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MITIGATION OF MOTION SICKNESS SYMPTOMS IN 360° INDIRECT VISION
SYSTEMS

by

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A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in Applied Experimental and Human Factors Psychology
in the Department of Psychology
in the College of Sciences
at the University of Central Florida
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Major Professor: E.J. Rinalducci

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ABSTRACT

The present research attempted to use display design as a means to mitigate the occurrence and severity of symptoms of motion sickness and increase performance due to reduced “general effects” in an uncoupled motion environment. Specifically, several visual display manipulations of a 360° indirect vision system were implemented during a target detection task while participants were concurrently immersed in a motion simulator that mimicked off-road terrain which was completely separate from the target detection route. Results of a multiple regression analysis determined that the Dual Banners display incorporating an artificial horizon (i.e., AH Dual Banners) and perceived attentional control significantly contributed to the outcome of total severity of motion sickness, as measured by the Simulator Sickness Questionnaire (SSQ). Altogether, 33.6% (adjusted) of the variability in Total Severity was predicted by the variables used in the model.

Objective measures were assessed prior to, during and after uncoupled motion. These tests involved performance while immersed in the environment (i.e., target detection and situation awareness), as well as postural stability and cognitive and visual assessment tests (i.e., Grammatical Reasoning and Manikin) both before and after immersion. Response time to Grammatical Reasoning actually *decreased* after uncoupled motion. However, this was the only significant difference of all the performance measures.

Assessment of subjective workload (as measured by NASA-TLX) determined that participants in Dual Banners display conditions had a significantly lower level of perceived physical demand than those with Completely Separated display designs. Further, perceived

temporal demand was lower for participants exposed to conditions incorporating an artificial horizon.

Subjective sickness (SSQ Total Severity, Nausea, Oculomotor and Disorientation) was evaluated using non-parametric tests and confirmed that the AH Dual Banners display had significantly lower Total Severity scores than the Completely Separated display with no artificial horizon (i.e., NoAH Completely Separated). Oculomotor scores were also significantly different for these two conditions, with lower scores associated with AH Dual Banners. The NoAH Completely Separated condition also had marginally higher oculomotor scores when compared to the Completely Separated display incorporating the artificial horizon (AH Completely Separated).

There were no significant differences of sickness symptoms or severity (measured by self-assessment, postural stability, and cognitive and visual tests) between display designs 30- and 60-minutes post-exposure. Further, 30- and 60- minute post measures were not significantly different from baseline scores, suggesting that aftereffects were not present up to 60 minutes post-exposure. It was concluded that incorporating an artificial horizon onto the Dual Banners display will be beneficial in mitigating symptoms of motion sickness in manned ground vehicles using 360° indirect vision systems. Screening for perceived attentional control will also be advantageous in situations where selection is possible. However, caution must be made in generalizing these results to missions under terrain or vehicle speed different than what is used for this study, as well as those that include a longer immersion time.

“Life’s what you make it”

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LIST OF ACRONYMS

AH	Artificial Horizon
CMV	Common Method Variance
FOV	Field of view
IMOPAT	Improved Mobility and Operational Performance through Autonomous Technologies
IVD	Indirect Vision Driving
MGV	Manned Ground Vehicle
NoAH	No Artificial Horizon
NOD	Nausea, Oculomotor, and Disorientation subscales of the SSQ
PAC	Perceived attentional control
SSQ	Simulator Sickness Questionnaire
UGV	Unmanned Ground Vehicle
VE	Virtual environment
VIMS	Visually induced motion sickness

CHAPTER ONE: INTRODUCTION

The United States Army is continually investigating ways to deploy troops more efficiently. Current methods in which this is being done include an increase in intelligence systems technologies and making combat vehicles smaller and lighter, resulting in fewer crew members (Smyth, Gombash & Burcham 2001). The U.S. Army Research Laboratory (ARL) has been involved in an ongoing succession of human factors studies that are aimed to improve intelligence systems technologies for crew stations (Chen & Barnes, 2012; Chen, Oden, Kenny & Merritt, 2010; Scribner & Gombash, 1998; Glumm, Marshak, Branscome, Wesler, Patton & Mullins, 1997). One of ARL's current interests in this regard is with the use of indirect-vision driving (IVD) systems.

Indirect-vision driving involves the use of a visual display inside a vehicle and an array of externally mounted cameras as a replacement for a direct view of the environment (Chen et al., 2010). When compared to direct-view driving, IVD increases the protection of crew members from fire, chemical, and biological hazards. In fact, IVD systems for driving, engagement and target search may be required in future combat vehicles in order to keep crews safe from high intensity combat lasers, since lasers can penetrate direct vision blocks (Smyth, Gombash & Burcham, 2001).

Although not currently implemented, indirect-vision systems can also be used for target detection tasks. Target detection can take place in stationary centers or inside combat vehicles using automated information systems while the vehicles are moving, or "on the move" (Hill & Tauson, 2005). In fact, stationary operation centers are predicted to be replaced by these

automated information systems while on the move (2005), necessitating an optimal display design for Soldiers to use for target detection. While head-mounted displays (HMDs) have been a common method for target detection in moving vehicles (Smyth, 2002), it is predicted that a 360° view will be implemented in the near future due to the need of a full field of view to safely and successfully execute security and target acquisition tasks (White & Davis, 2010).

Target detection performance tends to be better in stationary centers (Smyth, 2002). Working in a motion environment in general has been found to impact performance on a variety of other tasks. The question of how motion precisely affects an individual's ability to perform tasks is a fairly new concern (Wertheim, 1998), but it is an increasingly important topic due to the accumulation of human-machine interactions. In fact, the impact of a moving vehicle on performance is considered a major issue for the U.S. Army (Hill & Tauson, 2005).

Two main aspects of motion effects on performance have been identified to be that of perceptual and psychomotor effects or motion sickness effects (Wertheim, 1998). These aspects are no stranger to being investigated, and there are guidelines to assess, as well as to reduce, performance decrements due to both types of effects. However, despite current guidelines, it has recently been suggested that additional studies be conducted to further examine both of these aspects in order to help resolve potential decrements of crewmembers in manned ground vehicles (MGVs; Hill & Tauson, 2005). For example, vehicle motion and its accompanying vibration and noise can make certain physical movement and auditory tasks harder to perform (Cowings, Toscano, DeRoshia & Tauson, 1999). It has also been found that vibration of various frequencies, especially those at 30 Hertz (Hz), greatly disrupts vision (Hill & Tauson, 2005).

Although the guidelines to reduce performance decrements due to vibration are reported in a credible and esteemed source (ISO Standard 2631, 1997), there is some disagreement on its applicability (Griffin, 1997).

Additionally, previous research suggests that symptoms of motion sickness can negatively impact the operations of crew members on both individual and group tasks in manned vehicles (discussed in more depth below; Beck & Pierce, 1996, Cowings, Toscano, DeRoshia, & Tauson, 1999). This is a major issue considering that high instances of sickness have been noted in these situations, such as 74% of Marines in a study involving an amphibious assault vehicle (Rickert, 2000), and all Soldiers in a study conducted in manned ground vehicles (MGVs; Cowings, Toscano, DeRoshia, & Tauson, 1999). Further, working in motion environments can produce fatigue, a sopite-related sickness symptom, to up to twice the level of that of individuals working in stationary environments (Wertheim, 1998).

The topic of motion sickness has been studied extensively, and terms have been defined to indicate the specific environments or situations in which similar symptoms occur (e.g., simulator sickness is coined for symptoms that arise in simulators, cybersickness for those that are found in virtual environments, and seasickness for those that occur out at sea). This is helpful because different environments can produce different levels of severity of sickness symptoms. For example, both space and sea sickness have a high incidence of nausea and similar symptoms (with nausea reports being the highest in space sickness), while oculomotor disturbances are the highest form of simulator sickness symptoms (Kennedy, Drexler & Kennedy, 2010; Wilker, Kennedy, McCauley, Pepper, 1979). Additionally, an in depth analysis

conducted by Drexler (2006) revealed marked differences of symptom severity between simulator sickness and cybersickness.

In recent years, it has been found that the health and performance of individuals decrease while being exposed to visual information that differs from simultaneous motion that is being felt (e.g., Cowings, Toscano, DeRoshia & Tauson, 1999; Muth, 2009; Muth, Walker & Fiorello, 2006). These decrements are highly likely to be the result of motion sickness caused by uncoupled motion. Uncoupled motion is defined as an environmental condition where an individual is concurrently exposed to two mismatched or asynchronous motions (Muth, 2009). This term can also be used to describe both real (e.g., driving a vehicle on a moving ship) or virtual (e.g., being in a motion simulator while performing visual tasks on a screen that involves movement) situations (Muth, Walker & Fiorello, 2006). Therefore, performing a target detection task while concurrently being transported inside a moving vehicle is classified as uncoupled motion. In fact, this exact scenario has prompted one researcher to state: “It turns out that this is one of the nastiest things you can do to someone. It is extremely provocative” (Lackner, 1990; pp. 43).

The issue of uncoupled motion is a concern that is not limited to civilian or military personnel. Exposure to uncoupled motion is becoming more common in daily life situations due to the increase in automated driving systems that enable drivers to do other activities while in a moving vehicle (Davis, Animashaun, Schoenherr, & McDowell, 2008). There is also an increase in the implementation of entertainment systems in automobiles, planes, and other modes of transportation. Simply taking advantage of the ability to watch movies and sports or play video

games while commuting can cause unwanted and potentially detrimental side effects that are different in symptoms and severity than classic motion sickness. For example, the most recent operating system for Apple iPhone and iPads (iOS 7) reportedly has parallax and zoom features that are making users experience motion sickness symptoms including vertigo, headaches and nausea due to the motion on-screen (Reisinger, 2013). Since these are popular devices, they are likely to be used while individuals are commuting, which would exacerbate sickness effects. It is critical for uncoupled motion to be investigated more thoroughly in order to determine how to reduce unwanted symptoms for a potentially large percentage of the population.

The Improved Mobility and Operational Performance through Autonomous Technologies Army Technology Objective (IMOPAT ATO) has conducted studies involving IVD tasks inside MGVs while on the move and currently has several screen designs that are implemented for these tasks (Drexler, Elliot, Johnson, Ratka & Khan, 2012). The most common, as well as the most preferred (2012), is the Dual Banners Tile display, shown below (Figure 1).

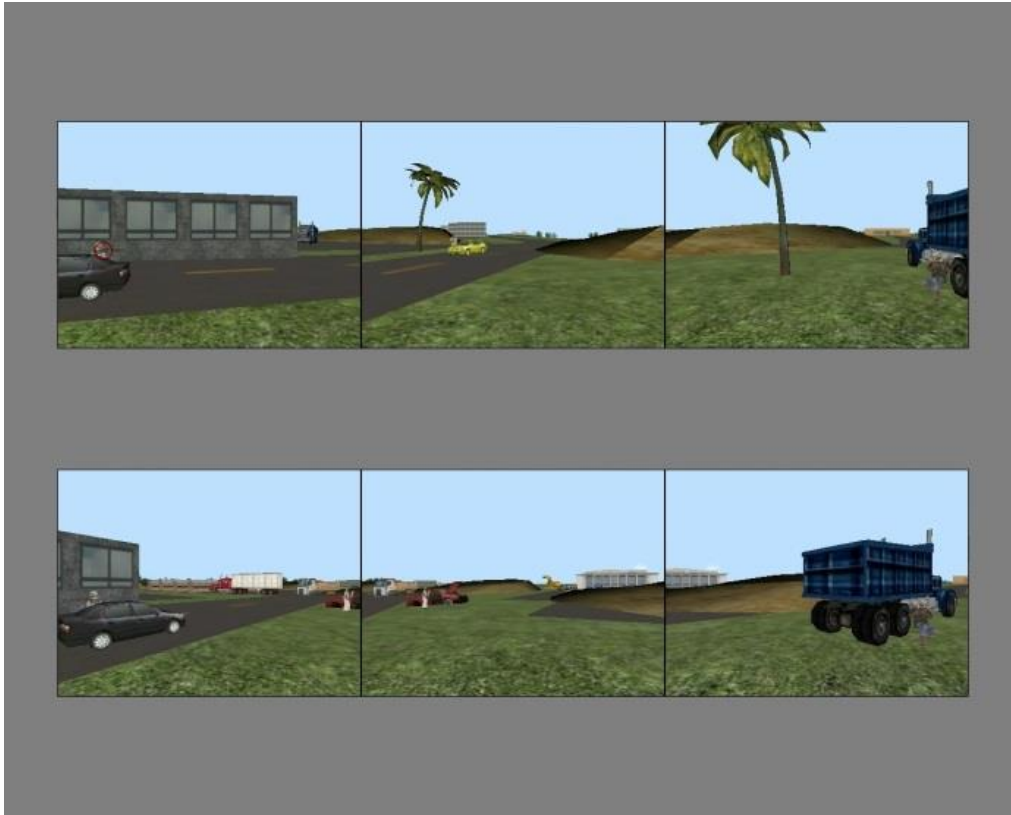


Figure 1: Original Dual Banners Tile Layout

This display is composed of six camera feeds that enable crewmembers, particularly the Commander (one who is not driving the MGTV) to observe a full 360° view of a particular environment. Each camera feed provides a 60° view, resulting in 180° front and back views. The Dual Banners Tile is currently the only display that enables crewmembers to have a 360° view on one screen. Unfortunately, field studies implementing the Dual Banners Tile display have resulted in reports of individuals experiencing motion sickness within just minutes of being on the move (J. Chen, personal communication, August 17th, 2012).

There is an abundant amount of research and interest on display technology and its relation to human performance, so much so that there is an international journal, aptly named

Displays, that covers human factors issues including human-computer interaction, applied vision, and measurements of visual performance relating to displays. Although there are criteria that aid in the design of displays which enable an individual to best extract information (Kennedy, 1990), there currently is no standard on the most effective design for reducing errors related to visual displays (Hill & Tauson, 2005). In regards to displays and motion sickness, a plethora of studies over the past few decades have revealed many visual display factors that play a role in susceptibility (which will be discussed in depth below). However, no research has been conducted on the layout of 360° IVD system screens and their relation to these issues. Additionally, there has been minimal investigation regarding how the visual scene affects sickness in uncoupled motion (Butler & Griffin, 2006), and research has yet to be conducted for potentially mitigating sickness through manipulations of 360° vision displays.

Research Aims

The purpose of the present research is to investigate whether manipulation of the display of a 360° indirect vision system during a target detection task in an uncoupled motion environment can lessen the severity and duration of sickness symptoms when compared to the currently implemented design. Additionally, and in connection with the former, the proposed research aims to find whether there is an optimal design that improves performance of the target detection task as well as performance after exposure.

Expected Contributions

Sickness that arises due to uncoupled motion is an important matter because of the expected implementation of 360° IVD systems for target detection tasks while on the move.

Although an immediate “easy fix” would be to only allow non-susceptible individuals to perform these tasks, this would diminish the flexibility of assignments (Hill & Tauson, 2005). Also, individuals may not be able to accurately predict if they would become sick, or how severe their symptoms would be, in this type of environment. From a human factors standpoint, it is imperative to investigate the effects of the devices that individuals interact with and whether or not they can be designed more effectively to minimize health risks and sickness performance decrements. Although training can be used to potentially reduce risks, evaluating the system itself is extremely beneficial to explore.

There currently is no research on the manipulation of a 360° visual system design and how this can potentially impact symptoms of motion sickness and performance. The expected key contributions from this study include, at the very least, a deeper understanding of whether display design for this particular vision system affects sickness symptoms during uncoupled motion and, potentially, a better design that results in less sickness than the currently used Dual Banners Tile display. If the study reveals a better design, it can easily be implemented into current missions, increasing both the health and safety of mission crews. Additionally, as will be discussed in more depth below, the proposed study will add to the currently limited knowledge of uncoupled motion and its effects on cognitive performance. Lastly, while this study is directly aimed towards military applications and the Ground Combat Vehicle program, it is possible that they may be generalized to a wider population due to the increase in use of visual displays while concurrently being exposed to motion during travel.

CHAPTER TWO: LITERATURE REVIEW

The background of this dissertation requires a selected review of target detection and IVD systems, motion and simulator sickness, uncoupled motion and potential performance decrements due to these factors. This chapter will discuss these issues along with current mitigation techniques, and will then conclude with the rationale of the research design.

Target detection is a common and necessary task for Soldiers. The 360° Dual Banners Tile visual display used by IMOPAT ATO (discussed in more depth below) enables an individual to view the full surroundings of an environment on one screen. This is beneficial in two major ways: first, a large FOV has also been found to reduce workload in unfamiliar environments (Scribner & Gombash, 1998). Second, this design reduces head movements that would be required to view the same surroundings on several different monitors, and this benefit will be discussed in more depth in the motion sickness section below.

The type of cameras used plays an important role in viewpoint disorientation and time delays (Anderson, Peters & Iagnemma, 2010). It has been found that the efficiency of the visual image or display can affect workload. Specifically, limited visual information has resulted in reports of higher workload (French et al., 2003), and excessive workload can result in an increase in errors and fatigue (Smyth, Gombash, & Burcham 2001). Thus, FOV, camera resolution, distortion and time delays are important influences on workload during target detection tasks. Other factors such as depth perception (i.e., monocular or stereovision) and level of autonomy have also been found to be important (Scribner & Dahn, 2008).

Stereoscopic, or 3D displays have been found to benefit performance on certain detection tasks when compared to monoscopic, or 2D displays. In some situations, stereoscopic displays reduce driving time (Drexler, Chen, Quinn & Solomon, 2012) and positioning error (Crooks, Friedman & Coan, 1975), as well as benefit remote manipulation tasks and increased recognition and detection of objects (Chen, Oden, Drexler & Merritt, 2010; Cole & Parker, 1988; Scribner & Gombash, 1998). Stereoscopic displays have specifically been found to provide benefits over monoscopic displays in negative terrain (i.e., environments with ditches or crevices) as a result of the increase in perception of depth (Drexler, Chen, Quinn & Solomon, 2012; Scribner & Gombash, 1998). However, the performance benefits found in stereoscopic displays tend to fade during repeatable tasks (Scribner & Gombash, 1998) and different types of terrain (Drexler et al., 2012). Further, stereoscopic displays have been found to increase visually induced motion sickness, or VIMS (discussed in more depth below), and higher levels of stress when compared to monoscopic displays (Scribner & Gombash, 1998).

There are various monocular cues that the human visual system uses in order to create the perception of depth (Cutting & Vishton, 1995). Examples of monocular cues include occlusion (when an object is partially or fully hidden from another object), relative size (the retinal size of objects at different distances), accommodation (the eye's ability for the lens to change in shape in order to focus on objects at different distances while maintaining a sharp retinal image), brightness, and shading, to name a few (1995). If the cameras used for target detection tasks can adequately provide monocular cues, operators can sufficiently maneuver around the environment and conduct reconnaissance tasks in the absence of stereoscopic displays.

The level of automation of target detection tasks and its effects on workload have been studied quite extensively over the past few decades (e.g., Chen, & Barnes, 2012; Kaber & Endsley, 2003; Endsley & Kaber, 1999; French, Ghirardelli, T.G., Swoboda J., Ho, S., Nguyen, H., Tokarcik, L., Walrath, J., & Winkler, 2003). Automation has been described to be able to range on a scale from 1 to 10, with 1 representing fully autonomous and 10 representing full manual control of the system (Endsley & Kaber, 1999). Target detection in manual control, or when an individual is responsible for all of the movements of a system moving through an environment, is associated with higher workload when compared to target detection that has some level of autonomy (Chen, Barnes, Quinn & Plew, 2011). It has been found that semi-autonomous unmanned ground vehicles (UGVs) can reduce workload if the tasks it encompasses are decision-making tasks, but increasing autonomy of too many tasks has been found to actually reduce performance (Endsley & Kaber, 1999). It is believed by some that, since no human involvement is required, the individual is out of the loop and the resulting performance decrements are due to a lower situation awareness of the environment (Endsley & Kiris, 1995). Situation awareness (SA) is defined as, “the perception of the elements in the environment within a volume of time and space (Level 1), the comprehension of their meaning (Level 2) and the projection of their status in the near future (Level 3)” (Endsley, 1988, p. 97).

A study conducted by Darken and colleagues (2001) investigated SA performance of participants while they were exposed to either a video of different bandwidth qualities as it moved through a building, or physically walking through the building along the same path. They found that the individuals walking through the building performed significantly better than any of the individuals viewing a video feed, regardless of the video quality. These results suggested

that passively viewing videos for detection tasks is greatly hindered, and the usefulness of UGVs is limited by this fact (Darken, Kempster & Peterson, 2001). However, a study conducted by French and colleagues manipulated the type of UGV control (i.e., a standard joystick controller, voice control, a combination of joystick and voice control, or a passive, fully autonomous condition) on performance of both an identification task and SA and found no effect for mode of control on performance (French et al., 2003). The researchers note that their passive viewing (autonomous) condition functioned perfectly and their participants knew they never had to intervene.

As will be mentioned in detail in the Procedure section, SA performance was assessed during this study. However, although the concept of which LOA is better for SA tasks during uncoupled motion is interesting, it is beyond the scope of the aims of the current study. Since the focus of this research is not to enhance SA performance to its most optimal level, manipulating LOA may have potentially resulted in unwanted heightened levels of workload and stress. Further, similar to the study conducted by French and colleagues mentioned above (2003), this study implements an automated UGV that functions perfectly and does not require any intervention from the participant. It is sufficient to simply note that situation awareness may be different in uncoupled motion environments using the same screen manipulations with different levels of LOA.

Motion Sickness and its Variants

Although this study concerns uncoupled motion, both motion sickness and simulator sickness in motion platforms are involved and therefore will be discussed in this section. An

understanding of how sickness arises and uncovering previous attempts to reduce symptoms can enable researchers to make informed predictions on how to mitigate sickness in newer, less investigated environments, such as uncoupled motion. However, as will be mentioned in more depth below, the cause and predictability of motion sickness and its variants are not fully explained by current theories. Further, the specific types of symptoms that arise are dependent upon many factors involved with the characteristics of the environment as well as the tasks and characteristics of the exposed individuals. Therefore, there is still much to be uncovered in order to entirely prevent motion sickness and its variants in any environment.

Motion sickness is a motion maladaptation syndrome (Kennedy & Fowlkes, 1992; Reason & Brand, 1975) that arises during exposure to real motion (e.g., travel, amusement park rides; Burcham, 2002), but the term has also been used to describe symptoms that are found during apparent motion (e.g., virtual environment systems, optokinetic drum; Reason & Brand, 1975). Consequently, motion sickness is often used as an umbrella term to describe similar symptoms that are observed in specific environments. Nonetheless, terms have been coined to differentiate between these environments (e.g., seasickness, simulator sickness, cybersickness, car sickness, space sickness, airsickness). This is useful because, although similar symptoms may arise, their causes—as well as their level of severity—can be reasonably different (Kolasinski, 1995). In other words, simulator sickness and other variants are a form of motion sickness, but they are not the same thing (Johnson, 2005). For example, simulator sickness observed from a fixed-base simulator is thought to be primarily visually induced (Kolasinski, 1995), whereas certain cases of classic motion sickness can arise due to vestibular stimulation alone (Money, 1970).

However, this is not to say that sickness is assumed to have one cause in certain environments; it is actually widely accepted that sickness can result from a multitude of factors. Simulator sickness is described as polygenic for this reason, since no one individual factor can be recognized as the cause (Kennedy & Fowlkes, 1992). For example, a simulator incorporating a motion platform cannot attribute outcomes of sickness solely to visual or vestibular simulation, but likely as a result of the combination of both. In fact, it has been suggested that simulator sickness observed in motion platforms may indeed be “classic” motion sickness due to the presence of low frequency vibration (Kennedy, Fowlkes, Berbaum & Lilienthal, 1992; Kolasinski, 1995). In support of this conjecture, although vibration alone is believed to be able to induce symptoms of classic motion sickness, it is also believed that vision plays an important role (Kennedy, Hettinger, & Lilienthal, 1988), particularly since perceived self-motion and orientation rely heavily on this sense (Kolasinski, 1995). The issues of vibration and vision will be discussed in more depth below.

Numerous symptoms of motion and simulator sickness have been observed and include, but are not limited to, nausea, vomiting, dizziness, disorientation, sweating, apathy and pallor. For this reason, simulator sickness has been described as polysymptomatic (Kennedy & Fowlkes, 1992). Several researchers have grouped these symptoms into classes in order to distinguish the origin from which they arise. For example, there is a common classification of 3 groups of symptoms: 1) perceptual and sensorimotor disruption involving the vestibular system (e.g., disorientation, inaccurate vestibulo-ocular or vestibulo-spinal reflexes, and disequilibrium); 2) perceptual issues associated with autonomic symptoms (e.g., nausea, vomiting, pallor, salivation); and 3) sopite-syndrome (e.g., drowsiness, mood changes, fatigue and need to sleep)

(Burcham, 2002). In addition to these classifications, there also is a widely accepted (and validated) classification of symptom types that are distinctively related to simulator sickness (Kennedy, Lilienthal, Berbaum, Baltzley & McCauley, 1989). This classification will be discussed below under Measures of Sickness.

Major Theories of Motion Sickness

Theories of motion sickness cannot be explained without mentioning the vestibular and visual systems. There is an abundant amount of information on the anatomical and physiological aspects of these systems, and they will only be summarized with their relation to motion sickness here. The vestibular system is comprised of the angular acceleration receptor system, the linear acceleration of the otolith organs (i.e., utricular and saccular maculae), and the ampullary receptors of the semicircular canals (Probst & Schmidt, 1998), located inside each of the inner ears. The otolith organs respond to an individual's linear accelerations and adjustments in orientation with respect to the force of gravity. The dense membrane of the otolith organs slide up or down when the head is tilted, and lags when the (upright) head is in transient acceleration or deceleration (1998).

The semicircular canals (i.e., superior, posterior and horizontal) are filled with fluid (i.e., endolymph) and inside the widened base (i.e., ampula) of each canal is a gelatinous wedge (i.e., cupula) that restricts the fluid from flowing through each base (Young, 2003). Cilia that are projecting from hair cells are located at the base of each cupula, and any movement of the fluid inside the canal will result in a slight movement of the cupula which will in turn bend the cilia (2003). The hair cells will fire as a result of this bending, which will consequently send a pattern

of discharges to the brain. Because the fluid is viscous and the canals are narrow, they act as approximate integrators of angular velocity, or rotational movements (Probst & Schmidt, 1998). Thus, the vestibular system contributes to movement and the sense of balance. The cochlea, which is a part of the auditory system, is attached near the otoliths and semicircular canals and together the three parts of the inner ear are called a labyrinth. Individuals who are born without a functioning vestibular system or are bilateral labyrinthine-defective never experience motion sickness (Kellogg, Kennedy & Graybiel, 1965).

The visual system collects and processes light in order to generate an image of an individual's surrounding environment. The retina, or the light-sensitive layer of tissue that lines the inside of the eye, plays a major role in creating these images. Although it is argued that the eyes cannot directly detect acceleration, they can sense motion by visual changes resulting from the body's change in position or as velocity in the peripheral visual field (Young, 2003). Just like the vestibular system and proprioception, the visual system contributes to balance and the maintenance of an upright posture. In fact, it has been found through balance tests which isolated these mechanisms that vision plays the biggest contribution to balance (Hansson, Beckman, & Hakansson, 2010).

The human body concurrently uses more than one system in order to properly control certain functions. An example of this is the vestibulo-ocular reflex (VOR), which is the eye's normal response to stabilize images on the retina during head movement. This is done by the generation of eye movements of equal and opposite angular displacement than a particular head rotation (Khater, Baker & Peterson, 1990). This ability relies on the information received by the

semicircular canals and their sensed head rotation (i.e., rotational VOR) and the otoliths and their sensed head translation (translational VOR). The “gain” is used to describe VOR accuracy, and is determined by the change in eye angle divided by the change in head angle during a given head movement. If the gain is not close to 1.0 (i.e., ideal VOR outcome), the image of an item/object can be blurred as a consequence of retinal slip. However, VOR recalibration and directional adaptation is possible in order to obtain clear vision after retinal slip (Gonshor & Melvill Jones, 1971; Khater, Baker & Peterson, 1990). Many factors can create changes in VOR output, such as damage to the vestibular or oculomotor systems and developmental change. Errors can also occur when the direction of visual field motion is different than the direction of head motion (Khater, Baker & Peterson, 1990) which, as discussed later, is an important issue in uncoupled motion environments.

There currently is no one theory that fully explains why motion sickness or its variants occur. Although there are several theories, the most commonly acknowledged theories will be discussed here. The most widely accepted theory is the sensory conflict (e.g., cue conflict, perceptual conflict, neural mismatch) theory (Reason & Brand, 1975; Probst & Schmidt, 1998). This theory states that sickness arises when there is a discrepancy, or conflict, either within or between particular senses (Reason & Brand, 1975). The former conflict can occur when one sense obtains information about the environment in the absence of signals that would be expected from other senses. An example of this is an individual using a fixed-base driving simulator and visually sensing motion while their vestibular system concurrently does not sense movement. The latter conflict can occur when information from one sense (or senses) contradicts the information being perceived from the other sense (or senses). If this theory holds

true, uncoupled motion would be the result of a discrepancy between primarily the visual and vestibular senses (Muth, Walker & Fiorello, 2006), since an individual would experience visual stimuli that does not match up with the motion that the vestibular system is experiencing, and thus creating a conflict.

