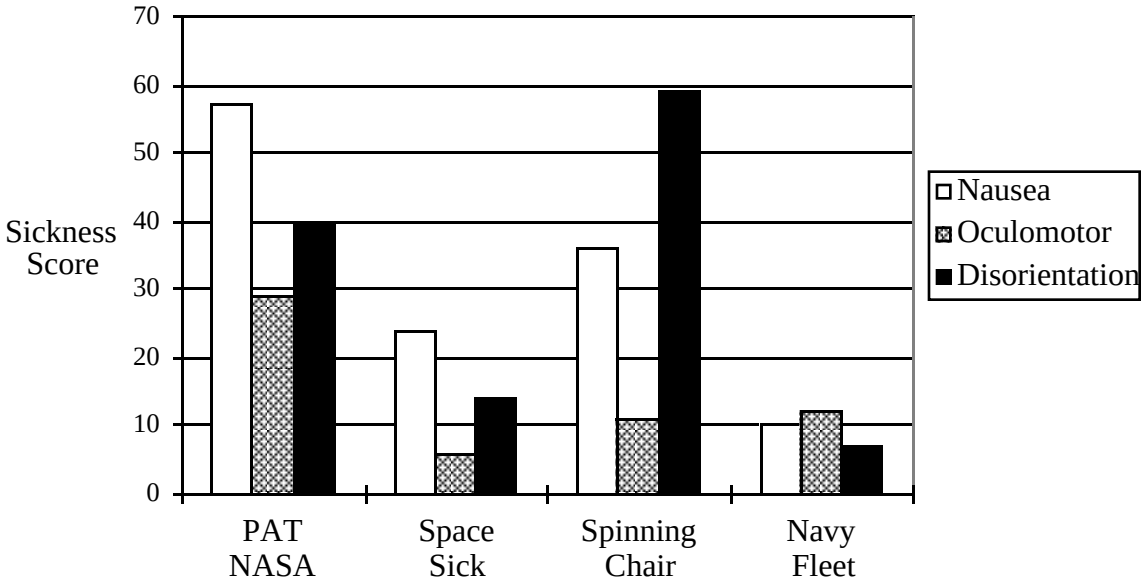

Figure 3. Symptom profiles for four environments, adapted from Kennedy et al. (1993a).

The diagnosis for the system is based on the pattern of symptoms that show up in the symptom profiles. For example, a high oculomotor sickness score would indicate a visual problem with the simulator. High disorientation indicates a problem with the system disorientating users. The same with the nausea subscale. Further insight can be obtained if one particular symptom in a subscale is the dominant contributor to that subscale score. Symptom profiles and their various diagnoses can then be used to compare systems against one another.

Appendix A shows the adaptation of the SSQ used in this study, the Virtual Environment Side Effects Questionnaire (VESEQ). The questionnaire was revised for this study to eliminate references to military applications and other non-related issues. Parts of the introductory portion of the SSQ have been incorporated into a pre-experimental questionnaire on general motion sickness history, described in the Method section and found in Appendix B.

The SSQ has proven to be useful, however, there are a few serious limitations. The SSQ cannot be administered unobtrusively during a session, and therefore cannot provide accurate time information on when the side effects occurred (when they started, peak occurrence of side effects, when they decreased). It would be highly impractical to give a participant a questionnaire every five minutes of a session to determine sickness over a period of time. Such an attempt would be highly disruptive, tedious, and time consuming for both the participants and the experimenter.

The SSQ also does not give entirely accurate information on differences in magnitude between side effects. The SSQ scores are computed based on ordinal information collected from the subject on whether they thought certain symptoms were non-existent, slight, moderate, or severe. These responses are then converted to an interval scale using mathematical procedures to obtain scales of similar variability (Kennedy, Lane, Berbaum, and Lilienthal, 1993). This limitation prevents a serious investigation into all the factors involved in causing side effects in VEs. Kennedy, Berbaum, and Lilienthal (1992a) themselves state that the study of symptoms may provide "a clue" or "insight" into identifying causes, but they caution against conclusions drawn from the SSQ symptom profiles alone.

The SSQ also is limited by defining motion sickness as 16 symptoms that can appear when a subject experiences side effects. Kennedy and his various co-authors often describe motion sickness symptoms as being polysymptomatic, being too numerous and varied to completely describe. The SSQ itself asks the subjects to rate far more symptoms than are used to calculate sickness scores. Calculating the sickness scores with only certain symptoms limits the measures ability to capture the whole sickness phenomenon that may be occurring as a result of side effects.

A more sensitive, rigorous, efficient, encompassing, and flexible measure is needed to investigate causes experimentally instead of gaining "insight" into causes. One attempt at such a measure came from the efforts of Regan (1993) and Regan and Price (1994).

Malaise Scale.

The measure developed by Regan (1993) and Regan and Price (1994) attempts to capture the complex phenomenon of side effects with what is termed the Malaise Scale (MS). This scale is a simple six-point system that uses one symptom, nausea, to categorize side effects experienced in VEs.

1 = No symptoms
2 = Any symptoms, but no nausea
3 = Mild nausea
4 = Moderate nausea
5 = Severe nausea
6 = Being sick

Regan (1993) uses this simplified measure to capture successive ratings of side effects experienced over time. The simplicity of the MS allows measurements to be made quickly during immersion sessions in a VE. Regan and Price (1994) used the scale to obtain a rating of malaise every five minutes.

The MS developed by Regan (1993) and Regan and Price (1994), while providing the ability to measure side effects over time, has its own major limitations. The MS simplifies the syndrome of side effects in VEs far too much. The side effects that develop in VEs are vastly more varied and complex than merely nausea. This limited scope of VE side effects makes the MS even more insensitive to the full syndrome of side effects in VEs than the SSQ. Regan argues that nausea is the most common symptom of motion sickness. That may or may not be true, however, nausea does not define sickness in VEs.

As with the SSQ, the MS is limited to pseudo-interval comparisons between side effects experienced. The six-point rating scale cannot easily be converted to a meaningful continuum. These serious limitations remove the MS and SSQ from consideration in a systematic investigation into the causes of side effects in VEs and the development of an empirical model of negative side effects.

Physiological Measures

Physiological measures have shown to vary considerably in their success at capturing differing types of motion sickness (Casali and Frank, 1988). The measures that have shown success tend to be specific for the task, proving successful for some scenarios while failing in others. Physiological measures are like the MS, only able to capture information on the exact body function that they are measuring. At this time it does not appear that one body response (e.g., heart-rate, skin conductance level, pupil dilation) is common to all motion sickness occurrences. Physiological measures, such as heart-rate, can vary considerably among individuals depending on exterior circumstances. In addition, different simulated environments may affect physiological parameters of the body in a variety of ways. A physiological measure would have to fully capture the phenomenon, have a consistent response for all individuals, and respond similarly for a variety of task environments to be effective.

Even if a physiological measure proves successful in the lab, the cost of implementing such a measurement tool for the general population could be quite high compared to simpler subjective reports. A physiological measure may play a useful role as a secondary measure of side effects experienced in VEs, and may yet prove to be useful as a primary measure, but will not be considered in this research.

Postural Stability

Any number of cognitive or physical tests can potentially be used in a pre/post-test comparison. Even more so than physiological measures, attempts at performance measures for motion sickness have come up short (Kolasinski, 1995). A commonly used performance measure in simulator sickness research is postural instability.

Postural stability is maintained through the same mechanisms that were described previously in the sensory conflict section: somatosensory, vestibular, and visual (Boff and Lincoln, 1988). The postural system is theorized to adapt to abnormal visual and vestibular cues from a simulated environment. Upon return to actual surroundings, a participant's postural system needs to re-adapt and the user exhibits unsteadiness, or "sea legs," until normal system functioning returns. Questionnaires cannot truly measure vestibular ataxia, or postural instability, physical tests must be used.

Various methods have been developed that revolve around standing and/or walking for set periods of time (Boff and Lincoln, 1988). A vestibular ataxia test typically used in simulator research has participants standing on one leg for a certain amount of time, and then the other leg, with the experimenter observing for imbalances. This test is most commonly referred to as the stand on preferred leg, stand on non-preferred leg (SOPL/ SONPL) test. A variation of this test was used in the current work to assess pre- and post-test postural stability.

Similar to the problems of the other measures discussed, the scope of symptoms involved in motion sickness far exceeds such a specific test. This would likely be true for any performance measure.

Magnitude Estimation

Magnitude estimation is the new measurement method attempted in this study for capturing negative side effect information associated with motion sickness. Psychophysics, in which magnitude estimation is a measurement tool, is the scientific study of a relationship between a stimulus and a subsequent sensation (Gescheider, 1985). In the experimental setting used, the stimulus is the VE and the sensation is the experience of negative side effects. While many sensations measured with magnitude estimation are more purely psychological than the experience

of side effects from immersion, the subjective report of side effects fits directly with measurement by magnitude estimation.

Magnitude estimation is a powerful and useful measure with many advantages as a measurement tool for side effects experienced from immersion into VEs. Efficient, with the ability to acquire large amounts of data quickly, magnitude estimation is ideal for experiments with large number of stimuli (Gescheider, 1985). The many varied factors that contribute to side effects experienced in VEs are the weakness of many of the measures discussed previously. The simplicity of the method allows it to be used in a wide range of experimental settings. VEs by their nature are wide ranging in tasks and design, with no set parameters between systems. Perhaps its most alluring trait, magnitude estimation allows the construction of a ratio scale of side effects experienced that can be compared from system to system with meaningful insight. The ratio scale allows comparisons such as system A yields twice the level of side effects experienced in users as system B.

Gescheider (1985) cites a variety of experiments with both psychological and physical parameters that successfully employed magnitude estimation. Loudness, brightness, and other simple stimulus-sensation responses were the origin of the method. Other continuums include warmth, cold, taste, vocal effort, angular acceleration, duration, muscle force, hardness, vibration, and seriousness of crimes among many others. Magnitude estimation has also been used successfully in VE research to capture the level of presence perceived by the user (Snow, 1996). The magnitude estimation technique has proven highly adaptable in its ability to measure stimulus - sensation situations.

With properly defined parameters, magnitude estimation should provide side effect information as broad as the SSQ with the flexibility and rapid ease of administration as the MS. The measure is more rigorous than both, providing ratio scale data. The measure would be ideal in future investigations into the causes of side effects in VEs, possibly leading to an empirical model. The sensitivity of the measure, combined with the ratio scale created will allow researchers to make valid, informative and detailed comparisons between VEs. No longer will comparisons be limited to relative levels of sickness based on created interval scale data. Ultimately, the successful implementation of magnitude estimation as part of the VE will allow the side effect measurements to be taken during a session in a VE without any interruption to immersion.

Evidence for Side Effects in VEs

Now that the various methods for measuring sickness in VEs have been discussed, experimental evidence for this phenomenon can be presented. Some level of participants reporting side effects appears in all VE studies when users are questioned on their presence. The studies cited below show that side effects occur over a wide range of tasks in a variety of VE systems. The measurement method of side effects varies between studies, but primarily self-report from the participant is used in one form or another. Only articles with formally presented data on side effects in VEs are presented. There is a large body of simulator sickness research (see Pausch, Crea, and Conway, 1992; and Kolasinski, 1995 for comprehensive literature reviews); however, the intent in this section is to show evidence for negative side effects in VE systems.

Regan (1993) and Regan and Price (1994) are among the few who have directly investigated side effects produced by immersion into VEs. The goal of the study they reported in these two articles was to document the frequency and severity of side effects of immersion in a particular VE. The participants in this study navigated and interacted with a series of rooms and objects within the rooms. Participants were directed to explore the environment, without specific task by task directions. Among the interactions possible, participants could play chess and operate a television remote control.

The main measurement method employed was the MS, developed for their experiment. Participants gave a rating on the MS every 5 minutes during a 20 minute session. In addition to the MS, Regan (1993) used the SSQ before and after VE immersion. A summary of the SSQ results was presented to show that nausea was the most significant problem with their VE system. No other details of the SSQ results were reported. Out of 146 participants (including male and female civilians, military personnel, and firefighters), 33% reported symptoms without nausea, 21% reported mild nausea, 5% reported moderate nausea, and 2% reported severe nausea. Some participants were compelled to withdraw from the experiment because of side effects experienced. 39% reported no symptoms experienced throughout the experiment. For users who did experience symptoms, the onset and severity increased as more time was spent immersed in the VE. Some symptoms continued to be present up to 10 minutes after the session, at which time testing ceased. Figure 4 shows the progression of symptoms throughout the experiment.

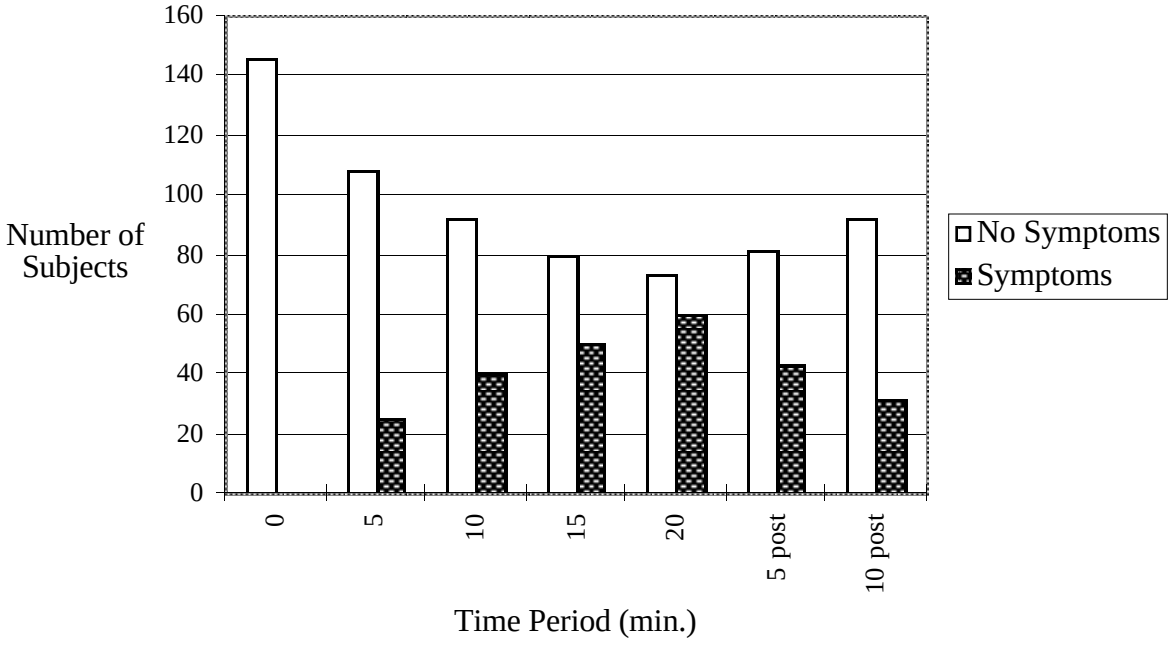

Figure 4. Progression of symptoms experienced during immersion in VEs, adapted from Regan and Price (1994).

Lampton, Kolasinski, Knerr, Bliss, Bailey, and Witmer (1994b) conducted a set of studies that directly investigated side effects from immersion into VEs. Four separate experiments were conducted to gather information on both side effects and aftereffects. The four experiments comprised a wide variety of tasks, environments, and two different VE systems. The SSQ was used to measure the incidence of symptoms experienced. In the first experiment, the Virtual Environment Performance Assessment Battery (VEPAB) tasks developed by Lampton, Knerr, Goldberg, Bliss, Moshell, and Blau (1994a) were used to examine a number of factors, including side effects, over a two day period. The second experiment extended the VEPAB sessions to six days. In the third experiment, subjects rehearsed route navigation in a virtual building. Experiment four also tested acquisition of route knowledge in the same virtual building. Experiments one, two, and four used HMDs with head-tracking, experiment three used a Fakespace Boom display. Head movements with boom displays are done by moving the display with the users hands, as opposed to tracking helmet movements with HMDs. Figure 5 shows a user with a Fakespace Boom display.

Figure 5. A user with a Fakespace Boom display.

The results of the SSQ sickness scores for the four experiments are shown in Figure 6. The four experiments had similar results, despite the difference in task environments and display devices.

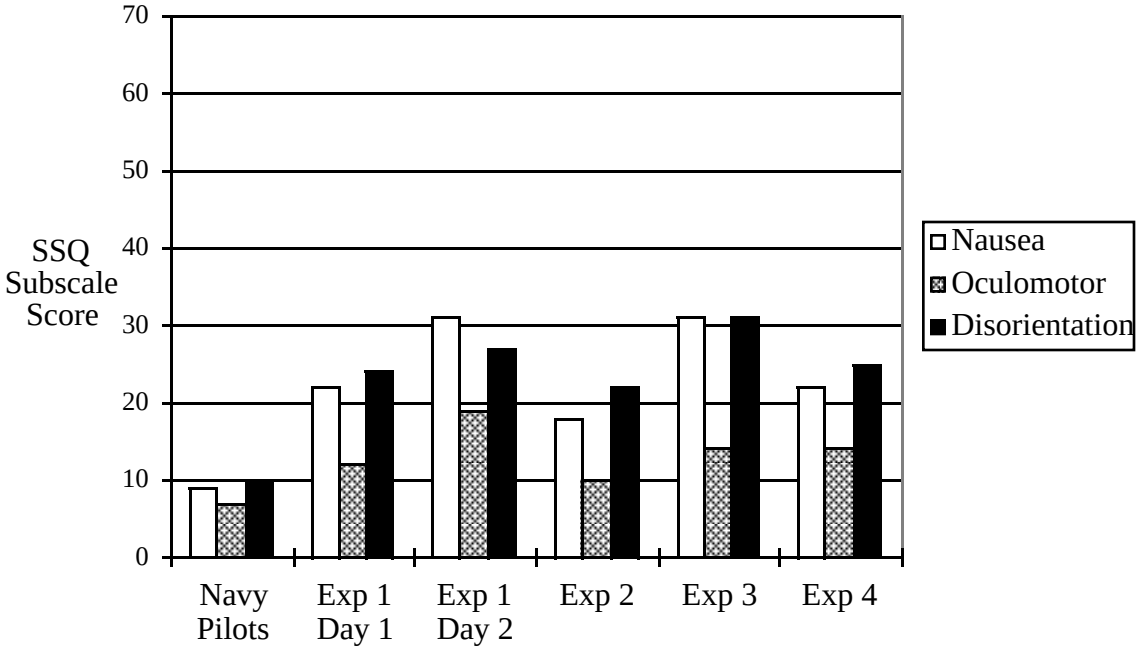

Figure 6. SSQ results for the four experiments conducted by Lampton et al. (1994b) and the US Navy pilots tested by Kennedy et al. (1993b).

The SSQ scores across the experiments are lower than some other reports (see Figure 3). However, they are significantly higher than those reported by Kennedy et al. (1993b) for the US Navy pilots used when devising the SSQ. Kennedy et al. (1993b) did not present symptom

profiles in their article, Lampton et al. (1994a) constructed the profiles from the scores reported for pilots by Kennedy et al. (1993b). In the four experiments 16 people (out of 129 participants, mostly college students) dropped out of the study due to motion sickness symptoms. Most of those who dropped out did so within the first 10 minutes of the session. Details on the other dropouts were not reported.

Several studies while researching other aspects of VEs have found incidents of side effects from immersion. Bailey and Witmer (1994) while conducting experiments on learning and transfer of spatial knowledge in VEs observed that most of their participants reported symptoms of sickness following a building walkthrough task. They did anticipate side effects before running the study and chose to administer the SSQ. The results showed some mild to severe symptoms developing after short periods of time in the VE. 16% of participants could not complete the experiment altogether.

In addition to examining incidence of side effects, Bailey and Witmer (1994) showed the experience of side effects can have negative impact on several aspects of the overall VE experience. They first compared the sense of presence with the experience of side effects. They found that the experience of side effects greatly decreased the sense of presence. A second comparison was made between performance and the experience of side effects. As with presence, the experience of side effects worsened navigation performance (wrong turns and traversal time), even when those side effects were not severe.

Slater and Usoh (1993a), also studying presence, informally asked participants how they felt after exiting a VE. The VE tasks included navigating a room, stacking blocks, dodging flying objects, dropping objects over a precipice, and observing an inverted room (floor switched with ceiling). Slater and Usoh (1993a) did not assess side effects experienced with any method described previously. They asked participants how they felt, checking one response from the following list: fine, excited, hot, nausea, eye strain, headache, confusion, or reality check. 85% of the responses were "other than fine".

Singer, Witmer, and Bailey (1994), in reporting more research results on presence, cite several of their studies where participants experienced side effects. The rate at which side effects were experienced was not given; however, correlation's between presence and side effects were reported. Singer et al. (1994) used basic task performance and building-interior route learning for their experimental scenarios.

Lampton et al. (1994a) developed a set of task environments to study VE systems, the VEPAB mentioned previously. While experimentally validating these standardized tasks, they discovered that a majority of their subjects were experiencing at least slight side effects. The SSQ was used to measure sickness, however, scores were not reported. The authors did mention that a third of the subjects reported moderate levels of symptoms. Eye strain was the most frequently reported symptom. Unfortunately, they did not expand their analysis of side effects in this article. This oversight occurred despite an earlier statement revealing their concern for side effects experienced by users in immersive VEs, "For practical applications, even mild effects may diminish training effectiveness... data for immersion systems are lacking."

In numerous papers Kennedy and others have transferred their knowledge of simulator sickness to the side effects experienced in VEs (Kennedy, Drexler, and Berbaum, 1994; Kennedy and Lilienthal, 1994; Kennedy et al., 1993a; Kennedy et al., 1993b; Kennedy et al., 1992a; Kennedy, Lane, Lilienthal, Berbaum, and Hettinger, 1992b). These papers bring up many concepts, but the data is generally the same: various VE systems are tested with the SSQ yielding symptom profiles of one magnitude or another. In nearly all scenarios notable side effects are found.

Symptom profiles from four systems studied by Kennedy et al. (1994) are presented in Figure 7. Each of the systems shown in Figure 7 utilizes an immersive HMD. The sickness scores presented in Figure 7 are much higher than those reported for systems without HMDs, (see the navy fleet sickness profile in Figure 3). Figure 7 may show different symptom profiles, but the authors make only limited conclusions about differences between each system. For example, the ARI system is said to have problems with vision. The authors themselves caution against attributing causation to certain aspects of the systems based on the SSQ results.

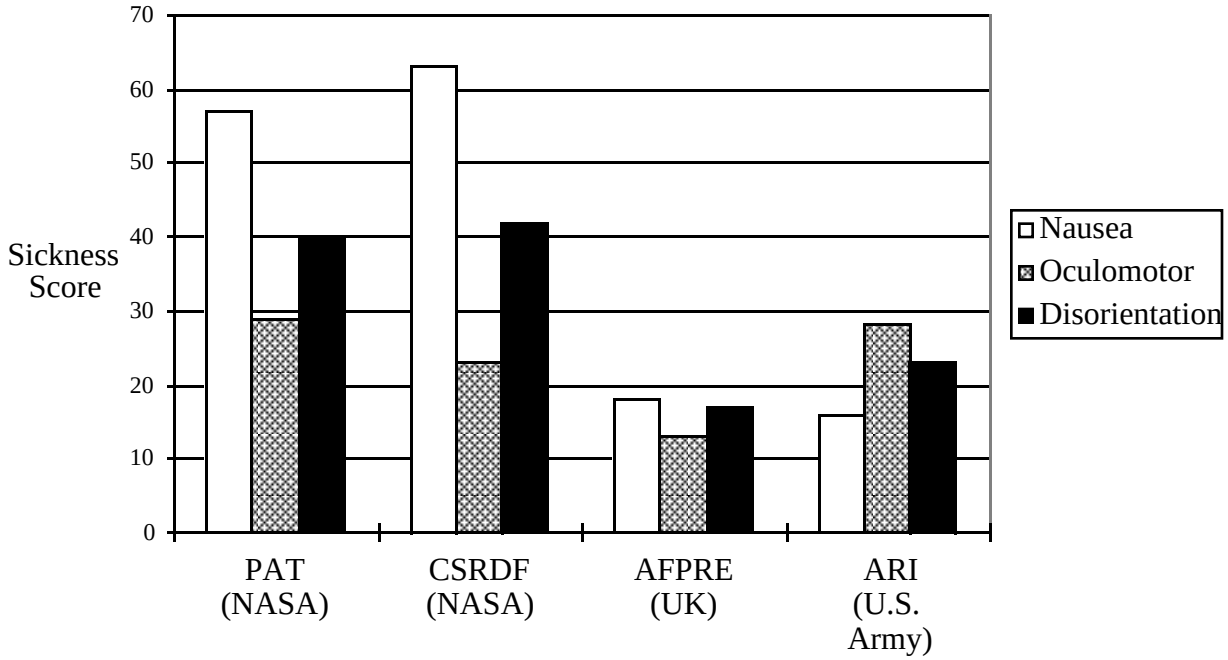

Figure 7. SSQ sickness scores for four systems using HMDs, adapted from Kennedy et al. (1994).

While the information has come from several different research directions, concrete empirical evidence exists that at least some, often most, participants in VE experiments experience some negative side effects. The exact nature of these side effects varies widely from subject to subject and system to system. What these side effects are and there possible causes need to be looked at further.

Symptoms and Causes of Side Effects

In the studies cited above there have been a wide variety of side effects reported by participants in both VE and simulator studies. The SSQ was specifically designed for simulator sickness; however, the symptoms for simulator sickness and the side effects in VEs are very similar. Along with the symptoms measured by the SSQ mentioned previously, other symptoms that may be observed include, but are not limited to: abnormal appetite, boredom, confusion, difficulty concentrating, drowsiness, faintness, fatigue, fullness of head, general discomfort, heavy breathing, mental depression, postural instability, sweating, visual flashbacks, and in rare cases vomiting. Together all these symptoms indicate a complicated and unwanted problem that many researchers have found in a variety of VE settings (Bailey and Witmer, 1994; Regan, 1993; Regan and Price, 1994; Van, 1995; Singer and Witmer, 1995; Slater and Usoh, 1993a; 1993b; 1993c; and Slater, Usoh, and Steed, 1994).

As many symptoms that have been found to develop from side effects, there are at least as many causes. Visual motion, a virtual body, and display field of view are just a few in the long list of potential factors. While these visual components of the VE may play a large role in the onset of side effects, many other factors involving the equipment, task environment, and individual differences among users are expected to show impact in producing side effects experienced in immersive VEs. A summary list of factors that have been found or theorized to cause side effects in VEs are listed in Table 1, with individual differences listed on the right.

