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THESIS

THE EFFECTS OF SLEEP ON THE PERFORMANCE OF MARINES FOLLOWING EXPOSURE TO WATERBORNE MOTION

by

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March 2013

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The transport of Marines and their equipment over potentially rough seas occur often as part of assault landings. Seasickness can be disabling to troops taking part in assault landings. Significant gaps exist in our knowledge and understanding of the effects of waterborne motion on the combat performance of infantry personnel embarked aboard amphibious vehicles.

This study was part of the Habitability Assessment Test (HAT) and was driven by a need to determine whether sleep is related to the performance of Marines embarked on amphibious vehicles. Understanding the effect of sleep on performance enables the separation of sleep as a covariate in the evaluation of how motion affects Marines embarked on amphibious vehicles. The sleep and performance of 61 participants was observed during the course of a three-week testing period with multiple lengths of motion exposure. Performance measures were taken on various tests including marksmanship, obstacle course, and cognitive testing; in addition a subjective questionnaire on motion sickness was administered. This study shows that sleep has a definite association with performance. Furthermore, this study uncovered a circadian effect that may have influenced the overall results of the HAT study.

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THE EFFECTS OF SLEEP ON THE PERFORMANCE OF MARINES FOLLOWING EXPOSURE TO WATERBORNE MOTION

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ABSTRACT

The transport of Marines and their equipment over potentially rough seas occur often as part of assault landings. Seasickness can be disabling to troops taking part in assault landings. Significant gaps exist in our knowledge and understanding of the effects of waterborne motion on the combat performance of infantry personnel embarked aboard amphibious vehicles.

This study was part of the Habitability Assessment Test (HAT) and was driven by a need to determine whether sleep is related to the performance of Marines embarked on amphibious vehicles. Understanding the effect of sleep on performance enables the separation of sleep as a covariate in the evaluation of how motion affects Marines embarked on amphibious vehicles. The sleep and performance of 61 participants was observed during the course of a three-week testing period with multiple lengths of motion exposure. Performance measures were taken on various tests including marksmanship, obstacle course, and cognitive testing; in addition a subjective questionnaire on motion sickness was administered. This study shows that sleep has a definite association with performance. Furthermore, this study uncovered a circadian effect that may have influenced the overall results of the HAT study.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAV	Amphibious Assault Vehicle
AAV-7A1 RAM-RS	Assault Amphibian Vehicle Reliability, Availability, Maintainability/Rebuild to Standard
AMTRAC	Amphibious Tractor
ANAM	Automated Neuropsychological Assessment Metric
ANOVA	Analysis of Variance
AVTB	Amphibious Vehicle Test Branch
CD&I	Combat Development and Integration
DOD	Department of Defense
ECS	Environmental Control System
EFV	Expeditionary Fighting Vehicle
ESS	Epworth Sleepiness Scale
FAST	Fatigue Avoidance Scheduling Tool
HAT	Habitability Assessment Test
HSD	Honestly Significant Differences
IRB	Institutional Review Board
LMTS	Laser Marksmanship Training System
LVT	Landing Vehicle, Tracked
MCLEAP	Marine Corps Load Effects Assessment Program
M-E	Morningness-Eveningness
MeanRT	Mean Response Time
MEQ	Morningness-Eveningness Questionnaire
mm	Millimeters
MOF	Military Operational Field
MOS	Military Occupational Specialty
mph	Miles per Hour
MRI	Mean Radius of Impact
MSAQ	Motion Sickness Assessment Questionnaire

msec	Millisecond
MSI	Motion Sickness Index
MSSQ	Motion Sickness Susceptibility Questionnaire
NM	Nautical Mile
NMph	Nautical Miles per Hour
NREM	Non-Rapid Eye Movement
PSQI	Pittsburgh Sleep Quality Index
REM	Rapid Eye Movement
RFID	Radio-Frequency Identification
SAFTE	Sleep, Activity, Fatigue, and Task Effectiveness
SDD-2	System Design and Demonstration-2
STE	Special Test Evolution
SWH	Significant Wave Height
USMC	United States Marine Corps
WAM	Wrist Activity Monitor

EXECUTIVE SUMMARY

Power projection is the cornerstone for the United States' twenty-first century Navy. The United States Navy has two means of projecting power overseas: air power and sea power. The most common naval contributions to power projection are strikes and amphibious assaults (Naval Operations Concept, 2010).

> Power projection, in its broadest sense, is the ability of a nation to apply all or some of its elements of national power—political, economic, informational, or military—to rapidly and effectively deploy and sustain forces in and from multiple dispersed locations to respond to crises, to contribute to deterrence, and to enhance regional stability. (Naval Operations Concept, 2010, p. 60)

Assault landings involve the transport of Marines and their equipment in small craft over potentially rough seas. Anecdotal reports during amphibious operations and training exercises have shown how seasickness can be disabling to troops taking part in such landings (Hill & Guest, 1945). Significant gaps exist in our knowledge and understanding of the effects of waterborne motion on the combat performance of infantry personnel embarked aboard amphibious vehicles.

The purpose of the Habitability Assessment Test (HAT) was to study the combat performance of Marines after their exposure to waterborne motion. This research was part of the HAT and was driven by a need to determine whether sleep is related to the performance of Marines embarked on amphibious vehicles.

In order to evaluate the effects of sleep and motion on the combat performance of Marines embarked on amphibious vehicles, the sleep and performance of 61 participants was observed over the course of a three-week testing period, with varying lengths of exposure to motion. Actigraphy data collected by the Wrist Activity Monitors (WAMs) during the training and testing period were analyzed using Respironics software as well as the Fatigue Avoidance Scheduling Tool (FAST), which uses the Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model. Performance measures were taken on

various tests including marksmanship, an obstacle course, and cognitive testing, as well as a subjective questionnaire on motion sickness.

This study supports previous findings that sleep has a definite effect on performance. Furthermore, this study uncovered a circadian effect that may have influenced the results. The study found that, in addition to the performance differences found due to circadian effect, there was degradation in performance experienced among the participants after exposure to waterborne motion.

Amphibious operations continue to be one of the main naval contributions to power projection. As nations' coastal defense capabilities increase, the minimum launch distance for amphibious vehicles is extended, thus causing Marines being transported in amphibious vehicles to be exposed to various sea states for longer periods of time. Future studies should be conducted to further investigate the effects of sleep and motion on combat performance.

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I. INTRODUCTION

> The 21st century sets the stage for tremendous increases in naval precision, reach, and connectivity, ushering in a new era of joint operational effectiveness. Innovative concepts and technologies will integrate sea, land, air, space, and cyberspace to a greater extent than ever before. In this unified battlespace, the sea will provide a vast maneuver area from which to project direct and decisive power around the globe. (Clark, 2002, p. 1)

A. BACKGROUND

> Power projection, in its broadest sense, is the ability of a nation to apply all or some of its elements of national power—political, economic, informational, or military—to rapidly and effectively deploy and sustain forces in and from multiple dispersed locations to respond to crises, to contribute to deterrence, and to enhance regional stability. (Naval Operations Concept, 2010, p. 60)

Power projection is the cornerstone for the United States' twenty-first century Navy. The United States Navy has two means of projecting power overseas: air power and sea power. The most common naval contributions to power projection are strikes and amphibious assaults (Naval Operations Concept, 2010). Although assault is the primary impetus for amphibious capabilities, their utility in conducting raids, demonstrations, withdrawals, and amphibious support to other operations is immense.

The Amphibious Assault Vehicle (AAV-7A1, first known as LVT-7) was initially introduced in 1972, and upgraded in 1982. This vehicle was designed as a troop transport vehicle, although it did not entirely focus on troop comfort. The Expeditionary Fighting Vehicle (EFV, formerly known as the Advanced Amphibious Assault Vehicle) was designed to replace the AAV-7A1. The EFV took on a more human-centered design, aimed at enhancing performance and increasing safety and user satisfaction. The cancellation of the EFV in January 2011 left the Marine Corps with the AAV or "AMTRAC," short for its original designation of “amphibious tractor,” as its primary amphibious assault vehicle. The AMTRAC has a maximum swim speed of 8.2 miles per hour (mph) (7.1 nautical miles per hour [NMph]) and the ability to sustain operations at sea for seven hours. In his appearance before the House of Representatives Armed Services Committee, Lieutenant General George Flynn, Deputy Commandant of Combat Development and Integration, stated that the minimum launch distance for amphibious vehicles is 12 nautical miles (NM) (Amphibious Operations, 2011). This distance is due to the increase in efforts of coastal nations to deny access to their borders. The coastal defense capabilities of these nations pose a substantial risk to both the AAV and the ships deploying them. This increased minimum launch distance will impose a transit time of over an hour for the current AAV for 12NM, which is only the minimum.

Assault landings require the transport of Marines and equipment in small craft over potentially rough seas. Previous operational experience and training has shown how seasickness can be disabling to troops taking part in such landings (Hill & Guest, 1945). Our understanding of the causes of motion sickness is still limited due to the vagueness of symptoms and the difficulty of their measurement (Keshavarz & Hecht, 2011). The 12-NM launch distance drives the need for understanding and quantifying the degradation in performance of infantry personnel embarked aboard amphibious vehicles.