A major problem with the sensory conflict theory is that it cannot adequately predict environments where a mismatch would occur, as well as not being able to explain why there are such extreme differences of symptom severity and duration of exposed individuals (Johnson, 2005; Kolasinski, 1995; Stoffregen & Riccio, 1991). Stoffregen and Riccio describe an ecological viewpoint to the sensory conflict theory (1991). From this viewpoint, an agreement within or between senses creates redundant input from the visual, vestibular and somatosensory systems, and any situation what would result in a lack of this redundancy would therefore create sickness symptoms. However, not all situations that lack redundancy induce sickness (e.g., Kennedy & Frank, 1983). Also, this theory cannot explain how environments with oscillations between 0.08-0.4 Hz induce sickness while a normal individual's standing sway, which is estimated between 0.01-0.4 Hz, does not produce motion sickness (1983). These and other discrepancies prompted Stoffregen and Riccio to conclude that the sensory conflict theory not only is unreliable, but may not even exist (1991).

The ecological theory of motion sickness argues that the likelihood of sickness is due to an individual's adequacy of postural stability (Stoffregen & Riccio, 1991). In other words, this "postural instability" theory is based on the suggestion that, rather than a sensory congruency, the physical response to perceived or real motion is what determines sickness. According to this

theory, individuals that are able to maintain postural stability in provocative environments will not experience sickness and those with postural instability (i.e., dystaxia) will be succumbed to symptoms of sickness. Therefore, this theory makes clear and testable predictions (Johnson, 2005). This approach explains how an environment that produces sensory conflict can result in certain individuals becoming sick while others do not experience any ailments. However, both the postural instability and sensory conflict theory are not individually sufficient to predict motion sickness. Therefore, both theories were taken into account during the design of this study.

Current Factors Known to Impact Sickness

As will be discussed in more depth below, the research design attempted to control for many known factors that contribute to sickness within financial, time and resource limitations in order to obtain a clearer view of the effects of visual display design manipulation during uncoupled motion. Although the cause of motion sickness is still not fully understood, several decades of research have uncovered numerous factors that are involved with the likelihood for sickness to arise. Below will mention known factors that are relevant to uncoupled motion, separating most factors into three categories: individual characteristics, visual display factors, and simulator/motion factors (adapted from Kolasinski, 1995). As mentioned by Kennedy and Fowlkes (1992), it is impossible to measure a factor's individual effect because of the interconnectedness of the factors as a whole. In other words, one factor cannot be fully separated and measured individually. Therefore, one cannot assume that a specific factor is more

important than any other factor; they all should be given equal importance, even though each factor can produce different outcome effects (Kolasinski, 1995).

Individual Factors

Numerous factors related to individual characteristics have been found to contribute to sickness susceptibility. These include but are not limited to age, previous motion history and simulator experience, gender, ethnicity, concentration level, current health, mental rotation ability, perceptual style, postural stability, and smoking/nicotine intake.

Susceptibility to motion and simulator sickness has been widely accepted to be the highest at a young age (2-12 years), then rapidly declines during 12-21 years of age, and becomes almost nonexistent by around 50 years of age (Reason & Brand, 1975). However, it is important to note that despite repeated citation of these findings, there is a strong belief held by others, for example Johnson (2005), who has personal experience and a background of simulator-based training of a vast number of aviators that show the opposite to be true (Johnson, 2005), where sickness increases during old age. Both perspectives will be discussed because of its importance to the current study.

Age is correlated with an individual's experience with different types of motion exposures, since the longer an individual has been alive, the more experience they are likely to have with a variety of motion environments. From a sensory conflict theory standpoint, although conflicts result from what the sensory systems expect to occur versus what is actually felt or experienced, the expected patterns are plastic and can be modified based on repeated experiences to particular conditions. It is suggested that the apparent adaptation that occurs with age is

related to long-term learning patterns that are found with other types of learning (Reason & Brand, 1975). However, it has been suggested that adaptation to sickness inducing environments-particularly with simulators-can result in higher levels of sickness symptoms upon the conclusion of the exposure (Kennedy & Frank, 1983; Regan, 1993).

It is interesting to note that there have been observations of highly experienced pilots being more susceptible to simulator sickness when compared to those with less flight experience (Miller, & Goodson, (1960). Kennedy and colleagues suggest that this occurrence may be the result of the highly experienced pilots' sensory expectancies based on actual flight, which consequently enables them to be more sensitive to the differences between real and simulated flights (Kennedy, Hettinger & Lilienthal, 1988). At the same time, not all studies observe this outcome in highly experienced pilots. This may be due to the fact that individuals who have a career relating to motion (e.g., pilots) are less likely to be susceptible to motion sickness in general (McCauley & Sharkey, 1992), which can be the result of more robust adaptation or the self-selection process of obtaining a job that involves motion (Kennedy, Hettinger & Lilienthal, 1988). In other words, individuals who are more susceptible to motion sickness would not opt to acquire these types of jobs.

Another way to explain increased simulator sickness that is sometimes observed in highly experienced pilots is age itself. For example, McGuinness and colleagues cited reports of increased susceptibility to vertigo and disorientation with age in 1,000 Naval aviators during investigation over a twenty-year period (McGuinness, Bouwman & Forbes, 1981). Physiological changes that occur during increasing age have been found to include postural reflexes, a reduction in strength of muscles that maintain posture, and an increase in postural sway (Kane,

Ouslander & Abrass, 1994). This explains why it is common for elderly individuals to experience falls, with dizziness and unsteadiness being among the symptoms of those that fall (1994). Therefore, the increase in postural instability due to physiological changes is predicted to increase motion sickness susceptibility from the standpoint of the postural instability theory, which is the opposite of the sensory conflict theory. One thing is similar about both of these viewpoints: susceptibility changes with age. This was taken into account during the design of this study.

Studies have found that females are more susceptible to motion sickness than males in a variety of motion environments, such as vehicles (Turner & Griffin, 1999), ships (Lawther & Griffin, 1988), and planes (Turner, Griffin & Holland, 2000). It is believed by some that increased susceptibility may be due to hormonal cycles, while others suggest it can also be the result of males who underreport symptoms (Biocca, 1992). It has also been found that females have larger fields of view, which can result in more visual disturbances thought to be associated with sickness (Kennedy & Frank, 1983). Regardless of the source or sources, motion sickness symptoms in females produce a higher variability than in males (Butler & Griffin, 2006), and this was considered for this study.

In addition to gender differences, previous studies have found differences in severity of sickness between European-American, African-American, and Chinese females, with Chinese females being reported as hyper-susceptible to motion sickness (Stern, Hu, LeBlanc, and Koch, 1993). A later study widened the scope and found that both males and females of Asian descent, regardless of where they were born or raised, were found to have significantly more severe

symptoms of sickness in a 3-part study (Stern, Hu, Uijdehaage, Muth, Xu & Koch, 1996). This aspect was also proposed for this study.

Other individualistic characteristics include the flicker fusion frequency threshold, which is the point at which an individual is able to perceive flicker on a display. It has been found that this threshold changes throughout the day based on the circadian rhythm (Grandjean, 1988), with the threshold increasing (i.e., perception of flicker occurs at a lower point) during the day and decreasing (i.e., perception of flicker occurs at a higher point) into the night. The circadian rhythm, also known as the “internal clock,” is the daily cycle of physiological activity in the body (Moorcroft, 2005). The circadian rhythm also has an impact on individual’s level of attention, concentration, and fatigue, as well as many other performance related factors. However, several studies have found that this threshold is also highly variable between individuals, with changes as a result of age, gender and intelligence (Kolasinski, 1995).

Individuals tend to be increasingly likely to be susceptible to motion sickness when they are not in their normal state of fitness (Kennedy, Berbaum, Lilienthal, Dunlap et al., 1987). Factors that play a role in this are whether individuals are suffering from a cold, under the influence of drugs or alcohol (Biocca, 1992), have a hangover, taking certain prescription medications (Young, 2003), or simply just not in their usual state of mind (Kennedy & Fowlkes, 1992). It has also been found that smoking or nicotine intake (Golding, Prosyankova, Flynn & Gresty, 2011) neuroticism, anxiety and introversion (Biocca, 1992) can influence motion sickness susceptibility. Therefore, it would be beneficial for researchers conducting any studies on motion sickness and its variants to gather this information with the use of questionnaires in

order to use them either to screen participants or as covariates to potentially reduce some of the variability of sickness results.

It recently has been found that an individual's Perceived Attentional Control (PAC; Derryberry & Reed, 2002) can impact severity of simulator sickness symptoms. Attentional Control asks questions on an individual's feelings on distractions and concentration, and these have been found to measure attention focus and shifting (2002). Recently, research has found that participants with lower PAC scores reported significantly higher simulator sickness when compared to high PAC participants (Chen & Joyner, 2009; Drexler, Chen, Quinn & Solomon, 2012). It is of interest to determine if the same results are found in uncoupled motion environments.

An individual's perceptual style has also been found to impact susceptibility. Perceptual style can point to the degree to which an individual is affected by the surrounding field of an item embedded within it. It was reported in one simulator study that all extremely field-independent participants had gotten sick and, although a few field-dependent participants also got sick, the researchers concluded that field-independent individuals are more susceptible to simulator sickness (Barrett & Thornton, 1968). However, the opposite results were found in a later study involving a swing-like device (Barrett, Thornton & Cabe, 1970). Despite inconsistent results, and even those who suggest that perceptual style may be unrelated to simulator sickness susceptibility (Frank & Casali, 1986), it still would be interesting to see if perceptual style can impact sickness in uncoupled motion when also compared to other factors such as sickness susceptibility, postural stability, attentional control.

As mentioned above, it has been found that individuals are able to adapt to situations that may have originally resulted in sickness due to the plasticity of our perceptual and perceptual-motor systems (Welch, 1978). In other words, experience within a certain environment can allow the perceptual system to acquire different expectations and thus avoid sickness in future exposures. Reason and Brand state that prolonged exposure will lead to a reduction and an eventual disappearance of symptoms of sickness in most people (Reason & Brand, 1975). However, the researchers state that it is necessary for there to be an absence of variation in the characteristics involved in the particular sickness-inducing environment in order for adaptation to occur (1975). Further, repeated exposures can potentially result in an additive effect of sickness severity, resulting in more pronounced symptoms, if one has not adapted yet (Kennedy & Fowlkes, 1992).

Sleep deprivation has been found to result in irregular vestibular habituation, increased vestibular sensitivity and a decreased recovery rate (Dowd, 1974), which can result in increased susceptibility to motion sickness. Additionally, inadequate sleep also has a major effect on performance variability. In addition to its resultant drowsiness, lowered vigilance and alertness (Martin, 2002; Moorcroft, 2005), sleep deficiency also causes fluctuations of reaction times, with sustained reaction time tasks being found to be the most sensitive to inadequate sleep (Dinges & Kribbs, 1991). Therefore, the amount of sleep individuals obtain was considered for this study in order to reduce variability in sickness severity and performance.

Visual Display Factors

Numerous display factors that are recognized to create visual disturbances will briefly be discussed. As will be mentioned, many of these factors are interrelated. Visual angle, which is also commonly referred to as FOV, is described as the display's horizontal and vertical angular dimensions (Pausch, Crea & Conway, 1992). Visual angle has consistently been found to be a determinant in sickness provocation (Drexler, 2006; Jones, Kennedy, & Stanney, 2004; Kennedy, Lilienthal, Berbaum, Baltzley & McCauley, 1989), where the majority of studies conclude that a wider visual angle produces more sickness effects. It has been suggested that this occurs because, as visual angle increases, the peripheral retina receives increased stimulation and results in increased vection, or illusory self-motion (Kennedy, Hettinger & Lilienthal, 1988). However, it is important to mention that one cannot rely on a smaller visual angle to aid in a reduction of sickness. For example, a study displaying a 15° visual angle of stimuli which appeared to have depth was found to induce vection and sickness in 30% of their participants (Anderson & Braunstein 1985). The researchers suggest that visual angle may not be as critical as the motion and texture cues presented within the display. Additionally, it is possible that wider visual angle has been found to provoke sickness in studies due to visual angle being wrongly defined, and deviations with 360° visual angle often have other factors which also may contribute to motion sickness (R. Kennedy, personal communication, January 22, 2013).

Resolution refers to the amount of detail that the display provides (Pausch, Crea & Conway, 1992). Higher resolution can increase disorientation effects (Bowman et al., 2002), while at the same time, poor resolution may be taxing on a user's visual system and produce symptoms such as eyestrain and headache (Drexler, 2006). Field-of-view (FOV) is related to

resolution, where a large FOV can result in a maximum point where the available pixels on the screen are more spread out (2006), which can magnify the effects of any distortions in the visual display (Kennedy, Fowlkes & Hettinger, 1989).

As mentioned previously, flicker frequency fusion threshold varies between individuals and within individuals throughout the day. If flicker is detected, it can be highly distracting and can produce eye fatigue (Pausch, Crea & Conway, 1992). In order to suppress flicker, refresh rate (which is hardware-determined) is necessary to be increased as luminance (i.e., the display's light intensity or brightness; Pausch, Crea & Conway, 1992) and FOV increases (Farrell, Casson, Haynie & Benson, 1988). Farrell and colleagues reported that displays with high refresh rates can allow luminance to be any level, as flicker will not be an issue (1988), but these displays cost more. Contrast refers to a ratio of the highest to lowest luminance that a display provides (Pausch, Crea & Conway, 1992). In order to achieve an adequate visual display, adjustments of contrast may necessitate adjustments of luminance and resolution (Kolasinski, 1995).

The scene content, or the amount of detail available in a particular scene, has been found to impact sickness based on its ability to affect the frame rate (i.e., update rate). Specifically, the computing power for the simulation is what determines the efficiency at which succeeding frames of a moving scene can be generated into the frame buffer for the display (Pausch, Crea & Conway, 1992). When scene content increases, the available computing power of the simulator is reduced and can result in visual lag of the scene. Update rate is an example of a transport delay, and it has been theorized that transport delays over 70 ms can be expected to produce symptoms of sickness (Kennedy, 1996). On a related note, realism has been referred as the

immersive effect one experiences while using a display that provides realistic scene content. As mentioned by Muth (2009), technology has enabled high-resolution displays to become more available and affordable, making it more likely for individuals to become immersed in certain tasks involving these displays.

Viewing region is the space in front of the display where an individual can be seated and is able to view an undistorted and high-quality view of the simulated scene (Pausch, Crea, & Conway, 1992). The center of the viewing region (i.e., design eyepoint) is considered the optimal position, and shifting away from the center can increase image distortion. It is possible for one to be in the viewing region but not in the design eyepoint, and it is suggested that symptoms of sickness and dystaxia result due to the distorted images (Pausch et al., 1992).

Simulator Factors

The task that individuals partake in has been found to impact sickness. This can be due to the task's physical requirements of the individual, such as those requiring head movements, which have been found to be a contributor to sickness (e.g., Dichgans & Brandt, 1973; Reason & Brand, 1975). Reason and Brand (1975) believe the restricted head movements associated with laying down (i.e., supine) may be the reason why there is a reduction in sickness in this position when compared to sitting or standing. Head movements are connected to Coriolis and pseudo-Coriolis stimulation, both of which can occur in an uncoupled motion environment. Coriolis stimulation arises when the axis of the body's rotation is not aligned with the head, which can happen when the head is tilted in a motion environment. Pseudo-Coriolis stimulation arises from head tilts during perceived self-rotation from visual information (Dichgans & Brandt, 1973). On

a related note, although not directly measured, Regan (1993) suggested that concentration level is associated with sickness susceptibility, where higher levels of concentration can result in lower levels of sickness.

Global visual flow refers to the rate of the flow of objects through the visual environment (McCauley & Sharkey, 1992). Global visual flow depends on the observer's velocity, visual range and altitude. Altitude in a simulator appears to be one of the greatest contributors to simulator sickness (Kennedy, Berbaum & Smith, 1993), where low altitudes indicate more movement than higher altitudes at the same speed. As briefly mentioned above,vection (i.e., illusory self-motion) can be caused by visual displays and has been found to affect the vestibular system (Kennedy, Hettinger, Lilienthal, 1988). It is believed that the amount ofvection experienced determines not only the realism of the simulator, but the likelihood of the simulator inducing sickness (Kennedy, Berbaum & Smith, 1993), although the correlation between realism sickness and presence is far from perfect (R. Kennedy, personal communication, October 30, 2013). However, it is believed that if an extreme sense ofvection is experienced, the likelihood of sickness depends on the comparability of the simulated and real-world situation (Kennedy, Berbaum & Smith, 1993).

Measures of Sickness

Prior to motion exposure, a useful means to assess an individual's history and background with motion is with the use of the Motion History Questionnaire (MHQ; Kennedy, Fowlkes, Berbaum & Lilienthal, 1992), or other similar questionnaires assessing motion experiences. The MHQ in particular has been found to predict 10% of variance in motion

sickness susceptibility (Kennedy et al., 1992). Developed in the 1960's to originally evaluate the susceptibility of pilots and sailors to air and seasickness, the MHQ was later modified in order to be used in broader domains (i.e., simulators and VR devices) and populations. For example, three additional scoring keys were created and validated, and in 2001, over 860 MHQs completed by college student participants were reported on an analysis of a VR study (Kennedy, Lane, Grizzard, Stanney, Kingdon & Lanham, 2001). The MHQ consists of a variety of questions relating to the exposure of certain environmental conditions (e.g., simulator, virtual reality, voyage at sea), as well as a self-assessment of symptoms individuals may have experienced in different motion environments.

There are a variety of ways to measure motion and simulator sickness. The most commonly used measure is the Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993), which is a self-assessment of symptoms that are present at the time the survey is being taken. This survey consists of 27 symptoms (16 of which are measured), and individuals are asked to rate the degree of severity of each on a 4-point scale (i.e., none, slight, moderate, severe). A weighted scoring procedure is used to create a Total Severity score, which is described to be an individual's overall sickness level. A factor analysis was conducted on numerous simulator sickness experiences, which resulted in three sickness subscales (i.e., Nausea, Oculomotor and Disorientation; Kennedy, Lane, Lilienthal, Berbaum & Hettinger, 1992), which allows researchers to investigate which systems the body was affected by as a result of immersion in the simulator (Lane & Kennedy, 1988). Specifically, the Nausea (N) subscale reveals symptoms that are related to gastrointestinal distress (e.g., nausea, stomach awareness). The Oculomotor (O) subscale reveals symptoms related to visual system

disturbances (e.g., eyestrain, headache, difficulty focusing). The Disorientation (D) subscale reveals vestibular system disturbances (e.g., dizziness, vertigo).

Although the SSQ and similar self-reports are widely used and are both fast and easy to administer and evaluate, there is a potential for participants to either under- or over-report symptoms (e.g., Cowings et al., 1999). Further, a study conducted by Kennedy and colleagues assessed sickness with the use of multiple measures after a variety of virtual environment (VE) exposure durations (Kennedy, Stanney, Compton, Drexler & Jones, 1999). It was found that objective measures of past pointing and postural stability (discussed below) were not correlated with participants' self-assessed sickness scores, although each of the tests were found to be reliable. The researchers suggest that these three tests may measure symptoms proceeding from different neural pathways, and self-reports alone do not suffice in the determination of whether an individual is experiencing symptoms (1999). Therefore, motion sickness and its variants can be more accurately measured with the use of objective tests in addition to self-assessment reports (Kennedy Hettinger & Lilienthal, 1988; Kennedy et al., 1999). Discussed below are several ways which this has been done.

Physiological measures that have been used to assess motion and simulator sickness include heart rate, respiration rate, finger pulse volume, skin temperature, skin conductance level. However, physiological measures are not always found to be sensitive, reliable, or even in the same direction (Johnson, 2005). Respiration rate has been found to be a sensitive index of both simulator and motion sickness (Casali & Frank, 1988; Johnson, 2005), but some individuals have an increase in respiration rate associated with sickness while others have a decrease in

respiration rate associated with sickness. Therefore, physiological measures are individualistic and not always easily interpreted. In addition, due to limited resources and finances, physiological effects were not be considered for the current study.

Cognitive measures have been used to uncover whether there is a change in performance due to exposure to real or apparent motion. Kennedy and colleagues assessed the cognitive performance of individuals who were immersed in a simulator to those in a control group (Kennedy, Fowlkes & Lilienthal, 1993) on Pattern Comparison, Grammatical Reasoning and Finger Tapping tests, all of which are part of the Automated Portable Test System (APTS), which is a computerized test battery (Kennedy, Lane & Jones, 1996). Although practice effects were expected, participants involved with simulator exposure showed less improvement on the Grammatical Reasoning and Pattern Comparison tasks when compared to the control participants. It was suggested that, out of the three measures, the Grammatical Reasoning is the most sensitive to disruption by stressors (Kennedy, Fowlkes & Lilienthal, 1993).

As briefly mentioned above, dystaxia is postural instability, disequilibrium, or an apparent lack of muscle coordination that can be observed in voluntary movements. (Note: ataxia is a more common term for this event, but this refers to the *complete* loss of muscle coordination and therefore will not be used to describe postural stability in this study). It is thought that the conflicting cues during immersion in a simulator or motion environment results in the body (specifically the visual, vestibular and proprioception systems) to try to adapt to the altered experience, which, upon completion of exposure, consequently creates a disruption in balance and coordination (Thomley, Kennedy & Bittner, 1986).

Dystaxia is not always observed after simulator exposure (Kennedy, Allgood, Van Hoy, & Lilienthal, 1987). It is possible that this is because less severe dystaxia may not be measurable with current tests, or they may not be sensitive enough (Kolasinski, 1995). Nonetheless, it is believed that the likelihood of dystaxia (whether it is the symptom itself, or its level of severity) increases as a result of the intensity and duration to exposure (Fowlkes, Kennedy & Lilienthal, 1987), which would support the postural stability theory of motion sickness. Kolasinski and colleagues reported a relationship between postural stability prior to simulator exposure and sickness symptoms after simulator exposure (Kolasinski, Jones, Kennedy & Gilson, 1994). Specifically, it was found that participants who were less posturally stable had increased symptoms and severity of Nausea and Disorientation subscale scores. While postural instability could simply be a sign of an individual who has an illness or is under the influence of drugs or alcohol (Fregly, 1974), it is an enlightening factor on the mechanism controlling simulator sickness if tested prior and after exposure (Kolasinski, 1995).

There are several ways to measure dystaxia. In the past, self-reports have been used (e.g., Baltzley, Kennedy, Berbaum, Lilienthal, & Gower, 1989). However, due to a potential for false reports, as well as its inability to accurately quantify dystaxia, it is beneficial to use a postural test. There are 4 basic tests, all of which instruct an individual to stand or walk in a specific way for either a certain amount of time or number of steps. Postural stability is then measured either by the amount of time the individual is able to maintain the particular stance or the number of steps that he or she is able to take. The basic tests have self-explanatory names: Stand-on-Preferred-Leg, Stand-on-Nonpreferred-Leg, Stand-Heel-to-Toe and Walk-Heel-to-Toe. All of these tests have a maximum time which is specified by the researcher in order to ensure that

individuals are adequately balanced by that particular time. All of these tests can be modified by particular factors, such as keeping eyes open or closed, folding arms across the chest or stretching them in front of the body, and standing in different positions (Kolasinski, 1995).

Several researchers have assessed the reliability of postural stability tests. One study evaluated all 4 tests with participants keeping their eyes closed and arms folded across their chest. Using correlation and analysis of means and variances, the researchers found that the Stand-on-Nonpreferred-Leg and Stand-on-Preferred Leg were more reliable than the Stand-Heel-to-Toe and Walk-Heel-to-Toe test, recommending that the Stand-on Nonpreferred-Leg test being the most reliable (Thomley, Kennedy & Bittner, 1986). However, it is important to mention that learning effects, or the effect of improving with increased practice, is suggested to occur with these tests (Thomley et al., 1986). Further, ceiling effects were observed each of the tests, with some occurring on the very first trial

Hamilton and colleagues conducted a two-phase study to evaluate 4 variations of the postural tests: Stand-Heel-to-Toe (referred to as Sharpened Romberg or Tandem Romberg) with arms folded and eyes closed, Stand-on-Leg-Eyes-Closed, Walk-on-Rail-Eyes-Open, and Walk-on-Line-Eyes-Closed (Hamilton, Kantor & Magee, 1989). During the first phase, participants were asked to perform the tests 10 times in order to stabilize performance. The test-retest reliability coefficients were found to be quite stable for each of the tests. Unlike the previous study conducted by Thomley and colleagues (Thomely et al., 1986), ceiling effects were not found, and this is thought to be due to Hamilton and colleagues increasing the difficulty of their modified tests by implementing narrow rails for participants to walk on (Hamilton et al., 1989).

The Stand-on-One-Leg-Eyes-Closed and the Sharpened Romberg tests were the only two that had reliabilities higher than .50, with the Stand-on-One-Leg-Eyes-Closed being the most reliable.

During the second phase of the study, the same participants were instructed to perform the tests both immediately before and after 12 minutes of exposure to a training flight simulator. Upon comparing the symptoms reported by participants using the SSQ to the postural tests, the Sharpened Romberg test was the only test sensitive enough to corroborate with dystaxia symptoms on the SSQ (Hamilton et al., 1986). It was also found to be the most reliable, sensitive and safe for subjects when compared to 15 other variants (Kennedy, 1993). However, Hamilton and colleagues state that more sensitive measures are needed in order for dystaxia to be measured more accurately.

Hand-eye coordination to measure the kinesthetic position sense has been systematically used in the past (e.g., Freedman & Rekosh, 1968; Kennedy, Stanney, Compton, Drexler & Jones, 1999). For example, a visuo-motor task such as pointing the finger to the nose can uncover fine motor disturbances and has been used successfully in past laboratory conditions (Welch, 1978) and are commonly used in field sobriety tests (Kennedy, 1990; National Highway Traffic Safety Administration, 2001). Because of the test's ability to measure sickness that may not be maintained through self-report or through postural stability tests, it was implemented in the current study.

Motion and Performance

Measures of motion on performance have resulted in inconsistent findings and conclusions by researchers. Wertheim (1998) noted two categories of effects of motion in

regards to performance: general effects and specific effects. General effects are motion sickness effects that consequently reduce motivation and increase fatigue and balance problems, resulting in possible performance decrements. Specific effects refer to the interference of motion on specific human abilities, such as cognitive (e.g., attention, pattern recognition), motor (e.g., manual tracking) and perceptual (e.g., visual or auditory detection; 1998) abilities.

Examples of general motion sickness effects that can impact performance include carelessness, lack of coordination, (Kennedy & Frank, 1985), the slowing down of work rate, loss of motivation, disruption of workload and complete abandonment of work altogether (Wertheim, 1998). Indeed, Benson (1978) reported that decrements in operational efficiency occur due to motion sickness, and numerous other studies have found similar effects (the pertinent ones relating to uncoupled motion will be discussed below). However, it is not uncommon for researchers to conclude that general effects have very little, if any, negative impacts on performance (Alexander, Cotzin, Hill, Ricciuti & Wendt, 1945; Johnson, 2005; Reason & Brand, 1975). For example, a variety of tasks that have been measured and compared between motion sick and non-motion sick individuals include (but are not limited to) postural stability, arithmetic computation, temporal sequencing, conceptual reasoning, mirror drawing, and optical accommodation and convergence. Out of all of the measured tasks, postural stability was the only measure that reliably showed decrements when compared to baseline tests (Alexander et al., 1945; Kennedy & Frank, 1985). Reason and Brand (1975) believed that motion sick individuals can respond effectively to the tasks at hand if they are highly motivated. The problem, however, is finding a way to ensure that individuals stay motivated (1975).

Previous studies measuring specific effects of a cognitive memory task during ship motion have found to either result in no observed decrements in performance (Bles & Wientjes, 1988) or a slight decrement that was later concluded to be due to motion sickness (i.e., general effects of seasickness), since the decrements disappeared when sickness symptoms decreased (Bless, Boer, Keuning et al., 1988; Bless, De Graaf, Leuning et al., 1991). These findings have resulted in some to conclude that there are no specific effects on at least a few cognitive abilities (Wertheim, 1998). Specific effects on motor tasks, however, have been found; a decline in accuracy of arm, hand and finger movements (McLeod, Poulton, Du, Ross, & Lewis, 1980) paper-and-pencil tests (Crossland & Loyd, 1993) and computerized tracking (i.e., visuomotor task; Wertheim Heus & Vrijkotte, 1995) were observed during ship motion simulators. Specific effects have also been found regarding perceptual tasks, particularly with regard to small visual detail (Mosely & Griffin, 1986; Wertheim, 1998). It has been noted that vibrations that occur in helicopters and other environments can generate slight eye movements or vibrations, which can result in a retinal slip and blur visual images (Wertheim, 1998), thus reducing the accuracy in detection and other perceptual tasks.

With regard to individuals in military vehicles, whole-body vibration, which is caused by a body being exposed to a vibrating surface, is of main concern for ground vehicle missions (Hill & Tauson, 2005). Vibration can vary in magnitude, frequency (Hz), direction and duration, all of which affect its significance on performance (ISO Standard 2631, 1997). The frequency of 0.2 Hz or near this range has been found to be the frequency with which sickness is highly likely to occur (McCauley & Kennedy, 1976; Money, 1970). It is important to also mention that

different vibration characteristics can occur simultaneously at different locations (e.g., seat, seat back, feet, display) (Boff & Lincoln, 1988).