Table 1. Possible Factors Affecting Side Effects in VEs.

acceleration rate changes	individual differences
actual motion	age
concentration	anxiety
cue asynchrony	arousal
freezing simulation	experience
head movement	field independent/field dependent
incorrect accommodation	fitness
infinity optics displays	gender
leading instructions	heredity
off-axis viewing	introversion
optical flow	medication/drugs
oscillations	mental rotation ability
postural control activity	motion sickness history
presence	neuroticism
pseudo-coriolis effect (motion & head turned to side)	non-functional vestibular system
	spatial ability
standing	
vection (perception of self motion)	
visual motion	
visual distortion	
weight on head	

The list in Table 1 is presented to show that there is a wide body of research that needs to be done in the field of VE side effects. The one factor that was manipulated in this study was head-tracking; more specifically, head movements coupled with scene changes. Head-tracking in the VE system is what directly influences head movements, and indirectly affects factors related to scene movement. Several studies have reported head-tracking as a particularly suspect factor in causing sickness, including the pilot study for the current work (Kennedy and Lilienthal, 1994; Lampton et al., 1994a; Dizio and Lackner, 1992; and Hettinger and Riccio, 1992).

Individual Differences.

An important aspect of Table 1 is the large number of factors listed under individual differences. The different characteristics in people that cause difficulties in any controlled research are particularly difficult to contend with in motion sickness-like side effect studies. Kennedy et al. (1992a) state some users suffer immediate side effects in the "best" simulators (least likely to cause side effects) and other users never experience any symptoms in the "worst" simulators (most likely to cause side effects). The reasons behind these varied responses is the individual differences among all of us. Efforts have been made to determine if there are any systematic changes to sickness susceptibility from specific individual differences.

Pausch et al. (1992) reviewed the simulator sickness literature on whether individual factors affect a users susceptibility to side effects, including gender, experience, and many others. Several investigations offer supporting evidence for claims that some individual differences are highly significant to susceptibility. Many other researchers present refuting evidence. The conclusion Pausch and others reached is that the rapidly changing technology coupled with the wide variety of task environments makes the effects of individual differences highly task dependent and difficult to predict.

Two of the more commonly investigated individual differences that can be queried with simple questionnaire data are gender and experience. Gender has not shown to be significant in various experiments, despite anecdotal evidence to the contrary (Frank, Casali, and Wierwille, 1988). Experience has been shown to be related to simulator sickness, especially in aircraft simulators when studying pilots. No participant was expected to have experience in the exact, or even nearly exact, environment that was used in the current research. However, information was collected to examine any possible relationships between computer experience and gender among others.

Presence

Along with the specific factors that may contribute to side effects shown in Table 1, there are several general reasons for the onset of side effects. One argument, perhaps hope, exists that these side effects will all disappear as the technology advances and artificial virtual worlds become more representative of the real world (Biocca, 1992). Included is the idea that as the sense of presence in the virtual world (belief in the illusion) increases, the incidence of side effects will decrease. However, this idea is not in concordance with simulator research and some interesting studies on presence in VEs.

Kennedy et al. (1992a) state in a review of 30 years of simulator research that systems scoring the highest on realism also had the highest incidence of simulator sickness. VE research shows a wider variation with its conclusions. Singer and Witmer (1995) found that presence and side effects in immersive VEs have a negative relationship. Previously they concluded that presence and side effects in VEs were positively related (Witmer and Singer, 1994). Bailey and Witmer (1994) found that presence and side-effects of VE have a significant negative relationship. However, the authors admit that this result was unexpected. Bailey and Witmer (1994) also state that individuals experiencing side effects are likely focusing on the symptoms and not their sense of presence in the VE. Thus, conditions that should result in both presence and side effects of immersive VEs result in a decreased sense of presence as soon as side effects from VE begin. In general, the same conditions that lead to presence lead to side effects in an immersive VE; however, the two phenomena cannot co-exist (Slater and Usoh, 1993a).

Aftereffects

The most disturbing set of side effects of immersion reported are the aftereffects that some users have experienced. Aftereffects are more commonly reported in simulator sickness studies; however, aftereffects resulting from immersion into VEs cannot be ignored. Distorted vision, confusion, headaches, and distorted motor control have all been reported hours or even days after sessions in simulators (Kennedy et al., 1992a). Fortunately the occurrence of long term aftereffects have been limited. Ungs (1987) in a study on aftereffects from simulator use found less than 5% of the participants experiencing long-term aftereffects. Unfortunately, there have been no results have been reported on aftereffects specific to VEs.

Adaptation

Adaptation to VEs, and a subsequent decrease in side effects experienced, has been reported by most researchers who studied sickness symptoms over a period of several days. Pausch et al.

(1992), in their literature review of simulator sickness, report that adaptation to simulator sickness is a common and universally accepted fact among researchers. Dizio and Lackner (1992) state that adaptation can occur in minutes, or take hours, or even days. Adaptation to VEs can also cause short lived side effects to occur upon re-emergence in the real world.

Adaptation is also part of a theory of susceptibility by Biocca (1992). Biocca discusses the possibility that all users "suffer" motion sickness in VEs, but that some adapt almost instantaneously to the environment, thus experiencing no symptoms. The idea is extended by Parker and Harm (1992) who discuss training astronauts with mental rotation tasks before space flights. Astronauts who received the training adapted much quicker than those without, experiencing less space sickness than astronauts without training.

Predicting Side Effects

Gender

With a good idea of what the side effects are and their general causes, and some reasonable methods for measuring them, one would hope that a way for predicting who would be susceptible to side effects would be available. However, the few efforts made on predicting who will experience side effects in virtual, or simulated environments has thus far achieved limited and debatable success. Any individual difference in Table 1, and any not in Table 1, could potentially act as a predictor for motion sickness susceptibility. Pausch et al. (1992) reviewed a number of these individual differences and concluded that it was near impossible to generalize correlations between them and incidence of sickness symptoms beyond the immediate system being analyzed. Casali and Frank (1988), in a review of simulator sickness research measures and symptomatology, agree that prediction attempts have for the most part lacked success.

The one factor that is studied most frequently in the literature as being a possible indicator for higher motion sickness-like symptoms is gender (mainly for its ease in data collection). There is plenty of anecdotal evidence that females experience more motion sickness than males, but statistically significant results are not seen. This postulate has been debated continuously over the years with the only definitive conclusion being that the task environment under study should be tested to see if the gender difference exists..

Perceptual Style

Along with gender, perceptual style has been investigated for many years in an attempt to uncover a possible correlation with side effect incidence. In some studies, perceptual style has shown to have a significant relationship with aspects of simulator sickness (Barrett and Thornton, 1968). The results in other studies sometimes directly contradict this finding, or provide evidence that the relationship is exactly opposite that shown in earlier work. While it has not shown clear significance in much, if any, research, the potential for perceptual style to act as a predictor for sickness in VEs is notable and should be examined further (Frank, Casali, and Wierwille, 1988).

Perceptual style is the tendency to perceive oneself as being inside a simulated environment and its sensory cues (an inside-out perspective or field dependent), or being separated from a simulated environment and its sensory cues (an outside-in perspective or field independent). Barrett and Thornton (1968) found that field independent participants had symptoms that persisted significantly longer than field dependent subjects. They theorized that field independent participants are more susceptible to conflicting of cues between the visual and vestibular senses. Furthermore, field dependent individuals draw their cues from the scene and are less aware of their physical self outside the simulated environment and thus experienced less conflict, and less sickness symptoms.

As alluded to earlier, perceptual style research has yielded results that are far from harmonious in their conclusions. While reviewing literature on the subject, Frank (1986) showed that the Barrett and Thornton (1968) data could be re-analyzed to show no differences between the two groups. Frank, Casali, and Wierwille (1988) in a study on driving simulator sickness found no significant results for perceptual style. To add further confusion, Barrett and Frank in other research projects found the opposite situation to be true, field dependent participants experienced more sickness than field independent participants. Frank further argues that the results of the rod and frame test used to measure perceptual style are quite sensitive to aspects of its administration, particularly viewing distance. Different research results in part appear to result as a function of different testing methods other than the rod and frame test. When administered carefully, the rod and frame test, and subsequently perceptual style, may yet yield clues to discomfort and other side effects in simulated environments.

Mental Rotation

In the section on adaptation side effects, mental rotation training was described as helping astronauts adjust to space sickness that some flight crew experience during missions (Parker and Harm, 1992). Parker and Harm (1992) found that astronauts undergoing mental rotation training before missions experienced less space sickness than those without. They concluded their article by stating that mental rotation tests may be able to predict who will and who will not get sick in simulated environments. They theorize that users with high mental rotation ability will be more resistant to motion sickness symptoms in VEs. With some evidence presented that a relationship may exist between the two, further investigation needs to be made.

Mental rotation and other individual differences have indicated some potential as a predictor for motion sickness-like symptoms. However, true prediction of who is susceptible, and to what level severity of the symptoms might be is still out of reach at this time.

Pilot Study

To begin preliminary investigation of some of the principles discussed in the literature review, a pilot study was conducted with two main purposes: 1) to determine if a maze task with head-tracking would elicit acceptable levels of side effects, and 2) to determine if any sickness difference between males and females was present. In addition to finding the answers for these two questions, a host of other relevant information was obtained. The experiment and research results are described below.

Bussi (1995) designed a maze task VE for an experiment comparing cognitive theories of navigation. The main structure of the maze, shown in Figure 8, remains unchanged from the Bussi design. Participants start the maze placed in a "car" looking down an open hallway. Navigation through the maze begins on a white square and ends on a black square. The car can be seen on a square in Figure 8 (the square's color should be white, but came out dark in the picture transformation).

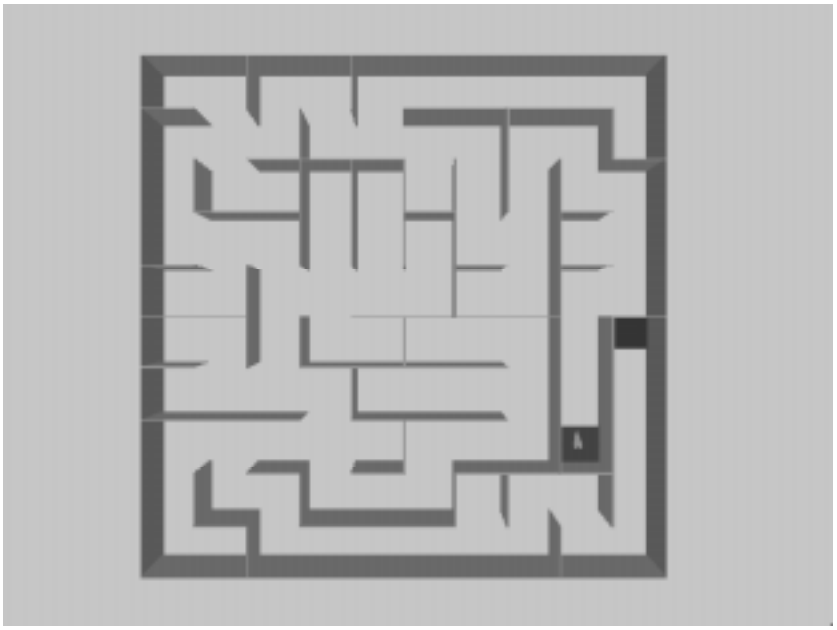

Figure 8. An overhead view of the maze (note: color has been removed for printing purposes).

While participants know they are in a car, only the front tip of the car can be seen, as shown in Figure 9. Figure 9 also shows the beginning of the maze, looking down the first corridor. The tip of the car can be seen in what appears in the VE as blue. The blue nose of the car is purposely angled so that the tip is wider than the sides so that participants always know which way the car is facing. In Figure 9 the starting block can be seen under the car. The walls are in the environment are brown and the horizon is a light blue.

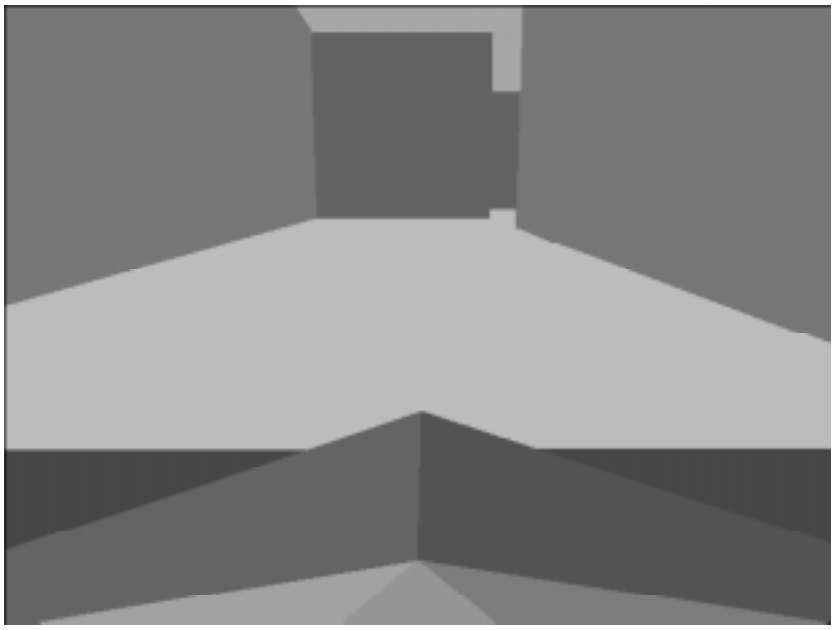

Figure 9. The beginning of the maze, with the tip of the car showing on the green starting block (note: color has been removed for printing purposes).

Underlying mechanisms in the maze environment were changed to allow for capture of time and error data. Time begins when the participant leaves the starting square and stops when the ending square is touched. Error data is collected in three ways: number of bumps into walls, number of wrong turns, and time in wrong paths.

Participants in the pilot study (four males and four females) were asked to complete three navigations of the maze from start to finish. The view displayed to subjects was that shown in Figure 9. The overhead map of Figure 8 was used for design purposes only. At the completion of the experiment (either finishing three maze trials, or dropping out), the participants completed an adaptation of the SSQ. Of the eight subjects starting the experiment, three dropped out due to side effects experienced. Figure 10 shows the symptom profile for the eight subjects. A symptom profile without the subjects that dropped out is shown in Figure 11.

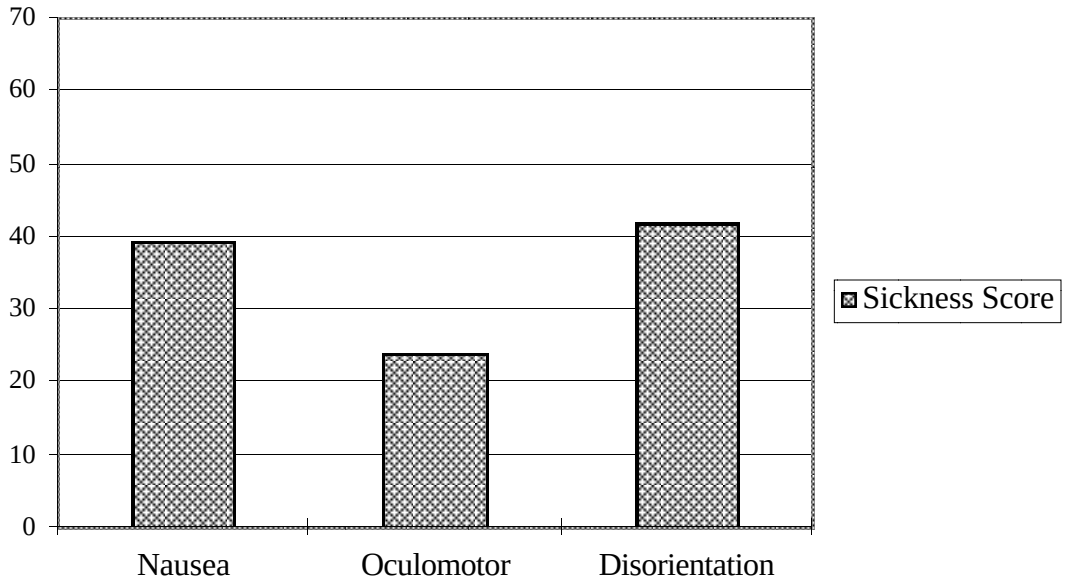

Figure 10. Sickness scores from the pilot study to assess side effects in the maze environment.

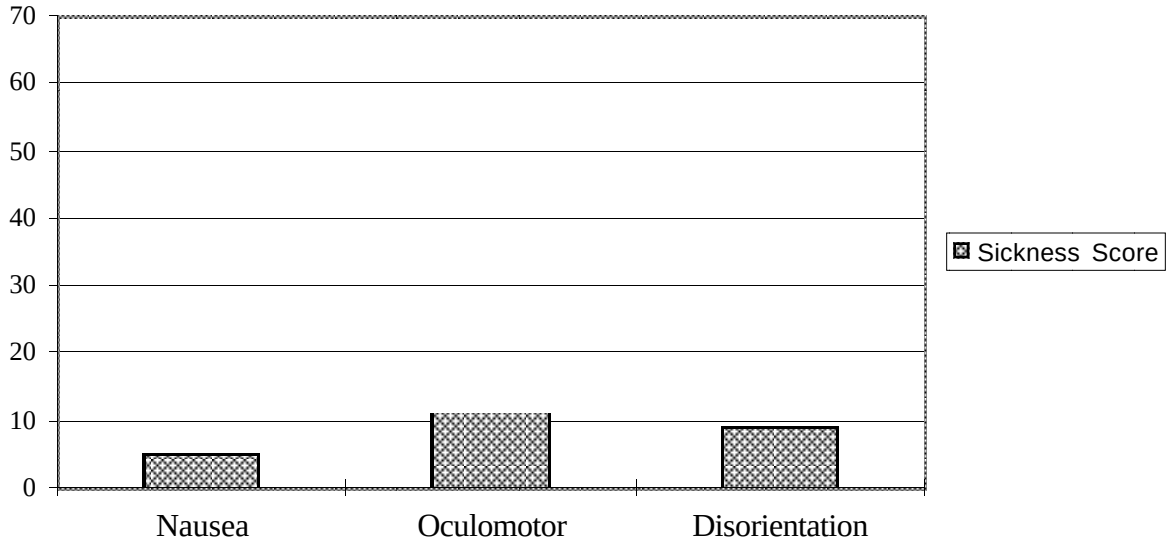

Figure 11. The pilot study symptom profile without the subjects that dropped out during the experiment.

The scores in Figure 10, including all the pilot subjects, are comparable to those found by Kennedy et al. (1993a), shown in Figure 3, and the four experiments of Lampton et al. (1994b), shown in Figure 6. The scores in Figure 11, without the dropped subjects, are similar in magnitude to those found in the Navy Fleet (Figure 3) and the Navy Pilots (Figure 6). Both Navy symptom profiles were developed from simulator systems without immersive HMDs. Figure 11 shows that even subjects that completed the three navigations through the maze experienced some symptoms of sickness. Only two of the eight subjects reported no symptoms at all. Total severity scores for the eight subjects averaged 38.33. Total severity scores without dropped subjects averaged 14.96.

The existence of motion sickness-like symptoms in the maze VE satisfies the first objective of the pilot study. The second objective, determining if there is a difference between males and females in the maze, was studied to determine if the maze task elicited gender differences. The total severity sickness scores for males and females for the maze VE were analyzed using a one-way ANOVA. The mean female total severity score was 39.27, the mean male total severity score was 37.40. The probability that there was no difference between these scores was .9580. These results show strong evidence that with university age participants, in the environment tested, there are no differences in the male and female total severity scores.

Other information in the pilot study was obtained by questioning the participants on the possible causes of symptoms they experienced. A number of subjects reported head-tracking as definitely contributing to disorientation in the VE. Some participants took breaks during the VE session to reorient themselves, during which they held their head as still as possible. Based on this information, head-tracking was included as an independent variable in the current work.

Some other revelations were obtained from informal discussions with participants days after the experiment. Subjects were contacted 2-4 days after the experiment and questioned on the occurrence of any aftereffects thought to be related to the VE session. Formal analyses were not

conducted, but some general information was obtained. Most subjects experienced no aftereffects after a few minutes were taken to rest following the VE session. Two subjects reported noticeable aftereffects thought to be related to the experiment. Both reported feeling a loss of appetite for the rest of the day following the experiment. One reported a light-headed feeling and stomach awareness for the rest of the day. The other subject reported not feeling well for the remainder of the next day following the experiment. Overall, subjects reported at most moderate levels of lingering motion sickness-like side effects. No debilitating effects, visual flashbacks, or loss of hand-eye coordination occurred.

The last component of the pilot study was a previous motion sickness incidence questionnaire. Age, hours of sleep the night before, participant perceived susceptibility to motion sickness, and many other factors all failed to show significant relationships with the experience of side effects in the VE. The one factor that did surface with a high correlation to severity of side effects experienced (.92) was previous incidence of air sickness. Other researchers have found that previous incidence of motion sickness can be of some limited help in predicting side effects experienced in users of VEs (Regan, 1993). The effect in this study lacks sufficient evidence to take the result too seriously.

Problem Statement

The literature review reveals that motion sickness-like side effects experienced by users of VEs is a multi-faceted research phenomenon. Many areas are in need of high quality, if not high quantity, empirical investigation. The current work attempted to address a number of these issues.

Present attempts at measuring negative side effects from immersion into VEs, while useful, are not satisfactory. This research attempted to develop and validate a rigorous, sensitive, flexible, efficient, ratio scale, relatively unobtrusive, method for measuring the negative side effects experienced in VEs. The basis for the measurement method is the psychophysiological method of magnitude estimation.

Several investigations have been conducted examining the symptoms that develop as a result of immersion into VEs. Few have analyzed what factors, and to what extent these factors contribute to the onset of negative side effects in VEs. This research begins that effort by investigating head-tracking and its effect on initiating negative side effects in users of VEs. Future research efforts will be able to use the magnitude estimation method to investigate systematically the causes of side effects in VEs and create an empirical model for VE sickness.

Prediction in the field of motion sickness has been largely unsuccessful (Pausch, 1992; Casali and Frank, 1988). Parker and Harm (1992) suggest that mental rotation testing may help predict who will be susceptible to motion sickness and who will not. Various simulator sickness studies have shown conflicting evidence for perceptual style and its relation to sickness susceptibility (Barrett and Thornton, 1968; Frank, Casali, and Wierwille, 1988). This research investigated the relationship between mental rotation, perceptual style, and other factors with the onset and severity of side effects from VEs.

Lastly, few studies have investigated the effects of time on motion sickness in VEs. This holds for both the side effects that are experienced within a VE session and any adaptation that may occur across several days of an experiment. This research examined both of these aspects of changing effects over time.

Goal Statements

The goals for this research are to:

1. Validate experimentally a magnitude estimation measurement method for negative side effects experienced by users in VEs.

2. Examine the effects of head-tracking (head movements coupled with scene changes) on negative side effects experienced by users in VEs.

3. Examine the effects of task environment (maze and office) on negative side effects experienced by users in VEs.

4. Examine the effects of time, both within sessions and between sessions, on negative side effects experienced by users in VEs.

5. Examine performance data in the maze task as it relates to negative side effects experienced by users in VEs.

6. Determine if any of several factors can serve as a predictor for negative side effects experienced by users in immersive VEs, particularly three-dimensional mental rotation ability and perceptual style.

Research Hypotheses

The research hypotheses for this research are:

1. Magnitude estimation is able to serve as a measure for negative side effects experienced in immersive VEs. Strong relationships between the magnitude estimation, postural stability, and VESEQ totals severity scores are expected. The results for the various experimental conditions for each measure should be similar in scale.

2. A significant difference in negative side effects experienced by users in immersive VEs exists between head-tracking on and head-tracking off.

3. A significant difference in negative side effects experienced by users in immersive VEs exists between the maze task environment and the office environment.

4. A significant difference in negative side effects experienced by users in immersive VEs exists between levels of time both within a session and between sessions.

5. Performance decreases as the severity of negative side effects experienced by users in immersive VEs increases.

6. Three-dimensional mental rotation ability is able to serve as a predictor for negative side effects experienced by users in immersive VEs. Perceptual style is not able to serve as a predictor for negative side effects experienced by users in immersive VEs. No other factors are expected to show evidence as a predictor for negative side effects experienced by users in immersive VEs.

METHOD

Experimental Design

A two factor within subjects experimental design was completed for the independent variables head-tracking and task environment. Head-tracking, a compelling VE component, was chosen from Table 1 based on research evidence described previously that shows it has a tendency to elicit motion sickness symptoms in some users. Head-tracking was either on or off. The second variable, task environment, was either a maze or an office. The environments differ in two main areas: the maze is a low detail navigation task, the office is a higher detail interactive exploratory task. The two factors were chosen in an effort to obtain a range of negative side effect inducing conditions.

Four dependent measures were collected: the VESEQ total severity scores, vision acuity scores, postural stability scores, and sickness magnitude estimates. The VESEQ, vision acuity, and postural stability scores were collected prior to and after the immersive VE sessions with the differences used as the dependent measures. The sickness magnitude estimates were collected every five minutes of the VE session, including an estimate at time zero. Depending on the analysis, the sickness magnitude estimate difference from the first estimate to the last, or each of the estimates at the respective times were used as the dependent measure. A fifth secondary dependent measure was used for the maze environments only: number of mazes completed.

Order of treatments across the four days of the experiment for each subject was balanced based on the Latin square in Table 2. Treatment 1 is head-tracking on and task environment 1 (maze), treatment 2 is head-tracking off in the maze, treatment 3 is head-tracking on in task environment 2 (office), treatment 4 is head-tracking off in the office.

Table 2. The balanced Latin Square to balance adaptation to environments and order effects.

		Treatments			
	1	1	2	4	3
Treatment	2	2	3	4	1
Order	3	4	1	2	3
	4	3	4	1	2

Participants

Participants, aged 18-34, came from the Virginia Tech university population. They were screened with tests for visual acuity and pre-existing conditions of motion sickness (see Appendix A, Part I for motion sickness history questionnaire). To be eligible for the study participants must be in their usual state of fitness, have not been ill in the last week, have had less than a total of two units of alcohol (a unit equals the number of 12 ounce beers + number of ounces of wine + number of ounces of hard liquor) in the last 24 hours, have not used any strong medication in the last 24 hours, have had at least six hours of sleep the night before, respond with no higher than slight for any symptom on the pre-session VESEQ, be free of any severe medical conditions, and possess at least 20/30 normal or corrected color vision acuity. Two potential participants failed to meet these requirements and were not allowed to continue with the study.

Experimental Apparatus

Virtual Environment Equipment Setup

Figure 12 shows a participant in the experimental apparatus. The experimenter used the display at the left of Figure 12 to monitor the progress of the sessions. The display showed the same image that was displayed in the HMD the subjects wore.

