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# Adaptation to Base Latency in a Head-Mounted Display Using a Performance Task to Facilitate Adaptation

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# ADAPTATION TO BASE LATENCY IN A HEAD-MOUNTED DISPLAY USING A PERFORMANCE TASK TO FACILITATE ADAPTATION

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# ABSTRACT

Head-tracked head-mounted displays (HMDs) have innate base latency, which has been associated with simulator sickness in users. The purpose of this study was to investigate whether users could adapt to base latency in HMDs shown by a reduction in simulator sickness symptoms. Additionally, this study aimed to investigate whether performing a point and shoot task while wearing an HMD with base latency would facilitate faster and more complete adaptation compared to performing a passive object location task. Forty participants were recruited for a 2 (condition) x 3 (experimental session) mixed ANOVA experiment. Participants completed three experimental sessions separated by 48 hours while wearing an HMD with base latency. All participants completed the same passive object location task during their first and third experimental sessions. During the second experimental session, participants completed either the passive object location task or an active point and shoot performance task. Subjective sickness and postural sway data were collected to assess whether participants adapted to base latency over time. A main effect of experimental session was observed such that participants experienced less sickness and less sway after the third experimental session compared to the first. A main effect of condition was expected such that participants in the performance task group would experience less sickness and less sway in the third experimental session than participants in the object location task group, but this was not observed. Additionally, an unanticipated interaction between experimental session and condition was observed such that participants in the control condition experienced less sickness and less sway sooner than participants in the performance condition. These

results indicate that adaptation to simulator sickness imposed by an HMD is possible, but a performance task does not appear to facilitate adaptation, but rather may serves as a distraction for participants that reduced symptoms when present.

# DEDICATION

I would like to dedicate this manuscript to my family, who were relentlessly supportive throughout this entire process.

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I would like to acknowledge Dr. Eric Muth—without his guidance and mentorship this document would not exist. Additionally, I would like to acknowledge and thank the rest of my committee, Dr. Jay Smart, Dr. Chris Pagano, and Dr. Adam Hoover. I would also like to acknowledge Ryan Mattfeld, who provided immense help in setting up the HMD, the camera capture system, the code to run the experiment, and the code to run the outside observer method. Without Ryan's help, none of this would have been possible, and I am very appreciative and grateful for his time. Finally, I would like to acknowledge my lab mate Sarah Beadle who supported me throughout this entire process. Sarah helped me troubleshoot any problem I ran into and was always there to lend a helping hand.

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# CHAPTER ONE

# INTRODUCTION

## Purpose

The purposes of this experiment were: 1) to examine whether humans could adapt to base latency in a head-mounted display (HMD); and 2) whether an active point and shoot performance task would facilitate greater adaptation than a passive object location task. Recently there has been an increase in use of virtual environments and HMDs for both professional and recreational uses (Lewis, 2015). It has been shown that just wearing an HMD can cause symptoms of sickness and reduce task performance. (Moss & Muth, 2011; Moss, Scisco, & Muth, 2008, Kinsella, et al., in press). There is evidence that the innate latency in HMD's may vary over time (Wu, Dong, & Hoover, 2013). This is cause for concern because variable latency has been linked to simulator sickness in users (St. Pierre et al., 2015; Kinsella et al., 2016). It is important for both scientists and developers of these technologies to evaluate and understand users' experience, before and after use, to understand side effects caused by these systems. This need, in part, is brought on by liability concerns, as use of these systems may cause negative aftereffects that have been observed to last for up to two hours after exposure (Kennedy & Stanney, 1996; Muth, 2010). Facilitating adaptation to these latency conditions may alleviate some of these concerns.

## Motion Sickness and Simulator Sickness

Motion and simulator sickness symptoms have been shown to result from HMD use (Moss, Scisco, & Muth, 2008). When investigating whether humans can adapt to

varying latency in HMDs, measuring self-reported sickness symptoms can be a way to test whether adaptation has occurred. Therefore, it is important to understand motion and simulator sickness symptoms, theories of motion sickness, and why simulator sickness occurs with HMD use.

**Symptoms of Motion Sickness.** Motion sickness is characterized by a cluster of symptoms such as nausea, cold sweating, salivation, apathy, fatigue, stomach awareness, disorientation, dizziness, pallor, vomiting, and ultimately incapacitation, resulting from either real or apparent motion (Reason & Brand, 1975; Kennedy, Drexler, & Kennedy, 2010). Nausea is one of the most common symptom and occurs in a variety of environments. It was initially studied in ship-heave motion, and was found to be more prevalent at specific frequencies. A ship motion simulation experiment that mimicked ocean wave oscillations, found nausea symptoms generated to be at a maximum around 0.2 Hz frequency of ship heave motion (O'Hanlon & McCauley, 1973).

**Theories of Motion Sickness.** This proposal draws from two theories of motion sickness: sensory conflict theory (Reason & Brand, 1975) and postural instability theory (Riccio & Stoffregen, 1991; see Appendix A for a detailed overview of both theories). Postural instability theory explains motion sickness and its relation to the external environment, while sensory conflict theory references sensory systems inside the body when explaining the cause of motion sickness. One thing both theories have in common is the claim that sickness results from an individual's persistence in trying to perform in a complex moving environment, as opposed to the natural environment we usually experience. Incorporating both views will allow for the use of subjective self-reported

sickness symptoms, and objective postural sway data to help answer the question at hand: can humans adapt to base latency in an HMD? See Appendix B for an overview of measures of postural sway.

**Simulator Sickness.** Motion sickness symptoms can also occur from apparent motion—this phenomenon is called visually induced motion sickness (VIMS; Kennedy, Drexler, & Kennedy, 2010). Simulator sickness is a subset of VIMS, and results in motion sickness-like symptoms stemming from visually perceived motion from a simulated environment (Kennedy, et al., 1993). Kennedy and Fowlkes (1992) describe simulator sickness symptoms to be similar to motion sickness and include nausea, stomach awareness, sweating, disorientation, eyestrain, salivation, headache, and dizziness. They also observed some people are highly susceptible to all symptoms of simulator sickness, while some only experience a few symptoms, and some experience no symptoms of simulator sickness. Kennedy and colleagues (1993) categorized simulator sickness symptoms into three main groups: disorientation, nausea, and oculomotor.

**Simulator Sickness in HMDs.** There is strong evidence that HMDs induce simulator sickness. Many aspects of HMDs have been investigated as potential causes of simulator sickness within virtual environments. One study comparing participants' simulator sickness while performing an object location task with and without an HMD found that peak sickness was greater when wearing an HMD, implying that characteristics of the HMD contribute to simulator sickness (Moss, Scisco, & Muth, 2008).

Characteristics such as field of view, resolution, and fidelity have all been explored in relation to simulator sickness. There has typically been a tradeoff between large field of view, high resolution and fidelity, and weight/size of the display. However, with improving technology, current HMDs have been able to provide larger field of views in lighter displays (Kim et al., 2015). Despite these recent improvements, one potentially sickening characteristic of HMD's, latency, continues to be a problem (Kim et al., 2015).

System latency is inherent in HMDs because it takes time for the system to update the display from initial movement to actuation. Here latency refers to lag between what the user's action and what appears in the HMD. Latency typically stems from sensor error and computer processing time in head-tracked HMDs. Additionally, this latency has been found to vary over time rather than remaining constant (Wu, Dong, & Hoover, 2013). There is evidence that this variable latency is a causal factor in simulator sickness, with more variation corresponding to higher levels of sickness symptoms (St. Pierre, et al., 2015). Similar to studies on the effects of ship oscillations on motion sickness, peak simulator sickness has been found around the 0.2 Hz frequency of latency (St. Pierre, et al., 2015; Kinsella, et al., 2016). In terms of sensory conflict theory and postural instability theory, varying latency serves as the challenging environment and/or novel stimulus that a user is trying in interact with. Latency causes a conflict between what the user expects compared to what is happening in their current varying environment. Additionally, as HMD users continue to try to perform in the challenging

environment, their postural sway may change. These factors can combine to produce sickness.

A recent study examined performance in an HMD with both base and varying latency conditions (Wilson, 2016). It was found that latency negatively affected performance, with varying latency causing worse performance than base latency. An interesting finding from this experiment was that there was no difference in simulator sickness between latency conditions. This was unexpected as previous findings demonstrated varying latency as more sickening than base latency (St. Pierre et al., 2015). The effect of a performance task on simulator sickness remains unclear; this contributes to the purpose of the current study.

**Adaptation**

Adaptation can be a way for users to overcome sickness symptoms from HMDs and better perform in the challenging environment. Sensory adaptation changes an individual's response to a provocative stimulus, allowing them to not have an aversive reaction to the stimulus. For example, when an individual walks from a bright room to a dark room, their pupils will immediately dilate to let the appropriate amount of light in for them to see their surroundings, called dark adaptation (Wolfe et al., 2015).

Adaptation to virtual environments requires adaptation to challenging perceptual rearrangements. Welch describes adaptation to perceptual rearrangements as "a semi-permanent change of perception, or perceptual motor coordination, that serves to reduce or eliminate a registered discrepancy between or within sensory modalities or the errors in behavior induced by this discrepancy," (Welch, 1978, p. 8). Within HMDs, the

discrepancy between visual and vestibular systems is caused by visual latency. Since this latency is variable, adaptation to it presents a particular challenge.

Adaptation to motion sickness is something that many experimenters have studied. While some conclusions have been made, it should be known that the topic is complicated and there is not a one size fits all approach to achieving adaptation. For example, Welch used prisms and active movement such as target pointing to show adaptation to a stable rearrangement is possible (1969; Welch & Abel, 1970); where other researchers focused more on exposure characteristics such as number of exposures and time between exposures to determine what is important for adaptation to take place (Stern et al., 1989). While these approaches differ, both get at fundamental questions about adaptation. The focus of this is on perceptual adaptation to motion sickness.

When adapting to motion sickness, Reason and Brand (1975) argue that it is not sensory adaptation, rather it is perceptual adaptation. The distinction here is that perceptual adaptation starts with a mismatch between two or more sensory inputs, and results in the eventual reduction of symptoms (Reason & Brand, 1975). Researchers describe three phases of adaptation to a perceptually challenging stimulus (Groen, 1960; Guedry, 1965; Reason, 1969; Reason, 1978):

1) Initial exposure phase—in this phase motion/conflict stimulus is present and motion sickness reactions occur;
2) Continued exposure phase—in this phase, adverse reactions decrease and eventually disappear through continuous interaction with the provocative stimulus;

3) And after-effect phase—in this phase initial motion sickness reactions return after exposure to provocative motion environment is over, and exposure to the normal environment occurs.

According to Reason, in order for adaptation to occur, individuals must be exposed to the stimulus for a continuous amount of time. He also claims the rate of adaptation is inversely related to the extent of the rearrangement—in other words, the more complicated the stimulus, the longer it will take us to adapt (Reason, 1978). This has been shown in the literature on adaptation—adapting to a simple stimulus such as a prism will take a minimal amount of time—as few as 10 trials of a pointing task, where adaptation to a continuously varying stimulus such as the motion on a ship in the ocean could take weeks, or longer (Pick & Hay, 1964; Welch, 1969; Reason & Brand, 1975; Stephens and Parsons, 2002). According to sensory conflict theory, motion sickness occurs when sensory inputs in the current situation conflict with what is expected in that situation based on a recent past experience, or sensory inputs conflict with one another in the current situation (Reason & Brand, 1975). In order to change what is expected for a sickening stimulus (i.e., for adaptation to occur), an individual must experience continuous exposure to the challenging stimulus so the novel patterns of spatial sensory input spur changes in the neural store. Then the patterns can become recognizable, making them less sickening, and/or, the discrepancy in sensory inputs can be ignored in favor of relying on sensory input that is most adaptive for performance.

Another aspect of adaptation is experiencing aftereffects, which cause the individual to have to re-adapt to the "normal" environment after adaptation occurs in a new environment. This is the third stage of adaptation according to Reason (1978), known as the aftereffect stage. This was demonstrated in a study looking at aftereffects of jogging, where when asked to jog in place after jogging on a treadmill, participants jogged forward instead of staying stationary (Anstis, 1995). This has also been shown in participants who were adapted to an optokinetic stimulus. When asked to walk in place after adapting to a rotating optokinetic drum, participants turned in the opposite direction of the rotating stimulus (Moss, Muth, & Beadle, MS under preparation). Welch describes this part of adaptation as experiencing "negative aftereffects" and defines this as having to readjust to the real world after adapting to a shifted stimulus (Welch, 1969).

Transfer of adaptation is another important aspect to consider. Many studies have looked at how adaptation to one stimulus can transfer to another stimulus. Reason and Graybiel (1969) found evidence for adaptation to counterclockwise rotations in a slow rotation room for several days can transfer to clockwise rotations in a rotating chair. But, this transfer of adaptation is between two very similar stimuli. Sickness from a rotating stimulus in one direction triggers nearly identical sensory inputs as a rotating stimulus in the opposite direction. However, transfer of adaptation from one type of motion stimulus to a completely dissimilar stimulus has proven harder to accomplish (Reason & Brand, 1975; Reason, 1978). Transfer of adaptation between two unrelated stimuli has been shown, but specific "pre-adaptation training" is important to facilitate the transfer (Mouloua, Smither, Kennedy, 2005). Some training programs for adaptation have proven

successful, but it seems to depend on the individual. The author is unaware of any evidence existing for adaptation transfer between two unrelated or dissimilar stimuli. This further adds to the argument that adaptation to motion stimuli is complicated, and there is no one size fits all approach.

**Facilitating Adaptation.** Many studies have set out to determine the best paradigm for adapting an individual to a sickening stimulus. The literature agrees that repeated exposures to a challenging stimulus can lead to measured decreases and eventual elimination of sickness symptoms (Reason & Brand, 1975; Reason, 1978; Parker & Parker, 1990). This can be explained by sensory conflict theory—the more exposures an individual has to the novel, challenging stimulus, the more likely it will become a recognized stimulus, and match the individual's expectations for that experience, or the more an individual can learn to deal with sensory inputs that disagree.

There is some debate in the literature as to what is more important for adaptation—number of exposures, or time between exposures to the sickening stimulus. One study found that after 10 exposures, all participants showed significantly fewer sickness symptoms, regardless of the time between exposures, indicating that the number of exposures was more important for a decrease in sickness symptoms than time between exposures. However, Stern and colleagues (1989) found that when exposed to an optokinetic stimulus three times, participants showed adaptation when sessions were separated by 48 hours, but not when separated by 4 – 24 days, indicating that time between exposures is important for adaptation to occur. Other studies have been successful in showing adaptation to an optokinetic stimulus after three exposures

separated by 48 hours (Hu, et al., 1991; Hu & Hui, 1997). Additionally, Lawson (2014) recommends that to *avoid* adaptation effects, exposures should be separated by one week, implying any amount of time under one week between exposures could lead to adaptation. Still, some experimenters, like Reason (1978), claim *continuous* exposure is key for adaptation. Graybiel and colleagues (1965) exposed participants to a slow rotating room for a continuous twelve-day period to look at adaptation effects, and found that adaptation to sickness occurred, but participants never fully adapted to feeling drowsy after twelve days. This conflict in the literature is further evidence that adaptation to motion is a complicated issue, and one strategy that works for one type of stimulus may not work for another type of stimulus.

***Individual Differences in Adaptation.*** There is evidence that some individuals may be unable to adapt to sickening environments. Reason claims that 5% of the population will never be able to adapt to a sickening stimulus regardless of the time they are exposed to the stimulus (Reason, 1974). Screening participants can be a way to reduce the chances that the experimental sample includes people who are unable to show adaptation to a sickening stimulus. When looking at the effect of a drug used to treat motion sickness symptoms, researchers only included participants who were highly susceptible to motion sickness (Muth & Elkins, 2007). No significant differences between the drug and a placebo were found, and the researchers suspected their recruited sample was too susceptible to sickness and recommend future studies to recruit a sample with intermediate susceptibility.

**The Role of Task Engagement in Adaptation.** While there is some disagreement on what is necessary for adaptation, the literature does agree that making active movements in the provocative stimulus when trying to adapt is better than making passive movements. Active movements allow the participant to interact with the environment in a dynamic way, like pointing to targets, and result in error corrective feedback; where passive movements only allow the participant to observe the environment and not fully interact with it. Studies have shown that individuals who are able to actively interact with their environment will adapt more quickly than individuals who are not (e.g., Held, 1965; Welch, 1969; Reason & Benson, 1978). Held (1961) created his "Reafference Hypothesis" to explain this, claiming active movements cause reafferance, which refers to sensory signals that are generated as a result of an intended, active physical movement. Reafferance initially produces illusory perceptions, but also promotes sensory rearrangement to neutralize those perceptions.

Welch has completed several adaptation studies examining whether active movements facilitated adaptation better than passive interactions with visually shifted environments. While he was able to see some adaptation in passive interactions, he found that active target pointing facilitates greater adaptation (1969). In one study he found that participants allowed to point to targets had enhanced visual-motor adaptation compared to participants who were not allowed to point to targets (Welch, 1969). Additionally, in the same study, he found that more concrete targets led to greater adaptation. Welch explains this finding using his "Information Hypothesis," in which he states there are many sources of information that can be helpful for adaptation, and the

more relevant information available to the individual, the more complete the adaptation. He claims that active target pointing provides more relevant information than passive observation of the environment. Welch claims this information comes in the form of error corrective feedback and the resulting adaptation can even be generalized to other behaviors not involving target pointing (Welch & Abel, 1970). Welch also claims that for sensory motor adaption to occur, participants need to experience the consequences of their actions in the shifted environment (1968). If they are forced to actively interact with the shifted environment, then they gain more information about the discrepancy between the shifted and actual environment.

This idea of feedback facilitating adaptation remains prevalent in the literature. When looking at sensorimotor adaptation to complex temporal delays, researchers found that participants can learn to perform complex tasks even with delayed feedback (Cunningham, Billock, & Tsou, 2001). When looking at different types of feedback when estimating distances in a virtual environment, all types of feedback lead to better estimations, but continuous visual feedback lead to the biggest improvement (Mohler, Creem-Regehr, & Thompson, 2006). Based on this research, providing participants with continuous visual feedback can help them gain more information about the environment and possible facilitate adaptation.

**Habituation and Distraction.** While adaptation involves sensory processing to become less sensitive to a stimulus over time, habituation involves actively shifting attention away from the stimulus to tune it out. This results in a reduction, or modification, in response to the provocative stimulus. Habituation can be short-term or

long-term, depending on the stimulus presentation and interval of stimulus exposure (Staddon, 1993). Habituation has been used to attempt to manage or prevent motion sickness. In a case report, Rine, Schubert, and Balkany (1999) found that habituation therapy involving challenging vestibular and visual stimulation, along with balance training, led to a reduction of symptoms and allowed the patient to function in the challenging environment.

Continuing with the idea of "tuning out" the provoking stimulus, Reason and Brand (1975) claim that motion sickness is less likely to occur when an individual's attention is directed outward towards an external event, rather than when their attention is turned inward on their own feelings. Recently, Bos (2015) found that using a high frequency vibration as well as a mental distraction task were both able to reduce experienced sickness individually and combined. Using physical or mental distraction is one way sickness may be able to be reduced. However, this may not always be feasible, especially if the individual is performing a task that requires their full concentration—a distraction task could take away from their performance, thus nullifying the effects of reduced sickness.

**Conditioned Responses.** Though seeming similar to adaptation, conditioned responses to conflicting stimuli differ in a few key ways. As previously stated, adaptation is a process that results in sensory processing becoming less sensitive to a provocative stimulus. A conditioned response is a learned response that is prompted by a conditioned stimulus. When trying to achieve adaptation to a motion sickness paradigm, precautions should be taken to avoid an aversive conditioned response to the laboratory

in which the experiment takes place. Motion sickness is not a desired outcome for most people and previous studies have used motion sickness paradigms to show taste aversions as a conditioned response. Klosterhalfen and colleagues (2000) showed participants who consumed a novel taste right before a rotating chair motion sickness paradigm developed an aversion to that novel taste, compared to participants that consumed the novel taste an hour before the paradigm and had water immediately before the motion sickness paradigm. Therefore, experienced nausea and motion sickness have the ability to cause an aversion to something novel and unrelated in participants. Another study found evidence for anticipatory nausea as a conditioned response to chemotherapy treatments (Nesse, et al., 1980). In this study, patients experienced nausea when entering the clinic in which they previously received chemotherapy treatments, even when they were just there for a post-treatment follow up appointment. This study provides evidence that experiencing nausea can cause individuals to have an aversive response to just the room in which they have previously experienced feeling sick. While this effect had a gradual onset, it is important to consider these implications when conducting a repeated measures study in a sickening paradigm.

One possibility for avoiding an aversive conditioned response is to introduce distraction during the participant's exposure to the provocative stimulus. There is evidence that introducing a distraction during a sickening protocol can reduce symptoms of motion sickness (Bos, 2015). If a distraction exists within a sickening protocol, it's likely that participant's sickness symptoms will not be as severe compared to exposure without the distraction. This could in turn reduce the likelihood of an aversive

conditioned response to the provocative environment. While participants would not be experiencing reduced symptoms from adaptation to the environment, the lack of an aversive conditioned response could still yield less sickness symptoms than if the conditioned response existed.

Since the goal of this experiment was to reduce sickness symptoms to varying latency through adaptation, an aversive conditioned response to the laboratory or experimental setting is undesirable. A simple solution to this problem is to implement a rule that excludes participants who have an extreme response to the stimulus; for example, setting a maximum sickness score for participants or ensuring participants can complete the entire protocol without stopping. With this protocol in place, participants would likely not have a chance to develop an aversive response to the stimulus.

**Current Study**

There is a gap in the literature regarding adaptation to latency in an HMD. It is known that there is innate latency in HMDs (Wu, Dong, & Hoover, 2013), and though technology is improving, it is unlikely that latency can be completely eradicated (Kim, et al., 2015). It is therefore important to investigate whether humans can adapt to base latency and what can aid in adaptation to improve user experience and performance in HMDs.

The present study examined three main questions: 1) could humans adapt to base latency in an HMD; 2) did a performance task facilitate adaptation to base latency in an HMD; and 3) was there an interaction between task and time (that is, did the type of task influence the amount of time necessary to adapt)? A repeated-measures study is was

conducted to better understand whether adaptation to base latency in an HMD was possible and whether a performance task served as an intervention to facilitate more complete adaptation. Participants were split into two groups and received three sessions of exposure each. One group only completed an object location task while wearing an HMD with base latency. The second group completed the object location task on their first and third visits, but completed a performance task consisting of an object targeting task on their second visit. All exposures were separated by exactly 48 hours. Adaptation was determined by a reduction in experienced sickness symptoms in the third session compared to the first session.

It is important to note that the present study did not utilize a head-tracked sensor in the HMD. There was no varying latency caused by sensor error present in the HMD display. The focus of the study was not on different types of latency, instead it was on HMD usage and whether adaptation to sickness was possible. Therefore, the HMD only had base latency. Base latency was implemented by displaying live camera feed through an image capture card to computer monitor, and then displayed to the HMD. This resulted in no manipulated latency in this study. The setup only caused latency through processing time through all modes of technology, and therefore is true constant latency. The base latency was measured to be 133.34 ms, and was measured using the outside observer method (Wu, Dong, & Hoover, 2013). This involved using a high speed camera to capture a real image and the image displayed in the HMD and measuring the latency between the two.

**Hypotheses.** To answer research question one, it was hypothesized that there would be a significant main effect of experimental session on adaptation to base latency in an HMD, such that participants would experience fewer sickness symptoms and less postural sway after the third session than after the first session. This hypothesis is supported by research showing adaptation to a sickening stimulus can occur after three exposures separated by 48 hours (Stern, et al., 1989; Hu, et al., 1991; Hu & Hui, 1997). Additionally, this hypothesis is supported by evidence showing repeated exposures to a challenging stimulus can lead to systematic decrease and potential elimination of sickness symptoms (Reason & Brand, 1975; Parker & Parker, 1990). Based on this research as well as sensory conflict theory, it was logical to predict that some form of adaptation would occur during participants' third exposure to the same sickening stimulus.

For research question two, a main effect of task was hypothesized such that participants in the performance task condition would have fewer sickness symptoms and less postural sway after the third experimental session than participants in the object location task condition. This hypothesis is supported by Welch's Information Hypothesis (Welch, 1969). Participants completing the performance task would have the opportunity to interact with varying latency in a different, active, and engaging way compared to participants who only completed the object location task. This additional interaction was predicted to provide the participant with more relevant information, such as visual feedback, useful in the adaptation process. Research shows that providing error corrective feedback to participants can not only lead to adaptation in that paradigm, but can possibly be generalized to adaptation for other behaviors (Welch & Abel, 1970).

For research question three, a significant interaction between task and experimental session was hypothesized such that participants in the performance task condition would have less sickness symptoms and less postural sway sooner than participants in the object location task condition. This hypothesis is supported by research showing active target-pointing tasks facilitate more complete adaptation than passive tasks in the challenging environment, and more concrete targets lead to greater adaptation (Welch, 1969). Since participants in the performance task condition would have the opportunity to interact with the varying latency in a different way than the object location task, as well as receive visual feedback for their actions in the challenging environment, it was expected that they would show signs of adaptation sooner than participants only experiencing the stimulus with a passive object location task.

# CHAPTER TWO

# METHODS

## Participants

A power analysis conducted through G*Power determined the sample size. Data using a varying latency condition and the same experimental session paradigm as this study (from St. Pierre, et al., 2015 and Kinsella, et al., 2016) were used to determine effect size input, which was .189. Alpha was set at 0.05 and power was set at 0.8. Results from the power analysis stated a total of 30 participants would be needed to see an effect. However, since our laboratory has not done an adaptation study previously, it was decided to over power the study, resulting in 40 total participants, with 20 participants per condition. Participants between the ages of 18 – 40 years, with no history of brain, heart, stomach, inner ear, or vision problems (other than corrected to normal vision) were recruited to participate. Anyone who self-reported being pregnant was not be eligible to participate. Individuals with corrected to normal vision were required to wear contacts, as the HMD would not fit over glasses. All participants completed a screening questionnaire that addressed these requirements prior to being scheduled to participate (see Appendix C).

## Design

A 2 (condition) x 3 (experimental session) mixed ANOVA was used (see Table 2.1). The independent variables were task type (object location only, or objection location + performance task) and experimental session. Task type was compared between subjects while experimental session was compared within subjects. The

dependent variables were sickness symptoms (measured from the simulator sickness questionnaire) and postural sway (measured from elliptical area, path length, and normalized path length).

| | **Session 1** | **Session 2** | **Session 3** |
|---|---|---|---|
| **Object location task** (N = 20) | OL | OL | OL |
| **Performance task** (N = 20) | OL | P | OL |

*Table 2.1: Overview 2 x 3 Mixed ANOVA design. "OL" refers to object location task, "P" refers to performance task.*

**Materials/Apparatus**

**HMD.** A *ProView TM XL 50* HMD (Kaiser Electro-Optics, Inc., Carlsbad, CA, 92010) was used for this experiment, shown in Figure 2.1. The *XL 50* is a bi-ocular HMD with a resolution of 1024 x 768 and a frame rate of 60 Hz. Eyecups made out of rubber-like molding made specifically for the *XL 50* were used to occlude external light from the environment. This is necessary to eliminate the discrepancy in height between the environment and the HMD display due to the camera being mounted on top of the HMD.


*Figure 2.1: Picture of HMD that will be used in this experiment*

The HMD had a 50° field of view (FOV) diagonally, 30° FOV vertically, and 40° FOV horizontally. It weighed 35 oz prior to camera being mounted.

**Digital Camera.** A GoPro Hero5 Black camera was mounted on top of the HMD. The resolution was set at 1920 x 1080p and frame rate was 120 fps and aspect ratio of 16:9. The field of view was set to the Narrow setting that comprised a 28 mm focal length, 37.2 degrees vertical field of view, 64.4 degrees horizontal field of view, and 73.6 degrees diagonal field of view.

A Magewell USB 3.0 HDMI Video Capture Dongle was used to convert the HDMI output from the GoPro to USB 3.0. This allowed the GoPro image to be streamed to the computer monitor in full 1080p image capture, which was displayed through the HMD.

VLC media player was used to display the image captured from the Magewell USB 3.0 HDMI Video Capture Dongle to the computer monitor. The monitor was then mirrored on the HMD display, so participants could see the monitor while wearing the HMD. The GoPro video was set to full screen, so participants could only see the camera image and nothing else when wearing the HMD.

**Polhemus Fastrak.** Posture data was measured using the Polhemus Fastrak. This involved a source cube emitting an electromagnetic dipole field and two sensors attached to the participant to track their position. The Polhemus Fastrak collected X and Y coordinates corresponding to the participants' postural sway. A custom MatLab code was used to calculate elliptical area, path length, and normalized path length. See Appendix B for more information on postural sway measures.

**Motion Sickness Susceptibility Questionnaire.** The Motion Sickness Susceptibility Questionnaire (MSSQ) is a multidimensional measure assessing motion sickness susceptibility (Golding, et al., 2006; see Appendix F). There are 18 items on this questionnaire, and participants are asked to rate their history of motion sickness from different types of motion on a scale of "*Never traveled*," "*Never felt sick*," "*Rarely felt sick*," "*Sometimes felt sick*," *Frequently felt sick.*" Participants do this twice, once responding for the first 12 years of their life (called MS-A), and once responding for the last 10 years (called MS-B). Each item gets a score of "t" (for never traveled responses) or 0 – 3 based on how often they felt sick. Two scores are calculated, one for MS-A and one for MS-B. MS-A and MS-B are calculated by summing the score for each item and multiplying it by 9. Then divide by 9 – the number of 't's for that section. To get a raw

MSSQ score, sum MS-A and MS-B. Scores can range from 0 – 27, where 0 is least susceptible and 27 is most susceptible.

**Simulator Sickness Questionnaire.** The Simulator Sickness Questionnaire (SSQ) is a measure of motion sickness symptoms in a virtual environment, called simulator sickness (Kennedy et al., 1993; see Appendix E). This questionnaire requires participants to respond to how they are feeling regarding 16 different sickness symptoms on a scale of none, slight, moderate, or severe, with corresponding raw scores of 0, 1, 2, 3. There are three subscales of this questionnaire: oculomotor, disorientation, and nausea. Each participant yielded a Total Severity (TS) score for each subscale by summing the individual items under each subscale. The maximum score is 235.62. The creators of the questionnaire stated SSQ scores between 5-10 indicate minimal symptoms, 10-15 indicate significant symptoms, and scores above 20 indicate a bad virtual environment simulator.

**Motion Sickness Assessment Questionnaire.** The motion sickness assessment questionnaire is a multi-dimensional questionnaire that can be used to measure motion sickness (Gianaros, et al., 2001; see Appendix F). It is a 16-item questionnaire and participants respond 1 – 9 for each item based on how they are feeling. A total score is calculated by summed the responses for each item. Scores range from 16 – 144, with 16 being the least sever sickness and 144 being the most severe sickness.

**Room Layout**. An object location task was used to challenge the participants' visual-vestibular interaction. Participants were required to locate 8 objects around the laboratory throughout the experiment. They did this by making head movements while

wearing the HMD. The layout of the room is shown in Figure 2.2. The objects, shown in Figure 2.3, were scale (A), clock (B), flag (C), fire (D), hall (E), cross (F), fan (G), and shelf (H). Participants' performance on the object location task was judged based on whether the object being located was in the visual display before the next object needed to be located.