B. OBJECTIVE

> We must maintain our military’s conventional superiority, while enhancing its capacity to defeat asymmetric threats. Our diplomacy and development capabilities must be modernized, and our civilian expeditionary capacity strengthened, to support the full breadth of our priorities. (White House, 2010, p. 5)

The United States Marine Corps (USMC) Combat Development and Integration (CD&I) Division seeks to revise and update the requirements for amphibious assault capabilities. Significant gaps exist in our knowledge and understanding about the effects of waterborne motion on the combat performance of infantry personnel embarked aboard amphibious vehicles. The Habitability Assessment Test (HAT) sought to provide more information on this topic by using an operationally relevant investigation into the performance of embarked infantry after a water transit aboard an amphibious vehicle. This study seeks to determine if the quality and quantity of an individual's sleep is related to combat performance after they have been exposed to waterborne motion on amphibious vehicles. This research is driven by a need to determine whether sleep is related to the performance of Marines embarked on amphibious vehicles. Understanding the effect of sleep on performance will enable the separation of sleep as a covariate in the evaluation of how motion affects Marines embarked on amphibious vehicles.

C. SCOPE, LIMITATIONS, AND ASSUMPTIONS

Participants in the HAT were active duty Marines between the ranks of Lance Corporal (E-3) and Sergeant (E-5), pooled from various commands. Sixty-one of the sixty-four Marines who volunteered for the study completed the required study training and were considered study participants. The majority of Marines in this study held Military Operational Specialties (MOSs) in infantry Military Operational Fields (MOFs) and were between the ages of 18 and 28. The study's participants may not be representative of the entire Marine Corps.

The study was conducted as a shore-to-shore transit. Shore-to-shore transit is not a normal operational situation since personnel required to conduct amphibious landings are typically onboard a naval vessel for an extended period before conducting an amphibious operation.

Testing for this study ran for five days. Data collection, for the test of record and the two special test evolutions (STEs), was preceded by five days devoted to training the study participants and the data collection team. Participants wore a Wrist Activity Monitor (WAM) and kept a sleep/activity log during the training period and throughout the entire study. Many of the study participants were combat veterans who had recently returned from either Iraq or Afghanistan. All participants were presumed healthy, with no apparent sleep disorders.

This study was a field study; therefore, sleep quantities and qualities derived from the actigrams, which were verified through sleep logs, are assumed to reflect the participants' actual sleep. Since this study was not a laboratory study, some of the sleep episodes that seem low are accepted as accurate, keeping in mind that these values would be unacceptable in a laboratory setting.

Since each participant had to run the test course individually, and due to limited testing equipment, time, and personnel, there were some delays in getting each participant through the test battery. There is some concern that participants going through the test battery at the end of the squad may have displayed different reactions than those going through immediately upon debarking the vehicles, since the former have additional time to recover. Due to training range restrictions on Camp Pendleton, there was no live firing during this test. The Laser Marksmanship Training System (LMTS) was utilized in lieu of live fire.

Due to changes in test requirements and the limitations of vehicle operating requirements, the test course was set up at two different locations, Pelican Point and Red Beach. Attempts were made to ensure that the courses were identical, yet several differences existed, mainly due to the difference in terrain between the two areas.

Treatments were conducted in waters surrounding the Camp Pendleton area in the month of August, a time at which seas have historically been calm. Therefore, the environmental conditions experienced during the conduct of this test must be taken into account when analyzing and reporting the results of the tests. The average Significant Wave Height (SWH) experienced throughout the testing resulted in a low Motion Sickness Index (MSI) throughout all test events. The lack of environmental extremes greatly reduced the ability to identify statistically and substantively significant differences.

Two types of test vehicles - EFVs and AAVs - were used for this study. Two EFVs and two AAVs were used as treatment platforms. Vehicles PV3 and PV4 are EFV System Design and Demonstration-2 (SDD-2) prototypes in the late stages of Developmental Test and Evaluation. Vehicles RAM1 and GATOR1 are Assault Amphibian Vehicle Reliability, Availability, Maintainability/Rebuild to Standard (AAVP7A1 RAM-RS) fielded vehicles, representative of those currently in use by the USMC.

D. THESIS ORGANIZATION

Chapter I describes the background of amphibious operations and its importance to the U.S. Navy. Chapter II contains a literature review of sleep, fatigue, sopite syndrome, actigraphy and an overview of the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model and the Fatigue Avoidance Scheduling Tool (FAST). Chapter III describes the methodology and data collection equipment and techniques used throughout the study. Chapter IV contains the analysis conducted. The discussion and recommendations on this study are described in Chapter V.

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II. LITERATURE REVIEW

A. OVERVIEW OF SLEEP

1. Sleep Requirements/Sleep Architecture

> Sleep is not a vast wasteland of inactivity. The sleeping brain is highly active at various times during the night, performing numerous physiological, neurological, and biochemical housekeeping tasks. These tasks are essential for everything from maintaining life itself to reorganizing and enhancing thinking and memory. (Maas, 2001, p. 6)

In normal people, sleep occurs in 90-minute cycles which span an eight-hour sleep period. The human brain shows two types of sleep over the course of this eight hour period: rapid eye movement (REM) and non-rapid eye movement (NREM). NREM is divided into five sleep stages starting with wakefulness, Stage 0, and Stages 1–4, which represent sleep which is increasingly deeper as it progresses through the stages.

During stage 1 sleep, an individual transitions from full wakefulness through drowsiness, and ultimately reaching real sleep. During this sleep stage, the individual often drifts in and out of awareness. Stage 2 is known as the first true sleep state; individuals during this sleep stage are easily aroused from sleep and therefore is best known as light sleep. Stages 3 and 4 make up the deep, slow-wave sleep, with Stage 3 being moderately deep sleep and Stage 4 being known as very deep sleep. During Stage 4 sleep, not only are people hard to awaken, but if you do prod them into consciousness, they may be disoriented for a few minutes (Coren, 1996). Figure 1 depicts typical sleep stages over an eight-hour sleep period. All stages depicted in Figure 1 are crucial for, and uniquely contribute to, the human body's restorative process. Any disruptions in sleep experienced by an individual that causes that individual to fully awaken diminishes the benefit of the sleep episode (Miller, Matsangas, & Shattuck, 2007).

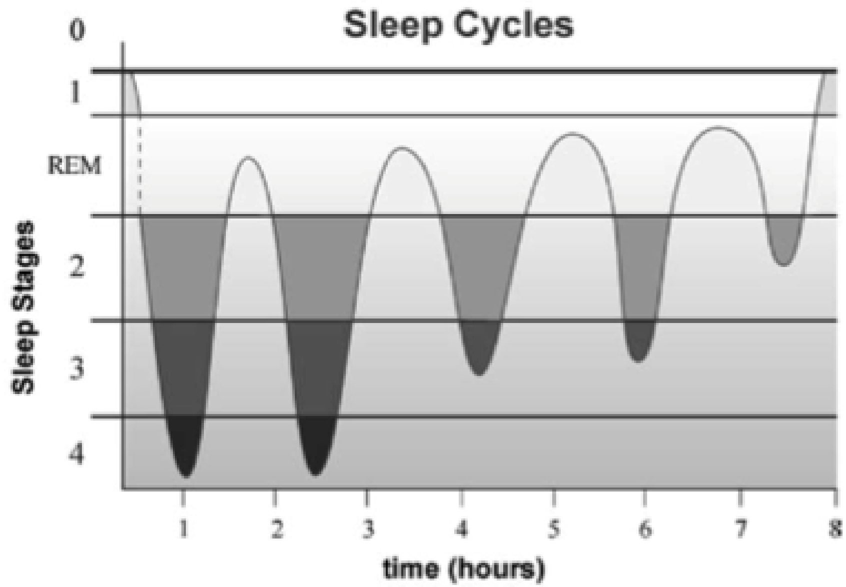

Figure 1. Depiction of Sleep Stages Over an Eight-Hour Period (From Miller et al., 2007).

Sleep and sleep deprivation have been studied in depth for the past several decades, yet sleep remains a mysterious, but vital, requirement for the sustainment of life. In his book, *Sleep and Wakefulness*, Nathaniel Kleitman (1939), one of the first scientists to study sleep, described it as simply "a periodic, temporary cessation or interruption of the waking state, the latter being the prevalent mode of existence for the healthy adult" (Coren, 1996, p. 13). Horne (1988, p. 6) defines sleep as "the rest and recovery from the wear and tear of wakefulness." Either way, sleep is described as a necessary function of human life: a function that, in fact, affects human performance. In order to achieve full cognitive functioning healthy adults require approximately eight hours of sleep each night (Anch, Browman, Mitler, & Walsh, 1988). There is, however, considerable variability among individual sleep requirements, in which some people require more while others require less than eight hours of sleep per night (Van Dongen & Dinges, 2000). Figure 2 illustrates the changes in sleep patterns over a typical lifespan.