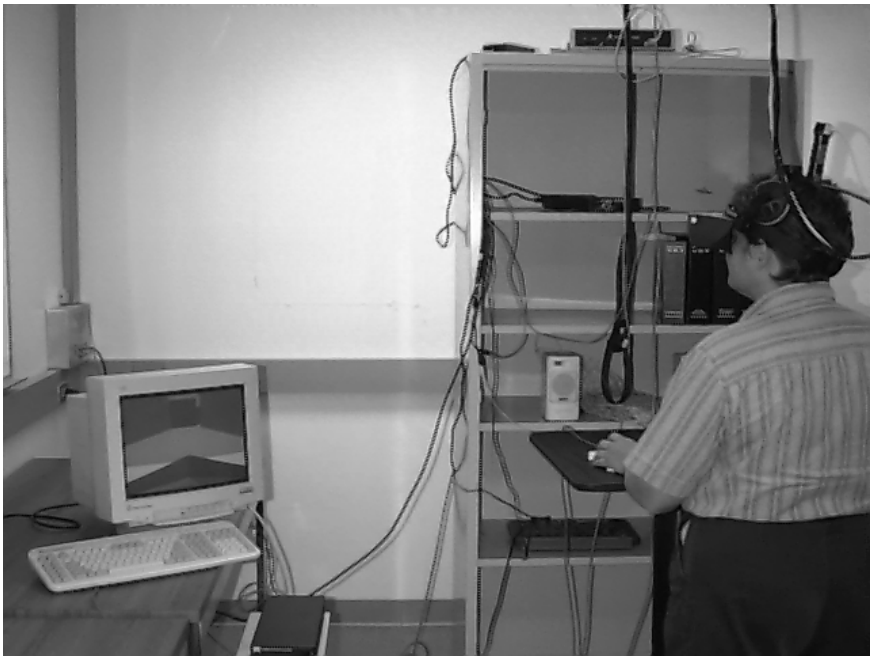

Figure 12. A participant in the VE experimental apparatus.

Navigation was conducted with a Logitech Magellan 3D Controller six degree of freedom pointing device (or space mouse). The space mouse is a puck shaped controller with slight displacement in the six directions providing the intended movement. For the tasks in this experiment, the participant was only able to traverse forward and backward, and rotate left and right. All other degrees of movement were turned off. A regular computer mouse was used for manipulation of objects in the VEs.

The HMD to display the task environments was the Virtual Research Systems, Inc. VR4 shown in Figure 1. The HMD has two 2.7" color LCDs with approximately 40 degrees full overlap field of view. The VR4 was specifically intended for high performance immersive applications (Virtual Research Systems, Inc., 1994).

Head-tracking was controlled with The Flock of Birds position and orientation measurement system. The receiver for The Flock of Birds was mounted on the HMD and a tracker was placed away from the subject to transmit information to the computer.

Virtual Task Environments

There were two task environments: a maze and an office. Both were programmed on Intel Pentium based PCs with Superscape Virtual Reality Software, version 4. The maze environment was described with the pilot study. The office environment is shown in Figures 13 and 14 below.

Figure 13. The office environment.

Figure 14. Another view of the office environment.

The office environment is a simple four walled room containing typical office items. Some items in the office were interactive, including a clock, calculator, desk drawers, cabinets, computer displays, and light switches. Participants were instructed to explore the environment based on messages that came from an instruction board in an adjacent room. The instruction board is shown in Figure 15.

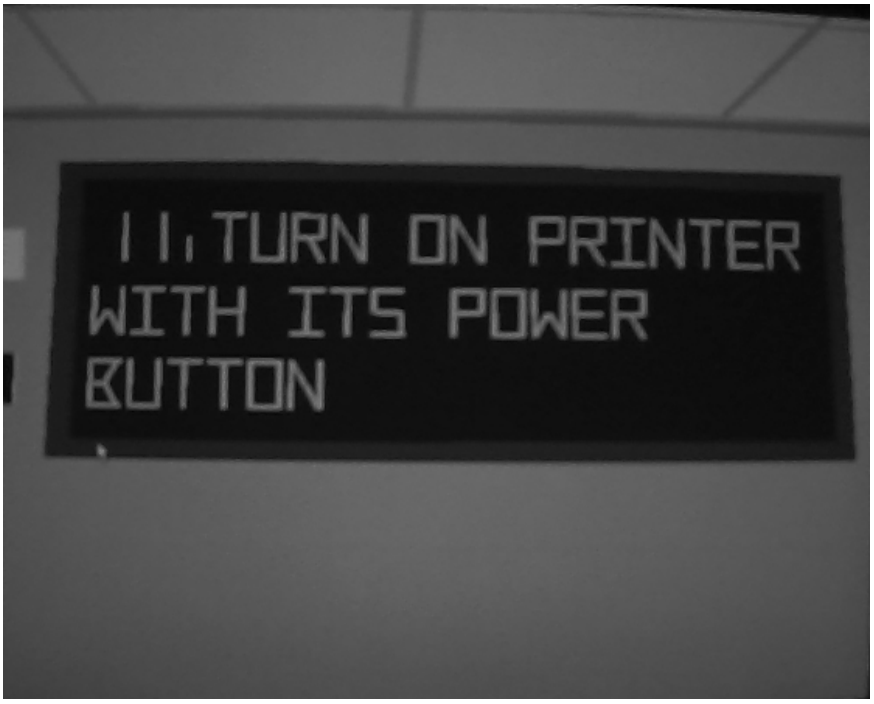

Figure 15. The instruction board in the office environment.

The instruction board contains guidelines such as the one seen in Figure 15 to lead the subject through a set of activities that feature the interactive items of the office environment. The participant cycles through the messages by activating either the white or black square to the side of the instruction board with a mouse click. The white square cycles the instruction board forward one message, while the black square cycles the instruction board back one message. Self-exploration by the participants was not discouraged, the only goal was to engage the subjects within the VE for 30 minutes. Instructions for the respective virtual task environments are shown in Appendix D.

Rod and Frame Setup

The test for perceptual style was conducted within an all black experimental room. The walls, floor, and ceiling of the room were covered with a non-reflective black cloth. A square frame (1.08 m) and a rod (1.02 m) were situated at one end of the room. The rod and frame were constructed from tubular pipe (19 mm). The pipe was then covered with reflective tape on the front edges. A chair and blacklight were located at the far end of the room away from the rod and frame. Upon turning off all other light sources than the blacklight, the room effectively became "invisible" except for the reflective rod and frame. The experimenter sat behind the rod and frame to manipulate controls for moving the rod and frame and measuring the rod's displacement from true vertical.

Vision Tests

A Bausch & Lomb Vision Tester was used to conduct three vision tests: near, far, and stereo vision acuity. Both near and far vision acuity tests used twelve progressively smaller symbols as shown in Figure 16 below. Near vision with the Bausch & Lomb Vision Tester uses a lens system to represent a paper at arms length. The far vision acuity uses a lens system that mimics the traditional 20-foot tests used to characterize vision. The participant was instructed to indicate in which direction (up, down, left, right) the odd symbol was located. The odd symbol was never in the center.

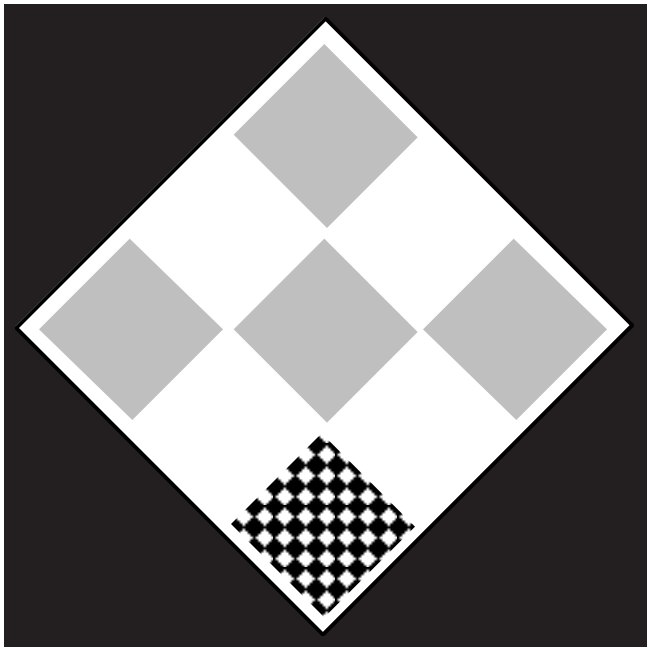

Figure 16. A sample visual acuity symbol.

The stereo acuity test presented twelve progressively smaller rows of numbers. In each of these rows one number would stand above the rest and appear to stick out closer to the eyes than the other ones. The participant was instructed to indicate which number it was.

Questionnaires

The VESEQ is shown in Appendix A. The VESEQ was adapted from the SSQ used to measure simulator sickness. The VESEQ was further modified, based on the pilot study, to eliminate irrelevant questions to this research. The VESEQ contains two sections, a pre-session assessment and a post-session assessment. The pre-session portion contains information relevant to the participants ability to continue in the experiment and current motion sickness condition questions. The post-session portion forms the basis of the symptom profiles seen in figures throughout this document. Total severity scores are also formulated based on the responses for the post-session portions of the VESEQ.

The Motion Sickness History Questionnaire (MSHQ) is shown in Appendix B. This questionnaire is comprised, in part, from the introductory portions of the SSQ and portions of the Motion History Questionnaire (from the same developers of the SSQ). It has been modified based on the results of the pilot study to eliminate questions not relevant to this research.

The mental rotation test used was based on the work of Shepard and Metzler (1971). Shepard and Metzler (1971) developed three-dimensional line drawings that were used in discrimination comparison tests. An example test stimuli is shown in Figure 17. The stimuli were adapted to a computerized test form by Vandenberg (1978), and later revised by Crawford and Christensen (1995) to a written test. The Crawford and Christensen (1995) version of the test was used for this experiment.

The Crawford and Christensen (1995) test has 20 questions based on the ability of participants to rotate the three-dimensional line drawings mentally. Participants are shown one primary object and asked to identify the same object in a set of four other objects. In the set of four secondary objects, two are the same as the primary (rotated slightly in one or the other direction) and two are different drawings entirely.

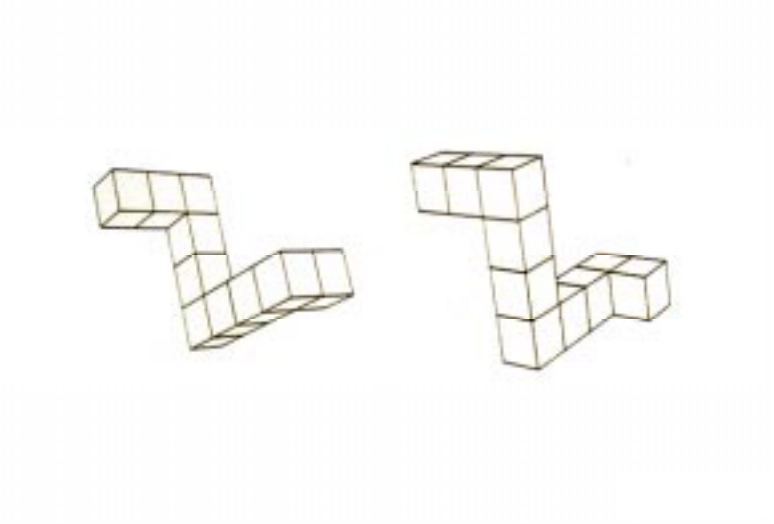

Figure 17. Example test stimuli for the mental rotation test.

Experimental Procedures

Session Protocol

The experiment consisted of four approximately two hour long sessions conducted over four separate days. Time between experimental sessions was limited to 48 hours. Normal events that occurred for every session were the immersive VE itself and the measurement of side effects (by vision, magnitude estimation, balance, and the VESEQ). The immersive VE portion of the experimental sessions was limited to 30 minutes. Magnitude estimates of side effects were collected during the immersive VE by the experimenter asking for a rating of the subject's overall sense of well-being. The other three measures were taken before and after the VE.

Events that were occurred only on the first day included screening subjects, signing the consent form, reading instructions, filling out the MSHQ, magnitude estimation training, and estimates of line lengths. On the second day subjects completed a written mental rotation test. On the third day subjects participated in a rod and frame test for perceptual style. On the fourth day subjects completed a short exit questionnaire, were debriefed, and paid for their time. Details of the various experimental portions of the study are presented below.

Screening Participants

Participants first read and signed the consent form, see Appendix C. Upon agreeing to continue with the experiment, additional screening tests were performed for spatial acuity.

Participants then completed the pre-session portion of the VESEQ to determine if any existing health conditions prevented continuing with the experiment. Subjects with pre-existing conditions of sickness, less than 20/30 vision, and over two units of alcohol consumed in the last 24 hours were not allowed to continue with the study.

Rod and Frame Test

Participants first read the Rod and Frame test Instructions (Appendix D) before being led to the testing room. The experimenter showed the way into the Rod and Frame testing room with a flashlight and instructed the participant to sit in a chair and wait quietly with their eyes closed for further direction. Sitting posture was adjusted until participants were in a pre-measured eye-to-frame position of 85.5 in. Subjects were asked to stay in as nearly the same position as they were able for the entirety of the Rod and Frame test. After about five minutes the experimenter instructed the participant to open his/her eyes and begin the first trial. Subjects indicated the orientation of the rod and began directing the experimenter to position the rod vertically to the world. When the participant was satisfied with the position of the rod, the experimenter asked for eyes to be closed once again while a measurement was made and the rod and frame were re-positioned for the next trial. Eight trials were performed for each subject.

Questionnaires

The MSHQ was administered one time on the first day of the experiment. The VESEQ was administered before and after each immersive VE session on each of the four testing days. Subjects simply filled out the questionnaires as indicated in the written instructions (see Appendix A for the VESEQ and Appendix B for the MSHQ).

For the Mental Rotation Test, participants first read two pages of instructions and performed some sample problems. The majority of the instructions were teaching exercises to familiarize the participant with the task. The test itself was administered in two parts, with ten problems in each section. Three minutes were allowed for both parts, with a short break between them when requested. Participants were instructed to "work as quickly as you can without sacrificing accuracy." It was explained that the score for the test reflected both correct and incorrect responses. Random guessing was discouraged. After reading the first two pages and performing the sample problems, the experimenter reiterated a few points to ensure the participant understood the task. A stopwatch was used to monitor the three minute sections.

Postural Stability

Postural stability was measured before and after each VE session. For the first session the experimenter demonstrated the correct postural stability position and procedure for testing. The postural stability testing position was standing straight up on one foot, with the other foot tucked behind the standing legs' knee, with the arms folded across the chest, and eyes closed. The participants were instructed to position their limbs in the order demonstrated. A stopwatch was used to time how long participants could hold the position once their eyes were closed. Five trials were performed on each leg, starting with the "preferred" leg, until a criterion of 30 seconds was reached. No further trials were performed on a given leg if the criterion was reached before the fifth trial.

Magnitude Estimation

The method of free-modulus magnitude estimation (free-modulus meaning no anchors provided) for measuring side effects from the VE was introduced to subjects with a line length estimation task. The line length estimates served two purposes: 1) practice for the participants in

making magnitude estimates; and 2) a check against previous line length research to ensure participants were using proper scaling techniques.

For the line length estimation task, the participants first read the magnitude estimation instructions provided by the experimenter and asked any questions (see Appendix D for instructions). For demonstration purposes the participants were asked to estimate the brightness in the experimental room. The experimenter then turned the lights down with a dimmer switch and asked for a second estimate. This allowed the participants to have a practical understanding of magnitude estimation.

After demonstrating magnitude estimation with room lights, the experimenter presented ten randomly sorted lines of different length on 8 1/2 by 11 in. sheets of paper to the participant one line at a time. The magnitude estimates of the lines by the subject were recorded on a scoresheet for later analysis.

Sickness Estimates

The magnitude estimates of negative side effects experienced during the VE sessions (sickness estimates) were obtained every five minutes of the experiment including one at the start and end of the VE immersion. A total of seven estimates were collected throughout each VE session (times: 0:00, 5:00, 10:00, 15:00, 20:00, 25:00 and 30:00). The experimenter, using a stopwatch to time the length of the VE session, would ask the participant for an estimate at each of appropriate times and record each estimate on a scoresheet.

Post-Session

After the experiment was over, any participants experiencing side effects from immersion were required to remain with the experimenter until the symptoms dissipated, up to an hour after the VE session. If serious debilitating effects had occurred, the participant would have been asked to avoid operating large machinery, including automobiles, for a period of six hours. No participants experienced symptoms severe enough to require this instruction.

At the end of the last experimental session the participant completed the final questionnaire shown in Appendix E and filled out a compensation form. Any questions about the whole experiment were answered at this time.

RESULTS

Data Reduction

Rod and Frame Test

The average deviation from true vertical was used for data analysis of the rod and frame test. No other information was analyzed from this test.

Mental Rotation Test

A scoring system adding one point for a correct answer and subtracted one point for each incorrect answer for the 10 questions in the two parts of the mental rotation test. The average score of the two parts was used in data analysis.

Vision Acuity

The raw number of test items correctly answered (1-12) was converted to visual angle for both the near and far vision acuity tests. For correlational data analysis, the visual angle prior to the VE session was used. For other data analyses, the difference in the post-VE session visual angle from the pre-VE session visual angle was used. For stereo acuity, the last level (1-12) correctly identified by the participant was used as the stereo acuity score. For stereo acuity the last level (1-12) correctly identified by the participant was used as the stereo acuity score.

Postural Stability

The lengths of time subjects could hold the testing posture, up to 30 seconds, were the postural stability raw times. Any trial where the participant achieved a time of 30 seconds before the fifth trial on any leg, pre- or post-session, received a 30 second score for the remaining trials. The raw times were summed over each leg for the pre- and post-sessions. An average score for both legs was computed for the post- and pre-sessions. The difference between the pre-session average from the post-session average was the score used in data analyses.

VESEQ

The VESEQ was reduced similar to the SSQ described earlier. Sixteen of the symptoms in the list are converted to three subscales by a series of arithmetic steps. Table 3 shows which symptoms contribute to each subscale. The three subscales are N - Nausea, O - Oculomoter, and D - Disorientation.

Table 3. The contribution of each symptom to a subscale score is indicated by a 1 in the subscale columns (N - Nausea, O - Oculomotor, D - Disorientation).

	Symptom	N	O	D
1	General Discomfort	1	1	
2	Fatigue		1	
3	Headache		1	
4	Eyestrain		1	
5	Difficulty focusing		1	1
6	Increased salivation	1		
7	Sweating	1		
8	Nausea	1		1
9	Difficulty concentrating	1	1	
10	Fullness of head			1
11	Blurred vision		1	1
12	Dizzy (eyes open)			1
13	Dizzy (eyes closed)			1
14	Vertigo			1
15	Stomach Awareness	1		
16	Burping	1		

The severity level of each symptom assigned by the participant (1 -None, 2 - Slight, 3 - Moderate, 4 - Severe) is assigned to the appropriate subscales as defined by Table 3 above. The individual symptom responses are then summed to obtain subscale subtotals. Table 4 shows an example of one participant's post-session responses and summation to subtotals.

Table 4. An example of converting the questionnaire responses to subscale subtotals.

Symptom	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Questionnaire Responses	0	0	0	1	1	0	0	0	0	0	1	0	0	1	0	0	
Subscale																	Subtotal
N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	3
D	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	3

The subscale subtotals are then multiplied by a conversion factor to obtain the subscale score. Finally, the three subscales are added and multiplied by another conversion factor to obtain the total severity sickness score. The conversion factors used are the same ones developed for the SSQ. For the Nausea subscale the conversion is Subtotal*9.54; for Oculomotor, Subtotal*7.58; and for Disorientation, Subtotal*13.92. The total sickness severity score is the three subscale scores summed and multiplied by 3.74. For the example given above the Nausea subscale score is 0, the Oculomotor subscale score is 22.74, the Disorientation subscale score is 41.76, and the total sickness severity score is 22.44.

For data analysis the difference between post-session and pre-session total sickness severity scores are used. Subscale score symptom profiles are computed for comparison purposes with prior research.

Magnitude Estimation

Data reduction for magnitude estimation follows the methods of Kies and Snow (1996), Snow (1996), and Engen, (1971). The fist step was ensuring that participants understood the concepts of estimating magnitudes as described above. Subsequent steps involve a series of conversions to transform the subject responses to analyzable data.

The calculations to reduce the magnitude estimation line length data are shown in Appendix F. A regression model for the average line length estimates is shown below in Figure 18. The regression equation is Y = 0.4635 + 0.9381X, R-Squared = 0.9980.

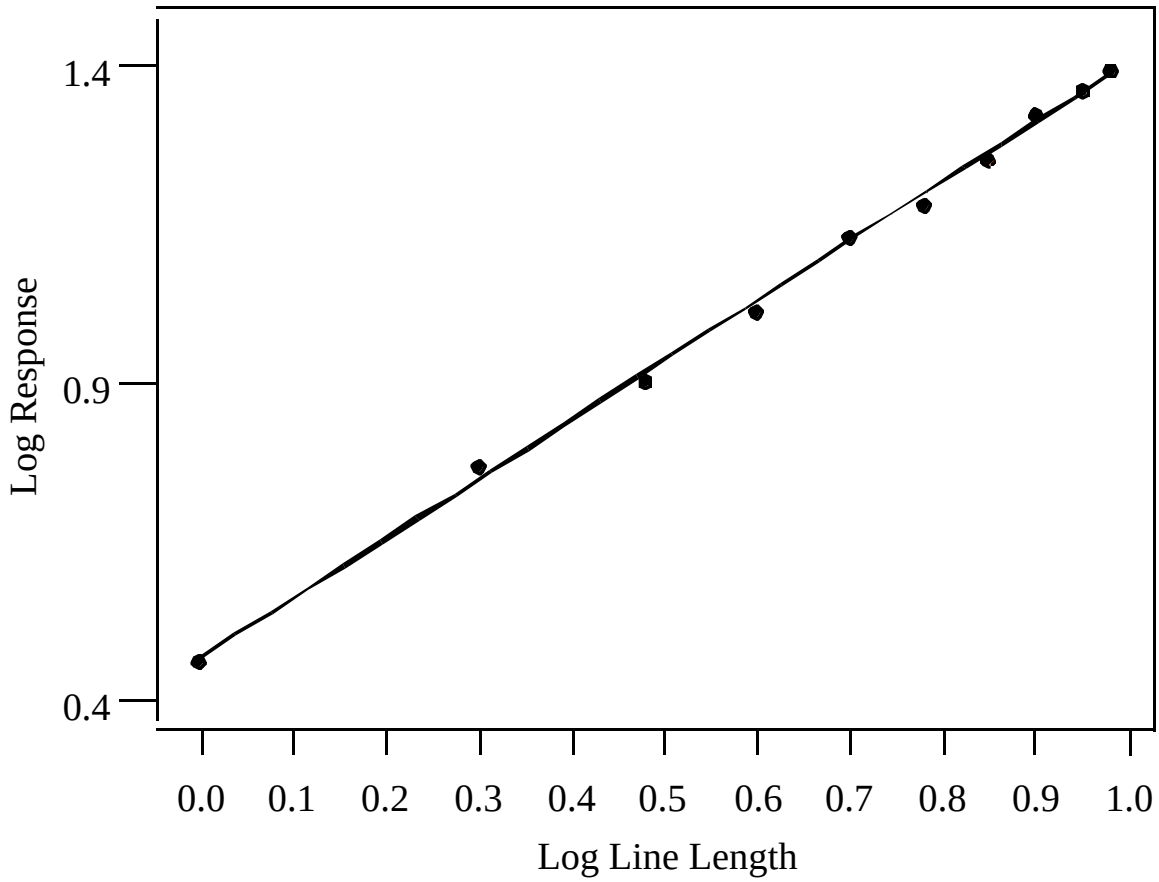

Figure 18. The power function of log response estimates to log line length.

The resulting psychological power function for line length from the figure above is $\psi = 2.91\phi^{.938}$. The equation is composed of the antilog of the intercept (2.91) times the physical stimulus (ϕ) with the exponent being the regression equation coefficient (.938). These values are compatible with existing research for line length estimation, showing that the current subjects were able to scale appropriately with magnitude estimation.

Free modulus magnitude data estimation (free modulus meaning not providing the participant with an anchor value) needs to be adjusted to eliminate inter- and intra- subject variability. Stevens (1971) describes the steps necessary for this data conversion called modulus equalization. A preliminary step is to sort the data into appropriate sets. A set of data is created each time a new

magnitude scale is used. For line length estimation, only one scale per subject was made. For the VE sickness estimates, a new scale was created each day at the beginning of the session. The Steven's steps are listed below:

1. Convert raw data estimates to their logarithmic values.

2. Calculate the mean of each set of log estimates to obtain each set modulus.

3. Calculate the mean of all the log estimates to obtain the common modulus.

4. Subtract the common modulus from each set modulus to obtain each set's constant offset from the common modulus.

5. Subtract the set constant from the log estimates in each set to obtain normally distributed data adjusted to a common modulus.

6. Take the antilog of all the normally distributed adjusted data values to obtain data ready for parametric analysis.

For the MANOVA and subsequent univariate tests, the sickness magnitude estimate differences between the last estimate and first estimate of the session are used. In the ANOVAs incorporating time as an independent variable, the estimates given for each level of time during a session are used.

Head-Tracking and Task Environment

MANOVAs were performed for the independent variables head-tracking and task environment with the dependent variables total severity score, vision acuity, postural stability, and sickness estimates. The MANOVAs were done in an attempt to control for Type I error and examine any interrelationships between the dependent variables.

The MANOVAs for the two factor four dependent measure design were not significant. Due to the insignificance of the MANOVAs, analyses on interrelationships between dependent measures were not performed. Table 5 and 6 show the MANOVA summary tables for head-tracking and task environment respectively.

Table 5. MANOVA summary table for head-tracking

MANOVA for Head-Tracking s = 1, m = 1, n = 5

CRITERION	TEST	STATISTIC	F	DF	P
Wilk's	0.55784	2.378	4	12	0.110

This tests use error term = Subject*Head

Table 6. MANOVA summary table for task environment.

MANOVA for Task Environment s = 1, m = 1, n = 5

CRITERION	TEST	STATISTIC	F	DF	P
Wilk's	0.53559	2.601	4	12	0.089

This tests use error term = Subject*Env

Some debate exists among researchers on the appropriateness of reporting univariate tests with non-significant MANOVA results (Koball, personal communication, August 13, 1997; Hand and Taylor, 1987; Finkelman, Wolf, and Friend, 1977; Lee, 1975). A significant MANOVA normally has significant univariates. An non-significant MANOVA normally has non-significant univariates. It is unusual for significant univariates to accompany non-significant MANOVAs; the case that does show up here.

One possibility for such a mismatch is when there are only a few significant results in the univariate tests and they are near $p = .05$ (Koball, personal communication, August 13, 1997). This scenario is similar to the data presented here. When this situation occurs, it is necessary to re-consider why the MANOVA was used and pay particular attention to the possibility of Type I error.

