5-2008

THE ROLE OF HEAD MOVEMENTS IN SIMULATOR SICKNESS GENERATED BY A VIRTUAL ENVIRONMENT

Alexander Walker
Clemson University, alexanw@clemson.edu

THE ROLE OF HEAD MOVEMENTS IN SIMULATOR SICKNESS GENERATED BY A VIRTUAL ENVIRONMENT

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Applied Psychology

---

by
Alexander D. Walker
May 2008

Accepted by:
Dr. Eric Muth, Committee Chair
Dr. Adam Hoover
Dr. Fred Switzer

ABSTRACT

Virtual environments (VEs) are being used in a variety of applications, including training, rehabilitation and clinical treatment. To effectively utilize VEs in these situations it is important to try to understand some of the effects of VE exposure. The purpose of this study was to investigate head and body movements in virtual and real environments during building clearing and the relationship between these movements and simulator sickness. The data for the current study were drawn from a larger team training study which investigated the use of VEs for training building clearing. The goal of the first part of this study was to compare head movements made in a real world (RW) environment to head movements made in a VE (Analysis I). The goal of second part of this study was to examine the relationship between head movements and simulator sickness in a VE (Analysis II). The first analysis used two independent samples t-tests to examine the differences between head movements made in a VE and head movements made in a RW environment. The t-tests showed that subjects in the VE moved their heads less, $t(23.438)=12.690$, $p<0.01$, and less often, $t(46)=8.682$, $p<0.05$, than subjects in the RW. In the second analysis, a 3 x 20 ANOVA found a significant difference between groups with low, med, and high simulator sickness scores, $F(2,21)=4.221$, $p<0.05$, $\acute{\eta}_p^2= 0.287$, where subjects who reported being the most sick tended to restrict their head movements more than the other two groups. For VEs to progress as a useful tool, whether for training, therapy, etc., it will be necessary to identify the variable(s) that cause people to become motion sick and restrict their head movement during VE exposure. Future studies should seek to investigate more continuous measures of

sickness, perhaps psychophysiological measures, and possible effects of a negative transfer of training due to the restriction of head movements in VEs.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Eric Muth, for introducing me to research and for all of his help and support during this long process. I would also like to thank my other committee members, Dr. Adam Hoover and Dr. Fred Switzer, for their support and unique guidance during this research. Special thanks go to the graduate team of Jason Moss, Tom Carpenter, Tom Epton, Marty Werner, and Kelly Waller, who helped with the data collection. I would also like to thank the Office of Naval Research VIRTE program for the funding that made this research possible.

Finally, I would like to thank my parents for their ever present support and encouragement that has been the guiding force behind all of my achievements.

TABLE OF CONTENTS

Table of Contents (Continued)

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Purpose

The purpose of this study was to investigate head and body movements in virtual and real environments during building clearing and the relationship between these movements and simulator sickness.

Building Clearing

Building clearing is a form of dynamic visual search where a person is required to perform a visual search while he/she moves through the environment. When performing any type of dynamic visual search task the visual and vestibular systems have to coordinate with head and body movements so that a person's gaze remains stable during the search.

Building clearing is a military task where teams, typically consisting of four or more individuals, move through a building searching to eliminate threats or "combatants" and secure non-threat assets, or "non-combatants," such as civilians. To complete the task soldiers must quickly and accurately search the environment while moving and neutralizing all threats (i.e. shoot or restrain). Almost the entire task of visual search during building clearing is done while moving. Though the search is done in an extreme environment building clearing can be used as a proxy for most types of dynamic visual search tasks.

The successful completion of a building clearing task requires two different types of movement, linear movement down a hallway and coordinated movement into a room. Movement down a hallway during building clearing follows very specific guidelines (Marine Corps Warfighting Laboratory). Generally, all four members will move as a coordinated unit called a 'stack.' To form a stack each person lines up behind the other with virtually no space between each body. As the team moves down the hallway the first person in the stack keeps his eyes, head, and weapon pointed forward to watch for any threats entering the hallway. The rest of the stack could be either searching the area overhead or the area behind the stack.

Transitions from the hallway into a room are quick and explosive. The team moves from a linear stack into one of several types of room entry techniques. There are four different room entry techniques: the cross, the buttonhook, limited penetration and straight entry (Figure 1.1). These entries are designed to get the team members through the fatal funnel, the danger area around the open doorway, quickly and without any collisions or confusion. Once the team members have entered the room they immediately move to the points of domination. The points of domination are areas along the perimeter of the room that allow the team members to efficiently scan the room with as little overlap as possible.

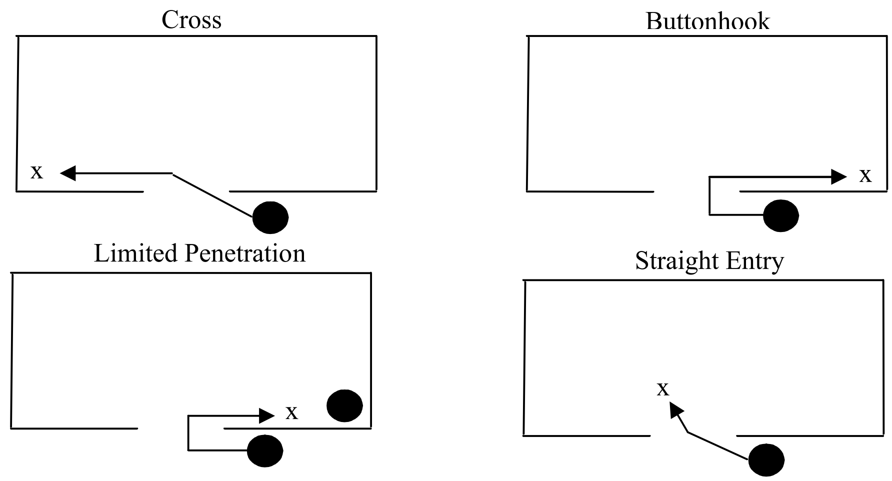


Figure 1.1. Examples of room entry techniques for building clearing

Regardless of room clearing technique the most efficient method for searching a room is for a soldier to direct his gaze wherever he points his weapon. The soldier attempts to keep his eyes pointed down the barrel of his weapon at all times during the search of a room. This 'guns and eyeballs' strategy allows a soldier to quickly search a room for enemy threats using both torso rotations and whole body movements. Therefore, in the current study, head, torso and whole body rotations are collectively defined as 'head movements.'

The Role of the Visual System during Building Clearing

Several different types of eye movements are used to search the visual environment, track objects through the visual environment, and to stabilize a person's gaze.

A person's visual acuity is best in the small region of the retina called the fovea. For this reason the eyes must be able to move in order to investigate the visual environment. Saccades are quick eye movements that allow the eyes to foveate, or fixate, on different locations in the visual environment. During a saccade the eyes can move as fast as 700°/sec (Blake & Sekular, 2006). These eye movements allow a person to quickly search the visual environment directly in front of them. Typically, a person can use saccadic eye movements to search approximately 205° of the visual environment before he/she must initiate additional head movements (May & Badcock, 2002). In typical situations it is likely that a person begins to move his/her head at some level of comfort, before the maximum range of eye movement is reached.

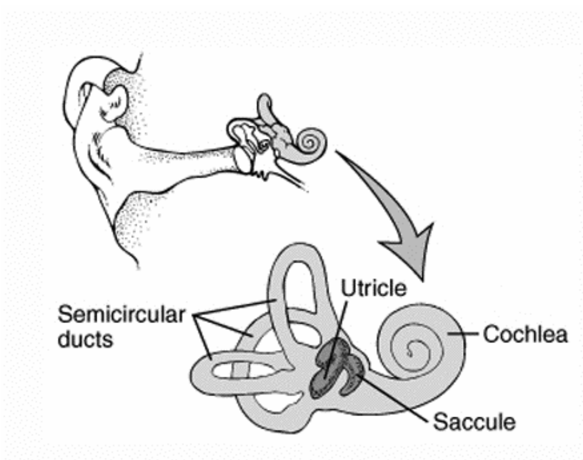
Smooth pursuit eye movements cause the eyes to move at a constant velocity to track a moving object through the visual environment (Blake & Sekular, 2006). Anyone who has ever tracked a fly as it buzzed around the room has used smooth pursuit eye movements. These eye movements are not typically used in a visual search task because they are primarily initiated when a person is tracking a particular object through the environment. Saccades and smooth pursuit eye movements make up the visual system's voluntary eye movements. The visual system also uses reflexive eye movements to compensate for both a moving visual scene and movement of the body.

Optokinetic nystagmus (OKN) is a reflexive eye movement in response to a moving, contoured visual field. OKN is a combination of smooth pursuit and saccadic eye movements (May & Badcock, 2002). A common example of the OKN happens when a person is stopped at train tracks watching a train pass. The eyes will use smooth pursuit eye movements to track the train as it enters one side of the visual field until it leaves the other side. When that occurs the eyes then use saccadic eye movements to snap the eyes back to the previous side in an attempt to resume tracking the train. This reflex will continue until the train has passed or until the person fixates on a stationary object. OKN eye movements are not pertinent to the task of building clearing.

Another reflexive eye movement is the vestibulo-ocular reflex (VOR). The role of the VOR is to retain gaze stability during head and/or body movements. To better understand how the VOR works it is important to understand what kind of inputs the visual system receives from the vestibular system.

The Role of the Vestibular System during Building Clearing

The vestibular system is one of several systems that provides cues concerning bodily motion. The vestibular system is located in the inner ear and consists of the semicircular canals and the otoliths. There are three semicircular canals in each ear, each oriented along three axes of rotation: yaw, pitch, and roll. (Figure 1.2)



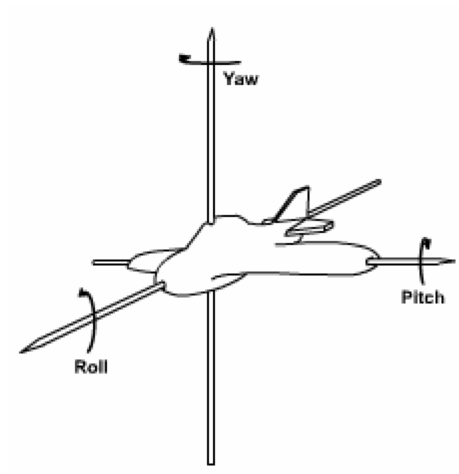


Figure 1.2- Diagram of the vestibular apparatus (www.qmw.ac.uk) and examples of yaw, pitch, and roll axes (scifiles.larc.nasa.gov)

The semicircular canals provide information about the rotation of the head by detecting changes in acceleration around each of the above axes. Because the semicircular canals detect rotational movement of the head, they help generate reflexive eye-movements (VOR) that keep the visual scene stable during head movements (Blake & Sekuler, 2006).

The VOR uses input from the vestibular system to drive eye movements during head and/or body movements. The function of the VOR is gaze stabilization as the head and/or body moves. As the head moves in one direction the VOR causes the eyes to move in the other direction. The result is a stable gaze. The VOR uses the rotational inputs registered by the semicircular canals to keep the retinal image of the visual environment stable during head rotation. The linear VOR uses translational inputs registered by the otoliths, described below, to keep the retinal image stable during linear head movements (Paige et al., 1998). Using that information the VOR initiates smooth eye movements at a velocity equal to that of head movement, but in the opposite direction (Johnston & Sharpe, 1994). The VOR is especially important during building clearing because a person must visually search an area while constantly moving his/her head and body.

While the semicircular canals act as angular accelerometers, the otoliths (utricule and saccule; Figure 1.2) act as multi-directional linear accelerometers. The otoliths provide information regarding linear movement of the body by detecting changes in linear acceleration. For example, while walking the otoliths provide some of the sensory input that lets a person know he/she is moving forward. They also provide input that the head is moving up and down. This input from the otoliths drives a linear VOR which allows a person's gaze to remain stable while the head moves up and down. Linear VOR can occur when the head is moved forward/backward, up/down, or side to side. Because the otoliths detect linear acceleration they also provide information about the direction of gravity (Reason & Brand, 1975).

The Role of Head Movements in Building Clearing

Head movements are also used to search the visual environment by increasing a person's potential field of view. The maximum range of horizontal head movements is approximately 158° (Woodson, 1981). Normally at some level of comfort a person would begin to rotate the shoulders before the head reached its maximum degree of rotation. Because the head and body are typically "locked" during building clearing, independent head movements do not play a large role in visual search.

The Role of Body Movements in Building Clearing

Body movements are used for both locomotion and rotation of the body in order to search the visual environment. The maximum range of shoulder rotation around the yaw axis, without moving the hips, is approximately 90° (Hamil & Knutzen, 1995). The best way to demonstrate this type of movement is to have a person sit in a chair and try to rotate his/her shoulders as far as possible. Normally, the torso can rotate using the hips a little more than 180°. Due to discomfort at extreme rotations it seems natural that a person would move his/her feet before his/her torso reaches its maximum rotation. Because the head and torso move together during building clearing almost all rotational movements are driven by the torso.

Building Clearing in Virtual Environments

A virtual environment (VE) is a computer-based technology that attempts to increase feelings of "presence" experienced while interacting with a computer generated environment (Hettinger & Haas, 2003). Presence can be defined as how 'involved' a person feels within a computer generated environment (Draper, Kaber, & Usher, 1998). There are a wide range of potential applications for VEs in the realms of training (Stedmon & Stone, 2001), rehabilitation (Holden, 2005) and clinical treatment (Wiederhold, & Wiederhold, 2000). One of the primary benefits of a VE is that it allows the user to train or participate in a situation that would ordinarily be prohibited due to cost, danger, or ethical considerations. For a more in depth review of VEs see Hettinger and Haas (2003). Building clearing is a prime target for training in a VE due to the dangerous nature of the task.

Head Mounted Displays (HMDs) in VEs

Two popular display options for VEs are projection displays and head/helmet mounted displays (HMDs). In a projection display, the VE is projected onto one or more large screens, or onto a dome-shaped screen. The benefit of a projection display is that it has the potential to free the user from cumbersome instrumentation. The drawback of a projection display is the large footprint it requires. The current experiment used HMDs. HMDs can come in a variety of shapes and sizes. Typically they involve a device that rests on a person's head with one or two displays positioned in front of the person's eyes. Figure 1.3 shows some examples of HMDs. The one on the far left is identical to the one used in the current study with the exception of the earphones.

Figure 1.3- Examples of HMDs, from left to right: nVis nVisor SX, Sony's Glasstron LDI-50BE, Interactive Imaging System's NFX-3D (www.stereo3d.com)

A tracking system is typically used in conjunction with the HMD so that head movements can be tracked and mapped into the VE. For example, if a user turns his or her head to the left with a 'tracked' HMD the visual scene shifts right across the HMDs display, simulating a left head turn in the VE. If the HMD was not tracked the visual scene would remain stationary on the display regardless of the head movements made.

HMDs have the benefit of taking up less space than a projection system. A drawback is that the users have to wear cumbersome equipment that is typically tethered to the main computer system through an umbilical cord. An umbilical cord is a long cord that connects the HMD to the main system and contains the audio, video and power connections. With an HMD the wearer usually has to stay in one location unless the cord is exceptionally long. The cord often becomes tangled, which can restrict the wearer's natural movements.

Motion Sickness

Motion sickness is a common phenomenon within moving environments and stationary environments with a moving visual scene. It is defined by Reason and Brand (1975) as "…a condition characterized primarily by pallor, cold sweating, nausea and vomiting that follows the perception of certain kinds of real or apparent motion." It has been suggested that motion sickness symptoms can be differentiated along four different dimensions: gastrointestinal, central, peripheral and sopite-related (Gianaros et al., 2001). The gastrointestinal dimension includes symptoms such as nausea, queasiness and upset stomach. The central dimension includes symptoms such as dizziness, lightheadedness, disorientation and blurred vision. The peripheral dimension includes symptoms such as general sweating, a clammy or cold sweat and feeling hot or warm. Finally, the sopite-related dimension includes symptoms such as feeling annoyed or irritated, tiredness and fatigue, and feeling uneasy. These negative effects of motion sickness can lead to a decrease in work rate, loss of motivation, disruptions of work and the complete abandonment of work all together (Wertheim, 1998).

Sensory Mismatch and Motion Sickness

One of the more popular theories for the cause of motion sickness is the sensory mismatch theory originally proposed by Reason and Brand (1975). In this theory, sensory mismatch refers to contradictory information provided within or between sensory systems.

Probst and Schmidt (1998) discuss two types of potential mismatch: vestibular-vestibular mismatch, and visual-vestibular mismatch. An example of vestibular-vestibular mismatch would be sitting in a rotating room and making head movements. In this case the semicircular canals detect several different angular accelerations at once. An example of visual-vestibular mismatch would be controlling a fixed-based flight simulator while aboard ship. Here the visual system is detecting the motion in the VE while the vestibular system is detecting the motion of the ship. It is even possible to have more than two types of mismatch. If someone were driving a vehicle aboard ship they would receive conflicting information from their visual and vestibular system as well as conflicting information within their vestibular system (e.g. movement of the vehicle versus movement of the ship).

Within these mismatch conditions two types of conflict can occur: when the sensory systems signal contradicting information or when one system signals information in the absence of an expected signal from the other system. The preceding paragraph contains examples of situations where the sensory systems signal contradictory information. An example where the vestibular system signals movement when the visual system does not is reading while a passenger in a car. While looking down at a book the visual system is not detecting any motion but the vestibular system is detecting the movement of the car. An example where the visual system signaling movement when the vestibular system does not is a person seated watching an IMAX movie. An IMAX movie is projected on a screen that occupies almost all of a person's visual field. Movement of the visual scene on the screen can lead the visual system to detect bodily motion while the vestibular system does not.

According to Reason and Brand's (1975) theory motion sickness is caused not only when inputs from various sensory systems conflict but also when present inputs conflict with expectations based on previous sensory experience. For example, when you are sitting in a stationary chair no mismatch exists: your visual system indicates that you are stationary; your semicircular canals detect no significant angular accelerations; your otoliths detect the pull of earth referenced gravity; and other kinesthetic senses detect that you are in a seated, stationary position. If you then place that chair in a moving vehicle with no windows to eliminate visual motion cues, the otoliths and the semicircular canals provide information that doesn't fit the expected sensory pattern associated with being seated and will create a mismatch with the input from at least the visual system.

There are numerous combinations of mismatch between the various sensory systems. The current study focuses on visual-vestibular mismatch. It is not the goal of this paper to debate or examine the mismatch theory. However, the mismatch theory provides a nice context for discussing the present work.

Head Movements and Motion Sickness

Head movements, specifically during the Coriolis oculogyral illusion (OGI), have commonly been used to elicit motion sickness in laboratory experiments (e.g. Kohl, Calkins, & Robinson, 1991; Golding, 1992; Golding & Stott, 1995). The Coriolis OGI, or cross-coupled angular acceleration, can occur when head movements are made around axes that are different than the axis of bodily rotation. For example, if a person were sitting in a chair rotating around the yaw axis (see Figure1.2) and he or she began nodding his or her head along the pitch axis, that person would experience the Coriolis OGI. When this happens the vestibular system detects rotational movement in several different directions at one time. For example, the chair is rotating around the yaw axis while at the same time the person seated in the chair is moving his or her head along the pitch and roll axes. Often the Coriolis OGI is inherent in certain tasks that are designed to examine the effects of motion sickness on performance. The Dial Test in the Pensacola slow rotation room (SRR) is one example of this (Kennedy & Greybiel, 1962). In this task a subject is required to monitor and adjust dials that are located all around his/her seated position. In order to read and adjust each dial the subject must move his/her head about axes that are different from the axis of the room rotation. Reason and Brand (1975) noted that across a variety of experiments in the SRR there was one common characteristic. If given freedom of control most subjects would quickly restrict their head movements in an attempt to reduce the nauseogenic stimulus.

