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Investigation of visually induced motion sickness: a comparison of mitigation techniques in real and virtual environments

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Investigation of visually induced motion sickness:

A comparison of mitigation techniques in real and virtual environments

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DEDICATION

To Gary Maurice Curtis and Lamont Toliver. Thank you for the inspiration and guidance. Rest in peace.

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ABSTRACT

Motion sickness affects almost all users of virtual reality, and can be a limiting factor in the use of virtual reality environments in applications for training, therapy and entertainment. However, some actions can be taken to reduce the severity of the motion sickness, known as mitigation techniques. One of the mitigation techniques examined in this thesis is an active hand-eye coordination task. The other is passive recovery, by way of removing one's self from the sickening stimuli and allowing time to pass, referred to as natural decay. Both tasks were used in physical reality and virtual reality settings, in order to rank the efficacy of each. The hypothesis was that a virtual mitigation task can be as effective as a physical mitigation task. Forty people participated in a within-subjects experimental design over two visits. Responses on the Simulator Sickness Questionnaire served as the measure for their motion sickness symptom severity. The research found significant differences between the physical and virtual hand-eye tasks, but no significant difference between the physical and virtual natural decay tasks. Further investigation of the differences in the physical and virtual hand-eye tasks is necessary to explain the significant differences; more analysis is required to conclude that natural decay while in a virtual environment is as effective as natural decay in the physical world.

CHAPTER 1. INTRODUCTION

When the Link Flight Trainer was invented in 1930, it revolutionized the training process of pilots. Until the Link Trainer's use, student pilots learned how to fly through instruction from a licensed pilot. After 1930, student pilots enjoyed a less expensive, less time-consuming and less dangerous training process (Angelo, 2000). Virtual reality as a medium for simulation training is nearing this revolutionary point. Advances in simulation training often turn into advances for the relevant training process. Virtual reality training simulations are currently implemented in a variety of fields, from military to medicine. However, motion sickness symptoms can complicate task performance while training. Training exercises that require the use of air or sea transports often lead to trainees experiencing some form of motion sickness symptoms. Researchers have found that some male infantry troops "were so debilitated that even simple tasks such as running would not have been possible" (Estrada et al., 2007).

This present research investigates an alternative to medicines for reducing the severity of motion sickness symptoms. While some strategies for mitigating motion sickness exist, each one requires the sufferer of motion sickness to withdraw from the sickening stimuli. However, in virtual reality, withdrawing from stimuli may be counterproductive to the goals of virtual reality exposure. Can a virtual reproduction of a physical mitigation task for motion sickness be as effective as the physical mitigation task itself? This research aims to answer this question and allow future studies to take place without the need to impair users of virtual reality.

The rest of Chapter 1 will introduce more key ideas and findings from past research to provide some background on motion sickness. Chapter 2 will present research that is critical to the research hypotheses and methods detailed in Chapter 3. Chapter 4 will report the findings of this research and in Chapter 5 there will be discussion and conclusions from the data.

1.1 Introduction of Key Terms

1.1.1 Motion Sickness

Hippocrates documented the symptoms we associate with motion sickness, namely nausea and disorientation (Rine et al., 1999). Motion sickness is so widespread that "all individuals possessing an intact vestibular apparatus can be made motion sick given the right quality and quantity of provocative stimulation" (Reason and Brand, 1975). Unfortunately, modern science has not completely determined the causes of motion sickness, nor the recovery from its symptoms.

Motion sickness actually encompasses a range of symptoms and can be subcategorized by the stimulus that causes the symptoms. The motion sickness profile is determined by the severity of the three main symptom groups of nausea, oculomotor symptoms and disorientation (Kennedy et al., 2010). The severity of these symptom groups is usually determined by the Simulator Sickness Questionnaire (Kennedy et al., 1993). The most common profiles of motion sickness include seasickness, carsickness, space adaptation syndrome, simulator sickness and a more recently studied subset of simulator sickness, referred to as visually induced motion sickness or VIMS, which is defined below. VIMS will be the subcategory of motion sickness examined in this research.

1.1.2 Simulator Sickness

After the invention of flight, simulators were created to teach prospective pilots how to control a plane. One of the early flight simulators was the Link Trainer. It included a pneumatic motion platform to provide pitch and roll cues for the trainee. Yaw cues were provided by an electric motor. A replica cockpit was also included and, when covered, allowed the trainee to fly solely by instruments. Essentially, the Link Trainer allowed pilots to fly in adverse weather conditions without risk of injury. As time went on, visual systems were eventually crafted for use with motion platforms. This approach allowed trainees to experience flying while completely removed from the terrain they flew over. Another effect was the possibility of "simulator sickness," or motion sickness caused by simulators (Angelo, 2000). The term “simulator sickness” can apply to any system that uses a simulator for aviation, medicine, or entertainment (Buker et al., 2012).

1.1.3 Simulator Sickness Questionnaire

The Simulator Sickness Questionnaire (SSQ) is a specific subset of questions from the Pensacola Motion Sickness Questionnaire (Kellogg et al., 1965) aimed at identifying motion sickness symptoms relevant to motion sickness caused by flight simulators and other vehicle simulators. The SSQ is administered as a written or oral survey of 16 symptoms with responses of ”none”, ”slight”, ”moderate”, or ”severe” or on a range from 0 to 3. The symptoms can be divided into three subcategories of nausea (N), oculomotor (O), and disorientation (D). To calculate the score for each subcategory, one must add together all the relevant symptom responses and multiply by a subcategory’s multiplier. Likewise, the total severity (TS) score is a sum of the symptom responses given by the participant multiplied by the TS multiplier. In other words, the relationship between the subcategory scores and TS scores are not simply additive. The minimum value for each score is 0, signifying no motion sickness symptoms. Higher scores signify more severe symptoms. The maximum value for each score is 200.34 for N, 159.18 for O, 292.32 for D, and 235.62 for TS (Kennedy et al., 1993).

1.1.4 Visually Induced Motion Sickness (VIMS)

Most forms of motion sickness, such as car sickness and seasickness, are associated with motions inherent with the mode of transportation. However, in visually induced motion sickness (VIMS), the person experiencing symptoms is often sitting still, but still perceives motion. This perception of self-motion is called vection. Vection is associated with visually induced motion sickness, so much so that devices called optokinetic drums, which are used to create a moving visual field while a subject sits still, are referred to as vection drums (Lo and So, 2001). These drums invoke optical flow, a two-dimensional velocity vector for each small region of the visual field which represents image motion (Heeger, 1987). Research in VIMS has uncovered that the symptoms of VIMS are typical of motion sickness. Also, vection and VIMS seem to be interconnected, as people resistant to vection are resistant to VIMS as well. Furthermore, labyrinthine deficient individuals are immune to motion effects, and while they can experience and report vection, they are immune to sickness from it (Kennedy et al., 2010).

1.1.5 Mitigation

In this paper, mitigation and readaptation may be used interchangeably, as both describe an action or a strategy to quicken one's recovery from motion sickness. Motion sickness mitigation techniques include taking medications, wearing motion sickness bands (Estrada et al., 2007), and hand-eye coordination tasks (Champney et al., 2007). Readaptation will be addressed in the hypothesis section of this chapter and a more detailed examination of mitigation techniques and readaptation strategies can be found in Chapter 2.

1.1.6 Virtual Environments

As technology has progressed further, the same goal of providing training while in an unfamiliar setting yet while located in a safe place remained the same. Today we use simulators in a wide variety of applications from training new members on a naval vessel (Amokrane et al., 2008) to training athletes to play rugby (Miles et al., 2012). And as the number of possible applications for simulation training has grown, deman for higher fidelity simulators has as well. A virtual environment (VE) can be defined in a number of ways, but a basic definition is a three-dimensional, interactive, real-time computer-generated simulation that provides direct input to the senses. VEs consist of a display for users to view the environment and a controller to interact with the objects in the environment (Kolasinski, 1995). Virtual environments have become classified as immersive and non-immersive VEs (Kozhevnikov et al., 2013). Most everyday computer use takes place in non-immersive desktop virtual environments (DVEs). DVEs are characterized by their display and input, which are seen as "outside" manipulations of an interior virtual world via keyboard and mouse, as opposed to direct manipulations through the use of motion tracked controllers. Motion sickness symptoms accompany DVE use, but are more prevalent in immersive virtual environments (IVEs), which utilize display systems like head-mounted displays (HMDs), large projection screens or powerwalls, and higher-end theater displays (Sharples et al., 2008).

1.1.7 Immersive Virtual Environments

IVEs are characterized by their level of both input fidelity and display fidelity. DVEs usually employ the use of a mouse and keyboard or joystick configuration (Lapointe et al., 2011). In contrast, IVEs have a range of input devices from location tracked apparel or joysticks to the IVE user's body itself. This provides the IVE user with a higher fidelity input and feedback system; instead of using a joystick to turn one's head in immersive virtual reality, one simply turns his or her head. Higher fidelity displays used in immersive virtual environments typically have stereoscopy features, allowing for depth and other binocular cues. Examples of stereoscopic IVE displays include the Oculus Rift head-mounted display and cave automatic virtual environments (CAVEs).

1.1.8 Presence

Presence is an individual's feeling of "being there" in whatever reality he or she is in. For virtual reality applications, gathering and acting on virtual sensory data instead of physical sensory data is a main aspect of presence (Jerome et al., 2005). Various questionnaires have been used to subjectively assess presence, such as the Short- Feedback Questionnaire (Kizony et al., 2006), the Slater-Usoh-Steed questionnaire (Usoh et al., 2000), and the Presence Questionnaire (Witmer and Singer, 1998). More recently researchers have attempted to discover an objectively measured relationship between presence and event-related electroencephalogram (EEG) potentials (Kober and Neuper, 2012). This research will make use of a modified Presence Questionnaire (PQ) 2.0, which contained 19 items that together measure presence, as well as contributing to four subcategories of involvement, sensory fidelity, adaptation/immersion and interface quality (Witmer et al., 2005). Presence is also negatively correlated with simulator sickness (Jerome et al., 2005).

1.1.9 Stereoscopic Acuity

Stereopsis is the ability to perceive depth as a result of difference in retinal disparity between the two eyes. Stereoscopic acuity, or stereo acuity, is the measure of the lower threshold at which a person perceives depth (Long and Siu, 2005). When used as a pre-exposure and post-exposure task, the change in stereoscopic acuity can be an objective indicator of visual fatigue (Chi and Lin, 1998). The random dot stereogram (RDS) is a pair of images comprised of randomly generated dots that requires a stereoscope or specialized glasses for viewing. These images lack depth cues such as shadows, perspective and cognitive effects. As a result, the RDS can produce a sensation of depth only when proper binocular fusion, the production of one image from two sources, occurs. By measuring the time for binocular fusion to occur for these images, one can determine the level of visual fatigue of the viewer (Kim et al., 2012).

1.1.10 Workload

The NASA Task Load Index (NASA-TLX) is a survey instrument designed to measure workload in six subcategories of mental, physical and temporal demands, frustration, effort and performance (Hart, 2006). It has been in use for over 20 years, throughout which time its validity has been tested and many modifications of it have spun off. In its original form, a weight is applied to the responses to minimize individual differences and at the same time increase between-rater reliability. Although it began as a subjective measure of workload in aviation studies, it has been applied to almost any research that has a workload component.

1.2 Causation Theories

The exact cause of motion sickness remains unknown, but is thought to be explained by two causation theories known as sensory conflict theory and postural instability theory. Further discussion about both theories can be found in Chapter Two. Sensory conflict theory is also known as sensory rearrangement or neural mismatch theory. Reason and Brand proposed that visually induced motion sickness can occur when the subject cannot move and “there is no physical stimulus to the vestibular receptors even if one may be implied by the visual stimulus.” Because VIMS can occur even when a subject is restrained (Faugloire et al., 2007), and thus no postural instability is possible, the experiment conducted for this research followed the sensory conflict theory proposed by Reason and Brand.

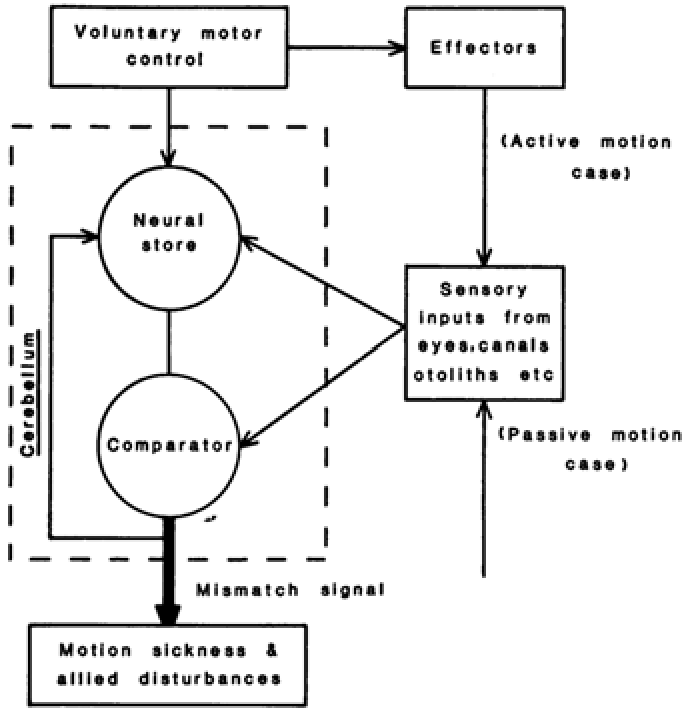

Figure 1.1 Structural components of the neural mismatch model

Figure 1.1 shows the qualitative model published as Fig. 2 by Reason (1978). Reason wrote that the neural store was the the key component for adaptation. He proposed that the neural store held past traces of combinations of command signals (efference) and the input patterns generated by the orientation senses (reafference). When an active movement starts, a copy of the command signal (efference-copy) is transmitted to the neural store, which retrieves and reactivates the reafferent trace combinations from previous experiences. The function of the comparator is to match the current sensory inputs with reafferent trace combinations selected from the neural store by the efference-copy. If there is a discrepancy between the present inputs and these stored patterns, a mismatch signal is generated which triggers the various neural and neurohumoral mechanisms mediating the nausea syndrome and the allied perceptual disturbances. A component of the mismatch signal is also fed back to the neural store where it causes a different retrieval strategy to be adopted. Readaptation should therefore help relieve motion sickness symptoms by lessening the discrepancy between the neural stores and sensory inputs via voluntary motor control. In 2008, Reason and Brand's theory and model was still valid, and has been used a basis for a more specific explanation and prediction of motion sickness (Bos et al., 2008).

1.3 Hypothesis

Physical readaptation strategies for visually induced motion sickness such as rail-walking and hand-eye coordination have been shown to accelerate relief from motion sickness symptoms more quickly than simply waiting with one's eyes shut (Champney et al., 2007). However, these strategies require that a person leave a virtual environment to begin mitigating these symptoms. A great disadvantage to many virtual reality studies is the limit on exposure time. As a result, this study investigates the effectiveness of a virtual mitigation technique, in which the person remains in the virtual environment, versus its physical analog. The hypothesis of this research is that a virtual mitigation task can be as effective at readaptation as a physical mitigation task, characterized by reduced SSQ scores.

1.4 Experiment

The experiment that was used to test the hypothesis was designed with two distinct phases. The first phase was designed to induce VIMS in 15 minutes or less by having participants navigate through a virtual corn maze. The second phase was the readaptation phase, in which participants were given a task to help mitigate the symptoms of VIMS. During both phases, participants verbally completed three SSQs in order to measure the severity of VIMS symptoms.

1.4.1 Induction Phase

The first phase of the experiment contained a corn maze designed to create VIMS in a small amount of time. Its design was influenced by some of the tasks found in the Virtual Environment Performance Assessment Battery (VEPAB) (Lampton et al., 1994). It was created with the Unity 3D game engine and features many stimuli known in literature to invoke VIMS such as loss of control (Dong et al., 2011), optokinetic drums (Lo and So, 2001), and quick vertical translations and oscillations (O'Hanlon and McCauley, 1974). Pilot tests, in which participants had movement and camera control, have shown that the stimuli from the maze can make VIMS symptoms appear by the end of the first lap. Each lap lasted seven and a half minutes when participants did not have movement control and were guided through the corn maze at a steady pace. The maze was over when the participant had been exposed for 15 minutes or completed two laps.

1.4.2 Mitigation Phase

The second phase of the experiment involved performing a mitigation task for 15 minutes. Participants completed either a physical peg-in-hole task or a virtual peg- in-hole task or quietly sat still. The latter condition is referred to as natural decay, which took place in either a virtual environment or in the experiment room.

Chapter Two will discuss more causation theories found in literature as well as virtual environments.

CHAPTER 2. BACKGROUND

Various display devices exist for viewing virtual environments. One major difference between three-dimensional (3D) IVEs and DVEs is that 3D IVEs involve egocentric navigation. Furthermore, experience in stereoscopic IVEs can significantly contribute to the sense of presence people can feel in virtual environments (Kozhevnikov et al., 2013). Some of the display devices for immersive virtual environments are head-mounted displays (HMDs) and cave automatic virtual environments (CAVEs). CAVEs immerse a user's entire body in virtual reality, while HMDs only cover the user's eyes. HMDs have also been reported to lead to more motion sickness in virtual environments than desktops and projection screens (Sharples et al., 2008). This chapter will discuss the causation theories for motion sickness and readaptation strategies for people affected by motion sickness symptoms.

2.1 Motion Sickness Causation Theories

The exact cause of motion sickness is still unknown. However, there are two major theories that attempt to explain the phenomenon of motion sickness. These theories are known as sensory conflict theory and postural instability theory. Both have been supported by other researchers, but the theory of sensory conflict provides a better explanation of the empirical data collected throughout the years. The two theories are detailed below as well as theories from the past.