MANOVAs are conducted for three reasons: to increase power, to control Type I error, and to assess interrelationships between dependent variables (Hand and Taylor, 1987). Strict MANOVA philosophy holds that univariates for a non-significant MANOVA cannot be presented (Finkelman, Wolf, and Friend, 1977; Casali, J. G., personal communication, August 14, 1997). However, MANOVAs approaching significance that are not reported may be shielding true significant results. One feasible option to bridge this disparity is to seek alternate controls to Type I error or set alpha levels lower than the standard $p < .05$ in the univariate tests.

Before taking this approach it is necessary to examine the relative seriousness of making a Type I error (Keppel, 1991). A Type I error in the present case for head-tracking measured by total severity score differences, $p = .0488$ (see Table 8), would falsely reject the hypothesis that there is no difference in head-tracking being on and head-tracking being off in the level of sickness induced in participants. The alternative hypothesis that there is a difference in head-tracking would be accepted. This result would only indicate a further need to investigate head-tracking and its role in inducing sickness symptoms in VE users. No standards in the literature have been made on this issue at this time, the VE research area is still very new. Thus, the implications of a Type I error in this instance would be minimal.

Given the information presented, the results of the univariates for the non-significant MANOVA will be reported provided the possibility of a Type I error is explored and the ramifications discussed. Corrections for positive bias based on maximizing the heterogeneity of covariance (Geisser-Greenhouse and Huynh-Feldt) cannot be used because there are only two levels for the main effects. The Geisser-Greenhouse and Huynh-Feldt corrections for Type I error calculate conservative F-ratios by maximizing heterogeneity of covariance. This is accomplished by setting degrees of freedom for the treatment condition equal to one, which already exists when there are only two levels. Therefore, no additional corrections to the p-values can be made.

Thus, Tables 7 to 10 show the univariate ANOVAs for the dependent measures postural stability difference, VESEQ total severity score difference, near vision acuity difference, and

sickness magnitude estimate difference. HT is head-tracking and TE is task environment. Significant results are shown in corresponding figures.

Table 7. ANOVA summary table for postural stability differences.

Source	DF	SS	MS	F	P
Subject	15	26311.346	1754.090		
HT	1	602.089	602.089	1.184	0.2937
HT * Subject	15	7628.602	508.573		
TE	1	543.473	543.473	0.617	0.4444
TE * Subject	15	13213.526	880.902		
HT * TE	1	382.203	382.203	0.319	0.5806
HT * TE * Subject	15	17973.106	1198.207		

There are no significant results in this analysis. The postural stability scores failed to detect negative side effects in any appreciable manner.

Table 8. ANOVA summary table for VESEQ total severity score differences.

Source	DF	SS	MS	F	P
Subject	15	10658.333	710.556		
HT	1	1505.634	1505.634	4.599	0.0488
HT * Subject	15	4911.177	327.412		
TE	1	813.248	813.248	2.244	0.1549
TE * Subject	15	5435.712	362.381		
HT * TE	1	78.899	78.899	0.168	0.6878
HT * TE * Subject	15	7051.280	470.085		

At the $\alpha = .05$ significance level, there is sufficient evidence ($p = .0488$) to reject the null hypothesis that the levels of head-tracking have equal impact on VE side effects as measured by the total severity scores calculated from the VESEQ. There are no other significant results in this analysis. As seen in Figure 19, head-tracking on yields higher total severity scores than head-tracking off.

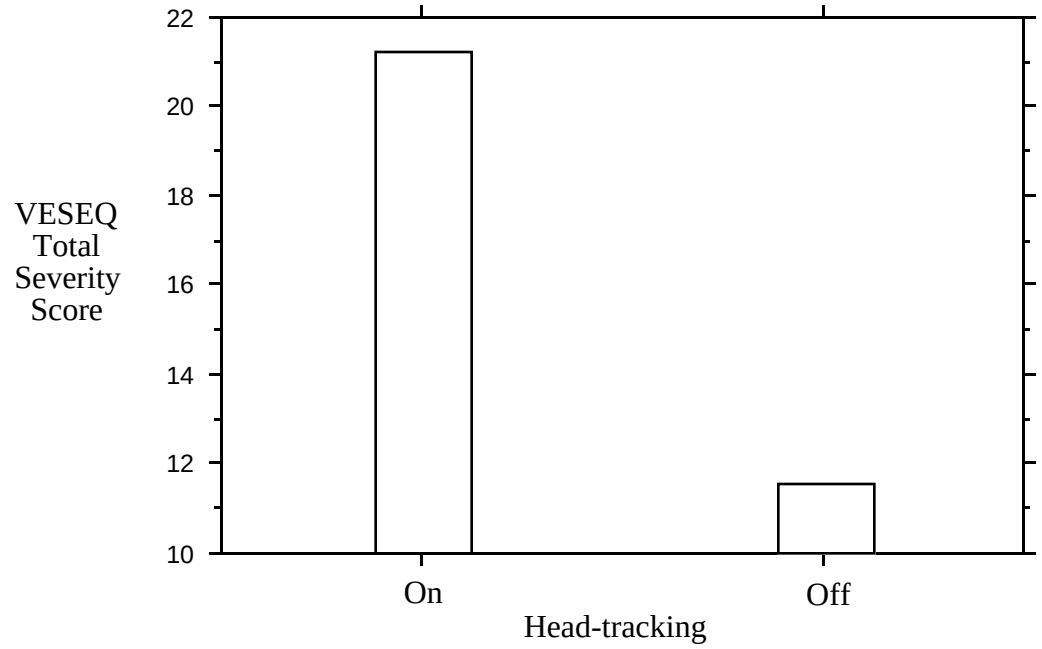

Figure 19. Main effect of head-tracking.

As was mentioned earlier, the univariate p-value for this result is near the $\alpha = .05$ level, while the corresponding MANOVA is non-significant. While Type I error has a greater possibility of occurrence as the p-value nears .05, the practical significance of head-tracking being a causative factor to side effects can be interpreted from the statistical significance of this result.

Table 9. ANOVA summary table for near vision acuity differences.

Source	DF	SS	MS	F	P
Subject	15	0.057	0.004		
HT	1	2.64E-04	2.64E-04	0.150	0.7040
HT * Subject	15	0.026	0.002		
TE	1	0.002	0.002	0.590	0.4544
TE * Subject	15	0.043	0.003		
HT * TE	1	0.002	0.002	1.135	0.3035
HT * TE * Subject	15	0.031	0.002		

There are no significant results in this analysis. The vision acuity scores failed to detect negative side effects in any appreciable manner.

Table 10. ANOVA summary table for sickness magnitude estimate differences.

Source	DF	SS	MS	F	P
Subject	15	1785.751	119.050		
HT	1	38.704	38.704	0.6360	0.4378
HT * Subject	15	913.493	60.900		
TE	1	373.118	373.118	10.8860	0.0049
TE * Subject	15	514.120	34.275		
HT * TE	1	36.105	36.105	0.4700	0.5037
HT * TE * Subject	15	1153.420	76.895		

At the $\alpha = .05$ significance level, there is sufficient evidence ($p = .0049$) to reject the null hypothesis that the levels of task environment have equal impact on VE side effects as measured by sickness magnitude estimates. There are no other significant results in this analysis. As seen in Figure 20 task environment 1, the maze, yields higher sickness estimates than task environment 2, the office. The strong significance of the p-value for this result allows small possibility for a Type I error.

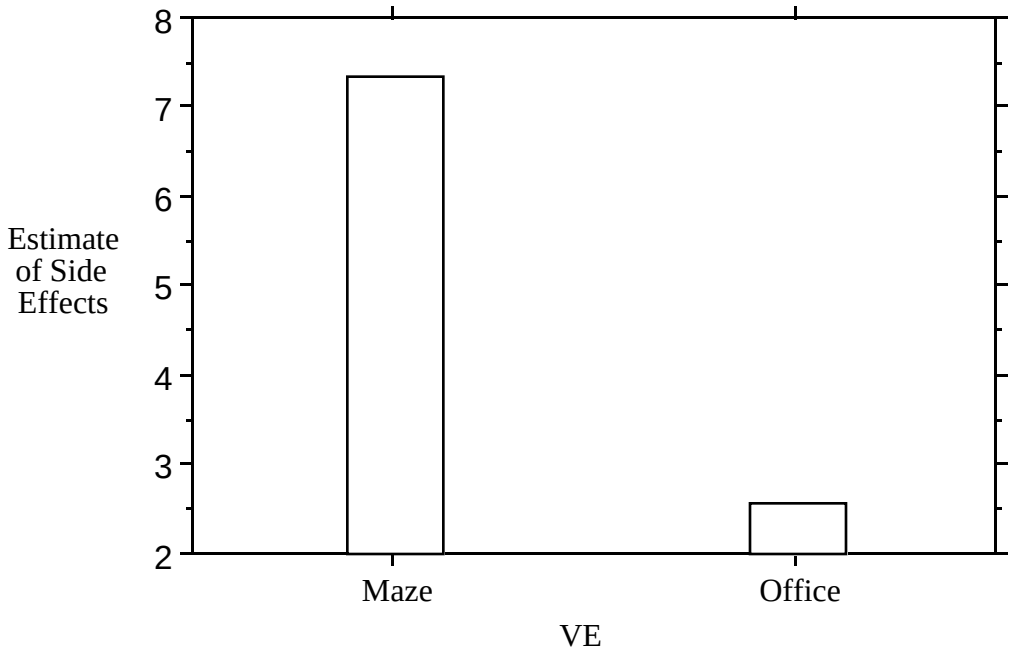

Figure 20. Main effect of task environment.

Head-Tracking, Task Environment, and Time

The magnitude estimation technique allows subjective capture of sickness measurements over time. Magnitude estimation is the only measure used in this experiment with that ability. The variable time (minutes into session), was added to the experimental design in the previous section to create a three factor ANOVA with sickness estimates as the sole dependent measure. Time (0, 5 ,10, 15, 20, 25, 30) was analyzed with head-tracking (on, off), and task environment (maze, office). Table 11 shows the ANOVA summary table.

Table 11. ANOVA for sickness estimates, including the variable time.

Source	DF	SS	MS	F	P
Subject	15	154.060	10.271		
HT	1	2.476	2.476	0.518	0.4829
HT * Subject	15	71.766	4.784		
TE	1	11.884	11.884	1.322	0.2681
TE * Subject	15	134.787	8.986		
Time	6	1283.868	213.978	9.525	0.0001
Time * Subject	90	2021.853	22.465		
HT * TE	1	22.660	22.660	4.167	0.0592
HT * TE * Subject	15	81.575	5.438		
HT * Time	6	230.888	38.481	3.598	0.0030
HT * Time * Subject	90	962.553	10.695		
TE * Time	6	319.655	53.276	5.747	0.0001
TE * Time * Subject	90	834.334	9.270		
HT * TE * Time	6	55.137	9.189	0.600	0.7295
HT * TE * Time * Subject	90	1378.052	15.312		

At the $\alpha = .05$ significance level, there is sufficient evidence ($p = .0001$) to reject the null hypothesis that the levels of time in session have equal impact on VE side effects as measured by sickness magnitude estimates. Figure 21 shows sickness estimates increasing throughout the session, with no evidence of the trend leveling off.

Post hoc comparisons using Tukey's Test at the $\alpha = .05$ significance level show sickness estimates for times 0 and 5 are significantly different than times 20, 25 and 30; sickness estimates for times 10 and 15 are significantly different than times 25 and 30; and sickness estimates for time 20 are significantly different than time 30.

Using a lack of fit test for a linear model, there was sufficient evidence ($p = .0000$) to reject the null hypothesis that there was no linearity in sickness magnitude estimates over time. In addition, there was insufficient evidence to suggest a lack of fit.

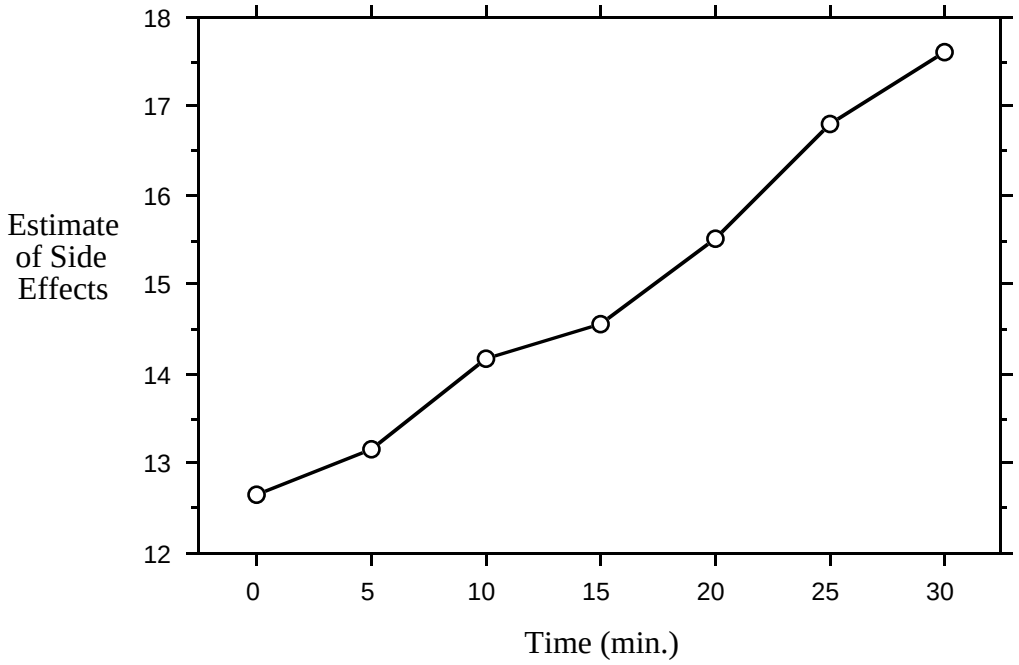

Figure 21. Main effect of time.

At the $\alpha = .05$ significance level, there is sufficient evidence ($p = .0030$) to reject the null hypothesis that the interaction of time and head-tracking have equal impact on VE side effects as measured by sickness magnitude estimates. Figure 22 shows sickness estimates increasing throughout the sessions for both head-tracking on and head-tracking off. Figure 22 also demonstrates sickness estimates for head-tracking on increasing at a higher rate than head-tracking off.

Post hoc comparisons using Tukey's Test at the $\alpha = .05$ significance level show sickness estimates for head-tracking on, time 0, are significantly different than head-tracking off, times 25 and 30; sickness estimates for head-tracking on, time 5, are significantly different than head-tracking off, time 30; and sickness estimates for head-tracking on, times 25 and 30, are significantly different than head-tracking off, times 0, 5, 10, and 15.

Using a lack of fit test for a linear model, there was sufficient evidence ($p = .0000$) to reject the null hypothesis that there was no linearity in sickness magnitude estimates in the time by head-tracking interaction. There was insufficient evidence to suggest there was a lack of fit.

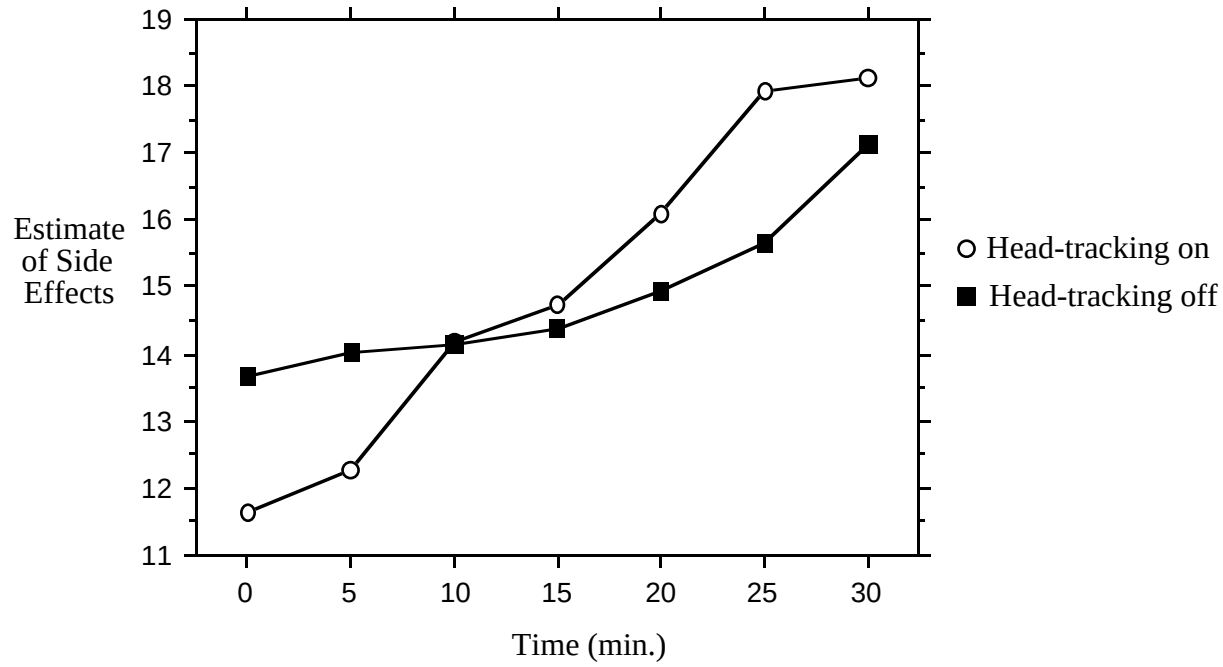

Figure 22. Interaction between head-tracking and time.

At the $\alpha = .05$ significance level, there is sufficient evidence ($p = .0001$) to reject the null hypothesis that the interaction of time and task environment have equal impact on VE side effects as measured by sickness magnitude estimates. Figure 23 shows sickness estimates increasing throughout the sessions for both tasks. Figure 23 also demonstrates sickness estimates for the maze increasing at a higher rate than for the office.

Post hoc comparisons using Tukey's Test at the $\alpha = .05$ significance level show sickness estimates for the maze at time 0 are significantly different than the office at times 20, 25, and 30; sickness estimates for maze at times 25 and 30 are significantly different than the office at times 0, 5, and 10; and sickness estimates for the maze at time 30 are significantly different than the office at times 15 and 20.

Using a lack of fit test for a linear model, there was sufficient evidence ($p = .0000$) to reject the null hypothesis that there was no linearity in sickness magnitude estimates in the time by task environment interaction. In addition, there was insufficient evidence to suggest a lack of fit.

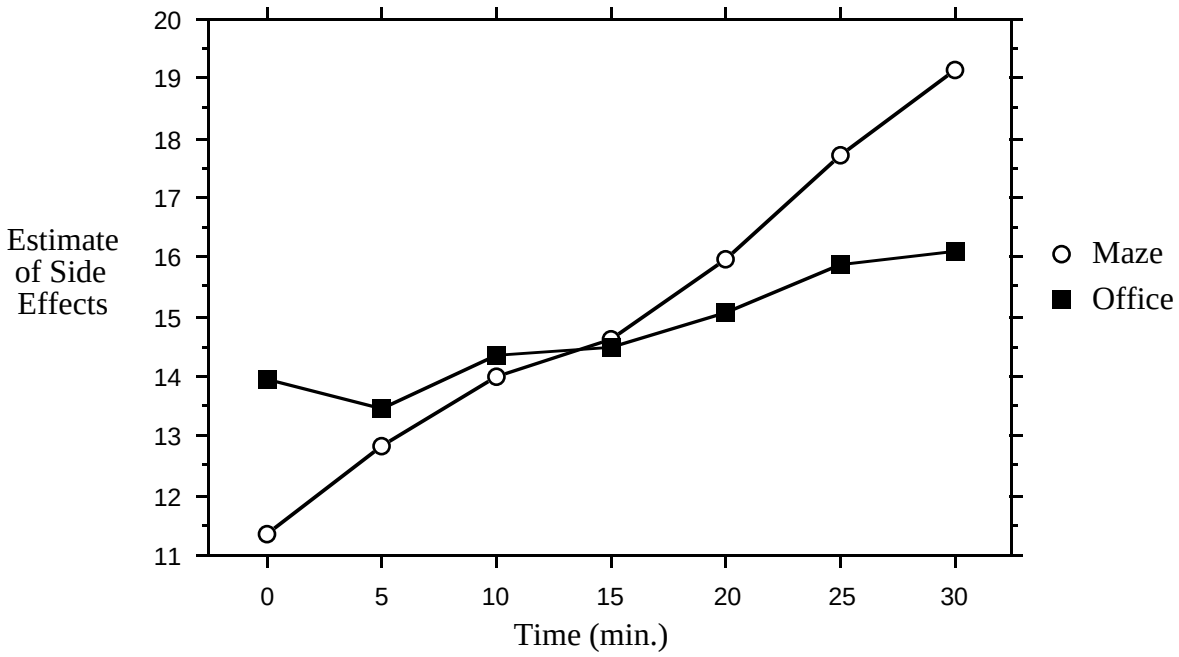

Figure 23. Interaction between time task environment and time.

Day and Time

An ANOVA was completed for the independent variables day and time to assess the effects of total time in the study, not just within each session but across the four days of the experiment. As with the previous analysis, due to the measurement of time within the session, this analysis is only possible with the sickness magnitude estimates. Table 12 shows the ANOVA summary table for day and time as measured by sickness estimates.

Table 12. ANOVA summary table for day and time measured by sickness estimates.

Source	DF	SS	MS	F	P
Subject	15	154.060	10.271		
Day	3	29.835	9.945	1.515	0.2234
Day * Subject	45	295.312	6.562		
Time	6	1283.868	213.978	9.525	0.0001
Time * Subject	90	2021.853	22.465		
Day * Time	18	239.049	13.280	1.012	0.4457
Day * Time * Subject	270	3541.570	13.117		

This analysis obtains the same significant result of time as measured by sickness estimates seen in Table 11. At the $\alpha = .05$ significance level, there is sufficient evidence ($p = .0001$) to reject the null hypothesis that the levels of time in session have equal impact on VE side effects as measured by sickness magnitude estimates. There are no other significant results in this analysis.

Head-Tracking in the Maze

An additional ANOVA was completed for the variable head-tracking as measured by number of mazes completed. The summary table is shown in Table 13 below.

Table 13. ANOVA summary table for head-tracking as measured by number of mazes completed.

Source	DF	SS	MS	F	P	G-G	H-F
Subject	15	211.719	14.115				
HT	1	3.781	3.781	1.076	0.3161	0.3161	0.3161
HT * Subject	15	52.719	3.515				

There are no significant results in this analysis. Head-tracking failed to show any effect on the number of mazes completed.

*VESEQ Symptom Profile*s

Symptom profile graphs were constructed to make limited comparisons with previous research utilizing SSQ or VESEQ questionnaires to measure simulator or VE side effects. Statistical analysis was not conducted on these graphs based on the cautions expressed in the literature concerning the SSQ. Symptom profiles are shown for each level of head-tracking with each level of task environment. In addition, symptom profiles are presented with one or the other variable collapsed across the other's conditions. And finally, a symptom profile averaged across all treatments is shown. Figures 24 to 27 show the symptom profiles for each of the treatment conditions. Figures 28 to 31 show the symptom profiles collapsed across one of the variables for each level of the other. Figure 32 shows the symptom profile averaged across all treatment conditions (Nau is Nausea subscale, Ocu is Oculomotor subscale, and Dis is disorientation subscale).

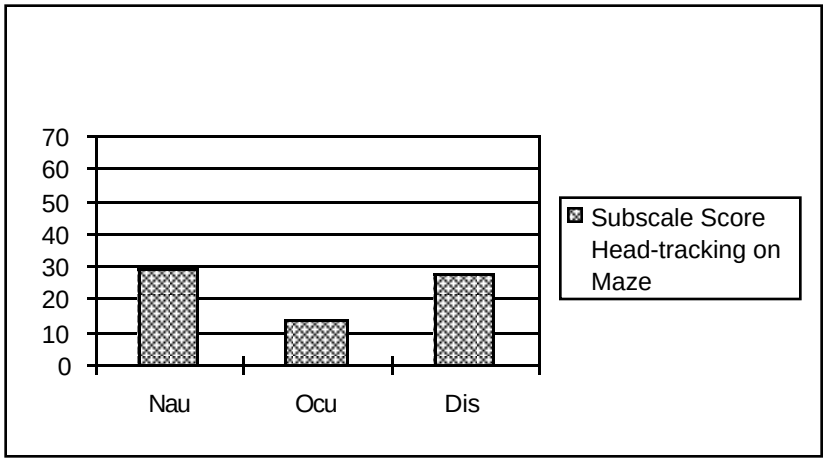

Figure 24. Symptom profile for the maze with head-tracking on.

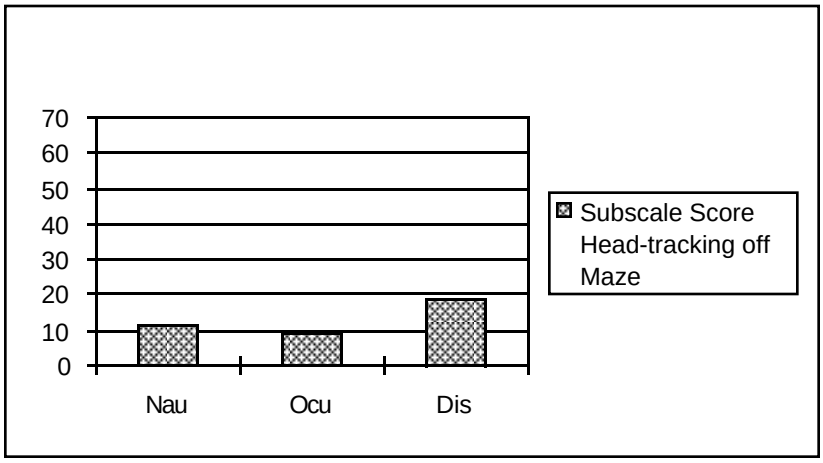

Figure 25. Symptom profile for the maze with head-tracking off.

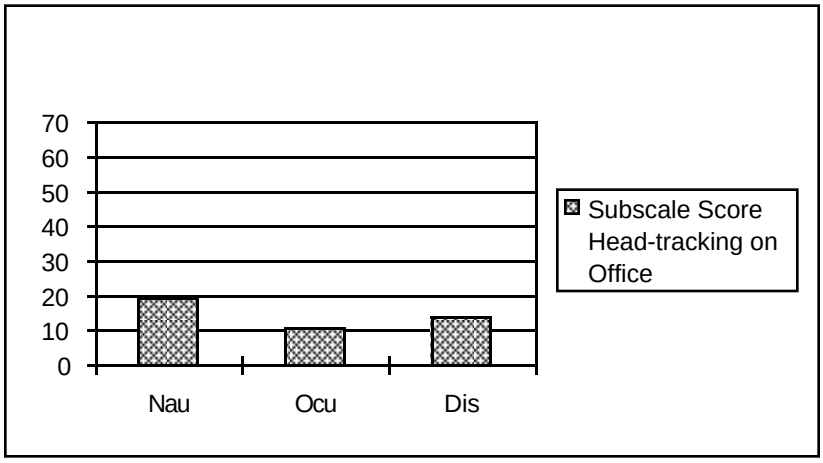

Figure 26. Symptom profile for the office with head-tracking on.