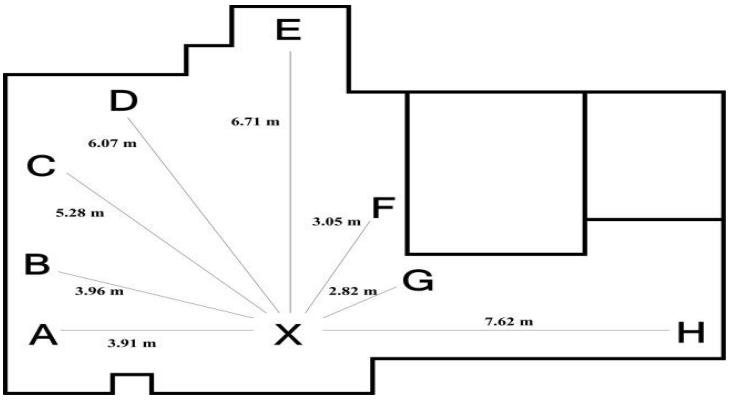


*Figure 2.2: Footprint of room layout for the object location task. Participants stood at 'X' and were asked to find objects placed from A – H.*


*Figure 2.3: Pictures and names of 8 objects making up the object location and target shooting tasks.*

**Object Location Task.** Participants were instructed to stand in a specific location in the laboratory and remain there for the duration of the task (Figure 3, X). A recording gave participants a direction and an object, and the participants made head

movements to find that object within the HMD, for example “left, clock.” See Appendix G for order of targets in each block. Participants were instructed to move only their head and neck to locate objects. If necessary, shoulder movements were allowed, but participants were instructed not to move their hips or legs during the task. The maximum horizontal head movement required was 180°. The minimum horizontal head movement was 35°.

**Performance Task.** Laser targets were co-located next to each of the 8 objects described in the “Room Layout” section. Laser targets (Cheap Shot™ Laser Target, Impulse USA, Inc., PO Bos 193, St. Louis, MO 60310) can be seen in Figure 2.4. Participants used a hand-held laser pointer (Laser 301, Red Laser Pointer Pen G301, 650nm, 0.2 W) to activate the targets. Participants were instructed to hold the laser in their dominant hand and extend their arm out in front of them. Participants were instructed to only move their neck, head, and arm holding the laser when locating the targets. Participants were instructed to pulse the laser to activate the target. Targets were modified to emit a 330 Hz tone at approximately 90db simultaneously with the illumination of the lights on the target. Participants scored a hit by illuminating the target before the next target instruction are given (approximately 3 seconds). Failure to illuminate the correct target within the time interval resulted in a miss.


*Figure 2.4. The Laser 301 laser pointer (left) and Cheap Shot Laser Target modified with 330 Hz buzzer (right) that will be used in this experiment.*

**Task Automation.** Custom computer code utilizing a computerized text-to-speech voice program was used to present the stimuli automatically for the object location task and performance task, as well as the MSAQ and SSQ at the appropriate times. During the performance task, audio was continuously monitored through a microphone so participants' performance could be determined by software. The software parsed the audio file in real time and calculated the time between audio instruction and activation of a buzzer, indicating a hit. Accuracy and time-to-hit were both calculated using this software. Time-to-hit was automatically recorded in a comma-separated values file (.csv) to be analyzed after the experiment. In the absence of a buzzer, a miss was determined, and the software recorded "-1" into the file. After the experiment, these values were replaced with 3, the total amount of time between object instructions.

**Optimizing Participant Screening.** It is important to establish a screening protocol when looking at adaptation to ensure the sample population has a relatively

similar motion sickness susceptibility and have the best chance at showing adaptation. Upper and lower bounds were established to achieve a relatively similar sickness experience for all participants. These constraints were loosely based on the literature. When examining whether experiencing nausea is actually necessary to show adaptation to a sickening stimulus, Hu & Hui (1997) tested two groups of participants, one that completed an entire motion sickness paradigm regardless of their experienced motion sickness, and one that stopped exposure at the onset of sickness symptoms. They found no statistical difference in number of sessions for full adaptation between the two groups, providing further evidence for the argument that participants do not need to experience high sickness symptoms to show adaptation to a sickening paradigm. These studies provide evidence for creating a moderate upper bound on experienced sickness symptoms during a screening procedure for the highest chance of showing adaptation in a sickening paradigm. Additionally, it seems obvious that there should be a lower bound to screening. If no sickness symptoms are initially experienced, then the participant will have nothing to adapt to.

**Sickness Screening Criteria for Current Study.** Acting as an "upper bound" on sickness, participants must have been able to complete all five blocks of trials during their first experimental session to be eligible for the next two sessions. This was to ensure participants did not develop a negative conditioned response to the HMD. Additionally, it was important that participants experienced some sickness symptoms to show adaptation. For this reason, participants must have had greater than 20 total SSQ score for at least one of the blocks of trials in the first experimental session to be eligible

for the next two sessions. Kennedy and colleagues (2003), suggest that SSQ scores greater than 20 indicate a problem with the simulator. Previous work in our lab also suggests that the median peak SSQ scores for participants who completed all five blocks of trials was 24.3, further corroborating greater than 20 for peak SSQ to be the screening criteria (St. Pierre, et al., 2015; Kinsella, et al., 2016).

**Procedure**

Once a participant volunteered for the experiment, they were scheduled to come to the lab for the first experimental session. Participants filled out an IRB informed consent (see Appendix J), the MSHQ, and the screening questionnaire. Participants were randomly assigned to the object location task only group or the performance task group. All participants completed the object location task during their first and third experimental sessions. The performance task group completed the target shooting task instead of the object location task during their second experimental session. A detailed procedure timeline can be seen in Appendix H.

The experimenter completed a protocol checklist while conducting the experiment (see Appendix K). After filling out the informed consent form, screening questionnaire and MSHQ-Short, the experimenter read experiment instructions to the participant from a script (see Appendix I). Participants were then led to the designated spot in the lab where they would stand for the duration of the experiment. The experimenter then physically pointed out where each of the objects in the object location task were located around the room. The reminded the participant to only move their head and neck when making head movements. They also told participants a hand railing would be in front of them for the

duration of the experiment, and if they ever felt unstable they could grab onto it. Finally, they reminded the participant they would be standing for about 20 minutes and instructed them not to lock their knees. The experimenter made sure the participant did not have any questions about the task before continuing.

After all instructions were given to the participant, the experimenter started the one-minute practice block. This was completed without the HMD, and the experimenter encouraged participants to ask questions during the task if anything was confusing. If the participant missed any object during the practice, the experimenter reminded the participant where that object was at the end of the practice.

After the practice block, the experimenter secured the Polhemus Fastrak sensor to the participants back and helped the participant don the HMD (which included a second Polhemus Fastrk sensor secured to the top of the helmet). The experimenter instructed the participant how to adjust the HMD and watched them put it on and adjust it to make sure they were doing it correctly. In some cases, the participant asked the experimenter for help with adjusting it, in which case the experimenter adjusted the HMD for the participant. After the HMD was correctly fitted to the participant's head, the experimenter started turned on the Polhemus Fastrak system to collect a two-minute baseline. During this time, the participants were instructed to stand still and face forward.

After the two-minute baseline, the experimenter verbally read the MSAQ and SSQ to participants and the participants verbally responded.

Then the experimenter started the experimental task automation. Each experimental session consisted of five blocks of trials, lasting around two minutes each. Each block of trials were separated by one minute, in which the participant completed an SSQ, given to them automatically by the automated computer software. The experimenter was responsible for recording the participant's response to the SSQ. After each block of trials, the experimenter reminded the participant that it was not the intention of the experiment to make them feel too uncomfortable, and if at any time they feel too uncomfortable to let the experimenter know and the session will be stopped immediately. At the end of the fifth block of trials the participant completed both the SSQ and MSAQ, given to them automatically by the computer software. After completing the MSAQ, the experimenter instructed the participant to stand for the post two-minute baseline. During this time the participant was instructed to stand still and look straight ahead while still wearing the HMD. At the end of the post baseline, the experimenter helped the participant take off the HMD and Polhemus Fastrak sensor.

After the first experimental session, the experimenter quickly assessed the participants' SSQ scores to make sure they had a peak score of 20 or higher, as stated in the screening section. If participants' peak SSQ score did not reach 20 or higher, or if they were not able to complete all five blocks of trials, the experimenter debriefed them on the purpose of the experiment, paid them $10, and dismissed them. If participants' scores did fall within the specified range of SSQ scores, the experimenter paid them $10 for their participation and scheduled them for the next two experimental sessions. Experimental sessions were separated by exactly 48 hours.

The second and third experimental sessions followed the same procedure already described. However, for participants in the performance task group, the experimenter explained the performance task to them during the second session instead of the object location task. After the second experimental session, participants received $20 for their participation. After the third experimental session, participants received $30 for their participation. Participants were debriefed on the purpose of the experiment after the third experimental session.

## Data Analysis

**Hypothesis Testing.** A 2 (condition) x 3 (experimental session) mixed ANOVA was performed to look for a main effect of condition, main effect of time, and an interaction between the two. Peak SSQ, post MSAQ scores, average elliptical area, summed path length, and summed normalized path length were dependent variables in the mixed ANOVA. Additionally, the same postural sway measures collected during the post baseline period were dependent variables in a mixed ANOVA examining participants' sway immediately after completing the experimental task.

# CHAPTER THREE

# RESULTS

Data were collected over three experimental sessions. The first session served as a screening session. Sixty-six Clemson University participants were screened, and 40 participants (20 female) passed the screening by scoring 20 or higher on the SSQ at any point during the experiment without needing to stop before the end of all trials. All participants that passed the screening were asked to come back for the following two experimental sessions. Demographics of participants that passed the screening are in Table 3.1. There were no statistical differences in motion sickness susceptibility between groups or genders.

| Condition | N | Male | Female | Age (Mean +/- SD) | Race (C/B/H/A/Prefer not to answer) | MSSQ (Mean +/- SD) |
|---|---|---|---|---|---|---|
| Control | 20 | 10 | 10 | 19.2 +/- 1.28 | 17/1/1/0/1 | 6.56 +/- 6.84 |
| Performance | 20 | 10 | 10 | 20.0 +/- 3.02 | 15/2/1/2/0 | 7.58 +/- 8.51 |
| All | 40 | 20 | 20 | 19.6 +/- 2.32 | 32/3/2/2/1 | 7.07 +/- 7.64 |

*Table 3.1: Participant demographics by condition.*

**Participant Withdrawal**

All participants that passed the screening came back for all three sessions of the experiment. One participant got the flu and was too sick to come in for their third session, so their data were discarded and a new participant was recruited to replace them. Thirty-nine participants were able to complete all 15 blocks of the experiment (5 blocks per session). One participant withdrew from the last experimental block during session three because he reported feeling nauseous and extremely faint. However, this

participant was able to complete SSQ 15 and post-MSAQ 3, and his data were included in the analysis.

**Hypothesis Tests: Subjective Simulator Sickness**

A 2 (condition) x 3 (experimental session) mixed ANOVA was conducted for each dependent variable to look for a main effect of time, and main effect of condition, and an interaction between the two.

Sickness was measured using peak SSQ scores and post MSAQ scores from each session. Histograms of these distributions are shown in Figures 3.1 and 3.2. A Shapiro-Wilk test was conducted to assess normality for each distribution. The Shapiro-Wilk statistic was significant for both distributions, indicating they did not follow a normal curve (Peak SSQ: $W(120) = .89$, $p < .01$; MSAQ: $W(120) = .79$, $p < .01$). The peak SSQ variable underwent a square root transform to correct to a normal distribution (see Figure 3.3). This scale is non-linear and is typically undergoes a square root transformation when published (Bland & Altman, 1996). Analysis of untransformed peak SSQ data can be seen in Appendix L.

Though the MSAQ data was positively skewed, it did not go through a transformation for analysis. MSAQ data are typically positively skewed. After undergoing a square root transform, the data were still positively skewed (see Figure 3.4). Additionally, each sample had the same positively skewed distribution. Therefore, data were analyzed without going through a transformation.

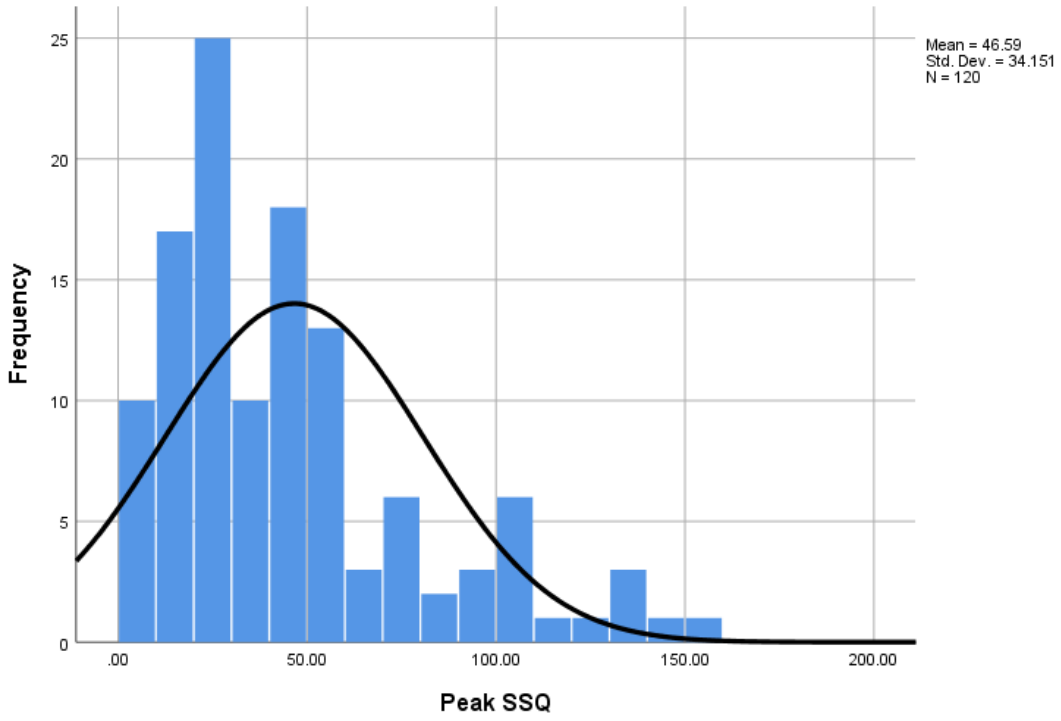


*Figure 3.1: Histogram of raw peak SSQ scores for all participants across all experimental sessions.*

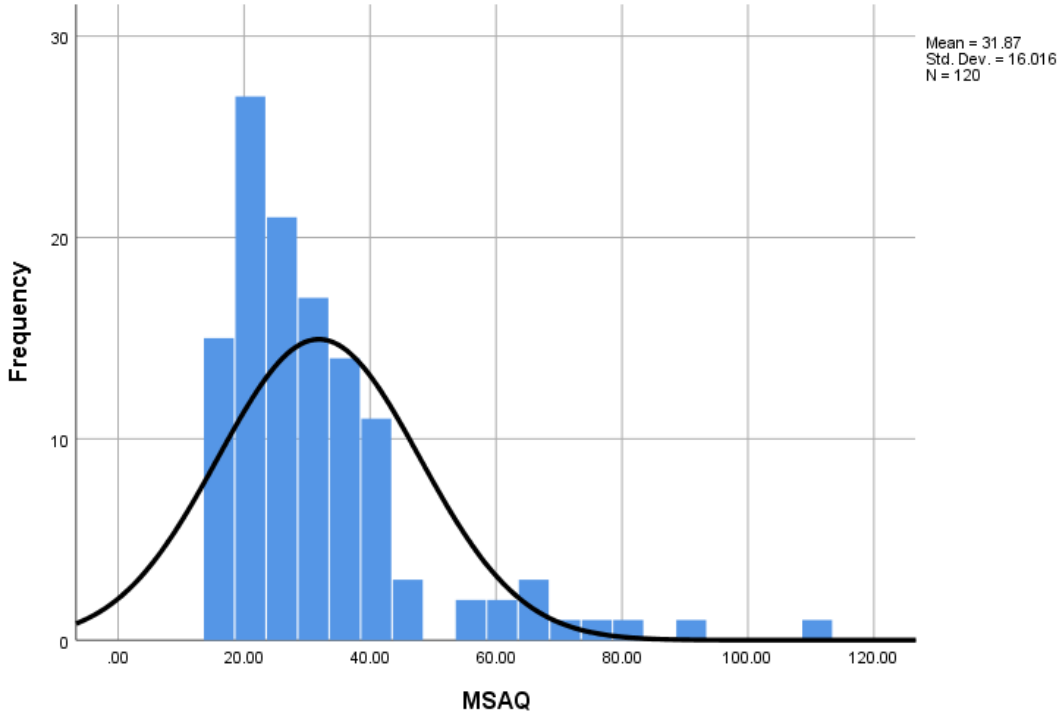


*Figure 3.2: Histogram of all post MSAQ scores across all experimental sessions for all participants.*

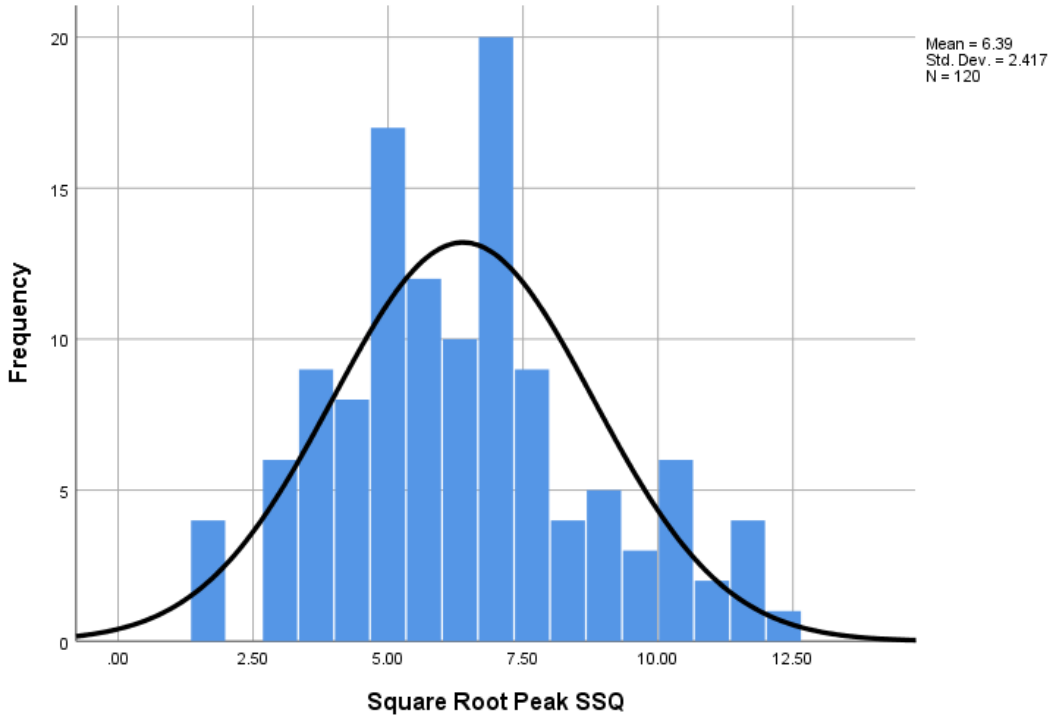


*Figure 3.3: Histogram of square root transform of peak SSQ scores for all participants across all experimental sessions.*

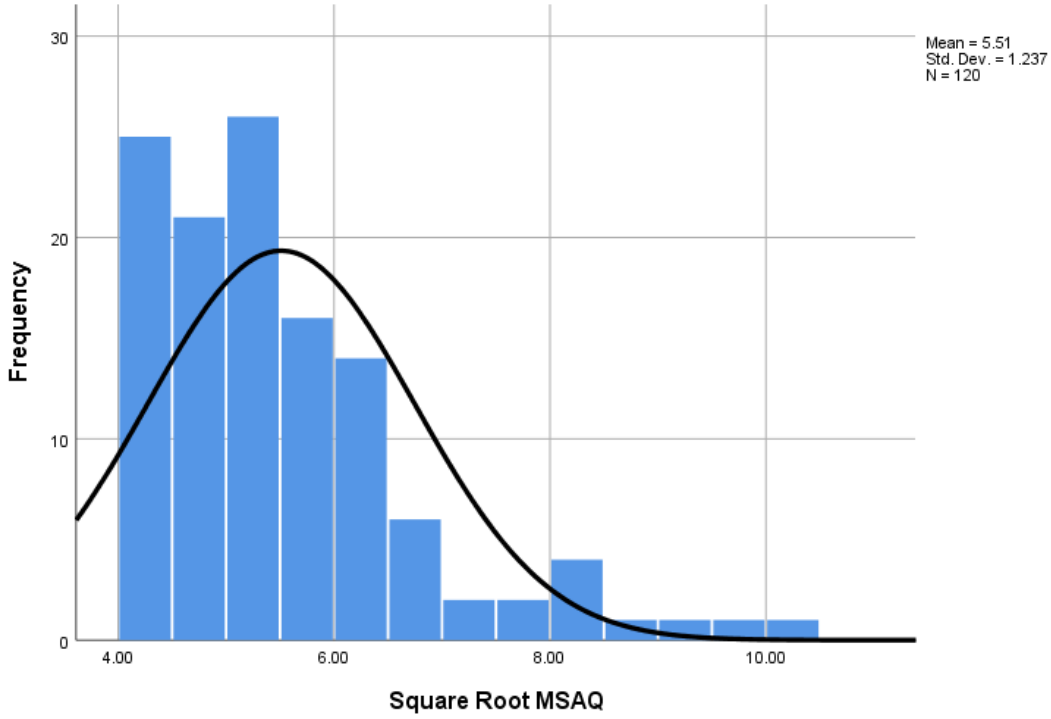


*Figure 3.4: Histogram of the square root transformation of post MSAQ scores for all participants across all experimental sessions; distribution is still positively skewed after transformation.*

**Outlier Analysis.** Box plots were made for each dependent variable and can be seen in Figures 3.5 and 3.6. When looking at post MSAQ scores, two participants were identified as potential outliers because they were at least 3 times outside the interquartile range. However, these participants were not identified in the peak SSQ data. Experimental notes for each of these participants were referenced to see if anything unusual occurred during data collection. There was no reason to exclude them based on experimenter notes, so all data were left in for analysis.

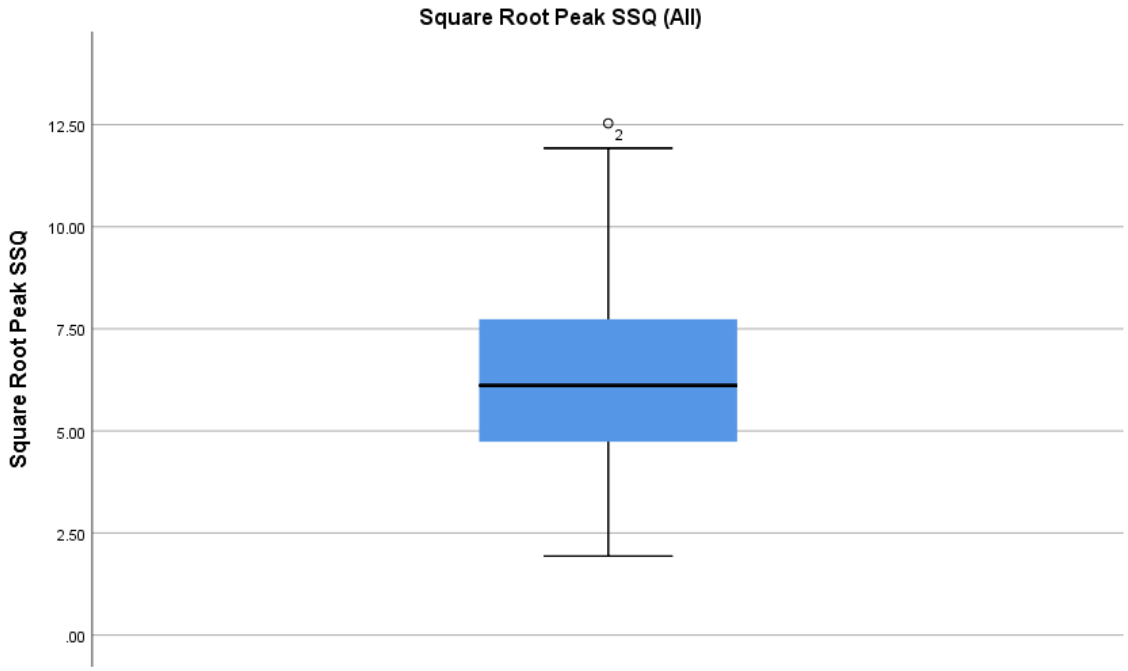


*Figure 3.5: Boxplot of square root transform of Peak SSQ scores for all participants across all sessions, 'o' denotes 1.5 times outside the interquartile range.*

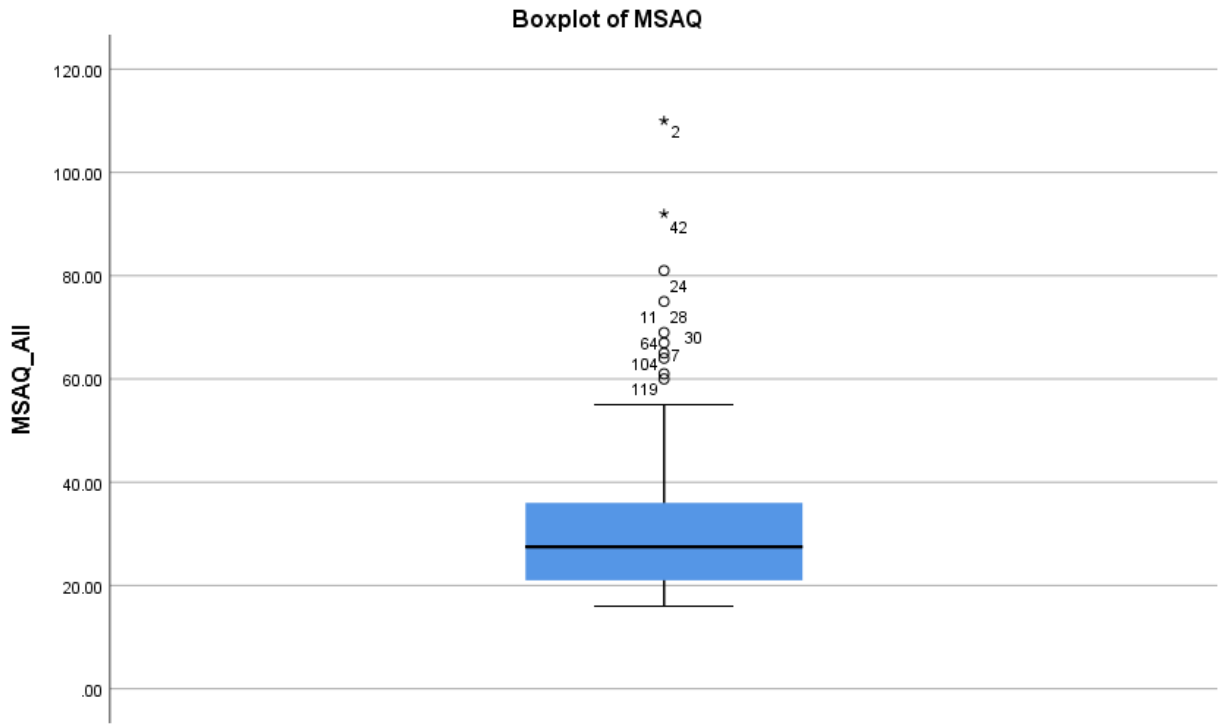


*Figure 3.6: Boxplot of post MSAQ scores for all participants across all experimental sessions, 'o' denotes 1.5 times outside the interquartile range, '*' denotes 3 times outside the interquartile range.*

***Peak SSQ***

Means and standard deviations for the square root transformed values of Peak SSQ are shown in Table 3.2. Figure 3.7 shows a line graph of average square root of Peak SSQ for each experimental session by condition. A significant main effect of condition was observed, such that participants had lower peak SSQ scores in session 3 compared to session 1, $F(2, 76) = 15.43$, $p < .01$, $\eta^2 = .29$. While means trended in the predicted direction, no significant main effect of condition was observed, $F(1, 38) = .63$, $p = .44$, $\eta^2 = .02$. No significant interaction was observed, $F(2, 76) = .64$, $p = .53$, $\eta^2 = .02$.

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 7.53 +/- 2.18 | 6.46 +/- 2.46 | 5.98 +/- 2.33 | 6.66 +/- 2.38 |
| Performance | 6.99 +/- 2.02 | 5.61 +/- 2.49 | 5.75 +/- 2.66 | 6.12 +/- 2.45 |
| Total | 7.26 +/- 2.09 | 6.04 +/- 2.48 | 5.87 +/- 2.47 | 6.39 +/- 2.42 |

*Table 3.2: Means and standard deviations for the square root of Peak SSQ scores in each experimental session by condition.*

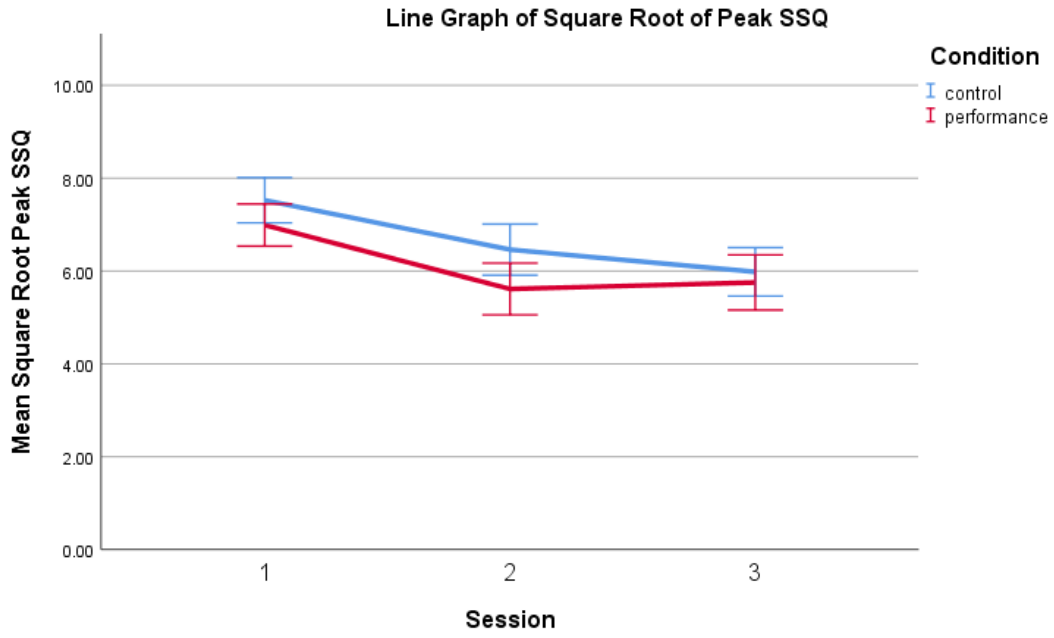


*Figure 3.7: Line graph of mean square root peak SSQ scores for all sessions by condition.*

***Post MSAQ***

Means and standard deviations for post MSAQ scores are shown in Table 3.3. Figure 3.8 shows a line graph of average post MSAQ scores for each session separated by condition. A significant main effect of session was observed such that participants' post MSAQ scores were lower in the third session than the first session, $F(1.42, 54.11) = 18.70$, $p < .01$, $\eta^2 = .33$ (the assumption of sphericity was violated, so a Greenhouse-Geisser correction was used, changing the between degrees of freedom from 2 to 1.42

and the within degrees of freedom to 54.11). No significant main effect of condition was observed, $F(1, 38) = .94$, $p = .34$, $\eta^2 = .02$. No significant interaction between condition and session was observed, $F(1.42, 54.11) = 1.57$, $p = .11$, $\eta^2 = .04$ (again, the assumption of sphericity was violated, so a Greenhouse-Geisser correction was used, changing the between degrees of freedom from 2 to 1.42 and the within degrees of freedom to 54.11.