Sensory mismatches due to head movements are not restricted to a moving environment. It is also possible to experience symptoms of motion sickness in a stationary environment when the visual scene moves, an experience known as vection. A common laboratory example of this is the circular vection created by an optokinetic drum. An optokinetic drum is a cylindrical room, with some type of pattern on the walls, where a person sits or stands in the center (Figure 1.4). The vertical pattern is then rotated around the person inside the drum. Because the rotating pattern occupies almost all of the visual field, it can produce the sensation that a person is physically rotating, an illusion called circular vection. If a subject is instructed to try to focus on the pattern, the pattern can also cause OKN eye movements as it rotates through a person's visual field of view.

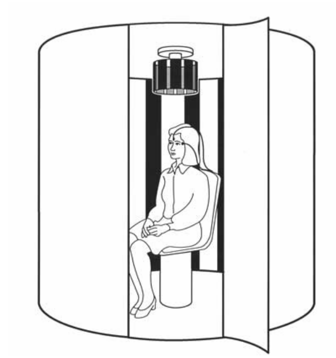


Figure 1.4. An example of an optokinetic drum (www.dizziness-and-balance.com/ practice/tracking_test.htm)

Stern et al. (1990) found in two separate studies that 58-60% of subjects report motion sickness symptoms when exposed to a rotating optokinetic drum. Tiande and Jingshen (1991) conducted a study using a rotating sphere and head movements to illicit motion sickness symptoms. The authors reported that when the stimulus was rotated in the yaw direction, the addition of head movements lead to increased symptoms of motion sickness.

Simulator Sickness in Virtual Environments

Simulator sickness is a form of motion sickness that can accompany exposure to simulators or VEs. Kennedy et al. (1993) developed a simulator sickness questionnaire (SSQ) which has three clusters or dimensions of simulator sickness symptoms: oculomotor, disorientation, and nausea. The oculomotor dimension includes symptoms such as eyestrain, difficulty focusing, blurred vision and headache. The disorientation dimension includes symptoms such as dizziness and vertigo. The nausea dimension includes symptoms such as nausea, stomach awareness, increased salivation and burping.

Though simulator sickness in flight simulators tends to be mild, that is not the case for simulator sickness in VEs. According to Stanney and Kennedy (1997) the average total score (TS) for simulators on the SSQ is around 10, while the average TS for VEs on the SSQ is around 20 and in some systems can be as high as 50.

Stanney, Kennedy, Drexler, and Harm (1999) investigated reports of motion sickness after exposure to a VE where subjects were required to wear HMDs and complete two separate tasks, object manipulation and locomotion, using a hand controller. The scores on the SSQ (Kennedy, Lane, Berbaum, & Lilienthal, 1993) showed a significant increase, from baseline, after 30 minutes of exposure to the VE and performance tasks.

Another study by Westerman, Cribbin, and Wilson (2001) showed that the use of a tracked HMD produced feelings of nausea. The authors examined the use of head tracking to navigate a three dimensional environment. The primary objective of their study was not to investigate the nauseogenic properties of HMDs but the authors did report their observations. The subjects of this study were split into two groups, one that used a CRT monitor to view the environment and one that used a tracked HMD. Within the HMD group, 25% of the subjects reported feelings of nausea during the experiment and two of those subjects had to withdraw their participation. None of the subjects in the CRT monitor condition reported any symptoms of sickness.

Cobb, Nichols, Ramsey, and Wilson (1999) examined 9 different studies that used a variety of different HMDs to expose 148 subjects to different VE systems. These experiments examined a wide array of effects that arose from performing different tasks within a VE. Results from all 9 of the experiments showed that 80% of the subjects reported symptoms of sickness during or after exposure to the VEs, with 5% of the subjects affected so severely that they had to withdraw their participation. An interesting observation during the experiments was that as the subjects' symptoms of sickness increased head movements decreased, suggesting that perhaps the head movements could have been a fairly strong nauseogenic stimulus.

There are a variety of factors that are thought to play a role in the onset of simulator sickness in VEs such as vection, visual lag and field of view (FOV; Stanney, Mourant, & Kennedy, 1998). Vection can be defined as the illusory sensation of motion that results from a moving visual scene. Visual lag can be described as the amount of time between the initiation of a head movement and the movement of the visual scene in a 'tracked' system. FOV refers to the amount of the visual scene a person can see without moving his/her head.

Vection

Navigation in a VE can result in feelings of vection due to the optic flow of the visual scene. This vection can lead to sensory mismatch between the visual and vestibular systems, which can in turn lead to symptoms of motion sickness as described above. Kennedy, Hettinger, and Harm (1996) looked at rotational vection and demonstrated how increasing the speed of the stimulus increases subjects' feelings of vection. Hu, Stern, Vasey, and Koch (1989) showed that increasing the speed of an optokinetic drum can increase symptoms of motion sickness. So and Lo (1999) created rotational vection by oscillating the visual scene in a head mounted display (HMD) and found that visual rotation around any axis (yaw, pitch, roll) leads to significant symptoms of motion sickness. These studies show that increasing the rotational speed of the visual stimulus, up to a certain point, can increase the onset of feelings of both vection and motion sickness.

Hu et al. (1989) found that sickness symptoms from circular vection peaked at a speed of 60°/sec and then they declined. Kennedy, Hettinger, and Harm (1996) also found that there were some participants who did not report any sensations of vection at rotational speeds above 220°/sec. One of the reasons Kennedy, Hettinger, and Harm (1996) cited for the lack of feelings of vection above a certain rotational speed was that OKN eye movements could not keep up with the rotating visual pattern. Hu and Stern (1998) found that the more OKN eye movements that are made the greater the feelings of vection and the greater the symptoms of motion sickness. This suggests that OKN plays a role in feelings of vection as well as motion sickness.

So, Lo, and Ho (2001) looked at the effect of increasing linear speed of navigation on vection and motion sickness in a VE. Their results supported the previous research finding that increasing linear speed increased the onset of feelings of vection and motion sickness. Linear and rotational speed can be associated with general navigation of a VE. Therefore, the mere act of moving around a VE could lead to symptoms of motion sickness.

Visual Lag

It has also been suggested that visual lag can contribute to symptoms of simulator sickness. Unfortunately, there are studies that both confirm and refute this theory. Dizio and Lackner (1997) varied the visual lag in the HMDs worn by subjects from 67ms to 300ms, which resulted in increasing visual lag experienced by the subjects. The results indicated that the severity of motion sickness as reported by the subjects, increased in a linear fashion as the amount of visual lag increased. However, another study conducted by Nelson, Bolia, Roe, and Morley (2000) observed that while reports of sickness increased with the amount of time subjects were exposed to the VE, the amount of visual lag that they experienced had no significant effect on reports of sickness.

Another problem with visual lag in a VE is that it interferes with the VOR. With visual lag, movement of the visual scene does not begin when the head first moves. Therefore, the initial VOR is incorrect and the visual scene seems to move with the head instead of remaining stable (Welch, 2003). This disruption of the VOR can make it difficult to search the virtual environment because the visual scene does not appear stable like it would during head/body movements in a real environment.

Field of View

Some studies have investigated the role that the visual FOV plays in motion sickness. Most of the evidence suggests that wide FOVs (DiZio, & Lackner, 1997; Stern, et. al., 1990) increase motion sickness. Stern et al. (1990) restricted subjects actual FOV while they were exposed to a rotating optokinetic drum and found that subjects reported significantly fewer symptoms with a restricted FOV compared to a control condition with a normal FOV, of ~180°(Blake & Sekular, 2006). Dizio and Lackner (1997) designed a study to test some of the potentially nauseogenic aspects of HMDs among them the visual FOV. The authors compared motion sickness symptoms between a full FOV, 138° wide by 110° high, and a halved FOV, 69° wide by 110° high. The results of Dizio and Lackner's (1997) study examining HMDs showed that halving the linear dimensions of FOV reduced reports of motion sickness by about half. This provides evidence that a smaller field of view in an HMD could help to reduce symptoms of motion sickness.

A smaller FOV can also be problematic in certain situations, specifically visual search tasks in a VE. During visual search in a VE if a person has a reduced FOV he/she would use fewer eye movements and more head movements in order to search the VE. Increased head movements in a tracked HMD can increase a person's exposure to visual lag. As discussed above, visual lag in a VE can lead to symptoms of simulator sickness. On the other hand, a larger FOV would allow more eye movements during visual search and less head movement, but again as described above, a larger FOV can also lead to increased symptoms of simulator sickness (DiZio, & Lackner, 1997; Stern, et. al., 1990), and increased feelings of vection (Allison, Howard, and Zacher, 1999). It is unclear whether a lager FOV and increased feelings of vection, or a smaller FOV and increased visual lag is more nauseogenic. Based on the preceding paragraphs it can be assumed that no matter what the FOV in a VE, simulator sickness will most likely present a problem.

Level of Control

Another proposed mediator of simulator sickness is the level of control the user has over the VE (Stanney, & Hash, 1998). In other words, does the user have complete freedom to move any direction he/she wants within the VE? Level of control can also be thought of as the more control a user has the more degrees of freedom he/she has control over. Previous motion sickness research has suggested that the severity of motion sickness can be significantly reduced if a person has more control over the motion he/she is experiencing (Rolnick, & Lubow, 1991). Stanney and Hash (1998) examined the effects of three different types of control on reports of motion sickness: active control, where the subject had control over all the degrees of freedom of movement; active-passive control, where the subject had control over only the degrees of freedom necessary for the task; and passive control, where the subject had no control and was "along for the ride." The authors found that while active control in the VE helped to reduce symptoms of sickness, complete control may not be optimal. Instead, subjects who could use only the degrees of freedom necessary for the completion of the task, reported significantly fewer symptoms. Therefore, it seems that the best level of control to reduce motion sickness may be dependent on the needs of the particular task being performed.

Present Study

It has been shown above that motion sickness can result from head movements during exposure to a VE as well as in a moving and/or stationary environment. Howarth and Finch (1999) went one step further and showed that motion sickness can result from head movements in a VE. In their study subjects navigated a VE using either a hand control or head movements. The results showed that the head movements led not only to greater reports of motion sickness but also longer lasting symptoms. Although most of the subjects recovered 10 minutes after the experiment, others failed to recover in such a short period of time. In addition, some subjects in the head movement condition reported a recurrence of symptoms after having reported no symptoms. One subject had symptoms which lasted up to 15 hours after the experiment. Observations from the experimenters also suggest that as subjects became more experienced with the virtual system they began to restrict their head movements, most likely to reduce the time to onset and severity of nausea.

Head Movements in a Virtual vs. Real World

The first analysis in this study was designed to look at the differences between head movements in a VE and head movements in a real world (RW) environment while completing a building clearing task. Current technology is such that the FOV in an HMD is usually less than a person's normal FOV. Therefore, it would be expected that when subjects completed the same type of task head movements would be greater in a VE than in a RW environment. Head movements should be greater due to the fact that more head movements must be made to receive the same amount of visual information. However, the data above indicate that individuals restrict their head movements in HMDs due to simulator sickness. Therefore, despite the task necessitating more head movements it was hypothesized that there would actually be fewer head movements made in a VE than in a RW environment.

The Relationship of Head Movements to Simulator Sickness in a VE.

Though previous studies (Howarth, & Finch, 1999; Cobb, Nichols, Ramsey, & Wilson, 1999) have provided anecdotal observations that subjects who get motion sick while using head-tracked HMDs tend to restrict their head movements, the literature has lacked studies that actually quantify the amount of head movement during motion sickness. The second analysis in this study was aimed at quantifying the amount of head movements made in a VE and determining whether or not subjects restrict their head movements when they become motion sick. Based on the preceding literature regarding head movements and motion sickness (e.g. Kohl, Calkins, & Robinson, 1991; Golding, 1992; Golding & Stott, 1995), and HMDs and motions sickness (Howarth, & Finch, 1999; Cobb, Nichols, Ramsey, & Wilson, 1999), it was hypothesized that subjects who display significant sickness scores would move their heads less than subjects who did not display significant sickness scores.

CHAPTER II

METHODS

Overview

This work is broken down into two analyses. The goal of Analysis I was to compare head movements made in a RW environment to head movements made in a VE. The goal of Analysis II was to examine the relationship between head movements and simulator sickness in a VE.

Subjects

The data for both analyses were drawn from a larger study entitled "Establishing Team Training Metrics through the Use of a Virtual Training Lab," which investigated the use of VEs for training building clearing. This study will be referred to as the Team Training study. The selection criteria for the Team Training study were as follows: subjects had to be male, have no previous experience with the task of building clearing, no history of severe motion sickness and have English as a first language. As subjects were first admitted to the Team Training study they were asked questions corresponding to the above criteria. If the subjects answered yes to all of the questions they were allowed to participant. If they answered no to any of the questions they were excluded from the study. The rationale behind these selection criteria was that the results of the Team Training study were to be applied to male combat Marines and the desire was to minimize simulator sickness. Subjects in the Team Training study were quasi-randomly assigned to 4 person teams in 1 of 4 training conditions: high immersion VE, low immersion VE, RW environment and training video only. The high immersion VE consisted of an immersion VE presented through a tracked HMD. The low immersive VE consisted of a VE presented on a 17 inch computer monitor. There were 6 teams in each condition except for the video only condition where there were only 5. Subjects were compensated approximately $10 an hour for their participation.

A secondary screening process was conducted for the high immersion VE condition. Experimenters checked subjects' Motion Sickness History Questionnaires (MSHQ; Reason & Brand, 1975) in an attempt to eliminate subjects who might become physically ill in the VE. Subjects who answered 'sometimes' or 'always' to the questions that asked how often they felt sick during several specific examples of motion and how often they vomited during several specific examples of motion were assigned to a condition other than the high immersion VE. See Appendix A for a copy of the MSHQ. The particular questions described here are the last two on the questionnaire. Only one of the subjects in the high immersion VE did not meet this criterion due to scheduling availabilities. Also, another subject that began the high immersion VE condition became too nauseous to continue after two trials. Therefore he and his team were switched to the low immersion VE condition. That team was replaced with another team of four. An independent-samples t-test showed that despite the secondary screening process there were no significant differences between the MSHQ scores of the subjects in the high immersion VE condition ($M=8.709$, $SE=2.754$) and the low immersion VE condition ($M=4.802$, $SE=1.377$), $t[46]= -1.268$, $p>0.05$.

Analysis I used 48 subjects ages 18-25, 24 from the high immersion VE condition and 24 from the RW condition.

Analysis II used the 24 subjects, ages 18 to 23, from the high immersion VE condition. In addition, the simulator sickness scores from the 24 subjects in the low immersion VE were compared to the scores in the high immersion VE as a control. Subjects in the low immersion VE condition should have reported low or no simulator sickness due to the fact that subjects in this condition did not have to move their heads to complete the task and were in a non-immersive environment.

Equipment

High Immersion VE.

The entire VE system was separated into 4 "pods" or stations. The equipment making up each pod consisted of an LED tracking system, an HMD, a weapon, a haptic vest, a small backpack and a 3ft high metal safety ring. The metal ring kept subjects from walking outside of the tracked area and from falling. Other supporting pieces of equipment included in the VE were the task software, spatial audio, tracking software and the computers to run the software.

Optical Motion Capture System. The system used in the high immersion VE was Phasespace's (San Leandro, CA) IMPULSE Motion Capture System. This camera-based system actively tracks LEDs (small lights) placed at various locations on the objects being tracked. Because the cameras track the LEDs from multiple directions, the computer is able to map the tracked objects' locations into the VE. As a result a person has the ability to actively move and 'look around' within the VE by moving his/her head and body. The system consisted of active LEDs, cameras, LED controllers, LED base stations and a server computer.

The active LEDs were a little smaller than a pencil eraser and the accompanying circuit board was approximately the size of a penny. Using visible red light each LED produced a unique frequency and therefore a unique ID. The LEDs for each subject were managed by an LED controller in the backpack. The LED controller used an onboard microprocessor and an RF transceiver to run the LEDs. The LED controller synchronized with the computer server through a 2.4 GHz transceiver, or base station.

Each IMPULSE camera used two linear detectors, with 16-bit dynamic range, to achieve an optical resolution of 3600 x 3600 or 12 megapixels. For each pod there were 8 cameras attached to a 12 x 12 ft scaffold (2 cameras per side). All of the cameras and each of the base stations were wired into the computer server. The server could output 3D position data at 480 Hz, with 10 ms latency.

HMD. The head mounted display used in this study was an NVIS nVISOR (Reston, VA), weighing approximately one kilogram, with a resolution of 1280x1024. The nVISOR had an adjustable eye relief (distance between screens and eyes) between 23 and 30 mm, an adjustable interpupillary distance (IPD) between 55 and 73 mm and a 100% overlapped, 60 degree physical FOV (diagonal) for each eye. The HMD was also equipped with LEDs for the tracking system which tracked head movement in the yaw, pitch and roll axes. There were 6 LEDs equally spaced around the crown of the HMD. There were also additional earphones (with a microphone) attached to the HMD to facilitate spatial audio and communication in the VE.

Weapon. The mock weapon used in this system was a modified M16 airsoft rifle. The rifle was fitted with 5 LEDs: 1 on the front sight post, 1 on the barrel, 1 on the main sight/handle and 2 on either side just above the magazine. The weapons used a Logitech

Wingman (Logitech, Fremont, CA) wireless joystick. The joystick was disassembled so that one of the buttons was connected to and activated by the trigger. The portion of the joystick that registered motion (forward/back and left/right) was connected to a small thumb joystick and placed in the left side of the rifle's barrel. Subjects used the joystick to walk forward/backward and to sidestep left/right.

Haptic Vest. Every subject in the high immersion VE was also required to wear a haptic feedback vest. This vest was made of tight fitting neoprene with haptic vibrators affixed to the inside layer. Through spatialized vibrations in the vest subjects received feedback regarding collisions in the VE.

Backpack. Each subject wore a small backpack that held the LED controller and was fitted with 5 LEDs for tracking movement. There were 2 LEDs on each side and 1 on the top of the backpack. The LEDs on the backpack permitted the tracking of torso movements (bending and rotation).

Building Clearing Task in the VE. The VE was created by Lockheed Martin (Bethesda, MD) for the Office of Naval Research. There were several pieces of software designed for the Department of Defense that made up the VE task. These pieces of software include: Gaiter, Mansim, OneSAF Testbed Baseline Semi-Automated Forces (OTBSAF) and Ansel. Gaiter used inputs from the Phasespace tracking system to map the movements of the subjects onto avatars, or virtual representations of the subjects. Mansim was used to model the VE and used inputs from Gaiter to map the avatars in the VE. Mansim received inputs from OTBSAF through the Joint Semi-automated Forces (JSAF) Gateway to create combatants and non-combatants within the VE. Finally, Ansel was used to record and store all of the data generated in the VE during each of the trials.