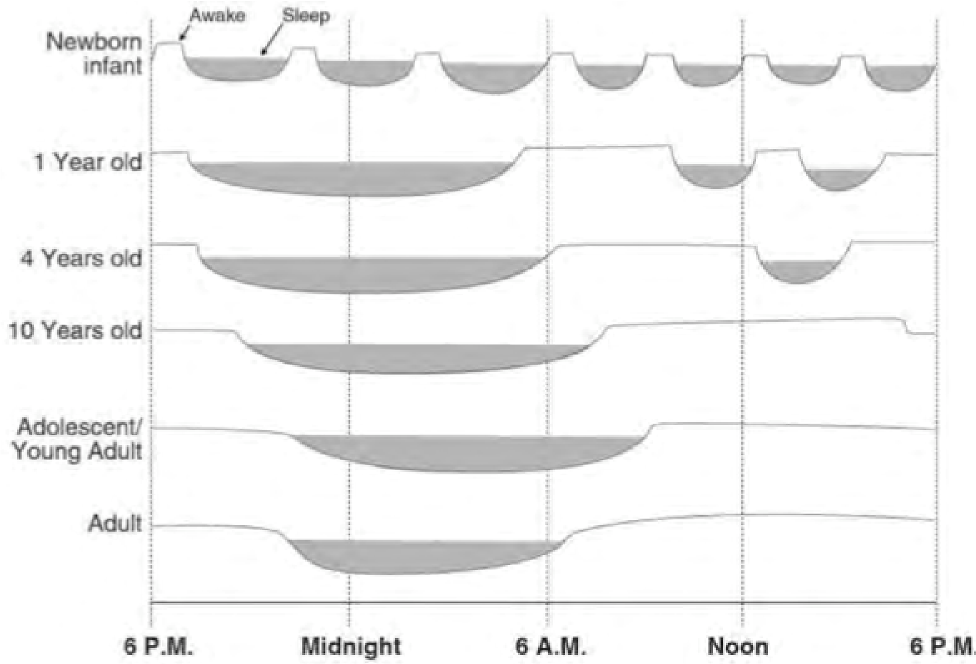

Figure 2. Sleep Patterns Over a Typical Lifespan
(From Miller, Matsangas, & Shattuck, 2007).

Throughout a person's life, he or she will experience various shifts in his or her sleep patterns. There is an interesting shift in sleep patterns for adolescents and young adults through their mid-20s. This age group actually requires anywhere from 0.50 to 1.25 hours more sleep per night than do their adult counterparts (Miller, Matsangas, & Kenney, 2011). This change is important for the discussion of sleep in the military since many service members, especially junior enlisted and junior officer ranks are primarily still in the adolescent and young adult sleep category, and, consequently, require anywhere from 8.50 to 9.25 hours of sleep per night to achieve full cognitive function(Miller & Shattuck, 2005).

2. Circadian Rhythms

Kleitman conducted the first study focused on discovering more about the biological clock in human beings in 1939. Kleitman's studies, as well as "free running" studies, which are designed to examine internal time clocks, confirmed the existence of an internal biological timer. Our daily sleep-wakefulness cycle reflects a number of changes that go on internally including fluctuations in pulse, blood pressure, and body temperature. The circadian rhythm is one that varies with a cycle length of around 24 hours which is seen in the 24-hour pattern of sleep and wakefulness. This pattern is one that is highly resistant to change (Miller et al., 2007).

The internal clock or circadian rhythm, however, is not exactly synchronized with our 24-hour day. Research indicates that without any cues to include light and temperature, most people have an intrinsic 24.5- to 25.0-hour clock (Horne, 1988). The circadian clock is governed by various cues or "zeitgebers," which is German for "time giver" (Matthews et al., 2000). Researchers believe that light is the primary zeitgeber, with meals, exercise, and social cues also affecting the circadian clock (Miller et al., 2007). Figure 3 depicts the relationship between sleep, body temperature, and cognitive performance throughout the sleep-wakefulness cycle.

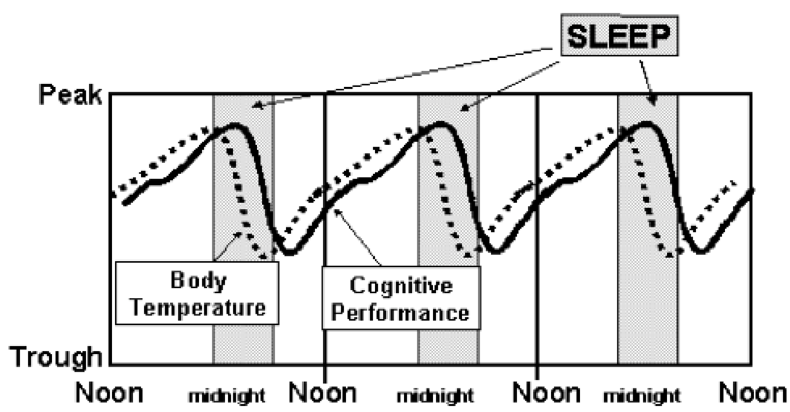

Figure 3. Relationship between Sleep, Body Temperature, and Cognitive Performance Throughout the Sleep-Wakefulness Cycle (From Wesensten, Balkin, & Belenky, 2000).

Just as there are circadian patterns in physiological measures, so also are there circadian patterns in performance. Building off Kleitman's early work, researchers have found and accept that, for many tasks, there is a strong correlation between the circadian rhythms of temperature and performance. Performance of these tasks shows a steep rise from early to midmorning, and then a slower rise to an evening peak (perhaps interrupted by a post-lunch dip), followed by a sharp decline into the hours of sleep (Holding & Hockey, 1983). The rise and decline in performance follows the natural tendencies of the neural processes controlling alertness and sleep. These neural processes in normal people cause increased sleepiness and reduced ability to function during early morning hours (between 0200 and 0700). This decline in alertness also occurs, albeit at a lesser level, during a specific period in the midafternoon (between 1400 and 1700), whether or not we have slept (Mitler et al., 1988).

3. Sleep Debt

The term "sleep debt" is widely used to describe the effects of sleep loss. Sleep debt is defined as "the cumulative hours of sleep loss with respect to a subject-specific daily need for sleep" (Van Dongen, Rogers, & Dinges, 2003, pp. 12). The term is also appropriate when discussing the effects of night-shift work, jet lag, untreated sleep disorders, and experimentally induced periods of sleep loss. In order to fully depict sleep researchers describe sleep as a reservoir, where it is considered to fill during nightly sleep episodes and deplete during times of wakefulness. Any time the sleep reservoir is not full, there is a "sleep debt" (Miller et al., 2007). Various forms of insufficient sleep can cause slept debt. Figure 4 shows the various categories of insufficient sleep.

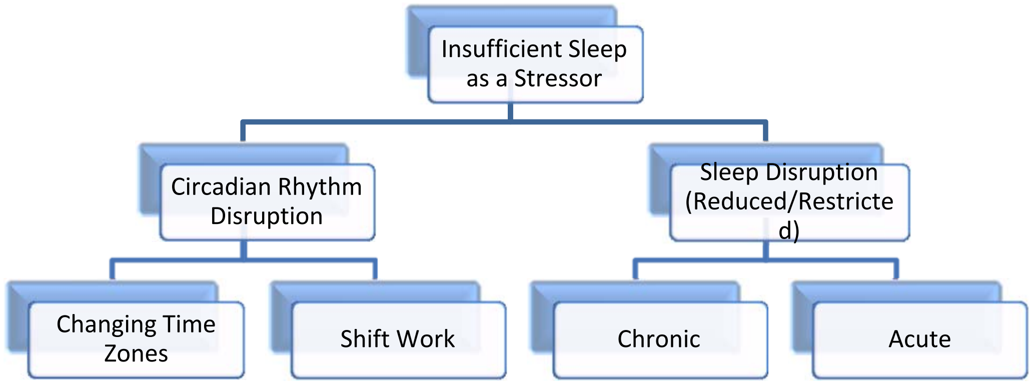

Figure 4. Categories of Insufficient Sleep (From Miller et al., 2007).

When deprived of sleep, the total amount of sleep loss accumulates over days. There are, however, other ways to build a sleep debt besides shortening the amount of daily sleep obtained by an individual. When sleep is disrupted or fragmented, people accumulate similar levels of insufficient sleep. These levels of insufficient sleep due to disrupted or fragmented sleep have direct effects on an individual's thinking ability and mental efficiency (Coren, 1996). While individual performance is sustained with nine hours in bed per night, three hours in bed per night shows an immediate performance deficit that, if carried out over various nights, continues to add up over each successive night. As depicted in Figure 5, performance by a group of subjects that was allowed nine hours in bed per night was maintained at a fairly even level while performance for a group with three hours in bed per night is reduced by 70% (Wesensten et al., 2000). Similarly, intermediate amounts of sleep (five and seven hours) also failed to sustain performance.