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 41.7 +/- 20.07 | 32.45 +/- 16.95 | 27.9 +/- 8.44 | 34.02 +/- 16.70 |
| Performance | 34.55 +/- 18.76 | 27.55 +/- 12.40 | 27.10 +/- 13.02 | 29.73 +/- 15.14 |
| Total | 38.13 +/- 19.52 | 30.00 +/- 14.87 | 27.5 +/- 10.84 | 31.88 +/- 16.02 |

*Table 3.3: Means and standard deviations of Post MSAQ scores in each experimental session by condition.*

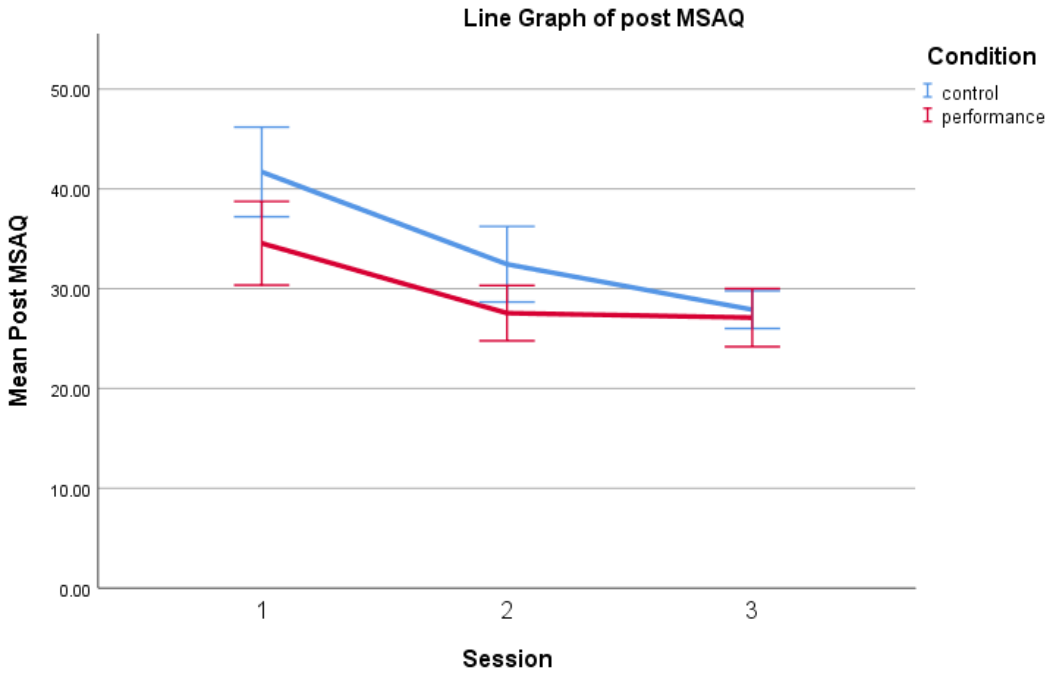


*Figure 3.8: Line graph of mean post MSAQ scores for all sessions by condition.*

## Exploratory Analysis: Subjective Simulator Sickness

### *Sum SSQ*

All participants completed all SSQs during the experiment, therefore, sum SSQ was be calculated as an additional measure of sickness. This measure was calculated by summing the SSQ score for each block during a session. Summed SSQ is different from Peak SSQ because it conveys how much sickness was experienced during the entirety of the experiment, as opposed to when they were feeling their worst in the experiment. A histogram of this distribution can be seen in Figure 3.9. A Shapiro-Wilk test was conducted to assess the normality of this distribution, $W(120) = .84$, $p < .01$. Results from this test indicate the normality assumption was violated, therefore, a square root transform was performed to achieve a normal distribution (see Figure 3.10). Analysis of untransformed sum SSQ data can be seen in Appendix M.

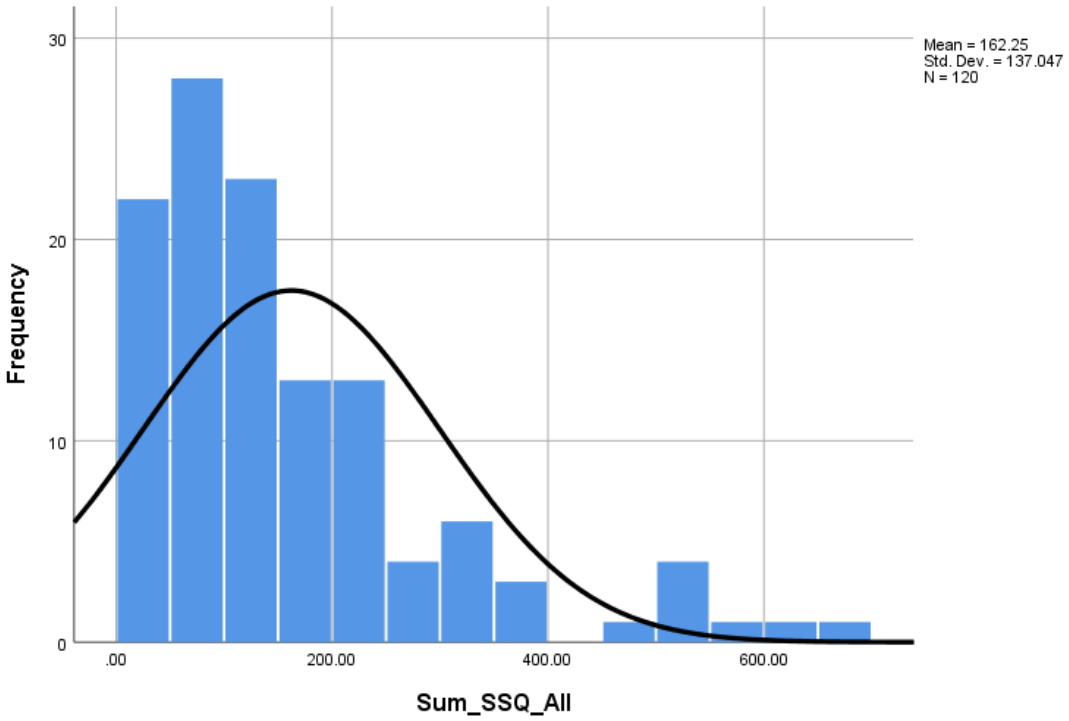


*Figure 3.9: Histogram of sum SSQ scores for all participants across all experimental sessions.*

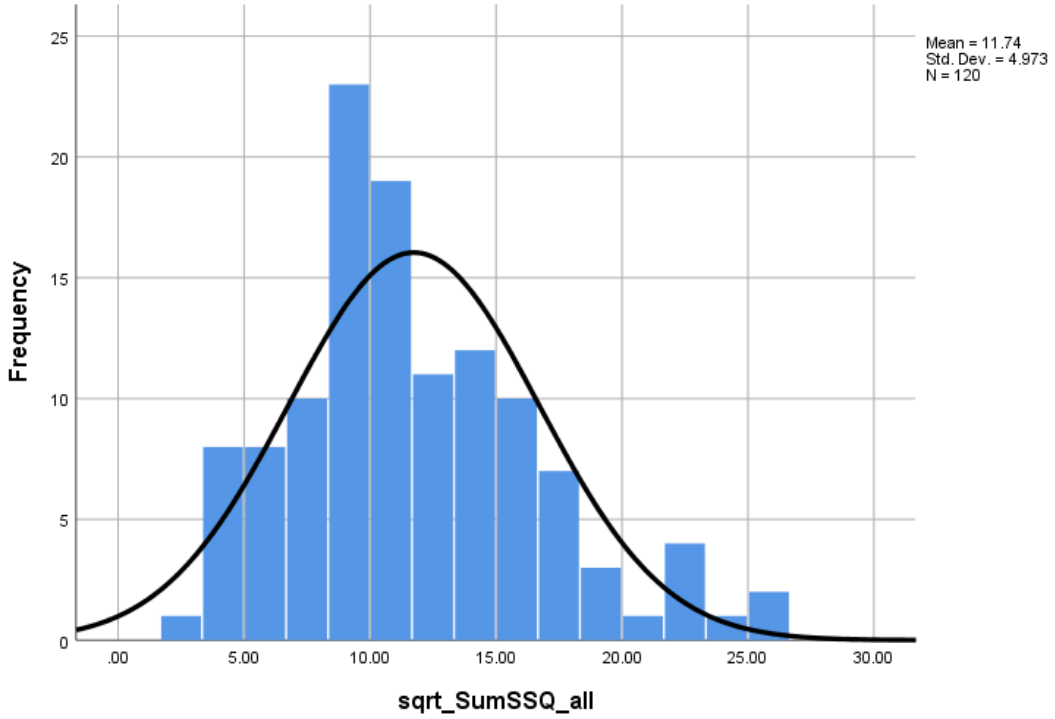


*Figure 3.10 Histogram of square root transform of sum SSQ scores for all participants across all experimental sessions.*

Means and standard deviations for the sum of SSQ scores are shown in Table 3.4. Figure 3.11 shows a line graph of average square root of sum of SSQ scores for each session separated by condition. A 2x3 mixed ANOVA was conducted to look for main effects of session and condition and an interaction between the two. A significant main effect of session was found, such that participants' sum SSQ scores were less in the third session compared to the first session, $F(1.72, 65.37) = 25.53$, $p < .01$, $\eta^2 = .40$. No significant main effect of condition was observed, $F(1, 38) = .01$, $p = .92$, $\eta^2 < .01$. No significant interaction between condition and session was observed, $F(1.72, 65.37) = .027$, $p = .96$, $\eta^2 = .001$.

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 13.95 +/- 5.00 | 11.16 +/- 4.75 | 10.29 +/- 3.84 | 11.80 +/- 4.75 |
| Performance | 13.89 +/- 5.10 | 10.89 +/- 5.06 | 10.24 +/- 5.02 | 12.49 +/- 8.00 |
| Total | 13.92 +/- 4.98 | 11.02 +/- 4.85 | 10.27 +/- 4.41 | 12.15 +/- 6.56 |

*Table 3.4: Means and standard deviations for the square root of Sum of SSQ scores in each experimental session by condition.*

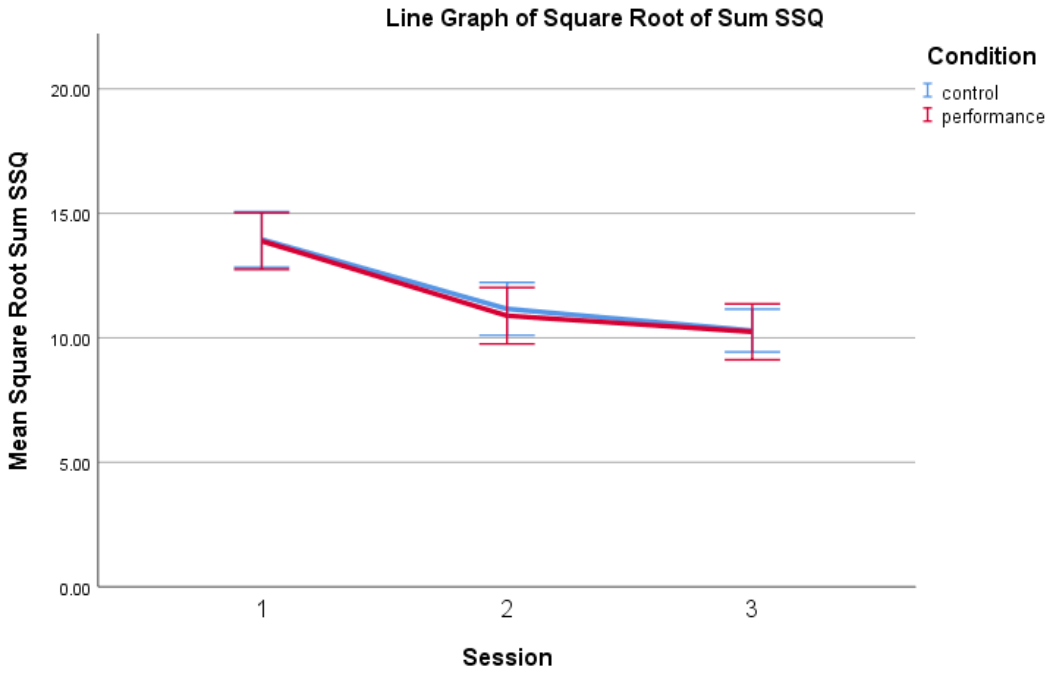


*Figure 3.11: Line graph of mean square root Sum of SSQ scores for all sessions by condition.*

***Simulator Sickness Split by Adaptation***

The body of research on this topic states that not everyone will be able to adapt to motion sickness (Reason & Brand, 1975). Because of this, data were split by whether symptoms were reduced in the third session compared to the first. A participant was categorized as showing adaptation if their:

- Peak SSQ score from the third session was less than Peak SSQ from the first session *or*

- Sum SSQ score from the third session was less than sum SSQ score from the first session *or*
- Post MSAQ score from the third session was less than post MSAQ score from the first session.

Descriptive statistics for adaptation can be seen in table 3.5. Thirty-five participants (87.5% of the sample) showed adaptation by this definition, 16 participants from the control condition and 19 participants from the performance task condition.

| Condition | N | Male | Female | Age (Mean +/- SD) | Race (C/B/H/A/Prefer not to answer) | MSSQ (Mean +/- SD) |
|---|---|---|---|---|---|---|
| Control | 16 | 8 | 8 | 19.13 +/- 1.36 | 13/1/1/0/1 | 6.32 +/- 6.99 |
| Performance | 19 | 9 | 10 | 19.89 +/- 3.09 | 15/2/0/2/0 | 7.98 +/- 8.55 |
| All | 35 | 17 | 18 | 19.54 +/- 2.45 | 28/3/1/2/1 | 7.22 +/- 7.80 |

*Table 3.5: Descriptive statistics for participants that demonstrated adaptation.*

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for differences in peak SSQ scores for participants who showed adaptation. Table 3.6 shows means and standard deviations for peak SSQ for participants that showed adaptation. Figure 3.12 shows a line graph of the square root of peak SSQ scores for participants that showed adaptation by condition. A main effect of session was observed such that participants had lower peak SSQ scores in the third session compared to the first session ($F(2, 66) = 24.57$, $p < .01$, $\eta^2 = .43$). There was no main effect of condition observed, and means trended opposite of the predicted direction, with participants in the performance condition showing higher Peak SSQ scores in session three compared to participants in the control condition ($F(1, 33) = .32$, $p = .58$, $\eta^2 = .01$. No significant interaction was observed, $F(2, 66) = 1.86$, $p = .16$, $\eta^2 = .053$.

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 7.83 +/- 2.21 | 6.27 +/- 2.58 | 5.54 +/- 2.33 | 6.55 +/- 2.52 |
| Performance | 7.00 +/- 2.08 | 5.64 +/- 2.55 | 5.70 +/- 2.73 | 6.12 +/- 2.50 |
| Total | 7.38 +/- 2.15 | 5.93 +/- 2.55 | 5.63 +/- 2.52 | 6.31 +/- 2.51 |

*Table 3.6: Means and standard deviations of square root Peak SSQ scores for participants that showed adaptation.*

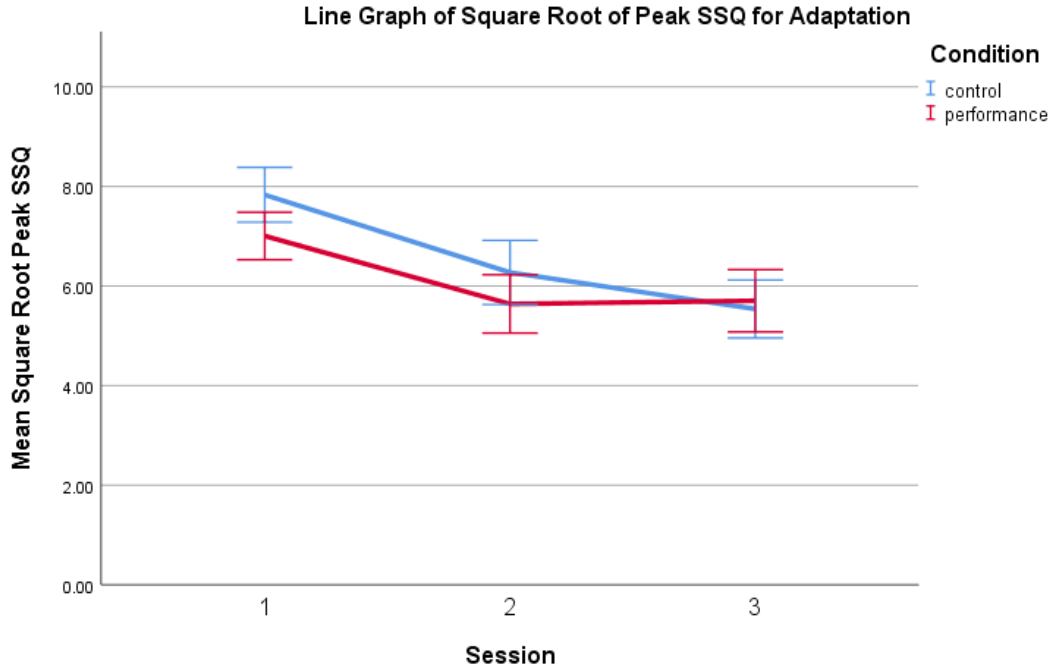


*Figure 3.12: Line graph of mean square root Peak SSQ scores for all sessions by condition for participants that showed adaptation.*

Results were similar when looking at post MSAQ scores for participants who showed adaptation. A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for differences in post MSAQ scores between participants who showed adaptation based on previously stated criteria. Means and standard deviations for these participants are shown in table 3.7. Figure 3.13 shows a line graph of post MSAQ scores for participants who showed adaptation by condition. A main effect of session was observed such that participants had lower peak SSQ scores in session three compared to session one,

($F(1.47, 48.40) = 28.80$, $p < .01$, $\eta^2 = .47$; the assumption of sphericity was violated, so a Greenhouse-Geisser correction was used, changing the within degrees of freedom from 2 to 1.47 and the between degrees of freedom from 66 to 48.40). No main effect of condition was observed, $F(1, 33) = .81$, $p = .38$, $\eta^2 = .024$. A significant interaction was observed such that participants in the control condition showed a steady decrease in symptoms (increase in inverse square root of post MSAQ scores) across sessions and participants in the performance group had symptoms level off in sessions 2 and 3, $F(1.47, 48.40) = 4.13$, $p = .033$, $\eta^2 = .11$.

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 44.94 +/- 21.14 | 32.75 +/- 18.58 | 26.31 +/- 8.52 | 34.67 +/- 18.35 |
| Performance | 35.26 +/- 18.99 | 28.12 +/- 12.48 | 27.11 +/- 13.37 | 30.16 +/- 15.39 |
| Total | 39.69 +/- 20.30 | 30.23 +/- 15.50 | 26.74 +/- 11.27 | 32.22 +/- 16.88 |

*Table 3.7: Means and standard deviations of post MSAQ scores in each experimental session by condition for participants who showed adaptation.*

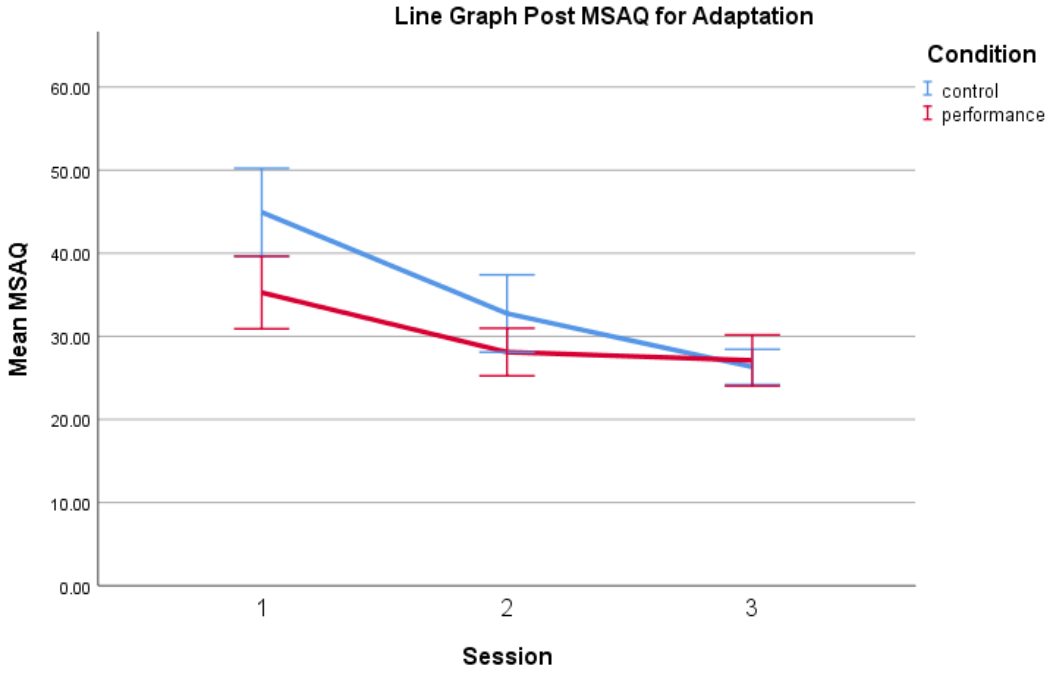


*Figure 3.13: Line graph of post MSAQ scores for all sessions by condition for participants that showed adaptation.*

When examining the sum of SSQ scores for participants who showed adaptation, results were slightly different from the previous two measures. Table 3.8 shows means and standard deviations for the square root of the sum SSQ scores. Figure 3.14 shows a line graph of mean square root of the sum SSQ scores by condition. Once again, a main effect of session was observed such that participants had a lower sum SSQ score in the third session than in the first session, ($F(2, 66) = 40.09$, $p < .01$, $\eta^2 = .55$). However, no main effect of condition or interaction was observed ($F(1, 33) = .052$, $p = .82$, $\eta^2 = .002$; $F(2, 66) = .80$, $p = .45$, $\eta^2 = .024$).

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 14.64 +/- 5.23 | 10.71 +/- 5.04 | 9.43 +/- 3.71 | 11.60 +/- 5.12 |
| Performance | 14.04 +/- 5.19 | 10.98 +/- 5.18 | 10.16 +/- 5.15 | 12.59 +/- 8.20 |
| Total | 14.32 +/- 35.14 | 10.86 +/- 5.05 | 9.83 +/- 4.50 | 12.14 +/- 6.95 |

*Table 3.8: Means and standard deviations for the square root of sum SSQ scores in each experimental session by condition for participants who showed adaptation.*

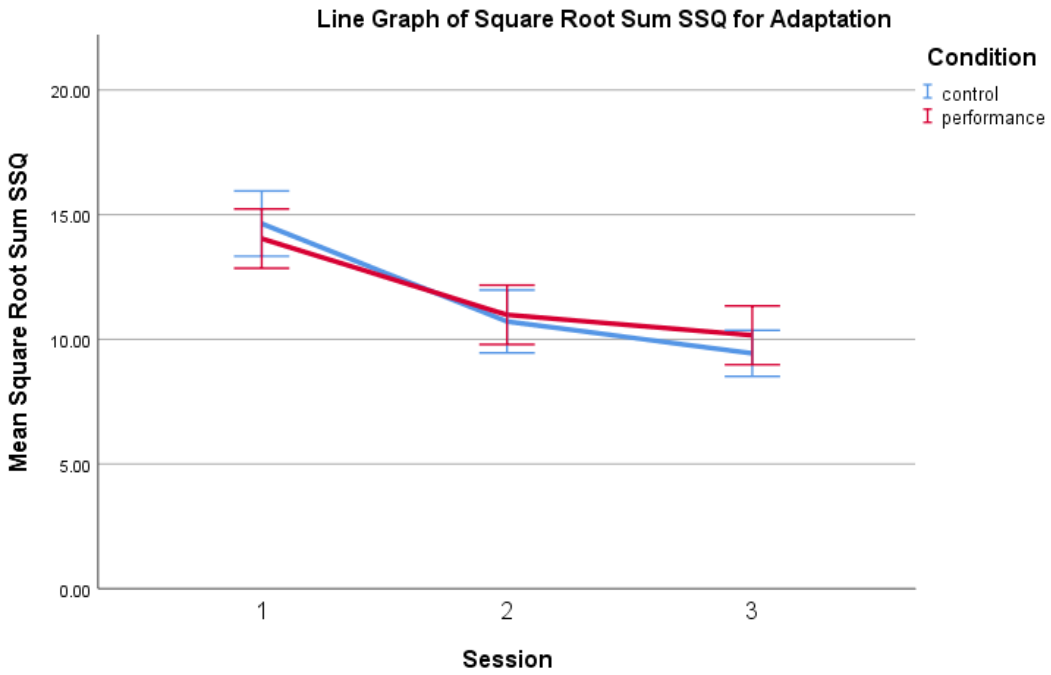


*Figure 3.14: Line graph of mean square root sum SSQ scores for all sessions by condition for participants that showed adaptation.*

**Hypothesis Tests: Postural Sway**

All comparisons were conducted using posture data collected from the experimental blocks *and* the post baseline measure after each experimental session. There was some loss of data due to equipment malfunction during the experiment. When data loss occurred, posture data from that experimental session were not included in the analysis. Analysis for each postural sway measure will include the total number of participants included for that measure. For both of these periods, each thirty-second bin was averaged (elliptical area) or summed across the blocks (path length and normalized path length) to get one average or sum measure for experimental blocks per experimental session or post baseline session.

### *Elliptical Area of Experimental Blocks*

Thirty-four participants (16 control condition, 18 performance condition) had valid elliptical area data from the experimental blocks for all three sessions. Elliptical area was measured in squared centimeters. Elliptical area data for experimental blocks were normally distributed (see Figure 3.15).

*Outlier Analysis.* Interquartile ranges were used to identify potential outliers. A boxplot of elliptical area during experimental blocks was used to examine data for outliers (see Figure 3.16). There were no extreme cases identified so all participants with valid data were used in analysis.

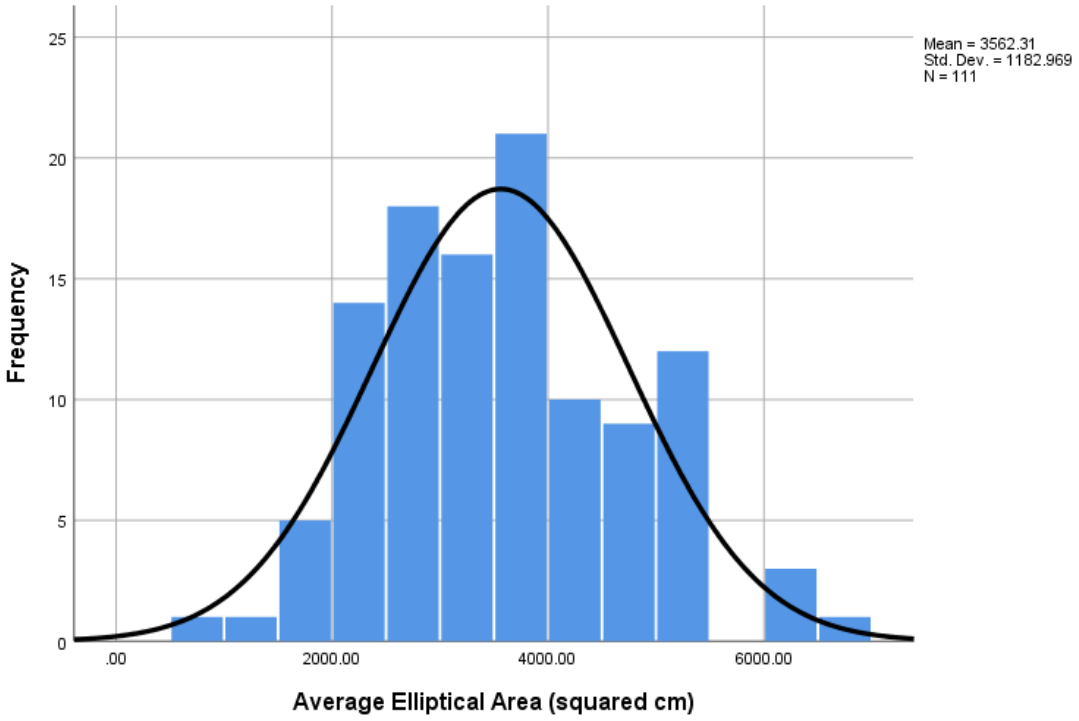


*Figure 3.15: Histogram of average elliptical area for all participants during all experimental blocks.*

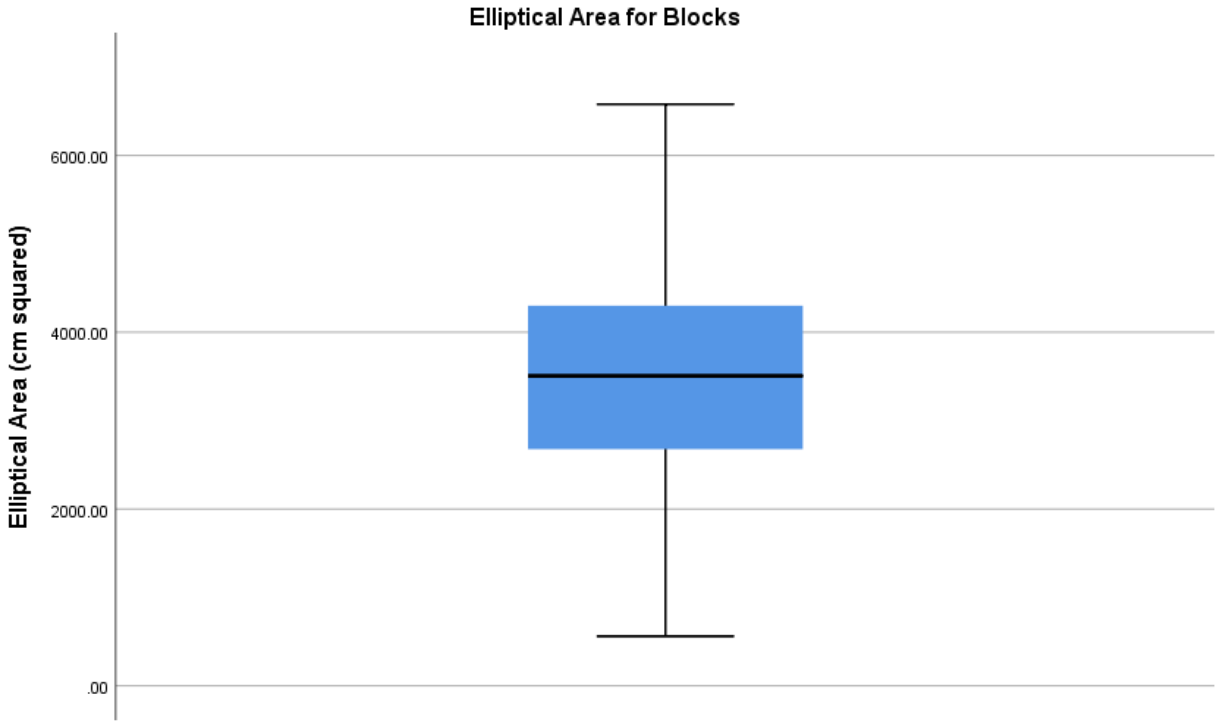


*Figure 3.16: Boxplot of elliptical area ($cm^2$) for participants during experimental blocks.*

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for a main effect of condition, session, and an interaction between the two. Table 3.9 shows means and standard deviations of elliptical area during experimental blocks for all three sessions by condition. Figure 3.17 shows a line graph of mean elliptical area for each session by condition. No significant main effect of session ($F(2, 64) = .39$, $p = .68$, $\eta^2 = .012$) or condition ($F(1, 32) = 1.57$, $p = .22$, $\eta^2 = .047$), or significant interaction were observed ($F(2, 64) = .049$, $p = .95$, $\eta^2 = .002$).