2.1.1 Pre-modern Causation Theories

Prior to World War II, many "blood and guts" theories were used as an explanation for motion sickness. These theorists believed that independent motion and disturbances in the viscera, in the circulatory system, or both, were responsible for nausea. During this time, many other theories were formed, often excluding the vestibular system, which is now known to play a crucial part. It was not until 1949, when a pregnant woman with a history of carsickness was administered Dramamine, that the realization of the vestibular system's impact occurred. In fact, it was considered so important that the "vestibular overstimulation theory" dominated motion sickness research until the 1960's. In the early years of the 1960's the popularity of the vestibular overstimulation theory waned as it failed to explain sickness from visual stimuli and phenomenon like "mal de débarquement," which is an experience of motion sickness symptoms upon returning from a sea voyage (Reason and Brand, 1975).

2.1.2 Sensory Conflict Theory

The most widely accepted theory for motion sickness, which this current study followed, is the sensory rearrangement or sensory conflict theory. Proposed by Brand and Reason in 1975, the main theory was that all situations which provoke motion sickness are represented by a condition of sensory rearrangement in which the motion signals received and transmitted by the eyes, the vestibular system and the nonvestibular proprioceptors are different not only with one another, but also with past experiences and those expectations. Reason and Brand listed six different kinds of sensory rearrangements that can induce motion sickness. Subsequent researchers have suggested that only one kind of sensory conflict existed (Bles et al., 1998). Bles et al. offered a different theory, the subjective vertical (SV) conflict theory, that the only conflict that causes motion sickness is between the expected or subjective vertical and the sensed vertical. In SV-conflict theory, the subjective vertical refers to the internal representation of gravity.

2.1.3 Postural Instability Theory

Stoffregen and Riccio (1991) disputed Reason and Brand's theory of sensory rearrangement. They asserted that nonredundancy from sensory organs does not always lead to conflict. An example would be stereopsis, the discrepancy between the two eyes that gives humans depth perception. They proposed instead that prolonged postural instability is the cause of motion sickness. Postural stability is defined as "the state in which uncontrolled movements of the perception and action systems are minimized." Thus, the opposite, postural instability, is not a complete loss of control. There can be variation in the magnitude of instability, and instability can persist over long periods of time without necessarily leading to loss of control (Stoffregen and Smart, 1998). Postural instability theory has been shown in literature to be flawed and insufficient to explain all occurrences of motion sickness, especially in cases where the participant experiencing the symptoms is immobile, as in visually-induced motion sickness.

2.1.4 Eye Movement Theory

More recently, Ebenholtz (2001) proposed that two specific eye movements, the optokinetic nystagmus and vestibular ocular response, induce motion sickness symptoms. The optokinetic nystagmus is the eye's pursuit of a target object from one end of a visual scene to another. When the eye can no longer pursue the object, it returns to the far side of the visual field and begins to pursue again. The vestibular ocular response keeps a target object on the fovea when the head is turning. Errors in these eye movements can result in headache, eye strain, and difficulty concentrating, which are commonly reported symptoms of visually induced motion sickness (Brooks et al., 2010). Future research should be able to further support or oppose Ebenholtz's theory.

2.2 Mitigation Techniques

2.2.1 Medication

Medicine for motion sickness symptoms do exist and target mainly the nausea and vomiting symptoms associated with motion sickness. In response to visual and vestibular input, increased levels of dopamine stimulate the medulla oblongata's chemoreceptor trigger zone, which stimulates the vomiting center within the reticular formation of the brainstem. The vomiting center also is directly stimulated by motion and by high levels of acetylcholine. Most drugs used to prevent motion sickness symptoms target these neurotransmitters. These drugs fall within three classes: antidopaminergics, anticholinergics, and antihistamines. Also, sympathomimetic agents are added to counter side effects (Estrada et al., 2007).

The most common motion sickness drugs are promethazine (an antidopaminergic), scopolamine (an anticholinergic) and meclizine (an antihistamine). However, each treatment comes with its own side effects. Promethazine can affect its users with sedation, sleepiness, blurred vision, and dryness of mouth. It has also been reported to cause decreases in performance, psychomotor function, information processing, and alertness. Meclizine can also cause drowsiness. Sympathomimetic drugs counteract motion sickness by themselves, but are more effective when taken with anticholinergics. However, the most effective sympathomimetic drugs have a high potential for abuse, and can cause psychotic episodes, tremors, and other side effects (Estrada et al., 2007).

2.2.2 Physical Activities

2.2.2.1 Rail Walking

Champney et al. (2007) offered rail walking on a 8-foot long nonslip surface with supporting rails. This readaptation strategy was aimed at recalibrating the vestibular system. It also served as a test for the postural instability theory. Based on the success of Benson et al. (1974), Champney et al. believed that rail walking would help fix any postural issues the participant encountered during virtual environment exposure. Instead, participants who used the rail walking readaptation strategy showed no significant differences between the start and end of mitigation for roll-axis sway, a postural stability performance measure. However, participants who completed a hand-eye task or natural decay did have significant differences between right after exposure and 15 minutes later. This suggests that rail walking requires future study, but does not seem to be an effective mitigation technique.

2.2.2.2 Hand-Eye Tasks

Based on experiments in air and underwater, it was found that hand-eye coordination tasks greatly improved adaptability over a passive approach (Kinney et al., 1970). Kinney et al. used various underwater tasks such as playing a variation of fencing, completing carpentry tasks, and placing pegs in a pegboard to prepare participants for a ball-dropping task to measure adaptability to a new environment, i.e. underwater. Each group that completed a task adapted better than the control group, who were tested as soon as they entered the water. In normal air, Champney et al. employed a pegboard task for adaptation as well. The pegs and pegboard used in their research was the Lafayette Pegboard Test (Lafayette Instruments # 32027), which is pictured in Figure 2.1. The test features a 5x5 grid of identical peg holes and is performed with the participant's preferred hand.

Figure 2.1 The Lafayette Pegboard Test

2.2.2.3 Acupressure

Another active way of mitigating motion sickness symptoms is through acupressure. Acupressure is a non-invasive, traditional Chinese technique that substitutes acupuncture needling with a method of applying skin pressure. The acupoint most commonly used to reduce vomiting is point six (P6) on the pericardium channel or meridian. As well as acupuncture and acupressure, acupoints may be stimulated by application of mild electric current (Sinha et al., 2011). Acupressure wrist bands have been found to be effective in older virtual environment users (Wesley and Tengler, 2005), but not useful for helicopter passengers, especially due to possible neuromuscular fatigue that may have led to an increased delay in response times to the Psychomotor Vigilance Task (Estrada et al., 2007; Drummond et al., 2005). As a result, wrist bands would not be appropriate for normal or consumer use of immersive virtual environments.

2.2.3 Passive Recovery

2.2.3.1 Natural Decay

Motion sickness symptoms subside on their own after the removal of sickening stimuli (McCauley and Sharkey, 1992). Natural decay is how motion sickness is most commonly mitigated, especially for virtual environments. However, aftereffects from motion sickness have been observed to last from 6 to 24 hours after exposure (Baltzley and Kennedy, 1989). Some people have even reported feeling aftereffects days after exposure (Kennedy et al., 2010). Consequently, waiting for effects to subside may not be the most appropriate strategy for recovery. In the present study, participants completed a natural decay task in the physical world by sitting quietly. For virtual natural decay, participants sat with a head-mounted display to view a scene that featured an independent visual background, which is discussed below.

2.2.3.2 Independent Visual Background

A type of natural decay technique has been investigated while virtual reality users remain in a virtual environment. An independent visual background (IVB) is a separate visual stimulus that is aligned with gravity and is inertially stationary. It has been used in projection-based systems and helped to mitigate motion sickness symptoms. It works similarly to trees in the case of carsickness, offering one a more stationary point of reference in the background against a quickly moving foreground. As a result, IVBS can be used as a mitigation technique in conditions where conflicting visual and inertial cues are likely to result in sickness (Duh et al., 2001, 2004). Independent visual backgrounds have been implemented in both physical and virtual environments. In the physical environment, the IVB was placed on a laboratory wall behind the virtual environment, which was shown on a semitransparent display (Prothero et al., 1999). In an virtual environment, an IVB was implemented as a grid in the distance of the visual scene. A prominently displayed IVB is shown to the participant during virtual natural decay mitigation.

CHAPTER 3. EXPERIMENTAL METHODS

3.1 Overview

This chapter explains the design, measures, tasks, and apparatus of the present experiment.

3.2 Participants

Participants were recruited from the student population of Iowa State University via email and in-class appearances in an undergraduate engineering course. Participants could not have implanted medical devices, be prone to seizures, nor be actively taking motion sickness medicine. Each participant signed a consent form that informed them of the risks and tasks he or she could expect. They were compensated with either extra credit in their class, a research study participation credit, or $20; their choice was awarded at the conclusion of the second study session.

3.3 Experimental Design

Participants were placed into one of 16 groups for our experimental design. Groups varied based on the mitigation task a participant performs (hand-eye vs. natural decay), the space in which the mitigation task is performed (virtual vs. real), whether the participant has movement control during the maze task (movement control vs. no control), and whether the participant changes the movement control condition on the second visit (control change vs. no change). The 16 groups are designated with letters A through P. The design did not contain an experimental control group. In this research, the word "control" refers to whether or not participants were in control of their movements during the maze task.

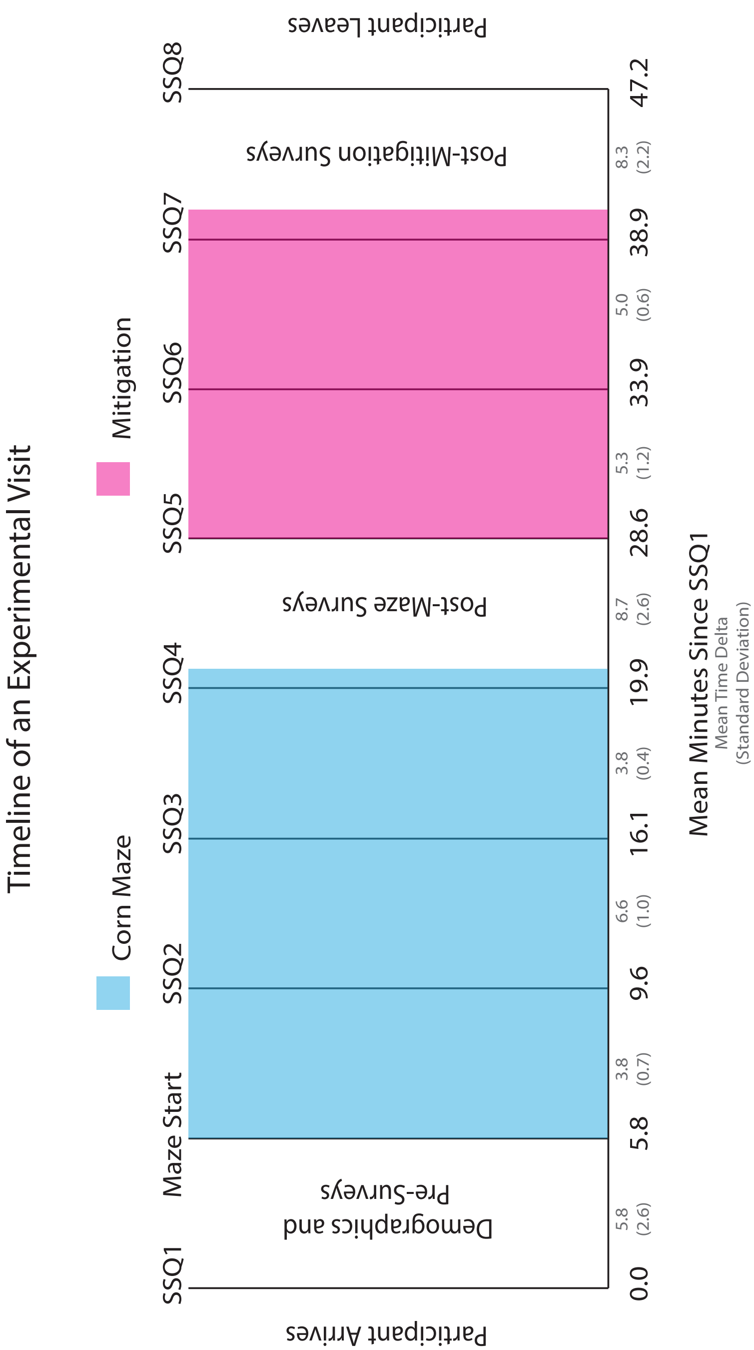

Figure 3.1 The timeline of the study.

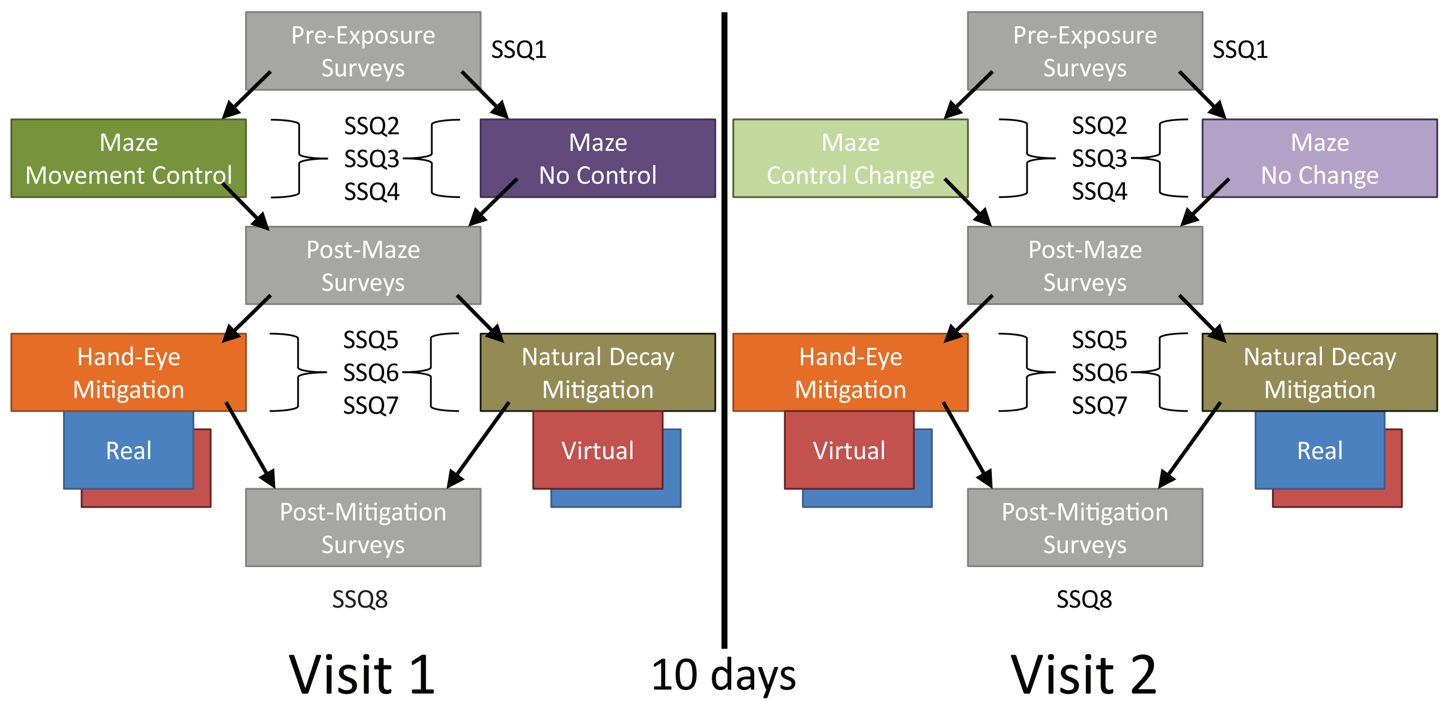

Figure 3.2 The different conditions of the experimental design.

Each participant completed two separate sessions, which included a maze and mitigation phase. Half of these 16 groups, Groups A through H, completed a different control condition each session and are shown in Table 3.1. The other groups, Groups I through P, completed the same control condition each session and are shown in Table 3.2. For example, a participant in Group A arrived on Visit 1 and navigated the maze with control, and then completed the hand-eye mitigation in the real environment. On Visit 2, after doing the maze with no control, the participant did the hand-eye mitigation again, but this time in the virtual environment. The two visits were at least ten days apart from each other, in order to counteract the benefit of repeated exposure, which is proposed to be two to five days (Kennedy et al., 2000). To summarize, each participant did the maze twice (Visit 1 and Visit 2), and in one visit their mitigation task was real, and in the other visit their mitigation task was virtual, though it was always the same type of task in both visits. Half of the participants had the same control mode in both visits and the other half did not. A timeline of the study is shown in Figure 3.1 and a graphical representation of the groups is shown in Figure 3.2. Note that the progression of time in the timeline is not to scale.

Table 3.1 The Control Change participant groups

	Visit 1			
	Real		Virtual	
	Hand Eye	Natural Decay	Hand Eye	Natural Decay
Control	A	B	C	D
No Control	E	F	G	H

	Visit 2			
	Real		Virtual	
	Hand Eye	Natural Decay	Hand Eye	Natural Decay
Control	C	D	E	F
No Control	G	H	A	B

Table 3.2 The No Change participant groups

	Visit 1			
	Real		Virtual	
	Hand Eye	Natural Decay	Hand Eye	Natural Decay
Control	I	J	K	L
No Control	M	N	O	P

	Visit 2			
	Real		Virtual	
	Hand Eye	Natural Decay	Hand Eye	Natural Decay
Control	K	L	I	J
No Control	O	P	M	N

3.4 Apparatus

Figure 3.3 The experimental station set up.

3.4.1 Computing Software and Hardware

The virtual tasks made use of the Unity game engine, the first iteration of the Oculus Rift head-mounted display Developer's Kit, referred to as DK1, the Razer Hydra controller, the

Logitech Dual Action gamepad and a Windows 7 personal computer. The personal computer used an nVidia 460 GTX graphics processing unit and an AMD Phenom X4 945 quad-core processor. The internals of the computer ensured that the virtual tasks were run without any graphical latency and without any feedback latency. While running the game inside Unity's editing mode, the graphics were able to refresh at a rate greater than 60 frames per second. Version 4.3 of Unity's 3D game engine was used to create the corn maze and the virtual mitigation tasks.