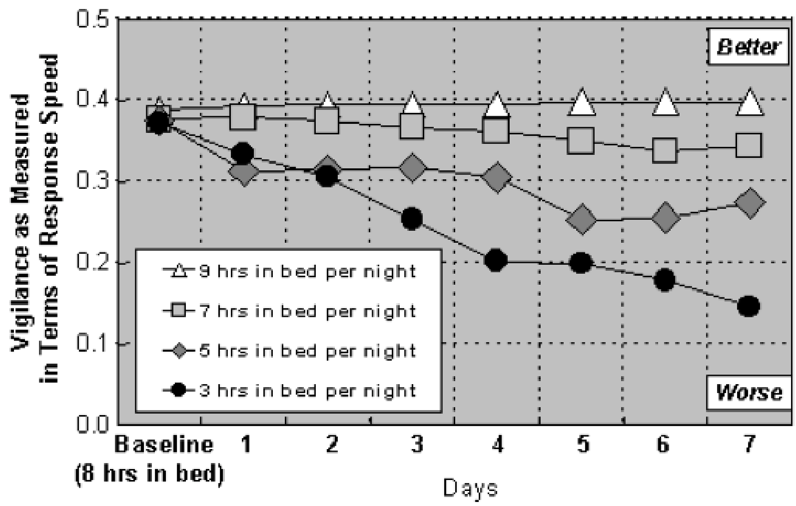

Figure 5. Seven Days of Restricted Sleep: Effects on Vigiliance (From Wesensten et al., 2000).

Sleep deprivation, whether due to restricted sleep or disturbed sleep, impairs mental operations. Total sleep deprivation inhibits overall effectiveness by causing substantial detrimental effects on those complex mental operations or cognitive performances necessary to achieve any effectiveness. Figure 6 shows that on a cognitive task requiring decision making, short-term memory and mathematical processing there is a deterioration in cognitive performance of about 25% for every 24 hours that the individual is awake (Wesensten et al., 2000). He observed that cognitive performance degrades by 75% after only 72 hours of total sleep deprivation.

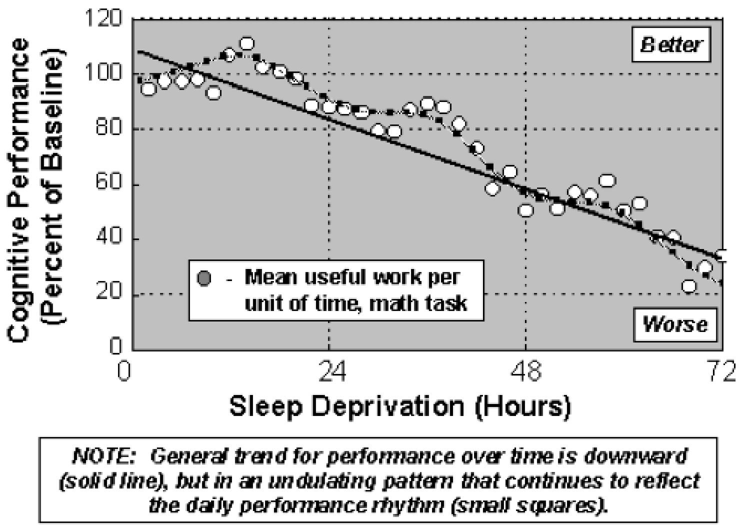

Figure 6. Effect of 72 Hours of Total Sleep Deprivation on Cognitive Performance (From Wesensten et al., 2000).

4. Morningness-Eveningness (M-E)

M-E preference has been described by Horne and Ostberg (1976) as a significant determinant of sleep patterns that can be assessed using a Morningness-Eveningness Questionnaire (MEQ). “Benjamin Franklin’s famous maxim, ‘Early to bed, early to rise makes a man healthy, wealthy, and wise’” (Coren, 1996, p. 90) clearly depicts the circadian tendency or predisposition that is referred to as “larks.” “Larks” show the psychological predisposition known as “morningness” and are early risers. Conversely, those individuals who wake up later and are more alert during evening hours display the predisposition called “eveningness” and are labeled as “owls.” “Larks” and “owls” both show a circadian rhythm, but their cycles differ, with the “owls” cycle peaking about two hours later (Coren, 1996). This difference is experienced throughout all of the physical cycles, including body temperature and fluctuations in various hormones.

5. Definition of Fatigue

Fatigue is caused by a variety of factors including sleep deprivation, sleep disorders, illness or disease, the effects of medications, or heavy stressful physical or mental exertion. Fatigue is characterized by a deterioration of mental and/or physical function. Impairment caused by fatigue is evident through various symptoms including reduced physical and mental performance ability, excessive sleepiness, depressed mood, and loss of motivation which can severely debilitate an individual when performing everyday tasks (Moore-Ede, 2009). Fatigue is a term also used to refer to feelings of tiredness to include bodily discomfort which is often due to prolonged activity (Matthews et al., 2000). Since fatigue is an abstract term that describes a person's internal state, in this thesis, fatigue is defined as weariness or exhaustion from sleep debt due to circadian desynchronization or insufficient sleep.

Fatigue has been shown to have detrimental effects on cognitive performance, motor skills, communication, and social skills (Flin, O'Connor, & Crichton, 2008). After one night without sleep, cognitive performance may decrease by 25% and, after two nights without sleep, cognitive performance can degrade to 40% of normal or baseline cognitive performances established after normal sleep period (Krueger, 1989). Dawson and Reid (1997) compared the effects of fatigue on performance to that of alcohol intoxication using a computer-based tracking task. Using this system, they were able to demonstrate that one night of sleep deprivation caused a performance impairment considered greater than the alcohol intoxication levels acceptable in most states. Furthermore, they were able to equate the loss of two hours of sleep to a performance decrement on psychomotor tasks equivalent to drinking two or three beers. The detrimental effects of fatigue on communication have been observed primarily through continuous operations. Whitmore and Fisher's study (1996) of a four-man bomber crew found that, over a 36-hour exercise, there was a reduction in voice intonation and a slowing of speech. Similarly, May and Klein (1987) found an impairment of verbal fluency and word retrieval in sleep-deprived military personnel. As for social skills, Horne (1993) observed that those individuals who participated in studies of sleep deprivation were all described anecdotally as having a lack of regard for normal social conventions, exhibiting childishness and impatience, being highly irritable, and exhibiting inappropriate interpersonal behavior.

6. Sleep Deprivation, Fatigue, and Performance Loss

Sleep deprivation systematically degrades performance even before people realize that they are so drowsy/sleepy that they fall asleep while on the job. Sleep-deprived people will push through to achieve their goal; they will continue to implement failed solutions without noticing the degradation in effectiveness imparted by their actions. Such sleep deprivation can and will have devastating effects on both individual and organizational performance and effectiveness, even when the persons involved are awake (Wesensten et al., 2000). Fatigue has been implicated in major accidents in all industrial sectors (Coren, 1996; Maas, 2001). Because most people experience greater sleepiness with a reduced ability to function during early morning hours (0200–0700) and, to a lesser degree, in the midafternoon (1400–1700), accidents have a tendency to follow this pattern. There is laboratory evidence that suggests "even brief episodes of sleep, called "microsleeps," produce inattention, forgetfulness, and performance lapses, particularly during the two zones of vulnerability in the 24-hour cycle" (Mitler et al., 1988, pp. 103). Figure 7 depicts the number of unintentional sleep episodes or microsleeps observed at various times of the day in the studies of Carskadon, Richardson, and Dement (1982) and Carskadon, Littell, and Dement (1985).

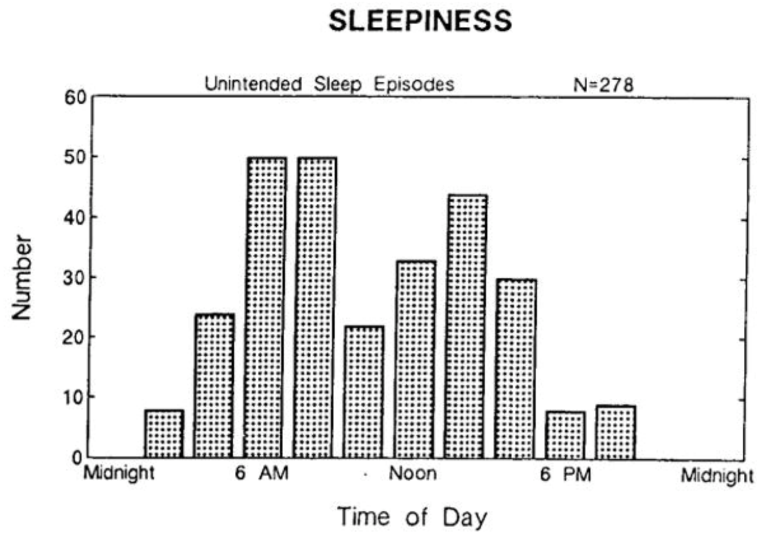

Figure 7. Number of Unintentional Sleep Episodes at Various Times of Day (From Mitler et al., 1988).

Figure 8 shows the distribution of 6,052 vehicular accidents judged by investigators to be fatigue-related, graphed as a function of time of day (Mitler et al., 1988).