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 3246.86 +/- 1086.31 | 3271.42 +/- 1363.4 | 3401.0 +/- 1020.17 | 3382.09 +/- 1115.78 |
| Performance | 3693.76 +/- 1338.46 | 3797.7 +/- 1169.59 | 3830.35 +/- 1270.93 | 3739.31 +/- 1229.69 |
| Total | 3483.45 +/- 1229.04 | 3550.04 +/- 1273.07 | 3628.30 +/- 1162.97 | 3562.31 +/- 1182.97 |

*Table 3.9: Means and standard deviations for elliptical area for all participants during all experimental blocks.*

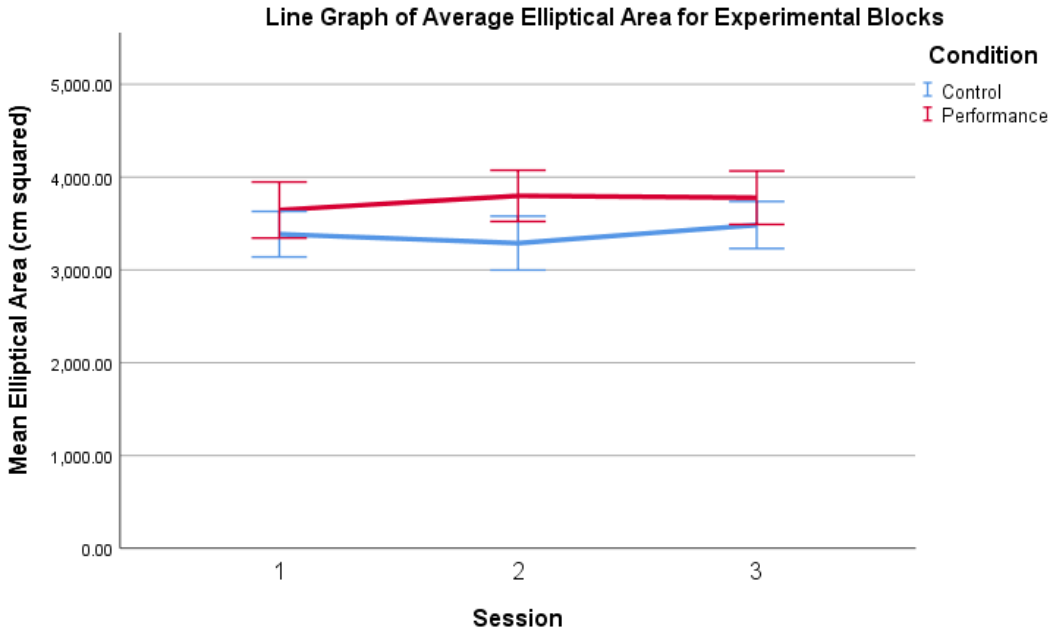


*Figure 3.17: Line graph of mean elliptical area during experimental blocks for all sessions by condition.*

***Elliptical Area of Post Baseline***

Thirty participants (14 control condition, 16 performance condition) had valid elliptical area data for post baseline for all three sessions. Elliptical area was measured in squared centimeters. Figure 3.18 shows a histogram of average post baseline elliptical area for all three sessions. Data does not appear to be normally distributed, so data were

transformed using a natural logarithm. Figure 3.19 shows the transformed distribution showing a normal distribution.

*Outlier Analysis.* Interquartile ranges were used to identify potential outliers. A boxplot of elliptical area during post baseline was used to examine data for outliers (see Figure 3.20). There were no extreme cases identified so all participants with valid data were used in analysis.

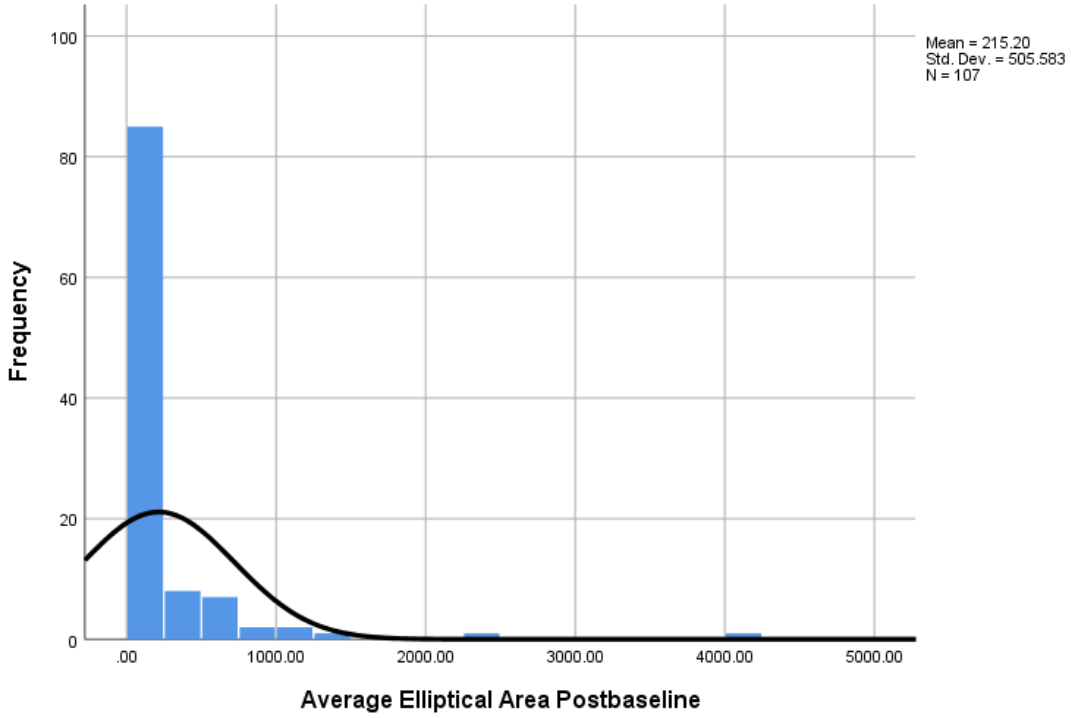


*Figure 3.18: Histogram of average elliptical area of post baseline for all sessions and conditions.*

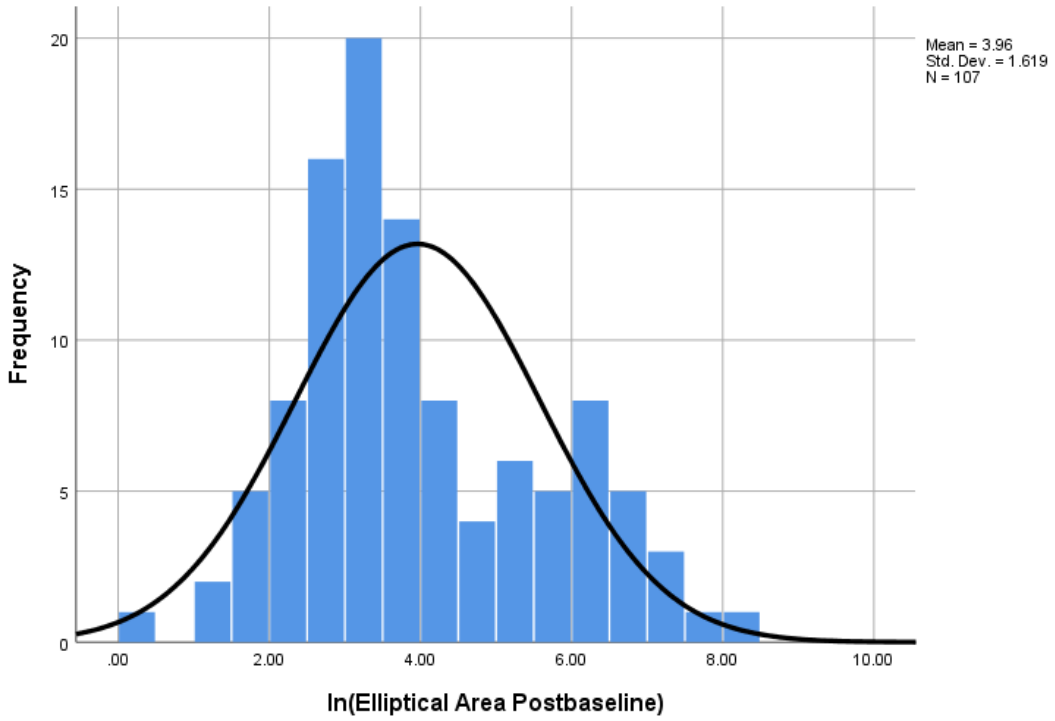


*Figure 3.19: Histogram of natural logarithmic transformation of average elliptical area data from all participants across all sessions and conditions.*

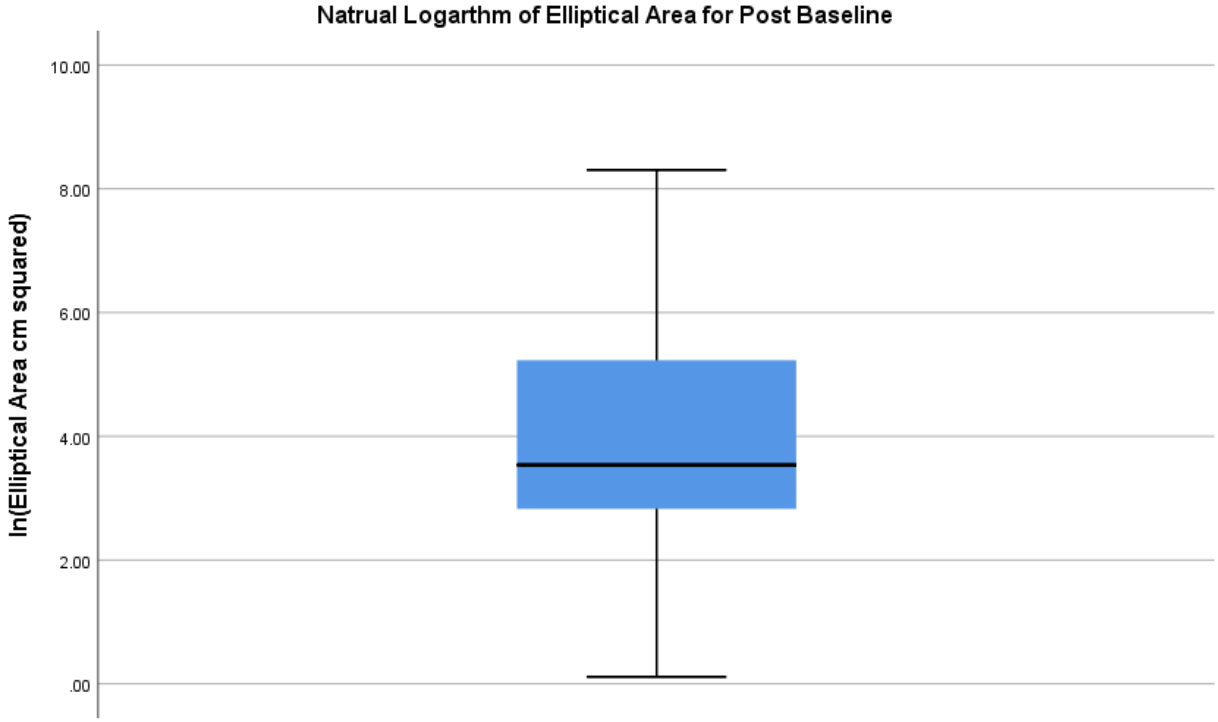


*Figure 3.20: Boxplot of natural logarithm of elliptical area ($cm^2$) from post baseline.*

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for main effects of condition, session, and an interaction between the two for post baseline elliptical area. Table 3.10 shows means and standard deviations of post baseline elliptical area for each condition across sessions. Figure 3.21 shows a line graph of mean post baseline measures for elliptical area by condition for each session. No significant main effect of session ($F(2, 56) = 1.46$, $p = .24$, $\eta^2 = .05$) or condition ($F(1, 28) = .080$, $p = .78$, $\eta^2 = .003$) were observed,. Additionally, no interaction was observed, $F(2, 56) = .054$, $p = .95$, $\eta^2 = .002$).

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 3.81 +/- 1.69 | 4.00 +/- 1.62 | 4.25 +/- 1.57 | 4.03 +/- 1.69 |
| Performance | 3.56 +/- 1.48 | 3.88 +/- 1.86 | 4.22 +/- 1.43 | 3.89 +/- 1.55 |
| Total | 3.68 +/- 1.56 | 3.94 +/- 1.72 | 4.23 +/- 1.47 | 3.96 +/- 1.62 |

*Table 3.10: Means and standard deviations of natural logarithm transformed elliptical area for post baseline for all participants.*

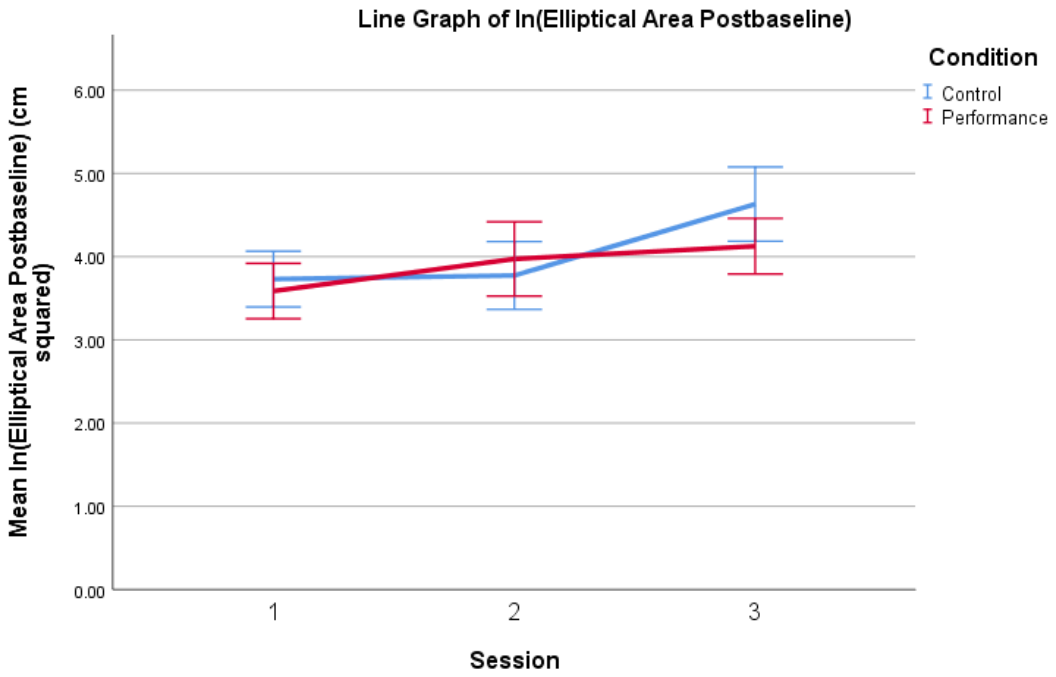


*Figure 3.21: Line graph of mean natural logarithm of elliptical area during post baseline for all sessions by condition.*

***Path Length of Experimental Blocks***

Thirty-five participants (17 control condition, 18 performance condition) had valid data for path length during the experimental sessions. Path length data was summed for each block, and average summed path length of each experimental block was calculated for each experimental session. A histogram of summed path length of experimental blocks shows a negative skew (Figure 3.22). To achieve a normal distribution, data went through a square root transformation (Figure 3.23).

*Outlier Analysis.* Interquartile ranges were used to identify potential outliers. Figure 3.24 shows a boxplot of path length data from experimental blocks. One participant was flagged as being outside three times the interquartile range for path length during the second set of experimental blocks. However, this participant was not

identified as an outlier for sessions 1 or 3. Experimenter notes were checked to see if anything unusual occurred during data collection for that participant and nothing was reported. Therefore, this participant was still included in the analysis.

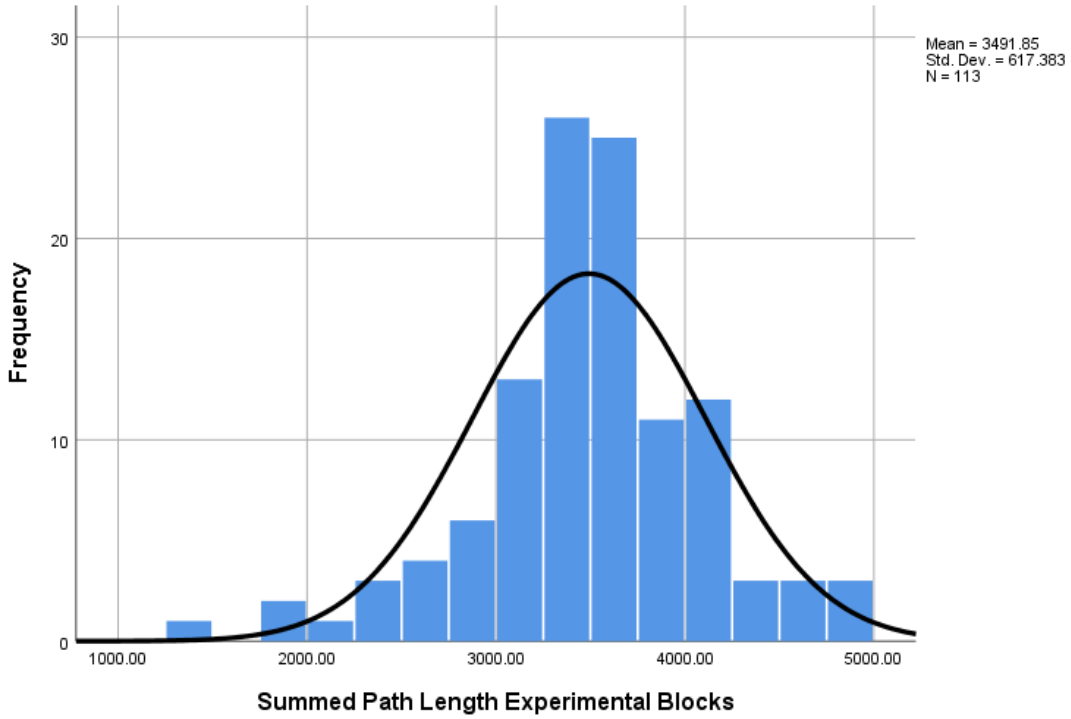


*Figure 3.22: Histogram of average summed path length data from experimental blocks for all participants.*

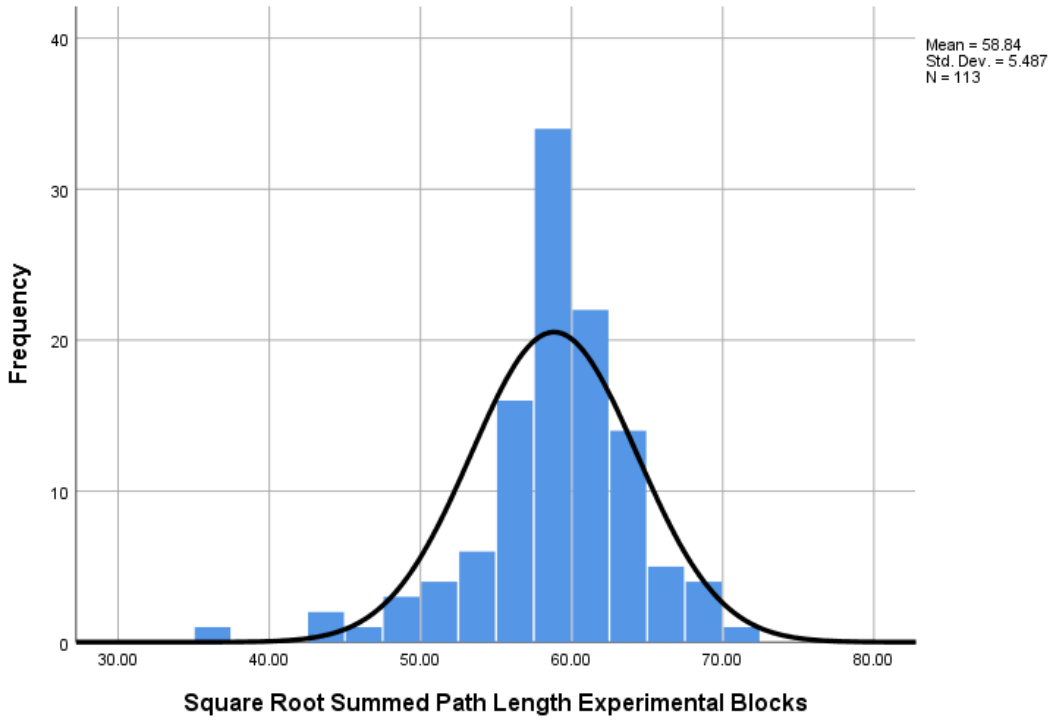


*Figure 3.23: Histogram of square root transformed average summed path length data from experimental blocks for all participants.*

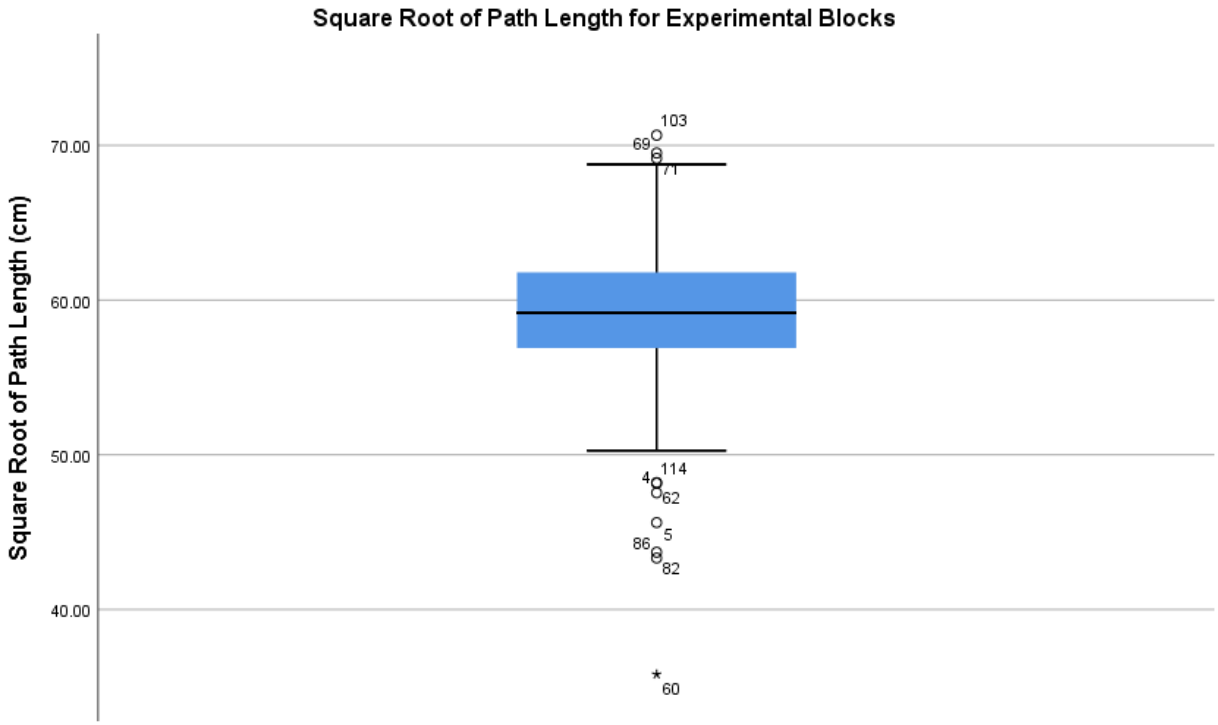


*Figure 3.24: Boxplot of square root of path length (cm) during experimental blocks.*

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for main effects of session and condition and an interaction between the two. Means and standard deviations for the square root of the summed path length for each experimental session can be seen in table 3.11. Figure 3.25 shows a line graph of average square root of summed path length for each session by condition. No main effects of session ($F(2, 66) = .053$, $p = .95$, $\eta^2 = .002$) or condition ($F(1, 33) = .10$, $p = .76$, $\eta^2 = .003$) were observed. No significant interaction were observed $F(2, 66) = .79$, $p = .46$, $\eta^2 = .023$).

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 59.44 +/- 3.94 | 58.23 +/- 7.67 | 60.01 +/- 4.80 | 59.05 +/- 5.54 |
| Performance | 58.44 +/- 5.74 | 59.51 +/- 4.40 | 58.46 +/- 6.28 | 58.62 +/- 5.47 |
| Total | 58.93 +/- 4.90 | 58.89 +/- 6.15 | 59.21 +/- 5.58 | 58.84 +/- 5.49 |

*Table 3.11: Means and standard deviations of square root transformed average summed path length measured in centimeters for all participants from experimental blocks.*

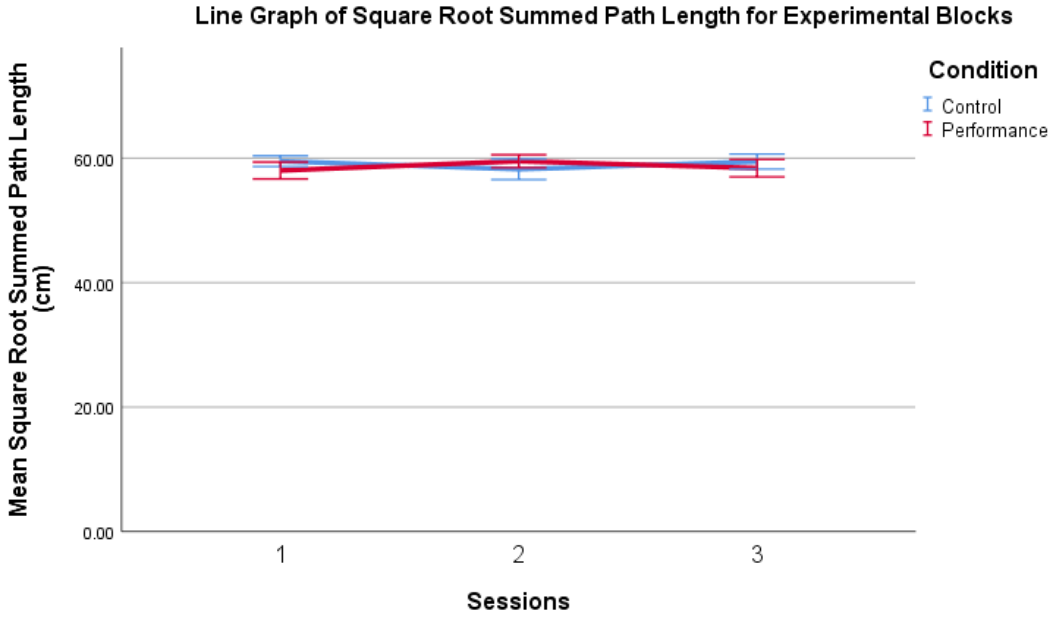


*Figure 3.25: Line graph of mean square root summed path length during experimental blocks for all sessions by condition.*

***Path Length of Post Baseline***

Twenty-eight participants had usable path length data for post baseline for all three sessions. Data were not normally distributed (Figure 3.26), so a logarithmic transform was conducted to achieve a normal distribution (Figure 3.27).

*Outlier Analysis.* Interquartile ranges were used to identify outliers for path length during post baseline measurement. Figure 3.28 is a boxplot demonstrating outlier analysis for path length during post baseline. No participants were identified as potential outliers.