In addition to the studies above, the perceptual and psychomotor performance of crewmembers in military vehicles has been found to be greatly affected particularly in the 4 Hz to 8 Hz range (Hill & Tauson, 2005). However, frequencies ranging anywhere from 0.5 Hz to 100 Hz are considered to have an effect on human performance (2005). While on the move in a manned ground vehicle, one study found that cognitive tasks are up to 46% less accurate and up to 40% slower than individuals at stationary sites (Schipani, Bruno, Lattin & King, 1998). Similar to previous conclusions, the researchers were sure to note that it was unclear as to the quantification of cognitive decrements due to the motion itself, or because of motion sickness effects. Nonetheless, *after* exposure to motion, Schipani and colleagues (1998) found decrements in cognitive tasks including selective attention, spatial orientation, inductive reasoning and memorization. Therefore, it is of interest for this study to measure cognitive tasks after exposure to an uncoupled motion environment to determine.

One of the main studies of critical importance to the proposed research is that of Cowings and colleagues (Cowings Toscano, DeRoshia & Tauson, 1999); these researchers investigated the effects of motion on performance, mood and symptoms of motion sickness in a manned ground vehicle (MGV) which contained four workstations in a compartment with no exterior view (Cowings, Toscano, DeRoshia & Tauson, 1999). The MGV conditions changed from park, move and short halt while Soldiers completed a series of Delta Performance Test Batteries. The Delta Performance Test Battery (DPTB) is an upgraded software version of APTS (Kennedy,

Jones, Dunlap, Wilkes & Bittner, 1985). The DPTB was proven to reliably measure the effects of environmental and chemical stressors on performance. The specific tests used were reaction time, code substitution, pattern comparison, preferred hand tapping, grammatical reasoning, spatial transformation or MANIKIN, and symptom diagnostic scale (Cowings et al., 1999). The researchers also used physiological measures and subjective motion sickness measures using the Coriolis Sickness Susceptibility Index (CSSI) (Graybiel, Wood, Miller & Cramer, 1968).

A significant decrease in performance and health measures were observed while the vehicle was moving (Cowings et al., 1999). Specifically, a performance decrement of more than 5% for at least 2 of the subtests was observed in 22 of the 24 participants. One-third of the participants' decrements were comparable to a blood alcohol level equivalency (BAL) of higher than 0.08, which is over the legal limit to operate a vehicle in most states (1999). Further, all participants experienced motion sickness, with 55% of the individuals experiencing moderate to severe symptoms (1999). Drowsiness, which was reported in 60-70% of participants, was the most commonly reported symptom. In fact, more than half of the participants were found sleeping during their field tests. Other reported symptoms were headache (up to 56%), increased warmth (45%), nausea (42%) and stomach awareness (20%). Although reports of nausea were high, only 15% of the participants experienced vomiting, and any reappearance of the episodes tended to occur in the same individuals (1999).

There are several issues with the study conducted by Cowings and colleagues (1999). First, the study was performed with both male (16) and female (8) participants. This potentially could have increased variability in the sickness and performance findings due to gender

differences (with the exception of reported nausea results, which have been found in one study to be slightly lower in females; Stanney, Hale, Nahmens & Kennedy, 2003). Second, their study was a within-groups design, and it was observed over the twelve days of field tests that several individuals began experiencing motion sickness symptoms even before the vehicle was moving. These “motion sickness” symptoms included dizziness, headache, and even nausea, and increased as the study progressed. The investigators suggested that this outcome may be the result of classical conditioning, where participants learned to expect to feel sick before the motion even began (Cowings et al., 1999). This is an important finding that was considered during the design of the proposed study.

The findings of Cowings and colleagues (1999) are consistent with the sensory conflict theory, particularly the visual-vestibular mismatch. Indeed, numerous other studies report that not only can motion sickness and potential performance decrements arise from the repetitive stop-and-go motion of vehicles, but the severity depends upon the visual scene (Griffin & Newman, 2006; Probst, Krafczyk, Buchele, & Brandt, 1982; Vogel, Kohlhaas & von Baumgarten, 1982). It has been found that a view of the road ahead (i.e., external view) produces the least symptoms, and an internal view produces the most sickness (Griffin & Newman, 2004). It has also been found that closing the eyes when exposed to an external view results in higher severity of symptoms when compared to those with their eyes open (2004), and closing the eyes when exposed to an internal view inside a simulator reduces sickness when compared to those with their eyes open (Bos, Mac Kinnon, & Patterson, 2005).

Butler and Griffin (2006) attempted to uncover whether there were differences in motion sickness symptoms in several internal and external (laboratory) views of a stationary visual scene in a driving simulator. This was done by investigating self-assessment reports after exposure to repetitive braking and acceleration using a motion platform with low-frequency, low-magnitude fore-and-aft oscillation (i.e., 0.1 Hz oscillation, 0.89 ms^{-2} acceleration magnitude). Participants were exposed to one of six scenes: 1) internal view of 2D black shapes on a white background; 2) external view of the same 2D shapes; 3) external view of six horizontal black lines; 4) a “real” 3D external view; 5) no view (blindfolded); and 6) internal collimated view of the 2D shapes. Contrary to studies that show the visual scene effects symptoms of sickness, the researchers found no significant differences on any viewing condition and sickness symptoms (2006).

It should be noted that the study conducted by Butler and Griffin (2006) only investigated differences of participants by self-assessment sickness reports, and no measurements of cognitive or postural differences were taken after the 30-minute exposure. Although the researchers state there is a possibility that there was a small effect of the visual scene that could not be picked up from self-assessed sickness reports (2006), the findings reveal the importance in both the type of motion and type of visual scene in attempts to reduce motion sickness and its variants. The researchers suggest that, since no difference in sickness was found between all groups, and particularly with the blindfolded group when compared to the others, the motion in cars is not exclusively caused by visual-vestibular sensory mismatch (2006). However, since the authors did not measure whether participants were actually focusing on the visual stimuli, it cannot be determined that these groups actually differed. Further, it should be noted again that it is impossible to tell if other measures of sickness may have revealed differences between groups.

Muth and Lawson (2003) conducted a study of uncoupled motion due to ship exposure and flight simulation. The researchers measured the performance of individuals in three groups: 1) piloting a flight simulator on land; 2) traveling on the Navy Yard Patrol boat with mild ship motion; and 3) piloting a flight simulator while concurrently traveling on the Navy Yard Patrol boat with mild ship motion. It was found that, although overt motion sickness symptoms did not differ, dynamic visual acuity tests were lower in the group experiencing uncoupled motion, which are the same results that were found in a previous uncoupled motion study involving ship and virtual environment exposure (Cohn, Muth, Schmorow, Brendley & Hillson, 2002). Although Muth and colleagues did not purposely examine uncoupled motion effects on task performance, the results supported the researchers' hypothesis that uncoupled motion effects are additive, not multiplicative (Muth & Lawson, 2003).

Muth and colleagues later conducted research in order to raise awareness on the issue of uncoupled motion and its effects on performance (Muth, Walker & Fiorello, 2006). Participants were asked to maneuver an Xbox video game car through traffic cones on a route as fast as possible without hitting the cones while concurrently sitting inside a stationary or moving vehicle with covered windows. The Motion Sickness History Questionnaire (MSHQ; Reason & Brand, 1975) was assessed prior to exposure, and participants' average score of 15.54 out of 180 prove that recruited individuals had relatively low sickness susceptibility, since a score of 45 is typically used to point towards high sickness susceptibility (Muth, Walker & Fiorello, 2006). Nonetheless, participants who were in the moving car condition took significantly longer to complete the video game task, were less accurate, and had higher SSQ and Motion Sickness Assessment Questionnaire (MSAQ) scores than those sitting in the stationary car condition. As

hypothesized, Muth and colleagues found that exposure to uncoupled motion produced significant performance decrements as well as higher motion sickness symptoms, even though the task requested to be completed was reasonably simple, and the motion they were exposed to was not provocative, with an average driving speed of 35 miles per hour during the scenario (Muth, Walker & Fiorello, 2006).

However, only 10 individuals were measured, 4 of which were females, and a within-subjects design was implemented (Muth, Walker & Fiorello). Additionally, the researchers noted that it is difficult to decipher the degree to which the performance decrements found in this study were attributed by the motion of the vehicle actually interfering with the task (i.e., specific effects), or by the physiological response due to being exposed by motion (i.e., general effects), but they do suggest that decrements were due to both types of effects (2006). A follow-up study was conducted in order to more thoroughly examine the specific and general effects of uncoupled motion on performance (Walker, Gomer & Muth, 2007). The same driving test conducted by Muth and colleagues (Muth, Walker & Fiorello, 2006) was implemented with a game pad in replacement of a steering wheel. The results verified that at least some of the resulting performance decrement was due to specific effects of motion on the individual, such as instances of the real car turning one direction while the participant attempted to turn the virtual car in the opposite direction (Walker, Gomer & Muth, 2007).

Aftereffects

Symptoms of sickness are not just an issue during or immediately after exposure to real or perceived motion environments; they can also arise or persist quite a bit of time after exposure has ended (Baltzley, Kennedy, Berbaum, Lilienthal & Gower, 1989; Hettinger & Riccio, 1992).

For example, one study observed 8% of participants having symptoms over six hours post VE Exposure (Baltzley et al., 1989). The U.S. Army has published guidance in order to increase individuals' safety when one experiences simulator sickness (Army Regulations, 2007), but there currently are no guidelines set to measure or protect individuals experiencing prolonged aftereffects. Aftereffects can impact the health and well-being of individuals involved (Baltzley et al., 1989; Kennedy et al., 1999). It has been suggested that the accidents that Naval personnel are involved in after coming ashore, which is the leading cause of injury and death during peacetime, can be due to aftereffects of motion (Kennedy & Frank, 1985). Aftereffects such as dystaxia can mark an enormous safety concern, since the central nervous system mechanisms that manage standing and walking are used in driving and steering, which is why field sobriety tests measure steadiness to determine if you are fit to drive (Kennedy, in Van Cott, 1990).

As briefly mentioned above, even if self-assessed motion sickness is not significant after exposure to uncoupled motion, physiological aftereffects can be observed (Cohn, Muth, Schmorrow, Brendley & Hillson, 2002; Muth & Lawson, 2003). A later study by Muth (2009) further investigated the impact of uncoupled motion on cognitive aftereffects and other motion effects, as well as the duration of decrements by measuring individuals immediately, 2, 4, 8, and 24 hours after exposure to quite a provocative environment. Participants sat in a repetitive, vertically oscillating simulator with an oscillation rate of 0.2 Hz. At the same time, participants wore an HMD that provided a visual flight scene that was not linked to the vertically oscillating motion. The pitch and roll, however, was self-generated by each participant via a flight stick and the HMD responded to participants' head movements. Concurrently, participants were asked to

distribute their weight between the seat and the footrest, which was made possible by leaning forward or back into the seat.

Immediately after a maximum of 1 hour of exposure to uncoupled motion, cognitive performance was equivalent to a 0.054 blood-alcohol level (BAL), which was significantly different from participants' pre-exposure scores (Muth, 2009). This decrease still remained after 2 hours, with a BAL of 0.051. However, by 4 hours post-exposure, performance was not significantly different than baseline levels, and remained to be "completely resolved" for each of the subsequent testing points (2009). Immediate postural stability decrements, measured by the Sharpened Romberg test, were also found (Muth, 2009). However, by 2 hours post-exposure, performance was not different from pre-exposure. Dynamic visual acuity was also measured, but unlike previous reports mentioned above, no decrements were found during any of the post-exposure testing times. Muth suggests this is because participants were exposed to a limited field of view, and the task did not require participants to move their heads to a high degree (2009). It was also suggested that, based on these findings, dynamic visual acuity may only be affected when the task requires active head movements that stimulate the VOR (2009). Nonetheless, the results demonstrate that exposure to quite provocative uncoupled motion can produce measureable cognitive- and stability-related aftereffects, but they seem to resolve between 2 and 4 hours after exposure.

Muth's findings are highly beneficial towards understanding aftereffects due to uncoupled motion exposure, but it must be noted that only individuals with prior flight experience were recruited. Although participants were asked to avoid flying for at least a week leading up to the study (Muth, 2009), these individuals have been found to respond differently to

motion environments than the general population, as discussed previously. A particularly interesting example is that, based on the demographics and performance results provided by Muth (2009), there was an individual who had considerably fewer flight hours (60 hrs) than the median (600 hrs) and average (827 hrs) of the group. This individual had no decrements in cognitive performance and was the only participant who actually *improved* in the Sharpened Romberg test during the immediate post-exposure testing (2009). However, his 2-hour performance results decreased (both cognitively and with balance). Importantly, his highest cognitive decrement (0.061 BAL) was found at 4 hours post-exposure, which counterintuitively was the same testing time where he also had the highest performance improvement both personally and between participants regarding the Sharpened Romberg test.

These findings prove how not just immediate motion sickness, but also the experience and duration of aftereffects, are largely individualistic. Muth described the necessity of further investigation on the specific relationship between the many other components of motion profiles, including the degree of uncoupling and the consequent sickness and aftereffects (Muth, 2009).

Current Motion Sickness Mitigation Techniques

It seems as though the surest way to reduce motion sickness, and potentially all variants, is through adaptation (Kennedy & Frank, 1985; Reason & Brand, 1975). Although adaptation does not happen immediately (McCauley & Sharkey, 1992), it has been found that sickness can subside after a certain period of time. However, adaptation is dependent on individual differences (Kennedy, Stanney & Dunlap, 2000) and the type of motion transformation (Welch, 1986). Additionally, while repeated exposures can reduce symptoms due to adaptation, it also

can potentially have an additive effect, resulting in more pronounced symptoms, if one has not adapted yet (Johnson, 2005). Therefore, one cannot rely on adaptation to resolve motion sickness symptoms when performance is necessary for safely and successfully conducting missions. This is why the investigation of other methods to mitigate motion sickness is crucial.

Various researchers have identified ways to explore motion sickness mitigation specifically in moving vehicles. There seem to be four main areas in this regard: vehicle design, personnel training, personnel selection, and “other” interventions, which include medication (Hill & Tauson, 2005; Rolnick & Gordon, 1991). Specific vehicle design suggestions include the notion of designing a vehicle to reduce the vibration frequencies that are known to create performance decrements, as well as the use of vibration dampeners and vibration coupling of observer to display (Hill & Tauson, 2005). Seating position, displays and control have been also suggested to be explored, although seating has been found to not reduce sickness symptoms in at least one study (Cowings, Toscano & DeRoshia, 1999). Further, direct versus indirect display views have been suggested to be a potential design factor, but as mentioned in the Introduction, indirect-vision systems may completely replace direct-vision driving in order to keep Soldiers adequately safe. Even if this weren’t the case, it is believed that direct-vision driving would not help Commanders required to use a monitor to perform target detection tasks while on the move.

Personnel selection was mentioned previously in the Introduction, and it should be noted again that this method could greatly reduce the flexibility of assignments. Training in the sense of providing information regarding the effects of motion on performance has been used in the past to potentially reduce motion sickness symptoms (Simulator Sickness Field Manual Mod 4,

Naval Training Systems Center, 1989, cf. Hill & Tauson, 2005). This could inform Soldiers of what is happening when they feel ill and what they can do about it (Hill & Tauson, 2005). However, this type of training can potentially lead to participants expecting to get sick, and thus actually experiencing symptoms, which as mentioned previously has occurred in a previous study (Cowings, Toscano, DeRoshia, & Tauson, 1999).

A variety of drugs have been tested over the years and there are a few that can reduce the occurrence or severity of motion sickness symptoms (Johnson, 2005; Muth & Elkins, 2007). However, there is no drug that completely eliminates motion sickness, and all drugs have side effects (Johnson, 2005). Additionally, training with the use of the Autogenic Feedback Training Exercise (AFTE), such as autonomic conditioning, as a means to mitigate motion effects has been found to reduce motion sickness better than some medication in astronauts during space travel (Cowings & Toscano 2000). It should be noted that although AFTE and certain drugs can bring promising benefits to motion environments, they are not a viable option from a human factors standpoint. Additionally, medication may not always be available. Further, it may not always be practical to modify certain types of vehicles or crewmember tasks. This is why the investigation of design relating to particular tasks is a reasonable means to potentially mitigate sickness during uncoupled motion, such as the situation regarding crewmembers (particularly Commanders), using indirect-vision screens to perform target detection tasks while on the move.

Previous research has been conducted to determine if an artificial horizon, or an Earth-referenced scene known for its use in aircraft, can reduce motion sickness. The artificial horizon can indicate pitch (fore and aft tilt) roll (rotational, or side-to-side tilt) and heave (vertical linear

motion) of a given vehicle's movement, but not all three are always employed. This technique has been implemented in VE devices that are used while concurrently onboard ships and is aptly called a Motion Coupled Virtual Environment (MOCOVE; Brendley, Cohn, Marti & DiZio, 2002; Cohn, Muth, Schmorow, Brendley & Hillson, 2002).

In one study, the impacts of an internal view, external view, and an artificial horizon projected on a wall were compared (Rolnick & Bless, 1989). Participants were immersed in a tilting room with simultaneous pitch and roll motion (i.e., 0.025 Hz and 0.1 Hz, maximum amplitude of 10°). The artificial horizon condition, which was produced by a rotating laser beam, was consequently found to produce less sickness effects when compared to the internal view (1989). Additionally, although there were significant differences of symptoms between the internal and external view (as was expected), no difference was found between the external view and the artificial horizon, which suggests that the implementation of an artificial horizon can reduce symptoms in at least some motion environments.

Bos and colleagues implemented an artificial horizon in a 6 degrees-of-freedom motion-based flight simulator (Bos, Feenstra & Van Gent, 2011). All participants were exposed to three conditions: 1) no visual motion; 2) 3D matrix of stars moving exactly opposite of the cab motion (i.e., Earth-fixed visual frame of reference); and 3) anticipatory trajectory using a rollercoaster like track. The artificial horizon was shown to reduce sickness severity by a factor of 1.6. Impressively, the anticipatory trajectory decreased the severity by a factor of 4.2 (2011). As largely beneficial of the anticipatory trajectory seems to be in reducing sickness severity, it is

unfortunately beyond the scope of the current study due to a lack of background to implement such a device for MGVs driving new or unfamiliar paths.

A more recent study was conducted with a 3 degrees-of-freedom ship motion simulator (Tal, Gonen, Wiener, Bar, Gil, Nachum & Shupak, 2012). In addition to the roll, pitch and heave artificial horizon visual scene, participants completed a series of self-assessed sickness questionnaires and performance test batteries during the 2 hour immersion in the simulator. Although there was a significant decrease in total sickness severity scores, sickness scores were still high for each of the four conditions, resulting in the researchers to conclude that artificial horizon cues account for a limited role in the pathogenesis of motion sickness (Tal et al., 2012). Nonetheless, these findings formed the basis of potential mitigation techniques during uncoupled motion in MGVs.

Rationale

A few important issues will be discussed in order to explain the basis for the design of this study. Muth, Walker and Fiorello (2006) speculated that military personnel can experience exacerbated effects similar to their uncoupled motion experiment based on the fact that military vehicles are often exposed to rough, off-road terrain, which creates more vigorous motion than the car movements their participants were exposed to. The purpose of this study was to investigate this potentially more provocative uncoupled motion condition, specifically with an off-road environment using a simulation of an MGV on the move while concurrently conducting a common (target detection) task using the Dual Banners display and variants of this display.

As mentioned in the Introduction, the Dual Banners display is the most preferred yet the most sickness inducing (Drexler, Elliot, Johnson, Ratka & Khan, 2012) display that Commanders use during IVD missions, and it is currently the only display that allows a full 360° view of the environment on the screen at one time. As will be mentioned in detail in the Apparatus below, this display was compared with a manipulation of the six camera feeds that make up the 360° view. This manipulation was exploratory, and has not been used in IVD tasks.

The aim of this manipulation was to determine whether vection effects that may be occurring due to the closeness in proximity of the Dual Banners camera feeds can be reduced by separating the feeds. However, while the same monitor was used for each condition, the camera feed separations may produce visual discomfort (thus potentially *increasing* oculomotor disturbances and other sickness symptoms), since participants will be required to move their eyes slightly further distances in order to adequately scan all 6 camera feeds. It should be noted that it is possible for any new display configuration to lead to sickness (Leibowitz, 1990), since new configurations have not been tested before and their effects are unknown.

As mentioned previously, the VOR occurs during head movements to stabilize the eyes on a given target. The position of the eyes can be modified during vertical vehicle movement while concurrently conducting tasks. In order to fixate on a target, an individual must overrule both the ocular and vestibular responses to bumpy vehicle movement (Ebenholtz, 1990). The VOR has been found to be adaptive in certain conditions, but it is predicted that prolonged exposure to vehicle motion while concurrently viewing displays will almost certainly lead to dysfunctional consequences (1990).

An artificial horizon has benefited in the reduction of sickness symptoms in previous motion environments (Bos, Feenstra & Van Gent, 2011; Rolnick & Bles, 1989; Tal, Gonen, Wiener, Bar, Gil, Nachum & Shupak, 2012). However, as pointed out by Butler and Griffin (2006), the motion conditions that can benefit from a visual scene in terms of a reduction in symptoms of motion sickness are yet to be established. Since keeping the eyes closed is not a viable option for crewmembers performing necessary tasks that can impact their safety while on the move, designing ways to simulate an external view has the potential to mitigate motion sickness in MGVs with indirect vision systems. Therefore, it is beneficial to examine whether an artificial horizon that is superimposed onto the Dual Banners Tile and other display manipulations can mitigate symptoms and severity of sickness.

Mayo and colleagues recently reported the importance of the horizon on individuals' postural control while at sea, where more sway was observed in closed-cabin conditions (Mayo, Wade & Stoffregen, 2011). Therefore, an artificial horizon can potentially lead to less sickness in terms of the postural instability theory. Additionally, an artificial horizon may also reduce the visual-vestibular conflict (Tal, Gonen, Wiener, Bar, Gil & Nachum, 2012) and aid in VOR responses due to the visual feedback of what the vestibular system is sensing, and thus potentially lead to less visual disturbances and sickness in terms of the sensory conflict theory. It should be noted that performance decrements are still found in studies implementing an artificial horizon (Tal et al., 2012), which is a great concern. This is why two different display configurations are also implemented to determine if either or both can allow participants to maintain performance both during and after exposure (discussed in Procedure).

Although individual differences vary greatly and it would be impossible to recruit individuals who have the same reaction and duration of symptoms in each condition, a between-subjects design is preferred over within-subjects for this study. This is because there are several exposure effects that could occur due to a within-subjects design. Specifically, participants would potentially: 1) have decreasing (Kennedy, Stanney & Dunlap, 2000) or increasing (Fowlkes, Kennedy & Lilienthal, 1987) symptom severity due to the longer duration of exposure; 2) have an increase in duration of aftereffects; 3) experience phantom symptoms due to the expectation of getting sick (Cowings et al., 1999); and 4) be subjected to order effects. Even if the study were to implement a counter-balancing scheme to reduce this factor, it would still be unclear if a particular condition's outcome was the result of the condition alone, as a result of the previous conditions the participant was exposed to, or the total duration in which the participant was immersed to the uncoupled motion environment.

In order to control for individual characteristic factors of motion and simulator sickness, a screening process was conducted to reduce several factors known to impact susceptibility. The best known user characteristic is susceptibility itself (Jones, Kennedy & Stanney, 2004), and the Motion History Questionnaire played a major role in the initial screening portion of the study. Recruiting individuals who have at least some experience of motion sickness in their past was welcomed for this study, since completely non-susceptible individuals would not reveal motion sickness symptoms, let alone changes in sickness severity between the display manipulations. However, uncoupled motion is reportedly more provocative than other motion environments, and it is possible that one can be non-susceptible to classic motion sickness and still experience motion sickness due to uncoupled motion.

Sleep quality and quantity are also important to obtain from participants because of documented studies which show that sleep deficiency results in significant performance decrements (Dinges, Pack, Williams et al., 1997) and disruptions in vestibular function (discussed previously). The amount of sleep that is required in order to feel well rested is highly variable between individuals. For example, there are reports of some individuals needing more than 10 hours of sleep each night, while some state that they feel well rested after less than two hours (Martin, 2002). Therefore, not only was sleep quantity assessed, but quality of sleep, normal duration of sleep, and information on whether or not a participant felt well rested were also obtained. This information may reduce potential variance since a sleep deficiency, even if only occurring for one night, has been found to cause attention lapses, which decreases performance (Webb, 1968).

Another sleep related issue that is of concern for this study is sleep inertia. Sleep inertia is a state of disorientation that can sometimes include amnesia for a period of time after awaking. This state can last anywhere from 5 minutes to over 2 hours after waking (Jewett, Wyatt, Ritz-DeCecco, et al., 1999; Martin, 2002). Similar to sleep deprivation, sleep inertia has been found to be associated with decrements in reaction time, visual-perceptual tasks and cognitive tasks (Dinges, Orne & Orne, 1985). Qualified participants were asked to provide the time they woke up on the day of the study.

This study implemented a monoscopic display for several reasons that were mentioned in the Target Detection subsection above: 1) symptoms of sickness that may be observed can be more directly associated with the design of the visual display itself, rather than the increase in

likelihood of VIMS that has been observed in stereoscopic displays; 2) the benefits of stereoscopic displays tend to fade during highly repeatable tasks, and one of the performance tasks using this display (discussed in depth below) involved detecting targets for 15 minutes; 3) the target detection task is a simulated environment free of negative terrain obstacles, and participants were not required to drive or maneuver the system responsible for providing the view of the target detection task. Thus, factors such as driving time and positioning accuracy that may be improved with stereoscopic displays were not an issue for this study; 4) monocular cues including occlusion, texture gradients, and relative size provided by the system and display enabled participants to adequately perceive depth during the task; and 5) since an artificial horizon feature was implemented, a monoscopic display is preferred so that participants are not exposed to the higher levels of visual stress associated with stereoscopic displays (which also lessens the likelihood of ocolomotor symptoms of sickness not related to display design).

A 15-minute duration of exposure to uncoupled motion was implemented for this study because of the high likelihood of the worsening of symptoms if exposure were longer (Stanney, Kingdon, Nahmens, & Kennedy, 2003). Since uncoupled motion has created sickness effects within minutes of exposure, 15 minutes was hypothesized to be sufficient to adequately measure differences without creating excessive discomfort.

The speed at which the simulated MGV moved throughout the simulated off-road environment was 10-18 mph. The fluctuation in speed resulted from either going up hills or taking turns, which slowed down vehicle speed, or going down hills, which resulted in a slightly faster speed. Although the Army sets minimum and maximum speeds for MGVs and other

vehicles on certain missions, the speeds are based on the type of terrain and the vehicle-terrain interaction (Baylot, Gates, Green, et al., 2005). Therefore, for this study, the experimenter and assistant both took preliminary runs through the simulated environment and determined that the 10-18 mph range was a safe speed that provided numerous angular motion effects given the uneven terrain (discussed more below). Further, the decision to maintain a slower speed will also be discussed under Limitations below.

The schedule of exposure, as well as the exposure time, was originally going to be fixed for this study. However, due to unavoidable limitations, it was no longer feasible to run only one participant a day (see Methods for more information). Of extreme importance was that participants would experience the exact same motion as well as the exact same visual movement through the target detection scenario, with display design itself being the only difference in order to more accurately measure screen manipulation; the global visual flow of the target detection task (i.e., the speed at which the UGV moved), as well as its scene content, remained the same. In order for this to occur, both the motion-based simulator route and target detection task scenario were created and recorded so that each participant experienced the same pre-determined routes at the same pre-determined speeds.

A touch screen, rather than a mouse, was used for the target detection task, even though recent findings suggest that a mouse is better in motion environments (Lin, Liu, Chao, & Chen, 2010). There are several reasons why a touch screen was implemented. First, touch screens are currently implemented on crew interfaces using 360° Dual Banners Tile and other displays (Drexler et al., 2012). However, the most important reason for using a touch screen relates to the

possibility that if participants did not hold onto their mouse tightly, the tilting motion of the cab would consequently result in the mouse falling down or be yanked out of the monitor. This would then result in the participant bending over or twisting around inside the moving cab in order to find the mouse or plug it back in, which would create the possibility of them harming themselves in the process. Another reason is that using a mouse in a bumpy, unpredictable environment is assumed to become very frustrating due to the highly magnified response of a mouse. While mouse sensitivity can be set to a lower level, there would be a potential for participants to become aggravated by the mouse not responding in the way it usually does. Of much less importance than safety and participant frustration, another issue is the possibility that, if the mouse became detached, this would have resulted in a loss of data collection.

Large individual differences in susceptibility, severity and duration of sickness have been found in constant conditions of novel motion, where the amount of time symptoms become apparent can range from minutes to several hours (Muth, 2009; Reason & Brand, 1975). For this reason, participants were held for a minimum of 1 hour post-exposure. Lastly, the measurement of sickness effects involved the use of self-assessment, postural stability, and cognitive and visual tests due to Kennedy and colleagues' recommendation that all three would more accurately evaluate post-effects from virtual environment (VE) exposure (Kennedy et al., 2009). Although uncoupled motion is different than VE exposure, subjective discomfort, balance and cognitive and visual tests are likely to be non-redundant aspects of post-effects of all (either visually or vestibularly-induced) motion situations. All three of these measures were used to determine the health of each participant and when they were capable to safely leave the study.