Figure 3.4 From the left, the Oculus Rift, Logitech Gamepad, and Razer Hydra.

3.4.2 Display Device

The Oculus Rift is a head-mounted display designed to for gaming and other consumer usage. The first iteration, referred to as DK1, included a 7" screen with a total resolution of 1280 x 800, providing 640 x 800 to each eye. The screen refreshes at 60 Hz and has an interpupillary distance of 64mm. The Rift is capable of tracking users' head movements with its three-axis gyroscope, three-axis magnetometer and three-axis accelerometer, which all have a sampling rate of up to 1000 Hz. The Rift enables a virtual environment to be viewed as a stereoscopic IVE. The DK1 is pictured on the left in Figure 3.4.

3.4.3 Controllers

Figure 3.5 Using the Logitech gamepad to navigate during a pilot test.

The Razer Hydra features a USB-powered, magnetic base with two motion-tracked controllers wired to the base. Razer reports the tracking is precise to 1 millimeter and 1 degree and has true six degree-of-freedom magnetic motion tracking. Razer reported that the Hydra has “low latency feedback.” Although there is a left and right controller, each controller was designed to be held in either hand. Each controller has 5 buttons, an analog stick with a button, a bumper and a trigger. The Logitech Dual Action gamepad is a wireless controller with two analog sticks, a directional pad, 6 buttons, 2 bumpers, and 2 triggers. Its layout is very similar to the Sony PlayStation analog stick controllers. If the participant had movement control during the maze, they used the Logitech gamepad to navigate. The controls were similar to modern first-person shooter games; the left thumbstick controlled forward and backward motion on the ground, as well as left and right strafing, the right thumbstick controlled rotation about the y-axis and Button 2 (bottom middle of the four buttons beneath the right thumb) allowed participants to jump over obstacles. Both controllers are shown in Figure 3.4.

3.4.4 Physical Task Apparatus

The physical task in this study is a peg-in-hole task. The version used was based on the Lafayette Pegboard, a smaller scale peg-in-hole task. The version used contained a 5x5 grid of drinking straws in which participants place pegs, which resembled thin chopsticks. The pegs were 305 mm long and four millimeters in diameter. The pegboard dimensions were 30 cm in length, 30 cm in width, and 10 cm in depth. The holes in the pegboard were six centimeters from each other in both length and width.

3.5 Surveys

3.5.1 Demographics

The demographics survey asked questions regarding age, gender, motion sickness history and experience with virtual environments, both two-dimensional and three-dimensional. Questions were related to sleeping and eating habits, in an attempt to establish a profile of an "at risk of motion sickness" participant. Past investigations of motion sickness have also included demographic questions (McMahan et al., 2012) regarding chemical and alcohol consumption, sleep habits (Stoffregen et al., 2000), body mass index (Stanney et al., 2003), empathy, spatial intelligence and immersive tendencies (Ling et al., 2013; Jerome et al., 2005).

3.5.2 Simulator Sickness Questionnaire

The simulator sickness questionnaire (SSQ) (Kennedy et al., 1993) listed 16 symptoms for participants to rate on a scale from 0 to 3, with 0 as "none," 1 as "slight," 2 as "moderate," and 3 as "severe." In the present study, the SSQ was asked verbally and served as the measure of motion sickness.

3.5.3 NASA Task Load Index

The NASA Task Load Index (NASA-TLX) (Hart, 2006) consisted of six subscales that determine a participant's overall workload for a task. The six subscales were Mental, Physical and Temporal Demand, Frustration, Effort and Performance. In the present study, the NASA-TLX was answered by the participant with paper and pencil as a baseline and after the corn maze and all mitigation tasks.

3.5.4 Presence Questionnaire

The presence questionnaire for this study was the PQ Version 2.0 (Witmer and Singer, 1998). Since the participants in the study did not have tasks with audio, the audio questions of the PQ were removed. This survey was completed via paper and pencil, after the corn maze and virtual mitigation tasks.

3.5.5 Random Dot Stereogram

The Random Dot Stereogram is a test of stereopsis (Kim et al., 2012). Using random dots to form a stereogram, participants must use polarized glasses and only binocular visual cues in order to see the difference of each item in the test. The test contained ten items, measuring stereo acuity in seconds of arc at 16 inches from 400 seconds to 20 seconds. It was taken as a baseline measure and after the corn maze and mitigation tasks.

3.6 Corn Maze

The corn maze included a series of turns, pits, optokinetic drums (Lo and So, 2001) and slides that were designed to stimulate visually-induced motion sickness. In one condition, referred to as the movement control condition, participants had control of both their forward velocity and acceleration via the gamepad controller and their camera viewpoint via the head-mounted display. The other condition, the no control condition, participants were "on-rails" and were moved through the maze without the ability to control their forward movement, but still able to change the camera view by turning the head. Each lap of the maze took seven

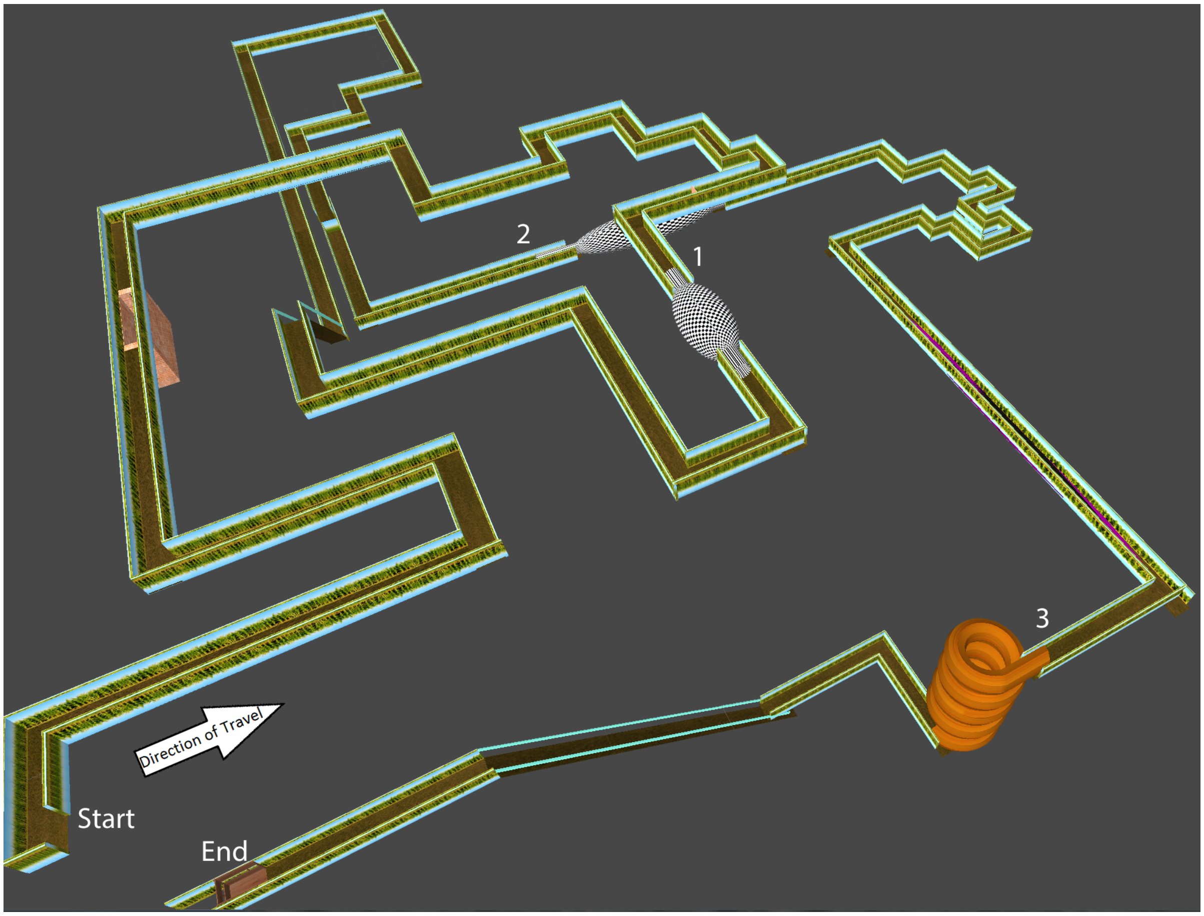

Figure 3.6 The corn maze, showing the direction of travel and the numbered checkpoints. Checkpoint 1 is the short rotator, 2 is the long rotator and 3 is the wooden slide.

and a half minutes to complete in the no control condition. The corn maze was over after the participant completed two laps or the participant had been exposed to the visual stimuli for 15 minutes.

At three checkpoints within the maze, the participant was asked the SSQ. Each checkpoint was accompanied by an invisible trigger, which logged the time the participant crossed the checkpoint. The first checkpoint (labeled 1 in Figure 3.6) was during the first lap was referred to as the long checkerboard rotator, which is a long checkerboard-tiled room resembling an optokinetic drum. The second checkpoint (labeled 2 in Figure 3.6) was during the second lap at the short checkerboard rotator. The final and third checkpoint (labeled 3 in Figure 3.6) was a wooden spiral slide during lap two. The SSQ was asked verbally by the researcher while the participant continued along the maze, with or without control. After the corn maze, the participant removed the HMD and completed a Random Dot Stereogram, a NASA-TLX, and a Presence Questionnaire.

3.7 Mitigation Tasks

After the Presence Questionnaire, each participant completed one mitigation task. There were two different tasks, hand-eye and natural decay. Each of these tasks happened in a physical space or a virtual space and lasted for 15 minutes. The SSQ was asked by the researcher at the beginning, after five minutes and after ten minutes into mitigation. If the participant completed a virtual mitigation task, the HMD was worn while answering the first mitigation SSQ. After the mitigation task was finished, the participant completed a Random Dot Stereogram, a NASA-TLX, and if the mitigation task took place in a virtual space, another Presence Questionnaire.

3.7.1 Physical Hand-Eye Mitigation Task

The physical hand-eye mitigation task was a peg-in-hole task. The pegboard consisted of a 5x5 grid of holes, which had drinking straws placed in them. The participant held the wooden pegs, with a pinch grip using the thumb and index finger, and filled in the pegboard from left to right, starting with the back row. Participants were instructed to stay seated and use only their dominant hand. If the participant completed the pegboard, the pegs were removed and the participants begun again.

Figure 3.7 The pegboard used in the experimental study, with drinking straws inserted to receive pegs. The rear left straw has a peg inserted.

3.7.2 Virtual Hand-Eye Mitigation Task

Figure 3.8 The virtual peg-in-hole task, with the pinch grip demonstrated.

The virtual hand-eye mitigation task took place in a virtual world designed in Unity. The mitigation VE was separate from the corn maze, and the participant was shown only a landscape, a pegboard, and pegs. While wearing the Oculus Rift DK1 head-mounted display, the participant used one of the Razer Hydra controllers to control a virtual peg. The Hydra was held with a pinch grip as well. However, because the Hydra controller is much heavier than the pegs used in the physical tasks, participants could use their middle finger as well, but were still required to use a pinch grip. Participants were instructed to place a peg into virtual straws starting with the back row, from left to right. When a peg was successfully placed, it was locked into position and a new peg appeared for the participant to manipulate. When the entire pegboard was completed, all the pegs were cleared and the participant started again.

The virtual hand-eye mitigation task was modeled after the physical hand-eye mitigation task. Several pilot tests were conducted in order to match time performance of the virtual task to the physical task. As a result, the movements in the virtual task and physical task were not a one-to-one ratio. In fact, implementing the virtual task this way would not be helpful as most people underperceive distances in virtual reality (Witmer and Kline, 1998). Instead, the virtual task was implemented such that the difficulty of the two tasks were similar and still required fine motor control. The virtual pegboard was also designed using the same dimensions as the physical pegboard.

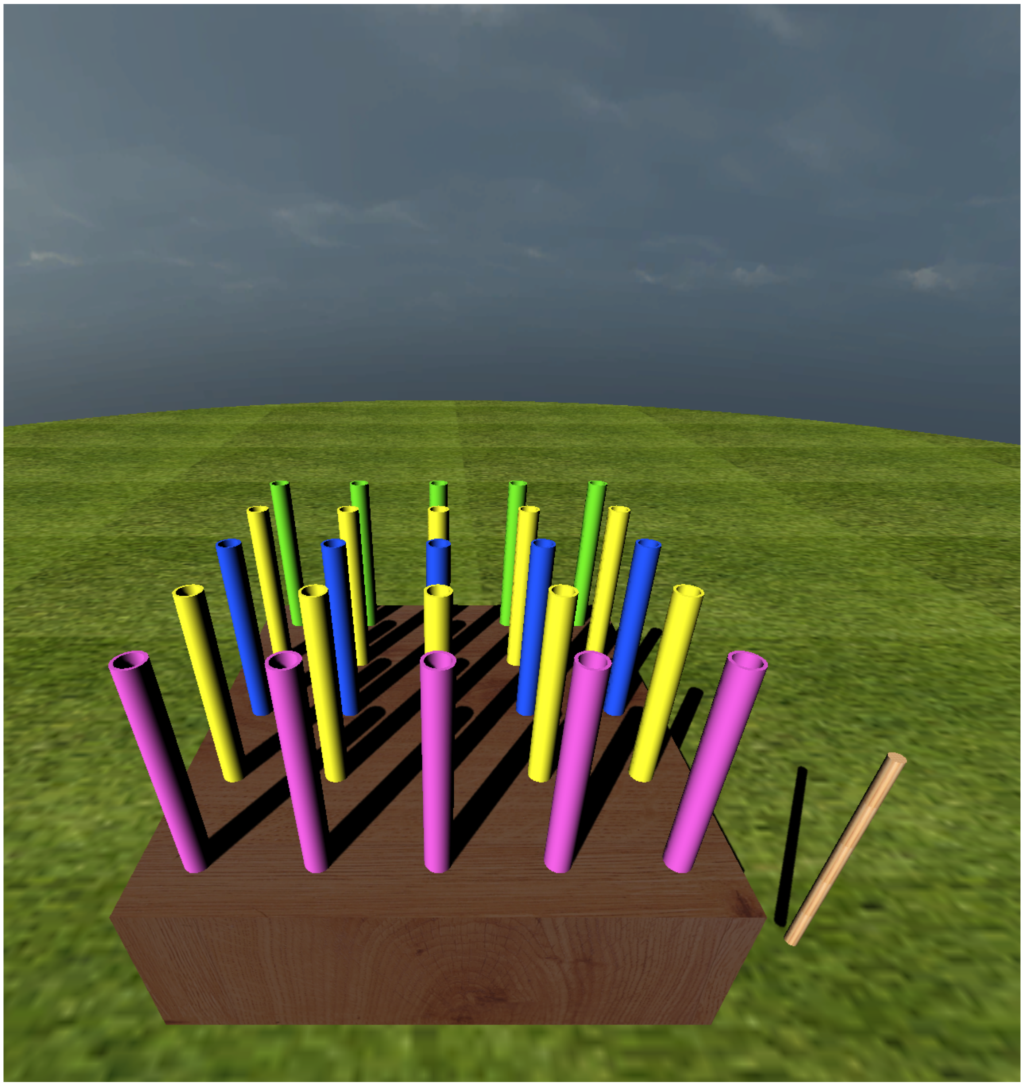

Figure 3.9 The participant's view of the virtual peg-in-hole task.

3.7.3 Physical Natural Decay

Figure 3.10 The physical natural decay condition.

Participants who performed the physical natural decay mitigation task were asked to sit quietly for 15 minutes. They were seated with their eyes open or closed. Participants who had this task also responded to the SSQ verbally.

3.7.4 Virtual Natural Decay

The virtual natural decay mitigation tasks also required that the participant sit quietly for 15 minutes. He or she continued to wear the HMD. During the virtual natural decay task, a landscape designed in Unity was shown to the participant. The participant looked around using the HMD, but could not move within the virtual scene. The virtual natural decay task also features an independent visual background (Duh et al., 2004) as a black grid, which is shown in Figure 3.11.