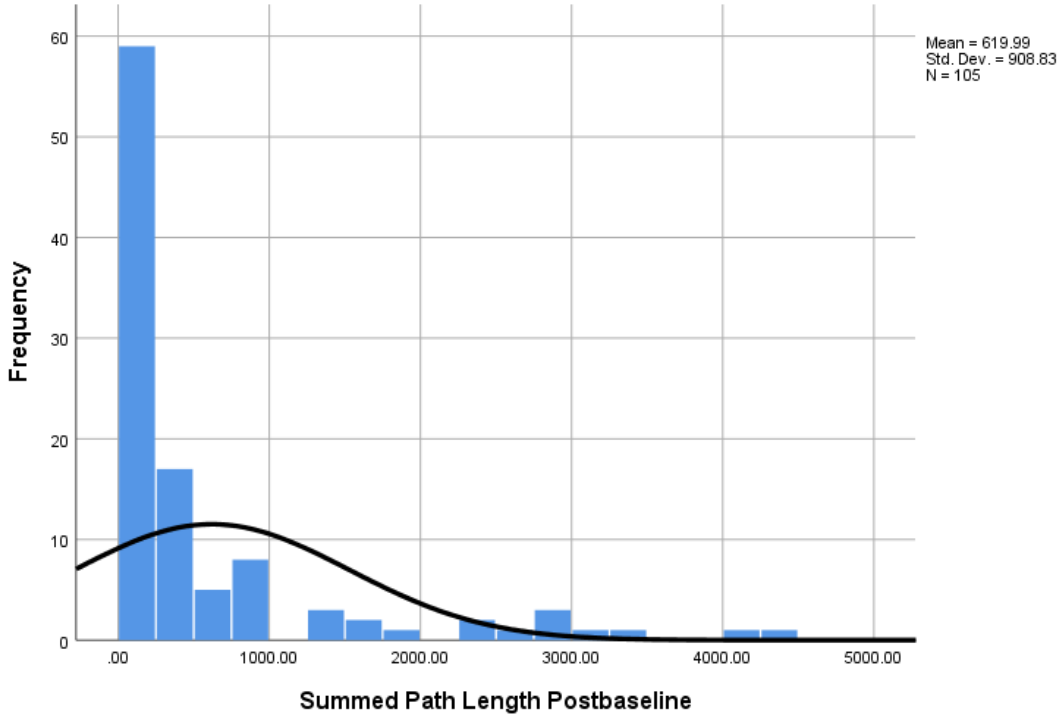


*Figure 3.26: Histogram of average summed path length data from post baseline for all participants.*

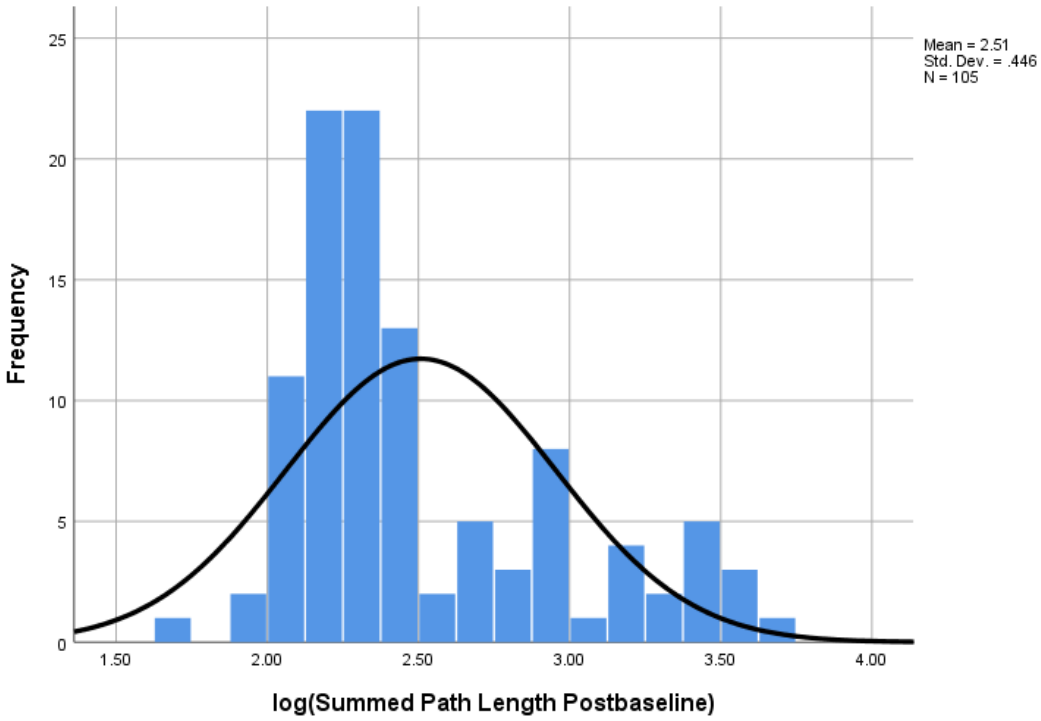


*Figure 3.27: Histogram of the logarithmic transformed average summed path length data from post baseline for all participants.*

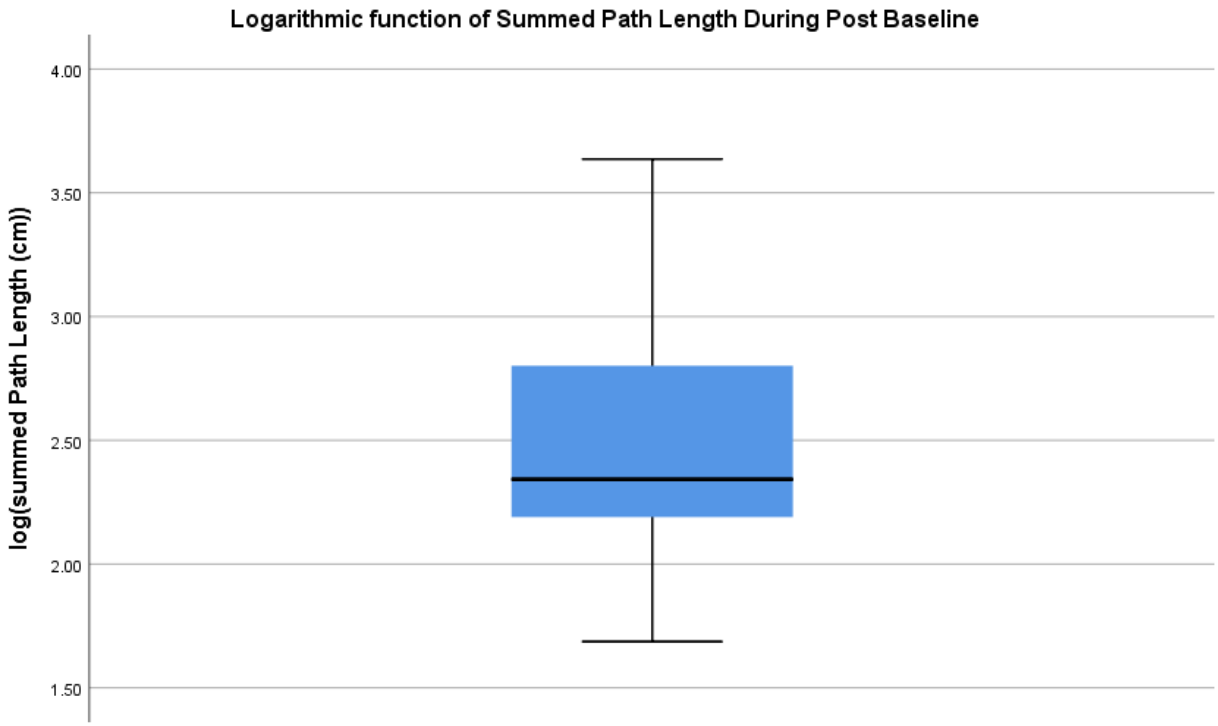


*Figure 3.28: Boxplot of logarithmic function of summed path length (cm) for post baseline.*

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for main effects of condition and session and an interaction between the two for summed path length during the post baseline for each experimental session. Means and standard deviations for post baseline path length can be seen in Table 3.12. Figure 3.29 shows a line graph of summed path length for post baseline by condition across sessions. No significant main effect of session or condition, ($F(2, 52) = .01$, $p = .99$, $\eta^2 = .00$; $F(1, 26) = .32$, $p = .58$, $\eta^2 = .012$. No significant interaction was observed, $F(2, 52) = .76$, $p = .48$, $\eta^2 = .029$).

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 2.62 +/- .62 | 2.51 +/- .46 | 2.48 +/- .36 | 2.54 +/- .48 |
| Performance | 2.40 +/- .41 | 2.49 +/- .48 | 2.52 +/- .38 | 2.47 +/- .41 |
| Total | 2.51 +/- .53 | 2.50 +/- .46 | 2.50 +/- .36 | 2.50 +/- .44 |

*Table 3.12: Means and standard deviations of logarithmic transform of summed path length measured in centimeters from post baseline for all participants.*

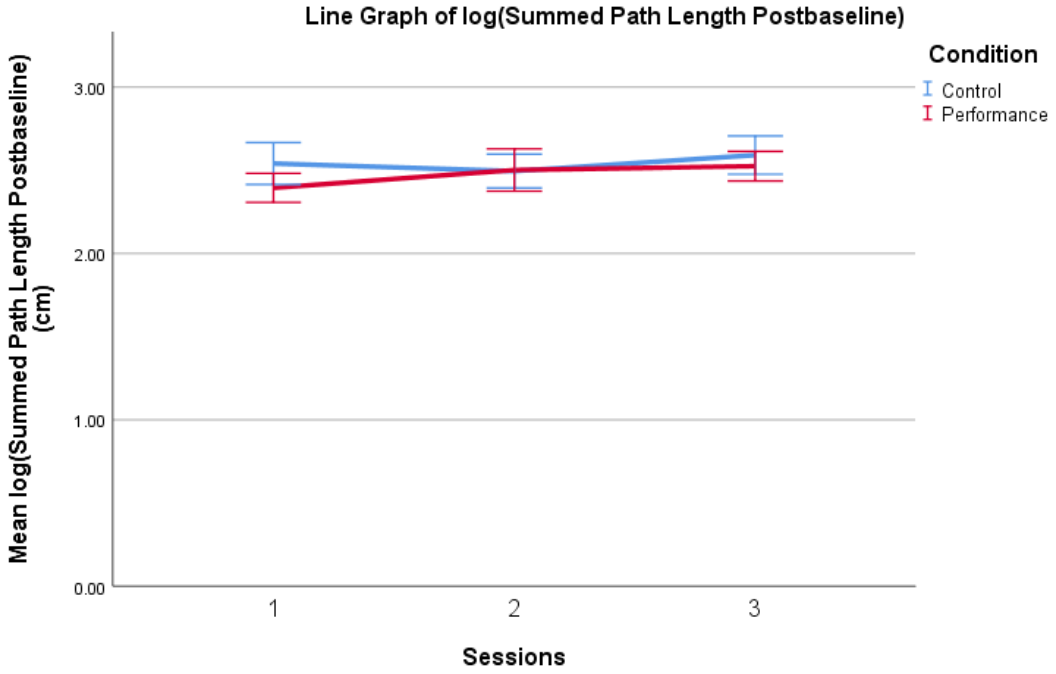


*Figure 3.29: Line graph of logarithmic transformed average summed path length from post baseline for all participants across sessions by condition.*

***Normalized Path Length of Experimental Blocks***

Thirty-four participants (17 control condition, 17 performance condition) had usable normalized path length data during each experimental session. Summed normalized path length data were normally distributed (see Figure 3.30).

*Outlier Analysis*. Interquartile ranges were used to identify potential outliers for normalized path length. Figure 3.31 shows a boxplot of normalized path length during experimental blocks. No participants were identified as potential outliers.

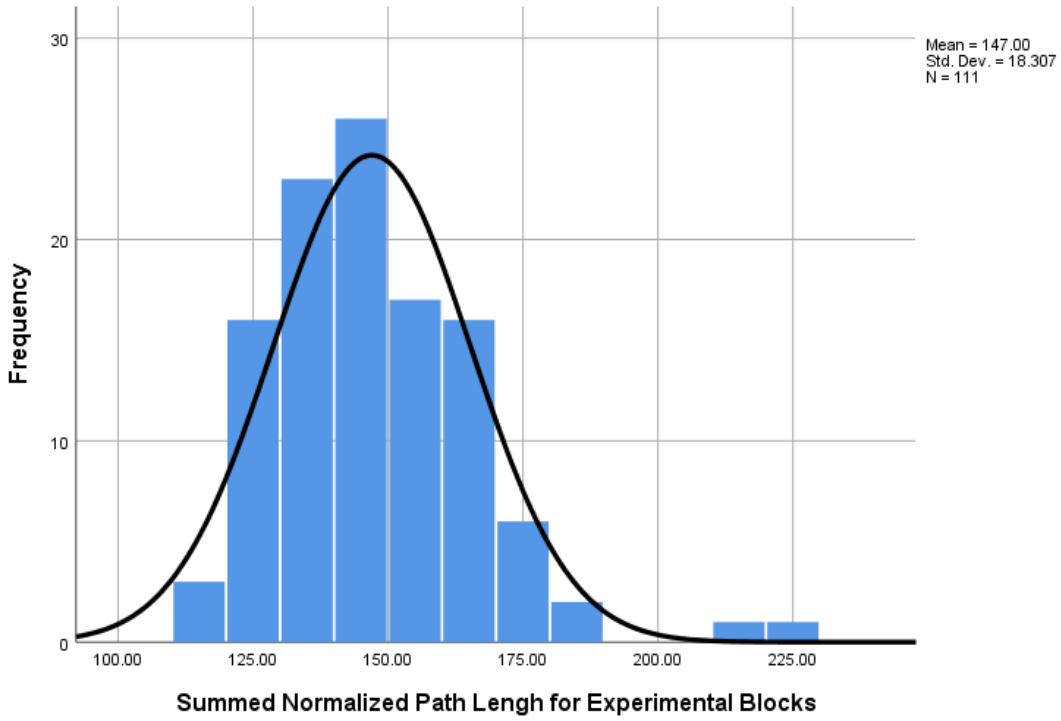


*Figure 3.30: Histogram of summed normalized path length data from experimental blocks for all participants and all sessions.*

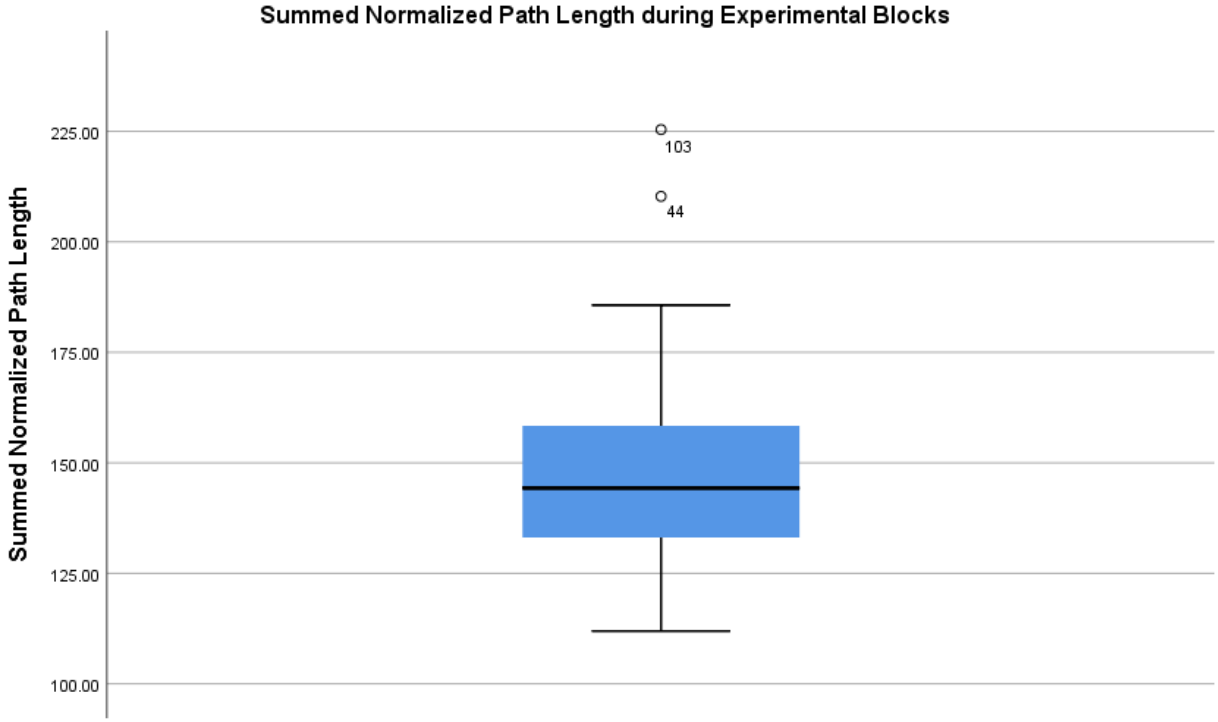


*Figure 3.31: Boxplot of summed normalized path length during experimental blocks.*

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for main effects of session and condition and an interaction between the two for summed normalized path length from the experimental sessions. Means and standard deviations for summed normalized path length from the experimental sessions can be seen in table 3.13. Figure 3.32 shows a line graph of summed normalized path length data for each session by condition. No significant main effect of session or condition were observed ($F(2, 64) = .095$, $p = .9$, $\eta^2 = .003$; $F(1, 32) = .57$, $p = .46$, $\eta^2 = .036$). No significant interaction between condition and session was observed, $F(2, 64) = 1.19$, $p = .32$, $\eta^2 = .036$.

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 149.35 +/- 18.20 | 147.05 +/- 14.78 | 152.55 +/- 22.42 | 148.90 +/- 17.72 |
| Performance | 144.49 +/- 16.07 | 149.93 +/- 22.33 | 143.85 +/- 17.95 | 144.99 +/- 18.87 |
| Total | 146.92 +/- 17.09 | 148.49 +/- 18.70 | 148.20 +/- 20.48 | 147.0 +/- 18.31 |

*Table 3.13: Means and standard deviations for summed normalized path length by condition for all experimental sessions.*

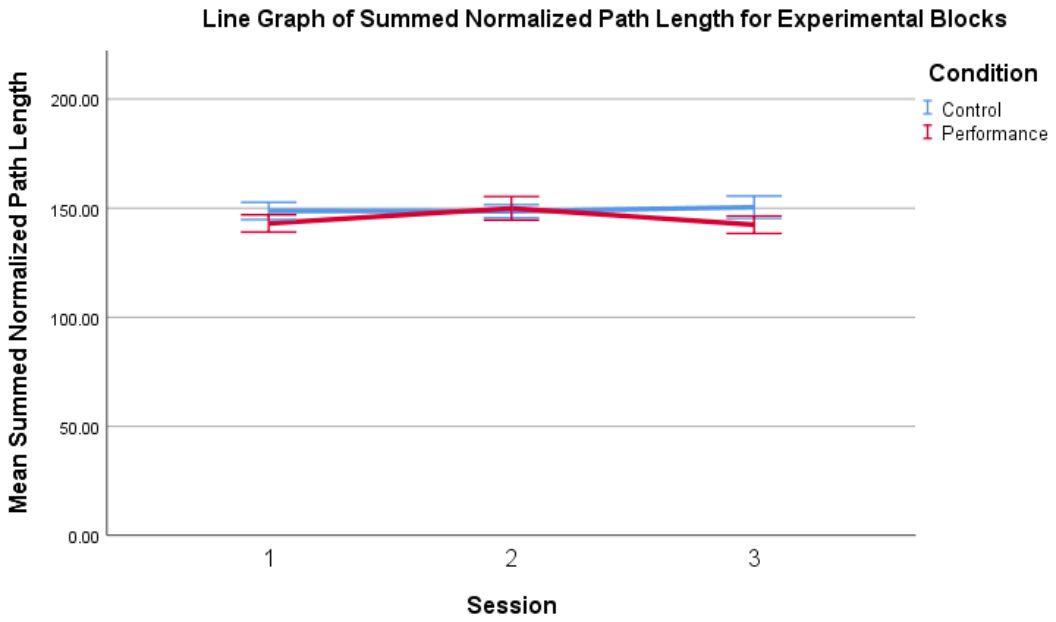


*Figure 3.32: Line graph of mean summed normalized path length during experimental blocks for all sessions by condition.*

***Normalized Path Length of Post Baseline***

Twenty-eight participants had usable normalized path length data from the post baseline for all three experimental sessions. Summed normalized path length data from post baseline were normally distributed (see Figure 3.33).

*Outlier Analysis*. Interquartile ranges were used to identify potential outliers for summed normalized path length during post baseline. Figure 3.34 shows a boxplot of summed normalized path length during post baseline. No participants were identified as potential outliers.

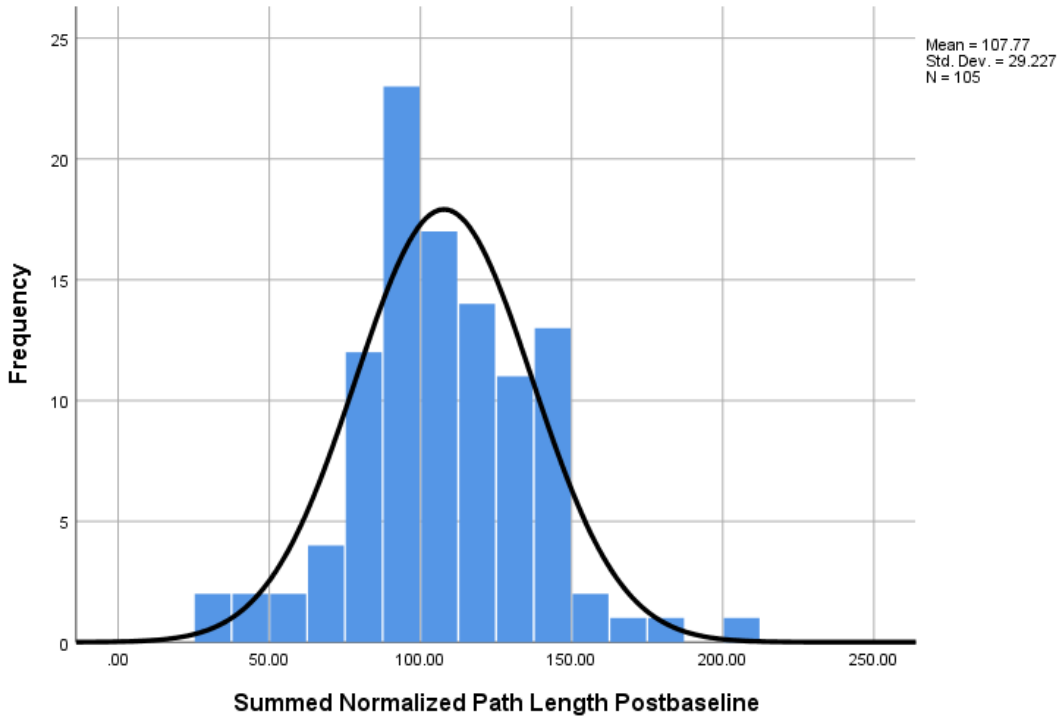


*Figure 3.33: Histogram of average summed normalized path length from post baseline for all participants across all sessions.*

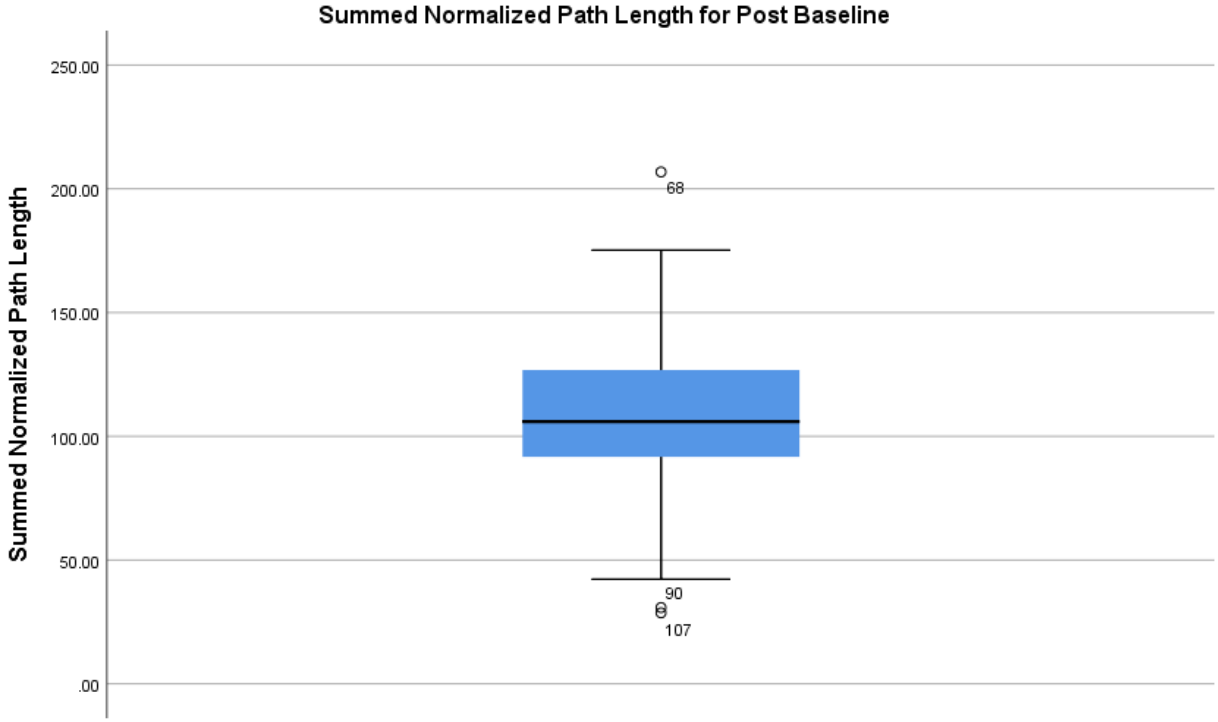


*Figure 3.34: Boxplot of summed normalized path length during post baseline.*

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for main effects of session and condition and an interaction between the two for summed normalized path length from the post baseline. Means and standard deviations for summed normalized path length from the post baseline for each session can be seen in Table 3.14. Figure 3.35 shows a line graph of summed normalized path length for each session by condition. A marginally significant main effect of session was observed, such that participants had lower normalized path length in the third session compared to the first session, $F(2, 52) = 2.95$, $p = .06$, $\eta^2 = .10$. No significant main effect of condition was observed, $F(1, 26) = .26$, $p = .62$, $\eta^2 = .01$. No significant interaction was observed, $F(2, 52) = .66$, $p = .52$, $\eta^2 = .025$.

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 115.46 +/- 26.70 | 109.60 +/- 35.13 | 90.14 +/- 35.55 | 107.29 +/- 32.23 |
| Performance | 113.20 +/- 26.01 | 109.60 +/- 19.75 | 103.65 +/- 33.19 | 108.29 +/- 25.99 |
| Total | 114.33 +/- 25.89 | 109.60 +/- 27.96 | 96.90 +/- 34.44 | 107.77 +/- 29.22 |

*Table 3.14: Means and standard deviations for summed normalized path length from post baseline for all participants.*

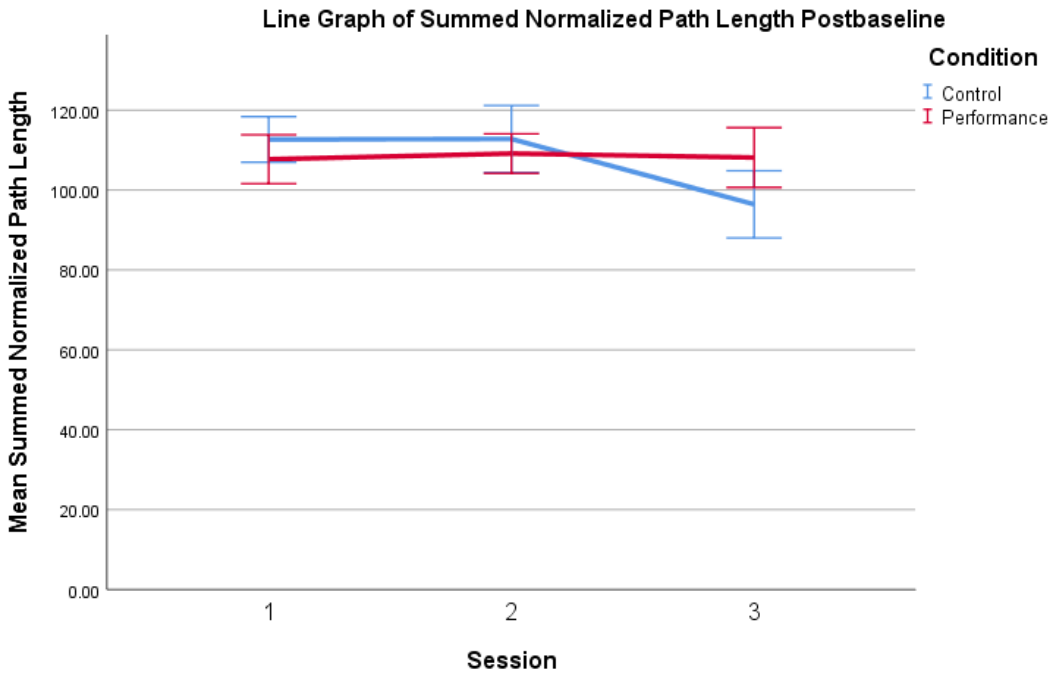


*Figure 3.35: Line graph of average summed normalized path length for all participants across sessions by condition.*

**Exploratory Analysis: Postural Sway**

***Posture Data Split by Adaptation***

Posture data was split by adaptation using the same adaptation criteria that was used for self-reported sickness data. Because normalized path length was the only measure that resulted in significant effects, normalized path length for participants that showed adaptation is the only posture measure explored more.

***Normalized Path Length***

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for main effects of condition and session and an interaction between the two for normalized path length for participants that showed adaptation. Means and standard deviations for summed normalized path length for participants that showed adaptation can be seen in

Table 3.15. Figure 3.36 shows a line graph of summed normalized path length for participants that showed adaptation by condition across sessions. A main effect of session was observed such that on average, a lower summed normalized path length was observed during the post baseline in the third session compared to the first, $F(2) = 3.408$, $p = .042$, $\eta^2 = .134$. No main effect of condition was observed, and means trended opposite of the predicted direction, such that participants in the control condition had lower summed normalized path length compared to participants in the control condition, $F(1) = 1.07$, $p = .32$, $\eta^2 = .046$. No significant interaction was observed, $F(2) = 1.23$, $p = .30$, $\eta^2 = .053$.

Further analysis of postural sway data can be seen in Appendix N.

| | Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| Control | 117.54 +/- 29.36 | 106.50 +/- 38.46 | 83.36 +/- 34.69 | 104.97 +/- 34.51 |
| Performance | 114.78 +/- 26.37 | 111.24 +/- 19.54 | 106.11 +/- 33.19 | 109.79 +/- 25.96 |
| Total | 116.-5 +/- 27.19 | 109.06 +/- 29.13 | 95.68 +/- 35.10 | 107.57 +/- 30.12 |

*Table 3.15: Means and standard deviations for summed normalized path length during post baseline for participants that showed adaptation.*

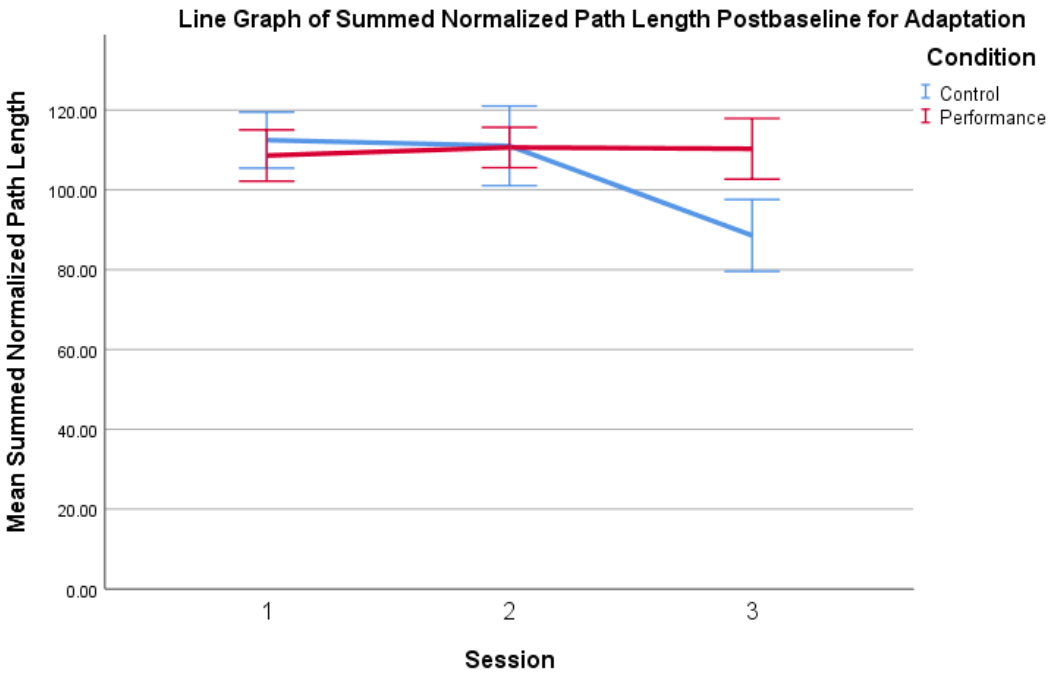


*Figure 3.36: Line graph of summed normalized path length from post baseline for participants that showed adaptation.*

# CHAPTER FOUR

# DISCUSSION

## Primary Purpose

The purpose of this study was two-fold: 1) to determine if participants could adapt to base latency in a head mounted display and 2) to determine if performing an active point and shoot performance task would facilitate greater adaptation than a passive object location task. It was predicted that participants would be able to adapt after three exposures to the stimulus, each separated by 48 hours. It was also predicted that participants who performed the active point and shoot task would show greater adaptation through less subjective sickness and postural sway in the third session compared to the participants who only performed the object location task for all three exposures.