The VE task was designed to train clearing a building room by room. The VE shoothouse consisted of a one story building with 15 rooms which varied in size, shape and furnishings (Appendix B). The rooms had no doors and were located on either side of the hallway which circled the building. This floor plan allowed the subjects to enter and exit at the same location. In the VE there were both combatants, enemy threats with weapons, and non-combatants, civilians without weapons. Combatants and non-combatants stayed in fixed locations. When a subject came within the line of sight of a combatant the combatant would shoot at the subject. When a combatant was shot he would fall to the ground and when a non-combatant was acknowledged (by clicking the locomotion joystick) he would go down on one knee. When a subject was shot his screen would turn red and he would be finished participating for that particular trial.

In order to complete one trial in the VE the team of subjects would go through the house counterclockwise, shooting combatants and acknowledging non-combatants. If all of the subjects were killed before the end of the trial the trial would end when the last subject was killed. During each experimental session subjects were required to complete 20 trials as a team.

Low Immersion VE.

The identical VE was presented in the low and high immersion VE conditions. Subjects completed the same building clearing task in both. In the low immersion VE subjects were required to sit at one of four stations. At each station there was a monitor, gamepad and headphones with a microphone. The task was presented on a 17' CRT monitor and subjects interacted with the environment using a Saitek P2500 rumble force gamepad (Saitek Industries, Torrance, CA). The gamepad allowed the subjects the same amount of control in the VE as subjects in the high immersion condition and it vibrated to provide haptic feedback about collisions. The headphones and microphone gave each subject the same communication abilities in the low immersion VE that subjects had in the high immersion VE. The low immersion VE did not in any way restrict the subject's visual field. However, the view of the task was limited to the CRT monitor.

Real World Environment.

The RW environment was Clemson University's 'instrumented' shoothouse. The shoothouse was 'instrumented' with a video tracking system. Inside the shoothouse subjects wore position tracked helmets and weapons, as well as wearable arousal meters (WAMs) for recording heart rate.

Video Tracking System. The tracking system in the RW environment consists of 36 cameras positioned on the top of the walls. The cameras record the video in order to track position locations of the subjects in real time (Hoover & Olsen, 1999). Position locations were updated at 20 Hz with an accuracy of approximately 10 cm.

Helmet. A Honeywell HM3300 (Honeywell, Morristown, NJ) digital compass was embedded in the helmet to track each subject's head movements around the yaw axis. This particular digital compass uses both an accelerometer and a magnetometer to provide orientation data. The head tracking data was sampled at 6-8 Hz. Despite the manufacturers published error of 1 degree, local tests have shown that across slow and fast movement the Honeywell HM3300 produces ~19 degrees of error (Waller, 2006). The helmet also contained 4 infrared sensors that detected 'hits' from the laser-tag like weapons. When a subject was 'hit' the helmet would play a voice recording saying "you are dead." The helmets wirelessly transmitted all data in real-time at 6-8 Hz via 802.11 (DPAC Technologies, Hudson, OH).

Weapon. The weapons in the RW were mock M16 airsoft rifles that were fitted with a Honeywell HM3300 (Honeywell, Morristown, NJ) digital compass and trigger-activated infrared lasers. When the trigger was pulled the weapons produced an audible beep to provide the subjects with feedback. The weapons wirelessly transmitted all collected data real-time at 6-8 Hz via 802.11 (DPAC Technologies, Hudson, OH).

Wearable Arousal Meter WAM. Each subject was fitted with a UFI Wearable Arousal Meter v. 2.4a (WAM; UFI, Morro Bay, CA) that recorded heart rate data throughout the entire testing session. Three self adhesive electrodes were placed on each subject and connected to the WAM with snap fetrodes. The WAM was worn around the waist with a belt and wirelessly transmitted all of its data real-time at 6-8 Hz via 802.11 (DPAC Technologies, Hudson, OH). None of the heart rate data were used in the current study.

Building Clearing Task in the RW. The RW shoothouse consisted of 4 rooms with no doors and sparse furnishings (see Appendix B for the floorplan). The shoothouse was populated with combatants and non-combatants. Combatants and non-combatants were paid 'actors' and fitted with the same equipment as the subjects with the exception of the WAM. When combatants or non-combatants were shot or acknowledged they would place their rifles at their sides and go down on one knee; the same applied for the subjects. To complete one trial the subjects had to move through all of the rooms in the shoothouse, shoot the combatants and acknowledge (yell "get down") the non-combatants. At least one subject had to survive for the successful completion of a trial.

If all of the subjects were shot before the completion of the trial, the trial would end when the last subject was shot. During each experimental session teams were required to complete 20 trials.

Materials

MSHQ

The Motion Sickness History Questionnaire (MSHQ; Reason & Brand, 1975) was administered prior to the experiment in order to assess the subjects' history of motion sickness. A copy of this self-report measure is located in Appendix A.

SSQ

The SSQ is a 16-item questionnaire designed to be administered before and after subjects are exposed to simulators or VEs (Appendix A). The SSQ was validated using data from 3,691 simulator hops and is often used to evaluate simulator sickness (Kennedy, Lane, Berbaum, & Lilienthal, 1993). The SSQ produces 3 sub-scores (Oculomotor, Disorientation, and Nausea) and a total sickness score. In this study only total SSQ scores were used. According to Stanney and Kennedy (1997) the average total SSQ score for flight simulator systems is 10, while the average total SSQ score for VEs is 20.

Other Questionnaires

Additional questionnaires that were administered in the Team Training study, but not used in any of part of the current study, were the NASA-TLX (NASA Ames Research Center), Presence questionnaire (Whitmer, & Singer, 1998), Team Efficacy questionnaire

(Design Interactive Inc., Oviedo, FL), and the Team Factors questionnaire (Switzer et al., 2005).

Procedure

The Team Training study for which these data were collected consisted of three phases: Phase I was an initial training/orientation session; Phase II involved training in one of four conditions; and Phase III involved testing in Clemson University's instrumented shoothouse. Four person teams were formed for Phase II and subjects remained in those same teams for testing in Phase III.

Phase I: Initial Training

The initial training was a 3-hour session that consisted of part lecture and part practical application given by a Marine subject matter expert. The lecture primarily focused on the basic techniques required to effectively clear a one-story building using a four man team but also included a brief history of military operations in urban terrain (MOUT). There were 9 initial training sessions involving 236 subjects.

Phase II: Team Training

Phase II was divided into 4 different conditions: high immersion VE, low immersion VE, RW, and no training (training video only). In each of these conditions subjects were assigned to 4 man teams based on the subjects' availability.

High Immersion VE. There were 6 teams in the high immersion VE condition (24 subjects). When a team arrived for training they would re-sign their original consent forms and ask any additional questions they may have had. The subjects would then watch a refresher training video which quickly covered all of the building clearing concepts they learned during Phase I. Following the 10.5 min refresher video the experimenters would explain the standardized feedback system that would be used during both training and testing (Appendix C). After a brief explanation of the task and the required equipment the subjects chose one of the four VE systems and the experimenters helped fit them into the system.

In order to familiarize subjects with the floor plan they first completed one practice trial without any combatants or non-combatants. They also completed a practice trial with combatants and non-combatants to experience what the interaction with the VE would be like during the experiment. After the practice trails the subjects completed 20 training trials. In between each trial subjects removed their HMDs. Standardized team feedback was given after trials 1, 2, 3, 4, 8, 12, 16, and 20. The SSQ was completed pre-training and after trials 1, 4, 8, 12, 16, and 20. The NASA-TLX was completed after trials 1, 10 and 20. At the completion of all 20 trials subjects also completed the Presence and Team Efficacy questionnaires. Subjects were allowed to stop for lunch during training. The timing of the lunch break varied based on the rate of trial completion. When the training was completed subjects were scheduled for Phase III. A copy of the experimental protocol for the high immersion VE is located in Appendix D.

Low Immersion VE. There were 6 teams in the low immersion VE condition (24 subjects). Subjects in the low immersion VE were trained using the same VE task as the high immersion VE, but the task was displayed on a 17' CRT computer monitor. Subjects were visually isolated so that they could only see and communicate with each other via the VE. The low immersion VE condition received the same feedback and questionnaire regimen as the high immersion VE condition. When the training was completed subjects were scheduled for Phase III. A copy of the experimental protocol for the low immersion VE condition is shown in Appendix D.

RW. There were 6 teams in the RW condition (24 subjects). In the RW training condition subjects were transported to the facility where the shoot house was located. Upon arrival at the shoot house subjects reviewed and re-signed their original consent forms before viewing the refresher video. After the video, the experimenters explained the training task and demonstrated the equipment that would be used. Subjects were allowed to walk through the shoot house to become familiar with the floor plan before beginning training. Subjects completed 20 trials in the shoot house. For each trial the combatants and non-combatants were located at specific locations throughout the shoot house. See Appendix B for a map of the combatant and non-combatant locations as well as the experimenter sheet showing where they were located for each trial. During training subjects completed the same standardized feedback regimen as the subjects in the VE conditions. The only questionnaires administered during the RW were the NASA-TLX after trials 1, 10, and 20, and the Team Efficacy questionnaire after the completion of trial 20. When the training was completed the subjects were scheduled for Phase III and transported back to the University. See Appendix D for an example of the experimental protocol for the RW training condition.

Phase III: Team Testing

The same 4 man teams that trained together in Phase II also tested together in Phase III. Every team completed the same testing phase at the real-world shoot house facility. Except for the order in which the subjects entered the shoothouse, the positions/number of combatants and non-combatants and the lack of a refresher video, the experimental protocol was the same during the testing phase as it was during the RW training condition (Appendix D). The only questionnaires administered during testing were the Team Efficacy and Team Factors questionnaires after trial 20. At the completion of the testing phase subjects were debriefed, paid and transported back to the university.

Data Reduction

In the current study head/body position data from two different types of motion tracking systems were used: active LED motion capture in the VE; and digital compasses in the RW. Both data sets required reduction. 'Head movement' was operationally defined as movement of the head through rotation of one or all of the following: the neck, the torso, and the entire body.

VE

Motion tracking data from the VE were saved to the main system as a 'platform' file. There was one 'platform' file for each trial which contained the asynchronously sampled tracking information for the HMD, backpack and weapon of each subject.

Using a locally designed program the 'platform' data were: 1) resampled at 20Hz; 2) converted from radians to degrees; and 3) separated into four files per trial, one for each subject. There were originally 120 'platform' files which resulted in 480 data files. Each data file contained one column of head position data for one subject during one trial.

Using a program designed in Matlab (The Mathworks, Inc., Novi, MI) the differences in the head position data were obtained for each file. The resulting data represented the differences between consecutive 20Hz (every 50 ms) samples of head position data. For example, if at one sample the subject's head was positioned at 45° and 50 ms later is was positioned at 90°, the difference between those two samples would be 45° (Figure 2.1). The absolute value of the difference was derived because the current study was not concerned with which direction the subjects moved their heads.

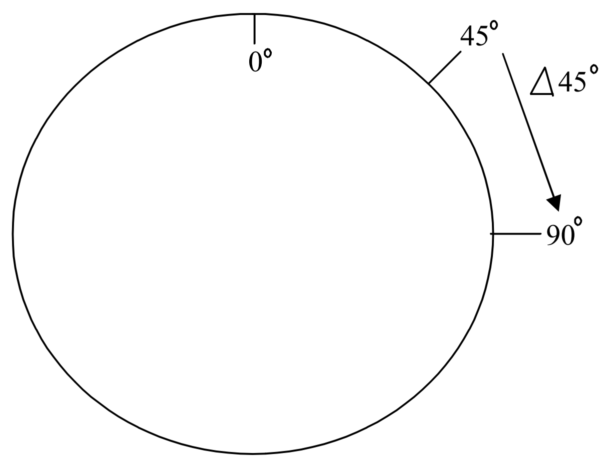


Figure 2.1. Example of how a difference in head position was derived

When a person's head passed the 0° mark in-between samples it would produce a difference that was not representative of the actual distance the head moved. For example if a subject's head was positioned at the 10° mark and then moved left to 350° mark, it would be a change of 20° (Figure 2.2). Unfortunately, the absolute difference between 10° and 350° is 340°. For that reason an "if, then" statement was written into the Matlab program. "If the difference between two head positions is greater than 180°, then subtract that difference from 360°." This logic came with the assumption that a subject would not move his head more than 180° in 50 ms. For a person to move their head 180° in 50 ms he would have to be rotating at a rate of 3600° per second, which is

100 rpm. This rate of self-rotation is highly unlikely during the building clearing task in the current study.

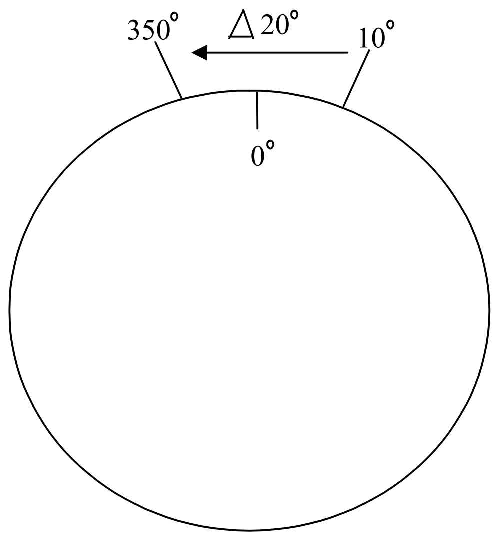


Figure 2.2. Example of a 20° head movement across the 0° mark

The resulting data in these 'difference' files represented the amount of head movement made each 50ms. There were times when the head did not move between two successive samples. Because the current study was only interested with the data during head movements, all of the differences derived when the head was 'not' moving were deleted. Differences that represented no head movements were defined as any difference less than 1° per 50 ms. The rationale for this was that the VE recorded data in decimal numbers, but the RW only recorded whole numbers. This meant that in the VE there were differences less than 1° per 50ms (e.g. 0.5, 0.8, 0.3), but in the RW there were no differences less than 1° per 50ms, other than 0. Appendix E contains examples of histograms which show that the majority of head movement differences for both conditions were less than 1° per 50 ms.

Before the data were analyzed they were aggregated in two ways. The first aggregation represented the average number of degrees the head moved in a 50 ms time step for each subject. The second aggregation represented the percent of time subjects spent 'not' moving their heads. This measure was derived by dividing the number of differences that were deleted from the data files by the total number of difference scores in each file.

RW

In the RW head position data were recorded in degrees and sampled at 20Hz. The Honeywell sensor sampled data and sent it to the main system at a rate of 6-8 Hz. The recording system oversampled the data by recording the latest sample received, at a rate of 20 Hz. These data were saved into one file per trial, per team. Using a locally designed program each initial RW file was split into 4 individual files, one for each subject. This resulted in one file, per subject, per trial. Next, a Matlab program was used to delete all of the errors in the data. Errors in the RW data occurred when a subject pitched or rolled his head more than 45° in any direction, the resulting error was represented with a '-1.' The remainder of the data reduction (calculating differences between samples, deleting differences less than 1° per 50 ms, and aggregating the data) was exactly the same as the VE data.

MSHQ

The MSHQ consisted of three questions concerning how often the subject has experienced certain types of motion, how often he felt sick during those certain types of motion and how often he vomited during those types of motion. The frequency scores were weighted based on the amount of experience a person had with each type of motion. Those corrected frequency scores were then added together and divided by the number of types of motion the subject had experienced. That number was then multiplied by the total number of types of motion on the questionnaire (9) to yield a total MSHQ score (Reason & Brand, 1975). The MSHQ data were only analyzed to determine whether there were any significant differences in motion sickness history between the subjects in the high immersion VE and the low immersion VE.

SSQ

Only the total score from each administration was considered, the SSQ subscales were not used in this analysis. As mentioned earlier, the exact lunch break was dependent on time, not trial. Therefore, it was possible that a subject could have had increasing symptoms of sickness up until lunch, but after taking a one hour break his symptoms may have diminished or disappeared entirely. This effect could occur at varying trial numbers. For this reason, only the peak SSQ scores reported across all administrations were used to define subjects' level of sickness for the purposes of determining who did and who did not become motion sick.

Data Analysis

Analysis I

Analysis I examined the differences in head movements made during the high immersion VE and RW training conditions. The head tracking data from the VE and the RW systems were compared using two independent samples t-tests. One t-test examined the differences between the average amount of head movements made in the VE and the RW. The other t-test examined the differences between the percent of time subjects spent 'not' moving their heads in the VE and RW.

Analysis II

Analysis II looked at the relationship between head movement data and sickness scores in the high immersion VE. In Analysis II both sets of aggregated data were first analyzed using a series of correlations. Two between-subjects Pearson's correlations were used to try to determine the general relationship between head movements and SSQ scores. One correlation compared average head movements and SSQ scores and another correlation compared the percent of time subjects spent 'not' moving their heads and SSQ scores. To see more specifically how SSQ scores and head movements varied together over time, two within-persons correlations were used. Each within-persons correlation involved a within-subjects correlation of SSQ scores and head movements for each individual. The resulting correlations were then averaged together to obtain the within-persons correlation between SSQ scores and either average head movements or the percent of time subjects spent 'not' moving their heads.

The head movement data were also analyzed using group level aggregate data. The 24 subjects in the high immersion VE condition were split two different ways in an attempt to investigate all possible effects of motion sickness on head movements. The first split was a median split at a peak SSQ score of 22.44, leaving 12 subjects in the 'not sick' group (SSQ below 22.44) and 12 subjects in a 'sick' group (SSQ above 22.44). The subjects were split in this way to preserve an equal number of subjects in the 'not sick' and 'sick' categories. Using this split, a 2 x 20 ANOVA was conducted on the average head movement data examining the differences between the 'not sick' and 'sick' groups over all 20 trials. Another 2 x 20 ANOVA was used to examine the differences between the same groups, the percent of time subjects spent 'not' moving their heads.

The second split was based on normative SSQ data collected by Kennedy et. al. (2003). Based on over 9,000 simulator exposures (in a variety of simulators) Kennedy et al. (2003) determined that SSQ scores can be categorized as follows: 0 represents no symptoms; less than 5 represents negligible symptoms; 5-10 represents minimal symptoms; 10-15 represents significant symptoms; 15-20 is where symptoms become a serious concern; and scores over 20 are indicative of a problem simulator. Considering the above categorization the subjects were split into three groups: 6 subjects with scores of 10 or less, 4 subjects with scores between 10 and 20, and 14 subjects with scores over 20. Using this split, a 3 x 20 ANOVA was conducted the differences between average head movements in the low, medium and high sickness groups, over all 20 trials. Another 3 x 20 ANOVA was conducted examining between the same three groups, examining the percent of time subjects spent 'not' moving their heads data.

Range of Head Movement

Independent measurements were conducted in the lab to understand what the typical range of head movements would be during the current study's building clearing task. Head movements could range from almost none when subjects were traveling down a hallway to about 53°/50ms during a buttonhook, which is the room clearing technique that requires the most head movement.

CHAPTER 3

RESULTS

Analysis I

The first analysis used two independent samples t-tests to examine the differences between head movements made in a VE and head movements made in a RW environment. The first t-test (Figure 3.1) showed that subjects in the VE moved their heads significantly less than subjects in the RW, $t(23.43)=12.69$, $p<0.01$. There was heterogeneity in the variance between the RW and VE conditions, therefore the ‘equal variances not assumed’ t-test was used in that analysis.