3.8 Assumptions

Due to the levels of independent variables and the experimental design, certain assumptions about the study had to be made. These assumptions are the following:

1. The order of mitigation tasks performed by a participant is negligible.

2. The participant's sex is negligible.

3. The participant's past virtual gaming experience is negligible.

4. The participant's lack of movement control during the first task is negligible.

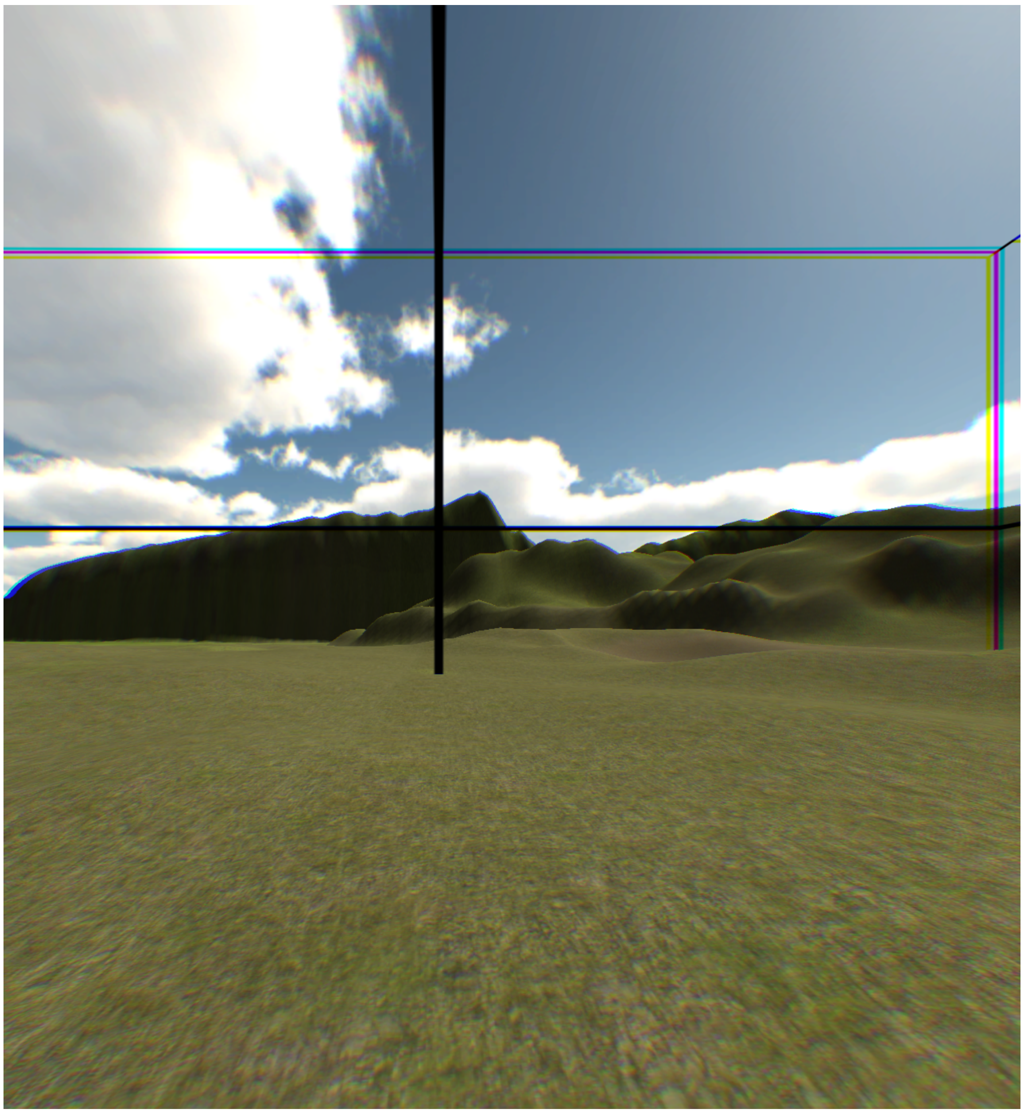

Figure 3.11 The virtual natural decay condition. The black lines form a cubic grid IVB.

3.8.1 Order of Mitigation Tasks

Past research of mitigation tasks have not included repeated visits of participants completing the same or differing tasks. As a result, it is unknown if participants will have any advantage or disadvantage by completing a real world mitigation task on Visit 1 versus Visit 2. It is predicted that the order of mitigation tasks between visits will not have an effect on SSQ scores.

3.8.2 Sex of Participant

Females usually report higher levels of sickness than males (Stanney et al., 2003; Häkkinen et al., 2006; Flanagan et al., 2005). Past research on mitigation techniques have not found any differences between men and women. This may be attributed to samples that did not contain enough females to study a difference, or may have simply not been reported. It is not expected that there will be a significant difference between female and male participants, which will enable both groups to be analyzed as one data pool.

3.8.3 Gaming Experience

Repeated exposures to a virtual world can lead to lower sickness in participants (Kennedy and Lane, 1992). It is unknown if video game experience induces a general repeated exposure effect, reducing sickness in unvisited virtual worlds. As a result, the prediction that differences in gaming experience will not have an effect has to be tested.

3.8.4 Movement Control

Currently, it is unknown if the stimuli responsible for motion sickness differ and affect recovery from motion sickness. Dong et al. (2011) found that drivers who had vehicular movement control experienced less motion sickness. Alternatively, Stanney et al. (2002) found that complete control (six degrees of freedom) over linear and rotational movement led to higher incidence of nausea, while streamlined control (three degrees of freedom) resulted in less nausea. The prediction for this research is that movement control will have no effect on the mitigation of motion sickness for participants.

3.9 Predictions

3.9.1 Visit

The time between Visit 1 and Visit 2 was set at 10 days to offset any benefits from repeated exposure, as the optimum time for accommodation effects has been shown to be between five to seven days, and no more than a week (Kennedy et al., 2000). The time between visits should also reduce the likelihood of a participant memorizing responses for surveys as well. As a result, it is predicted that there will not be significant differences between Visit 1 and Visit 2, during either phase of the experiment.

3.9.2 Mitigation Techniques

Considering the results of Champney et al. (2007), it is predicted that the order of the best mitigation technique will be physical hand-eye, virtual hand-eye, physical natural decay, followed by virtual natural decay. The hand-eye mitigation techniques should help to reconcile the participant's vision and proprioception, lessening the amount of sensory conflict. Since a sensory conflict is supposed to be the necessary condition for motion sickness, mitigating the conflict should lead to mitigated symptoms.

CHAPTER 4. RESULTS

4.1 Overview

This chapter presents the experimental findings of the mitigation study. First, there is a section of key terms and variables, to present the shorthand for independent and dependent variable names in tables, reports and charts. Simulator Sickness Questionnaire (SSQ) scores were analyzed using the procedure in Kennedy et al. (1993).

4.2 SSQ Terminology

4.2.1 SSQ Numbering

There were 8 SSQs during the experiment, which will be referred to as SSQ1, SSQ2, et cetera. SSQ1 is the baseline SSQ taken before the participant is exposed to virtual stimuli. SSQ2, SSQ3, and SSQ4 are taken during the maze task. SSQ5 is taken at the beginning of mitigation, SSQ6 is taken at 5 minutes into mitigation, SSQ7 taken at 10 minutes into mitigation, and SSQ8 taken when the participant exits the study. For data analysis, only the mitigation and exit questionnaires, SSQ5 through SSQ8, were used.

4.2.2 SSQ Subscales

The SSQ can be processed into subscales based on the severity of the symptoms reported. The subscales are Nausea (N), Oculomotor (O), and Disorientation (D). When the symptoms are all considered, the result is the Total Severity (TS) score. The scores are calculated by multiplying the sum of the corresponding symptom responses from the questionnaire with a specific subscale coefficient. The subscale coefficients are 9.54 for N, 7.58 for O, and 13.92 for D. The TS score is the sum of all subscale symptoms multiplied by 3.74. The minimum value for each score is 0, signifying no motion sickness symptoms. Higher scores signify more severe symptoms. The maximum value for each score is 200.34 for N, 159.18 for O, 292.32 for D, and 235.62 for TS (Kennedy et al., 1993).

4.3 Analysis

4.3.1 Demographics and Variables

57 participants completed at least one visit of the study. Of the 57 people that participated in the study, 17 were excluded from data analysis. Eight participants who did not have a return visit were removed. Seven participants who could not complete all of the mitigation phase SSQs on both visits were removed. One participant only completed one corn maze SSQ, and was removed. Finally, one participant did not understand the symptoms listed on the SSQ and was removed. Thus, for most analyses, $n = 40$.

The primary independent variables of the analyses were Reality and Visit. Both variables were analyzed using a within-measures test. The Reality variable had two levels, real and virtual, that described which mitigation task a participant performed. The Visit variable also had two levels, Visit 1 and Visit 2. The secondary independent variables were Movement Control and Control Change. These variables are secondary because they were not the focus of the study for this thesis. These independent variables also had two levels each, but were analyzed using a between-measures test. For Movement Control, participants either did or did not have movement control during the corn maze. Control Change described whether the participant kept the same movement control condition for both visits. In other words, if a participant had Control Change, for one visit she would have movement control but did not have movement control for her subsequent visit.

The tertiary independent variables included Real Mitigation First, Sex, and Gamer. These variables arose from the experimental design, rather than deliberately chosen by the researchers. The tertiary independent variables had two levels each, and were also analyzed using a between-measures test. Real Mitigation First described the condition in which a participant performed a real mitigation task, natural decay or peg-in-hole, on Visit 1. Sex described the sex of the participant. The Gamer variable indicated that the participant self-identified as a video gamer via the demographic survey. This was evaluated by the participant's response to the question, "Do you play video games?". Participants also responded to frequency of video game playing, but this was not used to determine gamers or non-gamers.

Of the 40 participants included in mitigation analysis, each completed a mitigation task in a virtual environment and a real environment. Each participant also completed a Visit 1 and a Visit 2. 23 participants had movement control during Visit 1 and 17 did not. Of the 23 who had movement control, 13 had movement control on Visit 2 as well, and 10 did not. Of the 17 who did not have movement control on Visit 1, nine did not have movement control again, and eight did have movement control. Consequentially, 18 participants experienced Control Change and 22 had no Control Change.

Of the 40 participants, 22 completed a real environment mitigation task during Visit 1, while 18 performed a VE mitigation task during Visit 1. 14 participants were females and 26 were males. Ages ranged from 19 to 38 (mean = 22.05, median = 21), using the demographic data from each participants' Visit 2. 27 participants self-identified as gamers and 13 self-identified as non-gamers. The gamers included four females and 23 males. The non-gamers included 10 females and three males. The numbers in each group are repeated below with their respective analyses.

Figures 4.1 and 4.2 display the sickness groups of the two visits. Participants in the Low sickness group reported a TS score of 37.4 or less. The Medium sickness group reported TS scores between 37.4 and 89.76, inclusive. Individuals in the High sickness group reported TS scores greater than 89.76. These numbers were based on the number and severity of symptoms that could be reported. The criterion for Low sickness was reporting 20% of the maximum severity of symptoms, while the criterion for Medium sickness was reporting 50% of the maximum severity of symptoms.

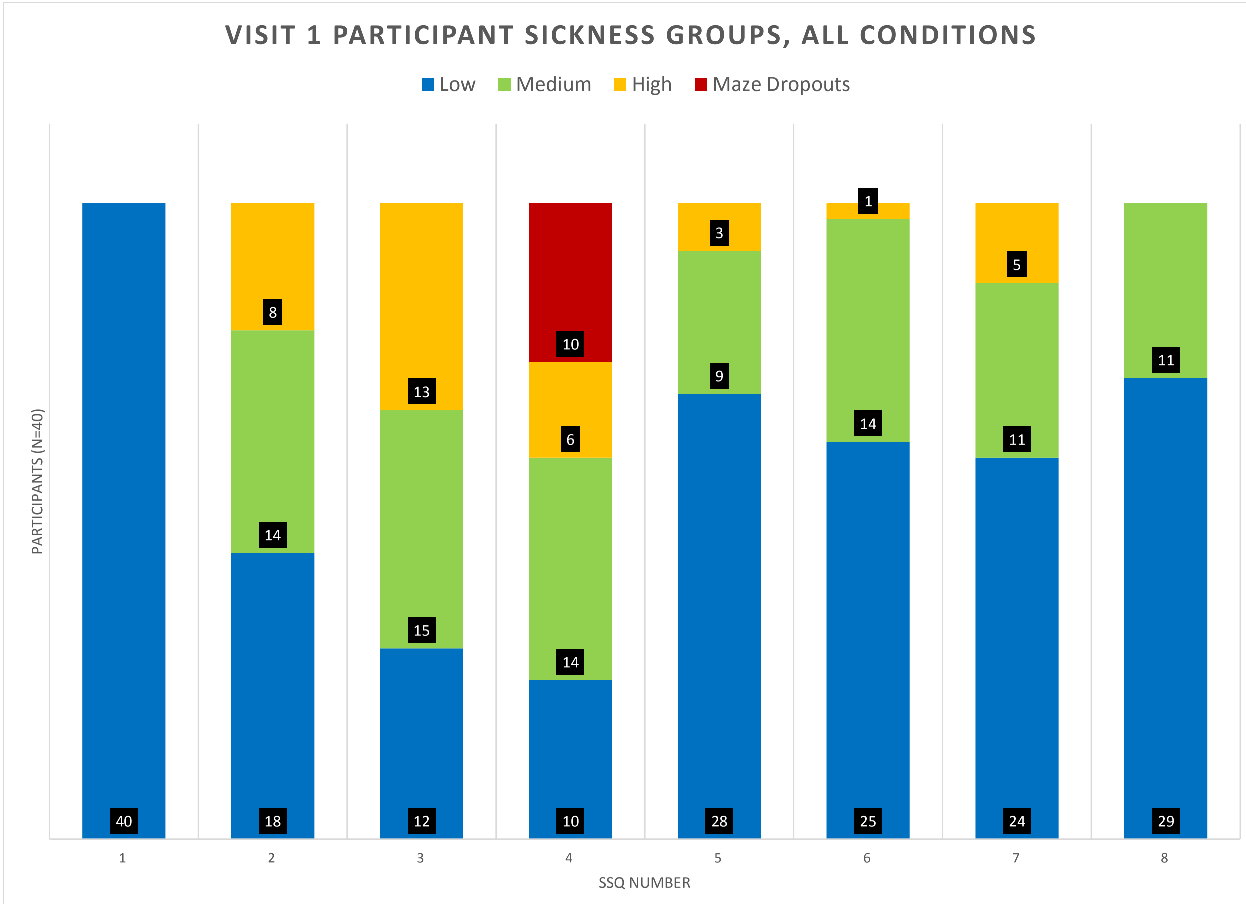

Figure 4.1 Stacked bar graph of low, medium and high sickness groups. Low <= 37.4; Medium <= 89.76; High > 89.76. All scores TS.

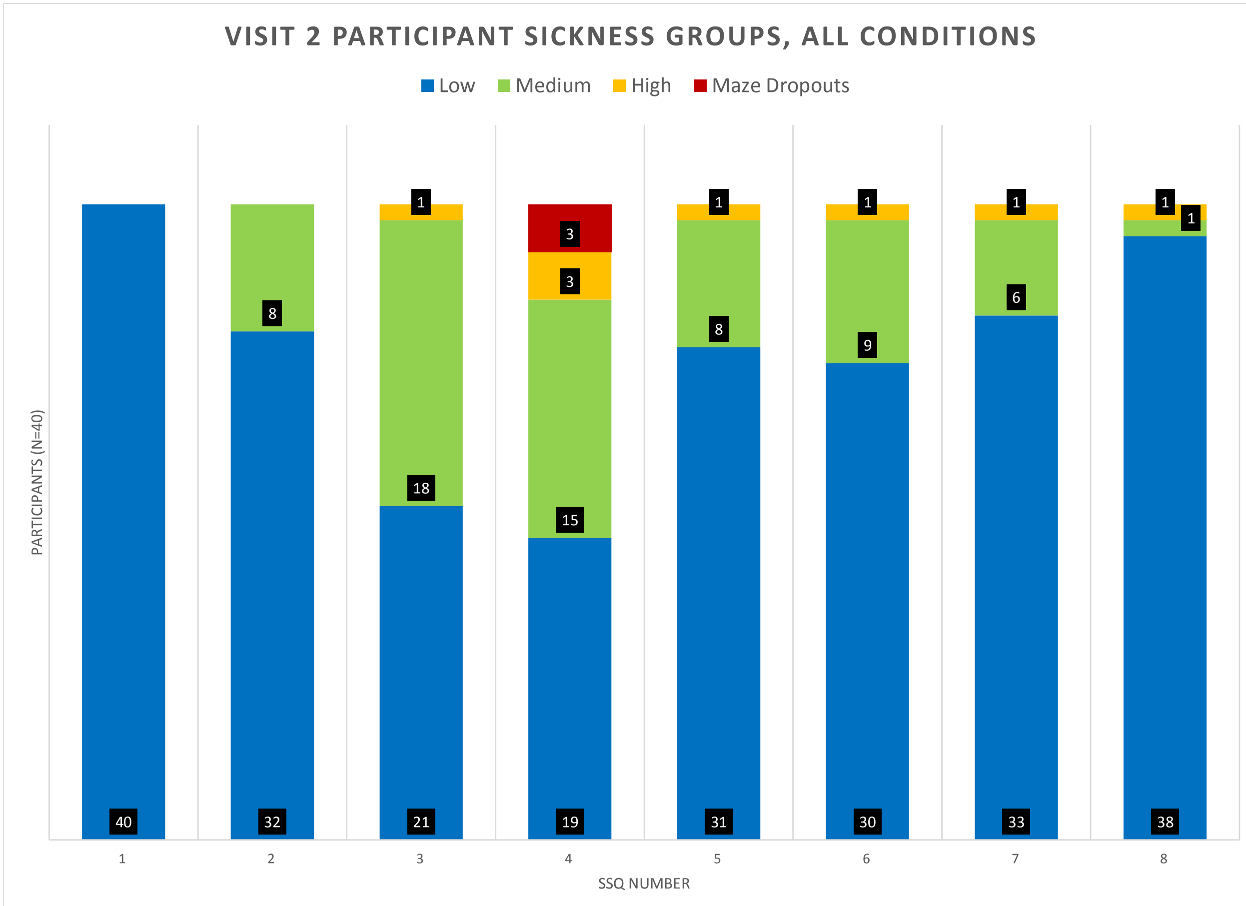

Figure 4.2 Stacked bar graph of low, medium and high sickness groups. *Low* $<=$ 37.4; Medium $<=$ 89.76; High $>$ 89.76. All scores TS.

4.3.2 Statistical Analysis

A one-way repeated measures ANOVA was used to investigate differences between the first and second visits. Visit was used as a within- measure independent variable and SSQ scores separated by visit number were used as dependent variables. A mixed ANOVA used Reality as a within-measure independent variable and SSQ scores separated by the setting of the mitigation task were used as dependent variables. Real Mitigation First, Sex, Gamer, Movement Control, and Control Change were used as between-measure independent variables. The ANOVA assumes that the data contains no outliers and that each level is normally distributed. Both of these assumptions were violated. Removing outliers from the data would have resulted in a severely reduced sample size. However, the ANOVA is considered robust enough to handle violations of these assumptions.

Please note that in the figures and tables below, an asterisk (*) denotes significance on a 95% confidence interval. A double asterisk (**) denotes significance on a 99% confidence interval.