## Effect of Time on Adaptation

A main effect of time was hypothesized such that participants would have less sickness and less sway in the third session compared to the first session. The subjective sickness data supported this hypothesis, as there was a reduction in peak SSQ, post MSAQ, and sum SSQ scores in the third session compared to the first session, regardless of what condition participants were assigned to. This supports previous findings from the literature that state repeated exposures to a challenging stimulus can lead to adaptation to that stimulus (Reason & Brand, 1975; Reason, 1978; Parker & Parker, 1990). Specifically, it has been shown that three exposures separated by 48 hours is the ideal spacing and number of exposures for motion sickness adaptation to occur (Stern, et al., 1989). The present study collected data over three sessions separated by 48 hours based

on that previous finding, and provides evidence that this exposure spacing can be generalized to simulator sickness as well.

Though the current findings support previous research stating participants can adapt after three exposures, not all participants showed adaptation. Further, many participants were not "fully" adapted to the stimulus after the third exposure, meaning they still would have passed the sickness screening after the third session that was done in the first session. Five participants, or 12.5% of the sample, did not show any reduction in sickness symptoms when comparing the third session to the first session. Additionally, only 13 participants, or about 33% of the sample, "fully" adapted, meaning they had sickness scores at or below the screening cut off at the end of the third session. This spread in adaptation adds to the notion that adaptation to simulator sickness is a complicated issue. While there is evidence that three experimental sessions are sufficient for adaptation, perhaps some participants needed more experimental sessions for adaptation to occur. Kennedy and colleagues claim that more exposures are needed for adaptation (Kennedy, Stanney & Dunlap, 2000), and perhaps more participants would have shown full adaptation if they participated in more experimental sessions. Additionally, Reason and Brand (1975) claim that *continuous* exposure to the challenging stimulus is necessary for adaptation to occur. Based on that research, lengthening the session time to provide continuous exposure may have led to more adaptation in participants.

While results from this experiment support previous findings that adaptation is possible, it is also adds to the literature that not everyone will be able to adapt to a

challenging environment and reduce or eliminate sickness symptoms. Reason and Brand (1975) state that about 5% of the population will never be able to adapt to motion sickness. In this study, 12.5% of participants did not show a reduction in simulator sickness after the third experimental session. As stated previously, perhaps more sessions or continuous exposure would have led to more participants showing adaptation. However, it is not unreasonable to expect that some participants will never adapt to simulator sickness resulting from an HMD. Furthermore, the 5% of the population estimate may be variable when considering differences between motion sickness and simulator sickness as a result of HMDs. HMDs bring their own set of challenges with respect to simulator sickness. HMDs have been shown to have challenging characteristics and it is known that just wearing an HMD can lead to simulator sickness in users (Moss, Scisco, & Muth 2008). Additionally, varying latency is a known factor in HMDs, and varying latency has been linked to simulator sickness (Wu, Dong, & Hoover, 2015; St. Pierre, et al., 2016, Kinsella, et al., 2016). Due to these extra factors, it is possible that more than 5% of the population might have trouble adapting to simulator sickness resulting from HMDs. If this is true, then findings from the current experiment may not be far off from what would be expected. This should be further explored in future studies incorporating a larger, broader sample size, with exposure time and number of sessions as independent variables.

**Effect of Performance Task on Adaptation**

It was hypothesized that there would be a main effect of condition on sickness such that participants in the performance task condition would show greater adaptation

than participants in the control condition. Neither sickness scores nor postural sway data supported this hypothesis. No significant main effects of condition were observed for peak SSQ, post MSAQ, or sum SSQ, or postural sway measures. Further, when data were split and only participants who adapted were examined, there still was no significant main effect on condition observed for any of the self-reported sickness measures. Interestingly, when looking at sickness scores for the participants in the control condition, there is a steady decrease from session one to session two and session two to session three. However, when looking at the performance condition, there is a decrease from session one to session two, but not from session two to session three. In some cases this led to a significant interaction, which will be discussed in the next section.

There was no evidence to support the hypothesis that completing an active performance task would allow participants to learn more about the challenging environment in the HMD through feedback and therefore show more adaptation. Literature agrees that when it comes to adaptation, making active movements while experiencing a provocative stimulus is better than passively observing the stimulus (e.g., Held, 1965; Welch, 1969; Reason & Benson, 1978). Surprisingly, results from this experiment do not support these findings. In this case, the performance task was meant to facilitate a new way to interact with the provocative environment (base latency in an HMD) by allowing participants to actively point, as well as get visual feedback from the laser pointer, and audio feedback from the target. However, participants were only able to actively engage with the environment during the second session, and had to experience it passively during the first and third. Perhaps transferring any knowledge gained from

the active session was not possible when participants went back to experiencing the environment passively in the third session. Literature on transfer of adaptation agrees that transferring adaptation from one stimulus to another is difficult, can require pre-adaptation training, and in some cases can depend on the individual (Mouloua, Smither, & Kennedy, 2005). While the stimulus did not differ in the current experiment, interaction with the stimulus differed by condition. It was expected that participants would transfer any knowledge gained the active task to the passive task. Perhaps for this to occur, participants should have received pre-adaptation training. A small amount of pre-adaptation training occurred in the current experiment through a one-minute practice block. However, a previous study found that five blocks of trials with 200 total target presentations were necessary for participants to perform this specific task at a ceiling effect (Wilson, 2016). The current study only gave participants a one minute practice block consisting of 20 target presentations, only 10% of what was deemed necessary to learn the task. Participants did not go through an in depth training period for this experiment because the focus was on them interacting with the environment, not on performance. Additionally, it was hypothesized that regardless of whether participants were still learning the task, they would still be getting new and valuable feedback from performing it. However, maybe more extensive training is necessary, as the learning curve for the task may have served as a distraction for participants in the performance task condition.

Finally, perhaps the reason there was no significant difference between the object location task and performance task is because the tasks themselves were not different

enough. While the performance task involved shooting a laser pointer, both tasks involved making head movements to find objects around the laboratory. Perhaps the performance task did not offer more or different feedback compared to the object location task. Results from this study demonstrated that adaptation occurred regardless of the task the participants performed. Maybe this was because both tasks were similar in nature with respect to the feedback participants received.

**Interaction between Condition and Session**

A significant interaction between condition and session was hypothesized such that participants in the performance task condition would experience more adaptation sooner compared to participants in the control condition. Research has shown that active target-pointing tasks can lead to more complete adaptation than passive tasks in a challenging environment (Welch, 1969). However, this hypothesis was not supported as the observed interaction in post MSAQ by adaptation was opposite of the predicted direction. When looking at participants that showed adaptation, a significant interaction was observed for post MSAQ scores such that participants in the performance task condition showed a decrease in sickness from session one to session two, but no change between session two and session three. Conversely, participants in the control condition showed a steady decrease in sickness scores across all three sessions. While there was not a significant interaction for peak SSQ scores, the means for this measure trended in the same direction as post MSAQ. This finding suggests that participants in the performance condition felt less sick during their second session when actively performing a task than they did for the first session, but when they went back to the passive task for

the third session, their sickness did not continue to decrease. However, participants in the control condition showed a decrease in sickness each time they came back to the lab.

One explanation for these results is that instead of engaging *more* with the challenging environment by actively shooting targets with a laser pointer, maybe the performance task served a distraction from the challenging environment, leading to lowered sickness scores during that part of the experiment only. Reason and Brand claim that motion sickness can decrease when one's attention is focused on something other than the challenging stimulus (1975). More recently, it was found that both physical and cognitive distraction led to a reduction in motion sickness (Bos, 2015). The performance task in this experiment was both cognitive, in that it was novel to the participants, and physical, in that participants had to move their body to successfully perform the task. Both aspects could have created a distracting element for the participants when completing this task, leading to a reduction in sickness symptoms from distraction, not adaptation. As previously mentioned, more extensive training may have alleviated the distracting nature of the performance task, but further research is needed to examine this.

**Postural Sway**

No significant main effects of session or condition or interactions between the two were observed when looking at participants' postural sway during the experimental blocks. This result demonstrates that participants' magnitude and spatial complexity of postural sway stayed consistent, regardless of what session or condition they were in. While it was hypothesized that a reduction in postural sway would be observed as adaptation occurred, this was not the case during the experiment. When thinking about

the nature of the task, this finding is not surprising. Magnitude of sway, measured by elliptical area and path length represent the amount of movement during the experimental task (Smart, Stoffregen, & Bardy, 2002; Stoffregen et al. 2000; Stoffregen and Smart, 1998; Smart, et al., 2014). Spatial complexity, measured by normalized path length, examines participants' twisting and turning in their postural sway (Donker et al., 2007; Donker et al., 2008). During the experimental blocks, participants were guided through a series of head movements, and to successfully perform the task, they were required to move in a specific way. Even in the second session when the performance task was performed by half of the participants, the order of the targets was the same, and participants still had to move in a similar way to what they did during the object location task. Because participants are moving in a predictable, prescribed way in all experimental sessions, it follows that no difference was found between these measures regardless of condition. This has been observed in previous studies in which the same task was used (Kinsella et al., 2017).

Due to the predictability of movement during the experimental blocks, postural sway was also analyzed during a two-minute post baseline. This occurred immediately after the experimental sessions. Participants were still wearing the HMD and were asked to look straight ahead for two minutes. No main effects of condition or session, or interactions were observed for magnitude of sway, measured by elliptical area and path length. This indicates that regardless of condition or session, participants had the same amount of postural sway movement during the two-minute post baseline. This finding is surprising after observing a main effect of session when looking at self-reported sickness

scores. Postural instability has been shown to precede sickness in some cases, and changes in sway, specifically in the amount of sway may lead to less postural control (Riccio & Stoffregen, 1991; Stoffregen & Smart, 1998). Based on previous research, it was expected that more postural instability, shown by greater magnitude of sway, would be observed after the first session compared to the third session, because more sickness was observed in the first session compared to the third session. However, in studies looking at postural sway magnitude and sickness, there have been no causal relationship identified between sickness and magnitude of sway. Perhaps changes in sway associated with sickness were actually caused by other factors, such as time or expermental task.

There was a main effect of session observed in spatial complexity of sway, measured by normalized path length, when looking at postural sway during post baseline. Overall, participants had less spatial complexity in their postural sway after the third session compared to the first session. This suggests that participants had less twisting and turning in their postural sway and more postural stability after the third session compared to their first session. This result provides more evidence that participants did indeed show adaptation after repeated exposures, as an increase in normalized path length has been associated with an increase in sickness (Smart, et al, 2014). Therefore, higher normalized path length after the first session compared to the third indicates participants felt sicker after the first session and then adapted as time went on in the third session. This is an objective finding showing adaptation that corroborates the main effect of session found in the self-reported sickness measures.

Only a main effect of session from postural sway measures adds to the findings from self-reported sickness measures that in this experiment, repeated exposure to the challenging environment was more important than the interaction with the environment. One reason why only one measure of postural sway was significant could be because of the screening criteria of this study. Typically in studies that examine postural sway and sickness, participants are separated into "sick" and "well" groups based on their experienced sickness (Smart et al., 2014). The "sick" group consists of participants that felt symptoms of simulator sickness and the "well" group consists of participants that felt no symptoms. These studies examine differences in posture between the two groups. It is possible that since participants must have experienced some sickness in order to pass the screening for the current study, the "well" group may have been screened out, and therefore not many differences were observed in postural sway measures. To further assess this, an analysis comparing participants who did not show adaptation to participants who demonstrated full adaptation can be seen in Appendix O. This analysis mimicks that of the "sick" (no adaptation) and "well" (full adaptation) groups.

**Sickness and Postural Sway**

Together, both self-reported sickness and postural sway measures tell a more complete story on adaptation to simulator sickness from this experiment. Both measures provide evidence that adaptation occurred. Participants felt less sick over time based on self-reported sickness symptoms, and participants had more spatial complexity in their postural sway after the first session than they did after the third session, again indicating they felt better as time went on. However, there is no evidence supporting a main effect

of condition from either self-reported sickness symptoms or postural sway. The performance task did not lead to more adaptation or changes in postural sway. In fact, it may have done the opposite as participants in the performance task condition did not continue to adapt in session three as those in the control condition did. While an interaction was predicted, the direction observed was not expected. Participants in the performance condition only showed adaptation from the first to the second session, and did not adapt further from the second to the third, while participants in the control condition consistently adapted to sickness in each session. Additionally, there were no observable differences between performance and control participants during the second session. Therefore, the performance task likely acted as a distraction for participants during the second session. If the performance task was helping participants adapt, there should have been an observable change in postural sway, as well as a continued decline in sickness scores in the second and third sessions.

While sickness scores did decrease in the second session for both conditions, participants in the performance task did not continue to experience a decrease in the final session. Perhaps this was because their attention was directed away from their sickness during the second session and onto the performance task, but then turned back to their sickness during the third session when they had nothing to distract them. Because participants were directing their attention outward towards an active task, participants were not experiencing as severe sickness symptoms as they did in the first session. However, in terms of sensory conflict theory, in order for adaptation to sickness to occur, participants must be exposed to the sickening stimulus multiple times (Groen, 1960;

Guedry, 1965; Reason, 1969; Reason, 1978). If participants were distracted during the second session, they may not have received the experience they needed with the challenging environment to overcome the sensory conflict from that environment in the next session (Reason & Brand, 1975; Reason, 1978). Without this experience, they would continue to feel sickness symptoms as a result of the challenging environment until they can form perceptual rearrangements that match the challenging environment to what they would expect to happen based on their experience in the real world.

**Limitations and Future Work**

The current experiment had a few limitations that should be noted. First, the sample population was primarily undergraduate students from Clemson University. This led to a very narrow age range among participants and limited diversity across the participant pool, both of which have been shown to affect motion sickness susceptibility (Golding, 2006). For more generalizable results, future studies should aim to recruit a broader sample population.

This experiment was a mixed design, with condition as a between subjects variable. This could lead to individual differences playing a role in the findings. Participants were screened to try to achieve a minimum sickness cutoff, but there was no maximum sickness cutoff, and therefore there were some differences in experienced sickness in the first session. Overall there were no effects of condition, but when looking at the means, the performance condition had lower mean self-reported sickness scores in the first session than the control condition. Participants were randomly assigned to control or performance conditions after they passed the screening in the first session, but

since data collection was occurring continuously, sickness scores from the first session could not be balanced across conditions. A future study could control for this by having a separate screening session not included in the experimental sessions, and screening all participants before collecting data in the experimental sessions. This way, sickness scores from the screening session could be balanced across condition assignment. The current experiment was not able to utilize this design due to time and resource constraints.

Another limitation from this study is that participants were only exposed to the challenging environment for three experimental sessions. While this has been shown to be enough for adaptation to motion sickness to occur in the past (Stern et al., 1989), other researchers have claimed different strategies (e.g. continuous exposure, Reason & Brand, 1975) work better for adaptation. Additionally, previous studies have focused on adaptation to motion sickness either through slow-rotating rooms or optokinetic drums. Adaptation to simulator sickness using an HMD to induce simulator sickness has not been examined, and because of this, perhaps a broader paradigm should have been used to look for adaptation. In the future, studies should incorporate exposure time and number of experimental sessions as independent variables to better identify optimal circumstances for adaptation to simulator sickness induced by an HMD.

Finally, while the experimental task has been used and published many times (Moss, Scisco, & Muth, 2008; St. Pierre, et al., 2015; Kinsella, et al., 2016, Kinsella, et al., 2017), there are some limitations associated with it. The current experiment changed the previously published paradigm slightly to incorporate posture baselines before and

after the experimental blocks. The changes resulted in over 20 minutes of standing for participants in each experimental session. This could be a possible confound in the data, as the potential for locking knees, or uncomfortable nature of standing in one spot for too long could have led participants to feel more light-headed, fatigued, or some other symptom of simulator sickness resulting from the experimental task and not the base latency in the HMD. For the most part, participants were asked to perform the same experimental task each time they came in (except for the second session for participants in the performance condition). Some participants quickly grew bored of the task, leading to an increase in "difficulty focusing" and "difficulty concentrating" items in the SSQ. These feelings were noted by the experimenter during data collection. While it was necessary to keep the HMD exposure the same across experimental sessions, changing the task slightly from session to session might alleviate boredom in participants. For example, head movements could remain the same, but object placement in the room could change between sessions. Or, new objects could be switched in for old objects between sessions, just to change things slightly for participants. Anything that could make the passive object location task slightly more engaging for participants may have alleviated boredom and resulted in more engagement with the task, potentially leading to more adaptation.

The current study only examined base latency in the HMD. Since participants showed adaptation to base latency, a logical next step is to examine whether adaptation to varying latency is possible. It has been shown that varying latency is innate in head-tracked HMDs (Wu, Dong, & Hoover, 2013). Varying latency is thought to contribute to

simulator sickness, so developing an adaptation paradigm can be valuable (St. Pierre, et al., 2015; Kinsella, et al., 2016). This can be examined using a similar 2 x 3 mixed design as the current experiment. However, since there were no main effects of the performance task, the next study should eliminate this variable and only look at passive exposure over three experimental sessions. See Table 4.1 for a study design that could examine this question.

| | Session 1 | Session 2 | Session 3 |
|---|---|---|---|
| Base Latency (replication of current findings)<br>N = 20 | OL | OL | OL |
| Varying Latency<br>N = 20 | OL | OL | OL |

*Table 4.1: Overview of 2 x 3 mixed ANOVA design, the proposed design for next experiment to examine whether adaptation to varying latency is possible. "OL" stands for object location task.*

**Conclusion**

In conclusion, results from this study provide evidence that adaptation to base latency in an HMD is possible with multiple exposures. Adding an active point and shoot task did not facilitate more complete adaptation. In fact, the point and shoot task may have served as a distraction and deterred adaptation among participants in that condition. While this study found evidence that adaptation is possible, further investigation is needed to better understand optimal adaptation conditions for users in an HMD with base latency. This is important because HMDs are becoming more prevalent for both recreational and professional purposes (Lewis, 2015). Training protocols are implementing mixed reality paradigms using HMDs for immersive and realistic training environments. However, it is known that prolonged HMD use can cause side effects such as simulator sickness and performance decrements, which is not optimal for transfer of

training. Having a better understanding of adaptation to side effects such as simulator sickness can have tremendous implications for fields such as training in which HMD use can be critical. It is important for scientists and technology developers to understand this work, as well as continue to investigate adaptation to sickness to improve user experience in HMDs.

# APPENDICES

# Appendix A

## Theories of Motion Sickness

### Sensory Conflict Theory

Sensory conflict theory is the most widely accepted theory of motion sickness. Reason and Brand (1975) theorized that motion sickness is a result of conflicting inputs from visual, vestibular, or proprioceptive motion cues in a current experience compared to a recent past experience, or a mismatch between inputs of these systems. These conflicts are usually between the visual and vestibular system. It is important to note that expectation plays a role in the conflict—the conflict exists between what is expected to happen in a given situation, based on a previous experience. Reason (1978) explains there are two important components of sensory conflict theory. First, all instances of motion sickness are caused by differing motion cues from the eyes, vestibular system, and non-vestibular proprioceptors. Second, the vestibular system must be involved directly or indirectly for motion sickness to ensue. Both of these components are involved in perceiving conflicting information from different sensory inputs, resulting in motion sickness. Typically, there is a synergistic relationship between different sensory systems such as the visual and vestibular system, in that they are providing the brain with consistent information. Conflict results when this synergistic relationship is broken by stimuli that do not match what is "normal" for a particular environment, or when the perceptual systems give conflicting information, and sickness follows. To understand why these sensory systems provide conflicting information in moving environments, a description of their anatomy and function is necessary.

***The vestibular system.*** The vestibular system and the visual-vestibular interaction both play a key role in experiencing motion sickness and simulator sickness. Each ear contains a vestibular apparatus located in the bony labyrinth of the inner ear (see Figure 5.1). The vestibular apparatus is used to sense head movements and respond to them through response signals. These response signals aid in eye movements, posture and balance, and perception of motion and orientation. The vestibular apparatus is crucial for normal everyday functioning, including, but not limited to standing, walking and reading.

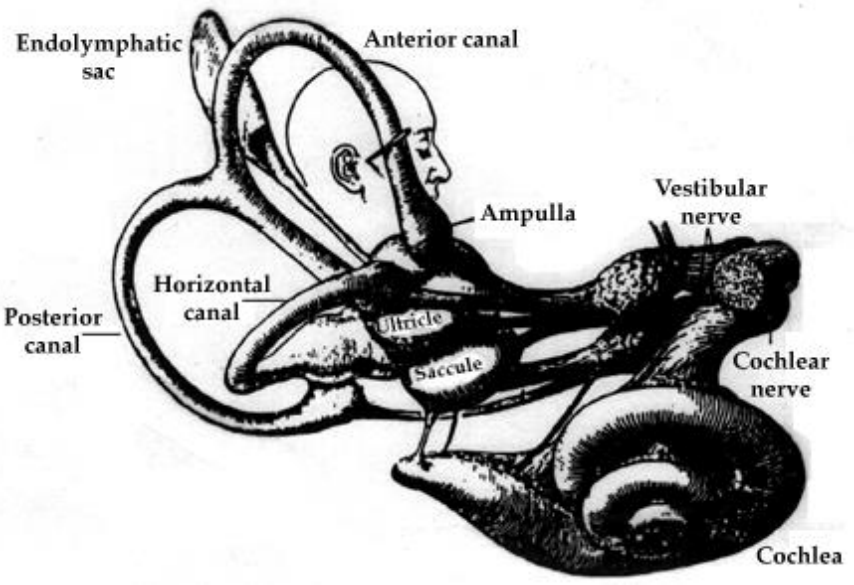


*Figure 5.1: One of two vestibular apparatuses located in the bony labyrinth of the inner ear (Howard, 1986a, as cited in Draper, 1996).*

Each vestibular apparatus contains semicircular canals and otolith organs that inform us of our head orientation and movement (Wolfe, et al., 2012). The three semicircular canals within each ear detect angular acceleration of the head. The two otolith organs in each ear detect linear acceleration changes in the head and head tilt. The

vestibular system plays a role when using an HMD by letting the user know how their head and body is positioned within the environment—regardless of the visual cues provided by the display.

The body has a vestibulo-ocular reflex that aids in vision during head movements by stabilizing images on the retina during head motion (Fetter, 2007). When the head moves, the vestibular apparatus senses the head movement and signals the oculomotor system, providing information about direction and rate of movement. Then the oculomotor system compensates for the movement with eye movements in the opposite direction of the head movement. Discrepancies between information from the vestibular apparatus and the visual system (i.e. visual-vestibular interactions) can cause conflict between what the vestibular system feels and what the visual system sees, which can result in discomfort and motion sickness (Reason & Brand, 1975; Lackner & Graybiel, 1981). Often, when using an HMD system, the display is projecting either augmented or virtual reality, and the user may be seeing movement that does not match what the vestibular system is telling them. The sensory conflict theory would explain this discrepancy as the cause for the experience of simulator sickness symptoms while using and HMD.

**Postural Instability Theory**

Postural Instability theory takes an ecological approach to explaining motion sickness by explaining sickness in relation to what is happening outside of the body instead of inside the body. It is based on a closed loop human-environment system such that the behavior of the human affects its relationship with the environment, and the

relationship between the human and the environment affects the behavior of the human (Riccio & Stoffregen, 1991). Therefore, the behavior of the human is dependent on its relationship with the environment.

This theory explains motion sickness as a result of prolonged postural challenges when an effective strategy for maintaining postural control is unavailable (Riccio & Stoffregen, 1991). Riccio and Stoffregen (1991) claim that motion sickness is produced by disruptions in action (postural instability) rather than deficiencies in perceptual processing. Unlike sensory conflict theory, postural instability theory claims that the vestibular system does not play an important role in motion sickness (Riccio & Stoffregen, 1991). Rather, Postural Instability Theory explains sickness that results from instability as a reaction to movement cues from the environment. The longer we try to maintain normal postural sway despite the challenges from the environment, the sicker we will get. Alternatively, the sooner we stop trying to control sway, the less sick we will be.

Many studies have provided evidence for postural instability theory. It has been shown that increases in variability, range, and velocity of postural motion precede the incidence of motion sickness (Stoffregen & Smart, 1998; Stoffregen et al., 2000; Smart, Stoffregen, & Bardy, 2002). Additionally, there is evidence that motion sickness follows significant increases in objective, measureable properties of postural motion (Smart, Stoffregen, & Bardy, 2002). For example, Smart and colleagues (2014) have shown that increases in magnitude and spatial complexities and a decrease in temporal complexity of postural sway precede motion sickness.

# Appendix B

## Measures of Postural Sway

### Measures of Postural Sway

Postural sway can be measured in terms of magnitude and structure of sway. Magnitude represents how much an individual is moving, and structure represents the complexity of the sway in terms of twisting, turning, and predictability. Four measures can be used to examine these components of sway: sample entropy, normalized path length, elliptical area, and path length. Sample entropy and normalized path length represent the overall structure of postural sway while elliptical area and path length represent the overall magnitude of postural sway. Previous studies have shown that in general, an increase in magnitude and spatial complexity and a decrease in temporal complexity precede sickness (Smart, et al., 2014).

***Sample Entropy.*** Sample entropy is a unit-less, univariate measure that indicates the amount of temporal complexity (or predictability) in postural sway (Richman & Moorman, 2000). This variable describes the overall structure of sway. High sample entropy is associated with high temporal complexity of sway. Sickness is associated with lower sample entropy. In other words, sway that is more rigid and predictable and less complex is associated with greater sickness, while sway that is less predictable and more complex is associated with less sickness (Smart, et al., 2014).

***Normalized Path-Length.*** Normalized path length is a unit-less two-dimensional measure that describes the amount of twisting and turning in sway coordination (Donker, Roerdink, Greven, & Beek, 2007; Donker, Ledebt, Roerdink, Savelsbergh, & Beek,

2008). The path length variable is normalized by dividing the *x* and *y* time series by their respective standard deviations. The variable, like sample entropy, represents the overall structure of sway. However, normalized path length indexes coordination spatial complexity rather than temporal complexity. A larger normalized path length represents more twisting and turning in the structure of postural sway, and therefore higher spatial complexity. An increase in normalized path length is associated with sickness (Smart, et al., 2014).

***Elliptical Area.*** Elliptical area is a two dimensional measure that describes the size of the area in which postural sway takes place. This variable describes the magnitude of the sway with respect to geometric size. Its units are the square of the units in which the data is collected (e.g. inches$^2$). A higher elliptical area indicates more movement from the participant. Studies have shown that an increase in sway magnitude often precedes motion sickness, therefore, an increase in elliptical area may contribute to motion sickness (Smart, Stoffregen, & Bardy, 2002; Stoffregen et al. 2000; Stoffregen and Smart, 1998; Smart, et al., 2014).

***Path Length.*** Path length provides information about the overall amount of postural sway from a participant. It is measured in the same units the data is collected in (e.g. inches). It represents the actual length of their movement. Path length is calculated by taking the sum of the distances between consecutive points using:

$$PL = \Sigma\sqrt{(x_{i+1}-x_i)^2 + (y_{i+1}-y_i)^2}$$

where *x* represents mediolateral data and *y* represents anterioposterior data from postural sway data and *i* represents instance of measurement (Donker, Roerdink, Greven, & Beek,

2007; Donker, Ledebt, Roerdink, Savelsbergh, & Beek, 2008). Like elliptical area, path length is a two dimensional variable that describes the magnitude of sway. Because studies have shown an increase in magnitude of sway often precedes sickness, greater path length is associated with sickness (Smart, Stoffregen, & Bardy, 2002; Stoffregen et al. 2000; Stoffregen and Smart, 1998; Smart, et al., 2014).

Appendix C

Screening Questionnaire

Subject Number: _____ **Date**: _____

**Screening Questions**

| Questions | Answers | Comments |
|---|---|---|
| Any stomach problems? | Y / N | |
| Any heart problems? | Y / N | |
| Any brain problems? | Y / N | |
| Any visual problems (other than glasses)? | Y / N | |
| Do you have any inner ear problems? | Y / N | |
| Do you smoke? | Y / N | |
| If female, are you pregnant? | Y / N | |
| Currently taking any medications? | Y / N | |
| Do you have any experience with helmet-mounted displays? | Y / N | |
| Do you have any experience with virtual reality simulators/environments? | Y / N | |
| Do you have vertigo? | Y / N | |
| Do you easily get motion sick? | Y / N | |
| Gender: | M / F | |
| Ethnicity: | | |
| Age: | | |
| Which is your dominant hand? | L / R | |
| When was the last time you ate? | | |

**Instructions for participants:**

1. No vigorous exercise for at least 1 hour before the experiment.

2. No smoking or using any tobacco product, drinking alcohol, or drinking caffeine for at least 8 hours before the experiment.