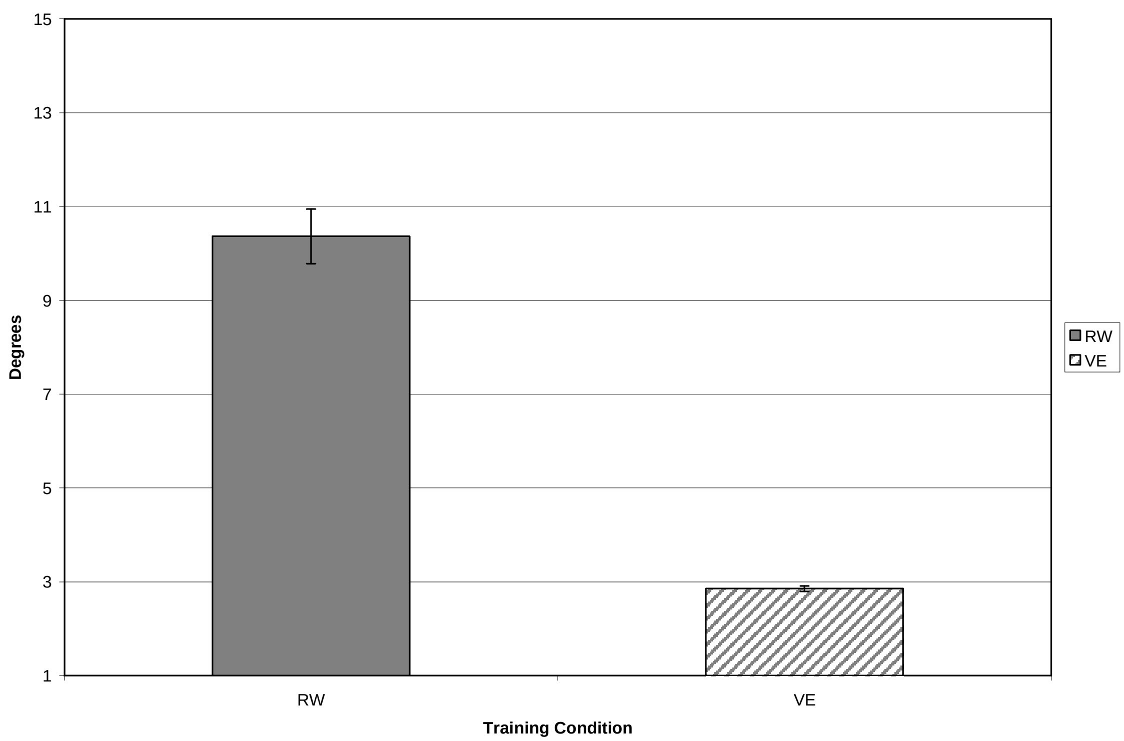


Figure 3.1. Average number of degrees the head moved in a 50ms time step, by condition

The second t-test (Figure 3.2) showed that subjects in the VE spent significantly more time 'not' moving their heads than subjects in the RW, $t(46)=8.68$, $p<0.05$.

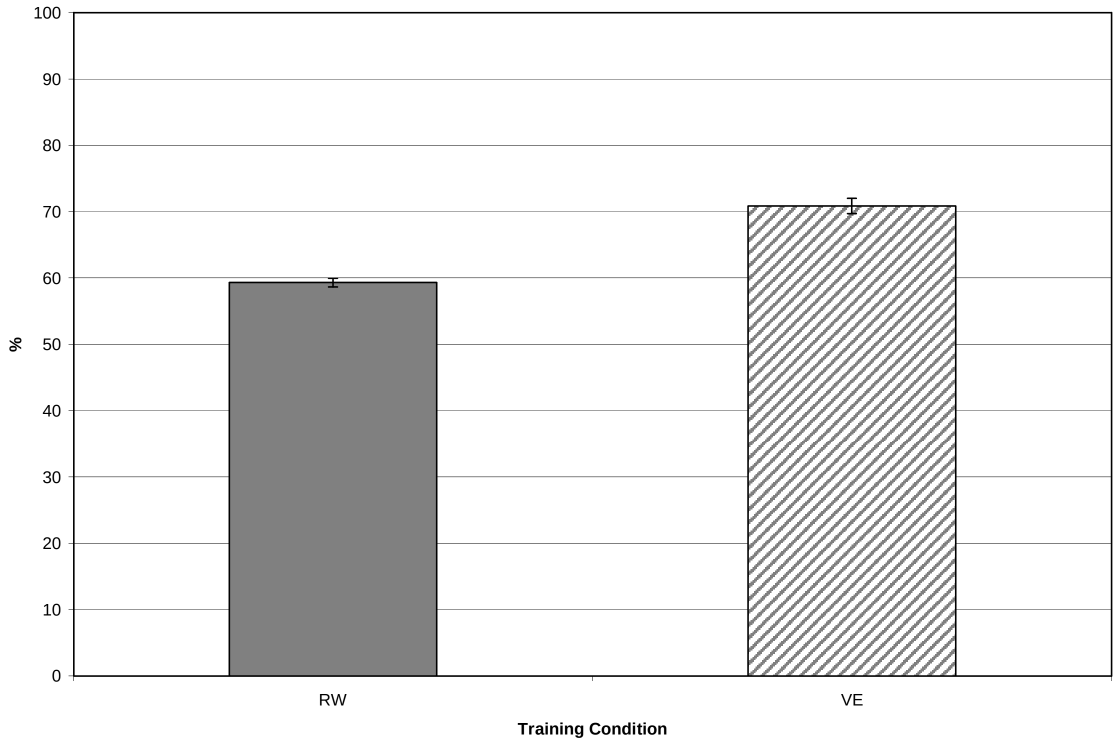


Figure 3.2. Percent of trial time subjects spent 'not' moving their heads, by condition

Analysis II

Initially, SSQ scores during the low immersion VE condition were compared to those during the high immersion VE condition. SSQ scores in the low immersion condition were significantly lower than SSQ scores during the high immersion condition (Figure 3.3), $F(1,46)= 24.21$, $p<0.01$, $\acute{\eta}_p^2=0.34$. There were no differences in SSQ scores over time, $F(1,46)=2.03$, $p>0.05$.

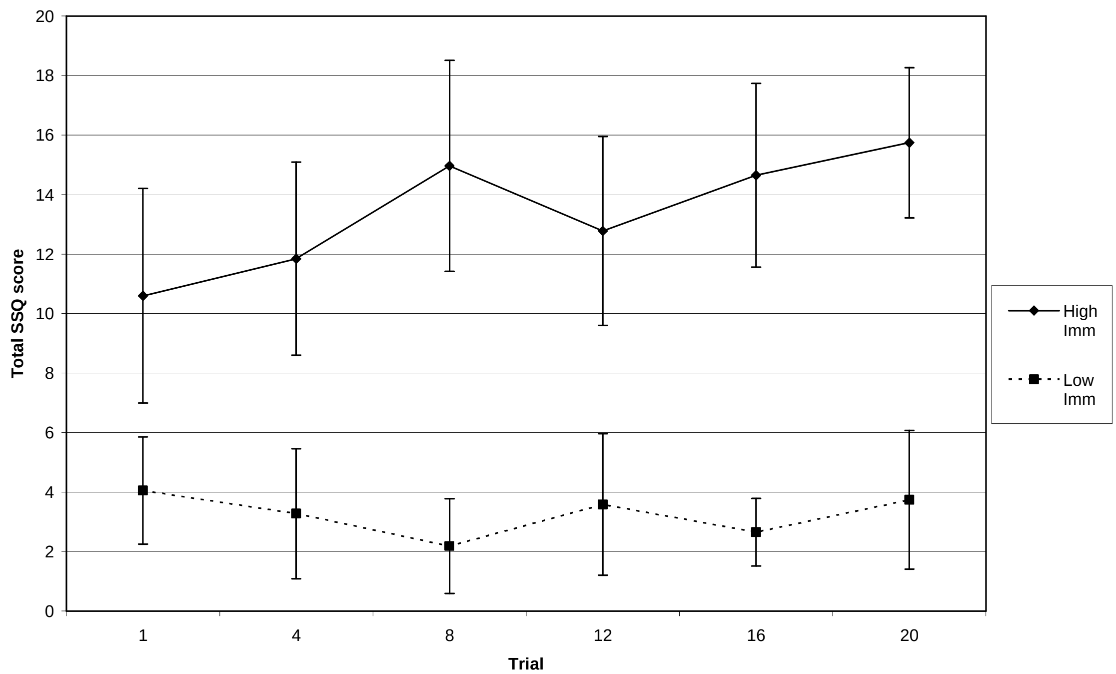


Figure 3.3. Average total SSQ scores across, by trial

In order to examine the relationship between head movements in the high immersion VE condition and SSQ scores, a series of correlations and ANOVAS were performed. There was no significant correlation between peak SSQ scores and head movements (*r*= -0.11, p>0.05), nor for peak SSQ scores and percent of time not moving their heads (r= -0.06, p>0.05) Also, there was not a significant within-subjects correlation of peak SSQ scores and average head movements over time (r= -0.10, p>0.05), nor for peak SSQ scores and percent of time not moving their head (r= 0.03, p>0.05).

Two ANOVAs were used to examine the difference of average amount of head movements between groups of varying sickness levels. A 2 x 20 mixed model ANOVA examined the differences between subjects who were median split into two groups (sick and not sick) at a peak SSQ score of 22.44 (Figure 3.4). There was no significant difference in average head movements between those two groups, $F(1,22)=0.01$, $p>0.05$, nor were there any significant differences over time, $F(19,418)=0.79$, $p>0.05$.

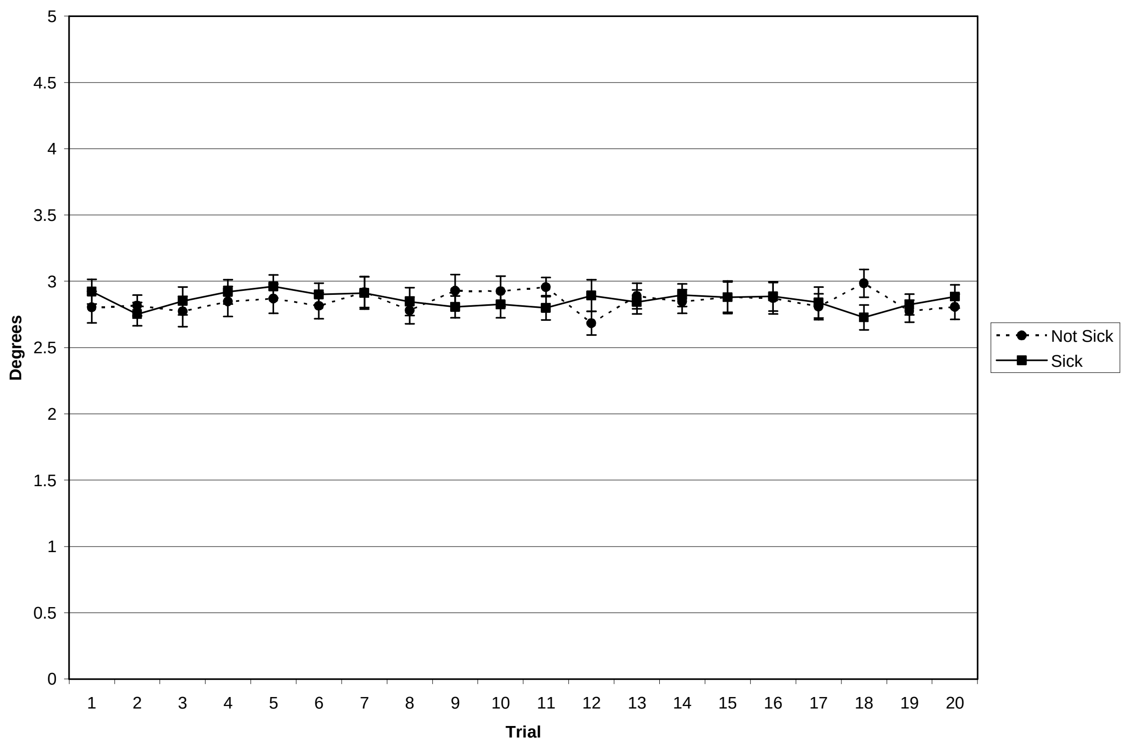


Figure 3.4. Average number of degrees the head moved in a 50ms time step for the 2-way split of peak SSQ scores, by trial

A 3 x 20 mixed model ANOVA examined the difference between subjects who were split into three groups based on Kennedy et al.'s (2003) classification of SSQ scores: low 0-10, medium 10-20, and high 20+ (Figure 3.5). There were no significant differences in head movements between the three groups, $F(2,21)=0.19$, $p>0.05$, nor were there any significant differences over time, $F(19,399)=1.14$, $p>0.05$.

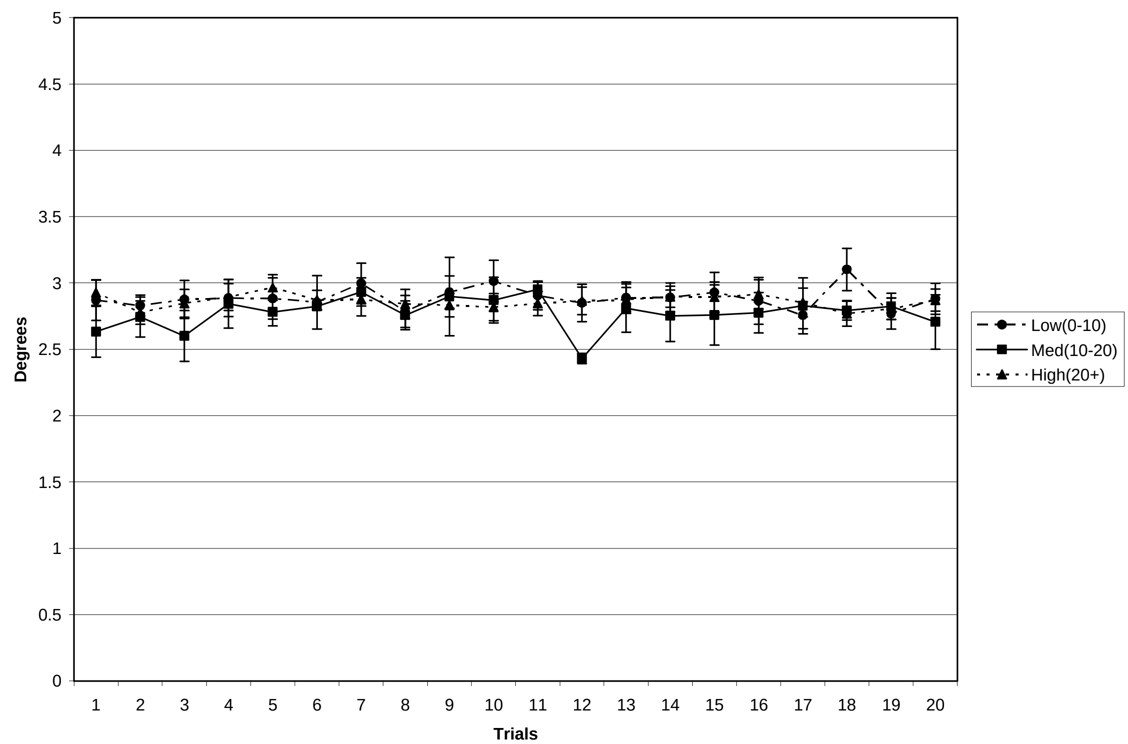


Figure 3.5. Average number of degrees the head moved in a 50ms time step for the 3-way split of peak SSQ scores, by trial

The same analyses described above were also used to examine the differences in the percent of time subjects spent 'not' moving their heads, greater than 1° per 50 ms. A 2 x 20 ANOVA (Figure 3.6) examining the median split groups found no significant differences between the two groups, $F(1,22)=1.52$, $p>0.05$, and no significant differences over time, $F(19,418)=0.94$, $p>0.05$.

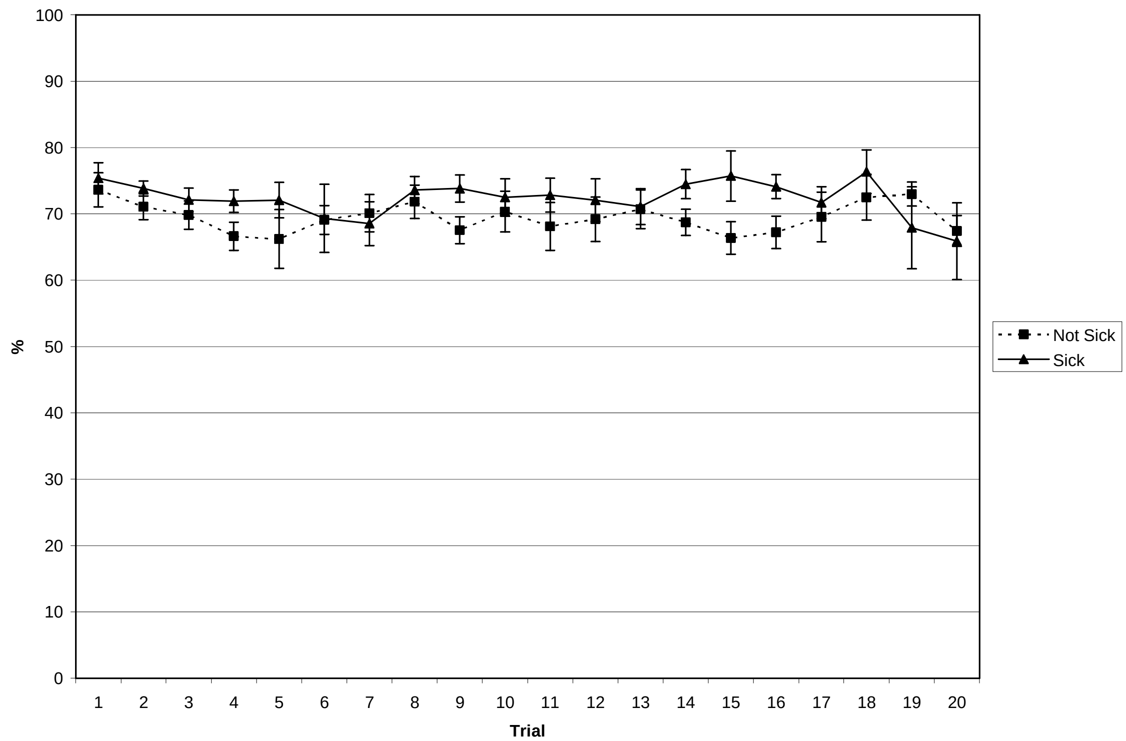


Figure 3.6. Time subjects spent 'not' moving their heads in the VE training condition for the 2-way split of peak SSQ scores, by trial

A 3 x 20 ANOVA examining the three groups split using Kennedy et al.'s (2003) classification of SSQ scores found a significant difference between the three groups, $F(2,21)=4.22$, $p<0.05$, $\acute{\eta}_p^2= 0.28$. Post hoc tests showed that subjects in the 20+ group moved their heads significantly less than the 10-15 group, and marginally less ($p<0.10$) than subjects in the 0-10 group (Figure 3.7). There were no significant differences between the 3 groups over time, $F(19,399)=0.80$, $p>0.05$.