4.3.3 Assumption Testing

As mentioned in Chapter Three, certain assumptions had to be made in order to include all secondary and tertiary independent variables together for data analysis of the primary independent variables. Those assumptions were the following:

1. The order of mitigation tasks performed by a participant is negligible.
2. The participant's sex is negligible.
3. The participant's past virtual gaming experience is negligible.
4. The participant's lack of movement control during the first task is negligible.

Each of the results of testing these assumptions are presented below. For example, an analysis of participants who performed the physical reality mitigation task on the first visit has been included, using a variable named "Real Mitigation First" to separate participants who did and did not satisfy this condition. An analysis was also conducted to investigate the differences between the first and second visit and any significance of those differences.

4.3.3.1 Real Mitigation First

Of the 40 participants, 22 performed the real mitigation task first and 18 performed the virtual mitigation task on their first visit. There were no statistically significant between-subject effects found that could be attributed to participants performing a physical mitigation task on the first visit, which upheld the prediction that the order of mitigation did not cause an effect. The results of the analysis and the mean SSQ scores of each group are shown in Table 4.1 and the Total Severity scores are shown in Figure 4.3.

4.3.3.2 Sex

Of the 40 participants, 26 were male and 14 were female. Significant differences were found in SSQ scores taken at the beginning of mitigation, which upheld the prediction that the sex of the participant would not have an effect during mitigation. The results of the analysis and the mean SSQ scores of each group are shown in Table 4.2 and the Total Severity scores are shown in Figure 4.4.

4.3.3.3 Gamer

Of the 40 participants, 27 self-identified as gamers and 13 did not. There were no statistically significant between-subject effects found in any of the SSQ subscales. These results align with the prediction that gaming experience would not affect motion sickness mitigation. The results of the analysis and the mean SSQ scores of each group are shown in Table 4.3 and the Total Severity scores are shown in Figure 4.5.

4.3.3.4 Movement Control and Control Change

Of the 40 participants, 23 participants had movement control during Visit 1 and 17 did not. Of the 23 who had movement control, 13 had movement control on Visit 2 as well, and 10 did not. Of the 17 who did not have movement control on Visit 1, nine did not have

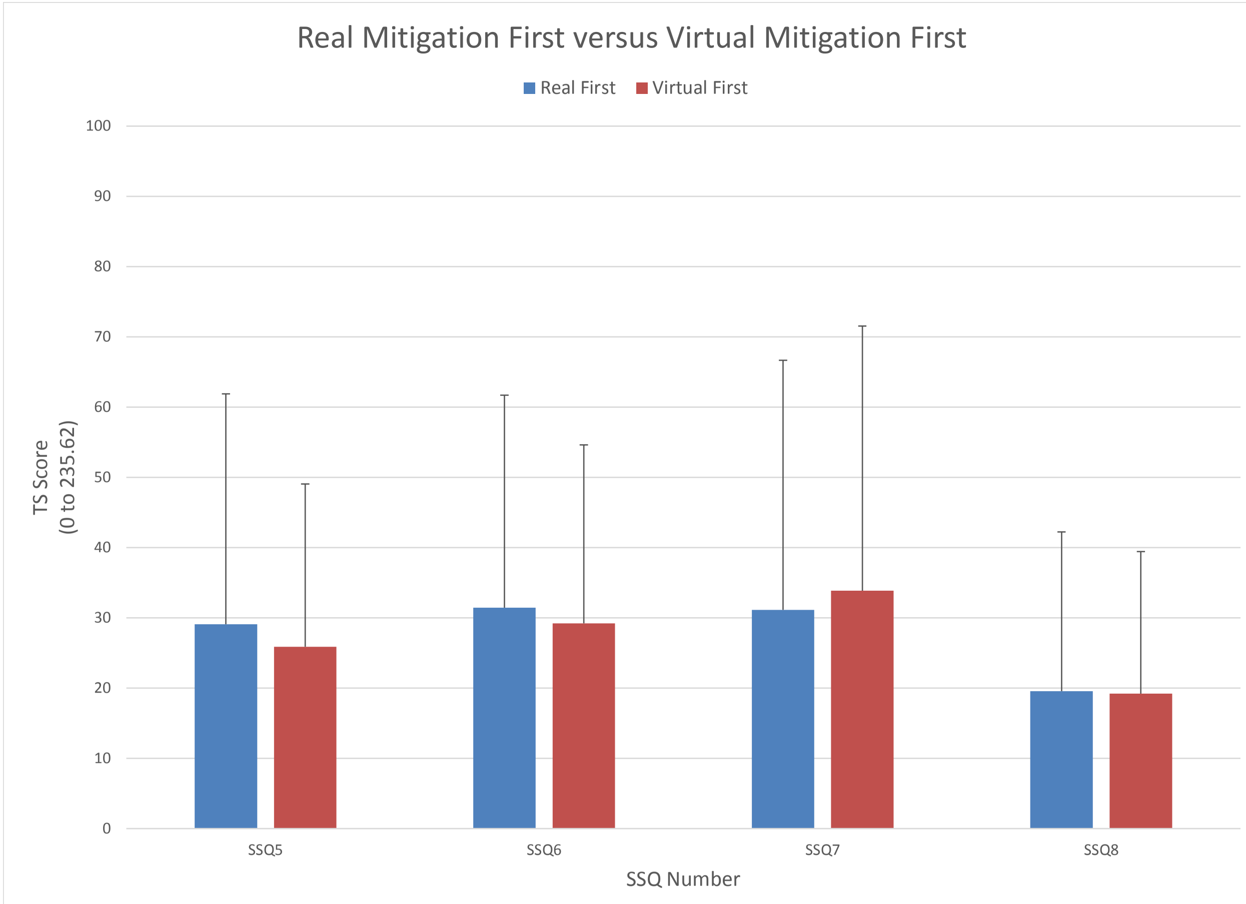

Figure 4.3 Real mitigation first vs. virtual mitigation first with positive standard deviation whiskers.

Table 4.1 SSQ scores between real mitigation first and virtual mitigation first were not significantly different.

SSQ 5 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.927	.493	.459	.959
Real First	23.42 (SD 28.98)	23.26 (SD 25.19)	31.32 (SD 40.40)	29.07 (SD 32.80)
Virtual First	18.02 (SD 18.07)	25.06 (SD 21.43)	23.97 (SD 30.61)	25.87 (SD 23.18)
Difference	5.40	-1.80	7.35	3.20

SSQ 6 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.605	.863	.851	.751
Real First	24.28 (SD 25.82)	28.77 (SD 26.19)	28.79 (SD 34.15)	31.45 (SD 30.23)
Virtual First	17.23 (SD 16.73)	29.90 (SD 23.41)	28.61 (SD 33.93)	29.19 (SD 25.41)
Difference	7.06	-1.13	0.18	2.26

SSQ 7 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.979	.796	.756	.843
Real First	23.63 (SD 29.13)	28.08 (SD 29.59)	29.74 (SD 41.01)	31.11 (SD 35.54)
Virtual First	23.59 (SD 26.15)	31.58 (SD 30.56)	33.64 (SD 52.34)	33.87 (SD 37.67)
Difference	0.05	-3.50	-3.90	-2.76

SSQ 8 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.367	.712	.541	.494
Real First	15.83 (SD 20.88)	17.40 (SD 19.79)	17.72 (SD 25.18)	19.55 (SD 22.68)
Virtual First	12.19 (SD 12.82)	20.42 (SD 20.41)	16.24 (SD 23.17)	19.22 (SD 20.21)
Difference	3.64	-3.02	1.48	0.33

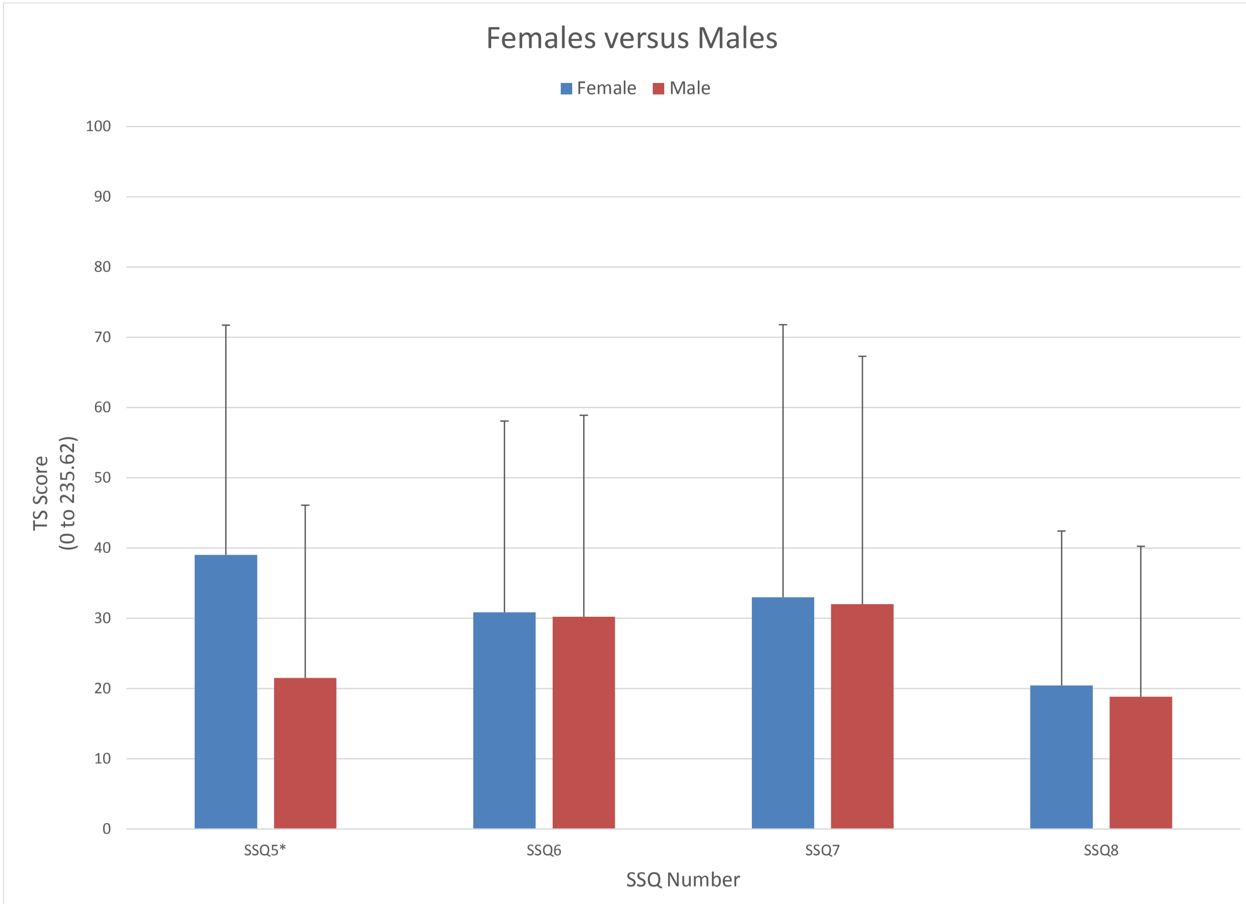

Figure 4.4 Females vs. males with positive standard deviation whiskers.

Table 4.2 Females versus males.

SSQ 5 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.027*	.053	.213	.049*
Female	31.69 (SD 27.24)	32.22 (SD 26.15)	39.77 (SD 44.30)	39.00 (SD 32.71)
Male	15.23 (SD 21.31)	19.68 (SD 20.81)	21.68 (SD 29.74)	21.51 (SD 24.58)
Difference	16.46	12.54	18.09	17.50

SSQ 6 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.399	.258	.469	.323
Female	20.78 (SD 19.44)	28.15 (SD 23.24)	32.81 (SD 38.11)	30.86 (SD 27.23)
Male	21.28 (SD 23.94)	29.88 (SD 25.84)	26.50 (SD 31.46)	30.21 (SD 28.68)
Difference	-0.50	-1.73	6.31	0.65

SSQ 7 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.416	.547	.799	.554
Female	23.17 (SD 26.15)	28.70 (SD 31.04)	36.29 (SD 56.87)	32.99 (SD 38.79)
Male	23.85 (SD 28.68)	30.17 (SD 29.55)	28.91 (SD 39.65)	32.01 (SD 35.28)
Difference	-0.68	-1.48	7.38	0.99

SSQ 8 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.972	.531	.656	.661
Female	12.95 (SD 14.74)	20.03 (SD 21.36)	20.38 (SD 26.65)	20.44 (SD 21.98)
Male	14.86 (SD 19.21)	18.08 (SD 19.41)	15.26 (SD 22.77)	18.84 (SD 21.39)
Difference	-1.91	1.96	5.12	1.59

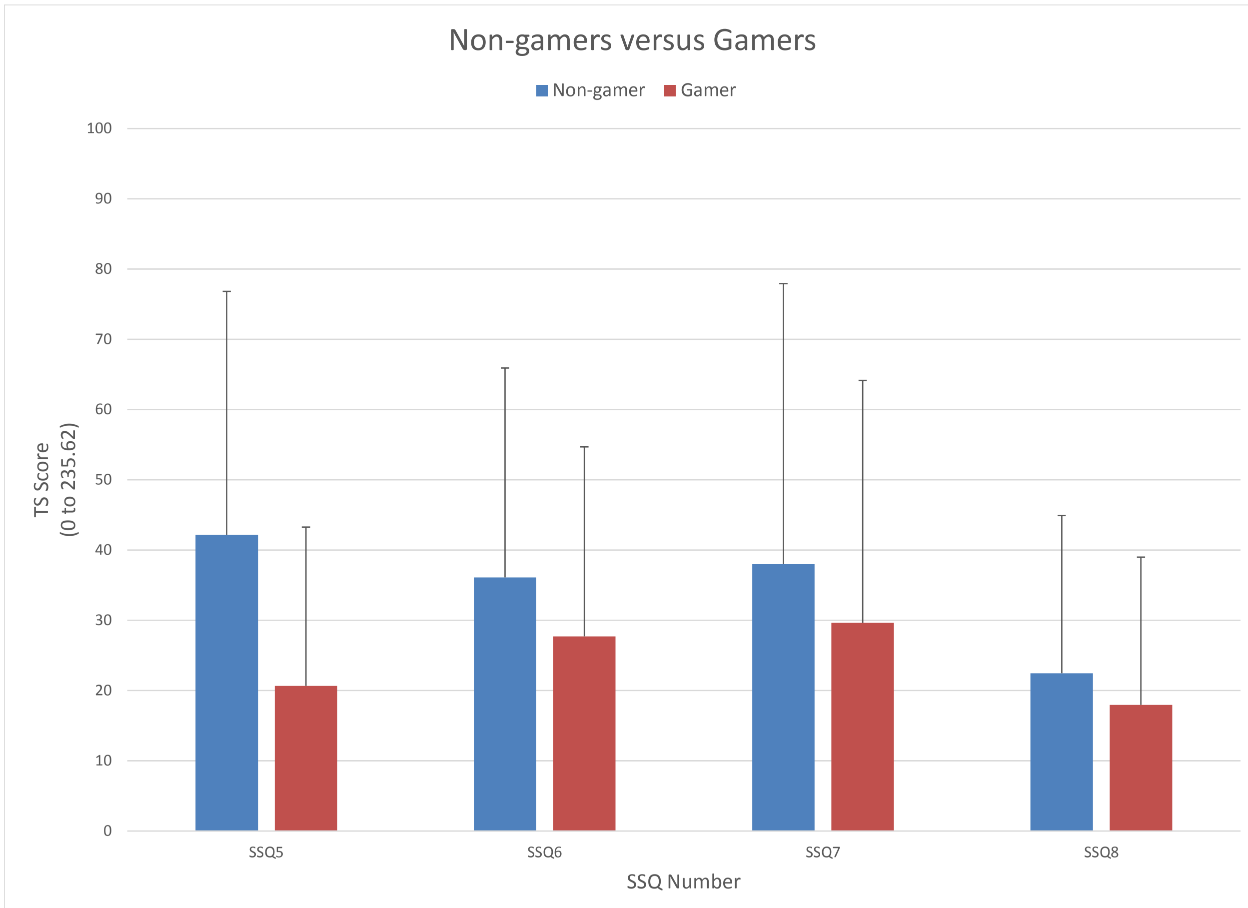

Figure 4.5 Non-gamers vs. gamers with positive standard deviation whiskers.

Table 4.3 Gamers versus non-gamers.

SSQ 5 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.597	.504	.393	.466
Gamer	15.55 (SD 21.23)	19.37 (SD 19.63)	18.56 (SD 24.78)	20.64 (SD 22.61)
Non-gamer	32.29 (SD 27.79)	33.82 (SD 27.81)	47.65 (SD 47.60)	42.15 (SD 34.68)
Difference	-16.74	-14.45	-29.09	-21.51

SSQ 6 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.608	.555	.198	.435
Gamer	19.43 (SD 23.73)	28.21 (SD 23.94)	22.94 (SD 27.06)	27.70 (SD 26.97)
Non-gamer	24.58 (SD 19.11)	31.49 (SD 26.92)	40.69 (SD 42.94)	36.11 (SD 29.79)
Difference	-5.15	-3.27	-17.75	-8.40

SSQ 7 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.900	.875	.782	.848
Gamer	22.44 (SD 28.30)	28.50 (SD 28.59)	25.26 (SD 38.34)	29.64 (SD 34.49)
Non-gamer	26.05 (SD 26.65)	32.07 (SD 32.89)	44.44 (SD 58.00)	37.98 (SD 39.93)
Difference	-3.61	-3.57	-19.17	-8.33

SSQ 8 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.778	.787	.417	.974
Gamer	14.13 (SD 19.06)	17.97 (SD 19.10)	13.15 (SD 21.36)	17.94 (SD 21.04)
Non-gamer	14.31 (SD 14.84)	20.41 (SD 22.05)	25.16 (SD 27.85)	22.44 (SD 22.46)
Difference	-0.18	-2.44	-12.02	-4.50

movement control again, and eight did have movement control. Consequentially, 18 participants experienced Control Change and 22 had no Control Change. For both Movement Control and Control Change, there was no statistically significant between-subjects effect that could be attributed to the participant having a different control condition on a subsequent visit. These results follow the prediction that these tertiary variables would not affect mitigation. The results of the analysis and the mean SSQ scores of each group for movement control are shown in Table 4.4 and the Total Severity scores are shown in Figure 4.6. The results of the analysis for control change are shown in Table 4.5 and the Total Severity scores are shown in Figure 4.7.