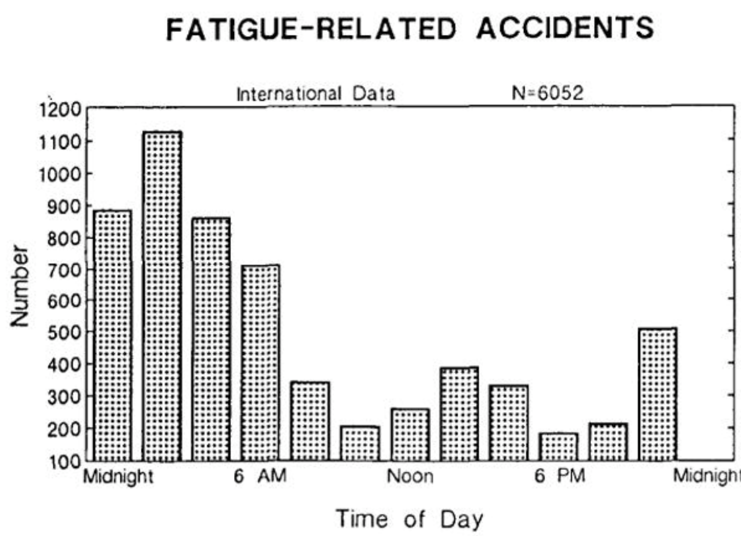

Figure 8. Number of Fatigue Related Accidents at Various Times of Day (From Mitler et al., 1988).

Time dependent drops in human ability to function efficiently can have a potentially catastrophic impact on a world that increasingly operates around-the-clock. Fatigue or sleep deprivation is the largest identifiable and preventable cause of accidents in various job fields. In the aviation industry, it is estimated that fatigue may be involved in 4%–7% of civilian aviation accidents (Kirsch, 1996) and between 4% and 25% of military aviation accidents (Caldwell, Gilreath, & Erickson, 2002). In the maritime industry, fatigue was a contributor to 16% of vessel accidents and 35% of personnel injury accidents (Raby & Lee, 2001). Fatigue causes on average 100,000 crashes and 1,500 fatalities each year, on U.S highways alone (Flin, O'Connor, & Crichton, 2008). An estimated 25%–35% of truck crashes in Australia are due to fatigue (Howarth, Triggs, & Grey, 1988). In an analysis of five studies of accidents reported in eight-hour shift systems (morning, afternoon, and night), the risk of injury was found to be 15% higher in the afternoon and 28% higher on the night shift than on the morning shifts (Spencer, Robertson, & Folkard, 2006).

B. SOPITE SYNDROME

Sopite syndrome is often characterized as a poor response to motion which may present symptoms such as drowsiness, fatigue, sleep disturbances, and mood changes (Graybiel & Knepton, 1976). It is very different from "regular" motion sickness or common fatigue, and may cause alterations in the performance of aircraft, motor vehicle and water vessel operators. "Drowsiness is one of the cardinal symptoms of motion sickness; therefore, a symptom-complex centering around "drowsiness" has been identified that, for convenience, has been termed the sopite syndrome" (Graybiel & Knepton, 1976, pp. 874). Sopite symptoms include:

- yawning;
- drowsiness;
- reluctance to work, either physical or mental; and
- unwillingness to participate in group activities.

Generally, the symptoms characteristic of sopite syndrome are merged together with symptoms associated with "regular" motion sickness. Sopite syndrome appears to occur at different periods in time with respect to the development and persistence of motion sickness. Graybiel and Knepton (1976) determined that the time course of sopite syndrome differs somewhat from that of the general symptomology of “regular” motion sickness. Sopite syndrome, however, can last long after nausea and vomiting have subsided, and can be debilitating to some individuals (Dobie, 2003; Graybiel & Knepton, 1976).

C. OVERVIEW OF ACTIGRAPHY

The use of actigraphy to study sleep/wake patterns has been present for for over 20 years (Ancoli-Israel et al., 2003). Actigraphy is a noninvasive method of monitoring rest and activity cycles. WAMs, or actigraphs, are devices that can be placed on the wrist to record movement, although they can also be placed on the ankle or torso (Ancoli-Israel et al., 2003). Actigraphs are precision activity-monitoring instruments that count the number of motion or acceleration excursions over a given interval. The wristwatch-like device objectively measures activity and rest patterns while worn on the nondominant wrist. Collected data are downloaded to a computer for display and analysis of activity/inactivity. Further analysis allows the user to estimate wake/sleep periods. The estimation of wake/sleep cycles is accomplished based on the observation that people move less when they are asleep and more when they are awake (Ancoli-Israel et al., 2003).

D. OVERVIEW OF SLEEP, ACTIVITY, FATIGUE, AND TASK EFFECTIVENESS (SAFTE) MODEL AND FATIGUE AVOIDANCE SCHEDULING TOOL (FAST)

The U.S. military has a great interest in human performance in operational environments. For a long time the Department of Defense (DOD) has been interested in applied research concerning fatigue especially in sustained continuous military operations (Hursh et al., 2004). In order to objectively measure performance decrements in military personnel due to fatigue or sleep deprivation, Dr. Steven R. Hursh, while working for the Walter Reed Army Institute of Research in 1996, developed a simple homeostatic fatigue model which he developed and integrated into an actigraph that would provide a continuous indication of performance (Hursh et al., 2004). Hursh further developed his original actigraph modeling structure and software in order to apply the findings to more practical applications. The model became known as the SAFTE model, which Hursh later used to create FAST. Attention deficits, slowed reactions, and difficulty with reasoning and decision making due to operator fatigue and time-of-day variations in cognitive effectiveness are prime contributors to errors, incidents and accidents in various industrial and military settings (Hursh et al., 2004). SAFTE attempts to predict the cognitive effectiveness of an individual based on prior sleep episodes. It can be used to discover potential problems with work/sleep schedules that can help managers optimize personnel management. The conceptual architecture for the SAFTE model is depicted in Figure 9. The cornerstone of the model is the sleep reservoir, which is a sleep-dependent process that governs the capacity of an individual to perform cognitive work. The sleep reservoir is considered “full” when the individual is well-rested and begins to deplete when the individual is awakened, and continues to deplete during hours of wakefulness. The sleep reservoir is replenished when the individual sleeps. Sleep accumulation or replenishment is determined by the quality and the intensity of the individual’s sleep. Sleep intensity is determined by time of day (circadian process) and the level of the sleep reservoir at the time of the sleep episode (sleep debt); sleep quality, however, is determined by external influences. The output of the SAFTE model is predicted effectiveness, which is also takes into account time-of-day (circadian) effects and the level of the sleep reservoir (Hursh et al., 2004).

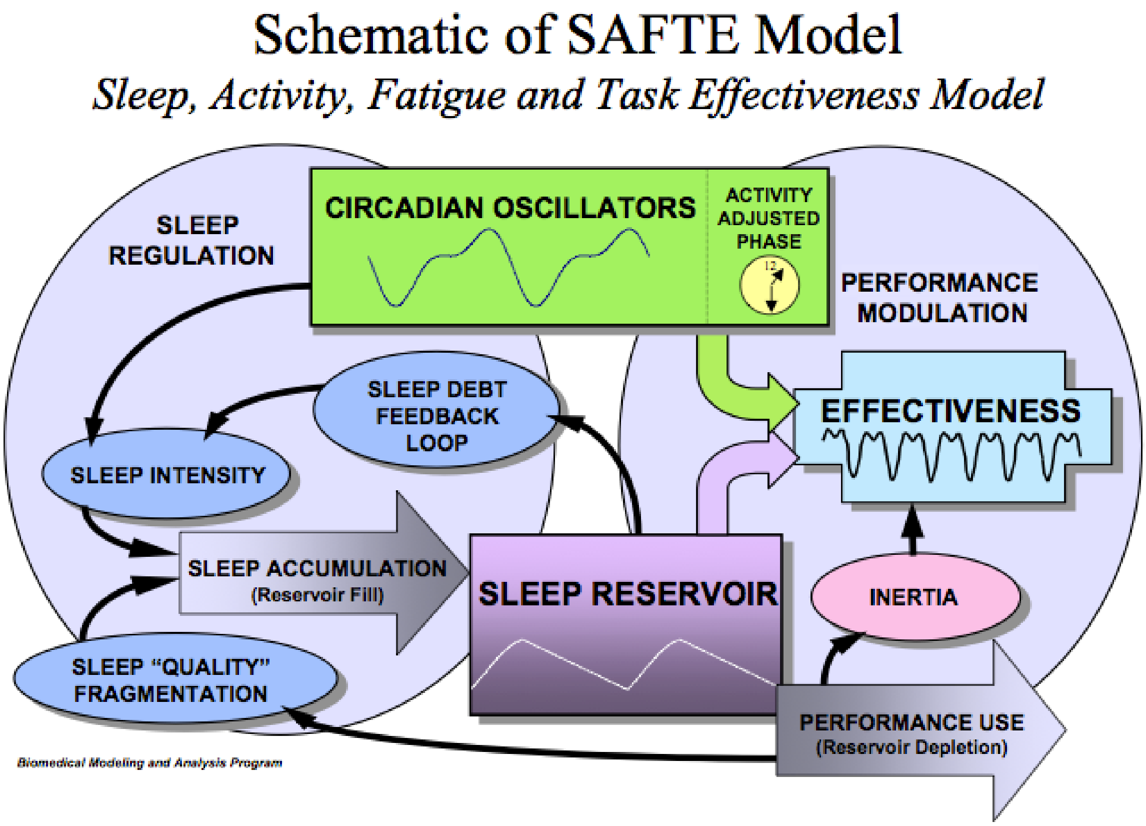

Figure 9. Block Diagram of the SAFTE Model (From Hursh, 2004).