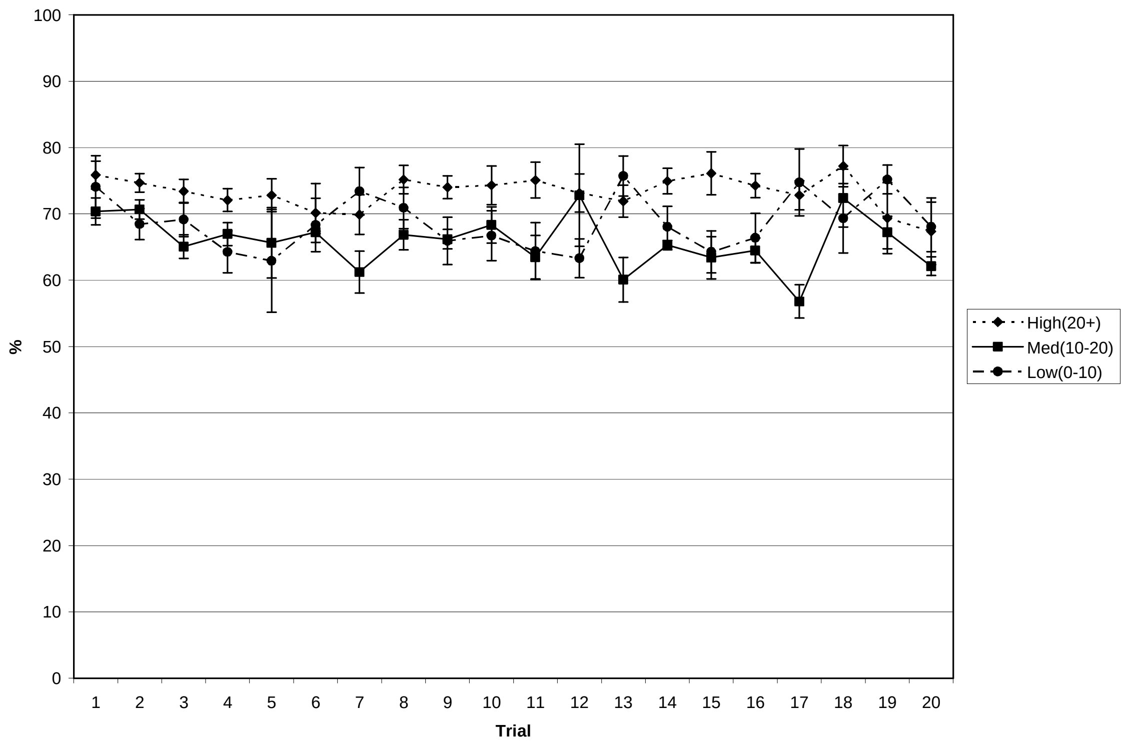


Figure 3.7. Time subjects spent ‘not’ moving their heads in the VE training condition for the 3-way split of peak SSQ scores, by trial

CHAPTER 4

DISCUSSION

Analysis I

The results of Analysis I demonstrated that subjects in the RW moved their heads significantly more and more often than subjects in the high immersion VE. Both the amount of the head movements made and the amount of time spent making those head movements were greater in the RW than in the VE. In the VE subjects had to wear an HMD which provided a limited FOV. Therefore, since the subjects in the VE were completing the same type of building clearing task as the subjects in the RW, the subjects in the VE should have moved their heads more in order to obtain the same amount of visual information as the subjects in the RW.

The results from Analysis I supported the first hypothesis of this study. Even though subjects in the VE could be expected to move their heads/bodies more than subjects in the RW they did not. In fact, they moved their heads/bodies significantly less and less often.

The results indicate that even though subjects in the two conditions were performing the same type of task, they were moving their heads/bodies differently. Because each subject was initially trained to scan a room by moving his head, torso and weapon together, it is possible that subjects in the two training conditions were using two different types of scanning methods.

There are several possible reasons why subjects may have moved their heads/bodies less in the VE than in the RW. One reason has to do with the physical restrictions of the HMD. At the beginning of the VE condition the subjects were warned to be careful with the equipment because some of the wires were delicate. This warning may have caused them to have more caution when moving around. Further, the HMD was connected to the main system through a long umbilical cord. This cord would at times become tangled which would require the experimenter to pause the system while the cord was unwound. The possibility of winding the cord and becoming tangled may have caused the subjects to restrict their movements. In addition to the cord connecting the HMD to the system the HMD was also somewhat heavy (~1 kg). The weight of the HMD could have caused a reduction in the amount and/or speed of head movements.

An additional hardware related explanation for the differences in head movements between the two systems could be attributed to the error in the RW tracking sensor. Systematic tests have shown that the Honeywell sensor used in the RW can have an average measurement error of about 20° (Waller, 2006). It is possible that the error in the sensor could have artificially increased the amount subjects moved their heads in the RW.

Immersion in the VE itself could also have been a factor in the reduction of head movements. Subjects may have been able to recognize the nauseogenic potential of the VE. Perhaps they noted the update delay in the visual environment when they moved around. By moving their heads slower it could have given the system more time to update the visual display and therefore reducing some of the lag. Subjects could also have tried to reduce their head movements to prevent feelings of circular vection. One or any combination of the variables above could possibly explain why subjects in the VE moved their heads less than subjects in the RW.

Finally, the head/body movement differences between the two systems could be due to differences in room scanning techniques. One possibility is that the subjects in the VE did not use the 'guns and eyeballs' technique to scan each room when they entered it. Subjects may have used a head movement only strategy and minimized the amount of torso and full body rotations that they made. Because the head has a more limited range of motion than the head and torso or head, torso and body, it would make sense that the subjects in the VE exhibited less head/body movements. Conversely, it is also possible that the subjects in the RW did not successfully utilize the 'guns and eyeballs' technique. The differences in head movements between the two conditions could be due to the fact that subjects in the RW were moving their heads independently of their body when not actively searching a room. In this case subjects in the RW would have used head/body movements while searching the room, as well as independent head movements in the hallways and after each room had been searched. Because of the way that the current study defined 'head movements' it is difficult to know whether the majority of movements were caused by independent head movements or combined head and body movements. Future studies should attempt to track and differentiate head, torso and full body movements.

Analysis II

The second analysis in this study investigated the hypothesis that subjects who became motion sick would move their heads less in a high immersion VE. Several different analyses were conducted in order to examine that relationship. The results of the general correlations and correlations over time provided no significant evidence that head movements and SSQ scores were related. However, all of the correlations but one, were in the correct direction. Head movements were also examined using several different ANOVAs. Only one of the ANOVAs conducted in Analysis II provided any indication that head movements were related to sickness scores.

When the subjects were split into three groups, based on Kennedy et al.'s (2003) classification of SSQ scores, there were significant differences in the amount of time subjects spent 'not' moving their heads (more than 1°/50 ms). Subjects who had peak SSQ scores of 20 or more spent significantly more time 'not' moving their heads than subjects who had peak SSQ scores between 10 and 20. Although not significant at the 0.05 level, the difference between subjects with peak SSQ scores above 20 and subjects with peak SSQ scores below 10 showed a trend in the same direction. These results provide some evidence that subjects who reported being the most sick tended to restrict their head movements.

The second hypothesis in this study was only partially supported. Generally the results showed that there was no discernable relationship between the amount of head movements made and simulator sickness. There was some evidence that the amount of time that subjects spent moving their heads was affected by sickness where subjects exhibiting high levels of sickness moved their heads less often.

In the context of the task being performed during this study the above results make sense. There are instances in the task where the subjects must shoot or be shot. In order to avoid being shot the subjects must make certain types of head/body movements (various scan paths and building clearing 'maneuvers'). Task demands may have required subjects to move their heads the same amount, regardless of their level of sickness, simply to complete the task. It is possible that when the task didn't specifically require head movements (e.g. exploring a room without a threat) subjects who were the most sick did not move their heads as often. Subjects who were less sick may have engaged in additional, exploratory scanning movements as they moved through the environment; whereas the subjects who were the most sick may have restricted their head movements until it was absolutely necessary for the completion of the task.

Based on these results it would seem that head movements do matter to subjects who report high levels of simulator sickness. It is also important to note that one of the selection criteria for the current study was that subjects have a low history of motion sickness. Therefore, the subjects in the current study represent a relatively skewed sample of the normal population. According to Stanney and Kennedy (1997) the average SSQ score in a VE is approximately 20. The average SSQ score in the high immersion VE condition was 13.42. Therefore, head movements in a VE could be important to a more representative sample of population susceptibility. Also, the sample size of the current study was relatively small due to the fact that the Team Training study required intact teams of four. Future studies should investigate some of the same metrics used in the current study, but with a larger sample that has more normally distributed MSHQ scores. It would also be interesting to examine head movements during VE tasks that allowed subjects to move their heads a much or as little as they wanted.

General Discussion

It is possible that the differences in the amount of time subjects spent moving their heads between the VE and the RW, could have been caused by increased symptoms of simulator sickness. As most subjects in the VE reported significantly elevated simulator sickness symptoms it is possible that many of them made a conscious effort to reduce the amount of time they spent moving their heads. The exact cause of this general restriction of head/body movements is unclear. It could have been one of any number of variables. For example, subjects may have been trying to reduce feelings of circular vection, reduce the amount of visual lag they experienced or even to avoid various physical entanglements with the system. Despite the cause of the differences in head/body movements between the two systems, the VE was meant to train subjects for building clearing in the RW. Based on the results of Analysis I it would seem that subjects training in the VE were not exhibiting the same head/body movement behaviors as subjects training in the RW.

Training transfer was not specifically tested in this study but it is possible that the differences in head movements between the VE and the RW could lead to negative transfer. There are many different definitions of the phrase "negative transfer." The current study refers to the definition given by Landrum (2005), "…negative transfer is demonstrated by the detrimental effect of a prior experiences on present performance." The literature agrees that training which utilizes one type of device or strategy can have a detrimental effect if a similar task is later performed on a different device or requires a different strategy. This effect of negative transfer has been recognized in realms of problem-solving, aviation and even complex motor skills (Landrum, 2005; Rayman, 1982; Schmidt & Young, 1987; Lewis, McAllister, & Adams, 1951).

In terms of this experiment, the VE used for training produced behaviors different enough from the RW environment that it could lead to negative transfer. As suggested above, the differences in head movements between the two conditions could be evidence that the subjects were using different visual scan strategies. In a building clearing type of task visual scanning is a very important skill. Proper visual scan techniques can ensure that a soldier identifies potential threats as quickly as possible. Failures in visual scan techniques could lead to missed threats and potential team fatalities. If subjects in the VE are learning improper visual scan techniques there could be dire consequences in the real life application of that skill. For this reason, it would be important to determine what caused the reduction in head/body movements in the VE.

When reexamining the literature it becomes evident that previous studies in VEs do not investigate head movements quantitatively. Most discussions and suppositions about the relationship between head movements and motion sickness in VEs are based on anecdotal evidence (Howarth, & Finch, 1999; Cobb, Nichols, Ramsey, & Wilson, 1999). Despite selecting subjects who were less susceptible to motion sickness, subjects in this study still experienced a significant increase in symptoms, with more than half exhibiting severe symptoms. Therefore, it is possible that something other than the variation in head movements caused increased simulator sickness scores.

One possible explanation is that the increase in simulator sickness scores could be partially attributed to feelings of linear vection. So, Lo and Ho (2001) showed that an increase in linear speed could increase the onset of feelings of linear vection and motion sickness in a VE. In the current study the subjects were constantly moving through the environment until they either ‘died’ or completed the trial. Therefore, while subjects could have reduced feelings of circular vection by restricting the amount of time they spent moving their heads it was not likely that they were able to reduce the feelings of linear vection as they moved throughout the environment. It is possible that subjects' feelings of linear vection may have been partially accountable for the increase in simulator sickness scores.

Another possible explanation is theoretical in nature. It could be that the weak relationship between head movements and simulator sickness was due to the motion sickness theory on which the second hypothesis was based. The following ecological theory of motions sickness was not discussed in the introduction because the sensory mismatch theory is still the most widely accepted theory on motion sickness. Since the mismatch theory did not help explain the patterns of head movements in this study, the postural instability theory was also considered.

Stoffregen and Riccio (1991) proposed a theory of motion sickness which is an alternative to the sensory conflict theory. Their theory suggests that motion sickness is caused by an inability to maintain postural stability. According to this theory, subjects who display greater postural instability, in the form of postural sway, are more likely to become motion sick. Smart, Stoffregen, & Bardy (2004) showed that measures of postural instability were able to predict visually induced symptoms of motion sickness. Subjects who displayed more postural instability before exposure to a moving room were also more likely to report symptoms of motion sickness. Stoffregen, et al. (2000) found similar results in a study using a fixed-base flight simulator.

According to the postural instability theory of motion sickness, the sensory conflict caused by voluntary head movements would not predict motion sickness in a VE or vice versa. Therefore, the differences in simulator sickness scores between subjects could have been the results of differences in the subjects' postural stability. Future studies of simulator sickness in VEs should consider measuring postural stability before and after exposure, to investigate whether postural instability correlates with reported simulator sickness symptoms.

Conclusions

For VEs to progress as a useful tool, whether for training, therapy, etc., it will be necessary to identify the variable or combinations of variables that cause people to become motion sick. This study attempted to link head movements to simulator sickness and found that while there is a small connection between the two, the exact causal nature of the relationship is still unclear. Future studies should seek to investigate more continuous measures of sickness, including psychophysiological measures, in order to examine how the relationship between head movements and sickness progresses over time.

The results of the first analysis provide some evidence to suggest that the training community should be cautious about the widespread use of VEs. While VEs provide a cost effective way to expose people to a wide variety of situations, in their current stage of development it may not be wise to rely on VEs to train all aspects of a task. Studies have shown that VE training can be very effective for training some types of tasks (e.g. Tichon, 2007; Arthur & Hancock, 2001; Stedmon & Stone, 2001), but it is possible that that effectiveness is not universal to all tasks. Future studies should investigate the ability of VEs to provide training transfer in a wide variety of tasks, including dynamic tasks such as building clearing, fire fighting and SWAT training.

APPENDICES

A: Questionnaires

Motion Sickness History Questionnaire

INTRODUCTION:
This questionnaire is designed to determine:
(a) how susceptible to motion sickness you are, and
(b) what sorts of motion are most effective in causing that sickness

QUESTIONNAIRE:
1. Indicate approximately how often you have traveled on each type of transportation by using one of the following numbers:

0 = no experience 1 = fewer than 3 trips 2 = between 5 and 10 trips 3 = more than 10 trips

Cars_____ Ships_____
Buses_____ Swings_____
Trains_____ Amusement
Airplanes_____ Rides_____
Small Boats_____ Others (specify)_____

Considering only those types of transport that you have marked 1, 2, or 3 (those that you have traveled on) go on to answer the two questions below. (Use the following letters to indicate the appropriate category of response):

N = Never R = Rarely S = Sometimes F =Frequently A = Always

2. How often did you feel sick while traveling? (i.e., queasy or nauseated?)
Cars_____ Ships_____
Buses_____ Swings_____
Trains_____ Amusement
Airplanes_____ Rides_____
Small Boats_____ Others (specify)_____

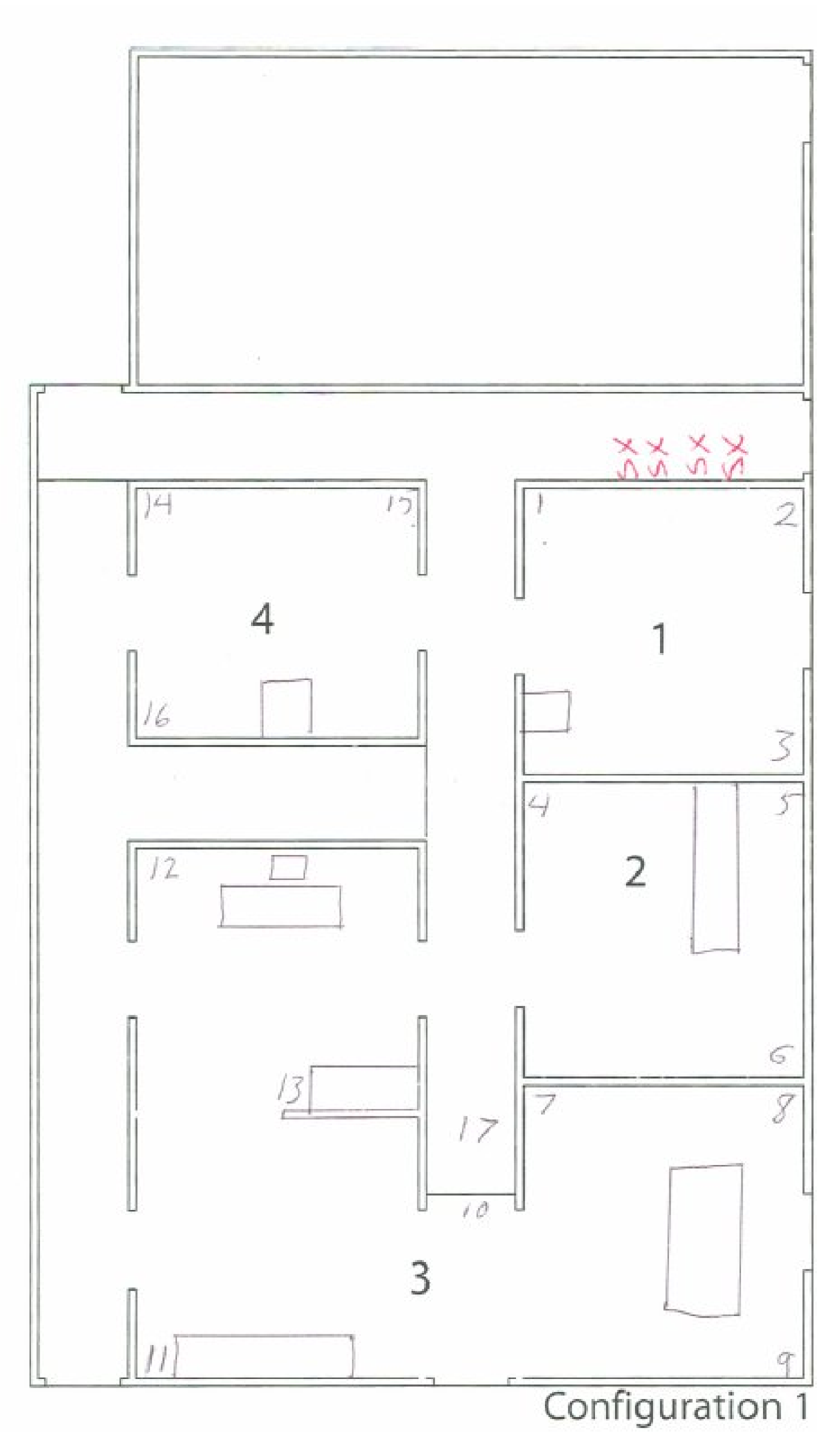
3. How often were you actually sick while traveling? (i.e., vomiting?)
Cars_____ Ships_____
Buses_____ Swings_____
Trains_____ Amusement
Airplanes_____ Rides_____
Small Boats_____ Others (specify)_____