Table 4.4 Movement control versus no control.

SSQ 5 Scores				
	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.690	.827	.300	.567
Movement Control	21.57 (SD 23.32)	23.23 (SD 24.04)	30.87 (SD 39.58)	28.21 (SD 29.62)
No Control	20.20 (SD 26.75)	25.19 (SD 22.91)	24.16 (SD 31.47)	26.84 (SD 27.93)
Difference	1.37	-1.96	6.71	1.37
SSQ 6 Scores				
	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.986	.740	.346	.694
Movement Control	20.32 (SD 19.25)	29.33 (SD 23.68)	31.77 (SD 37.54)	30.98 (SD 27.40)
No Control	22.17 (SD 26.23)	29.21 (SD 26.66)	24.56 (SD 28.06)	29.70 (SD 29.22)
Difference	-1.84	0.13	7.21	1.28
SSQ 7 Scores				
	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.835	.938	.562	.935
Movement Control	22.19 (SD 26.23)	28.84 (SD 29.58)	34.19 (SD 50.89)	32.12 (SD 36.70)
No Control	25.53 (SD 29.77)	30.77 (SD 30.72)	27.84 (SD 39.37)	32.67 (SD 36.31)
Difference	-3.34	-1.93	6.35	-0.55
SSQ 8 Scores				
	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.318	.478	.523	.371
Movement Control	11.20 (SD 12.93)	16.31 (SD 18.84)	16.04 (SD 24.90)	16.75 (SD 19.72)
No Control	18.24 (SD 22.20)	22.07 (SD 21.31)	18.42 (SD 23.42)	22.99 (SD 23.46)
Difference	-7.04	-5.76	-2.39	-6.24

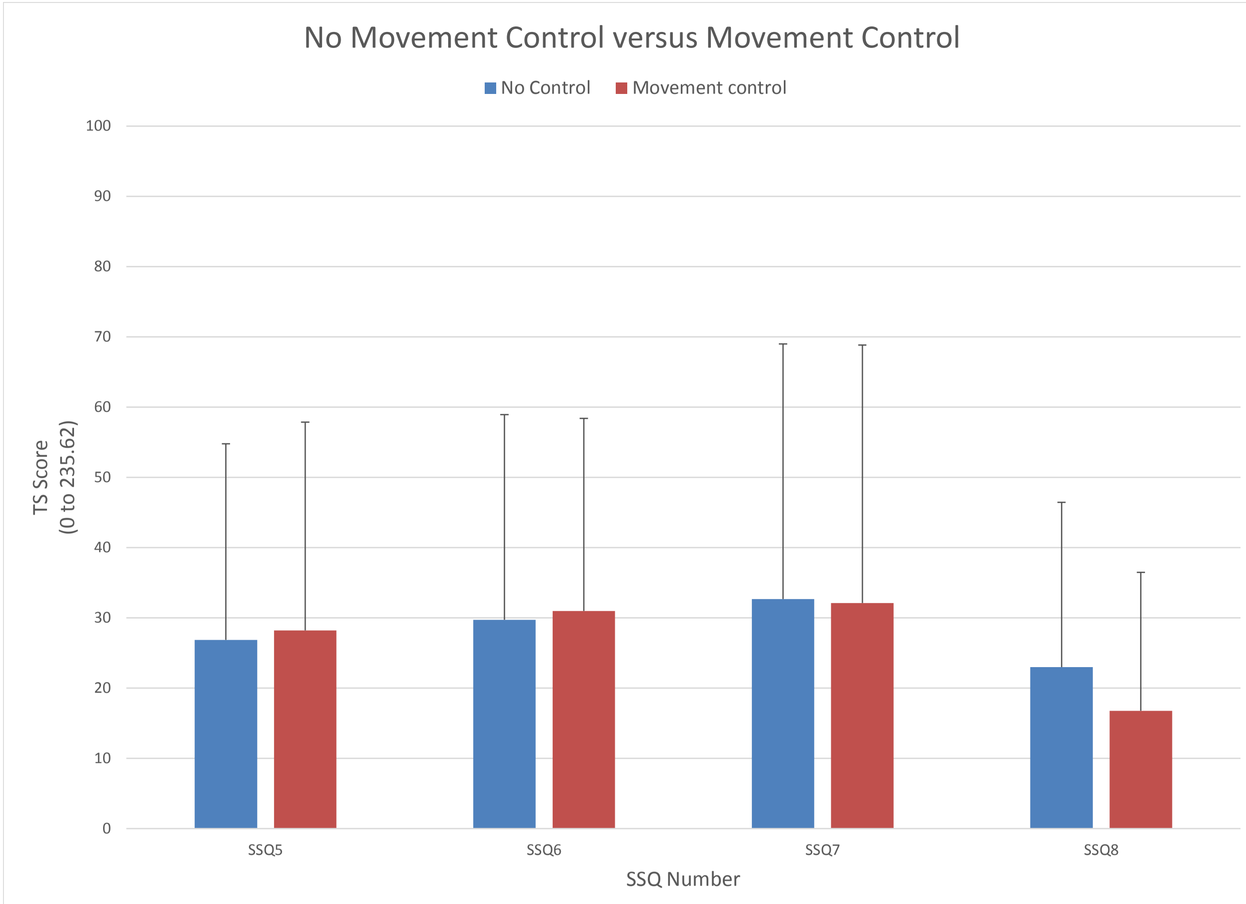

Figure 4.6 No movement control vs. movement control with positive standard deviation whiskers.

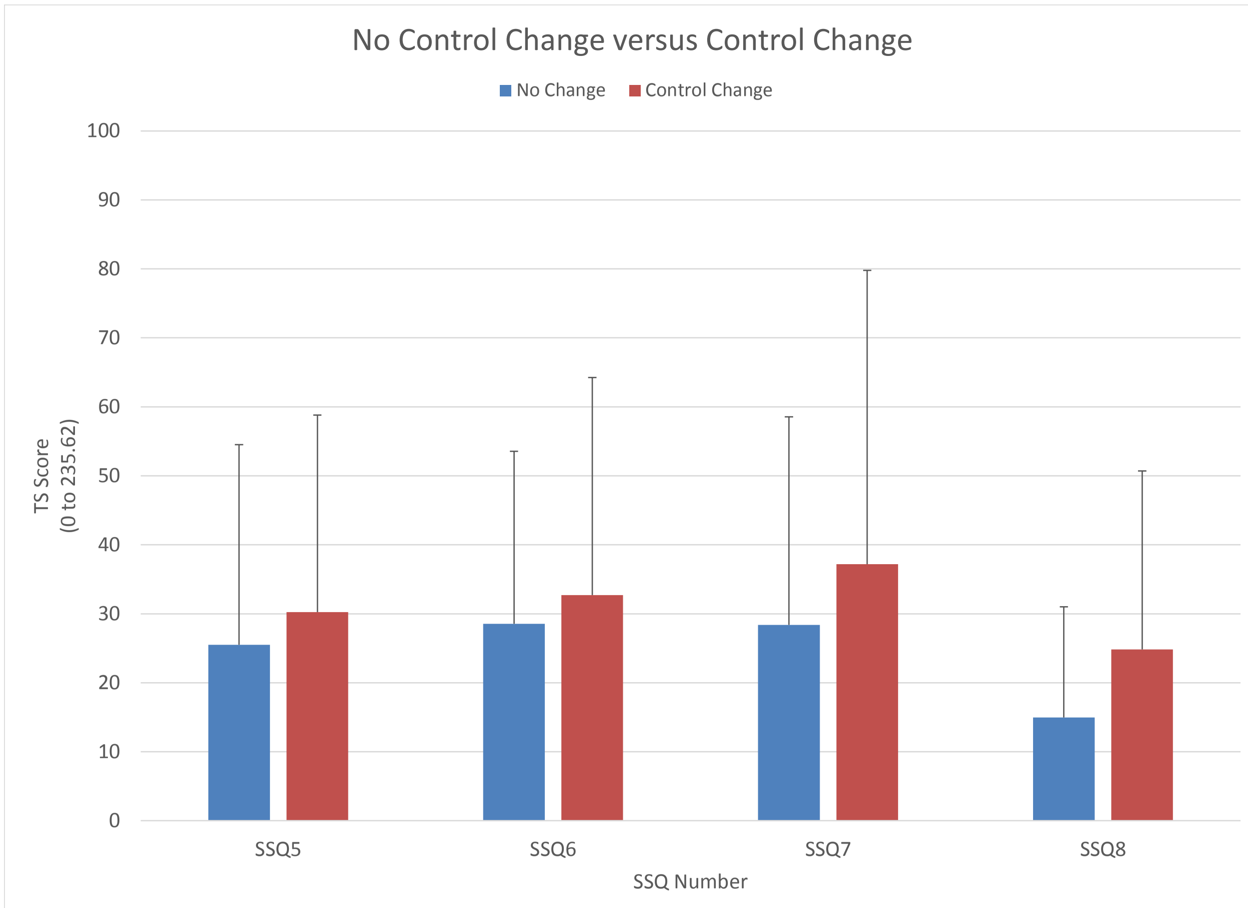

Figure 4.7 No control change vs. control change with positive standard deviation whiskers.

Table 4.5 Control Change versus No Control Change.

SSQ 5 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.615	.824	.557	.935
Control change	23.06 (SD 25.43)	26.53 (SD 23.45)	30.16 (SD 36.68)	30.23 (SD 28.59)
No change	19.30 (SD 24.21)	22.05 (SD 23.51)	26.26 (SD 36.30)	25.50 (SD 29.03)
Difference	3.76	4.48	3.90	4.73

SSQ 6 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.588	.966	.437	.983
Control change	23.06 (SD 25.33)	31.79 (SD 28.41)	29.77 (SD 37.23)	32.73 (SD 31.51)
No change	19.51 (SD 19.73)	27.22 (SD 21.58)	27.84 (SD 31.20)	28.56 (SD 25.01)
Difference	3.55	4.57	1.93	4.17

SSQ 7 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.894	.921	.869	.974
Control change	26.50 (SD 31.61)	33.69 (SD 35.44)	37.89 (SD 53.72)	37.19 (SD 42.60)
No change	21.25 (SD 24.07)	26.36 (SD 24.38)	26.26 (SD 38.82)	28.39 (SD 30.15)
Difference	5.25	7.33	11.63	8.80

SSQ 8 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.612	.212	.395	.303
Control change	17.23 (SD 21.61)	24.64 (SD 24.47)	22.04 (SD 26.49)	24.83 (SD 25.87)
No change	11.71 (SD 13.47)	13.95 (SD 13.96)	12.97 (SD 21.52)	14.96 (SD 16.05)
Difference	5.52	10.69	9.07	9.87

4.3.4 Prediction Testing

4.3.4.1 Visit

Each participant was asked to return for Visit 2 at least 10 days after the Visit 1. However, due to the maze dropouts, $n = 28$ for SSQ4. There were statistically significant within-subject effects found in SSQ scores. The results of the analysis are shown in Tables 4.6 and 4.7 and the Total Severity scores are shown in Figure 4.8 Partial ω^2 is the population effect size of the SSQ subscale.

4.3.4.2 Reality

A mixed ANOVA used Reality as a within-measure independent variable and SSQ scores separated by the setting of the mitigation task were used as dependent variables. Real Mitigation First, Task, Sex, Gamer, Movement Control, and Control Change were used as between-measure independent variables. Each of the 40 participants completed a physical mitigation task as well as a virtual mitigation task.

The mixed ANOVA found statistically significant within-subjects effects in many of the SSQ subscales. The results of the analysis are shown in Table 4.8. Partial ω^2 is the population effect size of the SSQ subscale. The Total Severity scores are shown in Figure 4.9.

4.4 Differences between Mitigation Tasks

Two one-way repeated measures ANOVAs were completed to investigate the differences in SSQ scores between participants when split by mitigation tasks. For each individual analysis, $n = 20$ as half of the participants performed the hand-eye mitigation task and the other half performed the natural decay mitigation task. Graphs of the data are shown in Figures 4.10, 4.11, 4.12, and 4.13.

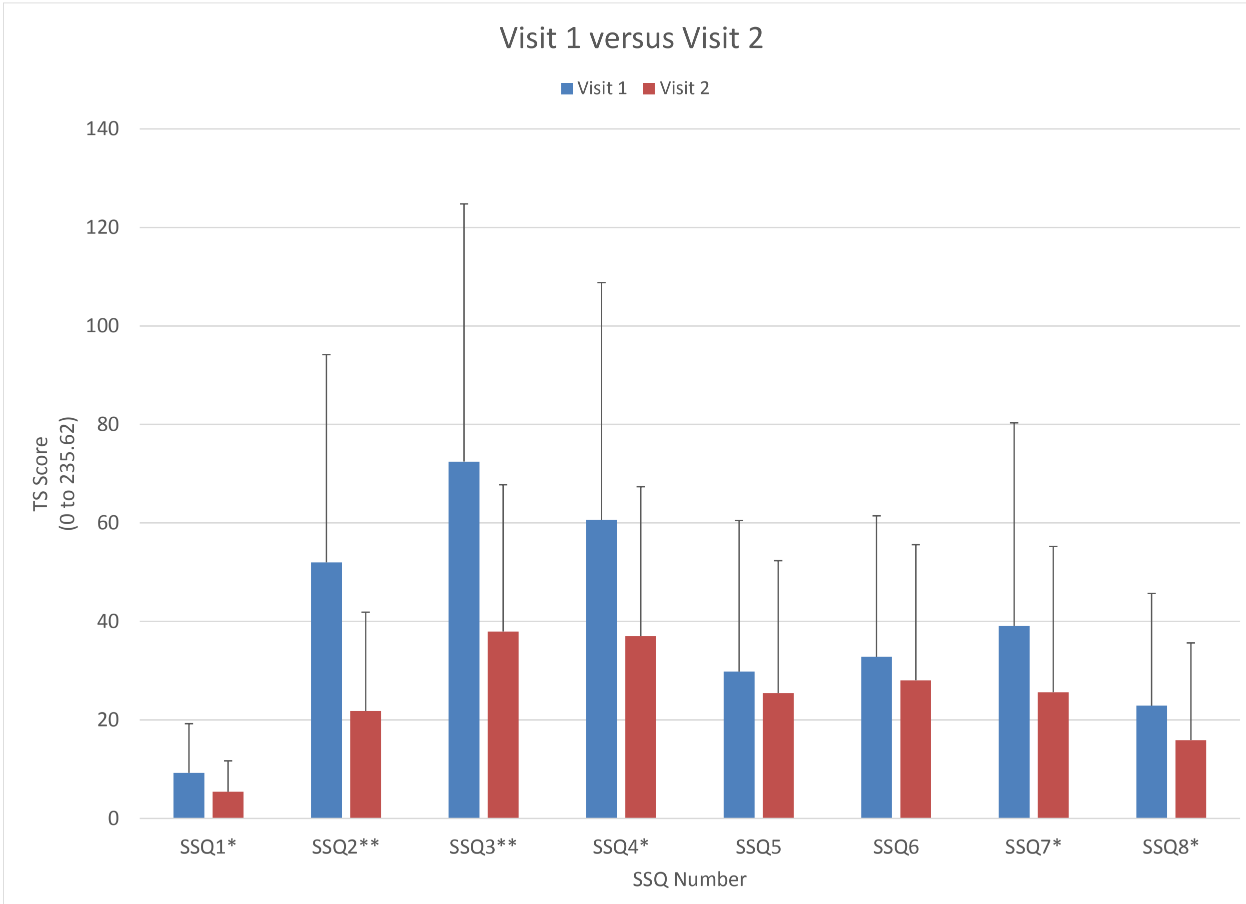

Figure 4.8 Visit 1 vs. Visit 2 with positive standard deviation whiskers.

Table 4.6 Maze SSQs, Visit 1 vs. Visit 2.

SSQ 1 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	0.036*	0.044*	0.058*	0.018*
Partial ω^2	0.045	0.040	0.034	0.060
Visit 1	7.39 (SD 9.78)	10.04 (SD 11.04)	5.22 (SD 8.15)	9.26 (SD 9.98)
Visit 2	4.29 (SD 6.46)	6.25 (SD 7.85)	2.44 (SD 5.36)	5.42 (SD 6.28)
Difference	3.10	3.79	2.78	3.83

SSQ 2 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	$< .001$**	$< .001$**	$< .001$**	$< .001$**
Partial ω^2	0.250	0.305	0.195	0.293
Visit 1	36.25 (SD 31.32)	40.74 (SD 30.16)	65.77 (SD 67.46)	51.99 (SD 42.18)
Visit 2	13.83 (SD 17.54)	18.95 (SD 17.42)	26.10 (SD 28.40)	21.79 (SD 20.09)
Difference	22.42	21.79	39.67	30.20

SSQ 3 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	$< .001$**	$< .001$**	$< .001$**	$< .001$**
Partial ω^2	0.221	0.247	0.199	0.256
Visit 1	58.67 (SD 44.20)	54.58 (SD 36.54)	83.87 (SD 74.63)	72.46 (SD 52.31)
Visit 2	31.01 (SD 28.72)	28.99 (SD 21.64)	42.80 (SD 40.05)	37.96 (SD 29.79)
Difference	27.67	25.58	41.06	34.50

SSQ 4 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	0.004*	0.001*	0.010*	0.001*
Partial ω^2	0.140	0.204	0.108	0.183
Visit 1	49.74 (SD 41.73)	47.65 (SD 35.84)	65.62 (SD 62.24)	60.64 (SD 48.16)
Visit 2	28.28 (SD 28.97)	28.70 (SD 23.73)	43.75 (SD 38.77)	37.00 (SD 30.36)
Difference	21.47	18.95	21.87	23.64

Table 4.7 Mitigation SSQs, Visit 1 vs. Visit 2. Significant differences found during SSQ5, SSQ7 and SSQ8.