FAST uses the SAFTE algorithm to produce a three-process model of human cognitive performance by integrating various types of information including circadian rhythms, cognitive performance recovery rates associated with wakefulness, and cognitive performance decay rates associated with sleep inertia (Hursh et al., 2004). Figure 10 is a graphical representation of a FAST output. The graphic displays predicted cognitive effectiveness as a function of time. The green area on the graph represents the effectiveness over time for someone experiencing normal sleep (90% effectiveness), while the yellow represents an area were the percentage of effectiveness is estimated to be between 65% and 89%. The red zone indicates a danger zone in which a person is not capable of performing any given task effectively based on his or her sleep history.

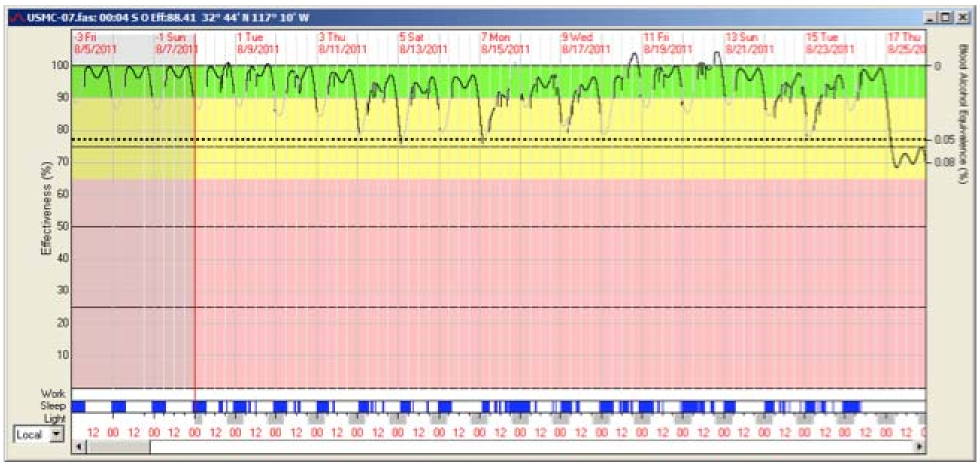

Figure 10. Depiction of FAST Output.

III. METHOD AND EXPERIMENTAL DESIGN

A. STUDY DESIGN

This thesis used data collected during the HAT, which used a within-subjects, repeated measures, quasi-experimental design with counterbalancing to control for order of exposure. In a repeated measures design, each individual serves as his or her own control (Girden, 1992). The HAT was designed to address the question of whether U.S. Marines exposed to waterborne motion in an amphibious vehicle experience a reduction in combat effectiveness.

1. Dependent or Outcome Variables

For the purpose of this study, the following dependent variables were used to assess Marines' ability to "shoot, move and communicate" (Amphibious Vehicle Test Branch, 2011, pp. 3–4).

- **Motion Sickness Assessment Questionnaire (MSAQ)**–Responses to a self-reported survey taken immediately after debarking from the vehicle and again following a one-hour recovery period.
- **Shoot: Laser Marksmanship Training System (LMTS)**–A spread of five shots measured before and after running an obstacle course pre- and post-exposure to motion.
- **Move: Obstacle Course Performance**–The length of time required to complete an obstacle course pre- and post-exposure to motion.
- **Communicate: Cognitive Battery Performance**–A cognitive test of executive function, which includes the Manikin Test, a Math Test, and a Switching Test; all subsets of the Automated Neuropsychological Assessment Metric (ANAM), was administered prior to and after exposure to waterborne motion.

2. Independent and Control Variables

The independent variables designed into the HAT study consisted of:

- **Duration of Waterborne Motion**–Exposure varied from 0 to 3 hours.
- **Vehicle Type**–EFV or AAV.
- **Ventilation Condition**–Environmental Control System (ECS) versus Ventilation. The air conditioning system, or ECS, was available for some of the EFV trials, while the AAV only used outside ventilation.

3. Covariates

We also sought to account for possible confounding factors such as:

- **Individual Sleep History**–Human performance varies as a function of fatigue due to sleep deprivation.
- **Circadian Effect**–Circadian rhythms are the naturally occurring biological fluctuations that vary with a cycle length of approximately 24 hours and are evident in the everyday sleep and wakefulness pattern. This pattern is one that is highly resistant to change. Therefore, the time of day at which the tests were administered was critical.
- **Motion**–The amount of motion experienced during each treatment exposure varied depending on the vehicle, the participants' location on the vehicle, and the sea state. Sea state varied somewhat over the course of the testing period.
- **M-E Preference**–At the completion of the HAT assessment, the morningness-eveningness preference of the participants was measured using the MEQ published by Horne and Ostberg (1976). This preference is a significant determinant of sleep patterns.

B. PARTICIPANTS

Sixty-four enlisted Marine volunteers were recruited for the study. Marines who did not complete all training requirements, including underwater egress training, were returned to their parent commands. Of the 64 Marines, 61 completed the training and were considered study participants. Participants were between the ranks of Lance Corporal (E-3) and Sergeant (E-5), pooled from various commands. The majority (44%) of Marines in this study was from infantry MOFs between the ages of 18 and 28.

The Motion Sickness Susceptibility Questionnaire (MSSQ) was administered to each study participant before they were assigned to one of four squads. Squad assignment was based on a stratified random assignment set by the scores derived from the MSSQ and the Marines' experience in amphibious vehicles. Participants were assigned to squads such that the participants' susceptibility to motion sickness and their experience in amphibious landings were balanced between those squads.

C. EQUIPMENT/APPARATUS

1. Wrist Activity Monitor (WAM)

Actigraphy is a noninvasive method of monitoring rest and activity cycles. WAMs are precision activity-monitoring instruments that count the number of motion or acceleration excursions over a given interval. Data are then downloaded to a computer for analysis. To collect sleep data from the study participants, we used Actiwatch Spectrum and Actiwatch 64 WAMs manufactured by Philips Respironics. Figure 11 shows the two WAMs used during this study.

Figure 11. Actiwatch Spectrum and Actiwatch 64 Wrist Activity Monitors.

2. Activity Log

Each participant was issued a paper activity log on which the participants indicated their activities throughout the day and night. Participants used the logs to record critical changes in their state. In particular, study participants indicated naps and major sleep episodes and when they woke up.

3. Respironics Actiware 5 Software

Respironics Actiware 5 software was used to analyze data collected from the WAMs. The software calculated daily sleep, nightly sleep, and the sleep efficiency of each participant. The software also provided analyzed data in the proper format for input into FAST.

4. Morningness–Eveningness Questionnaire (MEQ)

The MEQ consists of 19 questions specifically designed to determine when, during the daily temporal span, individuals have the maximum tendency to be active. This questionnaire was used to assess the M-E preferences of the participants. Most questions in the questionnaire are preferential in that the participant is asked to indicate when they would prefer to wake up or go to sleep, rather than the asking when they actually do. The questionnaire consists of multiple-choice questions, which are assigned values such that a score ranging from 16 to 86 is produced by their sum. Lower values correspond to evening chronotypes, while higher values indicate morning chronotypes.

5. Motion Sickness Assessment Questionnaire (MSAQ)

Motion sickness is an aversive behavioral state that affects several psychophysiological response systems (Gianaros et al., 2001). Therefore, it is viewed as a multidimensional construct with gastrointestinal, central, peripheral and sopite-related components. Participants were administered the MSAQ following the motion exposure treatment, allowing them to provide a self-assessment of their response to the various types of real or apparent motion using these distinguishable dimensions. The questions for the MSAQ are shown in Figure 12.

Instructions: Using the scale below, please rate how accurately the following statements describe your experience.

Not at all — Severely

1------2------3-------4------5------6------7------8------9

1. I felt sick to my stomach (G)
2. I felt faint-like (C)
3. I felt annoyed/irritated (S)
4. I felt sweaty (P)
5. I felt queasy (G)
6. I felt lightheaded (C)
7. I felt drowsy (S)
8. I felt clammy/cold sweat (P)
9. I felt disoriented (C)
10. I felt tired/fatigued (S)
11. I felt nauseated (G)
12. I felt hot/warm (P)
13. I felt dizzy (C)
14. I felt like I was spinning (C)
15. I felt as if I may vomit (G)
16. I felt uneasy (S)

Note. G: Gastrointestinal; C: Central; P: Peripheral; S: Sopite-related. The overall motion sickness score is obtained by calculating the percentage of total points scored: (Sum of points from all items/144) x 100. Subscale scores are obtained by calculating the percent of points scored within each factor: (Sum of Gastrointestinal items/36) x 100; (Sum of Central items/45) x 100; (Sum of Peripheral items/27) x 100; (Sum of Sopite-related items/36) x 100.

Figure 12. Motion Sickness Assessment Questionnaire (MSAQ) (From Gianaros et al., 2001).

6. Laser Marksmanship Training System (LMTS)

Test participants were required to fire five rounds, from the standing position, at a target 15 yards away. The target simulated an “E-type” silhouette positioned 300 yards away. The LMTS used during this study is depicted in Figure13.