Simulator Sickness Questionnaire

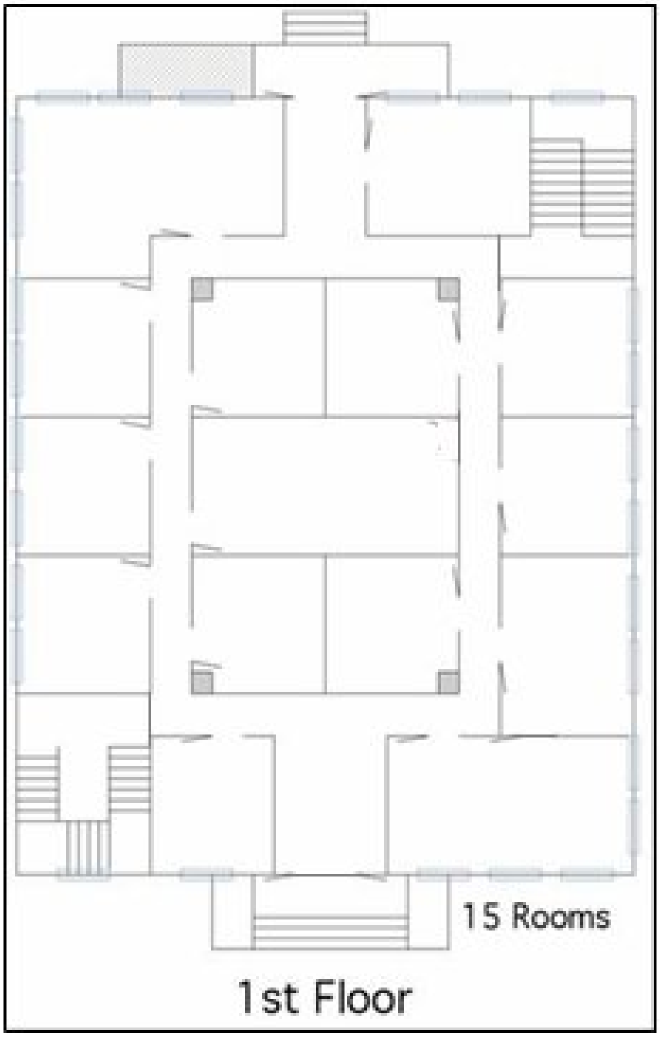
Directions: Rate your experience of the following (i.e., right now I feel:)

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

B: Shoothouse Supporting Documents



RW Shoothouse Layout



VE Shoothouse Layout

VE Shoothouse Layout

Real World Training

Team #

Trial	Stack Order				NC	C	Loc1	Loc2	Loc3	Loc4	Start	Stop
1	**3**	**4**	**1**	**2**	2	1	1	2	17			
2	**3**	**2**	**4**	**1**	1	3	13	4	16	9		
3	**1**	**3**	**2**	**4**	1	2	3	16	11			
4	**4**	**1**	**3**	**2**	2	1	6	14	15			
5	**3**	**2**	**1**	**4**	1	1	8	2				
6	**1**	**2**	**4**	**3**	2	1	7	6	1			
7	**2**	**4**	**1**	**3**	1	3	1	6	13	12		
8	**2**	**4**	**3**	**1**	1	1	4	5				
9	**1**	**3**	**4**	**2**	2	2	13	1	17	7		
10	**3**	**4**	**2**	**1**	2	2	2	4	15	3		
11	**1**	**3**	**2**	**4**	2	1	12	16	10			
12	**2**	**1**	**4**	**3**	2	2	10	15	11	3		
13	**4**	**1**	**2**	**3**	2	1	5	9	17			

Trial	Stack Order				NC	C	Loc1	Loc2	Loc3	Loc4	Start	Stop
14	**3**	**4**	**1**	**2**	1	3	9	8	17	11		
15	**2**	**1**	**3**	**4**	2	1	4	7	9			
16	**4**	**2**	**1**	**3**	1	1	9	6				
17	**1**	**3**	**2**	**4**	3	1	7	8	15	4		
18	**4**	**2**	**3**	**1**	1	3	9	4	15	1		
19	**1**	**3**	**4**	**2**	1	3	8	10	12	7		
20	**4**	**1**	**2**	**3**	3	1	10	16	3	9		

Subj. ID				
Stack #	**1**	**2**	**3**	**4**
WAM				
Gun				
Helmet				

Culminating Event Test

Team #:

Run	Stack Order				NC	C	Loc1	Loc2	Loc3	Loc4	Start	Stop
1	**4**	**3**	**2**	**1**	3	1	7	3	17	13		
2	**2**	**4**	**3**	**1**	1	1	7	12				
3	**3**	**2**	**1**	**4**	1	2	8	3	2			

4	**1**	**3**	**2**	**4**	2	2	6	4	13	10		
5	**4**	**2**	**3**	**1**	3	1	14	10	5	7		
6	**3**	**1**	**4**	**2**	2	1	10	7	14			
7	**4**	**1**	**2**	**3**	1	3	17	1	15	6		
8	**2**	**1**	**3**	**4**	1	2	13	11	3			
9	**4**	**2**	**3**	**1**	3	1	2	3	16	9		
10	**3**	**4**	**2**	**1**	2	2	15	4	10	16		
11	**1**	**4**	**2**	**3**	2	1	17	3	13			
12	**4**	**2**	**3**	**1**	2	1	12	17	1			
13	**1**	**2**	**4**	**3**	2	2	15	12	3	17		

Run	**Stack Order**				**NC**	**C**	**Loc1**	**Loc2**	**Loc3**	**Loc4**	**Start**	**Stop**
14	**1**	**3**	**4**	**2**	2	1	17	9	10			
15	**2**	**1**	**4**	**3**	1	1	7	8				
16	**3**	**2**	**1**	**4**	2	2	5	10	4	14		
17	**2**	**4**	**3**	**1**	1	1	10	12				
18	**4**	**3**	**1**	**2**	3	1	8	5	10	3		
19	**3**	**1**	**4**	**2**	1	1	4	6				
20	**1**	**3**	**2**	**4**	1	3	6	12	7	5		

Subj. ID				
Stack #	1	2	3	4
WAM				
Gun				
Helmet				

C: Standardized Feedback

The following describes the meaning of each of the eight (8) sections of the STAC DECS mnemonic as it pertains to the experimenters observing participants.

Survivability: Was any person shot and thus killed.

Self explanatory and will not be rated, participants will have immediate feedback as they will 'die' when shot.

Technique: Was the required technique use appropriately. This section covers the following subsections:

- Fatal Funnel Exited Quickly: did participants exit the fatal funnel immediately upon entry into the room. Stopping in the fatal funnel is a mistake. Participants must cross the threshold and move away from the fatal funnel.

  Mark a mistake when:
  -A participant lingers in a room's doorway
  -A participant stops in the doorway when engaged by enemy
  -A participant 'gets stuck' in the doorway.

  Rule: In the event that a mistake has been recorded for this subsection, the "Moved to Point of Domination Quickly" subsection is ONLY evaluated for criteria # 2 (did participants separate). Going to a Point of Domination is no longer valid or relevant as the purpose of going to the point of domination is to secure a safer position in the room upon entry.

- Coordinated Movements to Points of Domination Quickly: did participants, upon exiting the fatal funnel, moved directly to the room's point of domination or a corner of the room in a coordinated manner (e.g. not together into the same corner). In this scenarios a point of domination is considered to be a corner or location along a wall where together with other team members the participant has reduced the threat of danger to just a small section at front reducing or overlapping his sector of fire. In the VE scenarios some rooms may require pieing or popping a corner or room partition. In these select cases a point of domination is considered to be location just before the participant is forced to pie that dead-space. See figure below for example. This subsection is only relevant if the participant exits the "fatal funnel" quickly, as otherwise there is little if no value in continuing to the room's point of domination if one lingered in the doorway. If more than one participant enters the room, separation of the participants is necessary as they must move to different points of domination in the room. Only a 3rd and 4th man in the room may move to a position next to another participant as support firepower.
  - Criteria # 1: Did participant go to point of domination
  - Criteria # 2: Did they go to different points of domination

  Mark a mistake when:
  -A participant proceeds straight into a room without cautiously moving to a point of domination.
  -More than one participant moves simultaneously to the same point of domination.
  -Participants do not separate as they flow into the room.

- Pieing and Popping: upon approached dead space (within a room, doorway, or corner), did participants carefully cleared as much of it using either one of these methods without exposing themselves to other threats when feasible. When pieing L's or T's did participants used the coordinated assistance of another team member, or where both sides of the T cleared simultaneously.

  Mark a mistake when:
  -A participant does not use a pieing or popping technique when feasible (i.e. without exposing themselves) to clear dead space, or when a T was not cleared simultaneously from both sides.

Exposure and Awareness of Muzzle: These two sections have been merged for the observation evaluation and feedback as they share some of the same basic behavior components: giving away your position, and exposing oneself to a threat. In summary this is observed as: Did participants silhouetted into dead space or Did any participant flag their muzzle.

Exposure, mark a mistake when:
-A participant exposes himself to a doorway or window without facing it; when after entering a room a participant returns to the fatal funnel without facing it.
-A participant enters a room and is engaged by enemy on a room across the hallway.

Flagging, mark a mistake when:
-A participant approaches a doorway and is engaged by an enemy (i.e. gives away their position).
-Their muzzle or any part of their body is observed from within the room before the "gun's and eye balls" are observed.

Clearing & Discrimination: Were all individuals in a room killed or acknowledged appropriately and were all spaces cleared.

Mark a mistake when:
-A participant missed a combatant or noncombatant (i.e. left the room when someone remained inside).
-A participant kills a noncombatant. In the VE while the reverse may happen (acknowledge a combatant) it is harder if not impossible to detect. Look for shot vector from participant to enemy and if it hit but the enemy did not die it is an indication that the wrong behavior was exhibited.
-A participant left any dead-space unchecked (behind desks, partitions, tables, etc.)

Communication & Coordination: Did participants communicated correctly and behave as a team. Were all dangers identified, status communicated, and actions verbalized or signaled. Did the team maintain its integrity as a unit.

Mark a mistake when:
-A participant exits a room without calling "all clear"
-When dead-space exists but is not identified
-When "go" or other action command is not used to communicate initiation of a move.
-A participant separates himself from the group and continues the engagement by himself.

-When team fails to enter room immediately behind No.1 man upon "Go" command (i.e. lags behind or does not enter room).

Stacking: Did participants stack or position themselves for an action before executing (e.g. before entering a room or performing some other technique).

Mark a mistake when:
-Participants enter a room without stacking
-When participants do not form a tight stack (close enough to bump each other) before entering a room.
-When participants do not position themselves for an L or T shape clear, etc.
-When participants do not stack along a wall adjacent to doorway in which they will enter room.
-When there is not an obvious hesitation prior to entry once a stack position has been assumed.

Note: Care most be taken to understand the limitations of the VE and how this affects the observed behaviors.

Trial # _________		Any Mistakes?			
		1st Trial	2nd Trial	3rd Trial	4th Trial
S	**Survivability** - No Shots Received				
C	**Communication & Coordination -** Correct Executions and Confirmatory Calls				
S	**Stacking** - Stacking and Positioning Before Execution				
P	**Pieing and Popping**				
E A	**Exposure & Awareness of Muzzle** - Avoid Silhouetting and Flagging Muzzle				
F	**Fatal Funnel** Exited Quickly				
P	**Points of Domination**-Coordinated Movements To Points of Domination				
C D	**Clearing & Discrimination -** Engaged & Acknowledged All Entities Correctly, All Spaces Cleared				

D: Experimental Protocols

CE Study: Immersive VE Experimental Procedure Outline

GENERAL OVERALL NOTE TO REMEMBER: DO NOT TELL SUBJECTS THEY ARE FREE TO TERMINATE SESSION AT ANY TIME. They read that in the consent form…that is good enough. Also, do not make any comments regarding or referring to sim or motion sickness. If anyone asked if they are going to get sick or etc, respond with simply:

"**OUR GOAL IS TO GET YOU THROUGH TRAINING AS COMFORTABLE AS POSSIBLE"**

Welcome & Overview (< 3 min)

- Experimenter/team member introductions.
  - -This will be your team for the next session as well
- Give a brief overview of the day. Re-emphasize the purpose & seriousness of the study (i.e., to improve military training) and 12 people depending on you along with DOD. Also, inform that the subjects will have opportunity to have lunch.
- Have subjects re-initial & date the final page of their consent forms.

Refresher Training Video (10 min)

VE Familiarization Training (30 min)

- *Brief Subjects on Feedback Procedure & Required Forms (SSQ, TLX)*
  - o Have subjects read feedback definitions/criteria
  - o Show subjects the feedback form that they will receive between trials
  - o Inform subjects they are not able to ask experimenter questions regarding feedback, but may discuss amongst themselves and can refer back to definition/criteria pages
- *Equipment Brief* – (Summarize the materials used: HMD, Gun, Pod, Vest)
  - o **INFORM SUBJECTS TO BE VERY CAREFUL WITH EQUIPMENT AND TO NOT PLAY AROUND WITH ANY WIRES OR ETC AND ONLY USE AS PER INSTRUCTED.**
- *Helmet Mounted Display (HMD) Demonstration* – Show subjects how to:
  - o **Tighten/Loosen it with the top turn knob**
  - o **Tighten/Loosen it with the back turn knob**
  - o **Adjust eye slots with knobs on sides & dial on top**
  - o **Adjust headset earpieces and microphone**
    - ▪ **ONCE ADJUSTED PROPERLY, INFORM SUBJECTS ONLY KNOB TO ADJUST WHEN TAKING OFF AND PUTTING ON IS THE BACK TURN KNOB**

- *Weapon Demonstration* – Show subjects how to*:*
  - o **Move forward, backward, and side to side with the Joystick**
  - o **Hold & Fire the weapon (while keeping it out of the ring)**
  - o **Acknowledge non-combatants by pressing the joystick in**
  - o **Rotate in the pod. (Emphasize that movement is with respect to direction of their body and rotation requires them to turn their body)**

- *Review PowerPoint Printouts* (on discerning Combatants & Non-Combatants)
    - only distinguishing trait is combatants have weapons, non combatants do not
- *Discuss Audio & Collision Cues Present in the Simulation*
    - **3-D spatialization of sound (w/o hearing your own voice)**
    - **Haptic collision cues (walls, team members, getting shot)**

- *Immersion into VE*
    - **INFORM SUBJECTS TO ONLY MOVE AS INSTRUCTED BY EXPERIMENTER AND TO NOT TOUCH ANYTHING TILL TOLD SO**
    - **Assist subjects with putting on the vest and help tighten it so it's snug yet not uncomfortable.**
    - **Instruct subjects to enter the pod (& mention that the ring is a ref point)**
    - **Assist subjects in putting on the backpack. Ensure it is sitting on top of the haptic battery pack and not interfering with the wiring.**
    - **Administer Simulator Sickness Questionnaire (SSQ)**
    - **Assist subjects in donning the HMD and adjusting it.**
    - **Hand subjects the gun and aid in them situating it.**
    - **Have subjects communicate to each other and manipulate the controls to verify equipment is functioning properly.**
    - **Demonstrate how subject may become tangled or HMD feel snug on subject**
    - **Even though, we will be looking our best to see if you become tangled, tell the experimenter IMMEDIATELY if you become tangled and when HMD starts to feel like it is going to be pulled off your head. This is very expensive equipment we need to untangle you as soon as possible. The scenario will be paused. DO NOT move while the scenario is paused.**
- *Practice Session*
    - Experimenters will now load the practice training scenario to allow participants to manipulate controls to get accustomed to:
      (make sure to tell subjects to perform the below activities)
        - Background noises & sounds
        - Turning around
        - Moving in all directions
        - Communicating with each other
        - Aiming & Shooting at Dummy Targets (Not Each Other!)
        - Bumping into walls and/or each other to illustrate the collision cues

VE Practice Scenario Experimenter Instructions

This practice session was designed to allow you to get accustomed to training in a virtual environment.

**NOTE: You will be immortal during the practice scenario; however, this will NOT be the case in the experimental trials that follow.

Practice Scenario (10 min)

You begin outdoors next to a large 'warehouse-type' building. Take a few minutes to practice using the controls to move around the environment, and report any difficulties to the experimenter.

Once you are comfortable with the controls, make your way towards the staircase and doorway located on the side of the building. Also, try firing your gun and talking with your teammates to verify the sound is working.

DO NOT SHOOT YOUR TEAMMATES!

Upon entering the building, make your way to the area in the far left corner. This area is partitioned in a manner that resembles an office. Once there, please wait for the rest of your teammates and instructions from the experimenter before proceeding.

Your task is to employ the techniques you learned (in the initial training) to clear the spaces within these partitions. There could be any number of combatants or non-combatants inside. When the experimenter tells you to begin, you should stack outside the entryway, and proceed to clear the area. Once the area is secure, return to the partition entrance where you began and wait while the experimenter loads new people.. When told to do so, stack up and clear the partitioned area again.

This concludes your virtual environment familiarization training. Please notify the experimenter of any problems you may have experienced up to this point.

Experimental Trials

After completing the training scenario, participants will then be given instructions for the experiment and opportunity to ask any questions. Inform the subjects that if they have to use the bathroom during any point of the experiment, let the experimenter know. The following instructions will be read:

"You will now begin performing the room clearing task that you have been trained for. You will begin at the end of a building. After the experimenter tells you to start, you should proceed counter clockwise around the building (take right) clearing each room as you come to it. The people you encounter with weapons are combatants and should be engaged. People without guns are noncombatants and should be acknowledged. Use the techniques you learned in training to maximize your performance. If you are shot, you will die and as a result your system will freeze and you will not be able to continue. The team is to continue on after a teammate is shot. The experimenters will stop you once you have reached the end of the scenario. Good Luck."

- The participants will complete 20 trials.
- The scenarios will be presented as indicated in the table below.
- Audio cues will vary (S1 – Metaphoric Cues, S2 - No Metaphoric Cues).
- All scenarios will be presented with the same haptic cues.

<u>Before Each Trial</u>

- A new OTB scenario and a new sound scenario will need to be loaded.
- Launch ManSim.
- After loading the scenarios, the logger program will have to be started and the file named appropriately.
- The video recorder must be started.

- Once all participants are immersed and ready, the experimenter will tell them to start.

During Each Trial

- Experimenters will observe each scenario from the birds eye view screen.
- Note performance during each scenario using tick marks on the feedback form only up to L-Shape room. Stop after L-shape room.
- Experimenter will begin preparing surveys and feedback forms to give to subjects while they are finishing scenario
- Once the team has cleared the last room, the experimenter will stop the scenario
- Experimenter inform the tech experimenter that he is responsible for keeping his eye on the subjects regarding any obvious signs of sickness, falling over, etc. ALSO, to look for any tangled up subjects. We cannot rely on the subjects to let us know when they are tangled up.

After Each Trial

- ManSim should be closed, along with the OTB and sound scenarios.
- The logger and video recorder should be stopped. (Haptics may be left on)
- After the 1st, 10th and 20th trials participants will be given the NASA TLX.
- After trials 1, 4, 8, 12, 16 and 20 participants will be given the SSQ.
- After the first 4 trials and every subsequent 4th trial participants will be given the feedback form and allowed to discuss it for **2 minutes**.