Hypotheses

Main Hypotheses

Hypothesis #1: Display design, postural stability, and the individual differences of perceived attentional control and motion history will be significant predictors of Total Severity sickness scores, as measured by the SSQ.

Hypothesis #2a: Performance during uncoupled motion (i.e., target detection and situation awareness) will be higher in AH display conditions.

Hypothesis #2b: Cognitive and spatial performance will be lower for all display conditions immediately after exposure to uncoupled motion when compared to their baseline scores.

Hypothesis #3a: It has been suggested that motion platform simulators alone are a bigger contributor to disequilibrium than fixed-base simulators (Kolasinski, 1995). Uncoupled motion is a more provocative environment and it is expected that dystaxia will be present in all display conditions immediately after exposure. This will be measured by comparing baseline and post-exposure Sharpened Romberg scores.

Hypothesis #3b: Dystaxia will be the lowest (i.e., highest Sharpened Romberg scores) immediately after uncoupled motion exposure for individuals who are assigned to the Dual Banners display incorporating an artificial horizon (i.e., AH Dual Banners condition, discussed in Experimental Design below).

Additional Hypotheses

Hypothesis #4: Perceived workload, taken immediately after exposure, will be lower for AH display conditions.

Hypothesis #5a: There will be a difference in the NOD subscales of subjective sickness

immediately after exposure between the Dual Banners and the Completely Separated displays.

Hypothesis #5b: NOD subscale scores will be lower in AH display conditions.

Hypothesis #6a: Subjective sickness will be significantly different between baseline and 30-minute post-exposure administrations for all display conditions.

Hypothesis #6b: Subjective sickness will be lower in AH display conditions 30-minutes post-exposure.

Hypothesis #6c: Postural stability will be significantly different between baseline and 30-minute post-exposure administrations for all display conditions.

Hypothesis #6d: All potential aftereffects will be completely dissipate within 2 hours post-exposure.

CHAPTER THREE: EXPERIMENTAL PROCEDURE

Participants

Recruitment Phase

Screening measures to control several known factors of individual variability to sickness were implemented in order to more accurately uncover the potential impacts of display design during uncoupled motion. A recruitment form (Appendix B) was emailed to potential participants (i.e, individuals interested in participating). These individuals were those who have participated in previous studies conducted by the Army Research Laboratory, those who expressed interest through word of mouth, and those who responded from a UCF subreddit website post of the recruitment form.

The recruitment form listed the purpose of the research, the potential discomforts and risks, criteria for participation, compensation, and other pertinent information. The recruitment form included selected questions derived from the MHQ and a few additional questions. Potential participants were asked to complete the questions in order to determine their eligibility for the study.

The following questions were used to determine their eligibility to participate: 1) Do you get carsick? (Question 2); 2) Do you have difficulty reading in a car or other moving vehicle? (Question #3) 3) Do you have a history of any of the following: epilepsy, seizures, or heart problems? (Question # 4); 4) What is your ethnicity? (Question #6); 5) Do you have normal or corrected (glasses/eye contacts) 20/20 vision? (Question #7); 8) Do you have any balance problems? (Question #8); 9) In general, how susceptible to motion sickness are you? (Question

#10); 10) Have you ever had an ear illness or injury which was accompanied by dizziness and/or nausea? (Question #11); and 11) Are you in your usual state of fitness? (Question #12). Individuals who responded, “Yes,” to Questions #4, #8, #11, with an Asian descent to Question #6 and/or with vision that is more than 20/40 to Question #7 were not recruited for the experiment.

Testing Phase

Although it was originally planned to recruit as many individuals who described themselves as susceptible or extremely susceptible to motion sickness as possible (i.e., responses to Question #7, see Appendix B), only one out of the 117 interested individuals described themselves as such. Further, this individual decided to not participate prior to scheduling him for the experiment because he stated he did not want to feel sick. Therefore, the majority of recruitment was based off of individuals who responded, “Minimally” or “Moderately” to Question #7, those who responded getting carsick to Question #2 and/or those who stated having difficulty reading in a car or other moving vehicle to Question #3. However, it was uncommon for individuals to express that they were anything more than “minimally” susceptible to motion sickness.

Forty-five participants were recruited for this study. However, 9 participants were dropped due to the software working improperly during their target detection task, 3 participants were dropped due to calibration issues of the software, and 1 participant was dropped due to having an allergic reaction to the perfume an assistant was wearing when she walked into the lab during his baseline APTS administrations.

A total of 32 male individuals between the ages of 21 and 35 ($M = 24.3$, $SD = 3.8$) in the Orlando area who met the screening requirements were retained for this study. Participants received monetary compensation for their time at the rate of \$15/hour. Table 1 below lists the average age, MHQ score, anxiety level the day of the experiment (1-10, with 1 being lowest) and perceived attentional control of all participants in each condition.

Table 1: Participant Demographics per Condition

Condition	Age	MHQ Score	Anxiety Level	Perceived Attentional Control
NoAH Dual Banners	24.38 (3.58)	5.00 (3.55)	2.25 (1.28)	54.00 (2.93)
NoAH Completely Separated	26.13 (4.55)	3.13 (0.64)	2.00 (0.76)	57.00 (9.20)
AH Dual Banners	22.13 (0.99)	4.00 (2.07)	1.88 (0.99)	55.75 (7.94)
AH Completely Separated	24.75 (4.62)	3.50 (2.39)	1.63 (0.74)	57.50 (4.24)

Apparatus

Simulator

The Mark II Truck Driving Simulator, located in the Engineering II building at UCF, was used for this study (See Figure 2 below). This simulator consists of a Moog 6-DOF (degrees-of-freedom) motion-based platform, air brakes, and manual and automatic transmission configurations.



Figure 2: Mark II Truck Driving Simulator

The motion platform has a “military vehicle” capability to simulate the movements of MGVs; this setting was used (rather than the “truck” setting) for this study. The cab has a firm, flat vertical backrest. The seat includes a seatbelt which was utilized throughout the whole time

participants were in the simulator in order to ensure their safety. Additionally, an in-cab infrared camera and pin hole camera were used to observe the participant during the scenario, and Figure 3 below shows a picture of the video feed.



Figure 3: Video Feed of Participant during Uncoupled Motion Exposure

The original camera screens that usually show the simulated environment during normal use (seen above in Figure 2) were turned off. Further, in order to reduce the likelihood of ambient light outside of the simulator, all windows were concealed with covers. The light provided by the display screen inside the cab allowed participants to be aware of the location of the emergency stop button in the case they felt too sick to continue. If this button is pressed, the motion immediately stops and the cab returns to its normal, upright position. Additionally, a

garbage can lined with a garbage bag was securely placed directly to the left of the participant's seat in the event that he got sick before he is able to exit the cab. However, the emergency stop button and trashcan were never used during any of the simulator runs.

In order to mimic military vehicle missions, the motion platform was used to simulate both on-and off-road driving terrain. However, on-road driving simulated a dirt road in a swamp environment, so angular motion was also felt during these portions. A 15-minute long route was created and pre-recorded at 10 to 18 mph; the driving conditions included straight paths and basic left- and right-hand turns, driving over small obstacles such as rocks and uneven ground, as well as different elevations and side slopes. The recorded motion from this route was used for all participants.

It should be noted that a supplementary motion scenario driven at a lower speed was recorded to potentially be used in the event that the original motion scenario was too provocative. However, upon looking at sickness responses and health status information of individuals during pilot testing, it was concluded that it was not necessary to use the less provocative scenario. The maximum pitch and roll of the motion environment was recorded and is as follows. With zero representing an upright and level cab, the maximum angle to the left and right were 1.252° and 1.408° , respectively. The maximum angle up and down were 2.435° and 2.685° , respectively. These angular movements may not sound like major changes in movement, but the jerk of the motion (which unfortunately was unable to be measured) played a role in its provocativeness.

Display

A 17" LCD touch screen monitor was used for the target detection task. The physical dimensions (HxV) of the screen (not the whole display) are 13.3" x 10.6" (337.9 x 270.3mm).

Other specifications are listed in Table 2 below:

Table 2: Specifications of the GVision L7PH LCD

Pixel Pitch	-	0.264 x 0.264 mm
Maximum Resolution	-	1280 x 1024
Contrast Ratio	-	350:1 (typical)
Brightness	-	250 cd/m ²
Response Time	-	40 ms
Display Color	-	16 M
Viewing Angle	L/R	160°
	U/D	+65° ~ -80°
Input Signal	Video	RGB analog 0.7V peak to peak
	Sync	TTL Positive or Negative
Display Mode	-	SXGA 1280 x 1024 60/75 Hz

The monitor was mounted on the passenger side of the cab in order to mimic a Commander's position inside an MGV. Specifically, it was secured on the dashboard, directly in front of where participants were seated, with its center aligned with participants' eye level. The viewing distance from a seated individual's eyes to the monitor was 21 inches. However, it was common for participants to lean forward during the target detection task in order to maintain the proper visual angle throughout the task. When this occurred, the participant was instructed to remain seated with their back to the backrest of the seat. Table 3 below shows visual angle

specifications for a 21 inch distance from the screen, and Figure 4 shows the monitor placement inside the cab. It should be noted that Hyman (1990) has found that neck rotations are likely to occur when an individual is asked to rotate their eyes by more than 10°. As seen below in the horizontal visual angle specs, participants were exposed to more than double this distance. However, the display size and distance to screen is analogous to that of a Commander. Further, as discussed above, participants were also reminded to keep their heads still when rotational movement was observed by the experimenter.

Table 3: Vertical Visual Angle (VVA) and Horizontal Visual Angle (HVA) of Viewing Distance from Screen

Eye to screen (in.)	Height (in.)	Width (in.)	VVA (deg)	HVA (deg)
21	10.6	13.3	29.2	35.14



Figure 4: Placement of Monitor inside the Cab

Scenario

The pre-recorded target detection task environment was based on Fort Dix and generated in house by the Institute for Simulation and Training (IST). The terrain was loaded into a modified version of the Mixed Initiative Experimental (MIX) Testbed (Barber, Davis, Nicholson, Finkelstein, & Chen, 2008). The MIX Testbed is a distributed simulation environment for investigation into how unmanned systems are used and how automation affects performance. A 15-minute route was created and recorded in daytime conditions. The unmanned ground vehicle (UGV) drove along a paved road with minimal elevation so that the visual output was not provocative, and drove at a constant speed of 4 meters per second (8.94 miles per hour) to keep global visual flow set at a constant rate. The scenario was designed so that the UGV passed two

targets, or insurgents, per minute (30 total targets). Distracters (friendly soldiers and friendly civilians) were also placed in the scenario so that participants passed 4 distracters per minute (60 total distracters). This recorded route was not associated in any way with the movements of the motion platform and was used for all participants.

Each display design showed the UGV's environment on six 60° camera feeds, with the front 180° view being shown by the top three camera feeds, and the back 180° view being shown on the bottom three camera feeds, therefore depicting a complete 360° view of the target detection environment. The display resolution (i.e., pixel dimensions) and size of the Dual Banners display is 1280 x 1024 (width X height) pixels.

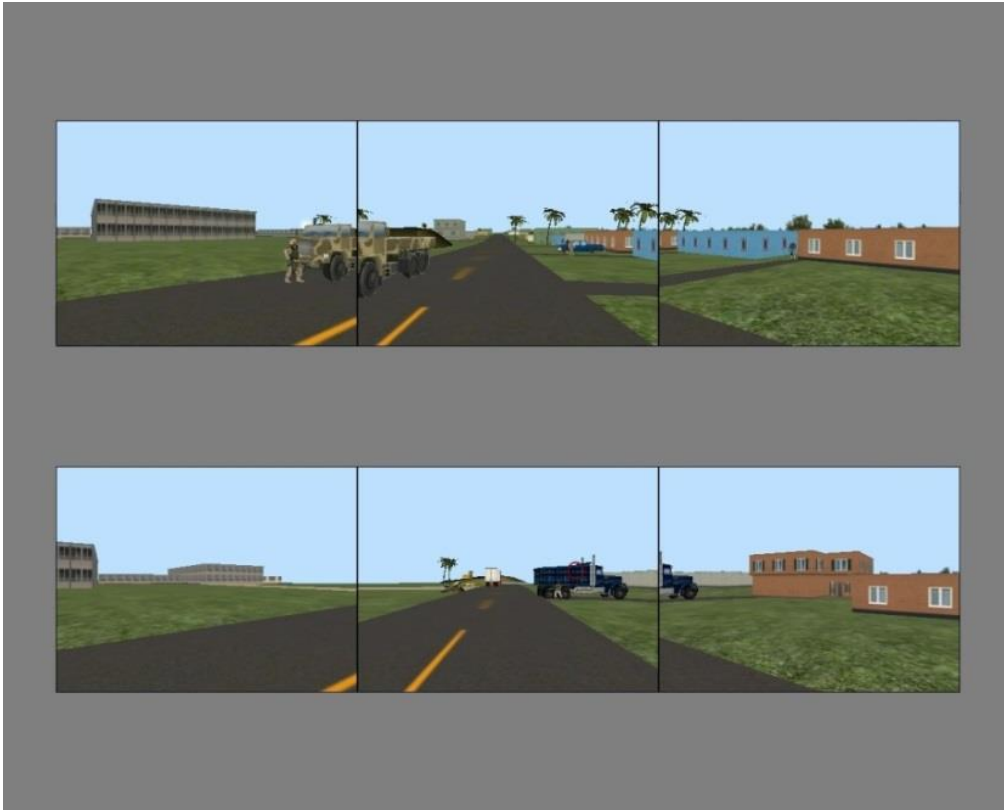


Figure 5: Dual Banners Tile Display

The size of each camera feed is 384 x 338 pixels, 3.99 x 3.498 inches (101.37 x 89.20 mm). In normalized numbers, where 1 = full screen width or height and 0.5 = half width or height, this ratio of each camera feed is 0.3 x 0.33. Both display designs have a 0.33 normalized gap (i.e., grey area separating the front and back 180° views). Further, the Completely Separated display (Figure 6) has 0.05 gaps in between each camera feed.



Figure 6: Completely Separated Display

As you can see from Figures 5 and 6 above, the camera feeds do not have a smooth transition between the feeds. Although computations could have been used to calibrate the camera views, this slight distortion is how Commanders see the outside view when using a 360° indirect vision display in real-time. For purposes of a more accurate study depicting how the display is currently used, calibration to make a smoother transition was not implemented.

Artificial Horizon

The artificial horizon was mathematically calculated to move in equal and opposite direction of the pitch and roll of the motion platform. Figures 7, 8 and 9 give examples of the visual display of the virtual horizon (note: the AH is at 8 pixels). Fuchsia was chosen as the color of the

artificial horizon because it stands out against the natural colors of the environment. Its size was set to 8 pixels thick, and the alpha (transparency) of the line was set to 50%.



Figure 7: Artificial Horizon in Dual Banners on Level Ground

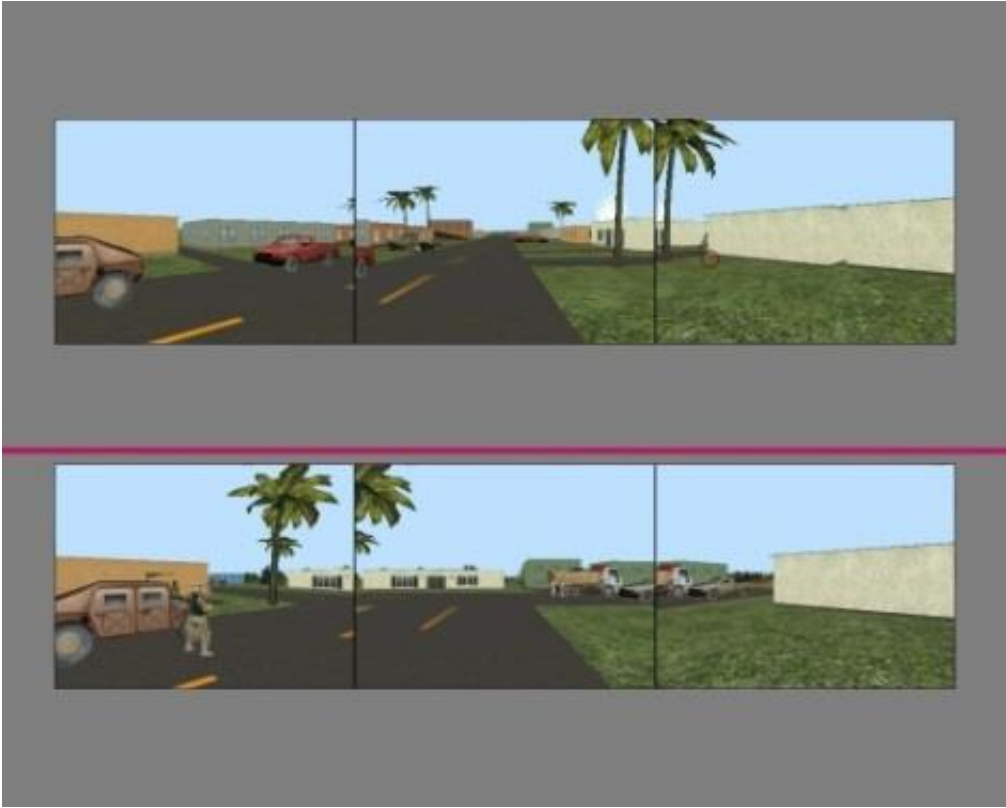


Figure 8: Artificial Horizon in Dual Banners on Elevated Ground

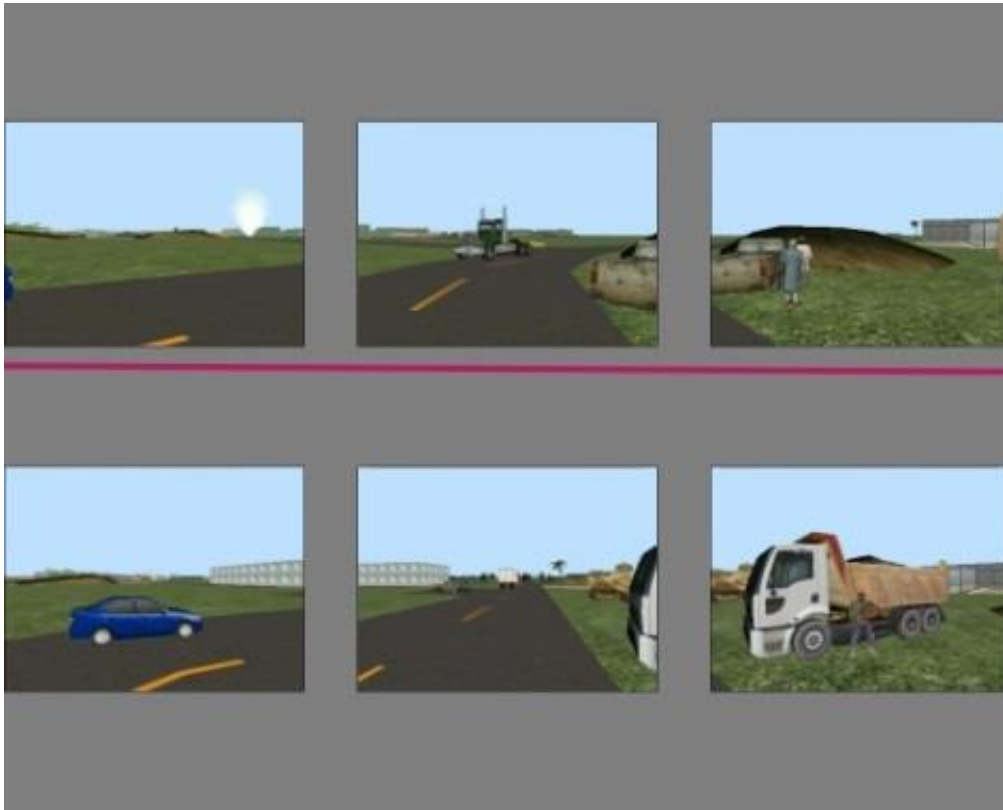


Figure 9: Artificial Horizon in Completely Separated on Declined Ground Slightly Sloped to the Left

Intercom

A two-way intercommunication system was used by both the participant and experimenter while the participant was in the cab. Their main use was to ask participants a series of SA questions and to hear participants verbally respond to threat detections, but participants were told to express to the experimenter if they wanted to stop at any time (although this never occurred).

Materials

A number of questionnaires, surveys and assessments were conducted in this study:

Motion History Questionnaire (MHQ). Portions of the MHQ (discussed above in Participants subsection; Appendix D) was used as a screening tool to determine eligibility to participate in the experiment, and the full questionnaire was administered during the experiment to be used as a variable in the data analyses.

Demographics Questionnaire. The demographics questionnaire (Appendix E) obtained information on the general background of the participant (e.g., age, major [if in school], usage of video games).

Current Health Questionnaire. This questionnaire was administered at the beginning of the study to help identify the participant's current state of fitness (Appendix F). Questions in this survey include caffeine intake, the number of hours participants slept the night before, the average number of hours of sleep they usually obtain, and the optimal number of hours they believe they need in order to feel well rested. They will additionally be asked if they felt the number of hours they slept the night prior was sufficient, as well as the time and their mood upon waking. These questions were taken to be used as covariates and potential variables in data analysis. Other questions include the amount of alcohol and drug intake participants had 24 hours prior to the experimental session, which determined if an individual was able to continue participating that day.

Attentional Control Survey. The Attentional Control Survey (Derryberry & Reed, 2002; Appendix G) is a paper-and-pencil questionnaire consisting of twenty questions that measures

attention focus and shifting (2002) and, as discussed above, has been found to be correlated to simulator sickness severity. The questionnaire was administered for this study to further this investigation on uncoupled motion.

Simulator Sickness Questionnaire (SSQ). Participants completed the SSQ (Appendix H) at various times throughout the study: at the beginning of the session, immediately following completion of the motion scenario, 30 minutes, and 60 minutes post-exposure. Participants with scores differing from their baseline SSQ also assessed their symptoms 24 hours post-exposure during a follow-up phone call or email by the experimenter.

NASA-TLX. The National Aeronautics and Space Administration-Task Load Index (NASA-TLX; Hart & Straveland, 1988) was used to assess participants' perceived workload after completion of the motion scenario (Appendix I). This questionnaire asks participants to rate their levels of workload in six areas: mental, temporal, physical, effort (mental and physical), frustration, and performance. Participants additionally are asked to complete pairwise comparisons for each subscale. Definitions of each subscale were provided on a sheet of paper for participants to use as a reference while completing their estimate of perceived workload.

Cube Comparison Test. Mental rotation, or an individual's ability to identify objects when they are not in their usual orientations, has been suggested to play a role in sickness found in Virtual Environments (VE; Parker & Harm, 1992). The Cube Comparison Test (Educational Testing Service, 2007a; Appendix J) was used in this study to determine if it explains any variability in uncoupled motion. This pencil-and-paper test asks participants to compare 21 pairs of 6-sided

cubes and determine if the rotated cubes are either the same or different in a timed (3 minutes) session.

Morningness-Eveningness Questionnaire (MEQ). Although Cowings and colleagues found no relationship between reported symptoms of drowsiness and circadian rhythms during their motion study (Cowings et al., 1999), the duration of which individuals were exposed to motion (4 to 5 hours each day) may have masked any circadian effects. It is possible that circadian influences on reports of motion sickness, if there are any, can be observed in motion exposures of shorter duration. The MEQ (Horne & Ostberg, 1976; Appendix K) is a 19 question survey that uncovers an individual's circadian rhythms, or natural daily cycle of numerous physiological functions. The MEQ's results show the general timeframes that an individual becomes tired, is most alert, and is likely to perform physical activities optimally in a 24 hour period. It also classifies each participant as a Morning Type (MT), Evening Type (ET), or Neither Type (NT). (e.g., ET's reach their peak performance level later MT and NT's). This questionnaire was administered with the expectation to help reduce variability of levels of sickness susceptibility based on the circadian change (such as flicker fusion frequency threshold).

APTS. Two of the APTS computerized test batteries (Kennedy, Jones, Dunlap, Wilkes & Bittner, 1985; Kennedy, Lane, & Jones, 1996) were used to assess the effects of exposure to the uncoupled motion environment and display design on participants' cognitive performance and visual perception. Due to limited time and resources, not all cognitive and visual perception measures can be used for the proposed study. Below is a description of the tests that will be used, both of which incorporate input to the computer by the use of a standard keyboard. Based

on previous research mentioned above (Kennedy et al., 2003), Grammatical Reasoning (GR) was used due to its sensitivity to disruption by stressors.

The GR cognitive test (Baddeley, 1968) instructs a participant to respond either “true” or “false” to a series of simple statements regarding the order of two letters, A and B by pressing “T” or “F,” respectively, on the keyboard. There are a total of five randomly generated grammatical transformations for statements that are used. The participant’s performance was scored based on the number of correctly identified transformations. The Manikin test (Benson & Gedye, 1963) is an assessment of the spatial transformation of mental images. This test shows a computer-generated figure on the screen in either a forward- or backward-facing position. The figure holds a set of different patterns in each hand, one of which matches the pattern that is presented below the figure. The test instructs a participant to determine whether the matching pattern is being held in the figure’s left or right hand by pressing the left or right arrow key. The orientation of the figure (i.e., forward or backward), pattern type and the hand holding the matching pattern were randomly generated throughout the 60 second trial. The participant’s performance was scored based on percent correct and response time. The GR and MK tests were administered four times to familiarize participants with the tests, two times immediately prior to exposure to uncoupled motion to be averaged and serve as the baseline, immediately post-exposure, then 30-minutes and 60-minutes post-exposure.

Sharpened Romberg. A postural stability test was administered to assess potential postural stability or balance dysfunction (i.e., dystaxia) due to uncoupled motion. The test was administered 10 times prior to uncoupled motion exposure, with the average of the best two out

of the last three administrations serving as the baseline. The test was also administered immediately post-exposure, 30 minutes post-exposure and 60 minutes post-exposure. Participants stood heel-to-toe while barefoot (with socks on) with their arms folded in front of them (hands holding opposite their shoulders) and their eyes closed (Thomley, Kennedy & Bittner, 1986). During the initial orientation of this test, participants had the opportunity to determine which foot they would like to be placed in front of the other, and then continued all future assessments with the same footing.

The participant were instructed to stand and maintain this position for 20 seconds (as 30 seconds in the same position has been found to be too difficult to complete for many participants; Kennedy et al, 1999). A stopwatch was used to measure the duration of the stance. Further, their steadiness was measured and combined with their time to create a composite score of postural stability ranging from 0-14: 0 = unable to keep stance for 5 seconds and wavers substantially; 1 = unable to keep stance for 5 seconds and wavers moderately; 2 = unable to keep stance for 5 seconds with minimal or no wavering; 3 = unable to keep stance for 10 seconds and wavers substantially; 4 = unable to keep stance for 10 seconds and wavers moderately; 5 = unable to keep stance for 10 seconds with minimal or no wavering; 6 = unable to keep stance for 15 seconds and wavers substantially; 7 = unable to keep stance for 15 seconds and wavers moderately; 8 = unable to keep stance for 15 seconds with minimal or no wavering; 9 = unable to keep stance for 20 seconds and wavers substantially; 10 = unable to keep stance for 20 seconds and wavers moderately; 11 = unable to keep stance for 20 seconds with minimal or no wavering; 12 = keep stance for 20 seconds and wavers substantially; 13 = keeps stance for 20 seconds and wavers moderately; 14 = keeps stance for 20 seconds with minimal or no wavering.

Substantial wavering is considered to occur if the participant tilts his body in any angle. Moderate wavering is considered to occur if the participant sways further than one inch in any direction away from his upright standing position. Minimal or no wavering is considered to occur when there is no visual detection of sway, or swaying that is less than one inch in any direction away from his upright standing position. A participant was marked that he is unable to maintain stance if he lifts or moves either one of his feet, opens his eyes or moves his arms during the stance.

Past Pointing. This measure was used to assess potential fine motor disturbances due to uncoupled motion. The test was administered 10 times prior to uncoupled motion exposure, with the average of the best two out of the last three administrations serving as the baseline. The test was also administered immediately after each Sharpened Romberg test post-exposure (i.e., immediately post-exposure, 30 minutes post-exposure and 60 minutes post-exposure).

Participants were instructed similarly to a field sobriety test (National Highway Traffic Safety Administration, 2001), which is to stand straight with their feet together, tilt their head slightly back and keep their eyes closed. Then, they will be asked to use their index finger (first using their dominant hand, then their non-dominant hand) to touch the tip of their nose. Participants were measured on a scale from 1 to 6: 1 = misses face; 2 = touches face (misses nose); 3 = touched nose, but not tip AND wavers substantially; 4 = touched nose, but not tip with minimal wavering; 5 = touched tip of nose AND wavers substantially; and 6 = touched tip of nose with little or no wavering. The amount and direction of potential of sway was noted and compared with Sharpened Romberg results.

SA Questions. Participants were asked SA questions 3, 6, 9, 12, and 14 minutes into the uncoupled motion scenario, but were only told that SA questions will be assessed (i.e., they did not know the timing of the questions). All questions were asked in the same order for each participant: 1) If the compass direction of the UGV was headed North at the beginning of the scenario, what is its current compass direction? (3 m); 2) How many left-hand turns has the UGV made? (6 m); 3) How long in minutes do you feel you have been on your mission? (9 m); 4) Has the UGV passed any females on this road? (12 m); and 5) Was the last threat you detected on the left- or right-hand side of the road? (14 m).