SSQ 5 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.632	.688	.042*	.370
Visit 1	21.70 (SD 23.86)	25.39 (SD 25.95)	32.71 (SD 40.31)	29.83 (SD 30.66)
Visit 2	20.27 (SD 25.76)	22.74 (SD 20.88)	23.32 (SD 31.58)	25.43 (SD 26.91)
Difference	1.43	2.65	9.39	4.40

SSQ 6 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.195	.372	.099	.156
Visit 1	22.90 (SD 21.58)	30.32 (SD 25.40)	33.06 (SD 37.12)	32.82 (SD 28.63)
Visit 2	19.32 (SD 23.22)	28.24 (SD 24.52)	24.36 (SD 30.03)	28.05 (SD 27.54)
Difference	3.58	2.08	8.70	4.77

SSQ 7 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.011*	.040*	.022*	.015*
Visit 1	28.38 (SD 29.66)	34.49 (SD 34.03)	40.72 (SD 55.27)	39.08 (SD 41.24)
Visit 2	18.84 (SD 24.96)	24.82 (SD 24.58)	22.27 (SD 33.03)	25.62 (SD 29.60)
Difference	9.54	9.67	18.45	13.46

SSQ 8 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.103	.051	.074	.048*
Visit 1	15.74 (SD 16.39)	22.17 (SD 21.94)	21.58 (SD 25.98)	22.91 (SD 22.78)
Visit 2	12.64 (SD 19.00)	15.35 (SD 17.46)	12.53 (SD 21.56)	15.90 (SD 19.75)
Difference	3.10	6.82	9.05	7.01

Table 4.8 Real mitigation versus virtual mitigation.

SSQ 5 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	0.276	.033*	.019*	.016*
Partial ω^2	0.004	0.055	0.071	0.075
Real mitigation	19.80 (SD 23.51)	19.90 (SD 21.56)	22.27 (SD 33.18)	23.56 (SD 26.22)
Virtual mitigation	22.18 (SD 26.05)	28.24 (SD 24.76)	33.76 (SD 38.72)	31.70 (SD 30.86)
Difference	-2.38	-8.34	-11.49	-8.14

SSQ 6 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.027*	.002*	.005*	.002*
Partial ω^2	0.060	0.147	0.115	0.141
Real mitigation	15.98 (SD 19.61)	20.85 (SD 19.02)	17.75 (SD 26.75)	21.32 (SD 22.55)
Virtual mitigation	26.24 (SD 23.94)	37.71 (SD 27.22)	39.67 (SD 36.84)	39.55 (SD 30.17)
Difference	-10.26	-16.86	-21.92	-18.23

SSQ 7 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.049*	.017*	.002*	.007*
Partial ω^2	0.043	0.073	0.148	0.100
Real mitigation	16.22 (SD 21.95)	20.47 (SD 23.17)	16.01 (SD 32.99)	20.76 (SD 27.40)
Virtual mitigation	31.01 (SD 30.91)	38.85 (SD 33.16)	46.98 (SD 52.34)	43.95 (SD 40.54)
Difference	-14.79	-18.38	-30.97	-23.19

SSQ 8 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	0.084	0.102	0.084	0.067
Partial ω^2	0.030	0.025	0.030	0.036
Real mitigation	10.02 (SD 14.32)	14.40 (SD 15.24)	11.14 (SD 18.97)	14.03 (SD 16.66)
Virtual mitigation	18.36 (SD 19.85)	23.12 (SD 23.22)	22.97 (SD 27.40)	24.78 (SD 24.44)
Difference	-8.34	-8.72	-11.83	-10.75

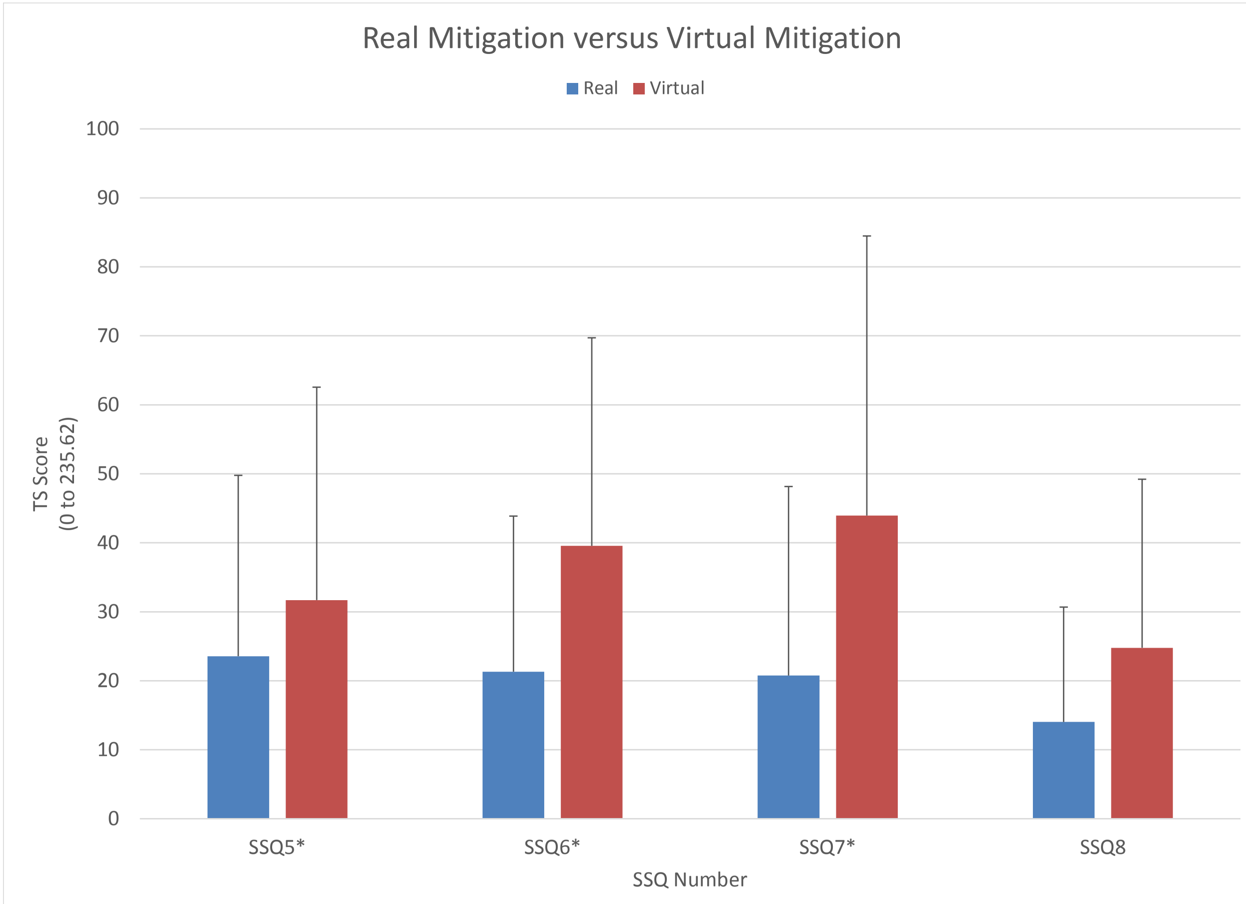

Figure 4.9 Real mitigation vs. Virtual mitigation with positive standard deviation whiskers.

4.4.1 Natural Decay

The one-way repeated measures ANOVA revealed no significant differences in any of the SSQ subscales during the mitigation phase for participants who completed a natural decay task. The results of the analysis are shown in Table 4.9.

Table 4.9 Real natural decay versus virtual natural decay.

SSQ 5 Scores	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.132	.289	.336	.187
Partial ω^2	0.036	0.005	-0.001	0.021
Real Natural Decay	24.33 (SD 26.53)	23.50 (SD 24.21)	26.45 (SD 37.76)	28.24 (SD 30.15)
Virtual Natural Decay	16.22 (SD 18.85)	17.81 (SD 13.97)	20.18 (SD 21.41)	20.57 (SD 18.7)
Difference	8.11	5.69	6.26	7.67
SSQ 6 Scores	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.433	.273	.285	.285
Partial ω^2	-0.009	0.007	0.005	0.005
Real Natural Decay	14.79 (SD 18.95)	19.33 (SD 19.12)	20.88 (SD 29.79)	20.94 (SD 23.45)
Virtual Natural Decay	18.13 (SD 17.21)	24.64 (SD 20.11)	29.23 (SD 24.28)	27.12 (SD 21.77)
Difference	-3.34	-5.31	-8.35	-6.17
SSQ 7 Scores	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.228	.147	.147	.152
Partial ω^2	0.014	0.031	0.031	0.030
Real Natural Decay	12.40 (SD 20.08)	15.54 (SD 21.79)	17.40 (SD 39.08)	17.20 (SD 27.92)
Virtual Natural Decay	19.56 (SD 23.05)	25.01 (SD 24.61)	34.10 (SD 40.51)	29.17 (SD 30.57)
Difference	-7.16	-9.48	-16.70	-11.97
SSQ 8 Scores	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.274	.452	.442	.374
Partial ω^2	0.007	-0.010	-0.010	-0.004
Real Natural Decay	9.06 (SD 14.01)	13.64 (SD 17.32)	12.53 (SD 25.51)	13.65 (SD 20.1)
Virtual Natural Decay	13.83 (SD 14.01)	17.81 (SD 17.78)	18.10 (SD 22.63)	19.07 (SD 18.83)
Difference	-4.77	-4.17	-5.57	-5.42

4.4.2 Hand-Eye

The one-way repeated measures ANOVA revealed significant differences in all of the SSQ subscales during the mitigation phase for participants who completed a hand-eye task. The results of the analysis are shown in Table 4.10.

Table 4.10 Real hand-eye versus virtual hand-eye.

SSQ 5 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.024*	< .001**	.002*	.001*
Partial ω^2	0.112	0.331	0.229	0.289
Real Hand-Eye	15.26 (SD 19.67)	16.30 (SD 18.45)	18.10 (SD 28.24)	18.89 (SD 21.35)
Virtual Hand-Eye	28.14 (SD 31.03)	38.66 (SD 28.88)	47.33 (SD 47.24)	42.82 (SD 36.67)
Difference	-12.88	-22.36	-29.23	-23.94

SSQ 6 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.001*	< .001**	.001*	< .001**
Partial ω^2	0.272	0.418	0.280	0.393
Real Hand-Eye	17.17 (SD 20.67)	22.36 (SD 19.28)	14.62 (SD 23.67)	21.70 (SD 22.23)
Virtual Hand-Eye	34.34 (SD 27.23)	50.79 (SD 27.51)	50.11 (SD 44.34)	51.99 (SD 32.69)
Difference	-17.17	-28.43	-35.50	-30.29

SSQ 7 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.005*	.002*	.002*	.001*
Partial ω^2	0.183	0.233	0.238	0.244
Real Hand-Eye	20.03 (SD 23.55)	25.39 (SD 24.00)	14.62 (SD 26.52)	24.31 (SD 27.12)
Virtual Hand-Eye	42.45 (SD 33.97)	52.68 (SD 35.34)	59.86 (SD 60.27)	58.72 (SD 44.49)
Difference	-22.42	-27.29	-45.24	-34.41

SSQ 8 Scores

	Nausea	Oculomotor	Disorientation	Total Severity
Significance (p)	.006*	.036*	.012*	.011*
Partial ω^2	0.177	0.092	0.146	0.147
Real Hand-Eye	10.97 (SD 14.93)	15.16 (SD 13.24)	9.74 (SD 9.14)	14.40 (SD 12.86)
Virtual Hand-Eye	22.90 (SD 23.86)	28.43 (SD 27.04)	27.84 (SD 31.29)	30.48 (SD 28.33)
Difference	-11.93	-13.27	-18.10	-16.08

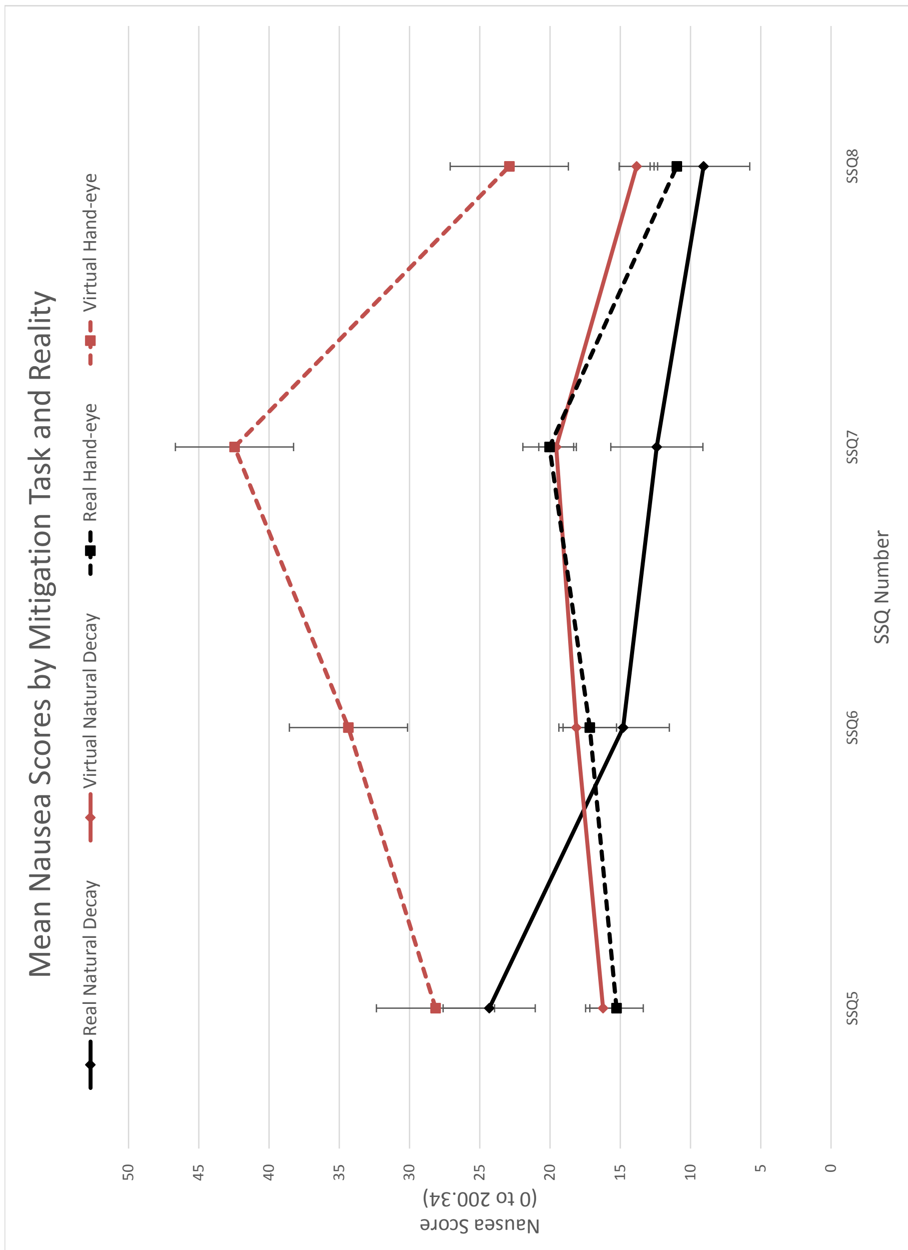

Figure 4.10 Mitigation Nausea scores.

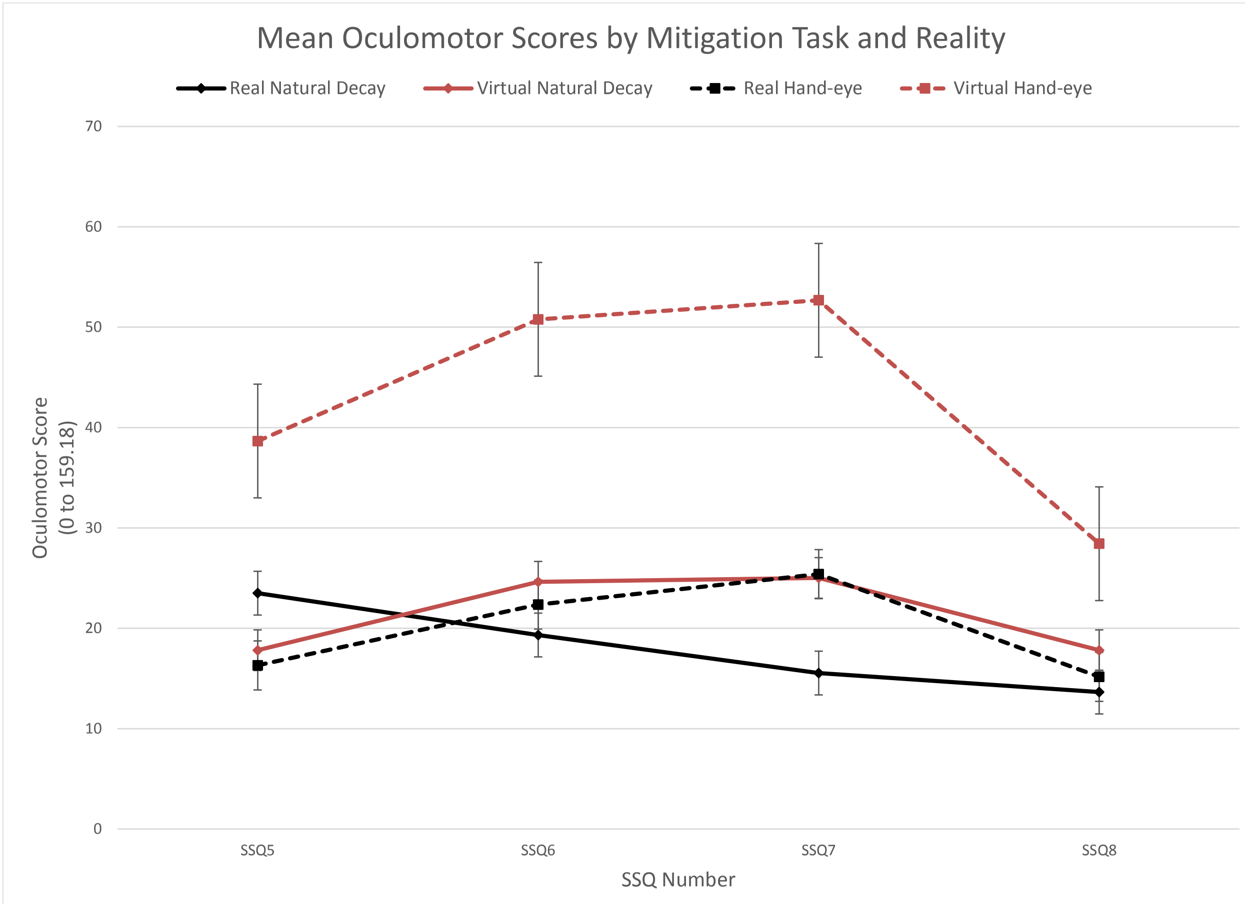

Figure 4.11 Mitigation Oculomotor scores.