VE Training

Trial	OTB scenario	Audio Scenario	Feedback Given?	Questionnaires
1	**1**	**S1**	✓	✓ **SSQ** ✓ **TLX**
2	**2**	**S1**	✓	
3	**3**	**S1**	✓	
4	**4**	**S1**	✓	✓ **SSQ**
5	**5**	**S2**		
6	**6**	**S2**		
7	**7**	**S2**		
8	**8**	**S1**	✓	✓ **SSQ**
9	**9**	**S2**		
10	**10**	**S2**		✓ **TLX**
11	**5**	**S2**		
12	**6**	**S1**	✓	✓ **SSQ**
13	**7**	**S2**		
14	**8**	**S2**		
15	**9**	**S2**		
16	**10**	**S1**	✓	✓ **SSQ**
17	**5**	**S2**		
18	**6**	**S2**		
19	**7**	**S2**		
20	**8**	**S1**	✓	✓ **SSQ** ✓ **TLX**

Post Experiment Questionnaires (16 min)
Participants will then complete the following questionnaires:

- Presence
- Team Efficacy
- Team Factors

Participants will then be tested to ensure they have no lingering effects from being immersed in the VEs prior to allowing them to leave. They will be debriefed and given a copy of the informed consent form.
DO NOT LET PARTICIPANTS LEAVE IF ARE OBVIOUSLY EXPERIENCING SIM SICKNESS. WAIT TILL SYMPTOMS SUBSIDE.

*****INFORM SUBJECTS AGAIN ON IMPORTANCE OF THEM SHOWING UP FOR THE TESTING SESSION. REMIND THEM THE DATE OF THE TESTING SESSION, TIME, AND WHERE TO MEET.**
"YOUR TEAMMATES, 12 EXPERIMENTERS AND THE DOD ARE DEPENDING ON YOU. ALSO, YOU WILL NOT GET PAID UNLESS YOU COMPLETE THE THIRD PHASE."

Before end of closing time, clean HMD with alcohol wipes and lens with lens cleaner.

****Final note: be as observant as possible and take notes/comments and time of any observation you make and log them in subject folder*******

CE Study: Desktop VE Experimental Procedure Outline

GENERAL OVERALL NOTE TO REMEMBER: DO NOT TELL SUBJECTS THEY ARE FREE TO TERMINATE SESSION AT ANY TIME. They read that in the consent form…that is good enough. Also, do not make any comments regarding or referring to sim or motion sickness. If anyone asked if they are going to get sick or etc, respond with simply:

"**OUR GOAL IS TO GET YOU THROUGH TRAINING AS COMFORTABLE AS POSSIBLE"**

Welcome & Overview (< 3 min)

- Experimenter/team member introductions.
  - -This will be your team for the next session as well
- Give a brief overview of the day. Re-emphasize the purpose & seriousness of the study (i.e., to improve military training) and 12 people depending on you along with DOD. Also, inform that the subjects will have opportunity to have lunch.
- Have subjects re-initial & date the final page of their consent forms.

Refresher Training Video (10 min)

VE Familiarization Training (30 min)

- Explanation of the feedback procedure and required forms (SSQ, TLX)
  - Have subjects read feedback definitions/criteria
  - Show subjects the feedback form that they will receive between trials
  - Inform subjects they are not able to ask experimenter questions regarding feedback, but may discuss amongst themselves and can refer back to definition/criteria pages
- Experimenter explanation of materials (headset & gamepad)
- Experimenter demonstration of the game pad controls:
  - *Left Analog Stick*: move forward/backward, sidestep left/right
    - Press down to 'acknowledge' a non-combatant
  - *Right Analog Stick*: look up/down, rotate left/right
  - *L-Button*: raise/lower weapon
  - *R-Button*: fire weapon
  - *Rumble Button*: activates vibration function (haptics)
- Review PowerPoint printouts for discerning Combatants & Non-Combatants
  - Combatants are to be killed. They have rifles. Non-combatants are to be acknowledged. They do not have rifles.
- Explain the 3-D spatialization of sound & haptic collision cues

    - Haptic cues are represented by the rumble of the game pad
- Assign subjects to desktops and assist them with donning the headset (if req.)

- Administer Simulator Sickness Questionnaire (SSQ)

- Practice Session
    - Experimenters will now load the practice training scenario to allow participants to manipulate controls to get accustomed to:
      (make sure to tell subjects to perform the below activities)
        - Background noises & sounds
        - Turning around
        - Moving in all directions
        - Communicating with each other
        - Aiming & Shooting at Dummy Targets (Not Each Other!)
        - Bumping into walls and/or each other to illustrate the collision cues

VE Practice Scenario Experimenter Instructions

This practice session was designed to allow you to get accustomed to training in a virtual environment.

NOTE: You will be immortal during the practice scenario; however, this will NOT be the case in the experimental trials that follow. **DO NOT SHOOT YOUR TEAMMATES.

<u>Practice Scenario (10 min)</u>

You begin outdoors next to a large 'warehouse-type' building. Take a few minutes to practice using the controls to move around the environment, and report any difficulties to the experimenter.

Once you are comfortable with the controls, make your way towards the staircase and doorway located on the side of the building. Also, try firing your gun and talking with your teammates to verify the sound is working.

DO NOT SHOOT YOUR TEAMMATES!

Upon entering the building, make your way to the area in the far left corner. This area is partitioned in a manner that resembles an office. Once there, please wait for the rest of your teammates and instructions from the experimenter before proceeding.

Your task is to employ the techniques you learned (in the initial training) to clear the spaces within these partitions. There could be any number of combatants or non-combatants inside. When the experimenter tells you to begin, you should stack outside the entryway, and proceed to clear the area. Once the area is secure, return to the partition entrance where you began and wait while the experimenter loads new people. When told to do so, stack up and clear the partitioned area again.

This concludes your virtual environment familiarization training. Please notify the experimenter of any problems you may have experienced up to this point.

Experimental Trials

After completing the training scenario, participants will then be given instructions for the experiment and opportunity to ask any questions. Inform the subjects that if they have to use the bathroom during any point of the experiment, let the experimenter know. The following instructions will be read:

"You will now begin performing the room clearing task that you have been trained for. You will begin at the end of a building. After the experimenter tells you to start, you should proceed counter clockwise around the building (take right) clearing each room as you come to it. The people you encounter with weapons are combatants and should be engaged. People without guns are noncombatants and should be acknowledged. Use the techniques you learned in training to maximize your performance. If you are shot, you will die and as a result your system will freeze and you will not be able to continue. The team is to continue on after a teammate is shot. The experimenters will stop you once you have reached the end of the scenario. Good Luck."

- ➢ The participants will complete 20 trials.
- ➢ The scenarios will be presented as indicated in the table below.
- ➢ Audio cues will vary (S1 – Metaphoric Cues, S2 - No Metaphoric Cues).

Before Each Trial

- A new OTB scenario and a new sound scenario will need to be loaded.
- ManSim must be launched.
- After loading the scenarios, the logger program will have to be started and the file named appropriately.
- The video recorder must be started.
- Once all participants are immersed and ready, the experimenter will tell them to start.

During Each Trial

- Experimenters will observe each scenario from the birds eye view screen.
- Note performance during each scenario using tick marks on the feedback form only up to L-Shape room. Stop after L-shape room.
- Experimenter will begin preparing surveys and feedback forms to give to subjects while they are finishing scenario
- Once the team has cleared the last room, the experimenter will stop the scenario

After Each Trial

- ManSim should be closed, along with the OTB and sound scenarios.
- The logger and video recorder should be stopped.
- After the 1st, 10th and 20th trials participants will be given the NASA TLX.
- After trials 1, 4, 8, 12, 16 and 20 participants will be given the SSQ.
- After the first 4 trials and every subsequent 4th trial participants will be given the feedback form and allowed to discuss it for **2 minutes** at the front of the room.

VE Training

Trial	OTB scenario	Audio Scenario	Feedback Given?	Questionnaires
1	1	S1	✓	✓ SSQ ✓ TLX
2	2	S1	✓	
3	3	S1	✓	
4	4	S1	✓	✓ SSQ
5	5	S2		
6	6	S2		
7	7	S2		
8	8	S1	✓	✓ SSQ
9	9	S2		
10	10	S2		✓ TLX
11	5	S2		
12	6	S1	✓	✓ SSQ
13	7	S2		
14	8	S2		
15	9	S2		
16	10	S1	✓	✓ SSQ
17	5	S2		
18	6	S2		
19	7	S2		
20	8	S1	✓	✓ SSQ ✓ TLX

Post Experiment Questionnaires (16 min)
Participants will then complete the following questionnaires:

- Presence
- Team Efficacy
- Team Factors

Participants will then be tested to ensure they have no lingering effects from being immersed in the VEs prior to allowing them to leave. Debrief subjects by asking if they have any general comments. Do not answer any questions since the study is not over yet. Full debrief can take place at end of testing session. Just note any general comments they have.

*****INFORM SUBJECTS AGAIN ON IMPORTANCE OF THEM SHOWING UP FOR THE TESTING SESSION. REMIND THEM THE DATE OF THE TESTING SESSION, TIME, AND WHERE TO MEET.**
"YOUR TEAMMATES, 12 EXPERIMENTERS AND THE DOD ARE DEPENDING ON YOU. ALSO, YOU WILL NOT GET PAID UNLESS YOU COMPLETE THE THIRD PHASE."

****Final note: be as observant as possible and take notes/comments and time of any observation you make and log them in subject folder*******

CE Study: Shoot-House Experimental Procedure Outline

Clemson:

- Meet subjects and actors in front of Brackett Hall
- Provide them ID holders for entry into AAMDC
- Load van and drive out to Anderson
- **Experimenter, make sure you have key to shoot-house**

Shoot-House:

HAVE TECH PUT BATTERIES AND ETC in equipment

Welcome & Overview

- Experimenter/team member introductions.
  -This will be your team for the next session as well
- Give a brief overview of the day. Re-emphasize the purpose & seriousness of the study (i.e., to improve military training) and 12 people depending on you along with DOD.
  - **"I will be showing a refresher training video, will familiarize you with the equipment being used, give you a walk-through of the building, and explain performance feedback to you."**
- Have subjects re-initial & date the final page of their consent forms.
  - Tell subjects they have the option of re-reading entire consent form.

Refresher Training Video

- Have tech experimenter start video

Task Description/Familiarization

- Describe task and stack order
  - "You and your team will clear this building by using the techniques you have learned in your previous training session as well as the refresher video."
  - "In a minute, you will receive subject number between 1-4, please remember your number."
  - "You will be placed in a stack order to start each trial. A stack order is simply the position you are in your 4 man stack."
  - "Between some trials, you will be given feedback on your performance. I will be watching overhead on a scaffold grading your performance based on certain criteria. Please take a few minutes now and read the criteria on which I am basing your performance."
  - Show subjects dry-erase feedback form and explain that they will see a tally mark for each and every mistake they make in each category. Inform subjects that they will be able to communicate with their teammates regarding feedback but CANNOT ask experimenter any questions. However, inform subjects that they can look back and read the "performance criteria/definitions" pages if they have any questions.
- Explain combatants and non-combatants
  - Combatants are enemies and will be carrying a rifle

- Non-combatants will not be carrying a rifle.
- You are to try to kill combatants before they kill you
- You are ONLY to acknowledge non-combatants
  - Acknowledge non-combatants by yelling at them to get down
  - Non-combatants will then get down on one knee

Equipment Demonstration

- Live demo of rifle and helmet
  - Show trigger
    - Fire trigger so subjects can hear "beeping" sound. Beeping sound provides feedback that you pulled trigger
  - Show red light of gun
    - If see red light on, you have been shot
  - Show helmet
    - Show how helmet is adjusted
      - In back and chin strap
    - When shot in helmet, you will hear, "You are dead."
      - Demo…shoot helmet with rifle
- **INFORM SUBJECTS TO SHOOT FOR HEAD**
- **ALSO, INFORM SUBJECTS, EQUIPMENT IS NOT PERFECT AND IF YOU FEEL YOU HAVE BEEN SHOT EVENTHOUGH THERE IS NO INDICATION FROM YOUR HELMET OR REDLIGHT ON RIFLE, TO GO DOWN AND BE DEAD. NOT TO ARGUE WHO SHOT WHO OR ETC. IF IT IS OBVIOUS YOU HAVE BEEN SHOT, YOU HAVE BEEN SHOT.**

- Show subjects heart rate monitor
  - You will wear this throughout the day. It takes heart rate measurements. 3 electrodes will be placed on your skin. You will not feel anything.
- **Inform subjects to be careful with equipment and to not play around with it.**

Walk Subjects through Shoot-House

- Inform subjects that they will be given a stack order before each trial based on their assigned subject number.
  - Ex: 3,2,4,1.
  - Show tape markings where subjects/stack will line up
    - Once given a stack order, you will line up here in your proper order
    - The markings on the wall represent your stack order, NOT YOUR subject number.
    - If given stack order 3,2,4,1…..subject 3 lines up in position one, 2 lines up in position 2, 4 lines up in position 3, and 1 lines up in position 4.
- Walk subjects briefly through building making sure they see all rooms. Tell subjects that experimenter will be standing on "that" scaffold noting performance
- Bring subjects back to control room

Describe Task

- You and your team are to clear this building. There will be combatants and non-combatants present. You are to kill all combatants and acknowledge non-combatants. To acknowledge non-combatants, you are to yell “get down.” Inform subjects not to be afraid to get loud…Experimenter, demo by yelling get down. Non-combatants will get down on one knee when acknowledged. Combatants will also get down on one knee and place rifle to side of them.
- Once you have cleared the building, one person in your team needs to yell “all clear.”
- At this point the trial is over and you can exit the building through the same door you entered
- When combatants are acknowledged or killed accidentally, when combatants are killed, and when you are killed, you are to get to one knee and are NOT to move.
- The experimenter will inform you when you can get up and are free to move out of the building. This goes for the actors as well.
- Between some trials, the experimenter will give you your team’s feedback form. At this time you may discuss amongst your team, but cannot ask the experimenter any questions regarding your performance or feedback. However, you are free to look back at the criteria/definition sheets.

Preparing Subjects for Equipment

- Assign subject numbers to subjects: 1-4.
- Record shoot-house subject number on subject data sheet
    - Make sure shoot-house subject number is recorded along with subject number (ie, subject 76 is # 3)
- Put on electrodes and start up heart rate monitors for ONLY subjects, NOT actors
    - Record which WAM each subject has
        - Ideally, keep wam 1 to subject 1, wam 2 to sub 2, wam 3 to sub 3 and wam 0 to sub 4. Also, if all equipment is working, keep same rifle and helmet number as wam #.

- **PROCEDURE FOR WAMS**
    - Wipe area on skin with the gel
        - Top center (I believe sternum)
        - Right and left in area of top rib
        - Right and left are on same horizontal plane
    - Put electrode attachment on these areas
    - Have subjects put wams on and fasten belt
        - Wam behind back
    - **PULL WIRES UP THROUGH BELT INORDER TO LEAVE SLACK IN WIRES.**
    - **BLACK ELECTRODE GOES ON TOP**
    - **GREEN ELECTRODE GOES ON SUBJECT’S RIGHT**
    - **RED ELECTRODE GOES ON SUBJECTS’S LEFT**

    - **START UP AND TURN ON WAMS**
        - Twist power knob on

- When "setup", hit O/E button
- When see "waiting for TCP Conf"
  - Press O/E until "skipped" message appears
- When "Input Stat Vors", press 1
- When "Select IBI Source", press 1
- When "Subject IP", press ↓
- Date, press ↓
- When see "Monitor", press O/E
- At this point should see line graph….should be anywhere from 300-900 or so
- Press O/E
- When "Start AM", press O/E
- **DONE**
- Continue until all 4 subjects are on

- **PASS OUT RIFLES AND HELMETS TO SUBJECTS AND ACTORS**
  - Record which helmet and rifle to each subject. Should have subject number, shoothouse number, wam #, rifle # and helmet #.
  - Record actors helmet and rifle number.
- **INFORM SUBJECTS TO NOT PLAY AROUND WITH EQUIPMENT. INFORM SUBJECTS TO LET EXPERIMENTER KNOW IF HE THINKS AN ELECTRODE FELL OFF. INFORM SUBJECTS TO LET EXPERIMENTER KNOW IF "YOU ARE DEAD" KEEPS GOING OFF FOR NO REASON.**
  - **If "you are dead" keeps going off, check antenna and pull back away from helmet.**

Describe procedure of run, when they go, and when they are finished

- Experimenter will give team stack order while they are standing outside building
- Subjects are to line up against wall in proper stack order in hallway. First in stack goes to #1 and etc
- Experimenter will tell subjects "GO" and at this time you are to begin the task of clearing the building
- When building is clear, someone yell, "ALL CLEAR."
- You are now to exit the building through the door you entered
- Actors and subjects who have been acknowledged or killed are to remain still until experimenter tells them that they can get up and return.
- Experimenter will give feedback form if calls for it
- **SUBJECTS ARE ONLY TO ENTER AND EXIT DOORWAY THEY ENTERED. INFORM SUBJECTS ALL OTHER DOORS AND CURTAINS ARE TO BE THOUGHT OF AS WALLS. THERE WILL BE NO COMBATANTS BEHIND CURTAINS**
- **ALSO, IT IS NOT NECESSARY TO CLEAR CEILINGS**
- **Remind subjects and actors to shoot for head**
  - **Remind if it is obvious that they have been shot and killed to go down and not to depend on the equipment**
  - **Remind if helmet begins to signal, "you are dead" when it is clear that you have not been shot, to continue with run until you have been killed and not to depend on helmet.**

Procedure for actors

- Actors are to be stationed behind shoot-house
- Experimenter puts combatants/non-combatants in proper position
- Inform actors that they are not to move in their position….cannot walk around. They can lean and etc, but cannot walk around.

COMMUNICATION AND START OF RUNS

- After experimenter puts actors in proper positions and confirms correct position
- Experimenter walks to subjects as they are waiting outside building and informs them of their stack order and to stack in hallway but "DO NOT GO UNTIL I GIVE GO COMMAND"
- Experimenter climbs back on scaffold
- Experimenter signals to control room via radio, "EXPERIMENTER READY"
- Control room signals back to experimenter, "RECORDER READY"
- At this point, experimenter yells to subjects, "GO"
- Subjects begin run.
- When subjects signal "ALL CLEAR", experimenter signals to control room via radio, "STOP"

EXPERIMENTERS RESPONSIBILITIES DURING RUN

- Once experimenter yells, "GO", experimenter starts time on stopwatch and records start time
- **USE 2 STOPWATCHES**
    - **KEEP ONE RUNNING ALL TIME IN CASE IF ONE STOP WATCH RESETS INCIDENTALLY**
- Experimenter observes and records feedback if it is a feedback trial.
- When subjects yell, "ALL CLEAR"
    - Experimenter stops time and records end time
    - Experimenter signals to control room via radio "stop"
- **When surviving subjects exit building, experimenter tells actors and killed subjects that they can exit building**
- Experimenter marks tally on dry-erase feedback form if it is proper feedback trial and shows subjects
- Experimenter marks which subjects and actors were killed
- While subjects are looking at feedback, experimenter goes behind building and sets up actors for next run

END OF RUNS

- Bring subjects back into control room
- Take helmets and rifles
- If training session, administer efficacy questionnaire?????
- If testing session, administer factor questionnaire?????
- If testing session, administer test
- Remove electrodes and turn off wams
- If training session, record total end time and record subject hours
- If testing session, pay subjects appropriate pay
- If training session, debrief by solely asking subjects if they have any general comments or observations. Record these but do not respond to them or answer any questions
- If testing session, debrief fully by explaining study

- 3 training techniques (VR, PC, Real-world) and one test in attempt to see which training technique provides best training
- **IF TRAINING SESSION, INFORM/REMIND SUBJECTS OF DATE AND TIME OF TEST SESSION AND LOCATION AND REMIND IMPORTANCE OF SHOWING UP**
    - Many experimenters depending on you as well as the DOD.
    - Remind subjects will NOT get paid until and unless complete next session
- Take subjects back to campus as soon as possible
    - Tech experimenter responsible for "clean up" and closing down shoot-house

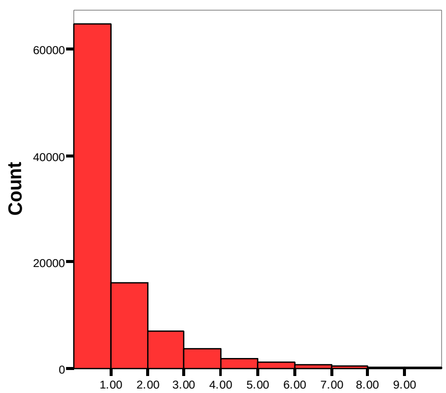
TAKE BACK SUBJECT FOLDERS TO CAMPUS AFTER EVERY SESSION

BE OBSERVANT AND NOTE IN SUBJECT FOLDERS ANY OBSERVATIONS AND RECORD AT WHICH RUN IT OCCURRED.