Procedure

Individuals who met the recruitment requirements were offered via email to participate in the study. This email provided a list of available dates and times for the individual to choose from in order to schedule a session. The email also included the Participant Verification Message (Appendix B), which listed several requirements and suggestions for the day of their experimental session.

The experimental sessions started at 8 AM, 11:30 AM and 3 PM. Upon arrival, the participant was randomly assigned to one of the four display conditions. The experimenter thanked the participant for their participation, and he then was asked to read and sign the informed consent form (Appendix F), which described the requirements and tasks involved in the study and notified him of the possibility of experiencing motion sickness symptoms such as eyestrain, dizziness and nausea. The form also clearly stated that participation was completely voluntary and that he may withdraw from the experiment at any time and for any reason without

penalty. Participants were allowed to ask questions at any time, and all questions were answered completely. The participant was asked to fill out the Current Health Questionnaire to ensure that he abided by the requirements and was able to continue with the experiment. The experimenter immediately reviewed the participant's responses to verify that he was eligible to continue. The participant was then asked to complete 2 sessions of the GR and MK computerized assessment tests. Next, the participant was shown how to perform the Sharpened Romberg test. He was asked to take off his shoes and perform the first administration of Sharpened Romberg. The participant was then shown how to perform the past-pointing test and was instructed to perform the test. The participant continued to perform four more rounds of the Sharpened Romberg and past-pointing, interchanging between the two for each round (with Sharpened Romberg being performed first).

Next, the participant was asked to complete the MHQ. Upon completion, the participant was given the Cube Comparison test, which was timed by the experimenter for 3 minutes by using a stopwatch. Immediately afterward, participants completed their 3rd and 4th sessions of the MK and PC computerized assessment tests and 5 more rounds of the Sharpened Romberg and past pointing tests. The participant was then given a 5-minute break.

Upon returning from break, participants sat in front of a laptop computer to view PowerPoint© training slides in order to familiarize themselves with the target detection task. These slides provided participants with examples of threats (i.e., insurgents: armed civilians and armed enemy soldiers) and were instructed to detect them by touching the screen immediately upon identification while the unmanned ground vehicle (UGV) drives its route. The training slides also showed the distracters that were in the environment (i.e., friendly civilians and

friendly (US) Soldiers). Training was self-paced, in which participants were allowed to investigate and compare threats to the distracters until they felt comfortable with the task. After the completion of the training slides, participants were verbally informed of their other tasks they were to perform during the target detection task (i.e., verbally identifying threats as they detected them [i.e., Threat 1, Threat 2, etc.], and verbally answering situation awareness [SA] questions). The participants then completed their 5th and 6th administrations of the MK and PC computerized assessment tests (the average of these two administrations were averaged to compute the individual's baseline scores) and were offered another a 5-minute break.

Upon returning from his break, the participant was led to the simulator room and asked to sit in the passenger side of the simulator. The participant's eye level to the center of the monitor as well as distance from eyes to monitor were assessed, and modifications of the monitor's height and distance were made if necessary. He then was instructed to secure his seatbelt, which was observed by the experimenter to ensure it was safely buckled. He was instructed to sit comfortably, but maintain an upright posture with his back firm against the backrest of the seat. He was instructed to refrain from making head movements throughout the duration of the scenario. The participant was asked to keep his feet square on the floor, and was reminded to only use his dominant hand for the target detection task while keeping his other hand rested in a stationary position in his lap. The participant was asked if he had any questions, and when he verbally stated he was ready, the door of the Mark II cab was closed.

The experimenter walked to a nearby room with glass windows that provided a clear view of the cab and sat in front of a monitor which provided a view of the camera feed of the

participant from within the cab. The experimenter used the intercom to verify with the participant that they can hear one another, and the experimenter then started a 1 minute practice route. The practice route did not include simulator motion. It began with the UGV passing all threats lined up along a road, and then provided a short scenario with threats hidden in the environment. This was used to verify that the participant understood and could adequately perform the target detection task. When the practice route was complete, the experimenter informed the participant that the motion scenario was about to begin. The experimenter then started the uncoupled motion scenario.

During the 15 minute uncoupled motion scenario, the experimenter verbally asked the SA questions (3, 6, 9, 12, and 14 minutes into the scenario) and wrote down the participant's responses. These questions, along with the verbal count of each threat the participant passed, were created to keep participants cognitively involved during exposure. In addition, the experimenter monitored the participant's head position throughout the scenario, and if head movements were observed, the experimenter verbally reminded him to maintain a still position and refrain from moving his head.

At the 15-minute mark, while the cab returned to its normal, stationary position, the SSQ appeared on the participant's monitor and was asked to complete it using the touchscreen. Also at this time, the experimenter approached the cab and opened the door to both allow the participant's eyes to adjust to the light and actively observe (and take note of) whether the participant displayed pallor, was sweating, or was shaking. Once the SSQ was completed, the experimenter assisted the participant out of the cab and asked him to take off his shoes and perform the Sharpened Romberg and past-pointing test. Following these tests, the participant

was seated to perform one administration of the MK and PC tests. Participants were then provided with an optional 5-minute break. While the participant was being timed for their next 30- and 60-minute rounds of SSQ, Sharpened Romberg, past-pointing and APTS administrations, he filled out the NASA-TLX, Demographics survey, Attentional Control assessment, and Morningness-Eveningness Questionnaire. Additionally, he were be free to move around the lab, take restroom breaks, and eat snacks.

The participant was kept a minimum of 1 hour post-exposure (3 hours total participation time), even if he was not displaying any symptoms of sickness. At the end of the experiment, the participant was debriefed. The participant was thanked for his participation and was asked if he had any questions or comments on the experimental procedure. A follow-up email by the experimenter was sent 24 hours after participation and was asked to assess their current symptoms using the SSQ.

A 2 x 2 between-subjects design of artificial horizon (No Artificial Horizon [NoAH] vs. Artificial Horizon [AH]) and display type (Dual Banners or Completely Separated) was implemented. Therefore, the experimental design used randomized placement of participants into one of the following four conditions (with 8 participants per condition): NoAH Dual Banners, AH Dual Banners, NoAH Completely Separated, and AH Completely Separated.

The dependent variables for the experiment were measures of motion sickness, which included a subjective measure (SSQ), objective measures of target detection performance (percent correct) and SA performance (percent correct) during uncoupled motion, as well as cognitive performance (GR) and visual perception (MK) (response time and percent correct), postural stability (Sharpened Romberg), and past-pointing after uncoupled motion.

In addition to the SSQ, other subjective measures for the experiment included workload assessment (NASA-TLX) perceived attentional control (Attentional Control Survey), and motion history (MHQ). Measures intended to be used as covariates were circadian rhythm (MEQ) and mental rotation ability (Cube Comparison Test).

Three measures were assessed in the experiment were ultimately not used for analysis. Past-pointing was found to have a major ceiling effect during the experiment, so performance assessment using this variable would not have been helpful. Hidden Patterns was a paper-and-pencil test that originally was intended to be used as a covariate, but in order to maintain degrees of freedom in analyses with a smaller sample size than predicted, it was dropped. However, the survey did serve the purpose of keeping participants on-site and involved while the experimenter timed them for their next assessments of sickness measures. Lastly, individuals verbally counted threats they detected while performing their target detection task during uncoupled motion exposure, but this was not considered for the study. Its main purpose was to keep participants mentally involved and focused on their task while immersed in the environment.

A multiple regression was intended to be used to uncover the predictive capability of Display Design, postural stability (labeled as balance), perceived attentional control and motion history on motion sickness severity as the outcome variable, as measured by the SSQ, after uncoupled motion exposure. Although SSQ Nausea, Oculomotor and Disorientation are subscales of Total Severity, it was of interest to look into all four separately due to differences in sickness symptomatology depending on a given motion environment. Since uncoupled motion is fairly new to being investigated, it would be beneficial to investigate the subscales for a more in-

depth look at symptom severity. Thus, four separate multiple regression analyses were intended to be run (Hypothesis #1).

In order for Display Design to be used for multiple regression, it must to be dummy coded into three variables. Thus, along with postural stability, attentional control and motion history, the model included six predictor variables. It has been recommended to have a minimum of 15 participants per predictor you intend to use in a multiple regression analysis (Stevens, 1996, p. 72). However, funding and simulator limitations resulted in a smaller sample size than planned. Due to this limitation, the p -value was set to .100 in order to uncover trends.

A two-way between-groups ANCOVA was intended to be used to assess the impact of display design on target detection and SA performance (Hypothesis #2a) as well as perceived workload (Hypothesis #4), with perceived attentional control and mental rotation ability as covariates

A mixed-model ANOVA was intended to be used to assess differences in cognitive performance and visual perception between display design conditions across the four administrations (Baseline, Post-Exposure, 30-min Post-Exposure, and 60-min Post-Exposure) (Hypothesis #2b, Hypothesis #6d).

A series of nonparametric Kruskal-Wallis tests were used to evaluate differences in postural stability (Hypothesis #3a, Hypothesis #3b) and sickness severity (SSQ Total Severity, Nausea, Oculomotor, and Disorientation) across the four display designs (Hypothesis #5a, #5b).

Lastly, a series of nonparametric Friedman tests were used to evaluate changes in postural stability (Hypothesis #6c) and sickness severity scores (SSQ Total Severity, Nausea,

Oculomotor, and Disorientation; Hypothesis #6a, #6b, and #6c) across the four administrations.

Significant differences were assessed with post-hoc Wilcoxon Signed Rank Test analyses.

CHAPTER FOUR: RESULTS

Main Results

This chapter provides the results from the main hypotheses. This study had multiple measures which resulted in an abundant amount of analyses. Although all of the data was important to report, some were not the driving factors of this study. These additional analyses are provided in Appendix M, but a discussion of all results will be discussed in the next chapter.

Model of Self-Assessed Motion Sickness

Standard multiple regression was used to assess the ability of four variables- Display Design (NoAH Dual Banners, NoAH Completely Separated, AH Dual Banners and AH Completely Separated), motion sickness susceptibility (MHQ), perceived attentional control (Attentional Control Survey) and postural stability (Sharpened Romberg) - to estimate motion sickness severity (SSQ Total Severity). Display Design was dummy coded into three variables, with NoAH Dual Banners serving as the reference group. Therefore, this resulted in six variables for the model. The p-value was set to .100 to uncover trends.

Using SPSS V21, Preliminary analyses were conducted to ensure no violation of the assumptions of normality, linearity, multicollinearity and homoscedasticity. First, the correlations of the independent variables were checked to determine that they show at least some relationship with SSQ Total Severity, as well as between each other, but not but not too high (above .7). Next, the collinearity statistics were observed to determine how much variability each independent variable was not explained by the other independent variables (i.e., Tolerance = $1 - R^2$). All independent variables had a value higher than .10. The Variance Inflation Factor

(VIF = inverse of Tolerance) was also observed, with all variables having values of less than 10. All of these observations were to ensure that multicollinearity was not observed in the data. The results are shown in Table 4 below:

Table 4: Results of SSQ Total Severity Variable Correlations and Collinearity Statistics

Total Severity Variables	Correlations	Collinearity Statistics	
	Pearson's r	Tolerance	VIF
NoAH Completely Separated	0.446	0.518	1.930
AH Dual Banners	-0.336	0.598	1.673
AH Completely Separated	-0.135	0.593	1.686
Motion History	0.060	0.899	1.113
Attentional Control	0.387	0.962	1.039
Balance	-0.223	0.819	1.221

Although normality of a response variable is not an assumption of regression, the residuals must be normal (Kleinbaum, Kupper, Nizam, & Muller, 2008). The Normal Probability Plot (P-P) of the Regression Standardized Residual (Figure 10) was used to observe whether the points lie in a reasonably straight line along the diagonal. Although the points are not snug to the line, it was determined that the data set is approximately normally distributed.

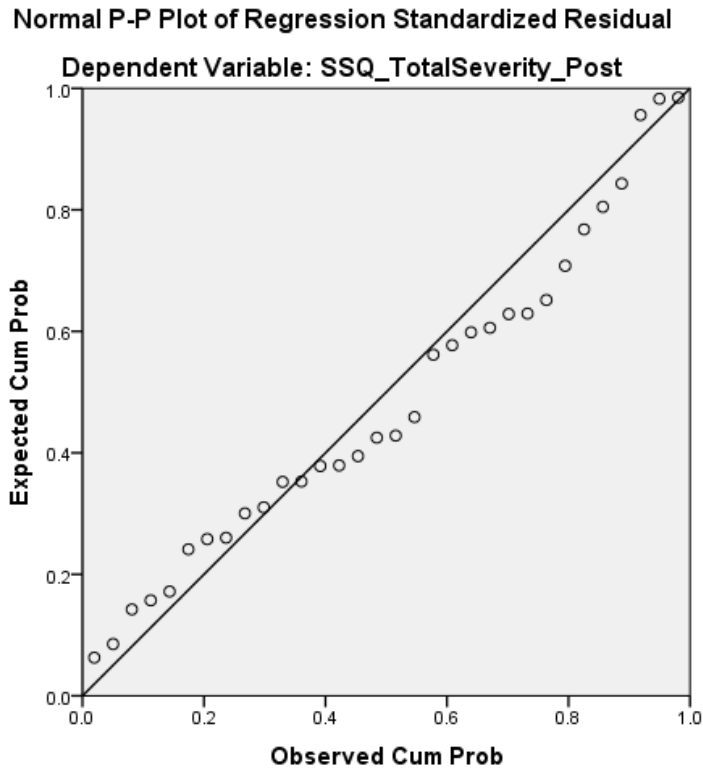


Figure 10: Normal P-Plot of Regression Standardized Residual of SSQ Total Severity

Inspection of the histogram (Figure 11) revealed a normal distribution with what may be considered an edge peak at one tail (Tague, 2004). However, the scatterplot revealed a roughly rectangular distribution with no standardized residual values of more than 3.3 or less than -3.3.

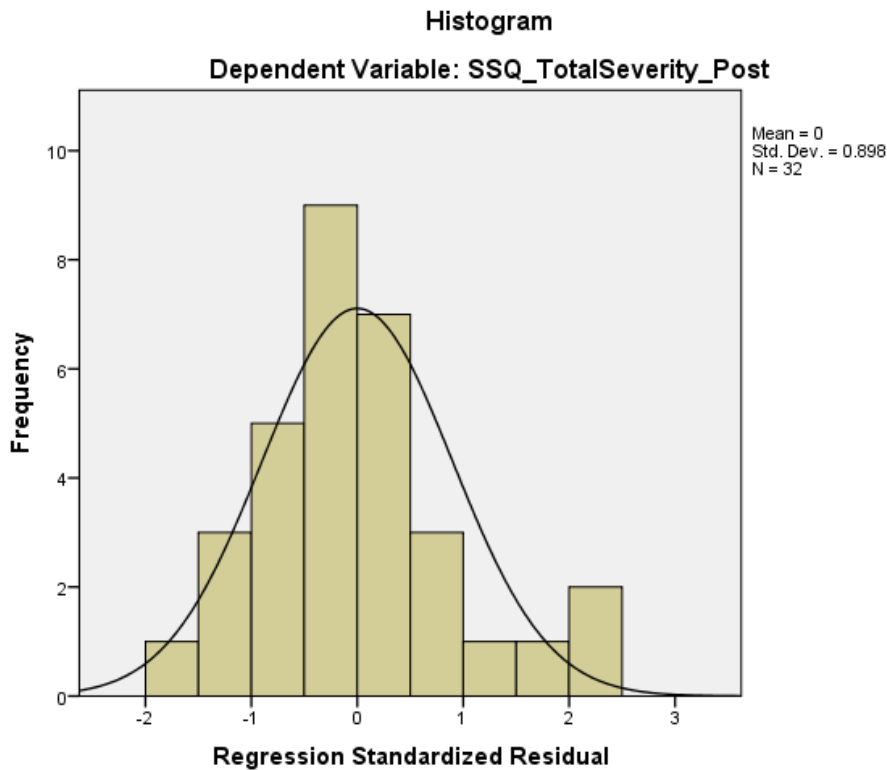


Figure 11: Histogram of Regression Standardized Residual of SSQ Total Severity

No cases had missing data and no suppressor variables were found. Table 5 displays the correlations between the variables, the unstandardized regression coefficients (B) and intercept, the standardized regression coefficients (β), the semipartial correlations (sr_i^2) and R^2 . R for regression was significantly different from zero, $F(6, 25) = 3.609, p = .010$. The regression coefficients Attentional Control ($sr_i^2 = .416, p = .009$) and AH Dual Banners ($sr_i^2 = -.282, p = .066$) differed significantly from zero. The 95% confidence limits for Attentional Control were .250 to 1.559. The 95% confidence limits for AH Dual Banners were -23.457 to .786.

Table 5: Standard Multiple Regression of Variables on Total Severity of Sickness

Variables	SSQ Total Severity (DV)	NoAH Completely Separated	AH Dual Banners	AH Completely Separated	Motion History	Attentional Control	Balance	B	β	sr^2	Sig
										(unique)	
NoAH Completely Separated	0.446							6.213	0.200	0.144	0.335
AH Dual Banners	-0.336	-0.333						-11.336**	-0.365	-0.282	0.066
AH Completely Separated	-0.135	-0.333	-0.333					-6.398	-0.206	-0.159	0.289
Motion History	0.060	-0.192	0.023	-0.100				1.007	0.176	0.167	0.266
Attentional Control	0.387	0.051	0.017	0.086	-0.115			0.904**	0.425	0.416	0.009
Balance -Post	-0.223	-0.304	-0.069	0.015	0.183	0.017		-0.700	-0.224	-0.202	0.179
								Intercept = -37.726			
Means	10.168	0.250	0.250	0.250	3.906	56.063	5.520				
Standard Deviations	13.675	0.440	0.440	0.440	2.388	6.420	4.370				
										$R^2 = .464^a$	
										Adjusted $R^2 = .336$	
										$R = .681^{**}$	
**p < .100											
^a Unique variability = .416											

Using the unstandardized regression coefficients (B), with all other things being equal, if the display being used is AH Split, SSQ Total Severity goes down by 11.336 units when compared to NoAH Dual Banners (i.e., the reference group and current display design). Although not statistically significant, if the display being used is AH Completely Separated, SSQ Total Severity goes down by 6.398 units when compared to the current display design. Additionally, although not significant, if the display being used is NoAH Completely Separated, SSQ Total Severity actually increases by 6.213 units. Altogether, 46.4% (33.6% adjusted) of the variability in total severity of sickness was predicted by knowing scores on these six IVs. A post-hoc power analysis was run using G*Power (Faul, Erdfelder, Lang & Buchner, 2007) and determined that, with an N of 32, a large effect size of 0.866, the statistical power was 93%.

Due to the significant findings in Total Severity of sickness, it was of interest to conduct multiple regression analyses on each of the SSQ subscales to determine if the same variables had more or less predictive value on specific symptoms of sickness indicated by the subscales provided by the SSQ (i.e., Nausea, Oculomotor and Disorientation). However, the raw data of each of the subscale scores led to a violation of at least one assumption. Each subscale was transformed into first square root, log, and \log_{10} , but unfortunately not all assumptions were fulfilled after transformations. Therefore, the subscales were not analyzed.

Objective Performance

Performance during Uncoupled Motion

A two-way between-groups ANCOVA was conducted to determine the impact of Display Type and Artificial Horizon on target detection rate (i.e., percentage of threats detected out of the

total encountered), with perceived attentional control and cube comparison as covariates. The main effect for Display Type, $F(1, 26) = 0.791, p = .382$, was not significant. Artificial Horizon was also not significant, $F(1, 26) = 0.582, p = .452$. Although not significant, individuals in the AH Completely Separated condition detected the most threats (see Table 6 below).

A two-way between-groups ANCOVA was conducted to determine the impact of Display Type and Artificial Horizon on SA query performance (i.e., percent correct), with perceived attentional control and cube comparison as covariates. The main effect for Display Type, $F(1, 26) = 1.314, p = .262$, was not significant. The main effect for Artificial Horizon was also not significant, $F(1, 27) = 0.015, p = .903$. The means and standard deviations of uncoupled motion performance are provided in Table 8 below.

Table 6: Means and Standard Deviations of Performance During Exposure across Conditions

Performance During Uncoupled Motion	Dual Banners		Completely Separated	
	NoAH	AH	NoAH	AH
Target Detection	67.93 (4.98)	68.33 (2.98)	68.77 (5.04)	77.50 (3.01)
SA Queries	50.00 (1.07)	40.00 (0.53)	32.40 (0.74)	42.60 (0.64)

Cognitive and Spatial Tests

A series of 2 x 2 x 2 mixed between-within subjects ANOVAS were conducted on the computerized visual and cognitive assessment tests (Manikin and Grammatical Reasoning). The between-subjects factors were Display Type (Dual Banners or Completely Separated) and Artificial Horizon (NoAH or AH), and the within-subjects factor was Administration (Baseline and Post-Exposure).

An ANOVA on MK Percent Correct scores revealed no main effect of administration, $\lambda = .982$, $F(1, 28) = .519$, $p = .477$, $\eta^2_p = .018$. There were no significant main effects of Display Type, $F(1, 28) = 1.144$, $p = .294$, $\eta^2_p = .039$, or Artificial Horizon, $F(1, 28) = 1.325$, $p = .259$, $\eta^2_p = .045$.

An ANOVA on MK Response Time scores revealed no main effect of administration, $\lambda = .987$, $F(1, 28) = .360$, $p = .554$, $\eta^2_p = .013$. There were no significant main effects of Display Type, $F(1, 28) = .223$, $p = .640$, $\eta^2_p = .008$, or Artificial Horizon, $F(1, 28) = 0.000$, $p = .990$, $\eta^2_p = .000$.

An ANOVA on GR Percent Correct scores revealed no main effect of administration, $\lambda = .988$, $F(1, 28) = .336$, $p = .561$, $\eta^2_p = .012$. There were no significant main effects of Display Type, $F(1, 28) = 1.794$, $p = .191$, $\eta^2_p = .060$, or Artificial Horizon, $F(1, 28) = 1.293$, $p = .265$, $\eta^2_p = .044$.

An ANOVA on GR Response Time scores revealed a significant main effect of administration, $\lambda = .824$, $F(1, 28) = 5.961$, $p = .021$, $\eta^2_p = .176$. There were no significant main effects of Display Type, $F(1, 28) = 0.214$, $p = .647$, $\eta^2_p = .008$, or Artificial Horizon, $F(1, 28) = 0.019$, $p = .893$, $\eta^2_p = .001$.

Postural Stability

Nonparametric Kruskal-Wallis tests were conducted in order to determine if there were any differences in postural stability (as measured by the Sharpened Romberg) across the four display design conditions (NoAH Dual Banners, NoAH Completely Separated, AH Dual Banners, AH Completely Separated) for Baseline and Post-Exposure administrations.

The results of the Kruskal-Wallis test on the Baseline data revealed that there was no significant difference in the Baseline postural stability scores across the four display designs, χ^2 (3, n = 32) = 0.575, $p = .902$, indicating that there were no differences between conditions prior to uncoupled motion exposure. There was also no significant difference across the four display designs at Post-Exposure, χ^2 (3, n = 32) = 1.188, $p = .756$.

Table 9 below lists the means, standard deviations and median scores of the Sharpened Romberg (the 30- and 60-min Post-Exposure results are listed in Appendix M).

Table 7: Postural Stability Medians, Means and Standard Deviations across Conditions and Administrations

Sharpened Romberg	NoAH Display				AH Display			
	Dual Banners		Completely Separated		Dual Banners		Completely Separated	
	Median	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)
Baseline	7	8 (4.140)	8	7.875 (2.850)	8	7.625 (3.260)	5.25	3.259 (3.259)
Post	6.5	6.5 (4.899)	2	4.938 (5.003)	4.5	4 (1.582)	6	5.123 (5.123)
30-Minute Post-Exposure	3.5	5.25 (5.339)	5	7.375 (5.041)	5	6.875 (4.912)	3.357	4.665 (4.259)
60-Minute Post-Exposure	4	5 (4.175)	5	6.5 (4.106)	3	4.125 (2.642)	4	4.227 (3.859)

CHAPTER FIVE: DISCUSSION

Implications for the Design of Indirect Vision Systems

Model of Motion Sickness

Results of the multiple regression analysis revealed that AH Dual Banners and perceived attentional control significantly contributed to the outcome SSQ Total Severity scores. Altogether, 33.6% (adjusted) of the variability in Total Severity of sickness was predicted by the variables used in the model. Therefore, Hypothesis 1, which stated that Display Design, postural stability, perceived attentional control and motion history would be significant predictors of SSQ sickness scores, is partially supported.

The most significant contributor to Total Severity was perceived attentional control (PAC), which supports previous research showing the relationship between PAC and motion sickness (Chen & Joyner, 2009; Drexler, Chen, Quinn & Solomon, 2012). Although this study was aimed to reduce sickness from a design standpoint, the results support the importance of selection when attempting to mitigate motion sickness. Individuals with high PAC tend to have lower SSQ scores than those with low PAC. Although speculative, it may be that those with high PAC do not particularly experience less sickness than low PAC individuals, but rather high PAC individuals are able to shift their attention away from sickness symptoms to focus on tasks at hand. This may consequently lead to these individuals reporting less severe symptoms on the SSQ. Moreover, those with low PAC who experience sickness may dwell in their symptoms due to their inability to easily shift their attention elsewhere. Although the reasons for high PAC

individuals reporting less motion sickness have not yet been investigated, the Attentional Control Survey is useful for attempting to mitigate sickness in uncoupled motion if selection is an option.

Display design significantly predicted Total Severity scores, with the artificial horizon incorporated onto the original Dual Banners display showing the lowest symptoms of sickness. These results support previous findings of an artificial horizon being able to reduce sickness in uncoupled motion environments (Brendly, Cohn, Marti & DiZio, 2002; Cohn, Muth, Schmorrow, Brendley & Hillson, 2002). The results of this study lead to the conclusion that it would be beneficial to implement an artificial horizon into 360° indirect vision systems. It is important to note, however, that the artificial horizon on the Completely Separated display was also lower than the original Dual Banners display, but it did not demonstrate a reduction as prominent as AH Dual Banners. This is likely due to participants having to move their eyes further distances in order to consistently scan the camera feeds on the screen for the Completely Separated display. As mentioned in more detail below, these results also support the importance of the layout of the display design on sickness symptoms.

Postural stability was not a significant predictor of SSQ Total Severity, which supports previous findings of no correlation between postural stability and self-assessed sickness scores (Kennedy, Stanney, Compton, Drexler & Jones, 1999). This study was an attempt to not only uncover whether display design can reduce symptoms of sickness, but to verify whether the postural stability theory could hold true, or at least shed some light on the consequences of uncoupled motion. However, the way in which postural stability was measured may have been more of an issue than of help.

Research on the reliability and validity of the Sharpened Romberg is limited, but the available research shows variations in test-retest reliability (Lanska & Goetz, 2000; Lee, 1998; Steffen & Seney, 2008) During data collection, postural stability was observed to fluctuate within participants during the first 10 administrations (i.e., before exposure to uncoupled motion). It may be that the Sharpened Romberg is *too* sensitive; it seemed as if frustration of not performing well during one administration affected performance in the following administrations. Further, the muscles required to maintain the posture may have produced fatigue across administrations and thus resulted in inconsistent postural stability. Nonetheless, although not significant, decrements in postural stability were found post-exposure to uncoupled motion, with the smallest decrement occurring in the AH Completely Separated condition. However, the postural stability theory of motion sickness cannot be supported or contradicted by the results of this study.

The MHQ was not a significant predictor of SSQ Total Severity, but this may be due to the population of participants used for this study. None of the participants were pilots or had experience with flight simulators or training simulators in general. Additionally, several participants listed carsickness and/or checked sickness symptoms due to exposure to busses, carnival rides, and even wide-screen movies, but since the MHQ does not incorporate these responses into the final score, these symptoms went unmeasured.

Objective Performance

Response time to Grammatical Reasoning actually *decreased* after uncoupled motion, which fails to support Hypothesis 2b stating that cognitive and spatial performance would be

lower for all display conditions immediately after exposure to uncoupled motion when compared to baseline scores. This significant result can be interpreted from a learning curve standpoint; it is possible that participants as a whole did not reach their peak in the learning curve prior to uncoupled motion exposure. However, GR accuracy (percent correct) was not statistically different from baseline to post-exposure, so it is possible that the difference may not be a learning curve issue. The results may potentially be due to taking a break from APTS and being involved with completely different tasks (i.e., target detection and SA queries) and this may have affected their efficiency with comprehending grammatical reasoning questions upon returning to the task.

It should be noted that percent correct is a poor metric for comparing means, and number correct (i.e., hits) is more reliable (R. Kennedy, personal communication, November 5, 2013). Post-hoc correlations were conducted between number correct and reaction time for both GR ($r = .597$) and MK ($r = .634$). Post-hoc correlations were also conducted to assess the relationship between percent correct and reaction time on both GR ($r = -.864$) and MK ($r = -.966$). Although number correct would result in greater precision of the outcomes, the correlations were high enough in this case that there would not have been much of a difference in the results if it were used.