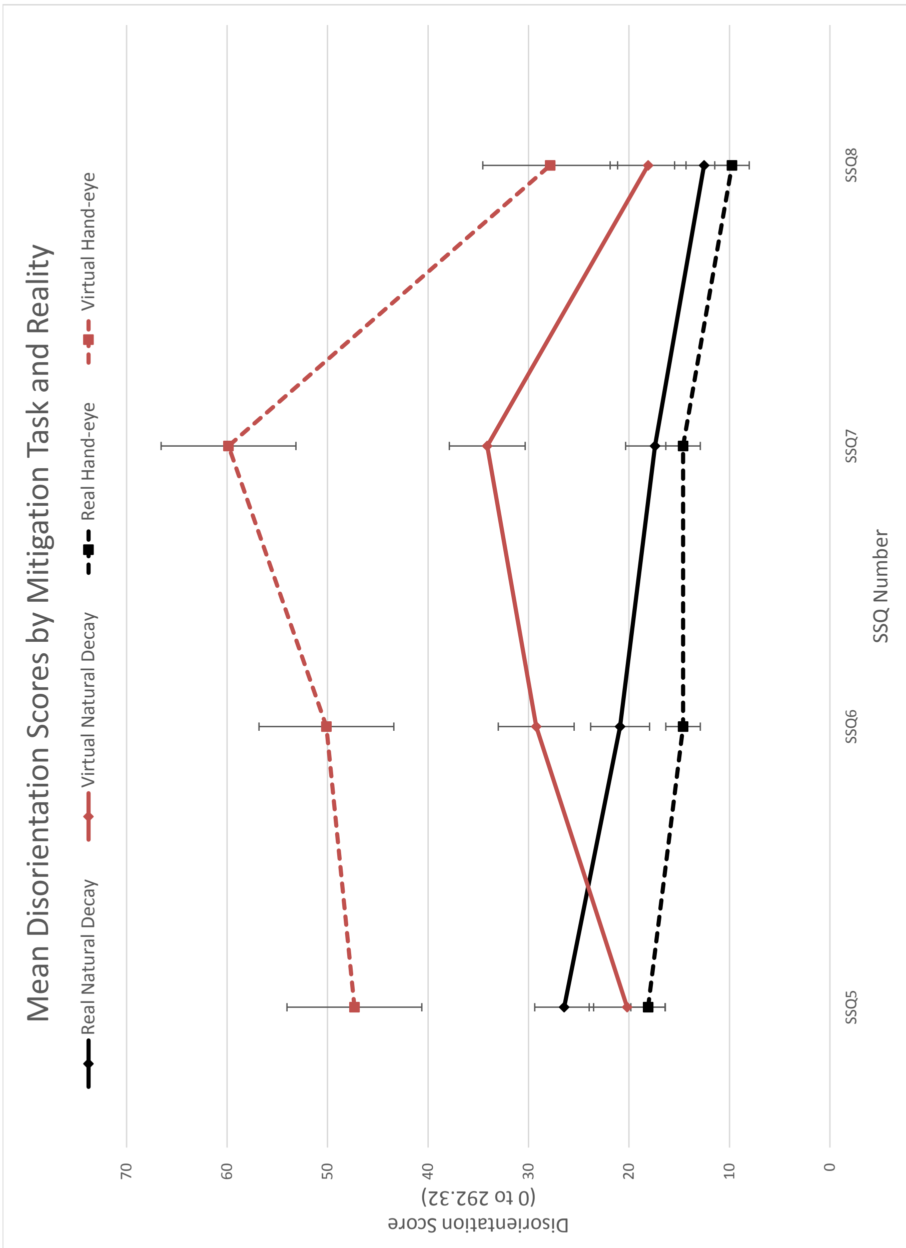

Figure 4.12 Mitigation Disorientation scores.

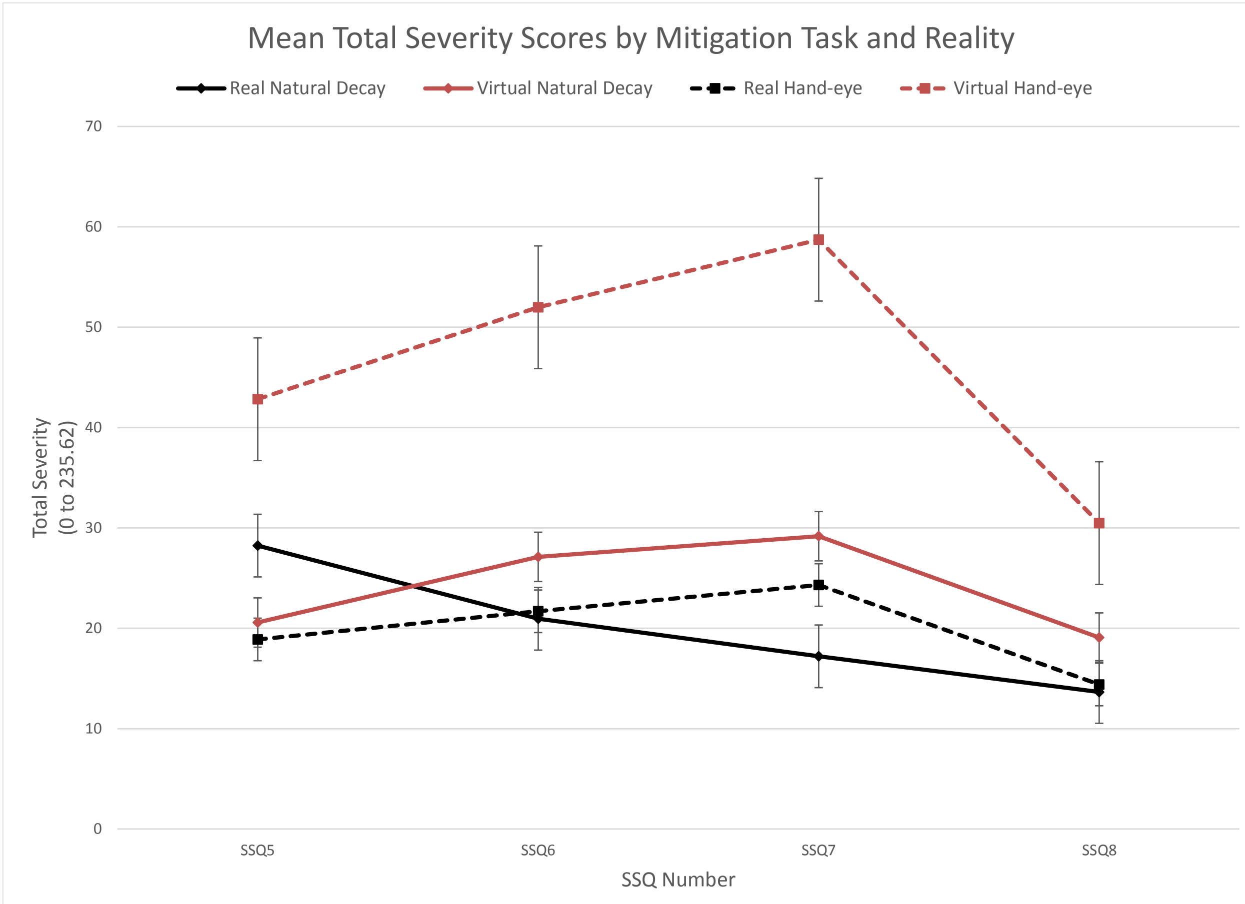

Figure 4.13 Mitigation Total Severity scores.

CHAPTER 5. CONCLUSION

5.1 Overview

This section will offer interpretations of the data presented in Chapter Four, a revisit of the hypothesis from Chapter One, limitations of the study, and future work that still needs investigation.

5.2 Assumptions

5.2.1 Assumption One: Order of Mitigation Tasks

No effect was found between participants who performed a real mitigation task on their first visit and then a virtual task on the second visit or vice versa. This result could be interpreted as the tasks were not similar enough to have a learning or accommodation effect or it is actually insignificant which mitigation technique is used first.

5.2.2 Assumption Two: Sex of Participant

The significant differences confirm results that past researchers have found. As a result, female and male participants were analyzed together during the mitigation SSQs. Because the assumption was tested as a null hypothesis, it is too early to conclude that the sex of a participant definitely does not hinder recovery. However, the results indicate that a participant's sex does not affect recovery from VIMS, which allows for generalized mitigation tasks between the sexes.

5.2.3 Assumption Three: Gaming Experience

Significant differences between gamers and non-gamers were only found in SSQ5 scores. Because these scores are taken before the mitigation task begins, it can be assumed that differences in SSQ5 scores can be attributed to the first phase of the study, in which participants became motion sick. Therefore, it is safe to assume that gaming experience is negligible for VIMS recovery.

5.2.4 Assumption Four: Movement Control

The present study's design assumed that participants who had motion control during the first phase of the experiment would be able to recover in the same manner as participants who did not have motion control. In other words, the conditions that cause motion sickness do not matter and the symptoms in both cases can be mitigated by the same task. As shown in the previous chapter, there is no significant difference in mitigation SSQ scores among participants who had movement control for both visits, for participants who had movement control for only one visit, and for participants who never had movement control during the first phase. For the scope of this experiment, it is safe to assume that motion sickness symptoms can be mitigated in the same manner, even if different stimuli led to the symptoms.

5.3 Visits

Significant difference were discovered between reported SSQ scores for SSQ7 and SSQ8. The experiment was designed to counteract any benefits from repeated exposure by requiring 10 days between Visit 1 and Visit 2. While repeated exposure may have led to lower scores, an interesting pattern arose for Visit 2 — participants began the study session in significantly better health. As reported in Chapter Four, participants had much lower mean SSQ scores in all subscales during Visit 2. Consequentially, either more time is necessary between virtual exposure, or two different IVEs should be used and counterbalanced to reduce accommodation effects.

5.4 Hypothesis

The hypothesis for this experiment was that a virtual mitigation task can be as effective as a physical mitigation task, characterized by SSQ scores. Based on the results of the previous chapter, the hypothesis is supported for participants who performed the natural decay mitigation task, but not for participants who completed the peg-in-hole mitigation task.

5.4.1 Natural Decay

There were no significant differences in SSQ scores reported between participants who completed the physical natural decay task and the virtual natural decay task. In this experiment, this reveals that any differences between recovery could not be attributed to the task setting. A conclusion from this analysis is that removing a participant from virtual reality is no better than allowing him or her to remain in the virtual world, but without sickness causing stimuli. An implication of this conclusion is that virtual scenes that feature and independent visual backgrounds can serve to mitigate motion sickness as well as removing a participant from the virtual environment. This is a design consideration for future virtual environments in which long exposure times are desired.

5.4.2 Hand-Eye

There were significant differences in SSQ scores reported between participants who completed the physical hand-eye task and the virtual hand-eye task. This result does not support the hypothesis that a virtual mitigation task can be as effective at reducing SSQ scores and a physical mitigation task. This could be attributed to the senses constantly adapting to a virtual environment and a real environment, despite the fact that the virtual environment is a replica of the physical environment. Furthermore, the virtual task lacked the affordances found in the physical task, namely force feedback from peg/straw collision and making contact with the pegboard inside the straw. Many participants commented on the difficulty of determining whether or not the virtual peg was inside the peg hole. Due to the nature of the controllers used, it was impossible to recreate the feeling of a near miss, which can easily be detected by a bent drinking straw in the physical task. A future direction for research in hand-eye tasks performed in virtual reality could use controllers that feature force feedback, such as the Geomagic Touch. This would add another affordance to placing pegs in holes.

Although the virtual hand-eye task was modeled after the physical hand-eye task, certain elements of the virtual task were inherently different. Due to the weight of the Razer Hydra controller, the pinch grip was modified to use the index and middle fingers in conjunction with the thumb. Adding an extra finger involved more muscles for the virtual task, changing the nature of the fine motor control to manipulate the virtual peg. Additionally, in order to make aligning pegs and straws in the virtual environment easier, rotation about the horizontal and depth axes was disabled for the virtual pegs. As a result, visual feedback about the orientation of the Hydra and virtual peg were further disconnected.

The results seem to indicate that the simple existence of fine motor control, which these hand-eye tasks were meant to rely on to mitigate motion sickness, is not as important in countering sensory conflict. Rather, reducing the conflict in expectations is likely more important. The virtual task, by design, violated expectations and past experiences a participant would have had about manipulating an object in six degrees of freedom. The broken visual feedback cycle, lack of tactile feedback, and differences in grip, originally thought to be inconsequential, may be responsible for greater sensory conflict. Although the virtual task was designed to realign the sensory conflict between the nonvestibular proprioceptors and eyes, it may have induced sensory conflict between current sensory input, past sensory experiences, and expectations built upon those past experiences. This could indicate that one type of conflict is more influential than another.

5.5 Mitigation Techniques

With the exception of the physical natural decay task, each task followed the same trend of increasing participant-reported sickness for the first five minutes of mitigation, followed by a decrease in scores after 10 minutes and at the end of the study. Currently, it is unknown if this trend is common in VIMS recovery, but there are some possible reasons for this pattern. The physical peg-in-hole task and the virtual tasks required the participant to be active and take in extra stimuli, which may induce VIMS. For example, the SSQ uses "general discomfort" and "fatigue" as measures of sickness, and the peg-in-hole tasks can become irritating after 10 minutes and feel uncomfortable or tired, due to the repetitive motion of placing pegs with an outstretched arm. Thus, participants could have reported the discomfort caused by mitigation, and the SSQ does not consider the source of the discomfort, only that it exists. Another reason for this trend could be that the effects of mitigation do not immediately appear. Until more research investigates the recovery process of motion sickness via tasks, it cannot be said when recovery begins and to what degree it is expected to help.

An unexpected outcome of this research is that physical natural decay was the best recovery method. In past experiments, engaging participants in a more active task was more effective than allowing them to rest (Champney et al., 2007). However, this could be explained by the differences in tasks. In the present study, the hand-eye task required the use of the whole arm over a wide area of motion. Champney et al. (2007) used a peg board that was considerably smaller, requiring finer motor control and possibly adding effectiveness. They also employed a shorter amount of time for the participants to perform the mitigation task; five minutes instead of the present study's 15 minutes. Another possibility is that the duration of virtual reality exposure affects the recovery time of the natural decay task. The current research required only 15 minutes of exposure, and not every participant reported significant increases in sickness by the end of that time.

5.6 Limitations

A limitation for all visually-induced motion sickness studies, the current research included, is relying on SSQ scores as a reliable measure of motion sickness. While it is the best tool for determining sickness, self-reported measures are vulnerable to irregular rating between and within raters, regardless of the rigorous research conducted to counter this irregularity. More objective measures such as stereo acuity tests for oculomotor symptoms or electrodermal activity sensors could provide a better insight to a participant's sickness, as well as aiding in standardizing sickness levels. However, SSQ scores still provide a valuable metric of sickness and any future methods of motion sickness reporting should benefit from the years of research that has used SSQ scores as a main indicator of sickness.

Another limitation of this study is the design and use of the virtual environment. The first phase of the study was designed specifically to induce VIMS in a small amount of time. Consequently, the virtual world used is not representative of the type of virtual environments that would be seen for everyday use. Other studies have included more typical designs, but require longer exposure times to reach a noticeable level of sickness. However, it is unknown whether it is the exposure time or the nature of the stimuli presented that is more influential in producing VIMS symptoms. Other researchers have attempted to predict the amount of motion sickness one should expect from a virtual scene, but even the best models cannot account for excessive motion, different navigation velocities, or a range of depth (Jennifer et al., 2004).

5.7 Future Work

Visually induced motion sickness poses a significant threat to the widespread use of virtual environments, because almost every person who immerses himself in a virtual environment will experience some form of motion sickness (Lampton et al., 1994). Yet, not everyone experiences the same severity of VIMS symptoms and the effects of individual differences and lifestyle choices need to be investigated further. Research in individual differences could also inform future models for expected motion sickness.

Future studies are also necessary to identify the cause and resolution of motion sickness. Even today the two main theories of sensory conflict and postural instability have support, yet involve different biological systems. For the time being, mitigation tasks are developed that account for both theories. Champney et al. (2007) employed rail-walking as a mitigation task, and measured effects that would be indicative of sensory conflict (3-D pointing) and postural instability (roll and x-axis sway). Future research into virtual mitigation tasks should also include metrics that are associated with postural instability.

As with many other virtual reality studies, time considerations played a major role in this research. While participants were excused only after feeling well, many participants did not return to their baseline sickness levels. A study that investigates motion sickness symptoms from the time the participant comes until he or she feels just as well would be instrumental in learning any recovery patterns that exist for all mitigation tasks, and any differences in recovery between mitigation tasks.

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