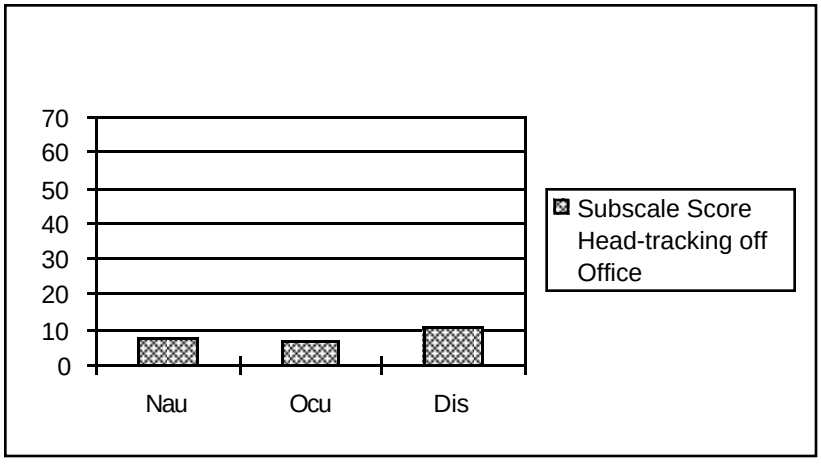

Figure 27. Symptom profile for the office with head-tracking off.

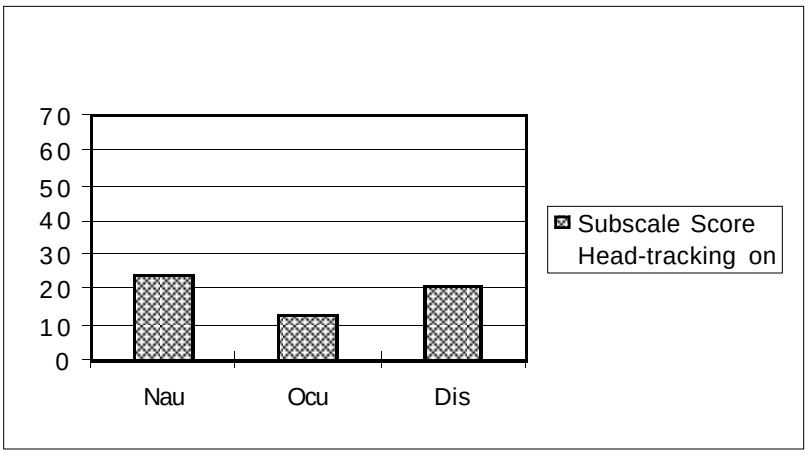

Figure 28. Symptom profile for conditions collapsed across head-tracking on.

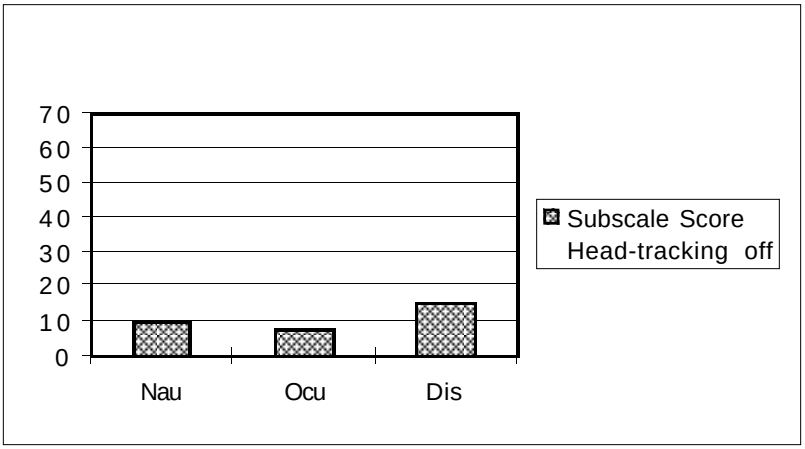

Figure 29. Symptom profile for conditions collapsed across head-tracking off.

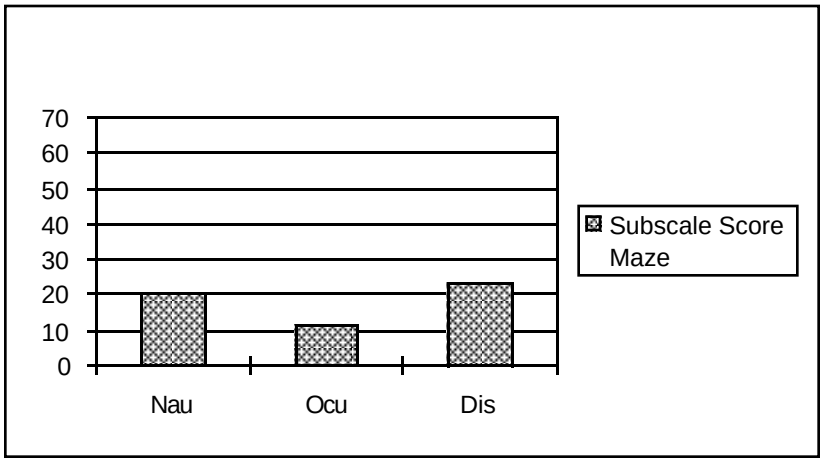

Figure 30. Symptom profile for conditions collapsed across the maze.

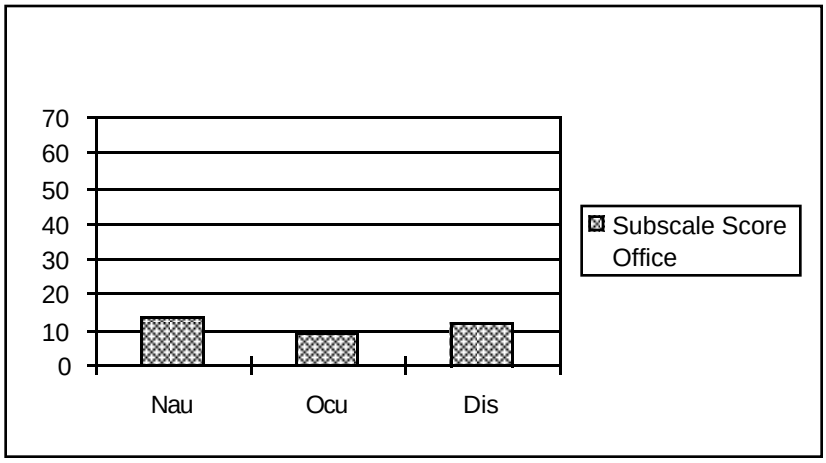

Figure 31. Symptom profile for conditions collapsed across the office.

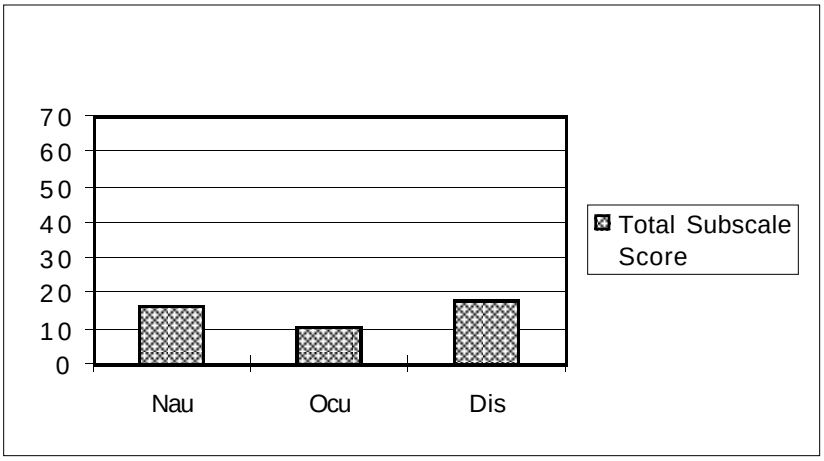

Figure 32. Symptom profile for all conditions combined.

Correlation Analysis

To see if any variables could serve as a predictor for negative side effects experienced, correlations were computed amongst all the information collected during the experiment. Appendix G shows the full correlation matrix tables for factors varying across the 16 subjects (Appendix G, Table 20), factors varying across the 64 experiment sessions (Appendix G, Table 21), and factors varying across just the maze conditions (Appendix G, Table 22). Appendix G also contains a table with definitions for all the factor label names (Table 19). A total of 420 correlations were calculated between the items from the questionnaires, tests, and experimental data. Finally, Appendix G shows trend diagrams for the significant relationships for correlations that are significant at the $\alpha = .01$ significance level.

Table 14 lists the correlations at the $\alpha = .01$ significance level that show sufficient evidence to reject the null hypothesis (all $p < .01$ using t-test for significance) that there is no correlation between the two items. Appendix G, Table 23, lists the correlations at the $\alpha = .05$ significance level that show sufficient evidence to reject the null hypothesis that there is no correlation between

the two items. To limit the possibility of erroneous results, only correlations that meet the more stringent $\alpha = .01$ significance level will be considered.

Table 14. A composite table of significant correlations at the $p < .01$ level.

Appendix G Table	Correlate 1	Correlate 2	R
20	Age	Stereo	-0.643
	Carsick	Gender	-0.882
	Chance	Suscept	0.636
	RFT-Avg	L-Air	0.734
	L-Elev	L-Autos	0.637
	L-Swing	L-Elev	0.693
	RFT-Avg	L-Elev	0.783
	RFT-Avg	L-Swing	0.753
	Rotate	Chance	0.634
21	Est-D	Bal-D	-0.342
	Q-Tot-D	Bal-D	-0.321

DISCUSSION

Nature of Side Effects in VEs

The nature of the sickness, or side effects experienced by subjects, in this study closely resembles that seen in other motion sickness experiments. The results show lower symptom profile scores than most other VE studies (see Figures 3, 6); however, this was not wholly unexpected as the VEs were purposely adjusted through pilot testing and design to limit severe symptoms. The negative side effects experienced were larger than non-immersive studies such as the US Navy pilots in Figure 6. Interestingly, the symptom profiles are slightly lower than those constructed in the pilot study. Overall the general pattern of symptoms is the same as other motion and simulator sickness research, including the pilot study, but with slightly lower values.

Symptoms that were actually observed during the experiment included the typical nausea, disorientation, stomach awareness, headache, difficulty focusing, burping, sweating, etc., that is commonly seen when instigating motion sickness. While no subject got sick, actual vomiting, nearly all other motion sickness-like symptoms were experienced by one subject or another during the study.

Considering the symptom profiles from the VESEQs, the nausea subscale appears to be the predominant symptom category in head-tracking on conditions. The disorientation subscale appears to be the predominant symptom category in the maze conditions. The oculomotor subscale on the other hand shows consistently lower scores across all conditions. This arrangement of subscale scores would indicate the VE systems did not appreciably induce any visual difficulties, but in various conditions did for nausea and disorientation.

The severity of symptoms rarely reached the extreme level, as indicated with the various measures or as observed by the experimenter. Most subjects, when they did experience symptoms, experienced them at mild to moderate levels. Furthermore, subjects typically developed only a few symptoms rather than a wide range of side effects. Only a few subjects required any post-session monitoring beyond the prescribed hour for any symptoms experienced.

The most compelling evidence that the VEs under study did not induce overly severe symptoms (i.e., nausea) is that no subjects dropped out of the experiment. A few subjects were forced to stop a session on a particular day, but all continued to the end of the four days. This occurred despite some subjects experiencing moderate to severe levels of side effects on the first day.

It was unsurprising that symptoms were limited to the mild and moderate levels. The VEs were designed to limit symptoms due to ethical and experimental constraints surrounding purposely inducing side effects in participants. A larger range of side effect inducing conditions would likely have had a considerable effect on the statistical power of the tests used in this study. Limiting of VEs effectively eliminated higher levels of side effects which would have had much higher contrast with some of the lower levels found in this study.

Head-Tracking

Based on the pilot study and literature review, conditions where subjects had the ability to move their head around and have the scene change (head-tracking) were expected to have higher incidence and severity of negative side effects experienced than conditions without. The results for the present study show some evidence to support this statement.

The only analysis to support the hypothesis that head-tracking affects levels of negative side effects experienced involves the total severity score univariate ANOVA from the MANOVA. In the

univariate using total severity score difference as a dependent measure, a main effect for head-tracking was narrowly significant. A closer look at the values for the means can yield more insight into the practical significance of this effect.

The graph of the means, Figure 19, shows head-tracking on with a mean total severity score over 21, and head-tracking off with a mean under 12. Kennedy et al. (1994) recommended to the Navy and Marine Corps that all flight simulator pilots scoring over a 20 on the SSQ be warned of their condition and not be permitted to leave the premises. Subjects with scores under 15 were deemed fit to resume normal activities. The values in this study directly compare to these recommendations.

In the present study, participants themselves often noted head-tracking (scene movements changing with head movements) as a cause for their symptoms. There is some question as to why the effect was not stronger, or did not even reach significance in most of the analyses. Participants certainly moved their head around extensively when the head-tracking was on. Subjects occasionally from moving their head around so much would snag the cables that came out of the HMD. Some instances were observed of participants holding their head still while head-tracking was on. These instances mainly occurred already after negative side effects were being experienced.

Observing the symptom profiles from the VESEQ for the respective task environments, the conditions with head-tracking on have considerably higher values for the nausea subscale while the oculomotor and disorientation subscales remain relatively unchanged. It would appear that head-tracking caused some nausea symptoms in subjects while not contributing to either oculomotor or disorientation symptoms. Nausea may be a direct symptom of head-tracking that an overall measure of negative side effects does not capture well. The measures used in this study may have been too broad to get strong significance for such a specific response inducing variable.

The other analysis that yielded information on head-tracking was the ANOVA analyzing the independent variables time, head-tracking, and task environment as measured by sickness magnitude estimates. These results showed a significant interaction between time and head-tracking. The incidence and severity of negative side effects increased over time at a higher rate when head-tracking was on than when it was off. Head-tracking does appear to at least exacerbate the experience of negative side effects if not directly induce them.

Task Environment

As with head-tracking, task environment was expected to show strong significance. The maze was expected to yield higher incidence and severity of negative side effects than the office due to the many turns required by the navigation. Similar to the head-tracking results, however, some analyses supported this hypothesis and others did not.

Like head-tracking, it was one of the univariate analyses from the non-significant MANOVA that showed a significant effect for task environment. Different from head-tracking was the dependent measure used in the univariate that showed the significant result. Measured by total severity scores, only head-tracking is significant; measured by sickness magnitude estimate differences, only task environment is significant. Unlike the head-tracking main effect, the task environment main effect in this case is quite strong.

An examination of the means shows that participants, on average, rate negative side effects in the maze over three times as severe as the office. The reader is cautioned against comparing sickness magnitude estimate values with VESEQ values. The numbers may appear smaller than with the total severity scores, but the true power in the sickness magnitude estimates is the ratio scale created through magnitude estimation. The estimate in any condition alone is not as valuable

as a comparison between estimates. In this case, the maze estimate is over 7 and the office estimate is near 2.5.

The need to navigate the maze appears to cause the difference in negative side effects experienced between the two conditions. Subjects often got lost in the maze, nearly always returning to the beginning square before eventually finding a path to the ending square. Many participants never found the ending square. Side effects symptoms, including frustration, seemed to be linked to the amount of navigation needed to traverse the maze.

Frustration was a factor of the maze that was not apparent in the office. Subjects would become frustrated at getting lost, or not being able to find the ending square, sometimes accusing the experimenter of lying that there was one. While no participant was truly upset, frustration did appear in the maze and not in the office. In the office, boredom was the side product akin to frustration in the maze.

Participants appeared to include this frustration aspect as part of their overall rating for how they came up with the sickness magnitude estimate for that period of time. As time went on and the ending square still was not found, frustration, and the sensation of negative side effects, would grow. This highlights an interesting aspect of sickness magnitude estimates, in that it encompasses more than just normal physical ailments due to motion sickness. Psychological components of motion sickness-like side effects, which are often overlooked, can be captured by magnitude estimation.

Some participants cited the monotony of the maze walls as a cause for their symptoms. The implication is that the continual movement of similar appearing items (the maze walls) was the cause for negative side effects, not the actual navigation through the maze. This would indicate more detail in the scene would lead to less negative side effects experienced. The office condition certainly had more detail than the maze. A maze with designer walls may have elicited less negative side effects.

As with head-tracking, the analysis incorporating time, measured with sickness magnitude estimates for all levels of time within session (0, 5, 10, 15, 20, 25, and 30 minutes), yielded an interaction between time and task environment. The experience of negative side effects worsened over time at a faster rate in the maze than in the office. The maze does not appear to exacerbate the experience of negative side effects like head-tracking, but does increase the anxiety of the situation.

The symptom profiles for the two environments support the “disorientation” participants felt when traversing the maze. The disorientation subscale score for both maze conditions was higher than those for both office conditions. The scores were in the 20 to 30 range for maze and near 10 for the office. The other two subscales did not differ noticeably between the two task environments.

It is interesting to note that while head-tracking and task environment showed significance in two separate analyses, nowhere did an expected interaction between the two result. Post-session comments by subjects alluded to this possible relationship. The interaction approached significance in the analysis including time as measured by sickness magnitude estimates, but did not reach the $\alpha = .05$ level. It was expected that head-tracking would cause more negative side effects in the maze environment than head-tracking in the office environment.

Time

The impact of time on side effects experienced was expected to vary in two distinctly different ways. As time continued within a session, the experience of negative side effects was expected to

increase due to length of immersion. As time continued between sessions, the experience of negative side effects was expected to decrease due to adaptation. The results supported one of these hypotheses and not the other.

Time within a session showed significantly higher incidence of side effects in the ANOVA examining the independent variables time, head-tracking, and task environment, and the ANOVA examining the independent variables time and day, as measured by sickness magnitude estimates. The main effect for time is the same in both analyses as the data set is the same.

The graph of means for time, Figure 21, shows a linear trend of increasing sickness magnitude estimates throughout the session. The difference in means between the estimate for the last time of the session and the first time is nearly double in magnitude. These results are consistent with Regan (1993, 1994, 1995) who analyzed nausea over time in VE sessions. Regan also found a consistently linear increase in negative side effects (nausea) over time. In neither experiment was there a leveling off of negative side effects. Both studies ceased testing at the 30 minute time period. For subjects who do experience side effects, only a continuing worsening of symptoms over time can be expected.

Time between sessions, or the difference from day to day, did not approach significance in any analysis. Adaptation was expected to occur as the subjects gained more experience in the VEs. This was not the case according to the data. Subjective comments made by participants indicated that adaptation did occur for some individuals, but not others. A heavy experimental investment was made in an effort to find an adaptation effect with no result. However, the number of days may not have been enough to show the effect, more sessions may be needed to find a true adaptation phenomenon.

Correlations

While none of the correlations analyzed lead to a true predictor of motion sickness in VEs, there are interesting results to discuss. Eleven significant correlations from the 420 calculated show significance at the $\alpha = .01$ level. Some were expected, others were surprising, and a couple are not entirely explainable. With so many correlations tested, there is a possibility of erroneous results due to statistical chance. The correlations that did reach significance at the a = .01 level are assumed for the purposes of discussion to be real effects.

The correlation between age and stereo vision acuity was not expected, however, the result is unsurprising. Without looking at the data one would suspect stereo vision acuity to decrease with age. The data plot in Appendix G, Figure 33, shows this relationship. It appears, unfortunately, that along with the deterioration of near and far vision acuity with age, the ability to discern objects at depth using stereo vision also decreases. The age range of subjects for this study was 18 to 34.

The correlation between gender and carsickness was not totally unexpected. Motion sickness studies commonly report females as having higher incidence and severity of side effects than males for a variety of sickness related factors. However, it was unusual that in this research gender was not correlated with any other measures that captured motion sickness than carsickness. The relationship, as expected, is that females report more incidence of carsickness than males.

An alternative hypothesis to females experiencing more carsickness than males involves who might be driving the car. Passengers have been shown to experience more motion sickness than drivers (Paush et al., 1992) . The same situation occurs in aircraft with the controlling pilot not experiencing symptoms while the co-pilot often does. If female participants in this study are more often passengers than drivers, this would lead to more carsickness in females. By common cultural tradition, the male is often the driver with the female as the passenger. No information on

this arrangement was collected, the hypothesis is suggested only as an alternative explanation to higher female carsickness.

Perceived overall susceptibility to motion sickness was correlated with pre-experiment perceived chances of experiencing negative side effects. It was fully expected that these two variables would correlate. Participants who have experienced a lot of motion sickness would expect to get motion sick in a motion sickness study. The data plot, as shown in Appendix G, Figure 35, supports this relationship.

The correlations involving the rod and frame test are both the most interesting and most confusing of all the results. The three variables that significantly vary with deviation on the rod and frame test are perception of flying in aircraft, riding in an elevator, and swinging in a swing. Each of the data plots, Appendix G, Figures 36, 39, and 40, show that a dislike for the respective variables is correlated with a higher deviation in the rod and frame test.

Each of the variables listed involve a situation where participants are in an environment that has a separate "field" from the rest of the world. The plane, the elevator, and the swing are the field, which are distinctly separated from the rest of the real world by their respective enclosures and/or movements. The RFT test directly measures such a phenomenon called field dependence/independence. Subjects with higher deviations in the rod and frame test are said to be field dependent. Their positioning of the rod is influenced by the frame (the field). In these relationships, subjects who tend to be field dependent (higher deviations), tend to dislike flying in aircraft, riding elevators, and swinging in swings. Subjects who tend to be field independent (lower deviations) tend to like flying in aircraft, riding in elevators, and swinging in swings.

Unfortunately, why this is the case is difficult to interpret. Field independent individuals are said to be more sensitive to body cues or the lack of body cues. They are supposed to be more in tune with what is really happening in relation to the rest of the world. Field dependent individuals are more likely to immerse themselves into a situation (plane, elevator, swing, VEs) with less attention paid to outside cues.

Why immersion-individuals dislike flying, swinging, etc., is unclear. Or why tuned-with-world individuals like flying, swinging, etc., is also unclear. The research involving field dependence/independence contains many conflicting results and opinions about what exactly it means to be field dependent or field independent (Frank, 1986). These results offer no solution to the confusion on this issue.

Two relationships involve correlates that are mutually liked, or disliked, by subjects. Perception of riding in an elevator was correlated with perception of riding in an automobile and swinging in a swing was correlated with riding in an automobile. Neither of these results are surprising. People who are comfortable with movement are comfortable with movement in many situations.

One test that held promise for being a possible predictor of negative side effects was the mental rotation test. However, the mental rotation test only showed a significant correlation with pre-experiment perceived chances of experiencing negative side effects. This relationship, shown in Appendix G, Figure 41, shows that subjects with higher mental rotation scores thought they were unlikely to experience negative side effects from immersive VEs.

The correlation between postural stability and sickness magnitude estimates was not unexpected. However, a meaningful interrelationship between the two dependent measures would have been more meaningful in the MANOVA had it turned out significant. The relationship in Appendix G, Figure 42, simply shows that low balance scores are correlated with high sickness magnitude estimates, both indicators for negative side effects.

Sickness Magnitude Estimates as a Measure

Measuring motion sickness is a seemingly simple task; however, the complex phenomenon has led to a variety of semi-effective methods to capture its essence. The new attempt in the present study is magnitude estimation of the negative side effects experienced, or the overall sense of well-being. The use of magnitude estimation provides several advantages described earlier. The question here is, was the measure successful as anticipated?

First, participants had no problem understanding the concept of magnitude estimates or understanding how to use them in the context of negative side effects experienced. Magnitude estimation has been used for a wide variety of stimuli, but not usually on one so multifaceted as the overall sense of well-being. The terminology "overall sense of well-being" became the standard phrase for requesting an estimate from participants during the pilot testing. An issue that continued throughout the whole study was how to rate the initial estimate. No "sickness" was felt at time zero, but an estimate could be made when a participant was asked about their overall sense of well-being. Only in one instance did this terminology not work out as intended.

One participant in their first session reported estimates that dramatically decreased from the first estimate until the last. The second to last estimate was 10 times smaller than the first estimate. The problem comes in analysis and interpretation, where it appears the subject entered the study at an inordinately high level of negative side effects experienced. This was not the case. Based on comments made during the session and some post-experimental questioning, the participant experienced overly heightened anxiety and apprehension prior to the first session. The subsequent immersion into the VE proved so enjoyable that the negative initial feelings were replaced by feelings of joy, happiness, and fun. The measure did indeed capture the overall sense of well-being, but not any experience of negative side effects (of which there were none). An examination of the VESEQ showed that the questionnaire provided no indication of any side effects either.

Rather than a negative, this situation highlights a strength of magnitude estimation. Physiological measures can only capture specific information about the body. Questionnaires can only capture information that is requested. Open ended questions could be asked, but then conversion into data ready for parametric analysis becomes an issue. Magnitude estimation has the ability to capture information that was not explicitly requested. The range of varied side effects possible in motion sickness requires a measure capable of capturing such information.

Motion sickness has many symptoms that researchers compose into long lists in attempts to describe the phenomenon. There are surely many other more subtle symptoms that are not known. Magnitude estimation allows capture of the traditional symptoms along with the more subtle ones if the subject is able to recognize they are there. It is not necessary to describe in words what is happening, they may be unable to, it is only necessary to realize something is not normal. The incident described above illustrates that this effect seems to be happening; however, without extensive questioning it would be difficult to determine to what extent.

A second issue with magnitude estimation for negative side effects is the data conversion. Strict use of magnitude estimation would dictate several measures made at the same stimulus. It is impossible to obtain the exact same stimulus for any two sets of measures in this use of magnitude estimation. The stimulus in this case is the state of the human body in its present state. For repeated measures, the exact same conditions would need to be replicated (head-tracking, environment, and the seven estimate times). However, this does not guarantee the same body conditions will develop. The phenomenon of adaptation to motion sickness precludes obtaining the same scale from day to day, even if the conditions are identical. The danger in taking only single measurements is the scales created by the subjects might not be correctly related. One role of the practice line estimates was to ensure against this possibility. There was no indication in the present study that any problems in data conversion occurred.

There are additional questions regarding magnitude estimation. The most interesting one is why did the pattern of results differ from those of the VESEQ total severity scores? The likely explanation is the measures are capturing slightly different information. It was already described above how magnitude estimation may be measuring additional factors that the questionnaire was unable to detect. It cannot be conclusively said, however, that the two would not capture similar results in a larger more focused study with more statistical power.

Given the issues discussed above, magnitude estimation proved to be a highly successful measure for side effects experienced in VEs. The measure was expected to be quickly and easily administered. Despite initial fears that magnitude estimation might be difficult to understand for subjects, the measure was very easy to use for both subjects and experimenter. The measure was expected to capture a wider range of side effects that could develop in VEs than other measures. The frustration, anxiety, boredom, and other effects that were unexpected did appear to be captured by magnitude estimation.