Unlike Shipani and colleagues (Shipani, Bruno, Lattin & King, 1998), this study did not observe cognitive decrements after exposure to uncoupled motion. However, the absence of decrements in GR and MK measures supports the findings of several other studies that found very little, if any, negative impacts on performance due to general motion sickness effects

(Alexander, Cotzin, Hill, Ricciuti & Wendt, 1945; Bles & Wientjes, 1988; Johnson, 2005; Reason & Brand, 1975). This can be thought of as a significant insignificance. As an extreme example, Soldiers can be involved in life-or-death situations where performing optimally during missions is necessary for survival. As mentioned previously, motivation is theorized to play a role in performance while motion sick (Reason & Brand, 1975). Participants in this study were not motivated to perform as if their life literally depended on it; these individuals knew they were being monetarily compensated for their participation, but they had no intrinsic motivation to perform optimally. Nonetheless, the results revealed no performance decrements even though symptoms of sickness were present.

Grammatical Reasoning was the only objective performance measure that was significantly different (albeit improving), which fails to support several hypotheses: Hypothesis 2a, which stated that performance during uncoupled motion (i.e., target detection and situation awareness) would be higher in AH display conditions; Hypothesis 3a, which stated that dystaxia would be present in all display conditions immediately after exposure; and Hypothesis 3b, which stated that dystaxia would be the lowest immediately after uncoupled motion exposure for individuals who are assigned to the Dual Banners condition.

Subjective Performance

Assessment of NASA-TLX scores (see Appendix M) determined that participants in Dual Banners display conditions had a significantly lower level of perceived physical demand than those in Completely Separated display designs. NASA-TLX defines physical workload as, “How much physical activity was required (that is, pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or

laborious?” (Appendix J; Hart & Straveland, 1988). This was not a hypothesized outcome, but it is an understandable one. The higher scores of physical demand in Completely Separated display conditions is likely due to participants having to move their eyes further distances constantly throughout the target detection task to scan all six camera feeds, thus being perceived as a more laborious task.

Significantly lower perceived temporal demand for participants in AH conditions was also found. Temporal demand is defined as, “How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?” (Appendix J; Hart & Straveland, 1988). Again, this was not a hypothesized outcome, but these results may be due to an artificial horizon potentially giving individuals a bit of a sense of normalcy during uncoupled motion and thus lowering the perception of time pressure. Participants without the artificial horizon may have been more aware of the asynchronous motion they were experiencing and thus felt a more “frantic” pace, resulting in higher temporal demand scores. Although physical and temporal demand were significant, the results did not support Hypothesis 4, which stated that perceived workload, taken immediately after exposure, would be lower for AH display conditions.

Self-Assessment of Motion Sickness

Results of the nonparametric Kruskal-Wallis tests on SSQ scores (see Appendix M) partially supported Hypothesis 5a, which stated that there would be a difference in NOD subscales of subjective sickness immediately after exposure between the Dual Banners and Completely separated displays. Specifically, the AH Dual Banners condition had significantly

lower Total Severity and Oculomotor scores than the NoAH Completely Separated display condition. Additionally, NoAH Completely Separated also had marginally higher oculomotor scores when compared to the AH Completely Separated condition. Since Nausea and Disorientation were not significant, these results partially support Hypothesis 5b, which stated that NOD subscale scores would be lower in AH display conditions.

It should be noted that there were a few instances where a Friedman test revealed a significant difference across administrations of the SSQ, but no significant differences were detected during post-hoc analyses (see Appendix M). This may be due to the low power of the Wilcoxon Signed-Rank Test, the stringent Bonferroni correction applied to the significance level, or both. However, it was still noted that a statistical difference was found. This was the case for Disorientation scores across administrations in the NoAH Dual Banners condition, and Figure 13 (Appendix M) shows that Disorientation was highest during the post-exposure administration.

It is important to mention the norms of SSQ scores in other motion environments in order to determine the strength of the stimulus (i.e., uncoupled motion environment) in this study. Drexler (2006) obtained SSQ data from 21 simulator studies and 16 VR studies and found that the average Total Severity score was 18.13 for simulators and 27.95 for VR devices. In this study, the Total Severity differed between conditions, but ranged from 2.34 to 20.57, with an overall average of 10.17. The most sickness inducing condition (NoAH Completely Separated) had slightly higher Total Severity scores than the average simulator data obtained by Drexler (2006), but the least sickness-inducing condition (AH Dual Banners) was far below average SSQ scores for simulators. Although many factors play a role in sickness susceptibility, the SSQ

results between conditions in this study confirm the importance of display design on the likelihood of sickness.

Aftereffects

There were no significant differences of SSQ scores, postural stability, cognitive performance and visual perception between display conditions 30- and 60-minutes post-exposure (see Appendix M for results). Further, 30- and 60- minute post measures were not significantly different from baseline scores, suggesting that aftereffects were not present up to this point. These results fail to support several hypotheses: Hypothesis 6a, which stated that subjective sickness would be significantly different between baseline and 30-minute post-exposure administrations for all display conditions; Hypothesis 6b, which stated that subjective sickness would be lower in AH display conditions 30-minutes post-exposure, and Hypothesis 6c, which stated that postural stability would be significantly different between baseline and 30-minute post-exposure administrations for all display conditions. Finally, Hypothesis 6d, which stated that all potential aftereffects would dissipate within 2 hours post-exposure was neither supported nor unsupported because no aftereffects were present during post-exposure administrations.

The results of no aftereffects observed in this uncoupled motion study are unlike the uncoupled motion findings of Muth (2009), who noted remaining decrements 2 hours after exposure. It is possible that there were symptoms of sickness *after* 60-minutes post-exposure, but limited resources prevented the ability to provide follow-up examinations on participants after their study session.

If finances and time allowed, it would have been beneficial to measure potential aftereffects for a longer period of time post-exposure, as well as to incorporate a control group into the design to determine how individuals not exposed to uncoupled motion performed on the target detection task and performance measures after the task (i.e., APTS, postural stability). It would have been particularly interesting to observe whether GR response time would have increased, decreased, or stayed the same during the 7th administration, which was the post-exposure measure for participants in this study.

Study Limitations

It is important to discuss the limitations involved with this study. This section will explain limitations with data collection and the generalizability of the results.

Several self-reports and paper-and-pencil tests were used for this study. This reveals an issue of common method variance (CMV). CMV is “variance that is attributable to the measurement method rather than to the constructs the measures represent” (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003, p. 879). While some scholars believe that CMV may be exaggerated (Crompton & Wagner, 1994), the consensus among most researchers is that CMV is a problem that must be controlled for (Podsakoff et al., 2003).

There are four common methods that are used to avoid or correct CMV, with the first of which dealing with the use of other sources of information to gather key measures. This unfortunately was impossible for this study, as the only way to obtain information gathered from the SSQ in a timely manner is the SSQ itself. This study attempted to assess sickness in other objective ways to determine if these scores corroborate with sickness: cognitive performance,

visual assessment, and postural stability. The other measures crucial for the study that required self-report were perceived attentional control, MHQ, and NASA-TLX. No other methods were found to be able to take the place of the self-report nature to obtain this information. This method of CMV reduction also suggests collecting data at different points in time. This also was not possible for this study, as the SSQ data needed to be collected at specific points in time during the experiment in order to measure baseline, immediate post, and potential severity 30 and 60 minutes post exposure.

The second method, which deals with procedural remedies, has been stated to reduce the likelihood of CMV and is the method that was incorporated for this study. Specifically, participants were assured that their answers were confidential and anonymous, that there was no right or wrong answer to the questionnaires, and were asked to answer questions as honestly as possible (Crampton & Wagner, 1994). Moreover, the questionnaires were spaced out throughout the experiment while they interchanged other tasks, such as the objective measures of balance and past-pointing, as well as APTS. Additionally, it is believed that fact-based questionnaires could reduce evaluation comprehension, making participants less likely to respond to questions with how they believe a researcher wants them to respond (Podsakoff et al., 2003). This study incorporated fact-based questionnaires, such as the Demographics and Current Health Questionnaires, which asks simple questions on their background (e.g., age, major, height, amount of sleep). The individual items on each of the questionnaires and self-assessment tests were concise and straightforward, which is believed to reduce the likelihood of CMV (2003).

It is important to mention that all participants were told that this study was a target detection task used to uncover performance changes due to display design. They were never

privity to the other displays that were being compared, and it was not until the end of the study that they were informed that sickness was specifically being measured. They simply were told that the SSQ, which was called the “Health Status Checklist” in the study, was being administered because it was protocol when using the motion simulator. Podsakoff and colleagues (2003) also recommend using different scale endpoints for the measures. Fortunately, the MEQ, Attentional Control, and NASA-TLX incorporate this technique, with some questions being scaled in the opposite order as other questions.

The third and fourth methods of reducing CMV include specifying complex relationships that would not likely be a part of participants’ cognitive maps, as well as a post hoc one-factor analysis to check whether variance can be largely attributed to a single factor. If this is found, other procedures can be implemented to control for the variance (Podsakoff et al., 2003). However, it was highly believed that CMV was not an issue for this study and that this was not a necessary step to take.

Although the purpose of this study was to measure whether visual display manipulations can aid in a reduction of the occurrence, severity or duration of motion sickness symptoms in uncoupled motion specifically for crewmembers of manned ground vehicles (MGVs), a motion-based simulator does not perform in the same way as a real vehicle. Specifically, most simulators cannot produce strong or long linear accelerations; instead, the sensation of accelerating quickly is simulated by the cabin tilting backward (which gives the sensation of being pushed into the seat and thus the sensation of moving forward; Wertheim, 1998). This results in the activation of the semi-circular canals, which are normally not activated in the acceleration of a real vehicle on flat land. However, in situations with low motion frequencies, it

is believed that the sensory conflict would be too weak to create an impact on symptoms of sickness due to this issue (Wertheim, 1998).

In this study, the vehicle simulation was driven at a similar speed throughout the route (i.e., 10 to 18 mph), with changes occurring due to driving up and down hills (resulting in a slower or faster speed, respectively) and did not quickly accelerate or decelerate. Further, the environment that was used represents uneven terrain environment, even during the “on-road” portions (which are analogous to unmaintained dirt roads). This increases the comparability of the motion and vestibular response that occurs during real off-road environments, but it cannot be assumed that the vestibular system would react in exactly the same way if it were exposed to the same route in a real MGV.

A different vestibular response also occurs with the simulation of large or long duration turning (Wertheim, 1998). In these instances, the motion platform tilts sideways, which results in the “wrong” activation of the semicircular canals (1998). This type of maneuver could not fully be avoided for this study as the route that was driven was not a straight, direct route. However, there were no turns that were large or in long duration (such as a looping interstate ramp). Once again, although restricting this type of simulator movement reduced different processing of the vestibular system due to the limitations of the simulator, it cannot be relied upon that the vestibular system reacted precisely the same way as it would if it were driving the scenario in an actual MGV.

The design of this study eliminated any potential adaptation and expectation effects on sickness scores because of the short duration of exposure and between-subjects design.

However, as mentioned previously, motion sickness susceptibility is highly individualistic, and severity of symptoms is not solely caused by exposure to motion. One out of the potentially expansive individual difference factors that cannot be controlled, although it impacts variability, is state of mind (Kennedy & Fowlkes, 1992). The amount of stress involved in crewmembers performing potentially life-threatening tasks is not in the slightest bit comparable to young male students who simply signed up for a controlled research study. It is safe to say that these two groups have a drastically different level of motivation to complete the task, which as discussed above, is theorized to play a role on performance during motion sickness. Other characteristics such as visual, cognitive and information-processing capabilities as well as the size of an individual can have different effects on sickness susceptibility and performance.

The major measure of motion sickness (SSQ) depended on subjective reports, and as discussed above, these may not always be accurate. Although postural stability was implemented, the observational method in which it was conducted for this experiment may have resulted in inaccuracy of participants' performance. Nonetheless, extreme caution was used while measuring individual performance, as well as determining whether or not an individual was in a healthy physical state to leave the experimental site.

On top of potential experiences of moderate motion sickness, there was a risk of eyestrain due to the 15 minute task of detecting threats. Asthenopia (e.g., eyestrain-related issues due to accommodation or attempts to accommodate or verge) can cause headache, and sometimes even upset stomach and vomiting (Ebenholtz, 1990). Due to the nature of the study, it may be possible that slight symptoms caused by Asthenopia were mistaken as effects of motion sickness.

The study recruited participants who have had no previous exposure to MGVs, as well as no exposure to simulators within the past week prior to the session in order to reduce the effects of experience and symptoms of simulator and motion sickness. However, the generalizability of this study to Soldiers using MGVs is limited due to these individuals being able to potentially have habituated or adapted to some extent to the specific vestibular stimulation that these vehicles produce. Specifically, although AH Dual Banners had significantly lower severity of motion sickness symptoms after the 15- minute exposure for college students, the same design used for military personnel on much longer exposure times (i.e., several hours or days) may not reduce the symptoms or discomfort that they experience. In other words, their symptoms may be more substantially due to other factors of the environment, such as long-term vibration exposure, and it is possible that the display design itself may be unable to help alleviate these symptoms. As an example, the Sople syndrome, which refers to chronic fatigue that can result due to prolonged exposure to long-term, low-grade motion (Lackner, 1990), was not considered an issue for this study but is a major concern for crewmembers on the move.

Military personnel may be different than the general population in other unexamined ways that can affect their susceptibility or responses to the same conditions proposed in this study. For one, they are generally in better physical shape, but they also may be on strict schedules that inhibit their ability to obtain a full night's rest for several weeks or months. Thus, these physiological differences can result in different responses between the general population and military personnel. Another limitation with the generalizability of this study is due to the fact that the motion platform and participant movements were highly controlled. Not only will kinematics be different for Soldiers based on other types of terrain they can experience, their

movement within the vehicle can be very different depending on the additional tasks they are assigned.

Systems used for target detection do not usually move at a significantly fast speed so as to ensure its safety (e.g., less potential damage, more surreptitious) and accuracy of the reconnaissance task. However, they can average as low as 0.59 mph on paved roads (“Test Operations Procedure,” 2010), which is significantly lower, or can reach a top speed of around 30 mph (Yamauchi & Massey, 2008), which is significantly faster than what was tested in this study (i.e., 8.94 mph). In addition to speed, the type of system and its height can create a different global visual flow than what was tested in this study. Specifically, this study simulated a UGV for the target detection task, but there are smaller systems that are closer to the ground which are also used for surveillance and reconnaissance tasks.

The physical operating orientations of the 15-minute recorded scenario were originally going to be measured for this study. This included the vibration frequency, magnitude, and the translations of sway, surge and heave in order to quantitatively describe the motion participants were exposed to. Unfortunately, funds necessary to obtain this information were depleted after being used to satisfy the other requirements of the study. This will make replicating this study nearly impossible if the same simulator and the same (saved) pre-recorded route are not used.

The target detection task for this experiment was not provocative; that is, the UGV drove and made left and right turns on level, paved roads, so the visual output was minimally shaky. While it is not uncommon for target detection tasks to occur on paved, level conditions (Drexler, Elliot, Johnson, Ratka & Khan, 2012), it is possible for military personnel to view systems and

perform target detection tasks using off-road terrain that consists of different elevations (e.g., hills, slopes), which would completely change the visual output and thus the uncoupled motion experience. Therefore, this is an additional factor that reduces generalizability.

Directions for Future Research

Adaptation has been said to be the surest way to reduce motion sickness (Kennedy & Frank, 1985; Reason & Brand, 1975). However, if that is not a viable option, the results of this study show that screening for perceived attentional control and incorporating an artificial horizon onto the Dual Banners display can mitigate sickness in a 360° uncoupled motion task. However, it is extremely important to repeat that the generalizability of the results of this study is limited. If the prediction of indirect-vision systems completely replacing direct-vision driving does in fact occur, it will be beneficial to incorporate an artificial horizon on screens that are used for target detection and surveillance, but more research must be conducted to determine if the same effects are found after longer motion exposures.

It would be valuable for future research to investigate the same display designs incorporated with much longer motion durations. It also would be beneficial to investigate different speeds and more provocative terrain for both the MGV and UGV. Further, selecting a different population to test would be extremely useful. Specifically, this study focused on only males of a non-Asian descent aging from 21-35, and who either were in or recently graduated from college. Selecting only Soldiers or groups of different ages, gender and/or ethnic backgrounds may have quite different outcomes. It would be valuable to compare results from these studies in order to obtain a more generalized view of the usefulness of specific display

designs and perceived attentional control on the mitigation of motion sickness in uncoupled motion environments. Lastly, but definitely not of least importance, it would be advantageous for future research to more thoroughly investigate the relationship between attentional control and motion sickness.

APPENDIX A: IRB APPROVAL LETTER



University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

**From: UCF Institutional Review Board #1
FWA00000351, IRB00001138**

To: **Stephanie A. Quinn**

Date: **June 25, 2013**

Dear Researcher:

On 6/25/2013, the IRB approved the following human participant research until 6/24/2014 inclusive:

Type of Review: UCF Initial Review Submission Form
Expedited Review Category # 7
Project Title: Effects of Indirect Vision Display Design on Target Detection
and Performance Tasks
Investigator: Stephanie A
Quinn IRB Number: SBE-13-
09454
Funding Agency: US Army Research
Laboratory Grant Title: N/A
Research ID: 1052585

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30 days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at <https://iris.research.ucf.edu>.

If continuing review approval is not granted before the expiration date of 6/24/2014, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a signed and dated copy of the consent form(s).

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual. On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

IRB Coordinator

APPENDIX B : PARTICIPANT RECRUITMENT FORM

Participant Recruitment

Participate in a Military Simulation Experiment!

Purpose of Research: You are invited to participate in a study investigating differences in remotely detecting targets using a robot from within a moving vehicle with different types of displays. You will use a simulated robot to perform reconnaissance missions (search for IED targets) in off-road terrains while you are seated in a simulated moving vehicle.

Discomforts and Risks: There is a slight chance that you may develop mild levels of motion sickness. The symptoms of motion sickness can include sleepiness, dizziness, headache, sweating, or nausea.

Participation Withdrawal: Participation in the study is voluntary. You can withdraw from the study at any time. Even if you come to the research location and start the study, you can change your mind and withdraw from the study at any time without penalty.

Criteria for Participation: You must be a male between the ages of 21-35, in good health, have no history of epilepsy, seizures, or heart conditions. You will not be able to participate in the study if you do not meet these criteria.

Time Commitment: Participation in the study will require approximately 3 to 5 hours of your time.

Compensation: Receive \$15/hr, research credit for your course (if offered by your instructor), or a combination of both.

Location of Research: The session will be conducted on the University of Central Florida's main campus in the Engineering II Building, room #117.

Investigators: Ms. Stephanie Quinn (squinn@ist.ucf.edu), University of Central Florida, Institute for Simulation and Training (UCF IST) and Dr. Rinalducci (Edward.Rinalducci@ucf.edu), Faculty Supervisor, Department of Psychology

Research funded by US Army Research Laboratory (ARL): Human Research Engineering Directorate (HRED) and Simulation and Training Technology Center (STTC)

This study is approved by the University of Central Florida Institutional Review Board

If you are interested in participating, please email your answers to the following questions to Stephanie at TargetDetectionExperiment@gmail.com

1. Please indicate all medication you regularly take:
 - a) NONE
 - b) Sedatives or tranquilizers
 - c) Aspirin, Tylenol, other analgesics
 - d) Anti-histamines
 - e) Decongestants
 - f) Anti-anxiety
 - g) Anti-depressants
 - h) Other (specify):

2. Do you get carsick?

(Circle one) YES NO

3. Do you have difficulty reading in a car or other moving vehicle?

(Circle one) YES NO

4. Do you have a history of and of the following: epilepsy, seizures, or heart problems?

(Circle one) YES NO

5. Have you recently gotten a flu shot?

(Circle one) YES NO If yes, how long ago? _____

6. What is your ethnicity? _____

7. Do you have normal or corrected (glasses/eye contacts) 20/20 Vision?

(Circle one) YES NO If no, what is your visual acuity? _____

8. Do you have any balance problems? _____

9. Are you color blind?

(Circle one) YES NO

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

Extremely___ Very___ Moderately___ Minimally___ Not at all___

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

(Circle one) YES NO

12. Are you in your usual state of fitness? (Circle one) YES NO

If not, please indicate the reason:

APPENDIX C: PARTICIPANT VERIFICATION MESSAGE

Participant Verification Message

Thank you for your interest in our study! You are scheduled to participate on _____ (Date) at _____ (Time) in Room #117 in Engineering II at UCF.

Please read the following notes carefully, as you will not be able to participate if you do not meet the requirements for the day of your study:

1. If you happen be sick the day of the study, please call Stephanie at (407) 572-3525 to reschedule. You will not be able to participate if you are not in your usual state of fitness. This includes head colds, ear or sinus infections.
2. Please refrain from eating a heavy meal 1 hour prior to the start of the study. It is highly recommended to bring a snack (or several) in case you get hungry during the experiment (remember, it can last up to 5 hours). There are also water fountains and vending machines available in the building.
3. Please get adequate sleep the night prior to the study.
4. Refrain from alcohol/drugs for 24 hours prior the experiment. Otherwise, you will not be able to participate.
5. If you smoke or chew tobacco, refrain from doing so at least 10 hours prior to the experiment.
6. Wear comfortable footwear and bring socks-you will be asked to take your shoes off for a portion of the study.
 - a. Dress comfortably. The room is air conditioned and may be cool. It is recommended that you bring a sweater/light jacket if you get cold easily.

Thank you, and I'll see you soon! Email Stephanie if you have any questions prior to your participation at TargetDetectionExperiment@gmail.com.

APPENDIX D: INFORMED CONSENT



Effects of Indirect Vision Display Design on Target Detection and Performance Tasks

Informed Consent

Principal Investigator: Stephanie Quinn, BS, MA

Faculty Supervisor: Edward Rinalducci, Ph.D.

Sponsor: Institute for Simulation and Training, University of Central Florida
Army Research Laboratory

Investigational Site(s): Engineering II Building, room #117
University of Central Florida

Introduction: Researchers at the University of Central Florida (UCF) study many topics. To do this we need the help of people who agree to take part in a research study. You are being invited to take part in a research study which will include about 90 males at the University of Central Florida and central Florida area. You have been asked to take part in this study because you are a student in a psychology class or expressed interest in participating. You must be between 21-35 years of age to be included in the study.

The person conducting this research is Stephanie Quinn of the Army Research Laboratory (ARL) and the Institute for Simulation and Training (IST) at UCF. Because the researcher is a graduate student, she is being guided by Dr. Edward Rinalducci, a UCF faculty supervisor in the Human Factors in Psychology Department.

What you should know about a research study:

Someone will explain this research study to you.

A research study is something you volunteer for.

~~Whether or not you take part is up to you.~~

You should take part in this study only because you want to.



- You can choose not to take part in the research study.
- You can agree to take part now and later change your mind.
- Whatever you decide it will not be held against you.
- Feel free to ask all the questions you want before you decide.

Purpose of the research study: The purpose of this study is to investigate how visual display design affects the performance of several tasks during and after a 15 minute uncoupled motion scenario. Uncoupled motion is a term that is used to describe two asynchronous motions that occur at the same time, such as riding in a car while simultaneously playing a video game. Similar tasks are currently being performed by military members in the Army. The objective of the study is to uncover whether a different arrangement of the visual information on a screen can improve performance during and after an uncoupled motion environment. In this study, you will sit inside a simulator that will imitate the motion of driving through terrain while simultaneously looking at a visual display to view a robot that is driving through a different environment on different terrain. You will be randomly assigned to a condition for you to view the robot's environment in a particular arrangement on the screen. Your participation will enable the researcher to potentially uncover a more optimal visual display design for similar tasks that are performed by military personnel.

What you will be asked to do in the study: A series of questionnaires and short tests will be administered throughout this study, and you will be asked to perform your best for each of the tests. Below is a list along with a brief explanation of each questionnaire or test:

1. The Current Health Questionnaire will be used to identify your current state of fitness. Questions in this survey include whether or not you currently have a cold, your caffeine intake and the number of hours you slept last night. Your answers will determine whether or not you are eligible to participate in the study today.
2. The Motion History Questionnaire asks simple questions regarding previous experiences to motion environments.
3. The Demographic Questionnaire will gather general information such as age, educational background, gaming experience and height, all of which may impact performance to the tasks involved in the study.
4. The Cube Comparison Test is a paper and pencil test that will be used to measure mental rotation, or your ability to identify objects when they are not in their usual orientations.
5. The Hidden Patterns Test is a paper and pencil test that will ask you to identify whether a particular shape is hidden within numerous examples of distracting information.
6. The Attentional Control Survey is a questionnaire that will be used to measure attention focus and shifting.
7. The ~~Morningness-Eveningness~~ Questionnaire will ask questions to determine your circadian rhythm cycles, which are your normal daily fluctuations of alertness and performance.
8. Two cognitive tests will be administered using a laptop computer several times throughout the study: Grammatical Reasoning and Manikin. Grammatical Reasoning

presents a series of questions regarding the order of two letters, A and B, and you will respond either true or false by pressing the letters "T" or "F" on a computer keyboard, respectively. Your performance will be scored based on the number of correctly identified transformations. The Manikin will show a picture of a sailor holding different shapes in his left and right hands. Either his back or torso will be facing the front of the screen for each trial, and you will be asked if a particular shape is in the sailor's left or right hand. Your performance will be scored based on your response time and the number of correct responses. Both of these tests take about 2 minutes each. They will be administered 5 times prior to the uncoupled motion task in order for you to become familiarized with the tasks and up to 6 times after the uncoupled motion task.

9. The NASA-TLX is a questionnaire that will be used to assess your perceived workload after you complete the uncoupled motion task.
10. The Health Status questionnaire will be administered before and several times after the uncoupled motion task to assess how you feel while you perform various tasks.

After you sign this consent form, you will be asked to fill out the Current Health Questionnaire and Motion History Questionnaire. If you are in your usual state of fitness and are eligible to continue, you then you will be instructed on how to perform a balance and past-pointing test. For the balance test (called Sharpened Romberg), you will take your shoes off and stand heel-to-toe with your arms folded in front of you and your eyes closed. You will be instructed to maintain this position for as long as you can or up to 20 seconds (at which time the experimenter will inform you that you can stop standing in this position). The past-pointing test, which will measure your motor skills, will be performed immediately after the Sharpened Romberg. For this test, you will be asked to stand straight, tilt your head slightly back, and keep your eyes closed. Then, you will be asked to use your index finger (on your preferred hand) to touch the tip of your nose. Your performance will be based on the accuracy of your aim as well as body sway while you stand in the proper position. The tests will take less than 1 minute each. You will be asked to perform both tests 10 times in order to familiarize yourself with the tests' body position requirements. After completing the 10 rounds, you will be instructed to put your shoes back on.

You will then be asked to run through 5 rounds of the Grammatical Reasoning and Manikin tests using a laptop computer. Afterwards, you will use the laptop to go through a self-paced Power Point training tutorial that will explain the target detection task that you will perform inside the simulator. These slides will show examples of threats (i.e., armed civilians [insurgents] and armed enemy soldiers) and you will be instructed to detect them by touching the screen immediately upon identifying them while the robot drives its route. The training slides will also show distracters that will be in the environment (i.e., friendly civilians and friendly Soldiers). You will be allowed to take as much time as you feel you need to investigate and compare threats to the distracters and feel comfortable with this task. After the completion of the training slides, you will go through a 1 minute practice route and will be monitored by the experimenter to verify that you understand and can adequately perform the task. You will then go through another round of the balance, past-pointing and cognitive tests and will be offered a short break.

Next, you will be instructed to sit inside the simulator. There will be a screen directly in front of your seat, which will be used for you to perform the target detection task. You will be instructed to fasten your seatbelt and sit in the cab for several minutes in order to feel comfortable inside

the simulator, as well as for you to verify that you can hear the experimenter through the simulator's intercom. You will be free to communicate to the experimenter throughout the task.

When you state that you are ready, the target detection task will start at the same time the simulator will drive through terrain. The simulator speed will be 10 to 15 mph. This uncoupled motion task will last 15 minutes. Immediately after the uncoupled motion task, you will be asked to fill out a Health Status questionnaire and one round of the balance, past-pointing and cognitive tests.

Next, you will start filling out the rest of the questionnaires listed above. In between filling out the questionnaires, the balance, past-pointing and cognitive tests will be administered every 30 minutes until your current performance matches your performance level prior to the uncoupled motion task.

Location: UCF Engineering II Building, room #117

Time required: We expect that you will be in this research study for 3.5 to 5 hours.

Videotaping: You will be videotaped for a portion of this study in order to obtain an accurate measure of your balance and motor skills. If you do not want to be videotaped, you will not be able to be in the study. Please discuss any questions or concerns with the researcher. The video will be erased immediately after your balance and motor tasks have been measured.

Funding for this study: This research study is being paid for by the University of Central Florida's Institute for Simulation and Training and the Army Research Laboratory.

Risks: There is a small risk that people who take part in this study will develop what is ordinarily referred to as simulator sickness. It occurs once in a while to people who are exposed to prolonged continuous testing in simulated environments. Symptoms consist of nausea and a feeling of being light-headed. The risk for this study is minimized as a result of the short duration inside the simulator. If you experience any of the symptoms mentioned, please tell the researcher and remain seated until the symptoms disappear.

The use of a monitor for the target detection task may cause slight eyestrain. However, this potential is not any greater than playing a regular video game for 15 minutes.

The balance and past-pointing tests may make you feel embarrassed if you do not immediately maintain your balance or touch your nose. Please keep in mind that these tests are meant to be a challenge, and this is the reason why 10 rounds of each test will be administered before your performance will be scored.