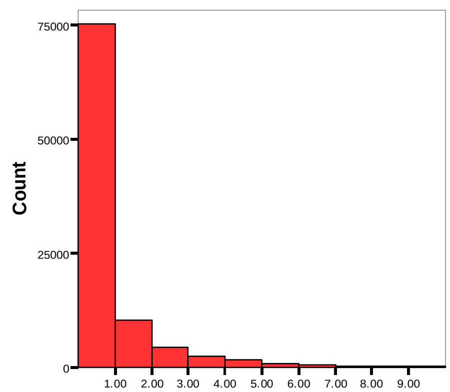
E: Histograms of head movement differences

Histograms of head movement differences for all 20 trials were performed on one randomly chosen subject from each team. The histograms show that head movement differences were skewed towards zero, or very little head movement.

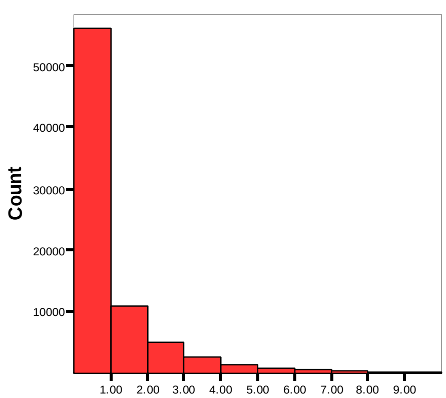
High immersion VE histograms:



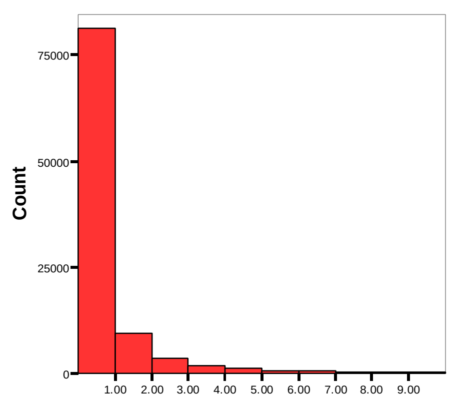
Team 21 Ss 3



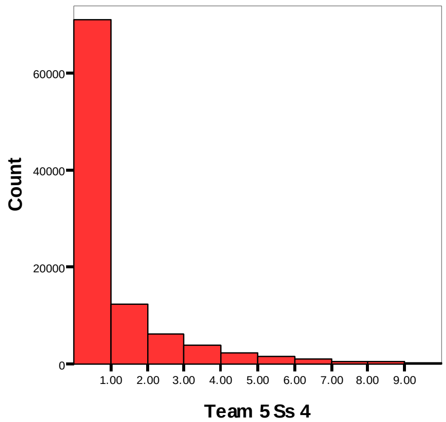
Team 14 Ss 1

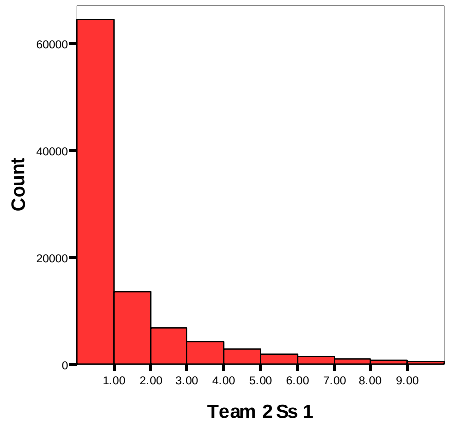


Team 8 Ss 2

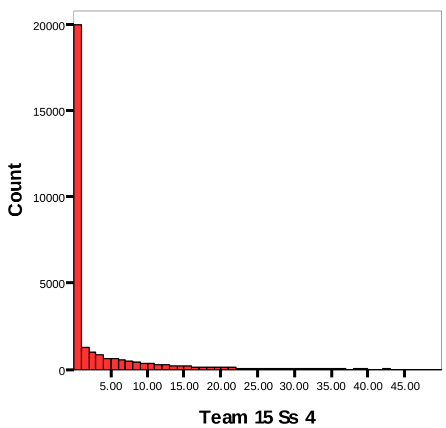


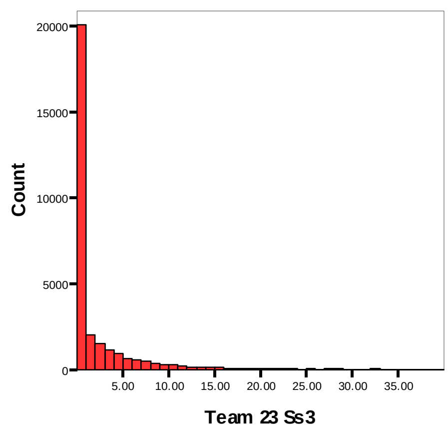
Team 7 Ss 3

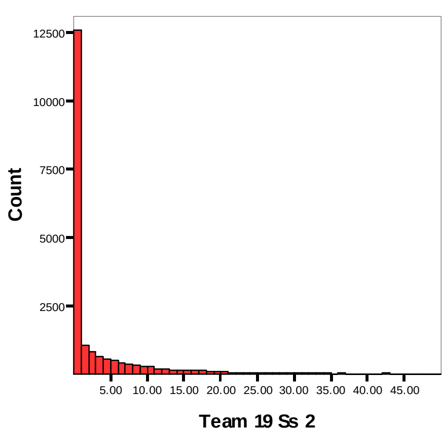


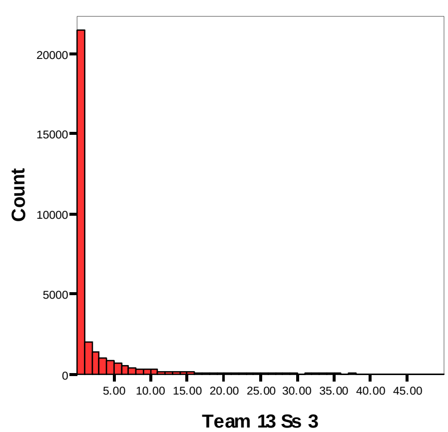


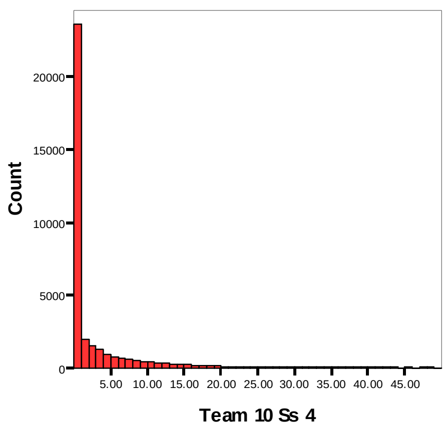
RW histograms:

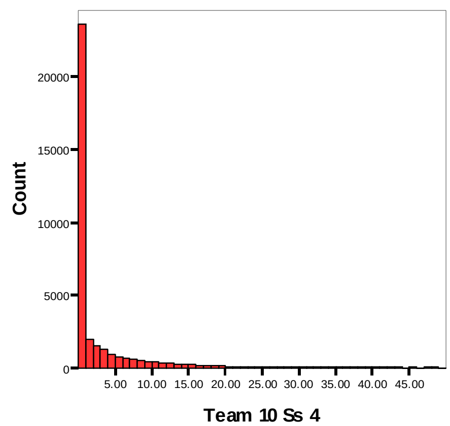









Count
20000
15000
10000
5000
0
5.00 10.00 15.00 20.00 25.00 30.00 35.00 40.00 45.00
Team 10 Ss 4


Count
20000
15000
10000
5000
0
5.00 10.00 15.00 20.00 25.00 30.00 35.00 40.00 45.00
Team 10 Ss 4

REFERENCES

Allison, R. S., Howard, I. P., & Zacher (1999). Effect of field size, head motion, and rotational velocity on roll vection and illusory self-tilt in a tumbling room. *Perception, 28*, 299-306.

Anderson, G. J., & Braunstein, M.L. (1985). Induced self-motion in central vision. *Journal of Experimental Psychology, 11,* 122-132.

Arthur, E. J., & Hancock, P. A. (2001). Navigation training in virtual environments. *International Journal of Cognitive Ergonomics, 5*, 387-400.

Blake, R. & Sekular, R. (2006). *Perception*. McGraw-Hill: New York, NY.

Cobb, S. V. G., Nichols, S., Ramsey, A., & Wilson, J. R. (1999). Virtual reality induced symptoms and effects (VRISE). *Presence*, *8*(2), 169-186.

DiZio, P., & Lackner, J. R. (1997). Circumventing side effects of immersive virtual environments. *Proceedings of the 7th International Conference on Human-Computer Interaction*, 24-29 August, San Francisco, CA.

Draper, J. V., Kaber, D. B., & Usher, J. M. (1998). Telepresence. *Human Factors*, *40,* 354-375.

Gianaros, P. J., Muth, E. R., Mordkoff, J. T., Levine, M. E., & Stern, R. M. (2001). A questionnaire for the assessment of the multiple dimensions of motion sickness. *Aviation, Space, and Environmental Medicine*, *72*, 115-119.

Golding, J. F. (1992). Phasic skin conductance activity and motion sickness. *Aviation, Space, and Environmental Medicine, 63,* 165-171.

Golding, J. F., & Stott, J. R. R. (1995). Effect of sickness severity on habituation to repeated motion challenges in aircrew referred for airsickness treatment. *Aviation, Space, and Environmental Medicine, 66*, 625-630.

Hamil, J. & Knutzen, K. M. (1995). *Biomechanical basis of human movement.* Williams & Wilkins: Media, PA.

Hettinger, L. J., Berbaum, K. S., Kennedy, R. S., Dunlap, W. P., & Nolan, M. D. (1990). Vection and simulator sickness. *Military Psychology, 2*(3), 171-181.

Hettinger, L. J., & Hass, M. W. (2003). Introduction. In L.J. Hettinger & M.W. Haas (Eds.) *Virtual and adaptive environments: applications, implications, and human performance* (pp. 1-19). Mahwah, NJ: Lawrence Erlbaum Associates.

Holden, M. K. (2005). Virtual environments for motor rehabilitation: review. Cyberpsychology & Behavior, *8*, 187-211.

Hoover, A., Olsen, B. D. (1999). A Real-Time Occupancy Map from Multiple Video Streams. In the proceedings of IEEE *International Conference on Robotics and Automation*, Detroit, MI, May 1999, 2161-2266.

Howarth, P. A., & Finch, M. (1999). The nauseogenicity of two methods of navigating within a virtual environment. *Applied Ergonomics*, *30,* 39-45.

Hu, S., & Stern, R. M. (1998). Optokinetic nystagmus correlates with severity of vection-induced motion sickness and gastric tachyarrhythmia. *Aviation, Space, and Environmental Medicine, 69*, 1162-1165.

Hu, S., Stern, R. M., Vasey, M. W., & Koch, R. L. (1989). Motion sickness and gastric myoelectric activity as a function of speed of rotation of a circular vection drum. *Aviation, Space, and Environmental Medicine, 60,* 411-414.

Johnston, J. L., & Sharpe, J. A. (1994). The initial vestibulo-ocular reflex and its visual enhancement and cancellation in humans. *Experimental Brain Research, 99*, 302-308.

Kennedy, R. S., & Graybiel, A. (1965). Symptomology during prolonged exposure in a constantly rotating environment at a velocity of 1 r.p.m. Aerospace Medicine, *33*, 817-825.

Kennedy, R. S., Hettinger, L. J., Harm, D. L., Ordy, J. M., & Dunlap, W. P. (1996). Psychophysical scaling of circular vection (CV) produced by optokinetic (OKN) motion: Individual differences and effects of practice. *Journal of Vestibular Research: Equilibrium & Orientation*, *6*, 331-341.

Kennedy, R. S., Lane, N. E., & Berbaum, K. S. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology*, *3,* 203-220.

Kohl, R. L., Calkins, D. S., & Robinson, R. E. (1991). Control of Nausea and autonomic dysfunction with terfenadine, a peripherally acting antihistamine. *Aviation, Space, and Environmental Medicine, 62*, 392-393.

Landrum, R. E. (2005). Production of negative transfer in a problem-solving task. *Psychological Reports, 97*, 861-866.

Lewis, D., McAllister, D. E., & Adams, J. A. (1951). Facilitation and interference in performance on the modified Mashburn apparatus: I. the effects of varying the amount of original learning. *Journal of Experimental Psychology, 41*, 247-260.

Marine Corps Warfighting Laboratory (2002). Project metropolis basic urban skills training (draft) handbook (Excerpts from MCWP 3-35.3). Quantico, VA.

May, J. G., & Badcock, D. R. (2002). Vision and virtual environments. In Stanney, K. (Ed.) *Handbook of virtual environments*. (Pp. 29-64) Mahwah, NJ: Lawrence Erlbaum Associates.

Nelson, T. W., Bolia, R.S., Roe, M. M., & Morley, R. M. (2000). Assessing simulator sickness in a see-through HMD: Effects of time delay, time on task, and task complexity. *Presented at the IMAGE 2000 Conference*, 10-14 July, Scottsdale, AZ.

Paige, G. D., Telford, L., Seidman, S. H., Barnes, G. R. (1998). Human vestibuloocular reflex and its interactions with vision and fixation distance during linear and angular head movement. *Journal of Neurophysiology, 80*, 2391-2404.

Probst, T., & Schmidt, U. (1998). The sensory conflict concept for the generation of nausea. *Journal of Psychophysiology (Suppl.), 12,* 34-49.

Rayman, R. B. (1982). Negative transfer: a threat to flying safety. Aviation, Space and Environmental Medicine, *53*, 1224-1226.

Reason, J. T., & Brand, J .J. (1975). Motion Sickness (London: Academic Press).

Riccio, G. E., & Stoffregen, T. A. (1991). An ecological theory of motion sickness and postural instability. *Ecological Psychology, 3*, 195-240.

Rolnick, A., & Lubow, R. E. (1991). Why is the driver rarely motion sick? The role of controllability in motion sickness. *Ergonomics, 34*, 867-879.

Schmidt, R. A., & Young, D. E. (1987). Transfer of movement control in motor skill learning. In S. M. Cormier & J. D. Hagman (Eds.), *Transfer of learning: contemporary research applications*. San Diego, CA: Academic Press. 47-79.

Smart, L. J., Stoffregen, T. A., & Bardy, B. G. (2002). Visually induced motion sickness predicted by postural instability. *Human Factors, 44*, 451-465.

So, R.H.Y., & Lo, W. T. (1999). Cybersickness: an experimental study to isolate the effects of rotational scene oscillations. *Proceedings - Virtual Reality Annual International Symposium*, 237-241.

So, R. H. Y., Lo, W. T., & Ho, A. T. K. (2001). Effects of navigation speed on motion sickness caused by and immersive virtual environment. *Human Factors*, *43*, 452-461.

Stanney, K. M., & Hash, P. (1998). Locus of user-initiated control in virtual environments: Influences on cybersickness. *Presence*, 7, 447-459.

Stanney, K. M., Kennedy, R. S. (1997). The psychometrics of cybersickness. *Communications of the ACM*, *40*, 67-68.

Stanney, K. M., Kennedy, R. S., Drexler, J. M., & Harm, D. L. (1999). Motion sickness and proprioceptive aftereffects following virtual environment exposure. *Applied Ergonomics*, *30*, 27-38.0.

Stanney, K. M., Mourant, R. R., Kennedy, R. S. (1998). Human factors issues in virtual environments: a review of the literature. *Presence*, *7*, 327-351.

Stedmon, A. W., & Stone, R. J. (2001). Re-viewing reality: human factors of synthetic training environments. *International Journal of Human-Computer Studies, 55*, 675-698.

Stern, R. M., Hu, S., Anderson, R. B., Leibowitz, H. W., & Koch, K. L. (1990). The effects of fixation and restricted visual field on vection-induced motion sickness. *Aviation, Space, and Environmental Medicine*, *61*, 712-715.

Stoffregen, T. A., Hettinger, L. J., Haas, M. W., Roe, M. M., & Smart, L. J. (2000). Postural instability and motion sickness in a fixed-base flight simulator. *Human Factors, 42*, 458-469.

Switzer, F. S. (2005). Team Factors Questionnaire. Unpublished Manuscript.

Tiande, Y., & Jingshen, P. (1991). Motion sickness severity under interaction of vection and head movements. *Aviation, Space, and Environmental Medicine*, *62*, 141-144.

Tichon, J. (2007). Training cognitive skills in virtual reality: measuring performance. *Cyberpsychology & Behavior, 10*, 286-289.

Waller, K. (2006). Developing a benchmark suite for the evaluation of orientation sensors. Un-published master's thesis, Clemson University, Clemson, SC, USA.

Welch, R. B. (2003). Adapting to telesystems. In L.J. Hettinger & M.W. Haas (Eds.) *Virtual and adaptive environments: applications, implications, and human performance* (pp. 129-167). Mahwah, NJ: Lawrence Erlbaum Associates.

Wertheim, A. H. (1998). Working in a moving environment. *Ergonomics. 41*, 1845-1858.

Westerman, S. J, Cribbin, T., Wilson, R. (2001). Virtual information space navigation: evaluating the use of head tracking. *Behavior & Information Technology*, *20*, 419-426.

Wiederhold, B. K., & Widerhold, M. D. (2000). Lessons learned from 600 virtual reality sessions. Cyberpsychology & Behavior, *3*, 393-400.

Wiker, S. F., Kennedy, R. S., McCauley, M. E., & Pepper, R. L. (1979). Reliability, validity and application of an improved scale for assessment of motion sickness severity (USCG Tech. Rep. No. CG-D-29-79). Washington, DC: U.S. Coast Guard Office of Research and Development.

Whitmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments, 7,* 225-240.

Woodson, W. E. (1981). *Human factors design handbook: information and guidelines for the design of systems, facilities, equipment, and products for human use*. McGraw-Hill Book Company: New York, NY.