The greatest strength of magnitude estimation is the ratio scale data that results. Given that negative side effects are correctly measured, the ratio scale information can be used to compare scenarios directly in ratio terms. In this study, comparisons were made to show effect size. The ratio scale allowed statements such as the maze environment resulted in eight times worse experience of side effects than the office environment, and the end of the session resulted in nearly twice the experience of side effects than the beginning of the session. The pseudo-interval scale created by the VESEQ cannot claim such power.

Conclusions

Conclusions can be made from this research on several of the hypotheses stated earlier. Given that results are highly dependent on the VE system under study, all the following conclusions strictly pertain to the current equipment configuration. However, generalizations to other immersive VE systems are appropriate.

- Head-tracking was the main factor of the VE setup that was expected to induce negative side effects. This research showed that head-tracking does produce more negative side effects in users.

- Task environments, maze and office, were expected to differ widely in their effects on inducing negative side effects. This research showed that the maze does produce more negative side effects than the office.

- Negative side effects over the time within a session were expected to differ. This research showed that negative side effects worsen over time at a constant rate.

- Negative side effects over time between sessions, from day to day, were expected to differ. This research cannot conclusively say that experience of negative side effects differed from one day to the next.

- Performance in the maze task was expected to vary with the severity of negative side effects experienced. This research cannot conclusively say that performance varied with severity of negative side effects experienced.

- Factors were looked at to determine if any predictive ability could result. This research cannot conclusively say that any factors have predictive capabilities for negative side effects.

- Magnitude estimation as a measure for negative side effects experienced in immersive VEs was expected to be useful and effective. Based on the results of the study, magnitude

estimation was a successful and effective measure of negative side effects induced by immersion into VEs.

- Magnitude estimation was also expected to have a strong relationship with postural stability and VESEQ total severity scores. This research cannot conclusively say such relationships do or do not exist. Magnitude estimation was also expected to have similar result profiles to those of postural ability and magnitude estimation. This research showed that magnitude estimation does not have similar result profiles to postural stability or VESEQ total severity scores.

The conclusions for the present research represent a small contribution to the larger research topic of motion sickness in VEs. The future is full of ample opportunities for continued research in the area.

Future Research

This research focused highly on the variables associated with the virtual task and the VE. Head-tracking is just one of many factors that may contribute to side effects experienced in immersive VEs. The various parameters that were not tested specifically that made up the task environments certainly contribute to side effects experienced. The host of variables associated with the display system (i.e., field of view, resolution, luminance contrast, etc.) were not manipulated. However, the importance of these factors in current technology is still a heavy consideration when discussing what causes side effects. A systematic evaluation of each of these factors, whether involving the VE task, the VE system hardware, or the very real individual, needs to be done to determine which of these factors can be ignored and which are true causes of side effects. An empirical model indicating what factors are more likely than others to induce negative side effects in VEs would be invaluable.

Adaptation is a well accepted fact among researchers of simulators and VEs. A study designed to look only at adaptation would likely show these effects. The current study had variations to the VE across each of the four days that may have hindered adaptation.

A potential predictor for side effects experienced in users remains an elusive goal. Many other attempts at predicting which users may experience negative side effects has failed. A focused effort on finding and developed a priori predictors of users experiencing negative side effects would be of great use to all users and potential users of VEs.

Future work extending the magnitude estimation measure could involve on-line use for capturing data in the VE itself rather than verbally requesting an estimate. The on-line application of magnitude estimation could further reduce the impact of the experimenter on measurement. A second adaptation of the magnitude estimation measure could involve taking estimates on three defined areas of side effects corresponding to the three subscales of the VESEQ. Total severity scores could then be computed to provide the overall level of side effects experienced. Perhaps the most intriguing possibility involving magnitude estimation of subjective experience in VEs is the potential to measure multiple psychophysiological phenomenon of VEs at one time. The relationship between presence and side effects could be captured with the use of two magnitude estimates at one time.

The ongoing development of VE systems depends in part on our ability as researchers to offer the user an enjoyable and productive interaction without negative side effects. This research hopes to bring us closer to that goal by demonstrating that magnitude estimation is an effective measurement method for negative side effects experienced in immersive VEs. This research also begins the effort to determine with certainty what variables induces negative side effects in VEs by investigating head-tracking and task environment.

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APPENDIX A: VIRTUAL REALITY SIDE EFFECTS QUESTIONNAIRE

VIRTUAL REALITY SIDE EFFECTS QUESTIONNAIRE

Date:_____

Subject #:_____

Side Effects from Virtual Reality Survey adapted from the Simulator Sickness Survey of the Essex Corporation, 1040 Woodcock Road, Orlando, FL 32803

PART I: PRE-SESSION ASSESSMENT

1. Have you been ill in the past week?

   Yes _____ No _____ If yes, please provide the following information:

   Nature and length of illness (include major symptoms):

   Are you fully recovered? Yes _____ No _____

2. How much alcohol have you consumed in the last 24 hours?

   # Beers _____ Ounces of Wine _____ Ounces of hard liquor _____

3. Please indicate any medication you have used in the past 24 hours:

   None _____

   Sedatives or tranquilizers _____

   Aspirin, Tylenol, other analgesics _____

   Anti-histamines _____

   Decongestants _____

   Other _____

   Specify:

4. How many hours sleep did you get last night?

   Hours _____

5. Please list any other comments regarding your present physical state which might affect your performance.

6. Assess your physical condition by circling the appropriate response below for each symptom.

General discomfort	none	slight	moderate	severe
Fatigue	none	slight	moderate	severe
Boredom	none	slight	moderate	severe
Drowsiness	none	slight	moderate	severe
Headache	none	slight	moderate	severe
Eye strain	none	slight	moderate	severe
Difficulty focusing	none	slight	moderate	severe
Increased salivation	none	slight	moderate	severe
Decreased salivation	none	slight	moderate	severe
Sweating	none	slight	moderate	severe
Nausea	none	slight	moderate	severe
Difficulty concentrating	none	slight	moderate	severe
Mental depression	none	slight	moderate	severe
"Fullness of the Head"	none	slight	moderate	severe
Blurred vision	none	slight	moderate	severe
Dizziness with eyes open	none	slight	moderate	severe
Dizziness with eyes closed	none	slight	moderate	severe
[1]Vertigo	none	slight	moderate	severe
[2]Visual flashbacks	none	slight	moderate	severe
Faintness	none	slight	moderate	severe
Over awareness of breathing	none	slight	moderate	severe
[3]Stomach awareness	none	slight	moderate	severe
Loss of appetite	none	slight	moderate	severe
Increased appetite	none	slight	moderate	severe

Desire to move bowels	none	slight	moderate	severe
Confusion	none	slight	moderate	severe
Burping	none	slight	moderate	severe
Other:				

[1] Vertigo is experienced as loss of orientation with respect to vertical upright.
[2] Visual illusion of movement or false sensations.
[3] Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

** STOP HERE **

PART II: POST-SESSION ASSESSMENT

1. Assess your physical condition by circling the appropriate response below for each symptom.

General discomfort	none	slight	moderate	severe
Fatigue	none	slight	moderate	severe
Boredom	none	slight	moderate	severe
Drowsiness	none	slight	moderate	severe
Headache	none	slight	moderate	severe
Eye strain	none	slight	moderate	severe
Difficulty focusing	none	slight	moderate	severe
Increased salivation	none	slight	moderate	severe
Decreased salivation	none	slight	moderate	severe
Sweating	none	slight	moderate	severe
Nausea	none	slight	moderate	severe
Difficulty concentrating	none	slight	moderate	severe
Mental depression	none	slight	moderate	severe
"Fullness of the Head"	none	slight	moderate	severe
Blurred vision	none	slight	moderate	severe
Dizziness with eyes open	none	slight	moderate	severe
Dizziness with eyes closed	none	slight	moderate	severe
[1]Vertigo	none	slight	moderate	severe
[2]Visual flashbacks	none	slight	moderate	severe
Faintness	none	slight	moderate	severe
Over awareness of breathing	none	slight	moderate	severe
[3]Stomach awareness	none	slight	moderate	severe
Loss of appetite	none	slight	moderate	severe

Increased appetite	none	slight	moderate	severe
Desire to move bowels	none	slight	moderate	severe
Confusion	none	slight	moderate	severe
Burping	none	slight	moderate	severe
Other:				

[1] Vertigo is experienced as loss of orientation with respect to vertical upright.
[2] Visual illusion of movement or false sensations.
[3] Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

2. If symptoms were experienced, what do you think caused them?

3. Describe any unusual events that occurred during your session?

4. Describe any problems you observed in the visual presentation of information.

5. Describe any other problems you encountered.

APPENDIX B: MOTION SICKNESS HISTORY QUESTIONNAIRE

MOTION SICKNESS HISTORY QUESTIONNAIRE

Date:_____

Subject #:_____

Motion History Questionnaire adapted from the Motion History Questionnaire of the Essex Corporation, 1040 Woodcock Road, Orlando, FL 32803

1. Date of birth _____

2. Gender M / F

3. Do you have any medical condition involving the heart or circulation? If yes, please provide the following information:

Nature of condition:

Major symptoms:

Does this condition affect your day to day activities? Yes _____ No _____

4. Are you in your usual state of fitness?

Yes _____ No _____ If no, please indicate reason.

5. In general, how susceptible to motion sickness are you?

Extremely_____ Very_____ Moderately_____ Minimally_____ Not at all_____

6. Have you been nauseated for any reason (including flu, alcohol, etc.) during the past eight weeks?

Yes_____ No_____ If yes, under what conditions:

7. Most people experience slight dizziness (not as a result of motion) three to five times a year. The past year you have been dizzy:

Greater than 3-5 times_____ 3-5 times_____ Less than 3-5 times_____ Never dizzy_____

8. Have you ever had an ear illness or injury which was accompanied by dizziness and/or nausea?

Yes_____ No_____ If yes, describe the illness:

9. From any experience in the air, how often would you say you get airsick?

Always_____ Frequently_____ Sometimes_____ Rarely_____ Never_____

10. From any experience at sea, how often would you say you get seasick?

Always_____ Frequently_____ Sometimes_____ Rarely_____ Never_____

11. From any experience in cars, how often would you say you get carsick?

Always_____ Frequently_____ Sometimes_____ Rarely_____ Never_____

12. Have you ever experienced any sort of simulator sickness?

Yes_____ No_____ If yes, describe the simulator and simulation:

Describe the symptoms. Include how long they lasted:

What do you think caused the problem:

13. Indicate a preference for the following devices/situations and circle any symptoms of motion sickness that your have experienced using them.

Aircraft

Like_____ Dislike _____ Neutral_____

Symptoms: none, headache, awareness of breathing, vertigo, pallor, sweating, drowsiness, dizziness, salivation, stomach awareness, nausea, vomiting, other:_____

Automobiles

Like_____ Dislike _____ Neutral_____

Symptoms: none, headache, awareness of breathing, vertigo, pallor, sweating, drowsiness, dizziness, salivation, stomach awareness, nausea, vomiting, other:_____

Cinerama or Wide-Screen Movies

Like_____ Dislike _____ Neutral_____

Symptoms: none, headache, awareness of breathing, vertigo, pallor, sweating, drowsiness, dizziness, salivation, stomach awareness, nausea, vomiting, other:_____

Elevators

Like_____ Dislike _____ Neutral_____

Symptoms: none, headache, awareness of breathing, vertigo, pallor, sweating, drowsiness, dizziness, salivation, stomach awareness, nausea, vomiting, other:_____

Long train or bus trips

Like_____ Dislike _____ Neutral_____

Symptoms: none, headache, awareness of breathing, vertigo, pallor, sweating, drowsiness, dizziness, salivation, stomach awareness, nausea, vomiting, other:_____

Merry-go-round

Like_____ Dislike _____ Neutral_____

Symptoms: none, headache, awareness of breathing, vertigo, pallor, sweating, drowsiness, dizziness, salivation, stomach awareness, nausea, vomiting, other:_____

Swings

Like_____ Dislike _____ Neutral_____

Symptoms: none, headache, awareness of breathing, vertigo, pallor, sweating, drowsiness, dizziness, salivation, stomach awareness, nausea, vomiting, other:_____

14. Have you ever been motion sick under any conditions other than the ones listed?

Yes_____ No_____ If yes, under what conditions:

15. If you were in an experiment where 50% of the subjects get sick, what do you think your chances of getting sick would be?

Certainly _____ Probably_____ Not sure_____ Probably not_____ Certainly not_____

APPENDIX C: INFORMED CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Measuring Side Effects in Immersive Virtual Environments

Investigator: Mike McGee

I. The Purpose of this Research

The purpose of this research is to compare subjective measures of side effects that develop from immersion into virtual environments (VEs).

II. Procedures

The virtual reality (VR) equipment was a helmet mounted display (HMD) for presenting graphics, a space mouse for navigating the VE, and a regular computer mouse for interacting with objects in the VE.

Your eligibility was determined by a Pre-Session Side Effects Questionnaire and vision tests. You will not be allowed to participate if you are ill with cold or flu symptoms, on certain medications, have pre-existing medical conditions involving the heart or circulation, or have any currently existing symptoms of motion sickness. Normal or corrected visual spatial acuity must be 20/40 or better (tested on a typical Bausch & Lomb vision tester). Upon determined eligibility, you will complete an additional questionnaire, a postural stability assessment (using stand on right/left leg test), a mental rotation assessment (using a written choice selection test), and a practice session with the VR equipment. A 30 minute session in the VE will then be conducted. Upon exiting the VE you will again be tested for vision and postural stability. Finally, a third questionnaire was filled out at the end of the session.

The experiment was conducted over four sessions separated by at least 24 hours. In each session you will complete the VE experimental tasks by following instructions from the experimenter. The sessions will differ by the virtual task environment in which the experiment will take place. Experiment time should not exceed two hours per session.

The experiment is being held in the rooms of the Human Computer Interaction Laboratory (HCIL) directed by Dr. Robert C. Williges. The HCIL is located in the Industrial and Systems Engineering Department, room 530 on the fifth floor of Whittemore Hall. Two rooms of the HCIL was used: one to run the VR portion of the experiment, and one to serve as a pre-screening and waiting room.

III. Risks

There are some risks to you in this study. The nature and content of VR present no inherent danger, unpleasant experiences, or emotional distress. However, different individuals may experience motion sickness-like side effects due to immersion into VR. Possible side effects include minor discomfort, blurred vision, disorientation, slight headaches, and nausea. If symptoms develop you was asked to stay with the experimenter in a waiting room for one hour after leaving the VE. All symptoms should dissipate in this rest period. If after one hour of rest

you or the experimenter feel that you should refrain from driving home, the experimenter will be available to drive. It is possible for some mild variations of the symptoms to appear and linger over the course of up to a day following the experiment.

IV. Benefits of this Project

This research will assist in ongoing efforts to determine if there are side effects to VR and what the causes might be. Determination of causes and evaluation of the symptoms will allow technological and intuitive improvements to VR for all future users to enjoy without side effects.

While this research should yield benefits to the above stated goals, no promise or guarantee is offered. Participation in this project should not depend on a guarantee of benefits.

You may contact the investigators listed at the end of this consent form to inquire about the results and conclusions of this research.

V. Extent of Anonymity and Confidentiality

You was identified only by a subject number in data analysis. No written results of this study was traceable to a participant by name.

VI. Compensation

You will be paid $5 per hour.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time without penalty. If you choose to withdraw, you was compensated for the portion of the time of the study completed, rounded up to the hour. You are free not to answer any questions or respond to any experimental situations that you choose without penalty.

There may be circumstances under which the investigator may determine that you should not continue the experiment. You was compensated for the portion of the project completed.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University.

IX. Subject's Responsibilities

I voluntarily agree to participate in this study. I agree to undergo the procedures of this experiment as described above.

X. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

_____ _____

Signature Date

A copy of this Informed Consent form was provided to you.

Should you have any questions about this research or its conduct, you may contact:

Mike McGee
Investigator
(540) 231-8293

Dr. Robert C. Williges
Faculty Advisor
(540) 231-6270

H.T. Hurd
Director, Sponsored Programs
Research Division
(540) 231-5281

APPENDIX D: INSTRUCTIONS:

INTRODUCTION AND GENERAL INSTRUCTIONS

This experiment in part is attempting to develop a measure for side effects experienced in virtual reality (VR). It is also attempting to develop a process of predicting who might and who might not experience side effects in VR. This was accomplished by a series of pre-VR tests and then immersions into virtual environments.

You will undergo screening as described in the consent form in the first session. Passing these tests you will undergo two additional assessments. These are mental rotation ability and perceptual style. These assessments was described to you by the experimenter. These are assessments only, not pass/fail tests; however, the experiment is designed to fill specific categories of mental rotation ability and perceptual style. You may not fit the slots needed to fulfill the experimental design. You was compensated accordingly if this is the case.

If you do qualify for the study you will fill out an additional questionnaire, receive a measurement for balance, and then begin the VR portion of the study. The additional questionnaire is involved with the development of a measure for VR side effects. Additional instruction was provided to you on this measurement method to be used during the actual VR session.

You may or may not experience side effects during this study. You should not expect symptoms to develop, just acknowledge any that do. At worst nothing more than moderate nausea should occur. If more extreme symptoms develop, inform the experimenter immediately.

Please ask all questions you have before the VR experimental session begins. The experimenter was happy to explain anything involved in the experiment to you. There are no hidden agendas in this research.

After the VR session you will receive an additional questionnaire, and repeat the vision and balance tests. In addition any symptoms that did develop was monitored to make sure they dissipate before leaving the laboratory, up to an hour after the study. Inform the experimenter at that time if you feel you need additional assistance.

This experiment is conducted over 4 sessions, separated by at least 24 hours. Each session should take no more than 2 hours.

MAGNITUDE ESTIMATION INSTRUCTIONS

During this experiment you was asked to assign a number to quantify your experience of negative side effects from the virtual reality. Negative side effects may include headaches, dizziness, vertigo, nausea, eyestrain, sweating, confusion, burping, salivation, stomach awareness, difficulty focusing, blurred vision, disorientation, dizziness, or other symptoms. Your job is not to assign a number based on the magnitude of any one side effect, but the impact all the side effects have on your overall feeling of well being. This number may be any number that you feel is appropriate. You was asked for a number every five minutes of the experiment to assess your perceived level sickness. Any number may be assigned in your first rating. Subsequent number assignments should be based on this first number. If you feel twice as sick as you did previously, assign a number twice as large as you did before. If you feel 10 times as sick, assign a number 10 times as large. If you feel half as sick, assign a number half as large. There is no upper restriction on the numbers you are allowed to use. You are asked to limit your number assignments to positive numbers. You may use decimals or fractions as you deem necessary.

Please ask any questions at this time, it is important this concept is understood.

To practice this number assigning procedure, you will use it to judge the length of 20 lines. These lines was presented to you one at a time in a random order. Assign a number to each line that matches your impression of its length. Assign any number to the first line that seems appropriate.

MAZE TASK INSTRUCTIONS

You will complete navigation through a virtual maze for a period of 30 minutes. The starting square is white. The ending square is black. The experimenter will reset the maze after each successful completion of the maze. A "car" was provided as the navigation device in the virtual world. It is controlled through the use of a space mouse. The space mouse is configured to traverse forwards and backwards and turn left and right. The helmet is configured to look up, down, left, and right, roll left and right, and traverse forward, backward, up, and down. No actual traversing from the helmet will occur as you will remain stationary in a chair. The car will have a blue tip at its front edge that tapers off to the left and right. Use the blue tip to re-position yourself as you look around the maze. The left and right turning of the space mouse has been dampened to encourage you to use your head to look around the maze for correct paths. Navigate the maze as quickly as you can with as few wrong turns and bumps into the walls as possible. An audio cue is present to indicate a bump into a wall. Instructions for the use of the space mouse and the helmet mounted display was provided by the experimenter.

OFFICE TASK INSTRUCTIONS

You will explore and interact with an office environment for a period of 30 minutes. The exploration was guided by an instruction board in the virtual environment. The instruction board messages can be cycled through from one to the next, and back if necessary, by two activation buttons to the side of the board. The messages are numbered. Please proceed through the messages in order. The messages sometimes skip by quickly when using the activation buttons, make note on which number message you are on and go back if needed. The experimenter will demonstrate the instruction board before the experiment begins. This is not a timed session. You do not need to finish all the instructions in the message board. The directions are merely activities to fill the 30 minute time period. You are encouraged explore as you complete the instructions. Instructions for the use of the space mouse, regular mouse, and helmet mounted display was provided by the experimenter.

ROD AND FRAME INSTRUCTIONS

The purpose of this test is to determine how well you can establish the upright (that is vertical) under various conditions. Vertical or upright is defined as parallel to the outside walls of this building and perpendicular to the floor of this room. You will be asked to close your eyes upon entering a darkened testing room. When instructed, you will open your eyes and see a square frame and within it a rod (see the figure below). The experimenter can tilt the frame or the rod to the left or right, either independently or together. On each trial you are to describe the initial positions of the rod and of the frame, and then direct the experimenter in adjusting the rod to true vertical position. If you perceive that the rod is not vertical, tell which direction to move the rod to make it vertical. The experimenter will turn the rod a little at a time. After each turn if you still perceive the rod as tilted, say so. There is no limit to the number of times you can ask for the rod to be moved in either direction. When you perceive the rod to be vertical, say so. The experimenter will direct you to close your eyes again while a small light is turned on and the rod and frame are reset for the next trial. It is important for your eyes to stay adjusted to the dark room. Eight trials will be performed.

If you have any questions feel free to ask them now or during the experiment.

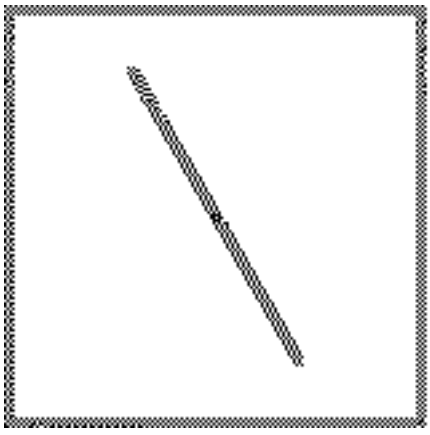

Figure. The rod and frame apparatus.

APPENDIX E. THE POST-EXPERIMENT QUESTIONNAIRE

Circle the response that describes your agreement or disagreement with the following statements.

1. I believed in the virtual reality illusion, felt a sense of presence in the environments, and felt immersed in the virtual worlds.

1 - Strongly agree 2 - Agree 3 - Somewhat agree 4 - Indifferent 5 - Somewhat disagree 6 - Disagree 7 - Strongly disagree

2. I use computers often.

1 - Strongly agree 2 - Agree 3 - Somewhat agree 4 - Indifferent 5 - Somewhat disagree 6 - Disagree 7 - Strongly disagree

3. I enjoyed the experiment.

1 - Strongly agree 2 - Agree 3 - Somewhat agree 4 - Indifferent 5 - Somewhat disagree 6 - Disagree 7 - Strongly disagree

APPENDIX F. MAGNITUDE ESTIMATION CALCULATIONS FOR LINE LENGTH

Table 15. The raw data estimates.

sub	line 1	line 2	line 3	line 4	line 5	line 6	line 7	line 8	line 9	line 10
1	1.0	3.0	4.0	6.0	6.0	10.0	8.0	10.0	11.0	11.5
2	1.0	2.0	3.0	4.0	5.0	7.0	10.0	10.0	12.0	15.0
3	20.0	40.0	50.0	60.0	100.0	85.0	101.0	150.0	160.0	170.0
4	2.0	4.0	5.0	5.0	6.0	7.0	8.0	8.0	8.5	9.0
5	1.0	3.0	4.0	5.0	6.0	6.0	7.0	7.0	8.0	9.0
6	1.0	2.0	3.0	4.0	5.0	6.0	6.0	8.0	9.8	10.0
7	1.0	2.0	2.5	4.0	6.0	6.0	7.0	7.5	8.0	9.0
8	1.0	2.0	3.0	4.0	5.0	4.0	5.0	6.0	6.0	8.0
9	1.0	2.0	3.0	4.0	5.5	6.0	7.0	9.0	9.0	10.0
10	2.0	4.0	6.0	8.0	10.0	11.0	15.0	17.0	18.0	18.0
11	4.0	5.0	7.0	10.0	11.0	15.0	20.0	18.0	22.0	21.0
12	10.0	20.0	30.0	40.0	60.0	60.0	80.0	80.0	90.0	95.0
13	10.0	20.0	25.0	25.0	35.0	60.0	45.0	80.0	90.0	95.0
14	2.0	4.0	5.0	6.0	8.0	10.0	12.0	17.0	17.0	20.0
15	0.5	1.0	1.0	2.0	3.0	3.0	4.0	5.0	5.0	5.0
16	3.0	6.0	8.0	8.0	11.0	12.0	13.0	15.0	16.0	17.0

Table 16. The log of the data estimates showing the row mean (common modulus) and row mean minus the grand mean (constant offset).

sub	log 1	log 2	log 3	log 4	log 5	log 6	log 7	log 8	log 9	log 10	me	me-gme
1	0.0000	0.4771	0.6021	0.7782	0.7782	1.0000	0.9031	1.0000	1.0414	1.0607	0.7641	-0.3066
2	0.0000	0.3010	0.4771	0.6021	0.6990	0.8451	1.0000	1.0000	1.0792	1.1761	0.7180	-0.3527
3	1.3010	1.6021	1.6990	1.7782	2.0000	1.9294	2.0043	2.1761	2.2041	2.2304	1.8925	0.8218
4	0.3010	0.6021	0.6990	0.6990	0.7782	0.8451	0.9031	0.9031	0.9294	0.9542	0.7614	-0.3092
5	0.0000	0.4771	0.6021	0.6990	0.7782	0.7782	0.8451	0.8451	0.9031	0.9542	0.6882	-0.3825
6	0.0000	0.3010	0.4771	0.6021	0.6990	0.7782	0.7782	0.9031	0.9912	1.0000	0.6530	-0.4177
7	0.0000	0.3010	0.3979	0.6021	0.7782	0.7782	0.8451	0.8751	0.9031	0.9542	0.6435	-0.4272
8	0.0000	0.3010	0.4771	0.6021	0.6990	0.6021	0.6990	0.7782	0.7782	0.9031	0.5840	-0.4867
9	0.0000	0.3010	0.4771	0.6021	0.7404	0.7782	0.8451	0.9542	0.9542	1.0000	0.6652	-0.4054
10	0.3010	0.6021	0.7782	0.9031	1.0000	1.0414	1.1761	1.2304	1.2553	1.2553	0.9543	-0.1164
11	0.6021	0.6990	0.8451	1.0000	1.0414	1.1761	1.3010	1.2553	1.3424	1.3222	1.0585	-0.0122
12	1.0000	1.3010	1.4771	1.6021	1.7782	1.7782	1.9031	1.9031	1.9542	1.9777	1.6675	0.5968
13	1.0000	1.3010	1.3979	1.3979	1.5441	1.7782	1.6532	1.9031	1.9542	1.9777	1.5907	0.5201
14	0.3010	0.6021	0.6990	0.7782	0.9031	1.0000	1.0792	1.2304	1.2304	1.3010	0.9124	-0.1582
15	-0.3010	0.0000	0.0000	0.3010	0.4771	0.4771	0.6021	0.6990	0.6990	0.6990	0.3653	-0.7053
16	0.4771	0.7782	0.9031	0.9031	1.0414	1.0792	1.1139	1.1761	1.2041	1.2304	0.9907	-0.0800
											1.0707	<-gme