Benefits: The tasks in this study will enable you to learn more about your balance and aiming skills. We cannot promise any other benefits to you or others from your taking part in this

research. However, possible benefits include becoming more knowledgeable with and receive first-hand experience regarding uncoupled motion tasks that occur in the military.

Compensation or payment: You will receive compensation immediately after the conclusion of participation. Participants may expect to spend between 3.5 and 5 hours in this study, for which you may elect to receive either course credit at a rate of 1 credit per hour, cash payment at a rate of \$15.00 per hour, or a combination of the two. Maximum course credit will be 5 credit hours, while maximum cash credit will be \$75.00.

For military personnel: You should check with your supervisor before accepting payment for participation in this research.

Confidentiality: Your participation in this research is confidential. The data collected will be stored and secured in a locked file cabinet in the Principal Investigator's office. Data with no identifying information (i.e., your name will not be associated with your data) will be encrypted and transferred to a password-protected computer for data analysis. After the data is put in the computer file, any paper copies of the data will be shredded. Publication of the results of this study in a dissertation, journal, or presentation at a meeting will not reveal personally identifiable information. The researcher will protect your data from disclosure to people not connected to this study. However, complete confidentiality cannot be guaranteed because representatives of UCF such as the IRB (Institutional Review Board) are permitted by law to inspect the records obtained in this study to insure compliance with laws and regulations covering experiments using human subjects. In addition, because this research is sponsored by the Department of Defense and the U.S. Army, the Army Human Research Protections Office is eligible to review the research records.

Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints, or think the research has hurt you, talk to Stephanie Quinn, Graduate Student, Applied/Experimental and Human Factors in Psychology, College of Sciences, at (407) 572-3525, squinn@ist.ucf.edu, or Dr. Rinalducci, Faculty Supervisor, Department of Psychology, at (407) 823-5860, or by email at Edward.Rinalducci@ucf.edu.

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901. You may also talk to them for any of the following:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You want to get information or provide input about this research.

Withdrawing from the study: If you decide to leave the study, please inform the investigator so that she can properly terminate whichever activity you are working on. The person in charge of the research study can remove you from the research study without your approval. Possible reasons for removal include not being in your usual state of health upon arrival, alcohol or drug intake, not displaying sufficient ability to perform tasks after training, or displaying signs of simulator sickness. The sponsor can also end the research study early. We will tell you about any new information that may affect your health, welfare or choice to stay in the research.

Your signature below indicates your permission to take part in this research.

DO NOT SIGN THIS FORM AFTER THE IRB EXPIRATION DATE BELOW

Name of participant

Signature of participant

Date

Signature of person obtaining consent

Date

Name of person obtaining consent



APPENDIX E: MOTION HISTORY QUESTIONNAIRE

MOTION HISTORY QUESTIONNAIRE

Developed by Robert S. Kennedy & colleagues under various projects. For additional information contact:
Robert S. Kennedy, RSK Assessments, Inc., 1040 Woodcock Road, Suite 227, Orlando, FL 32803 (407) 894-5090

1. Approximately how many total flight hours do you have (as a pilot, copilot, or navigator)? ____ hours
2. How often would you say you get airsick?
Always ____ Frequently ____ Sometimes ____ Rarely ____ Never ____
3. a) How many total flight simulator hours? ____ Hours
b) How often have you been in a virtual reality device? ____ Times ____ Hours
4. How much experience have you had at sea aboard ships or boats?
Much ____ Some ____ Very Little ____ None ____
5. From your experience at sea, how often would you say you get seasick?
Always ____ Frequently ____ Sometimes ____ Rarely ____ Never ____
6. Have you ever been motion sick under any conditions other than the ones listed so far?
No ____ Yes ____ If so, under what conditions?
7. In general, how susceptible to motion sickness are you?
Extremely ____ Very ____ Moderately ____ Minimally ____ Not at all ____
8. Have you been nauseated for any reason during the past eight weeks?
No ____ Yes ____ If yes, explain.
9. When you were nauseated for any reason (including flu, alcohol, etc.), did you vomit?
Easily ____ Only with difficulty ____ Retch and finally vomited with great difficulty ____
10. If you vomited while experiencing motion sickness, did you:
a) Feel better and remain so?
b) Feel better temporarily, then vomit again?
c) Feel no better, but not vomit again?
d) Other - specify
11. If you were in an experiment where 50% of the subjects get sick, what do you think your chances of getting sick would be?
Almost certainly would ____ Almost Probably would ____ Probably would not ____ Certainly would not ____
12. Would you volunteer for an experiment where you knew that: (Please answer all three)
a) 50% of the subjects did get motion sick? Yes ____ No ____
b) 75% of the subjects did get motion sick? Yes ____ No ____
c) 85% of the subjects did get motion sick? Yes ____ No ____
13. Most people experience slight dizziness (not a result of motion) three to five times a year. The past year you have been dizzy:
More than this ____ The same as ____ Less than ____ Never dizzy ____

Listed below are a number of situations in which some people have reported motion sickness symptoms. In the space provided, check:

- (a) your PREFERENCE for each activity (that is, how much you like to engage in that activity), and
 (b) any SYMPTOM(s) you may have experienced at any time, past or present.



SITUATIONS	PREFERENCE			SYMPTOMS													
	L I K E	N E U T R A L	D I S L I K E	V O M I T E	N A U S E A	S T O M A C H A W A R E N E S S	I N C R E A S E D	A S I N E S S	D I Z Z I N E S S	D R O W N I N E S S	S W E A T I N G	P A L L O R	V E R T I G O *	A W A R E N E S S O F B R E A T H I N G	H E A D A C H E	O T H E R S Y M P T O M S	N O N E
Aircraft																	
Flight simulator																	
Roller Coaster																	
Merry-Go-Round																	
Other carnival devices																	
Automobiles																	
Long train or bus trips																	
Swings																	
Hammocks																	
Gymnastic Apparatus																	
Roller / Ice Skating																	
Elevators																	
Cinerama or Wide-Screen Movies																	
Motorcycles																	

*Stomach awareness refers to a feeling of discomfort that is preliminary to nausea.

**Vertigo is experienced as loss of orientation with respect to vertical upright.

APPENDIX F: DEMOGRAPHICS QUESTIONNAIRE

Demographics Questionnaire

Participant # _____ Age _____ Major _____ Date _____ Gender _____

1. What is the highest level of education you have had?

Less than 4 yrs. of college _____ Completed 4 yrs. of college _____ Other _____

2. When did you use computers in your education? (*Circle all that apply*)

Grade School Jr. High High School
Technical School College Did Not Use

3. Where do you currently use a computer? (*Circle all that apply*)

Home Work Library Other _____ Do Not Use

4. For each of the following questions, circle the response that best describes you.

How often do you:

Use a mouse? Daily, Weekly, Monthly, Once every few months, Rarely, Never

Use a joystick? Daily, Weekly, Monthly, Once every few months, Rarely, Never

Use a touch screen? Daily, Weekly, Monthly, Once every few months, Rarely, Never

Use icon-based programs/software?

Daily, Weekly, Monthly, Once every few months, Rarely, Never

Use programs/software with pull-down menus?

Daily, Weekly, Monthly, Once every few months, Rarely, Never

Use graphics/drawing features in software packages?

Daily, Weekly, Monthly, Once every few months, Rarely, Never

Use E-mail? Daily, Weekly, Monthly, Once every few months, Rarely, Never

Operate a radio controlled vehicle (car, boat, or plane)?

Daily, Weekly, Monthly, Once every few months, Rarely, Never

Play computer/video games?

Daily, Weekly, Monthly, Once every few months, Rarely, Never

5. Which type(s) of computer/video games do you most often play if you play at least once every few months?

6. Which of the following best describes your expertise with computers? (*check \surd one*)

____ Novice

____ Good with one type of software package (such as word processing or slides)

____ Good with several software packages

____ Can program in one language and use several software packages

____ Can program in several languages and use several software packages

7. Are you in your usual state of health physically? YES NO

If NO, please briefly explain:

9. Do you have normal color vision? YES NO

10. Do you have prior military service? YES NO If Yes, how long _____

APPENDIX G: CURRENT HEALTH QUESTIONNAIRE

Current Health Questionnaire

ID # _____

Time & Date _____

Note: If you wish, you may refuse to answer specific items

- 1 Are you in your usual state of fitness? (Circle one) YES NO

If not, please indicate the reason:

2. Have you been ill in the past week? (Circle one) YES NO

If "Yes", please indicate:

a) The nature of the illness (flu, cold, etc.):

b) Severity of the illness: Very ~~Very~~

Mild

Severe

c) Length of illness: ~~Hours~~ Days

d) Major symptoms:

e) Are you fully recovered? YES NO

3. How much alcohol have you consumed during the past 24 hours?

12 oz. cans/bottles of beer ounces wine ounces hard liquor

4. Please indicate all medication you have used in the past 24 hours.

a) NONE

b) Sedatives or tranquilizers

c) Aspirin, Tylenol, other analgesics

d) Anti-histamines

e) Decongestants

f) Other (specify):

5. a) How many hours of sleep did you get last night? _____

- b) Was this amount sufficient? (Circle one) YES NO
- c) How many hours of sleep do you usually obtain? _____
- d) If you could sleep for as long as you wanted in order to receive optimal rest, how many hours do you think this would be? _____
- e) What time did you wake up today? _____
- f) What was your mood upon waking? (e.g., well rested/agitated/tired/stressed, etc.)

- g) Is this the normal mood you usually feel upon waking? YES NO
If "No," please indicate your usual mood upon waking _____
7. Do you smoke cigarettes/chew tobacco? YES NO
If "Yes," please indicate the last time you smoked/chewed _____
8. a) On a scale from 1 to 10, with 1 being none and 10 being extreme, what do you rate your general level of anxiety today? _____
b) Using the same scale, what is your normal level of anxiety on an average day? _____
9. Do you consider yourself to be (please circle): an INTROVERT or EXTROVERT?
10. Have you received a flu shot in the past 6 months? YES NO
If "Yes," please share the date (do the best of your ability) _____
11. Have you been exposed to a motion simulator or virtual environment within the past week? YES NO
12. Please list any other comments regarding your present physical state which might affect your experience today.

APPENDIX H: ATTENTIONAL CONTROL SURVEY

Attentional Control Survey

For each of the following questions, circle the response that best describes you.

- It is very hard for me to concentrate on a difficult task when there are noises around. Almost never, Sometimes, Often, Always
- When I need to concentrate and solve a problem, I have trouble focusing my attention. Almost never, Sometimes, Often, Always
- When I am working hard on something, I still get distracted by events around me. Almost never, Sometimes, Often, Always
- My concentration is good even if there is music in the room around me. Almost never, Sometimes, Often, Always
- When concentrating, I can focus my attention so that I become unaware of what's going on in the room around me. Almost never, Sometimes, Often, Always
- When I am reading or studying, I am easily distracted if there are people talking in the same room. Almost never, Sometimes, Often, Always
- When trying to focus my attention on something, I have difficulty blocking out distracting thoughts. Almost never, Sometimes, Often, Always
- I have a hard time concentrating when I'm excited about something. Almost never, Sometimes, Often, Always
- When concentrating, I ignore feelings of hunger or thirst. Almost never, Sometimes, Often, Always
- I can quickly switch from one task to another. Almost never, Sometimes, Often, Always
- It takes me a while to get really involved in a new task. Almost never, Sometimes, Often, Always
- It is difficult for me to coordinate my attention between the listening and writing required when taking notes during lectures. Almost never, Sometimes, Often, Always
- I can become interested in a new topic very quickly when I need to. Almost never, Sometimes, Often, Always
- It is easy for me to read or write while I'm also talking on the phone. Almost never, Sometimes, Often, Always
- I have trouble carrying on two conversations at once. Almost never, Sometimes, Often, Always
- I have a hard time coming up with new ideas quickly. Almost never, Sometimes, Often, Always
- After being interrupted or distracted, I can easily shift my attention back to what I was doing before. Almost never, Sometimes, Often, Always
- When a distracting thought comes to mind, it is easy for me to shift my attention away from it. Almost never, Sometimes, Often, Always
- It is easy for me to alternate between two different tasks. Almost never, Sometimes, Often, Always
- It is hard for me to break from one way of thinking about something and look at it from another point of view. Almost never, Sometimes, Often, Always

**APPENDIX I: SIMULATOR SICKNESS QUESTIONNAIRE
("HEALTH STATUS CHECKLIST")**

Health Status Checklist

Participant Number: _____ Date: _____

Note: If you wish, you may refuse to answer specific items

Please indicate how you feel **right now** in the following areas, by **circling** the word that applies

Symptom	Symptom Intensity or Amount			
General discomfort	None	Slight	Moderate	Severe
Fatigue	None	Slight	Moderate	Severe
Boredom	None	Slight	Moderate	Severe
Drowsiness	None	Slight	Moderate	Severe
Headache	None	Slight	Moderate	Severe
Eye strain	None	Slight	Moderate	Severe
Difficulty focusing	None	Slight	Moderate	Severe
Salivation increased	None	Slight	Moderate	Severe
Salivation decreased	None	Slight	Moderate	Severe
Sweating	None	Slight	Moderate	Severe
Nausea	None	Slight	Moderate	Severe
Difficulty concentrating	None	Slight	Moderate	Severe
Mental depression	None	Slight	Moderate	Severe
"Fullness of the head"	None	Slight	Moderate	Severe
Blurred Vision	None	Slight	Moderate	Severe
Dizziness with eyes open	None	Slight	Moderate	Severe
Dizziness with eyes closed	None	Slight	Moderate	Severe
*Vertigo	None	Slight	Moderate	Severe
**Visual flashbacks	None	Slight	Moderate	Severe
Faintness	None	Slight	Moderate	Severe
Aware of breathing	None	Slight	Moderate	Severe
***Stomach awareness	None	Slight	Moderate	Severe
Loss of appetite	None	Slight	Moderate	Severe
Increased appetite	None	Slight	Moderate	Severe
Desire to move bowels	None	Slight	Moderate	Severe
Confusion	None	Slight	Moderate	Severe
Burping	None	Slight	Moderate	Severe
Vomiting	None	Slight	Moderate	Severe
Other				

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Visual illusion of movement or false sensations of movement, when not in the simulator, car, or aircraft.

*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea

APPENDIX J: NASA-TLX

NASA TLX Workload Assessment

Instructions: Ratings Scales

I am interested in the “workload” you experienced during this scenario. Workload is something experienced individually by each person. One way to find out about workload is to ask people to describe what they experienced. Workload may be caused by many different factors and we would like you to evaluate them individually. The set of six workload rating factors was developed for you to use in evaluating your experiences during different tasks. Please read them. If you have a question about any of the scales in the table, please ask about it. It is extremely important that they be clear to you.

Definitions

Title	Endpoints	Descriptions
MENTAL DEMAND	Low / High	How much mental and perceptual activity was required (that is, thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low / High	How much physical activity was required (that is, pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low / High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	Poor / Good	How successful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals?
EFFORT	Low / High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	Low / High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Please evaluate workload. Rate the workload on each factor on a scale. Each scale has two end descriptions, and 20 slots (hash marks) between the end descriptions. Place an “x” in the slot (between the hash marks) that you feel most accurately reflects your workload.

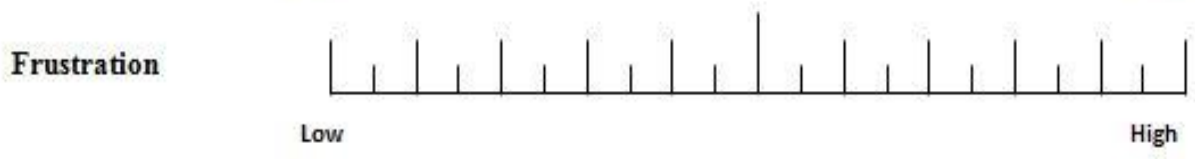
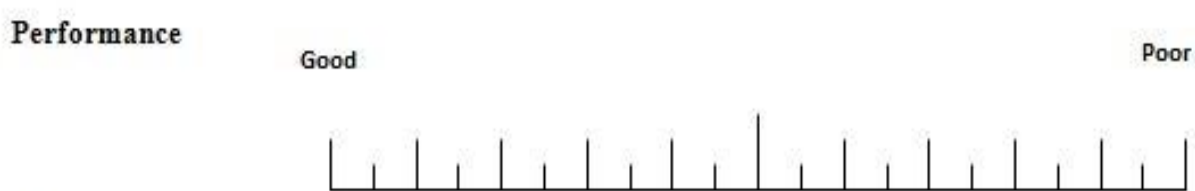
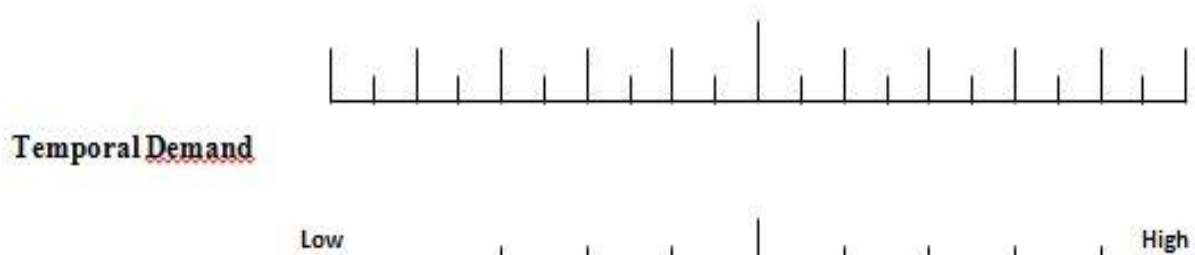
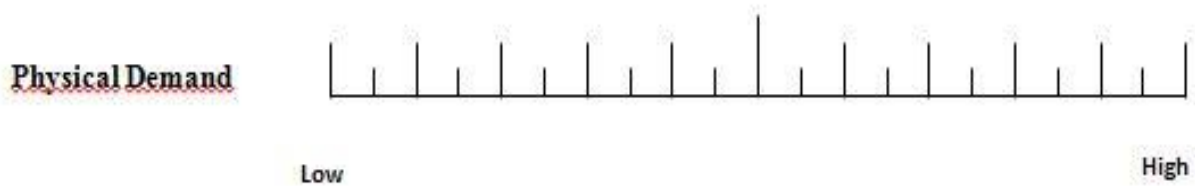
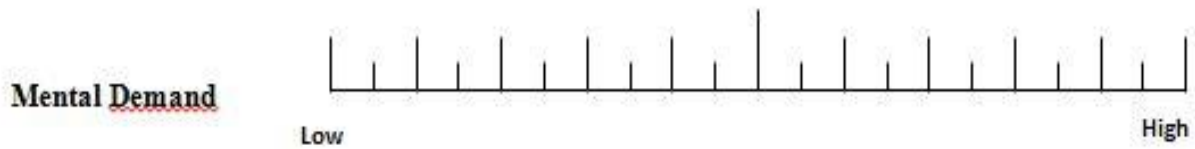
After you have finished the entire series, the pattern of your choices will be used to create a weighted combination of ratings into a summary workload score.

Your workload includes all of the duties involved in your task (e.g., detecting targets, answering SA questions and using display).

Participant ID: _____

TLX Workload Scale

Please rate your workload by putting a mark on each of the six scales at the point which matches your experience.



APPENDIX K: CUBE COMPARISON TEST

Name _____

CUBE COMPARISONS TEST -- S-2 (Rev.)

Wooden blocks such as children play with are often cubical with a different letter, number, or symbol on each of the six faces (top, bottom, four sides). Each problem in this test consists of drawings of pairs of cubes or blocks of this kind. Remember, there is a different design, number, or letter on each face of a given cube or block. Compare the two cubes in each pair below.

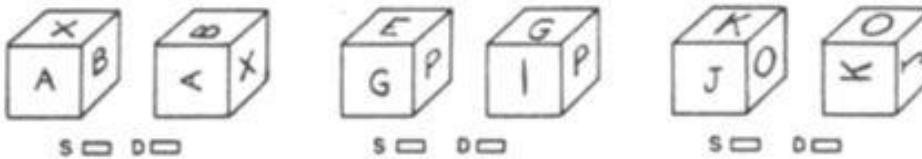


The first pair is marked D because they must be drawings of different cubes. If the left cube is turned so that the A is upright and facing you, the N would be to the left of the A and hidden, not to the right of the A as is shown on the right hand member of the pair. Thus, the drawings must be of different cubes.

The second pair is marked S because they could be drawings of the same cube. That is, if the A is turned on its side the X becomes hidden, the B is now on top, and the C (which was hidden) now appears. Thus the two drawings could be of the same cube.

Note: No letters, numbers, or symbols appear on more than one face of a given cube. Except for that, any letter, number or symbol can be on the hidden faces of a cube.

Work the three examples below.



The first pair immediately above should be marked D because the X cannot be at the peak of the A on the left hand drawing and at the base of the A on the right hand drawing. The second pair is "different" because P has its side next to G on the left hand cube but its top next to G on the right hand cube. The blocks in the third pair are the same, the J and K are just turned on their side, moving the O to the top.

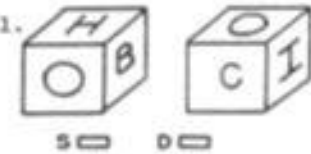
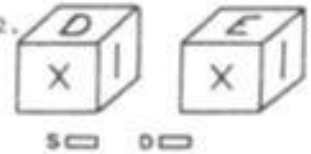
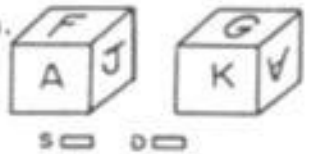
Your score on this test will be the number marked correctly minus the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you have some idea which choice is correct. Work as quickly as you can without sacrificing accuracy.




You will have 3 minutes for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP.




DO NOT TURN THE PAGE UNTIL YOU ARE ASKED TO DO SO.




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Part 1 (3 minutes)




1.  2.  3. 

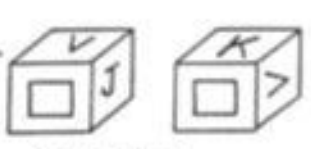

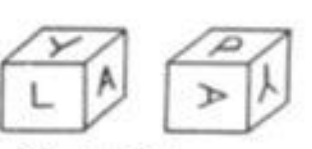
4.  5.  6. 

7.  8.  9. 

10.  11.  12. 

13.  14.  15. 

16.  17.  18. 

19.  20.  21. 

DO NOT GO ON TO THE NEXT PAGE UNTIL ASKED TO DO SO. STOP.

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APPENDIX L: MORNINGNESS-EVENINGNESS QUESTIONNAIRE

Morningness-Eveningness Questionnaire

Instructions:

- Please read each question very carefully before answering.
- Please answer each question as honestly as possible.
- Answer ALL questions.
- Each question should be answered independently of others. Do NOT go back and check your answers.

1. What time would you get up if you were entirely free to plan your day?

5:00 – 6:30 AM
6:30 – 7:45 AM
7:45 – 9:45 AM
9:45 – 11:00 AM
11:00 AM – 12 NOON
12 NOON – 5:00 AM

2. What time would you go to bed if you were entirely free to plan your evening?

8:00 – 9:00 PM
9:00 – 10:15 PM
10:15 PM – 12:30 AM
12:30 – 1:45 AM
1:45 – 3:00 AM
3:00 AM – 8:00 PM

3. If there is a specific time at which you have to get up in the morning, to what extent do you depend on being woken up by an alarm clock?

Not at all dependent
Slightly dependent
Fairly dependent
Very dependent

4. How easy do you find it to get up in the morning (when you are not woken up unexpectedly)?

Not at all easy
Not very easy
Fairly easy
Very easy

5. How alert do you feel during the first half hour after you wake up in the morning?

Not at all alert
Slightly alert
Fairly alert
Very alert

6. How hungry do you feel during the first half-hour after you wake up in the morning?

Not at all hungry
Slightly hungry
Fairly hungry
Very hungry

7. During the first half-hour after you wake up in the morning, how tired do you feel?

Very tired
Fairly tired
Fairly refreshed
Very refreshed

8. If you have no commitments the next day, what time would you go to bed compared to your usual bedtime?

Seldom or never later
Less than one hour later
1-2 hours later
More than two hours later

9. You have decided to engage in some physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 7:00 – 8:00 am. Bearing in mind nothing but your own internal “clock”, how do you think you would perform?

Would be in good form
Would be in reasonable form
Would find it difficult
Would find it very difficult

10. At what time of day do you feel you become tired as a result of need for sleep?

8:00 – 9:00 PM
9:00 – 10:15 PM
10:15 PM – 12:45 AM
12:45 – 2:00 AM
2:00 – 3:00 AM

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last for two hours. You are entirely free to plan your day. Considering only your own internal “clock”, which ONE of the four testing times would you choose?

8:00 AM – 10:00 AM

11:00 AM – 1:00 PM

3:00 PM – 5:00 PM

7:00 PM – 9:00 PM

12. If you got into bed at 11:00 PM, how tired would you be?

Not at all tired

A little tired

Fairly tired

Very tired

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which ONE of the following are you most likely to do?

Will wake up at usual time, but will NOT fall back asleep

Will wake up at usual time and will doze thereafter

Will wake up at usual time but will fall asleep again

Will NOT wake up until later than usual

14. One night you have to remain awake between 4:00 – 6:00 AM in order to carry out a night watch. You have no commitments the next day. Which ONE of the alternatives will suite you best?

Would NOT go to bed until watch was over

Would take a nap before and sleep after

Would take a good sleep before and nap after

Would sleep only before watch

15. You have to do two hours of hard physical work. You are entirely free to plan your day and considering only your own internal “clock” which ONE of the following time would you choose?

8:00 AM – 10:00 AM

11:00 AM – 1:00 PM

3:00 PM – 5:00 PM

7:00 PM – 9:00 PM

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last for two hours. You are entirely free to plan your day. Considering only your own internal “clock”, which ONE of the four testing times would you choose?

8:00 AM – 10:00 AM

11:00 AM – 1:00 PM

3:00 PM – 5:00 PM

7:00 PM – 9:00 PM

12. If you got into bed at 11:00 PM, how tired would you be?

Not at all tired

A little tired

Fairly tired

Very tired

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which ONE of the following are you most likely to do?

Will wake up at usual time, but will NOT fall back asleep

Will wake up at usual time and will doze thereafter

Will wake up at usual time but will fall asleep again

Will NOT wake up until later than usual

14. One night you have to remain awake between 4:00 – 6:00 AM in order to carry out a night watch. You have no commitments the next day. Which ONE of the alternatives will suite you best?

Would NOT go to bed until watch was over

Would take a nap before and sleep after

Would take a good sleep before and nap after

Would sleep only before watch

15. You have to do two hours of hard physical work. You are entirely free to plan your day and considering only your own internal “clock” which ONE of the following time would you choose?

8:00 AM – 10:00 AM

11:00 AM – 1:00 PM

3:00 PM – 5:00 PM

7:00 PM – 9:00 PM

16. You have decided to engage in hard physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 10:00 – 11:00 PM. Bearing in mind nothing else but your own internal “clock” how well do you think you would perform?

Would be in good form
Would be in reasonable form
Would find it difficult
Would find it very difficult

17. Suppose that you can choose your own work hours. Assume that you worked a FIVE hour day (including breaks) and that your job was interesting and paid by results). Which FIVE CONSECUTIVE HOURS would you select?

5 hours starting between 4:00 AM and 8:00 AM
5 hours starting between 8:00 AM and 9:00 AM
5 hours starting between 9:00 AM and 2:00 PM
5 hours starting between 2:00 PM and 5:00 PM
5 hours starting between 5:00 PM and 4:00 AM

18. At what time of the day do you think that you reach your “feeling best” peak?

5:00 – 8:00 AM
8:00 – 10:00 AM
10:00 AM – 5:00 PM
5:00 – 10:00 PM
10:00 PM – 5:00 AM

19. One hears about “morning” and “evening” types of people. Which ONE of these types do you consider yourself to be?

Definitely a “morning” type
Rather more a “morning” than an “evening” type
Rather more an “evening” than a “morning” type
Definitely an “evening” type

APPENDIX M: ADDITIONAL RESULTS

Self-Assessed Sickness across Experimental Conditions

A series of nonparametric Kruskal-Wallis tests were conducted in order to determine if there were any differences in SSQ scores across the four display designs (NoAH Split, NoAH Completely Separated, AH Split, AH Completely Separated) for each of the four SSQ administrations (Baseline, Post-Exposure, 30-min Post Exposure, and 60-min Post-Exposure). These analyses were measured at the p -level of 0.05.

The Kruskal-Wallis test was conducted on the Baseline SSQ data in order to determine if there were differences in subjective sickness scores prior to uncoupled motion exposure. The results revealed that there was no significant difference in the Baseline Total Severity scores across the four display designs, $\chi^2(3, n = 32) = 2.106, p = .551$. There were also no significant differences in the Baseline SSQ subscale scores: Nausea, $\chi^2(3, n = 32) = 2.156, p = .541$; Oculomotor, $\chi^2(3, n = 32) = 0.394, p = .942$; and Disorientation, $(3, n = 32) = 3.000, p = .392$. Table 11 shows the median SSQ Total Severity and subscale scores (i.e., N, O, and D) for the Baseline administration by display design. Table 11 provides the median Total Severity and NOD subscale scores for the Baseline administration across conditions.