Figure 13. Laser Marksmanship Training Simulator (LMTS) BeamHit® equipment (From Amphibious Vehicle Test Branch, 2012).

The spread of the five shots was measured before and after running the obstacle course during the pre- and post-treatment test batteries to provide the metric for measuring the effects of motion on the participants.

7. Obstacle Course

An obstacle course, derived from the Marine Corps Load Effects Assessment Program (MCLEAP), was developed for the study. Participants were required to navigate a series of obstacles that were intended to challenge their balance and agility. The obstacle course consists of a balance log, six bounding rushes, one wall and one window obstacle, an agility cone run, and an inclined balance beam. Figure 14 is a representation of how the obstacle course was set up for the study.

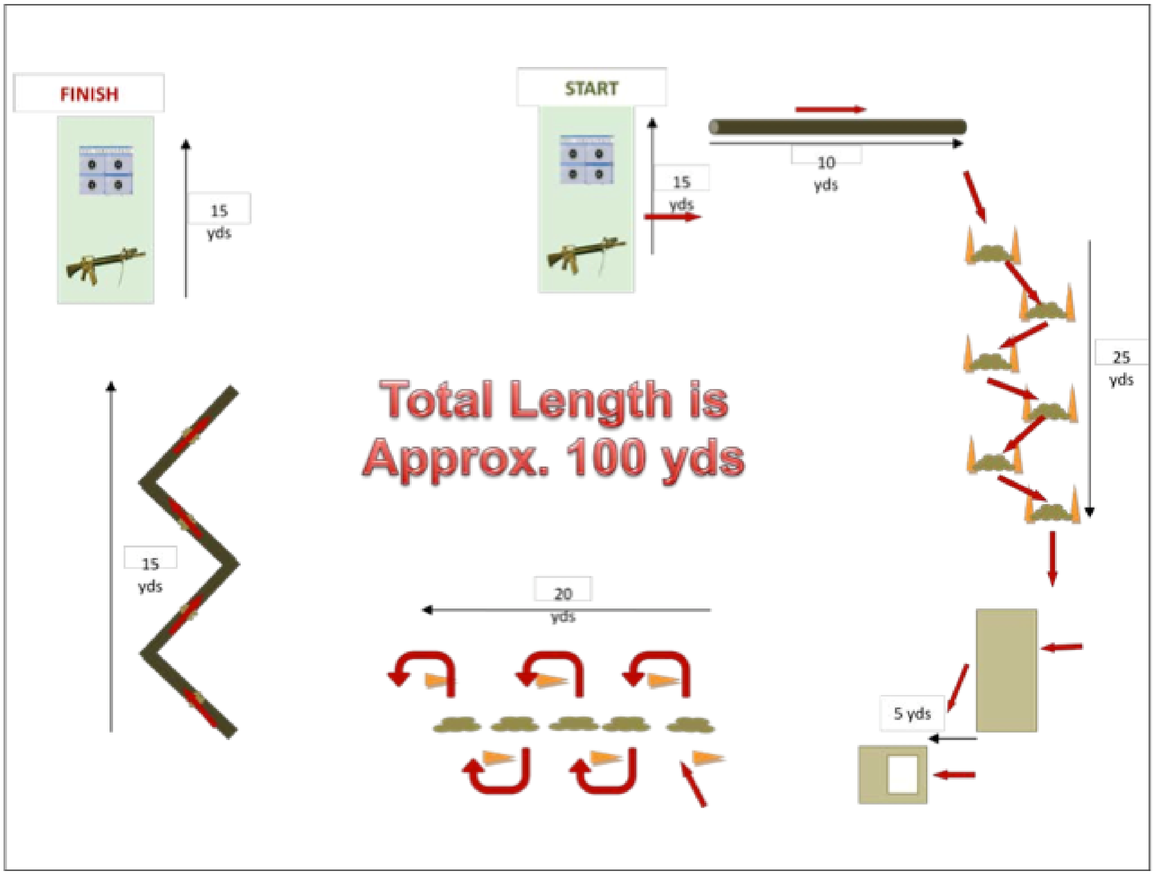

Figure 14. Obstacle Course Layout, Pelican Point (From Amphibious Vehicle Test Branch, 2011).

8. Cognitive Battery

The cognitive battery was a cognitive test of executive function, which included the Manikin Test, a Math Test, and a Switching Test. All of these are subsets of the Automated Neuropsychological Assessment Metric (ANAM). The ANAM is a computer-based test battery designed and fielded by the U.S. Army for assessing cognitive function.

a. Manikin Test

The Manikin Test is a visual-spatial test that requires the participant to identify the hand in which a manikin is holding an object pictured below the manikin. The test assessed the participants' ability to discern three-dimensional spatial rotation ability, left-right orientation, problem solving, and attention

(ANAM4 User Manual, 2007). Throughout the cognitive testing, participants saw a picture similar to Figure 15 as part of the Manikin Test.

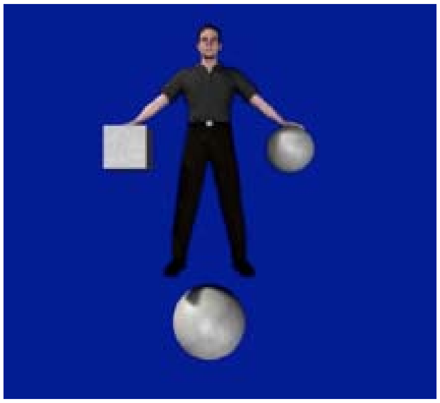

Figure 15. Manikin Test (From ANAM4 User Manual, 2007).

b. Math Test

The Math Test assesses mathematical processing requiring the participant to solve a basic, three-step mathematical equation (e.g., “4 + 8 – 5 =”). The participant must then determine whether the result is greater or less than five. The math test assessed the participants’ basic computational skills, concentration, and working memory (ANAM^{TM}, 2008). The mathematical problem was displayed in the format of Figure 16.

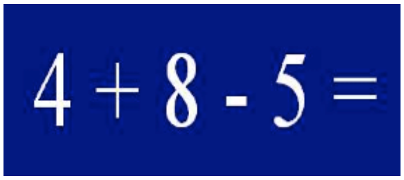

Figure 16. Mathematical Processing (From ANAM4 User Manual, 2007).

c. Switching Test

The Switching Test consists of a red arrow that points at the task the participant is required to complete. The switching test assessed the participants' executive function and directed attention (ANAM4 User Manual, 2007). The red arrow in Figure 17 represents the switching function in the cognitive test.

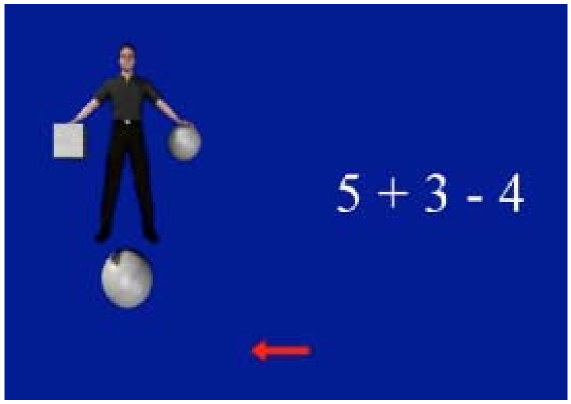

Figure 17. Switching Test (From ANAM4 User Manual, 2007).

9. Radio-Frequency Identification (RFID) Tags

RFID Tags were attached to each participant's vest in order to accurately identify and tag the participants as they ran the obstacle course. RFID tags use a wireless, noncontact system that uses radio-frequency electromagnetic fields to transfer collected data from the tag attached to the participant's vest to the computer. Participants were identified and tracked when entering and leaving the obstacle course. RFID tags similar to those in Figure 18 were attached to the participants' bibs.

Figure 18. Radio-Frequency Identification (RFID) Tags.

10. Amphibious Assault Vehicle (AAV)

The AAV-7A1 is the current amphibious troop transport of the USMC. The AAV is used by USMC Assault Amphibian Battalions during amphibious operations to transport and land Marines and their equipment in a single lift from Naval vessels. The AAV-7A1 is also used to conduct mechanized operations and combat support in subsequent missions ashore. The two AAVs used during the study are shown in Figure 19.

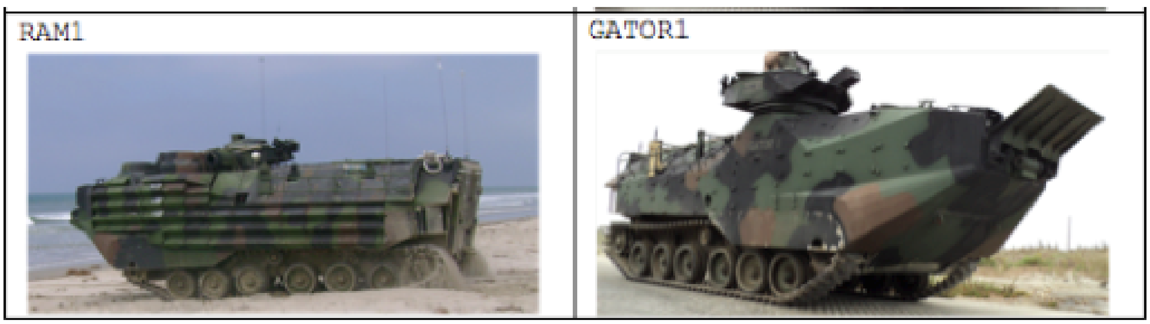

Figure 19. Amphibious Assault Vehicles Used for Testing (From Amphibious Vehicle Test Branch, 2012).