Table 17. The normally distributed data adjusted to a common modulus.

sub	line 1	line 2	line 3	line 4	line 5	line 6	line 7	line 8	line 9	line 10
1	0.3066	0.7837	0.9086	1.0847	1.0847	1.3066	1.2097	1.3066	1.3480	1.3673
2	0.3527	0.6537	0.8298	0.9548	1.0517	1.1978	1.3527	1.3527	1.4319	1.5288
3	0.4792	0.7802	0.8772	0.9563	1.1782	1.1076	1.1825	1.3543	1.3823	1.4086
4	0.6103	0.9113	1.0082	1.0082	1.0874	1.1543	1.2123	1.2123	1.2387	1.2635
5	0.3825	0.8596	0.9845	1.0814	1.1606	1.1606	1.2275	1.2275	1.2855	1.3367
6	0.4177	0.7187	0.8948	1.0197	1.1166	1.1958	1.1958	1.3208	1.4089	1.4177
7	0.4272	0.7282	0.8251	1.0292	1.2053	1.2053	1.2723	1.3022	1.3303	1.3814
8	0.4867	0.7877	0.9638	1.0887	1.1857	1.0887	1.1857	1.2648	1.2648	1.3898
9	0.4054	0.7064	0.8825	1.0075	1.1458	1.1836	1.2505	1.3597	1.3597	1.4054
10	0.4174	0.7184	0.8945	1.0195	1.1164	1.1578	1.2925	1.3468	1.3716	1.3716
11	0.6143	0.7112	0.8573	1.0122	1.0536	1.1883	1.3132	1.2675	1.3546	1.3344
12	0.4032	0.7042	0.8803	1.0052	1.1813	1.1813	1.3063	1.3063	1.3574	1.3809
13	0.4799	0.7809	0.8779	0.8779	1.0240	1.2581	1.1331	1.3830	1.4342	1.4576
14	0.4592	0.7603	0.8572	0.9364	1.0613	1.1582	1.2374	1.3887	1.3887	1.4592
15	0.4043	0.7053	0.7053	1.0064	1.1825	1.1825	1.3074	1.4043	1.4043	1.4043
16	0.5571	0.8581	0.9831	0.9831	1.1214	1.1592	1.1939	1.2561	1.2841	1.3104

Table 18. Antilog of data ready for parametric analysis.

sub	line 1	line 2	line 3	line 4	line 5	line 6	line 7	line 8	line 9	line 10
1	2.0257	6.0772	8.1030	12.1544	12.1544	20.2574	16.2059	20.2574	22.2831	23.2960
2	2.2527	4.5053	6.7580	9.0106	11.2633	15.7686	22.5266	22.5266	27.0319	33.7898
3	3.0145	6.0291	7.5363	9.0436	15.0726	12.8117	15.2234	22.6089	24.1162	25.6235
4	4.0763	8.1526	10.1908	10.1908	12.2290	14.2671	16.3053	16.3053	17.3244	18.3434
5	2.4124	7.2372	9.6497	12.0621	14.4745	14.4745	16.8869	16.8869	19.2993	21.7117
6	2.6162	5.2324	7.8486	10.4648	13.0810	15.6972	15.6972	20.9296	25.6387	26.1620
7	2.6740	5.3481	6.6851	10.6962	16.0442	16.0442	18.7183	20.0553	21.3923	24.0663
8	3.0668	6.1337	9.2005	12.2673	15.3342	12.2673	15.3342	18.4010	18.4010	24.5346
9	2.5434	5.0869	7.6303	10.1737	13.9888	15.2606	17.8040	22.8908	22.8908	25.4343
10	2.6146	5.2291	7.8437	10.4583	13.0728	14.3801	19.6092	22.2238	23.5311	23.5311
11	4.1139	5.1424	7.1993	10.2848	11.3132	15.4272	20.5695	18.5126	22.6265	21.5980
12	2.5304	5.0607	7.5911	10.1215	15.1822	15.1822	20.2430	20.2430	22.7733	24.0385
13	3.0193	6.0387	7.5483	7.5483	10.5676	18.1160	13.5870	24.1546	27.1740	28.6836
14	2.8790	5.7580	7.1975	8.6369	11.5159	14.3949	17.2739	24.4714	24.4714	28.7898
15	2.5369	5.0737	5.0737	10.1475	15.2212	15.2212	20.2950	25.3687	25.3687	25.3687
16	3.6067	7.2134	9.6178	9.6178	13.2245	14.4267	15.6290	18.0334	19.2357	20.4379

APPENDIX G. CORRELATION TABLES AND FIGURES

Table 19 shows definitions for the labels in the correlation tables. Tables 20 through 22 show the correlation tables. Table 23 shows a composite table of significant correlations at the $p < .05$ level.

Table 19. Definitions for all the abbreviated labels in correlation tables.

Label	Definition	Source
Pres.	Perception of presence for the task environments	Final questionnaire
Comp	Computer experience	Final questionnaire
Enjoy	Enjoyed the experiment	Final questionnaire
Stereo	Stereo acuity	Vision test
Near-Avg	Average near vision acuity	Vision test
Age	Age	MSHQ
Gender	Gender	MSHQ
Suscept	Overall susceptibility to motion sickness	MSHQ
Nau	Nausea experienced in last eight weeks	MSHQ
Diz	Dizziness episodes in last year	MSHQ
Ear	Ear infections	MSHQ
Airsick	Frequency of airsickness	MSHQ
Seasick	Frequency of seasickness	MSHQ
Carsick	Frequency of carsickness	MSHQ
L-Air	Perception of flying in aircraft	MSHQ
L-Autos	Perception of riding in cars	MSHQ
L-Imax	Perception of watching Imax movies	MSHQ
L-Elev	Perception of riding in elevators	MSHQ
L-Train	Perception of riding on trains	MSHQ
L-Merry	Perception of riding on merry-go-rounds	MSHQ
L-Swing	Perception of swinging in a swing	MSHQ
Chance	Perceived chances of getting ill	MSHQ
RFT Avg	Average deviation in the rod and frame test	RFT test
Rotate	Mental rotation ability score	Mental rotation test
Q-D-Av	Average total severity score difference, pre/post session	VESEQ
Bal-D-Av	Average postural stability difference, pre/post session	Postural stability tests
Est-D-Av	Average sickness estimate difference, pre/post session	Sickness estimates
Vis-D-Av	Average vision difference, pre/post session	Vision tests
Sleep	Hours of sleep before session	VESEQ
Bal-D	Postural stability differences per session	Postural stability tests
Vis-D	Vision differences per session	Vision tests
Est-D	Sickness estimate differences per session	Sickness estimates
Q-Tot-D	Total severity score differences per session	VESEQ
Mazes	Number of mazes completed per session	
Day	Day in which session was held	

Table 20. Correlations for items varying across the sixteen subjects (R > 0.498 are significant at p < 0.5).

	Pres.	Comp	Enjoy	Stereo	Near-Avg	Age	Gender	Suscept
Comp	-0.071							
Enjoy	0.279	0.233						
Stereo	-0.121	-0.161	0.036					
Near-Avg	-0.034	-0.001	-0.020	0.085				
Age	-0.279	0.315	-0.251	-0.643	-0.019			
Gender	0.099	0.066	0.177	0.051	0.375	0.220		
Suscept	0.191	-0.128	0.098	0.028	-0.256	-0.258	-0.416	
Nau	0.229	0.255	-0.183	-0.211	-0.271	0.118	0.000	-0.215
Diz	-0.110	0.242	0.000	0.000	-0.010	0.312	0.320	0.222
Ear	-0.300	-0.095	-0.113	0.000	-0.107	0.290	0.160	0.400
Airsick	0.313	-0.319	0.212	-0.049	-0.182	-0.224	-0.539	0.548
Seasick	0.062	0.091	0.178	0.051	-0.382	-0.378	-0.252	0.314
Carsick	-0.012	0.041	0.089	0.051	-0.257	-0.373	-0.882	0.454
L-Air	-0.033	-0.154	0.118	-0.170	-0.161	-0.107	0.167	0.000
L-Autos	-0.025	0.017	-0.183	-0.158	-0.181	0.267	0.258	-0.501
L-Imax	0.062	-0.316	-0.295	0.170	-0.420	-0.321	-0.417	0.058
L-Elev	0.032	0.346	-0.076	-0.175	0.114	0.198	0.322	-0.149
L-Train	0.112	-0.373	-0.134	-0.154	0.178	-0.326	-0.189	0.210
L-Merry	0.296	0.461	0.118	0.272	0.145	-0.378	0.167	-0.092
L-Swing	-0.103	0.343	-0.295	-0.426	-0.182	0.357	0.000	-0.173
Chance	-0.036	0.161	0.157	-0.362	-0.346	0.116	-0.517	0.636
RFT-Avg	0.078	0.122	-0.093	-0.234	-0.200	-0.076	-0.088	0.073
Rotate	-0.037	0.197	-0.093	-0.251	-0.192	0.070	-0.574	0.269
Q-D-Av	0.093	0.385	0.471	-0.063	-0.266	-0.023	0.095	0.202
Bal-D-Av	-0.119	-0.533	-0.430	0.369	-0.035	-0.256	-0.227	0.012
Est-D-Av	0.269	-0.202	0.238	-0.524	0.087	0.207	0.304	-0.204
Vis-D-Av	-0.028	0.028	0.210	0.293	0.481	-0.075	0.594	-0.335

	Nau	Diz	Ear	Airsick	Seasick	Carsick	L-Air	L-Autos
Diz	-0.372							
Ear	-0.372	0.590						
Airsick	-0.386	-0.163	0.144					
Seasick	0.228	-0.182	-0.262	0.023				
Carsick	-0.098	-0.222	-0.061	0.520	0.143			
L-Air	-0.086	0.160	0.053	-0.220	0.546	-0.126		
L-Autos	0.333	-0.124	-0.289	-0.479	0.293	-0.423	0.602	
L-Imax	0.269	-0.234	-0.234	0.212	0.131	0.289	0.070	0.162
L-Elev	0.249	0.155	-0.258	-0.558	0.284	-0.284	0.536	0.637
L-Train	0.098	-0.545	-0.182	0.113	0.333	0.238	0.378	0.098
L-Merry	0.086	-0.160	-0.374	-0.140	0.210	-0.042	0.000	0.086
L-Swing	0.269	0.033	-0.234	-0.387	0.131	-0.131	0.348	0.592
Chance	-0.134	0.391	0.201	0.394	0.419	0.475	0.271	-0.172
RFT-Avg	0.205	-0.042	-0.268	-0.184	0.566	0.055	0.734	0.614

Rotate	0.204	-0.003	0.015	0.206	0.490	0.423	0.193	0.101
Q-D-Av	0.172	0.315	0.182	-0.103	0.387	0.005	0.074	-0.228
Bal-D-Av	-0.202	-0.241	-0.081	0.076	-0.376	0.191	-0.359	-0.234
Est-D-Av	-0.030	0.080	-0.020	0.180	0.082	-0.392	0.329	0.147
Vis-D-Av	-0.546	0.394	0.235	-0.057	-0.316	-0.468	-0.011	-0.156

	L-Imax	L-Elev	L-Train	L-Merry	L-Swing	Chance	RFT-Avg	Rotate
L-Elev	-0.022							
L-Train	0.079	0.284						
L-Merry	0.070	0.393	0.126					
L-Swing	0.304	0.693	0.079	0.348				
Chance	0.108	0.055	-0.028	-0.320	0.108			
RFT-Avg	0.386	0.783	0.466	0.382	0.753	0.306		
Rotate	0.054	-0.076	0.016	-0.272	0.020	0.634	0.189	
Q-D-Av	-0.456	-0.180	-0.313	-0.162	-0.381	0.342	-0.247	0.352
Bal-D-Av	0.249	-0.244	0.182	-0.069	-0.150	-0.394	-0.257	-0.521
Est-D-Av	-0.078	-0.111	-0.040	-0.283	-0.089	0.171	0.021	0.145
Vis-D-Av	-0.347	-0.208	-0.404	0.201	-0.320	-0.351	-0.358	-0.333

	Q-D-Av	Bal-D-Av	Est-D-Av
Bal-D-Av	-0.521		
Est-D-Av	0.217	-0.522	
Vis-D-Av	0.081	-0.172	0.353

Table 21. Correlations for items varying across the 64 experiment sessions (R > 0.247 are significant at p < 0.5).

	Alco	Sleep	Bal-D	Vis-D	Est-D
Sleep	0.098				
Bal-D	0.275	0.267			
Vis-D	0.057	0.115	0.034		
Est-D	-0.260	-0.193	-0.342	0.176	
Q-Tot-D	-0.147	-0.270	-0.321	-0.065	0.252

Table 22. Correlations for items varying across maze task environment (R > 0.350 are significant at p < 0.5).

	Head	Mazes	Day	Q-Tot-D	Bal-D	Est-D
Mazes	-0.119					
Day	0.000	0.304				
Q-Tot-D	-0.223	-0.151	-0.409			
Bal-D	-0.018	0.079	0.163	-0.432		
Est-D	-0.003	-0.067	-0.046	0.278	-0.263	
Vis-D	0.160	0.035	0.198	-0.029	0.019	0.156

Table 23. A composite table of significant correlations at the $p < .05$ level.

Table	Correlate 1	Correlate 2	R
20	Bal-D-Av	Comp	-0.533
	Age	Stereo	-0.643
	Est-D-Av	Stereo	-0.524
	Airsick	Gender	-0.539
	Carsick	Gender	-0.882
	Chance	Gender	-0.517
	Rotate	Gender	-0.574
	Vis-D-Av	Gender	0.594
	Airsick	Suscept	0.548
	L-Autos	Suscept	-0.501
	Chance	Suscept	0.636
	Ear	Diz	0.590
	L-Train	Diz	-0.545
	Carsick	Airsick	0.520
	L-Elev	Airsick	-0.558
	L-Air	Seasick	0.546
	RFT-Avg	Seasick	0.566
	L-Autos	L-Air	0.602
	L-Elev	L-Air	0.536
	RFT-Avg	L-Air	0.734
	L-Elev	L-Autos	0.637
	L-Swing	L-Autos	0.592
	RFT-Avg	L-Autos	0.614
	L-Swing	L-Elev	0.693
	RFT-Avg	L-Elev	0.783
	RFT-Avg	L-Swing	0.753
	Rotate	Chance	0.634
	Bal-D-Av	Rotate	-0.521
	Bal-D-Av	Q-D-Av	-0.521
	Est-D-Av	Bal-D-Av	-0.522
21	Bal-D	Alco	0.275
	Est-D	Alco	-0.260
	Bal-D	Sleep	0.267
	Q-Tot-D	Sleep	-0.270
	Est-D	Bal-D	-0.342
	Q-Tot-D	Bal-D	-0.321
	Q-Tot-D	Est-D	0.252
22	Q-Tot-D	Day	-0.409
	Bal-D	Q-Tot-D	-0.432

Figures 33 to 43 show trend diagrams for the significant correlations shown in Table 14. Figure 33 shows the relationship between stereo vision acuity (level reached in stereo vision test) and age (years).

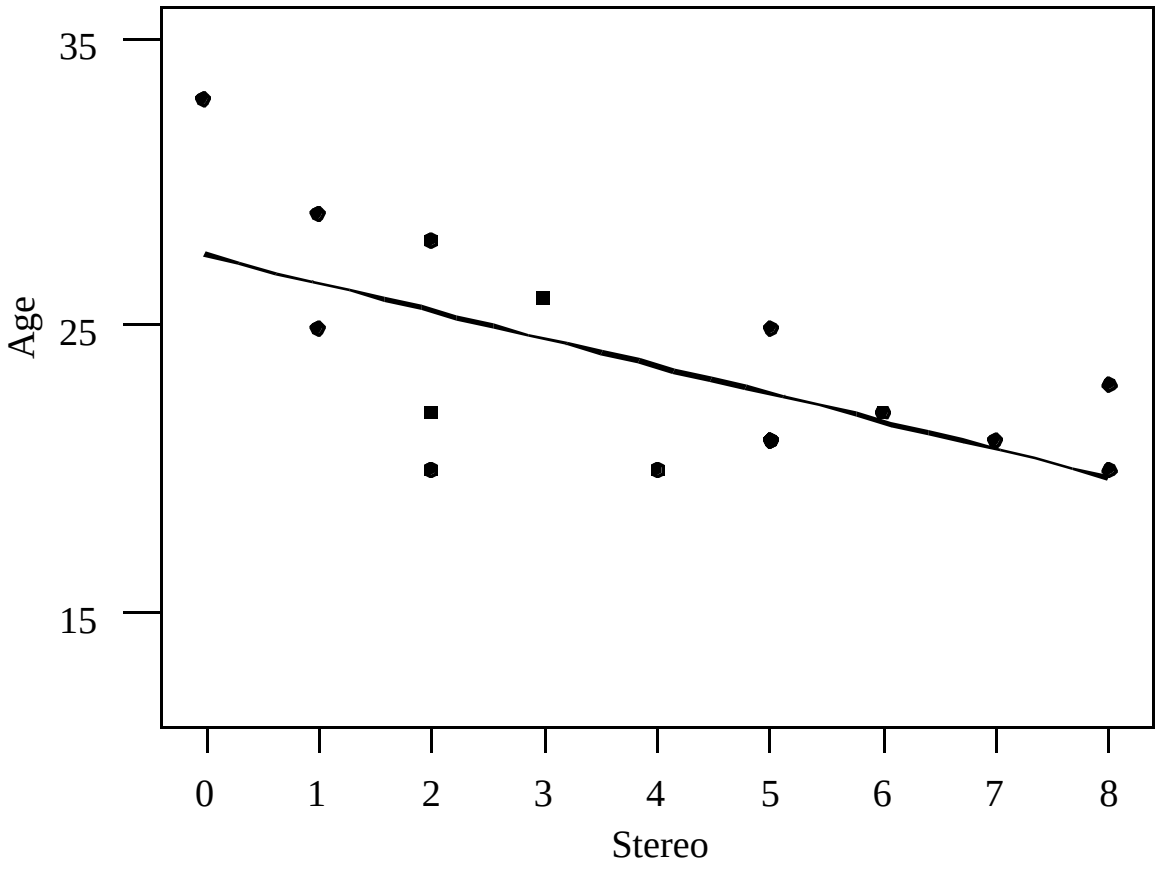

Figure 33. The correlation between stereo vision acuity and age .

Figure 34 shows the relationship between gender (1 - male, 2 - female) and frequency of carsickness experienced (1 - always, 2 - frequently, 3 - sometimes, 4 - rarely, 5 - never).

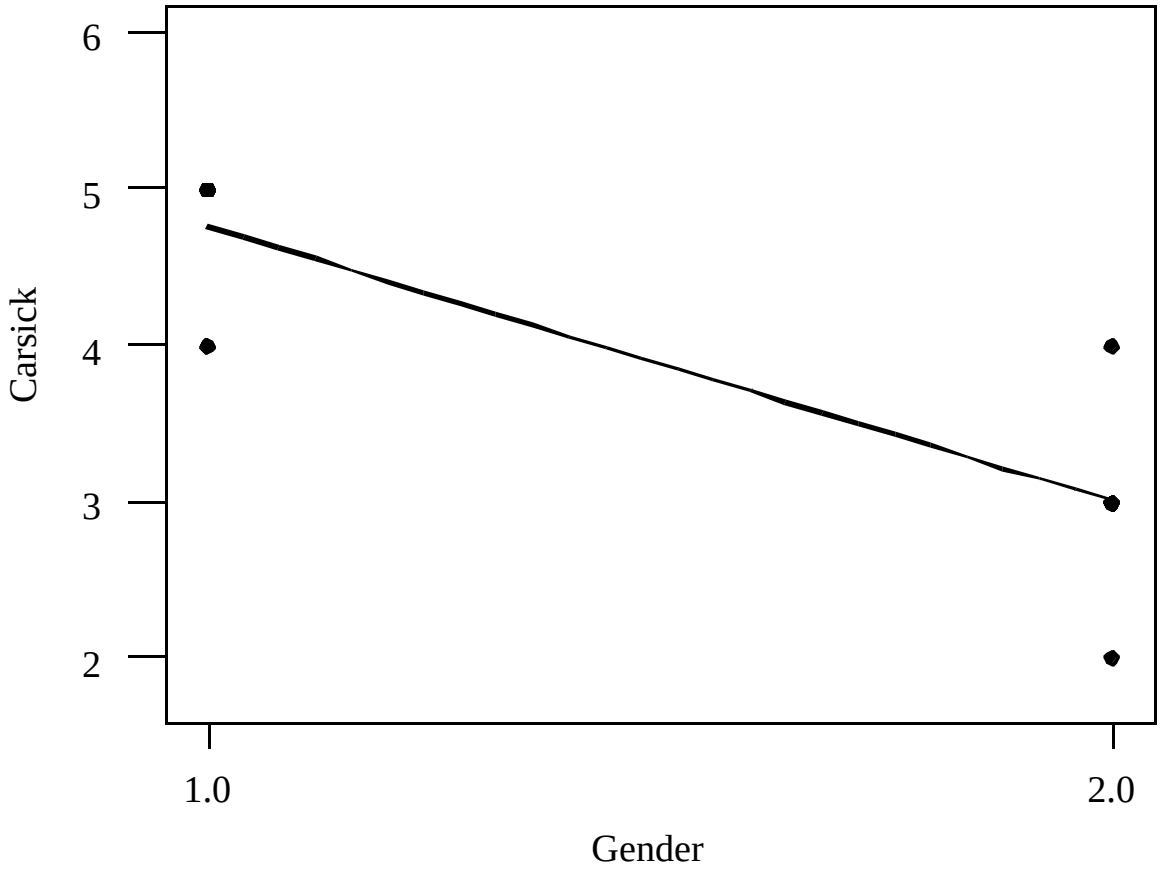

Figure 34. The correlation between gender and past history of carsickness.

Figure 35 shows the relationship between overall susceptibility to motion sickness (1 - extremely, 2 - very, 3 - moderately, 4 - minimally, 5 - not at all) and perceived chances of getting sick in the present experiment (1 - certainly, 2 - probably, 3 - not sure, 4 - probably not, 5 - certainly not).

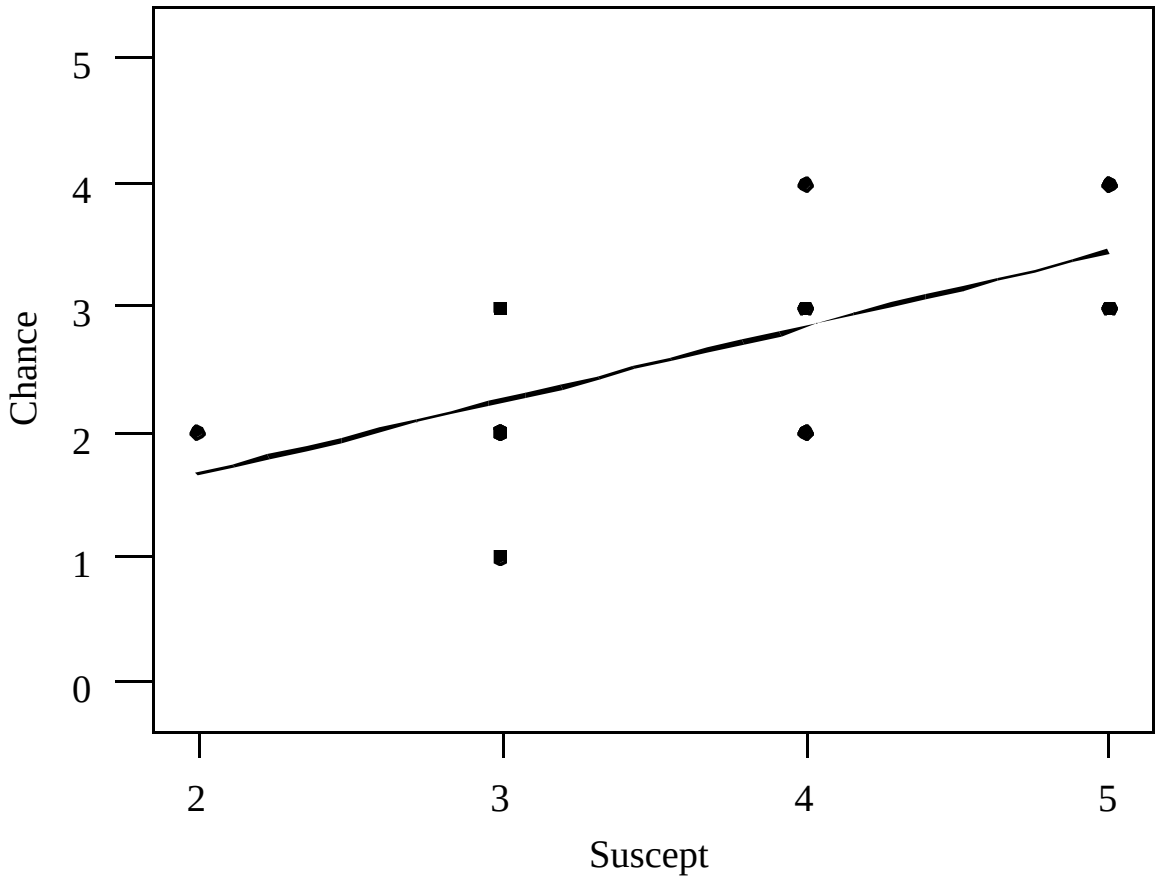

Figure 35. The correlation between overall susceptibility to motion sickness and perceived chances of getting sick in the present study.

Figure 36 shows the relationship between perception of flying in aircraft (1 - like, 2 - neutral, 3 - dislike) and average deviation on the rod and frame test.