Table 8: Median SSQ Scores for Baseline Administration

SSQ Baseline Median Scores	NoAH Display		AH Display	
	Dual Banners	Completely Separated	Dual Banners	Completely Separated
Total Severity	1.87	0	0	0
Nausea	0	0	0	0
Oculomotor	0	0	0	0
Disorientation	0	0	0	0

Post-Exposure Administration

The results of the Kruskal-Wallis test on the Post-Exposure SSQ data revealed a marginally significant difference in Total Severity scores across the four display designs (Gp1, $n = 8$: NoAH Dual Banners, Gp2, $n = 8$: NoAH Completely Separated, Gp3, $n = 8$: AH Dual Banners, Gp4, $n = 8$: AH Completely Separated), $\chi^2(3, n = 32) = 7.598, p = .055$. Medians and Mean Ranks (as seen below in Table 12) were inspected prior to running post-hoc analyses to select a few key groups to compare in order to keep the alpha at a manageable level. Follow-up post-hoc analysis using Mann-Whitney U tests between pairs of conditions revealed a significant difference between NoAH Completely Separated ($Md = 13.090$) and AH Dual Banners ($Md = 1.870$), $U = 6.500, z = -2.731, p = .005, r = .6$. This is a large effect size.

There was also a significant difference in Oculomotor scores, $\chi^2(3, n = 32) = 9.161, p = .027$. Follow-up post-hoc analysis using Mann-Whitney U tests between pairs of conditions revealed a significant difference between NoAH Completely Separated ($Md = 15.160$) and AH Dual Banners ($Md = 0$), $U = 7.000, z = -2.765, p = .006, r = .69$. There was also a marginally significant difference between NoAH Completely separated and AH Completely Separated ($Md = 6.633$), $U = 14.500, z = -1.903, p = .057, r = .476$, which is a moderate effect size.

There were no significant differences across the four display dimensions in Nausea, $\chi^2(3, n = 32) = 5.697, p = .127$, or Disorientation, $\chi^2(3, n = 32) = 6.058, p = .109$. Table 9 lists the means, standard deviations, and median scores of the post-exposure administration between conditions, and Figure 12 shows the mean oculomotor scores between conditions.

Table 9: Medians, Means and Standard Deviations of SSQ Post-Exposure Scores

SSQ Post	NoAH Display				AH Display			
	Dual Banners		Completely Separated		Dual Banners		Completely Separated	
	Median	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)
Total Severity	5.61	10.753 (15.282)	13.09	20.570 (18.213)	1.87	2.338 (2.782)	5.61	7.013 (7.050)
Nausea	0	3.5775 (7.098)	9.54	11.925 (9.875)	0	2.385 (4.416)	0	7.155 (13.249)
Oculomotor	7.58	11.370 (15.692)	15.16	19.898 (16.175)	0	1.895 (3.508)	7.58	6.633 (7.512)
Disorientation	6.96	13.920 (19.686)	13.92	22.620 (30.621)	0	1.740 (4.921)	0	3.48 (6.443)

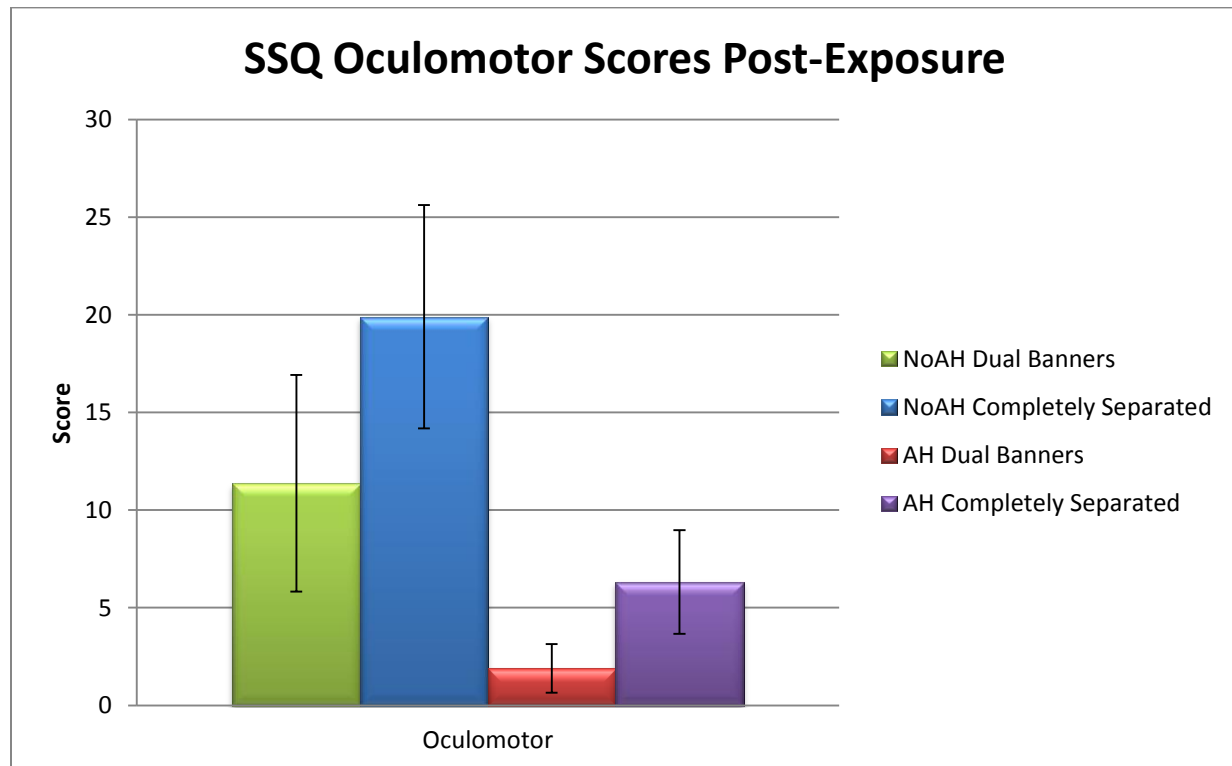


Figure 12: Mean Oculomotor Scores across Conditions Post-Exposure

30-Min Post-Exposure Administration

The results of the Kruskal-Wallis test on the 30-minute Post-Exposure SSQ data revealed no significant differences in the Total Severity scores across the four experimental conditions, $\chi^2(3, n = 32) = 1.504, p = .681$. There were also no significant differences in the 30-minute Post-Exposure subscale scores: Nausea, $\chi^2(3, n = 32) = 1.890, p = .596$; Oculomotor, $\chi^2(3, n = 32) = 1.027, p = .795$; and Disorientation, $\chi^2(3, n = 32) = 2.350, p = .503$. Table 13 below provides the SSQ 30-min Post-Exposure results.

Table 10: Medians, Means and Standard Deviations of SSQ 30-Min Post-Exposure Scores

SSQ 30-min Post-Exposure	NoAH Display				AH Display			
	Dual Banners		Completely Separated		Dual Banners		Completely Separated	
	Median	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)
Total Severity	0	8.415 (16.086)	1.87	5.4125 (8.926)	3.74	3.74 (3.998)	3.74	11.6875 (20.035)
Nausea	0	3.576 (7.098)	0	3.576 (4.937)	0	3.576 (4.937)	4.77	10.733 (13.907)
Oculomotor	0	10.423 (18.977)	0	4.738 (10.672)	3.79	4.738 (5.640)	0	12.318 (23.253)
Disorientation	0	6.960 (14.881)	0	5.22 (10.357)	0	0 (0)	0	5.220 (14.764)

60-Min Post-Exposure Administration

The results of the Kruskal-Wallis test on the 60-minute Post-Exposure SSQ data revealed no significant differences in the Total Severity scores across the four experimental conditions, $\chi^2(3, n = 32) = 2.209, p = .530$. There were also no significant differences in the 60-minute Post-Exposure subscale scores: Nausea, $\chi^2(3, n = 32) = 1.541, p = .673$; Oculomotor, $\chi^2(3, n = 32) =$

2.359, $p = .501$; and Disorientation, $\chi^2 (3, n = 32) = 2.350, p = .474$. Although not significant, the NoAH Dual Banners condition had the highest SSQ Total Severity and subscale scores at the 60-minute mark, which can be seen in Table 14 indicating the median, mean and standard deviation of scores.

Table 11: Medians, Means and Standard Deviations of SSQ 60-Min Post-Exposure Scores

SSQ 60-Minute-Post	NoAH Display				AH Display			
	Dual Banners		Completely Separated		Dual Banners		Completely Separated	
	Median	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)
Total Severity	1.87	11.220 (18.860)	0	1.870 (3.463)	0	2.805 (3.871)	1.87	4.675 (4.794)
Nausea	0	4.770 (7.212)	0	1.193 (3.373)	0	2.385 (4.416)	0	2.385 (4.416)
Oculomotor	3.79	13.265 (21.724)	0	1.895 (3.509)	0	3.790 (5.730)	0	6.633 (7.512)
Disorientation	0	10.440 (20.714)	0	1.740 (4.921)	0	0 (0)	0	3.480 (11.181)

Self-Assessed Sickness across Administrations

A series of nonparametric Friedman tests were conducted in order to determine if there was a change in SSQ scores across the four administrations (Baseline, Post-Exposure, 30-min Post Exposure, and 60-min Post-Exposure) within each of the Display Design conditions (NoAH Split, NoAH Completely Separated, AH Split, and AH Completely Separated). A p -value was set to .05 for these tests. For significant results, post-hoc analyses using Wilcoxon Signed Rank Tests were conducted on the following comparisons: Baseline and Post-Exposure, Baseline and 30-min Post-Exposure, and Post-Exposure and 60-min Post-Exposure. Since post-hoc analysis

involved three comparisons, a Bonferroni correction was applied (resulting in a significance level of $0.05/3 = .017$).

SSQ NoAH Dual Banners Display

For the NoAH Dual Banners condition, the results of the Friedman test indicated that there was no significant difference in SSQ Total Severity scores across the four administrations, $\chi^2(3, n = 8) = 2.389, p = .496$. There also was no significant difference in Nausea, $\chi^2(3, n = 8) = 0.857, p = .836$, or Oculomotor scores, $\chi^2(3, n = 8) = 4.295, p = .231$. There was, however, a significant difference in Disorientation, $\chi^2(3, n = 8) = 9.200, p = .027$.

However, post-hoc analysis with Wilcoxon Signed-Rank Tests and a Bonferroni correction revealed no significant difference between Baseline ($Md = 0$) and Post-Exposure ($Md = 6.96$) scores, $z = -1.857, p = .063$, Baseline and 30-min Post-Exposure ($Md = 0$) scores, $z = -1.414, p = .157$, and Post-Exposure and 60-min Post-Exposure ($Md = 0$) scores, $z = -1.414, p = .157$. Figure 13 below shows NoAH Dual Banners SSQ scores across administrations using mean scores.

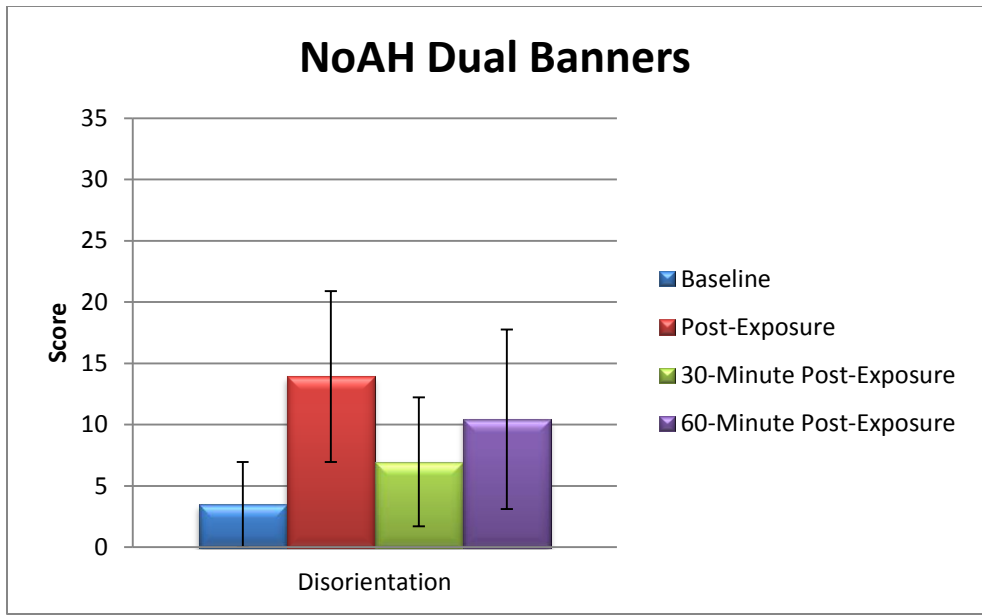


Figure 13: Mean SSQ Disorientation Scores across Administrations for NoAH Dual Banners Condition

NoAH Completely Separated Display

For the NoAH Completely Separated display condition, the results of the Friedman test revealed a significant difference in SSQ Total Severity scores across the four conditions, $\chi^2(3, n = 8) = 15.393, p = .002$. Post-hoc analysis with Wilcoxon Signed-Rank Tests and a Bonferroni correction revealed a marginally significant difference between Baseline ($Md = 0$) and Post-Exposure ($Md = 13.090$) scores $z = -2.371, p = .018$, as well as Post-Exposure and 60-min Post-Exposure ($Md = 0$) scores, $z = -.742, p = .018$. There was no significant difference between Baseline and 30-min Post-Exposure ($Md = 1.870$) scores $z = -.742, p = .458$.

There was also a significant difference in the Nausea subscale, $\chi^2(3, n = 8) = 9.720, p = .021$. However, Post-hoc analysis with Wilcoxon Signed-Rank Tests and a Bonferroni

correction revealed no significant differences between Baseline ($Md = 0$) and Post-Exposure ($Md = 9.540$) scores $z = -1.633, p = .102$, and Baseline and 30-min Post-Exposure ($Md = 0$) scores $z = 0, p = 1.000$. A marginally significant difference between Post-Exposure and 60-min Post-Exposure ($Md = 0$) scores was observed, $z = -2.264, p = .024$.

There was a significant difference in the Oculomotor subscale, $\chi^2(3, n = 8) = 17.471, p = .001$. Post-hoc analysis with Wilcoxon Signed-Rank Tests and a Bonferroni correction revealed a significant difference between Baseline ($Md = 0$) and Post-Exposure ($Md = 15.160$) scores, $z = -2.388, p = .017$, and a marginally significant difference between Post-Exposure and 60-min Post-Exposure ($Md = 0$) scores, $z = -2.375, p = .018$. There were no significant differences between Baseline and 30-min Post-Exposure ($Md = 0$) scores, $z = -0.816, p = .414$.

There was also a significant difference in the Disorientation subscale, $\chi^2(3, n = 8) = 10.750, p = .013$. However, Post-hoc analysis with Wilcoxon Signed-Rank Tests and a Bonferroni correction revealed no significant differences between Baseline ($Md = 0$) and Post-Exposure ($Md = 13.920$) scores $z = -2.060, p = .039$, Baseline and 30-min Post-Exposure ($Md = 0$) scores $z = -1.342, p = .180$, and Post-Exposure and 60-min Post-Exposure ($Md = 0$) scores, $z = -2.060, p = .039$. Figure 14 below shows the mean SSQ scores across administrations for this condition.

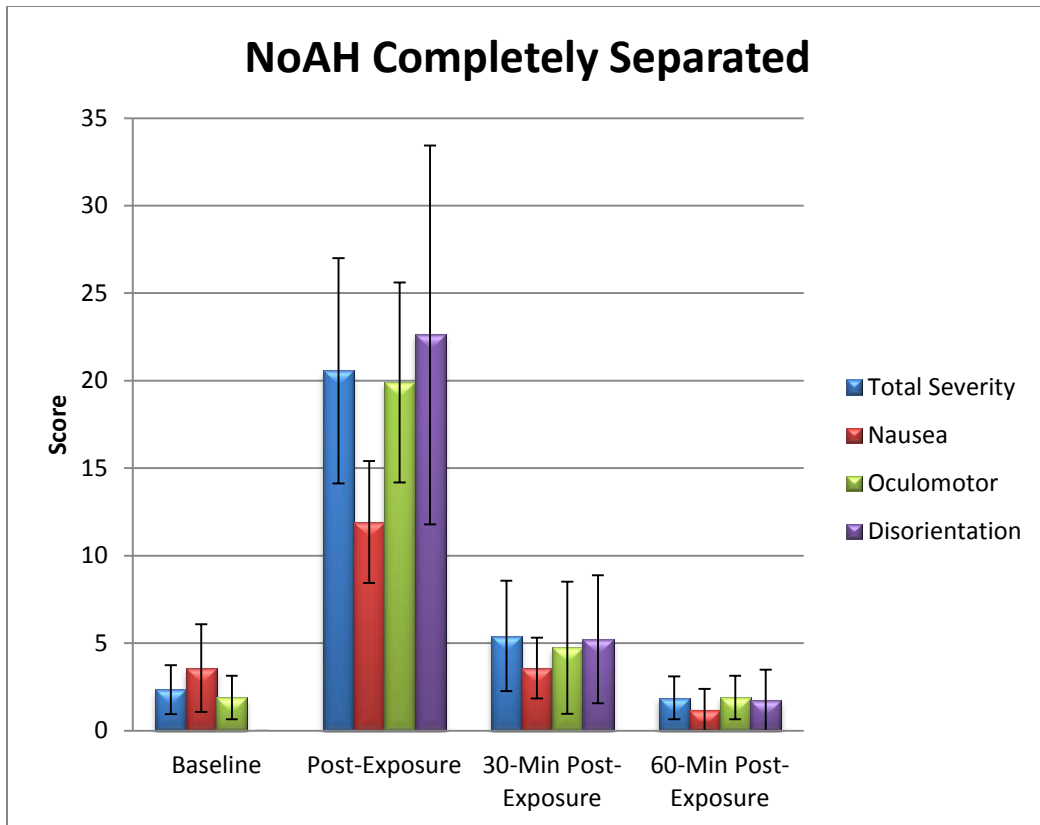


Figure 14: Mean SSQ Scores across Administrations for NoAH Completely Separated Condition

AH Dual Banners Display

For the AH Split display condition, the results of the Friedman test revealed no significant difference in SSQ Total Severity scores across the four administrations, $\chi^2(3, n = 8) = 1.923, p = .589$. There was no significant difference in Nausea, $\chi^2(3, n = 8) = 4.000, p = .261$, Oculomotor, $\chi^2(3, n = 8) = 1.941, p = .585$, or Disorientation subscales, $\chi^2(3, n = 8) = 3.000, p = .392$.

AH Completely Separated Display

For the AH Completely Separated display condition, the results of the Friedman test revealed a significant difference in SSQ Total Severity scores across the four conditions, $\chi^2(3, n = 8) = 8.809, p = .032$. However, Post-hoc analysis with Wilcoxon Signed-Rank Tests and a Bonferroni correction revealed no significant differences between Baseline ($Md = 0$) and Post-Exposure ($Md = 5.610$) scores $z = -2.032, p = .042$, Baseline and 30-min Post-Exposure ($Md = 3.740$) scores $z = -2.060, p = .039$, and Post-Exposure and 60-min Post-Exposure ($Md = 3.740$) scores, $z = -0.921, p = .357$.

Further, there was no significant difference in Nausea, $\chi^2(3, n = 8) = 5.438, p = .142$, Oculomotor, $\chi^2(3, n = 8) = 2.500, p = .475$, or Disorientation subscales, $\chi^2(3, n = 8) = 2.429, p = .488$. Figure 15 below shows the mean SSQ Total Severity scores across administrations for this condition.

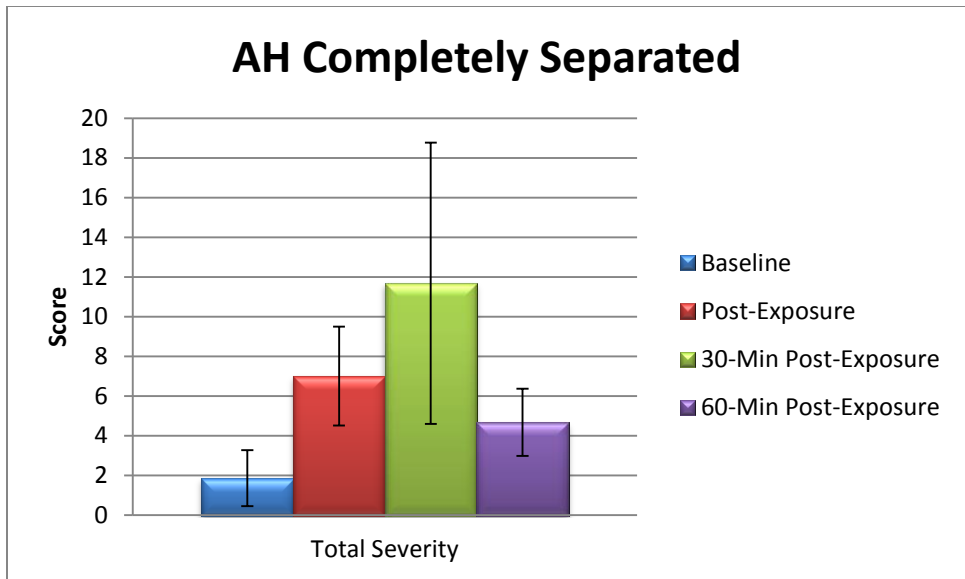


Figure 15: Mean SSQ Total Severity Scores across Administrations for AH Completely Separated Condition

Postural Stability

Nonparametric Kruskal-Wallis tests were conducted in order to determine if there were any differences in postural stability (as measured by the Sharpened Romberg) across the four display design conditions (NoAH Dual Banners, NoAH Completely Separated, AH Dual Banners, AH Completely Separated) at 30-min Post-Exposure and 60-min Post-Exposure administrations.

There were also no significant differences across the four display designs at 30-minute Post-Exposure, $\chi^2 (3, n = 32) = 1.501, p = .682$, or 60-minute Post-Exposure, $\chi^2 (3, n = 32) = 1.838, p = .607$. The means and standard deviations for each administration are listed above in the Results section in Table 7.

Perceived Workload

The weighted means and standard deviations for each of the NASA-TLX workload measures are provided below in Table 10.

Table 12: Total Perceived Workload across Conditions

NASA-TLX Measures	Dual Banners		Completely Separated	
	NoAH	AH	NoAH	AH
Total Workload	58.167 (17.80)	50.71 (8.11)	62.75 (59.04)	59.04 (8.79)
Mental Demand	73.75 (18.66)	63.13 (17.1)	75.63 (4.17)	76.88 (19.99)
Physical Demand	7.50 (5.35)	13.75 (9.91)	22.50 (11.65)	11.25 (5.82)
Temporal Demand	56.88 (31.16)	35.63 (11.78)	46.88 (27.12)	33.13 (9.23)
Performance	45.63 (20.95)	33.13 (7.04)	55.00 (20.87)	45.00 (18.90)
Effort	67.50 (23.45)	71.88 (9.23)	71.88 (8.84)	60.63 (23.97)
Frustration	48.75 (28.25)	33.75 (21.17)	44.38 (20.26)	53.75 (26.02)

A two-way between groups ANCOVA was conducted on the NASA-TLX data (i.e., Total Workload and the six subscales) with perceived attentional control and mental rotation ability as covariates. This was conducted to determine the impact of Display Type (Dual Banners vs. Completely Separated) and Artificial Horizon (NoAH vs. AH) across NASA-TLX scores. The subsections below provide the results for Total Workload and each of the subscales (Mental Workload, Physical Demand, Temporal Demand, Performance, Effort and Frustration).

An ANCOVA on Total Workload scores found no main effect for Display Type, $F(1, 26) = 3.285, p = .081$. Artificial Horizon was also not significant, $F(1, 26) = 1.233, p = .277$. Although not statistically significant, Total Workload was higher in the Completely Separated display conditions ($M = 60.90, SD = 7.12$) when compared to the Dual Banners conditions ($M = 54.44, SD = 13.91$).

An ANCOVA on Mental Demand found no significant main effect for Display Type, $F(1, 26) = 2.650, p = .122$. Artificial Horizon was also not significant, $F(1, 26) = 0.372, p = .547$.

An ANCOVA on Physical Demand found no interaction of Display Type and Artificial Horizon, $F(1, 26) = 0.037, p = .849$. The main effect for Display Type was significant, $F(1, 26) = 5.083, p = .033, \eta^2_p = .164$, with individuals in Dual Banners conditions ($M = 10.63, SD = 8.34$) perceiving significantly lower physical demand than those in Completely Separated conditions ($M = 16.88, SD = 10.63$). Artificial Horizon was not significant, $F(1, 26) = 0.231, p = .635$. Figure 16 below displays the physical demand mean and standard error scores across conditions

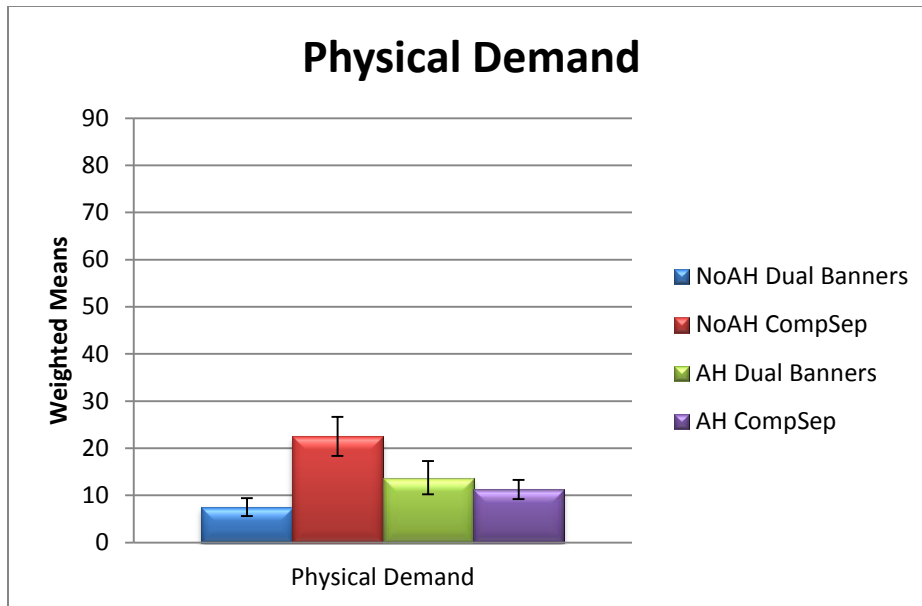


Figure 16: Physical Demand Means across Conditions

An ANCOVA on Temporal Demand found no interaction of Display Type and Artificial Horizon, $F(1, 26) = 0.037, p = .849$. There was no main effect for Display Type, $F(1, 26) = .371, p = .548$. The main effect of Artificial Horizon was significant, $F(1, 26) = 4.625, p = .041$, with those without an artificial horizon perceiving a higher temporal demand ($M = 51.88, SD = 28.69$) than those with an artificial horizon condition ($M = 34.38, SD = 10.30$). However, the effect size was small, $\eta^2_p = .151$). Figure 17 below shows the Temporal Demand mean and standard error scores across conditions.

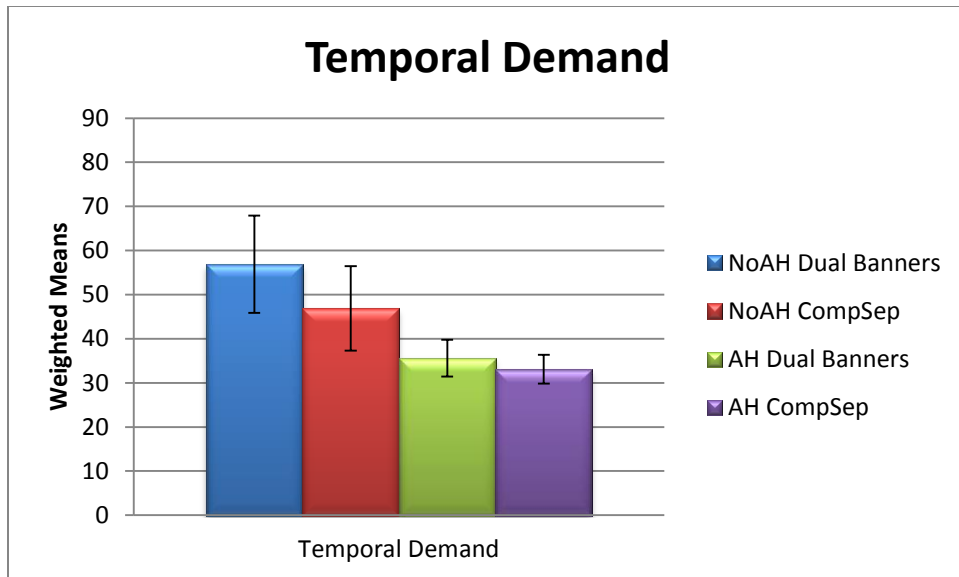


Figure 17: Temporal Demand Means across Conditions

An ANCOVA on Performance found no main effect for Display Type, $F(1, 26) = 2.308$, $p = .141$, or Artificial Horizon, $F(1, 26) = 2.937$, $p = .098$. An ANCOVA on Effort scores found no main effect for Display Type, $F(1, 26) = 0.108$, $p = .745$, or Artificial Horizon, $F(1, 26) = 0.022$, $p = .885$. Lastly, an ANCOVA on Frustration also found no main effect for Display Type, $F(1, 26) = 0.634$, $p = .433$, or Artificial Horizon, $F(1, 26) = 0.066$, $p = .799$.

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