# Appendix D

## Motion Sickness Susceptibility Questionnaire-Short

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. Sickness here means feeling queasy or nauseated or actually vomiting

**Your childhood experience only** (before 12 years of age), for each of the following types of transport or entertainment please indicate

1. **As a child (before age 12),** how often you **felt sick or nauseated** (tick boxes)

| | Not Applicable - Never Traveled | Never Felt Sick | Rarely Felt Sick | Sometimes Felt Sick | Frequently Felt Sick |
|---|---|---|---|---|---|
| Cars | | | | | |
| Buses or Coaches | | | | | |
| Trains | | | | | |
| Aircraft | | | | | |
| Small Boats | | | | | |
| Ships, e.g. Channel Ferries | | | | | |
| Swings in playgrounds | | | | | |
| Roundabouts in playgrounds | | | | | |
| Big Dippers, Funfair Rides | | | | | |
| | t | 0 | 1 | 2 | 3 |

**Your experience over the last 10 years (approximately),** for each of the following types of transport or entertainment please indicate

2. **Over the last 10 years,** how often you **felt sick or nauseated** (tick boxes)

| | Not Applicable - Never Traveled | Never Felt Sick | Rarely Felt Sick | Sometimes Felt Sick | Frequently Felt Sick |
|---|---|---|---|---|---|
| Cars | | | | | |
| Buses or Coaches | | | | | |
| Trains | | | | | |
| Aircraft | | | | | |
| Small Boats | | | | | |
| Ships, e.g. Channel Ferries | | | | | |
| Swings in playgrounds | | | | | |
| Roundabouts in playgrounds | | | | | |
| Big Dippers, Funfair Rides | | | | | |
| | t | 0 | 1 | 2 | 3 |

# Appendix E

## Simulator Sickness Questionnaire

**Simulator Sickness Questionnaire (SSQ)**

Subject Number: Date: Session:

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

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

# Appendix F

## Motion Sickness Assessment Questionnaire

MSAQ Score Sheet
Participant # _____ PRE POST

I felt sick to my stomach

1——2——3——4——5——6——7——8——9

I felt faint-like

1——2——3——4——5——6——7——8——9

I felt annoyed/irritated

1——2——3——4——5——6——7——8——9

I felt sweaty

1——2——3——4——5——6——7——8——9

I felt queasy

1——2——3——4——5——6——7——8——9

I felt lightheaded

1——2——3——4——5——6——7——8——9

I felt drowsy

1——2——3——4——5——6——7——8——9

I felt clammy/cold sweat

1——2——3——4——5——6——7——8——9

I felt disoriented

1——2——3——4——5——6——7——8——9

I felt tired/fatigued

1——2——3——4——5——6——7——8——9

I felt nauseated

1——2——3——4——5——6——7——8——9

I felt hot/warm

1——2——3——4——5——6——7——8——9

I felt dizzy

1——2——3——4——5——6——7——8——9

I felt like I was spinning

1——2——3——4——5——6——7——8——9

I felt as if I may vomit

1——2——3——4——5——6——7——8——9

I felt uneasy

1——2——3——4——5——6——7——8——9

# Appendix G

## List of Targets

| Block # 1 | H / M 1 | Block # 2 | H / M 2 | Block # 3 | H / M 3 | Block # 4 | H / M 4 | Block # 5 | H / M 5 |
|---|---|---|---|---|---|---|---|---|---|
| Left Clock | 1 | Right Shelf | 41 | Left Fire | 81 | Right Fan | 121 | Left Flag | 161 |
| Right Cross | 2 | Left Scale | 42 | Left Scale | 82 | Left Flag | 122 | Right Cross | 162 |
| Right Shelf | 3 | Right Flag | 43 | Right Cross | 83 | Right Fan | 123 | Left Hall | 163 |
| Left Hall | 4 | Right Hall | 44 | Left Flag | 84 | Left Cross | 124 | Right Shelf | 164 |
| Right Fan | 5 | Right Cross | 45 | Right Cross | 85 | Left Fire | 125 | Left Hall | 165 |
| Left Fire | 6 | Right Fan | 46 | Left Clock | 86 | Left Flag | 126 | Right Fan | 166 |
| Right Hall | 7 | Left Scale | 47 | Right Fan | 87 | Right Cross | 127 | Left Cross | 167 |
| Right Fan | 8 | Right Fire | 48 | Right Shelf | 88 | Left Fire | 128 | Left Scale | 168 |
| Right Shelf | 9 | Left Scale | 49 | Left Fire | 89 | Right Shelf | 129 | Right Fan | 169 |
| Left Clock | 10 | Right Fan | 50 | Right Shelf | 90 | Left Flag | 130 | Left Scale | 170 |
| Right Flag | 11 | Left Cross | 51 | Left Scale | 91 | Right Fan | 131 | Right Fan | 171 |
| Left Scale | 12 | Left Clock | 52 | Right Hall | 92 | Left Flag | 132 | Left Hall | 172 |
| Right Fan | 13 | Right Shelf | 53 | Left Scale | 93 | Left Scale | 133 | Left Clock | 173 |
| Left Flag | 14 | Left Fire | 54 | Right Hall | 94 | Right Hall | 134 | Right Shelf | 174 |
| Left Scale | 15 | Right Cross | 55 | Right Fan | 95 | Right Fan | 135 | Left Fire | 175 |
| Right Shelf | 16 | Right Fan | 56 | Left Hall | 96 | Left Scale | 136 | Right Cross | 176 |
| Left Fire | 17 | Left Fire | 57 | Right Shelf | 97 | Right Fire | 137 | Left Fire | 177 |
| Right Cross | 18 | Left Scale | 58 | Left Fan | 98 | Right Hall | 138 | Right Fan | 178 |
| Left Fire | 19 | Right Hall | 59 | Left Flag | 99 | Right Fan | 139 | Left Hall | 179 |
| Right Fan | 20 | Left Fire | 60 | Right Shelf | 100 | Left Fire | 140 | Left Flag | 180 |
| Left Clock | 21 | Left Flag | 61 | Left Fan | 101 | Right Fan | 141 | Left Clock | 181 |
| Right Shelf | 22 | Left Scale | 62 | Left Fire | 102 | Left Fire | 142 | Right Cross | 182 |
| Left Clock | 23 | Right Fan | 63 | Right Shelf | 103 | Right Shelf | 143 | Right Shelf | 183 |
| Right Flag | 24 | Left Hall | 64 | Left Flag | 104 | Left Hall | 144 | Left Cross | 184 |
| Right Shelf | 25 | Left Clock | 65 | Left Scale | 105 | Left Flag | 145 | Left Clock | 185 |
| Left Fire | 26 | Right Fan | 66 | Right Fan | 106 | Right Fire | 146 | Right Fan | 186 |
| Left Flag | 27 | Left Hall | 67 | Left Hall | 107 | Left Scale | 147 | Left Scale | 187 |
| Right Fan | 28 | Left Flag | 68 | Left Clock | 108 | Right Hall | 148 | Right Fan | 188 |
| Left Hall | 29 | Right Shelf | 69 | Right Cross | 109 | Left Scale | 149 | Left Cross | 189 |
| Left Fire | 30 | Left Fire | 70 | Left Scale | 110 | Right Hall | 150 | Left Flag | 190 |
| Right Hall | 31 | Right Cross | 71 | Right Fan | 111 | Right Fan | 151 | Left Clock | 191 |
| Right Shelf | 32 | Right Shelf | 72 | Left Hall | 112 | Left Fire | 152 | Right Fire | 192 |
| Left Hall | 33 | Left Clock | 73 | Right Shelf | 113 | Right Fan | 153 | Right Cross | 193 |
| Left Clock | 34 | Right Hall | 74 | Left Clock | 114 | Left Cross | 154 | Left Flag | 194 |
| Right Shelf | 35 | Right Cross | 75 | Right Hall | 115 | Left Clock | 155 | Left Clock | 195 |
| Left Fire | 36 | Right Shelf | 76 | Right Shelf | 116 | Right Fan | 156 | Right Hall | 196 |
| Left Scale | 37 | Left Fire | 77 | Left Clock | 117 | Right Shelf | 157 | Right Shelf | 197 |
| Right Flag | 38 | Right Cross | 78 | Right Flag | 118 | Left Cross | 158 | Left Cross | 198 |
| Right Fan | 39 | Right Shelf | 79 | Right Shelf | 119 | Left Flag | 159 | Left Clock | 199 |
| Left Hall | 40 | Left Fan | 80 | Left Clock | 120 | Right Cross | 160 | Right Flag | 200 |
| **Total Misses** | | | | | | | | | |

# Appendix H

## Detailed Experimental Timeline

| HMD ADAPTATION EXPERIMENT WITHIN-SUBJECTS DESIGN | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Experimental Session 1 | | | | | | | | | | |
| Part 1 (training—no HMD) | | | | Part 2 (experiment—with HMD) | | | | | | |
| **Surveys** | **2 Minute Baseline** | **Block 1** | **Pre** | **Block 1** | **Block 2** | **Block 3** | **Block 4** | **Block 5** | **Post** | **2 Minute Baseline** |
| Consent | (task instructions given) | 40 Trials | MSAQ | 40 Trials | 40 Trials | 40 Trials | 40 Trials | 40 Trials | MSAQ | |
| MSSQ-Short | | | SSQ | SSQ | SSQ | SSQ | SSQ | SSQ | | |
| Screening | (don HMD) | | | | | | | | | (doff HMD) |
| 10 | 2 | 2 | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| Total Time Part 1 = 19 minutes | | | | Total Time Part 2 = 20 minutes | | | | | | |
| Total Time Experimental Session 1 = 39 minutes | | | | | | | | | | |
| 48 Hour Break | | | | | | | | | | |
| Experimental Session 2 | | | | | | | | | | |
| Part 1 (Training—No HMD) | | | | Part 2 (Experimental Session—with HMD) | | | | | | |
| | **2 Minute Baseline** | **Block 1** | **Pre** | **Block 1** | **Block 2** | **Block 3** | **Block 4** | **Block 5** | **Post** | **2 Minute Baseline** |
| | (task instructions given) | 40 Trials | MSAQ | 40 Trials | 40 Trials | 40 Trials | 40 Trials | 40 Trials | MSAQ | |
| | | | SSQ | | | | | | | |
| | (don HMD) | | | SSQ | SSQ | SSQ | SSQ | SSQ | | (doff HMD) |
| | 2 | 2 | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| Total Time Part 1 = 9 minutes | | | | Total Time Part 2 = 20 minutes | | | | | | |
| Total Time Experimental Session 2 = 29 minutes | | | | | | | | | | |
| 48 Hour Break | | | | | | | | | | |
| Experimental Session 3 | | | | | | | | | | |
| Part 1 (Training—no HMD) | | | | Part 2 (Experimental Session—with HMD) | | | | | | |
| | **2 Minute Baseline** | **Block 1** | **Pre** | **Block 1** | **Block 2** | **Block 3** | **Block 4** | **Block 5** | **Post** | **2 Minute Baseline** |
| | (task instructions given) | 40 Trials | MSAQ | 40 Trials | 40 Trials | 40 Trials | 40 Trials | 40 Trials | MSAQ | |
| | | | SSQ | | | | | | | |
| | (don HMD) | | | SSQ | SSQ | SSQ | SSQ | SSQ | | (doff HMD) |
| | 2 | 2 | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| Total Time Part 1 = 9 minutes | | | | Total Time Part 2 = 20 minutes | | | | | | |
| Total Time Experimental Session 3 = 29 minutes | | | | | | | | | | |

## Appendix I

## Experimenter Script

[Welcome participant into the lab and ask them to have a seat at the table.

Ask the participant to read and sign the IRB approved consent form. Have them initial the front page and sign the back page. After they sign make sure they do not have any questions or concerns about the form.

Instruct participant to complete the screening questionnaire and the MSSQ-Short. Before reading, tell participant you will be reading from a script, but they can interrupt you at any time if they have questions.]

"Thank you for coming in today. This is a three part study. Today is part 1 and will serve as a screening session. I am not going to tell you what I will be screening for because I don't want it to bias your behavior at all, but just know that not everyone will get to participate in all three parts of the study. However, you will get paid for each day that you come in, so you will get paid for today regardless of whether you pass the screening or not. If you are able to participate in the following two sessions you will be compensated at the end of each session.

Now I'm going to give you a brief overview of what we will be doing today. This experiment will involve you wearing a head mounted display (HMD) with a camera mounted on the top.

[Point to HMD so participant knows what you are talking about.]

You will wear the HMD for around 20 minutes. Because of the camera, you will see the lab exactly as it is around you—it's not actually a virtual environment. While wearing the HMD you will be completing an object location task, which just means you're going to make head movements to find different objects around the room. You will be listening to a recording, and you will hear a direction left or right, and an object. All you have to do is turn your head in that direction until you see the object. A new direction and object will be said every 3 seconds. Each direction will be relative to the object you just found, so you do not have to move your head back to center each time. It will go pretty fast, so if you miss an object that's okay, you can just move on to the next one. We will start with a short practice block, then there will be 5 blocks of trials, each one lasting 2 minutes.

In between blocks we will take a short break and I will give you some surveys to assess how you are feeling. During this time I just want you to look straight ahead and not move your head around. You will still be wearing the HMD.

There will be a total of 5 blocks, with a one minute break in between, so the total time in the system will be about 20 minutes.

My goal is not to make you feel too uncomfortable, and if at any time you start to feel too uncomfortable, please let me know and we will stop right away. However, know that if you take the HMD off before the end of the experiment, that will end your participation and you won't be able to take part in future sessions."

# Appendix J

## IRB Approved Informed Consent Form

Information about Being in a Research Study
Clemson University
**Effects of Helmet-Mounted Display Characteristics on User Experience**

**Description of the Study and Your Part in It**
You are invited to participate in a research study conducted by Dr. Eric R. Muth. The purpose of this research is to examine the effects of various helmet-mounted display characteristics such as size and speed of the display on a user's experience with the display as well as the relationship between various eye parameters to use experience.

Your part in the study will be to:

1. Have the distance between your 2 eyes measured.

2. Wear a helmet-mounted display (HMD) through which you will view either objects in the real world or imaginary objects in a simulated world. An HMD is a video display that is worn on your head like a small set of binoculars. To limit your vision to only the HMD video display, you may wear goggles under the HMD similar to swimming goggles.

3. Make a series of timed head movements as you view various objects located in either the real or simulated world that you are looking at.

4. "Shoot" at targets around the room with a laser pointer.

5. Complete several questionnaires asking you questions about your personal health history and motion sickness experiences.

6. Wear two small sensors (one in the middle of your back attached with a velcro belt around your torso, and one on top of the HMD) that will track your position in space.

It will take you approximately 1 hour and 45 minutes to complete this study. You may be asked to return to complete this study multiple times if you are willing.

**Risks and Discomforts**
There are certain risks or discomforts that you might expect if you take part in this research. They include none/some/all of the following symptoms: dizziness, weakness, nausea, headache, vomiting. Notify the researcher immediately if you experience any of these symptoms. These symptoms may go away when the HMD is removed. If you experience any of the symptoms after the study, please contact Redfern Health Center at 656-2451.

**Possible Benefits**
We do not know of any way you would benefit directly from taking part in this study.

However, this study may lead to a better understanding of which characteristics of HMDs make them more user friendly. There are very few published studies examining design characteristics of HMDs. Studying these characteristics will lead to better HMD design for both military and civilian applications.

**Incentives**
By participating in this study, you will receive a monetary payment of $10 for the first session or any portion thereof you participate in and an additional $20 if you participate in a second session or any

portion thereof and an additional $30 if you participate in a third session or any portion thereof. You may also receive up to 3 course extra credits from participating.

Note, the same course/extra credit is available for a non-research activity that involves the same effort and time investment (see your course instructor for more information on credit alternatives).

**Protection of Privacy and Confidentiality**
We will do everything we can to protect your privacy and confidentiality. We will not tell anybody outside of the research team that you were in this study or what information we collected about you in particular. Your name and the information collected from you for the study will be kept in separate locked locations such that your name and the information that is collected from you are not linked in an easy manner. Your identity will not be revealed in any publication that might result from this study or shared without your permission.

We might be required to share the information we collect from you with the Clemson University Office of Research Compliance, the federal Office for Human Research Protections and/or the Office of Naval Research. If this happens, the information would only be used to find out if we ran this study properly and protected your rights in the study.

**Choosing to Be in the Study**
You do not have to be in this study. You may choose not to take part and you may choose to stop taking part at any time. You will not be punished in any way if you decide not to be in the study or to stop taking part in the study. If you decide not to take part or to stop taking part in this study, it will not affect your grade in any way.

If you choose to stop taking part in this study, the information you have already provided will be kept in a confidential manner.

**Contact Information**
If you have any questions or concerns about this study or if any problems arise, please contact Dr. Eric R. Muth at Clemson University at 864-656-6741.

If you have any questions or concerns about your rights in this research study, please contact the Clemson University Office of Research Compliance (ORC) at 864-656-0636 or irb@clemson.edu. If you are outside of the Upstate South Carolina area, please use the ORC's toll-free number, 866-297-3071.
**Consent**

**I have read this form and have been allowed to ask any questions I might have. I agree to take part in this study.**

Participant's signature: _____ Date: _____

A copy of this form will be given to you.

# Protocol Checklist

**Participant ☐☐-☐☐ , Date _____**

| ☑ | Phase | Interaction with participant | Various: Posture | Various: Notes |
|---|---|---|---|---|
| | | | | |
| ❑ | Preparation | Welcome | | |
| ❑ | | Provide and discuss informed consent | | |
| ❑ | | Clarify study is 3 sessions | | |
| ❑ | | Screening questionnaire | | |
| ❑ | | Ask participant last time they ate | | |
| ❑ | | MSSQ-short | | |
| ❑ | | Introduce task | | |
| ❑ | Experimental set up | Move to HMD station, put on HMD | **Attach sensors** | |
| ❑ | and baseline | 2 minute baseline | **Start Baseline Posture** | |
| | | | **End Baseline Posture** | |
| ❑ | | Pre SSQ | | |
| ❑ | | Pre MSAQ | | |
| ❑ | | Turn on camera/HMD, Adjust lens distance | | |
| ❑ | **Exposure** | **Trial 1** | **Start HMD Posture** | |
| ❑ | | **SSQ 1** | | |
| ❑ | | **Trial 2** | | |
| ❑ | | **SSQ 2** | | |
| ❑ | | **Trial 3** | | |
| ❑ | | **SSQ 3** | | |
| ❑ | | **Trial 4** | | |
| ❑ | | **SSQ 4** | | |
| ❑ | | **Trial 5** | | |
| ❑ | | **SSQ 5 (Post)** | | |
| ❑ | | **Post MSAQ** | **End HMD Posture** | |
| ❑ | Secondary Measures | 2 minute posttest posture | **Start Post Posture** | |
| ❑ | | | **End Post Posture** | |
| ❑ | | Remove HMD | **Remove Sensors** | |
| ❑ | | Score SSQ | | |
| ❑ | **Debrief/wrap up** | **Debrief/Confirm next session** | | |
| ❑ | | **Give participant money/sign money form** | | |

Notes:

Appendix L

Analysis of Untransformed Peak SSQ Data

**All Participants**

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for differences in peak SSQ scores. Table 5.1 shows means and standard deviations for peak SSQ scores for each condition and session. Figure 5.2 shows a line graph of peak SSQ data over time. A significant main effect of session was observed such that participants experiences less sickness in the third session compared to the first session, $F(2, 76) = 11.85$, $p < .001$, $\eta^2 = .238$. No significant main effect of condition was observed, $F(1, 38) = .445$, $p = .50$, $\eta^2 = .012$. No significant interaction between condition and session was observed, $F(2, 76) = .829$, $p = .44$, $\eta^2 = .021$.

| | Session 1 | Session 2 | Session 3 | Total |
|---|---|---|---|---|
| Control | 61.15 +/- 36.45 | 47.50 +/- 35.36 | 40.95 +/- 32.18 | 49.87 +/- 35.16 |
| Performance | 52.74 +/- 33.39 | 37.40 +/- 31.78 | 39.83 +/- 33.63 | 43.32 +/- 33.09 |
| Total | 56.94 +/- 34.76 | 42.45 +/- 33.58 | 40.39 +/- 32.50 | 46.59 +/- 34.15 |

*Table 5.1: Means and standard deviations for peak SSQ for all participants by session and condition.*

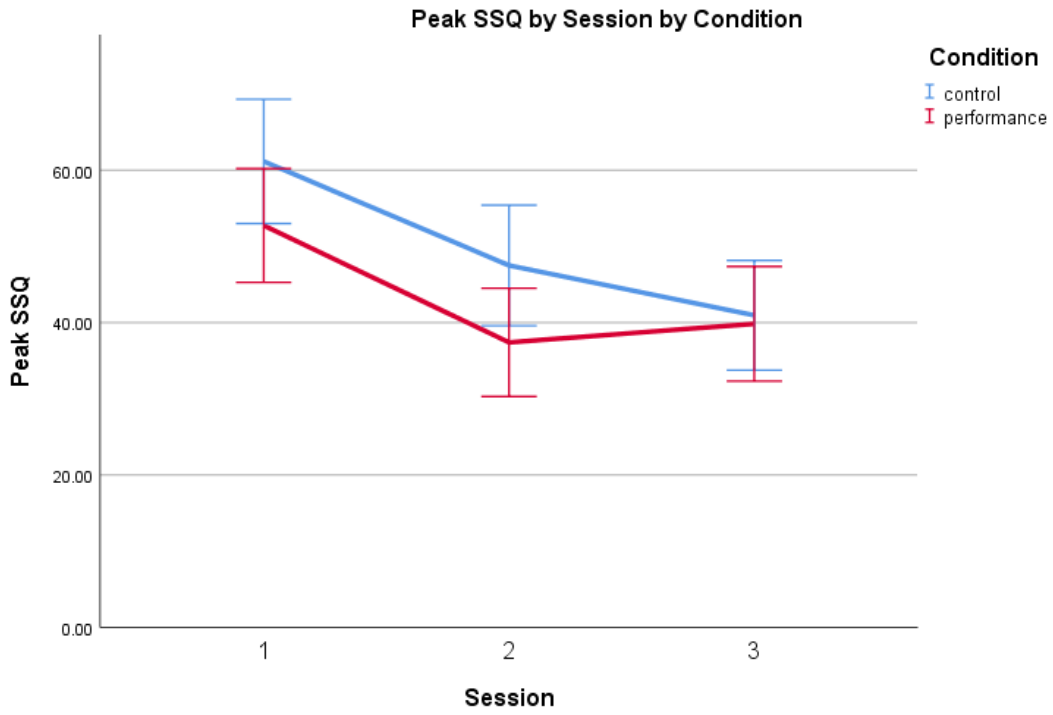


*Figure 5.2: Line graph of peak SSQ over time by condition.*

**Participants that Adapted**

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for differences in peak SSQ scores for participants that showed adaptation. Table 5.2 shows means and standard deviations for peak SSQ scores for each condition and session. Figure 5.3 shows a line graph of peak SSQ data over time. A significant main effect of session was observed such that participants experiences less sickness in the third session compared to the first session, $F(2, 66) = 19.61$, $p < .001$, $\eta^2 = .373$. No significant main effect of condition was observed, $F(1, 33) = .252$, $p = .62$, $\eta^2 = .008$. No significant interaction between condition and session was observed, $F(2, 66) = 1.61$, $p = .081$, $\eta^2 = .073$.

| | Session 1 | Session 2 | Session 3 | Total |
|---|---|---|---|---|
| Control | 65.92 +/- 38.19 | 45.58 +/- 36.88 | 35.76 +/- 32.58 | 49.09 +/- 37.40 |
| Performance | 53.15 +/- 34.25 | 37.99 +/- 32.54 | 39.57 +/- 32.58 | 43.57 +/- 33.88 |
| Total | 58.99 +/- 36.14 | 41.46 +/- 34.28 | 37.83 +/- 33.21 | 46.09 +/- 35.47 |

*Table 5.2: Means and standard deviations of Peak SSQ for participants that showed adaptation.*

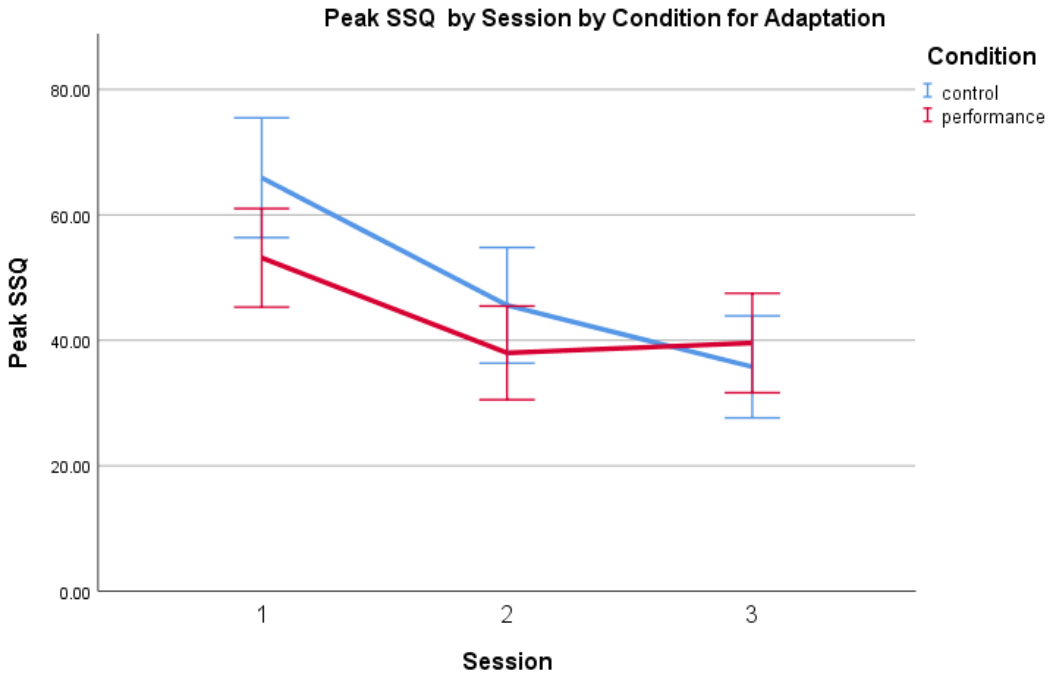


*Figure 5.3: Line graph of Peak SSQ scores for participants that showed adaptation.*

## Appendix M

### Analysis of Untransformed Sum SSQ Data

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for differences in sum SSQ scores. Table 5.3 shows means and standard deviations for sum SSQ scores for each condition and session. Figure 5.4 shows a line graph of sum SSQ data over time. A significant main effect of session was observed such that participants experiences less sickness in the third session compared to the first session, $F(2, 76) = 11.85$, $p < .001$, $\eta^2 = .238$. No significant main effect of condition was observed, $F(1, 38) = .445$, $p = .50$, $\eta^2 = .012$. No significant interaction between condition and session was observed, $F(2, 76) = .829$, $p = .44$, $\eta^2 = .021$.

| | Session 1 | Session 2 | Session 3 | Total |
|---|---|---|---|---|
| Control | 218.42 +/- 164.28 | 146.05 +/- 124.78 | 119.87 +/- 87.17 | 161.44 +/- 133.86 |
| Performance | 217.48 +/- 170.29 | 142.87 +/- 125.81 | 128.84 +/- 111.28 | 163.06 +/- 141.29 |
| Total | 217.95 +/- 165.15 | 144.46 +/- 123.69 | 124.36 +/- 98.77 | 162.25 +/- 137.05 |

*Table 5.3: Means and standard deviations for sum SSQ scores for all participants by session and condition.*

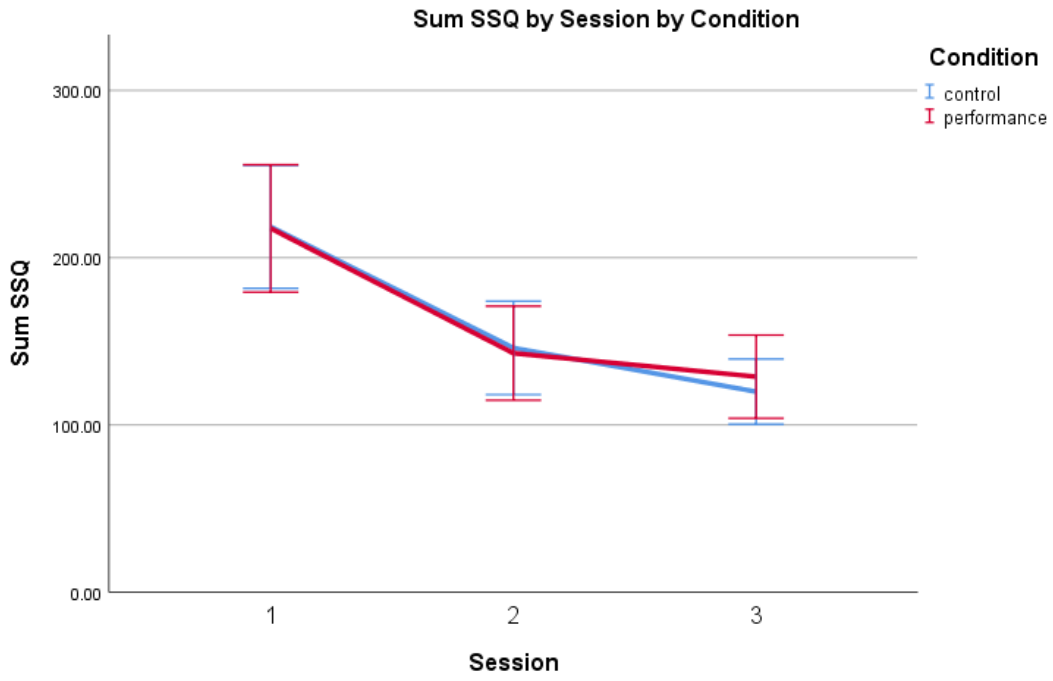


*Figure 5.4: Line graph of sum SSQ scores for all participants.*

**Participants that Adapted**

A 2 (condition) x 3 (session) mixed ANOVA was conducted to look for differences in sum SSQ scores for participants that showed adaptation. Table 5.4 shows means and standard deviations for sum SSQ scores for each condition and session. Figure 5.5 shows a line graph of sum SSQ data over time. A significant main effect of session was observed such that participants experiences less sickness in the third session compared to the first session, $F(1.64, 54.10) = 26.86$, $p < .001$, $\eta^2 = .449$ (the sphericity assumption was violated, therefore a Greenhouse-Geisser correction was used, changing the within degrees of freedom from 2 to 1.64 and the between degrees of freedom from 66 to 54.10). No significant main effect of condition was observed, $F(1, 33) = .016$, $p = .91$, $\eta^2 = .00$. No significant interaction between condition and session was observed,

$F(1.64, 54.10) = .879$, $p = .402$, $\eta^2 = .026$ (again, the sphericity assumption was violated, therefore a Greenhouse-Geisser correction was used, changing the within degrees of freedom from 2 to 1.64 and the between degrees of freedom from 66 to 54.10).

| | Session 1 | Session 2 | Session 3 | Total |
|---|---|---|---|---|
| Control | 240.06 +/- 175.51 | 138.61 +/- 133.32 | 101.92 +/- 84.58 | 160.20 +/- 145.85 |
| Performance | 222.63 +/- 173.35 | 146.06 +/- 128.42 | 128.34 +/- 114.31 | 165.68 +/- 144.44 |
| Total | 230.60 +/- 171.98 | 142.65 +/- 128.42 | 116.26 +/- 101.25 | 163.17 +/- 144.41 |

*Table 5.4: Means and standard deviations for sum SSQ for participants that showed adaptation.*

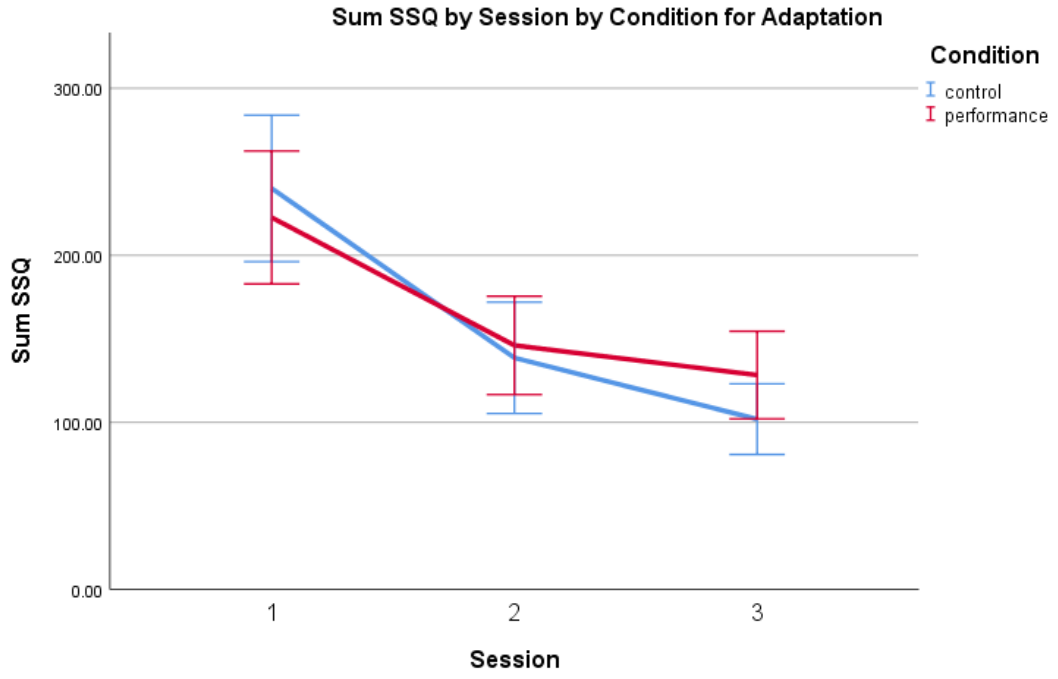


*Figure 5.5: Line graph of sum SSQ for participants that showed adaptation.*

## Appendix N

## Further Analysis of Postural Sway Data

### Unaggregated, Postbaseline Postural Sway Measures for All Participants

Due to the low sampling rate of the posture data, postural sway measures were examined using unaggregated data so more measurements could be used in the analysis. Only post baseline was examined based on previous findings from hypothesis testing. There were three 30-second samples recorded for each post baseline period, therefore nine total 30-second bins were included when conducting the ANOVA for each dependent postural sway variable. A 2 (condition) x 9 (time) mixed ANOVA was conducted to further examine differences in elliptical area and path length from the post baseline measurement. No statistically significant findings were observed.