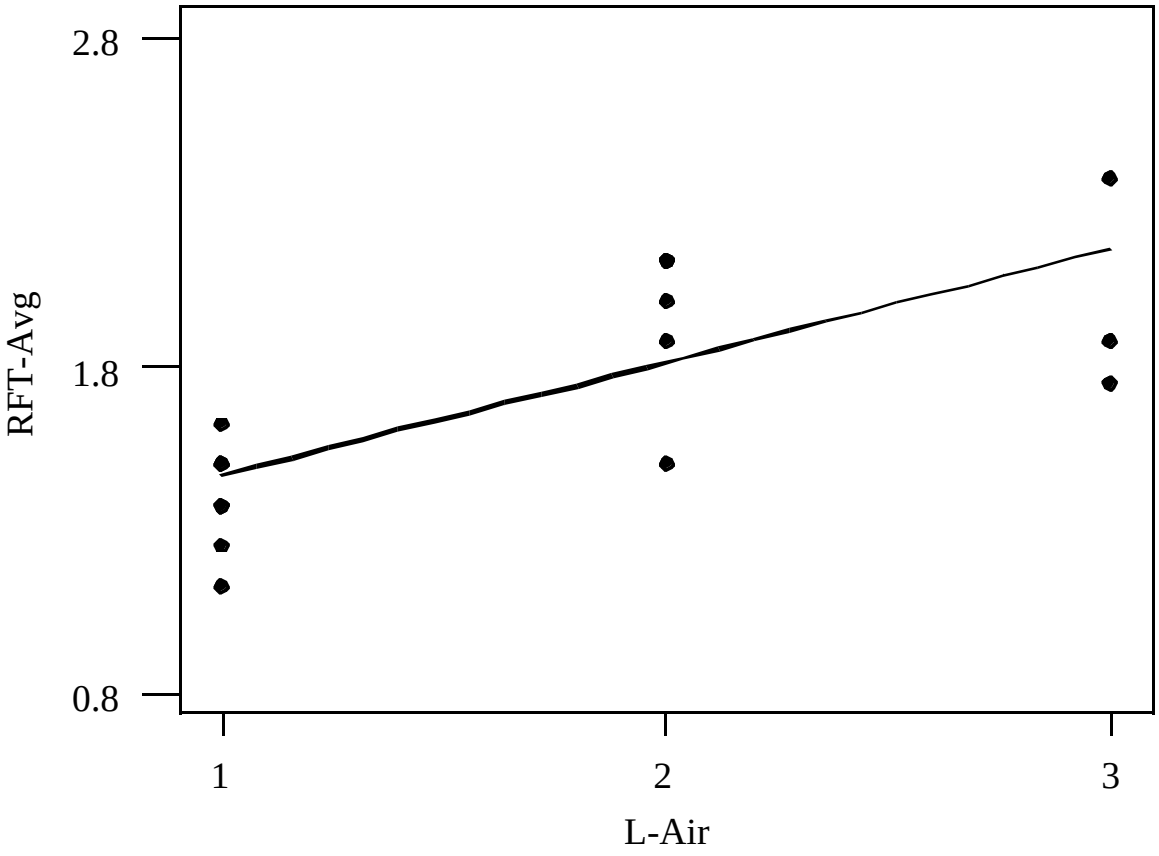

Figure 36. The correlation between perception of flying in aircraft and average deviation in the rod and frame test.

Figure 37 shows the relationship between perception of riding automobiles (1 - like, 2 - neutral, 3 - dislike) and perception of riding in elevators (1 - like, 2 - neutral, 3 - dislike).

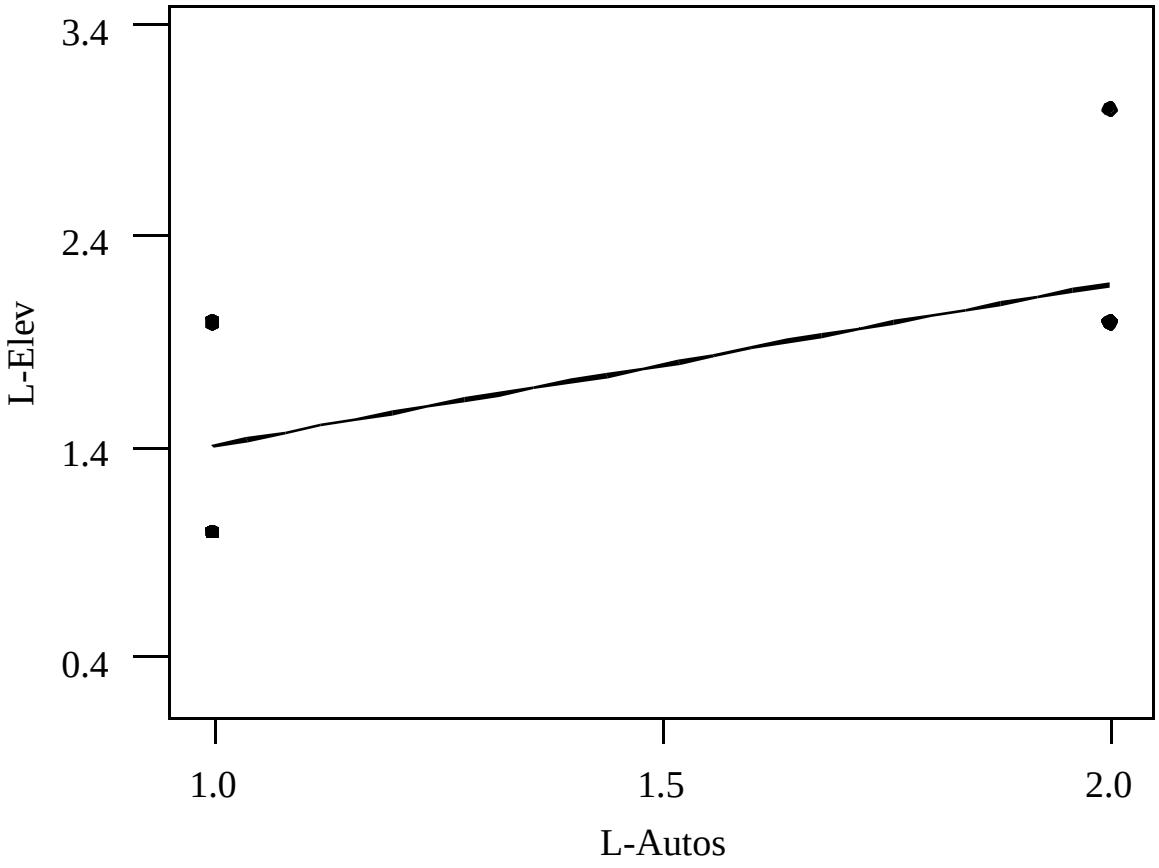

Figure 37. The correlation between the perception of riding in automobiles and the perception of riding in elevators.

Figure 38 shows the relationship between perception of riding in elevators (1 - like, 2 - neutral, 3 - dislike) and the perception swinging in a swing (1 - like, 2 - neutral, 3 - dislike).

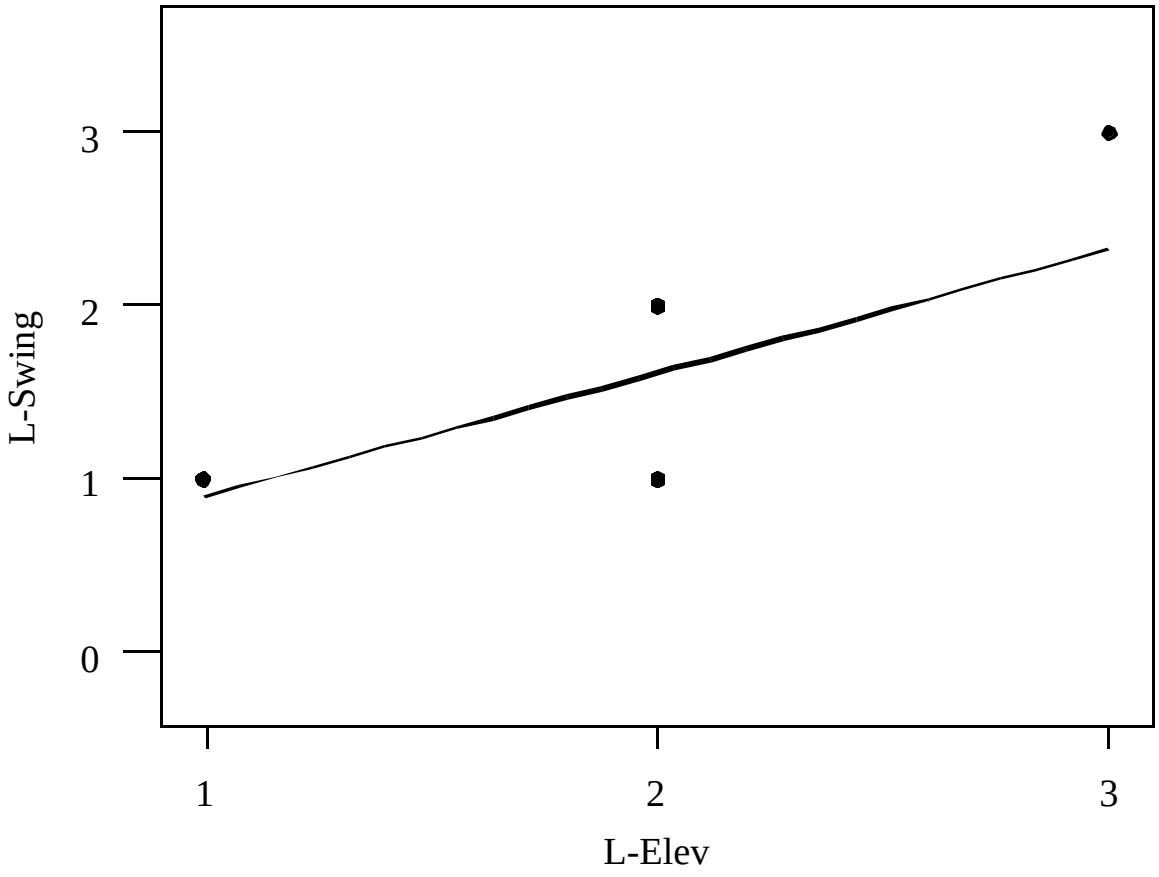

Figure 38. The correlation between the perception of elevator rides and the perception of swinging on a swing.

Figure 39 shows the relationship between perception of riding in elevators (1 - like, 2 - neutral, 3 - dislike) and average deviation in the rod and frame test.

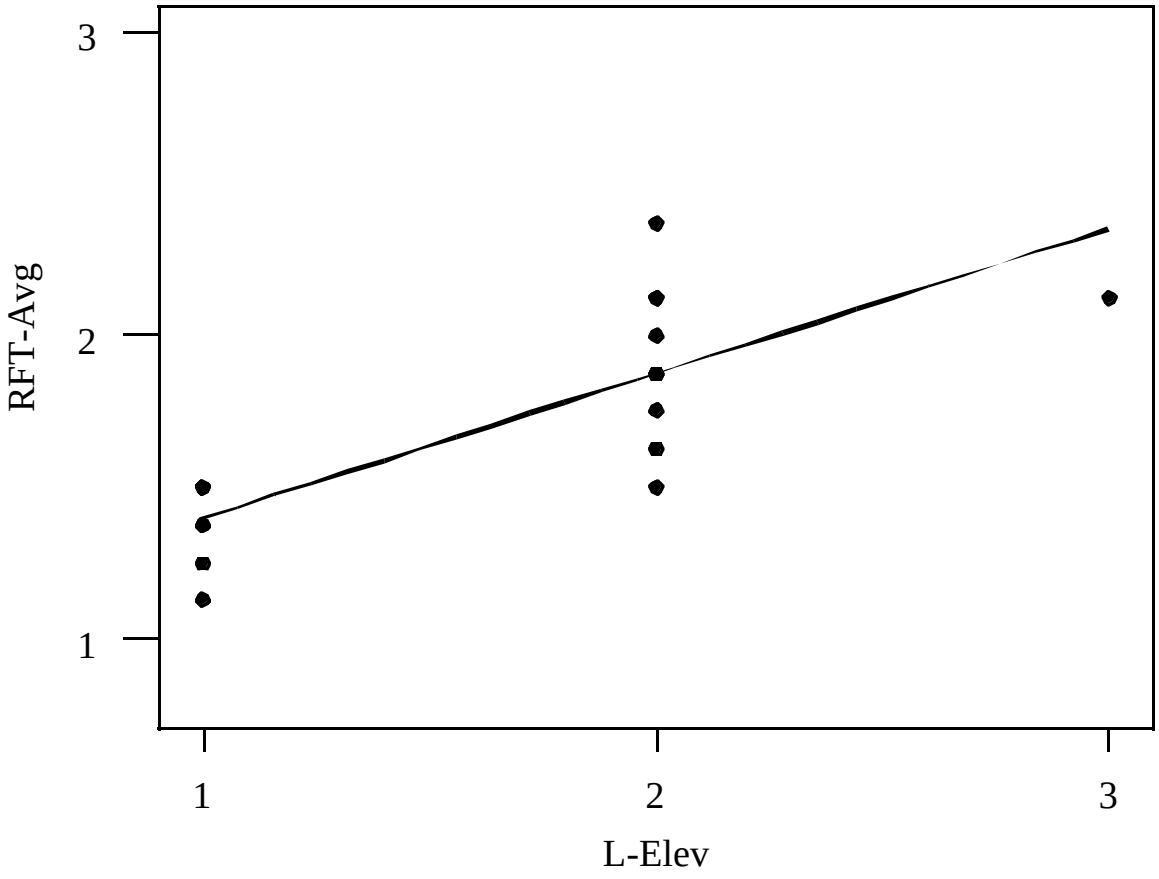

Figure 39. The correlation between the perception of elevator rides and the average deviation in the rod and frame test.

Figure 40 shows the relationship between perception of swinging in a swing (1 - like, 2 - neutral, 3 - dislike) and the average deviation in the rod and frame test.

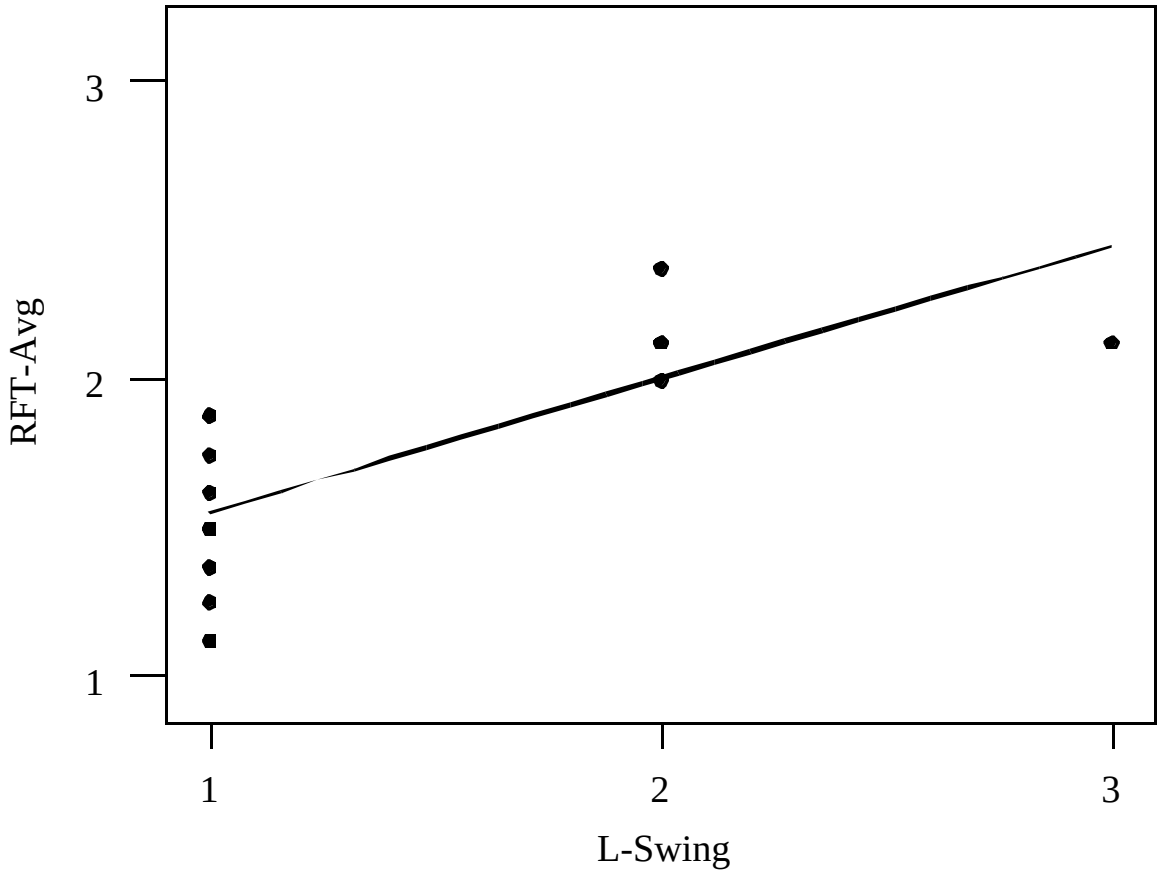

Figure 40. The correlation between the perception of swinging on a swing and the average deviation in the rod and frame test.

Figure 41 shows the relationship between perceived chances of getting sick in the present study (1 - certainly, 2 - probably, 3 - not sure, 4 - probably not, 5 - certainly not) and the score on the mental rotation test.

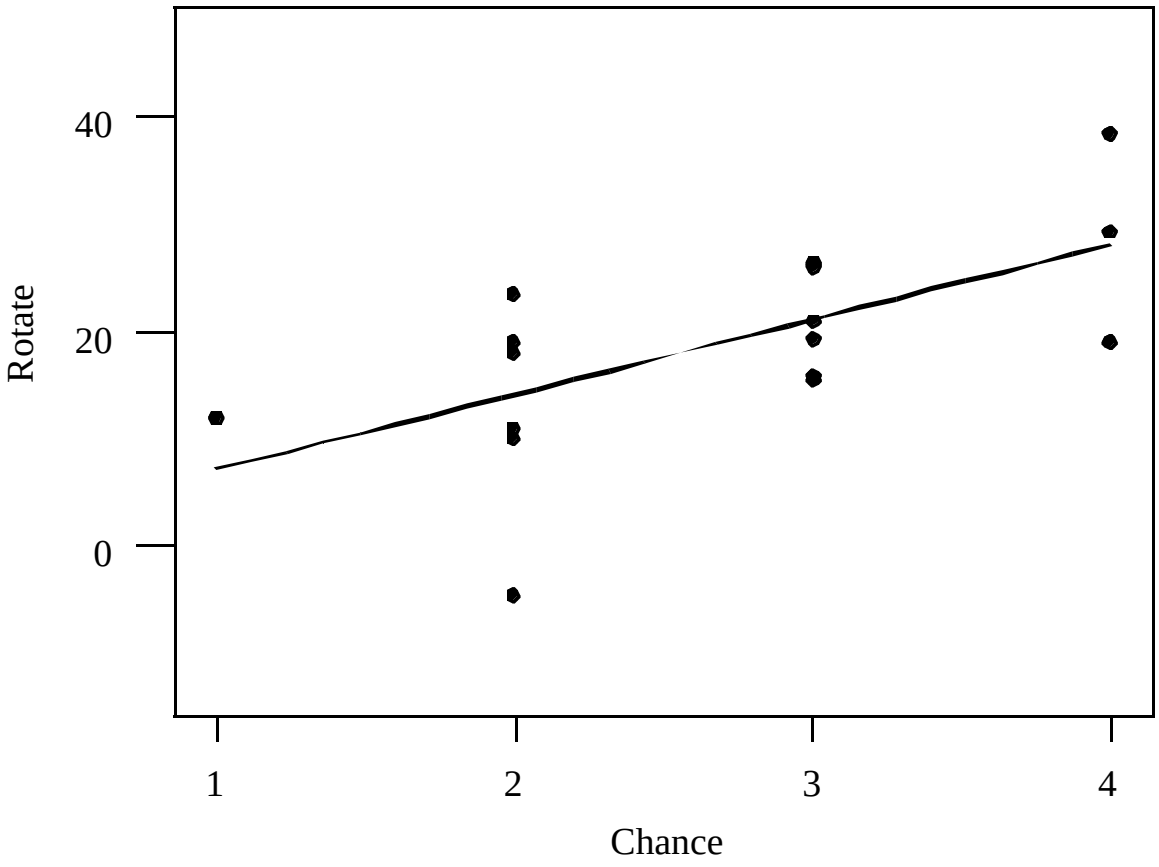

Figure 41. The correlation between perceived chances of getting sick in the present study and mental rotation test score.

Figure 42 shows the relationship between postural stability differences and the sickness estimate difference per session.

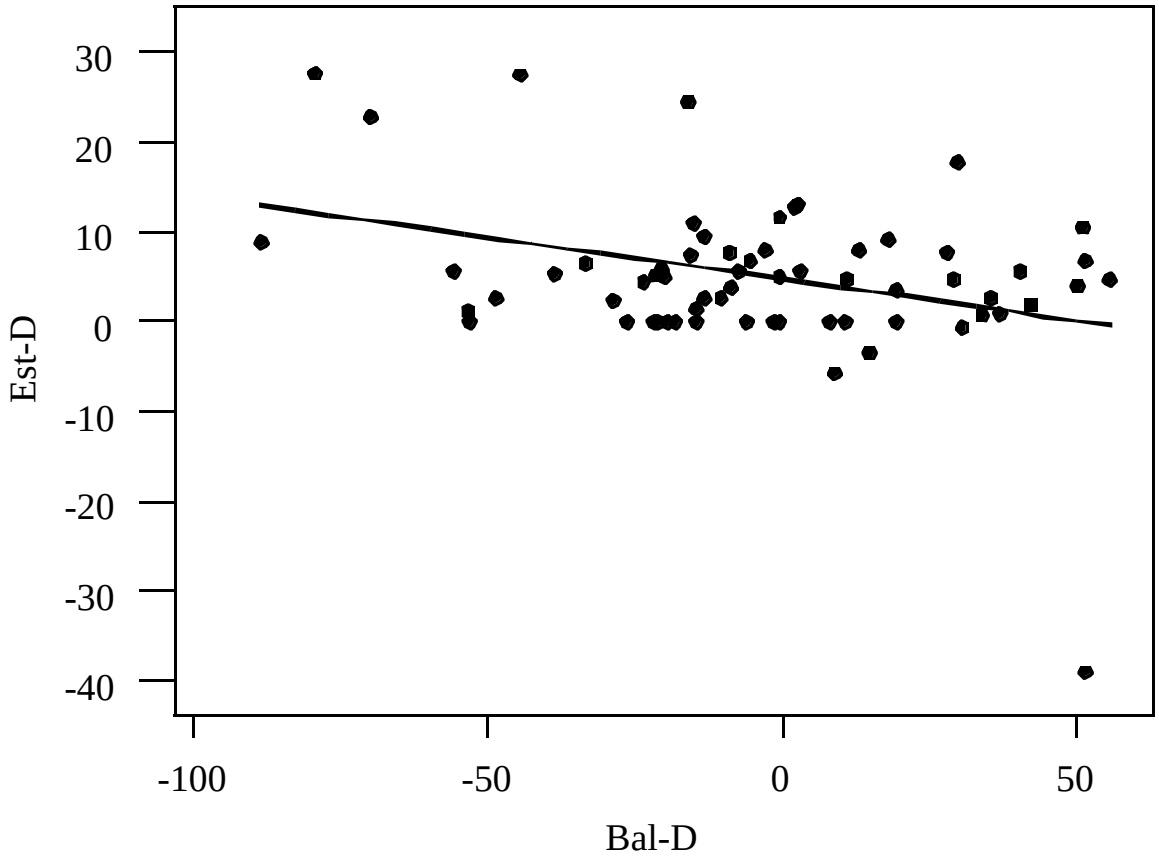

Figure 42. The correlation between the postural stability differences per session and the sickness estimate difference per session.

Figure 43 shows the relationship between postural stability differences and the total severity score difference per session.

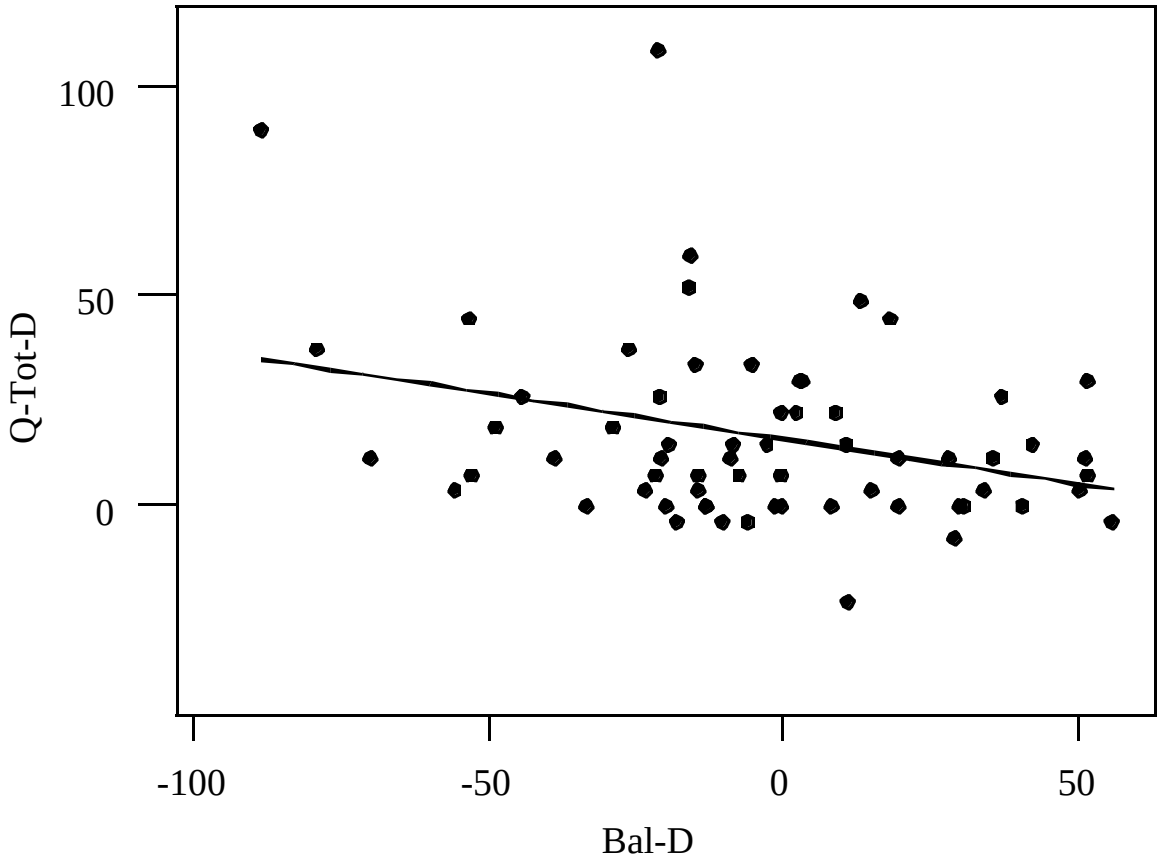

Figure 43. The correlation between the postural stability differences per session and the total severity score difference per session.

VITA

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Michael graduated from the University of Illinois at Urbana/Champaign in 1988 with a B.S. in Psychology. His research interests include virtual environments, video-conferencing, and human-computer interaction.