#### *Normalized Path Length*

A 2 (condition) x 9 (time) mixed ANOVA was conducted to further examine differences in normalized path length from the post baseline measurement. Twenty-nine participants (15 control, 14 performance) had complete data for all three post baseline measurements and were included in this analysis. Means and standard deviations can be seen in Table 5.5. Figure 5.6 shows a bar graph of the data over time. A significant main effect of time was observed, $F(3.95, 106.55) = 14.592$, $p < .001$, $\eta^2 = .351$ (the sphericity assumption was violated and a Greenhouse Geisser correction was used, changing the within degrees of freedom from 8 to 3.95 and the between degrees of freedom from 216 to 106.55). No significant main effect of condition was observed ($F(1, 27) = .763$, $p = .195$, $\eta^2 = .027$). No significant interaction was observed ($F(3.95,$

106.55) = .688, $p$ = .6, $\eta^2$ = .025; the sphericity assumption was violated and a Greenhouse Geisser correction was used, changing the within degrees of freedom from 8 to 3.95 and the between degrees of freedom from 216 to 106.55).

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Control | 51.74 +/- 15.55 | 32.95 +/- 16.12 | 29.58 +/- 14.05 | 48.87 +/- 16.60 | 27.75 +/- 18.51 | 30.99 +/- 17.72 | 37.51 +/- 22.25 | 20.49 +/- 10.07 | 26.14 +/- 18.24 |
| Performance | 57.02 +/- 16.50 | 29.18 +/- 12.84 | 27.01 +/- 6.59 | 50.01 +/- 13.91 | 29.98 +/- 9.10 | 29.98 +/- 8.82 | 40.32 +/- 16.55 | 30.13 +/- 12.98 | 33.19 +/- 18.78 |
| Total | 54.29 +/- 15.95 | 31.13 +/- 14.49 | 28.34 +/- 10.98 | 49.42 +/ 15.10 | 28.65 +/- 14.52 | 30.50 +/- 13.91 | 38.87 +/- 19.41 | 25.15 +/- 12.37 | 29.54 +/- 18.52 |

*Figure 5.5: Means and standard deviations by 30-seconed sample for normalized path length during post baseline measurement.*

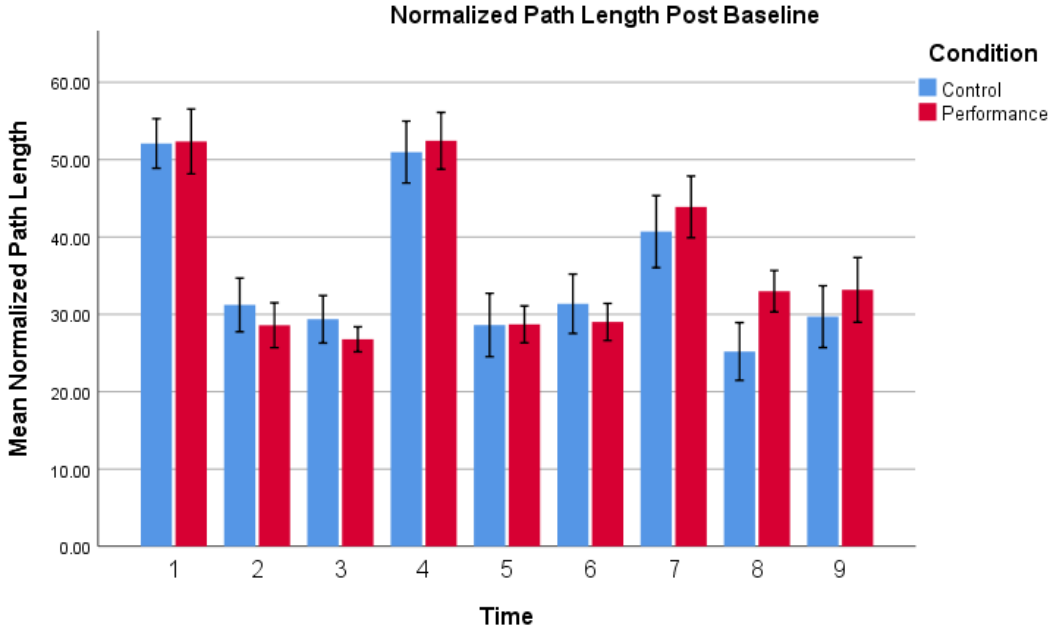


*Figure 5.6: Bar graph of mean normalized path length for each 30-second sample during post baseline measurement by condition.*

**Unaggregated, Postbaseline Postural Sway Measures for Participants that Adapted**

The same analysis was done on unaggregated poste baseline postural sway for participants that showed adaptation. No statistically significant findings were observed for elliptical area or path length.

***Normalized Path Length***

A 2 (condition) x 9 (time) mixed ANOVA was conducted to further examine differences in normalized path length from the post baseline measurement. Twenty-nine participants (15 control, 14 performance) had complete data for all three post baseline measurements and were included in this analysis. Means and standard deviations can be seen in Table 5.6. Figure 5.7 shows a bar graph of the data over time. A significant main effect of time was observed, $F(3.99, 91.66) = 10.252$, $p < .001$, $\eta^2 = .308$ (the sphericity assumption was violated and a Greenhouse Geisser correction was used, changing the within degrees of freedom from 8 to 3.99 and the between degrees of freedom from 184 to 91.66). No significant main effect of condition was observed ($F(1, 23) = 2.001$, $p = .172$, $\eta^2 = .08$). No significant interaction was observed ($F(3.99, 91.66) = 1.02$, $p = .402$, $\eta^2 = .042$; the sphericity assumption was violated and a Greenhouse Geisser correction was used, changing the within degrees of freedom from 8 to 3.95 and the between degrees of freedom from 216 to 106.55).

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Control | 50.25 +/- 16.60 | 34.95 +/- 17.38 | 30.67 +/- 15.61 | 45.28 +/- 15.78 | 27.24 +/- 20.76 | 31.17 +/- 19.89 | 34.57 +/- 24.13 | 19.32 +/- 10.59 | 22.52 +/- 14.81 |
| Performance | 56.67 +/- 17.11 | 30.05 +/- 12.92 | 28.06 +/- 5.49 | 49.81 +/- 14.46 | 30.80 +/- 8.28 | 30.64 +/- 8.82 | 40.09 +/- 17.20 | 31.45 +/- 12.50 | 34.56 +/- 18.80 |
| Total | 53.59 +/- 16.83 | 32.40 +/- 15.10 | 29.31 +/- 11.33 | 47.63 +/- 14.97 | 29.09 +/- 15.33 | 31.17 +/- 14.85 | 37.44 +/- 20.56 | 25.62 +/- 12.95 | 28.78 +/- 17.75 |

*Table 5.6: Means and standard deviations by 30-seconed sample for normalized path length during post baseline measurement for participants that showed adaptation.*

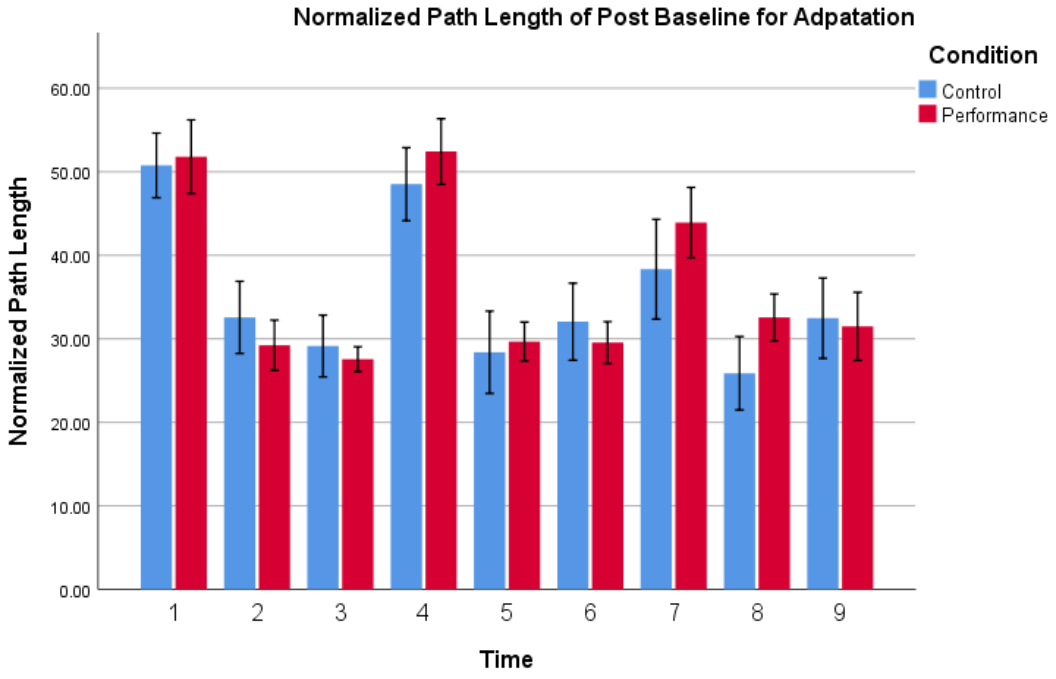


*Figure 5.7: Bar graph of unaggregated normalized path length data during post baseline for participants that showed adaptation.*

## Appendix O

### Further Analysis of Posture Data by "No Adaptation" and "Full Adaptation"

To examine whether posture differed between participants who experienced different sickness levels, participants were split into a "no adaptation" group and a "full adaptation group." These groups served as the "sick" and "well" comparison groups typically done by postural sway analysis researchers. Five participants were in the "no adaptation" group and 13 participants were in the "full adaptation" group. Table 5.7 shows descriptive statistics for these participants.

| Condition | N | Male | Female | Age (Mean +/- SD) | Race (C/B/H/A/Prefer not to answer) | MSSQ (Mean +/- SD) |
|---|---|---|---|---|---|---|
| No Adaptation | 5 | 3 | 2 | 19.8 +/- 1.10 | 4/0/1/0/0 | 6.00 +/- 7.04 |
| Some Adaptation | 22 | 9 | 13 | 19 +/- 1.02 | 20/1/0/0/1 | 6.00 +/- 6.02 |
| Full Adaptation | 13 | 8 | 5 | 20.46 +/- 3.71 | 9/2/1/1/0 | 9.30 +/- 10.08 |

*Table 5.7: Descriptive statistics of participants who showed either no adaptation or full adaptation.*

A 2 x 3 mixed ANOVA was conducted for each of the postural sway measures using data from the post baseline period only. Figures 5.8, 5.9, and 5.10 represent line graphs of each of the postural sway data measures. No significant main effects or interactions were observed for elliptical area or normalized path length. A marginally significant main effect of adaptation level on path length was observed, $F(1, 13) = 4.36$, $p = .057$, $\eta^2 = .25$.

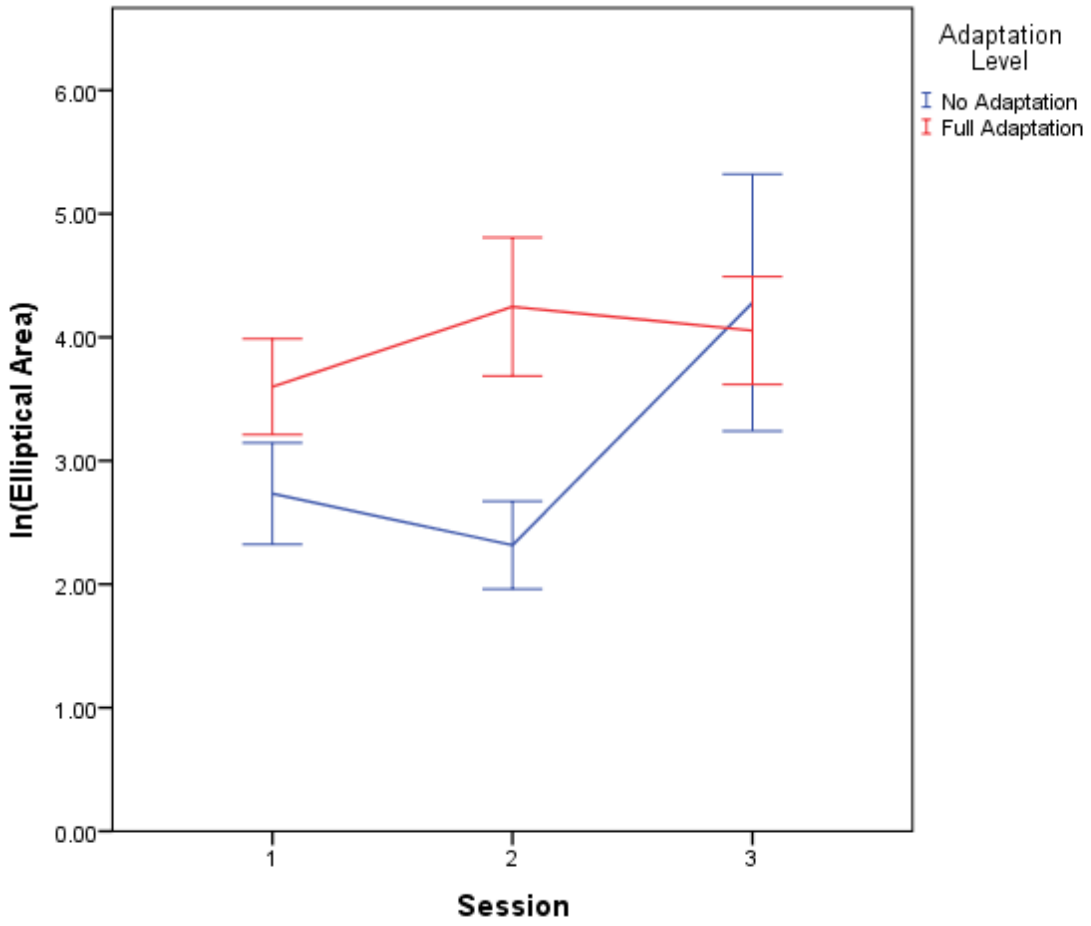


*Figure 5.8: Line graph of the natural logarithm of elliptical area measured in squared centimeters collected during post baseline for participants that showed either no adaptation or full adaptation.*

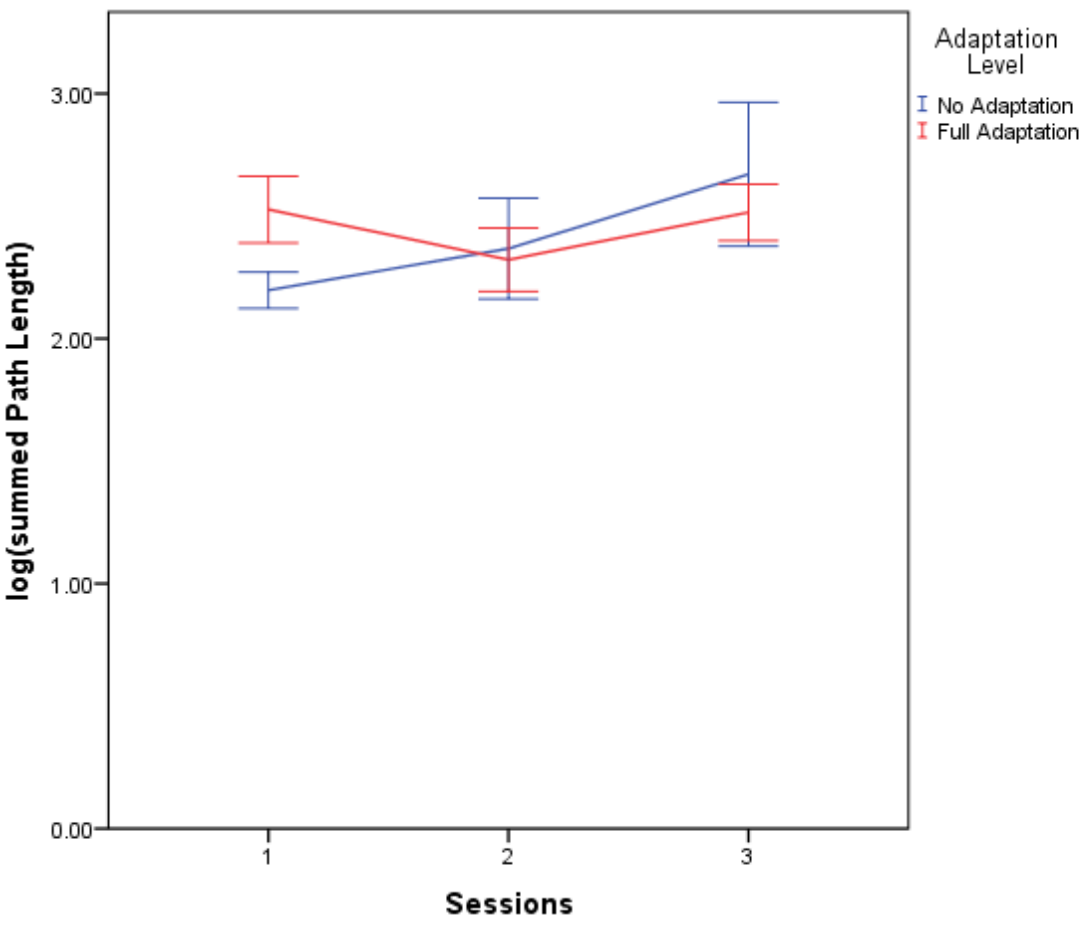


*Figure 5.9: Line graph of the logarithm of path length measured in centimeters collected during post baseline for participants that showed either no adaptation or full adaptation.*

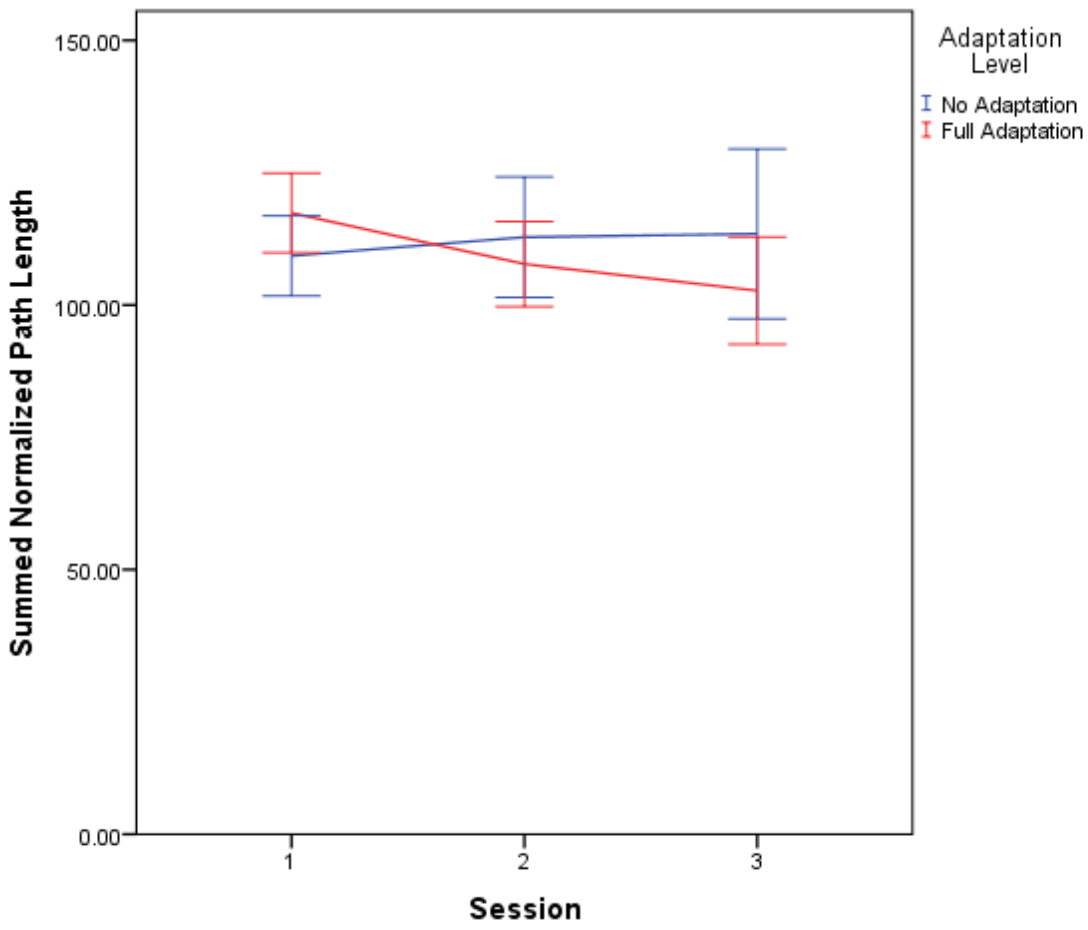


*Figure 5.10: Line graph of summed normalized path length collected during post baseline for participants that showed either no adaptation or full adaptation.*

## Appendix P

### Analysis of Data from Performance Task

Two measures of performance were collected during the second experimental session for the performance condition: reaction time and number of hits. Reaction time was measured in seconds and was calculated as the time between the verbal target presentation and buzzer indicating a target hit. If a participant did not get a hit on a particular target presentation, their reaction time was recorded as 3 seconds, as this was the time between each target presentation. Each time a participants correctly hit the target, the target buzzed. Hits were calculated by counting each a target buzzed, indicating the participant hit the center of the target before the next target presentation occurred. The maximum reaction time for each block was 120 seconds. The maximum number of hits for each block was 40. The total possible reaction time for the experimental session was 600. The total possible number of hits for the experimental session was 200. Means and standard deviations for average reaction time, total reaction time, and number of hits for each block can be seen in Table 5.8. Figure 5.11, 5.12, and 5.13 show line graphs of each performance measure over the five experimental blocks during the second experimental session.

| | Block 1 | Block 2 | Block 3 | Block 4 | Block 5 | Total |
|---|---|---|---|---|---|---|
| Average Reaction Time (seconds) | 2.15 +/- .34 | 1.93 +/- .43 | 1.86 +/- .42 | 1.64 +/- .39 | 1.55 +/- .37 | 1.83 +/- .36 |
| Summed Reaction Time (seconds) | 86.45 +/- 13.81 | 77.26 +/- 17.01 | 74.49 +/- 16.95 | 65.46 +/- 15.43 | 62.18 +/- 14.67 | 365.47 +/- 71.22 |
| Total Hits | 22.37 +/- 8.21 | 26.05 +/- 7.48 | 28.11 +/- 7.02 | 31.63 +/- 6.00 | 33.16 +/- 5.67 | 141.42 +/- 31.52 |

*Table 5.8: Means and standard deviations of reaction time and number of hits for each block during the second experimental session.*

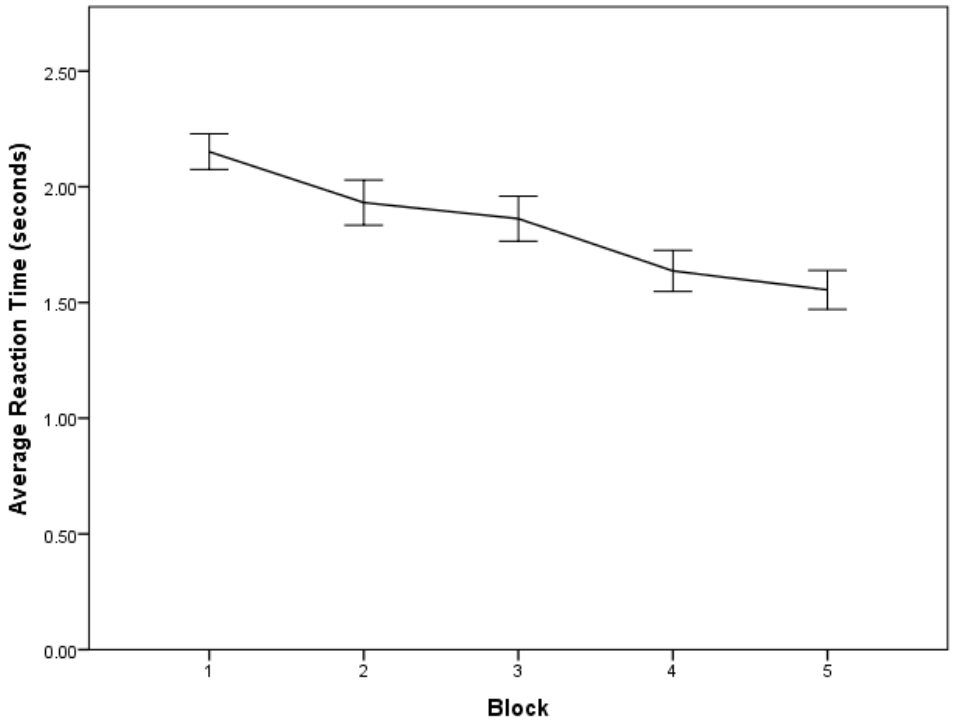


*Figure 5.11: Line graph of average reaction time measured in seconds over the five experimental blocks during the second experimental session. Maximum average reaction time per block was 3 seconds.*

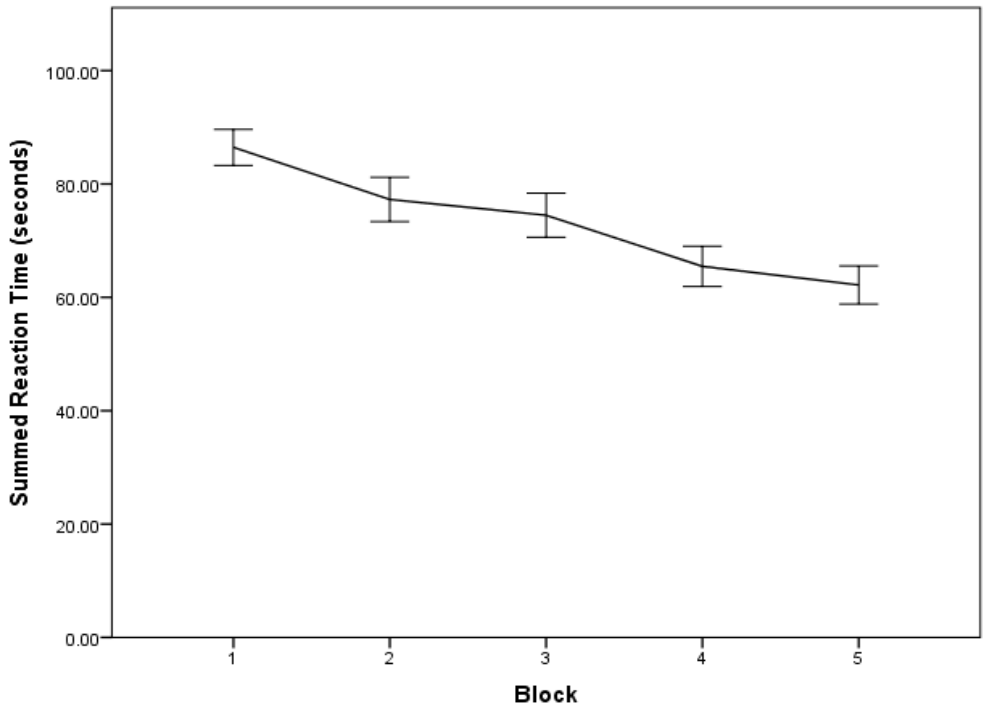


*Figure 5.12: Summed reaction time measured in seconds over the five experimental blocks during the second experimental session. Maximum summed reaction time per block was 120 seconds.*

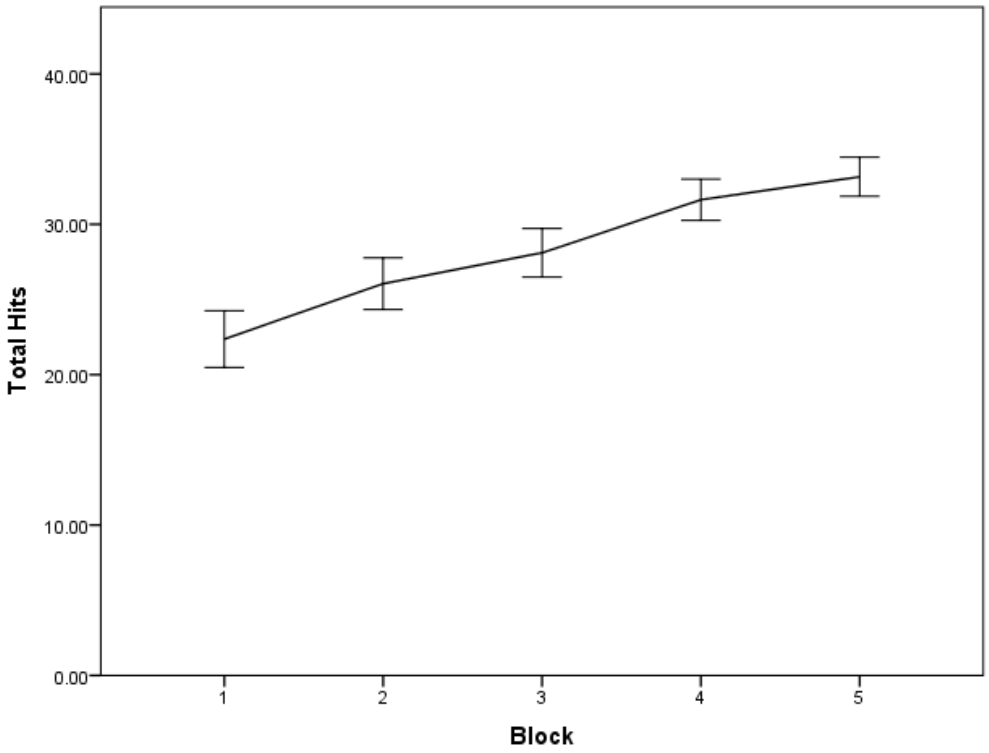


*Figure 5.13: Line graph of total hits for each experimental block during the second experimental session. Maximum number of hits per block was 40.*

Pearson's correlation was used to examine the association between performance and sickness. Correlations between average reaction time, summed reaction time, number of hits, peak SSQ, sum SSQ, and post MSAQ were calculated. No significant correlations between performance measures and sickness measures were observed.

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