11. Expeditionary Fighting Vehicle (EFV)

The EFV, formerly known as the Advanced AAV, was designed to replace the AAV-7A1. The EFV is a tracked-amphibious vehicle possessing both land and water mobility. It is designed to have sufficient range over land to proceed to inland objectives after completing an over-the-horizon, high-speed water transit. The two EFV's used throughout the study are pictured in Figure 20.

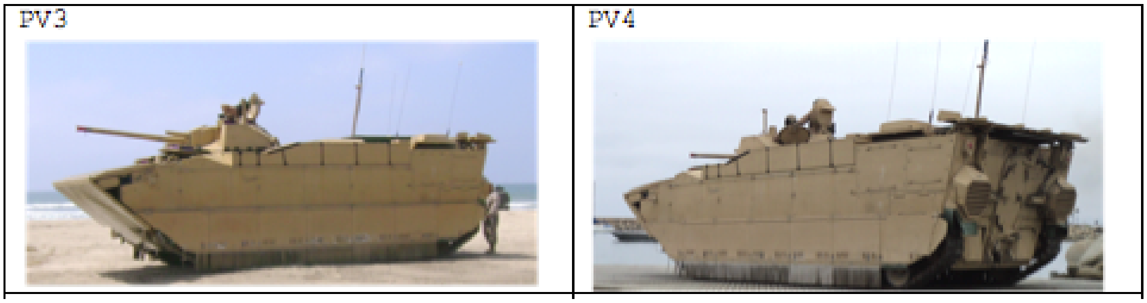

Figure 20. Expeditionary Fighting Vehicles used for testing (From Amphibious Vehicle Test Branch, 2012).

D. PROCEDURES

Prior to beginning the study, each participant was briefed per the requirements set forth by the Naval Postgraduate School's Institutional Review Board (IRB) on the goals of the study, what they were expected to do, the risks of the study, and that they could remove themselves from the study at any point without any repercussions. Once informed consent was obtained, each participant was asked to fill out a series of questionnaires, including a demographic questionnaire and the MSSQ. These questionnaires were used to create a stratified random assignment to a squad.

Each participant was issued a WAM as well as an activity log on which the participant indicated their activities throughout the day and night for the duration of the study. Participants were given instructions on the use of the WAMs and the activity logs and were reminded daily to fill out their activity logs. Data from the WAMs were analyzed using Respironics Actiware 5 software. The software allowed for the calculation of daily sleep, nightly sleep, and sleep efficiency. The actigraphy data from the WAMs were validated using the self-reported activity logs collected from the participants. Data from WAMs, when used along with activity logs, is known to provide unbiased estimates of the quantity and quality of sleep acquired by the participant (Ancoli-Israel et al., 2003).

1. Training Week

Data collection for the test of record was preceded by five days devoted to training the participants as well as the data collection team. Training of the participants was conducted to familiarize the participants with the test battery in an effort to overcome any learning effect, which could affect the results. During this week, participants followed a “crawl, walk, run” methodology in order to become familiar with all aspects of the study.

2. Test of Record

The same schedule was followed for each of the test days. All participants mustered at 0700, at which point the pre-treatment battery was administered. The pre-treatment battery included a marksmanship test using the LMTS, an obstacle course, a cognitive test, a daily pretest questionnaire, followed by a second marksmanship test.

Once the pre-treatment battery was complete, squads were assigned to their treatment group for either 0, 1, 2, or 3 hours of waterborne motion exposure. Participants were then loaded into their assigned vehicles and the treatment (motion exposure) was carried out. Immediately upon exiting their respective vehicle, participants went through the post-treatment battery. The post-treatment battery consisted of the MSAQ, a marksmanship test, an obstacle course, a cognitive test, a daily post-treatment questionnaire, followed by a second marksmanship test. As a means of ensuring that the participants were recovered from motion exposure, a one-hour recovery period was designed into the testing; this period was followed by a third cognitive test. Participants were debriefed after their one-hour recovery period and cognitive test. Each squad was debriefed as to how they believed the testing went as well as how they felt at various stages of the evolution. Figure 21 depicts the basic testing procedure for each test day.

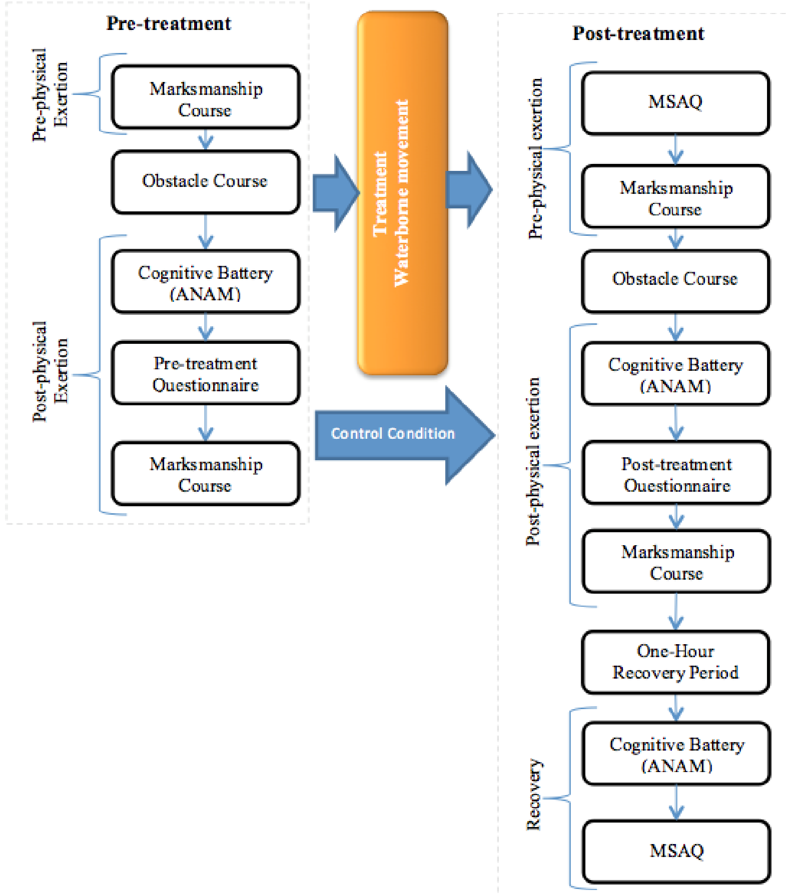

Figure 21. Basic Testing Procedure for Each Test Day
(From AVTB Habitability Assessment Test Plan, 2010)

3. Post-test

The M-E questionnaire was administered to the participants once testing was finalized in order to determine individual chronotypes or M-E tendency. WAMs were collected after the final test evolution. Data from the WAMs were then downloaded and analyzed using Respironics Actiware 5 software.

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IV. RESULTS

A. POSTULATES AND ASSUMPTIONS

Significant gaps exist in our knowledge and understanding about the effects of waterborne motion on the combat performance of infantry personnel embarked aboard amphibious vehicles. It is, however, difficult to separate the effects of sleep and motion on performance. This research seeks to determine whether sleep, in addition to motion, is related to the performance of Marines embarked on amphibious vehicles. Understanding the effect of sleep on performance enables the separation of sleep as a covariate in the evaluation of how motion affects Marines embarked on amphibious vehicles. In order to understand the effect of sleep on performance, this analysis focuses on whether the quality and quantity of an individual's sleep is related to that individual's combat performance before and after exposure to waterborne motion in amphibious vehicles.

Sleep Quality: It is assumed that sleep quality varied among the participants throughout the study. As sleep quality decreased, it is expected that the participants' performance would decrease. The metrics used to determine sleep quality for each Marine were based on the sleep efficiency of their major nighttime sleep episode.

Sleep Quantity: It is assumed that sleep quantity varied among participants. The metric used to determine sleep quantity for each Marine was their daily sleep duration over a 24-hour period. Daily sleep duration was composed of all daytime naps and nighttime sleep episodes.

Circadian Effect: Performance follows the natural tendencies of the neural processes controlling alertness and sleep. During early morning hours (0200–0700) humans experience an increase in sleepiness as well as a lower capacity to function and, while to a lesser degree, experience the same for a brief period in the midafternoon (1400–1700) (Mitler et al., 1988). We examine the possibility of a circadian effect in Section E.

Marksmanship: Marines are trained marksmen. One of their mottos is "Every Marine is a rifleman." Sleep history, however, affects performance on a wide variety of tasks. The metric used to determine marksmanship score is the Mean Radius of Impact (MRI) or spread in millimeters (mm) of five shots fired in a at each period. A smaller spread reflects better, more consistent shooting than a larger spread. The spread is measured based on each participants' grouping or cluster. As participants obtain less sleep, their marksmanship scores are expected to decrease.

Obstacle Course: As sleep quality and quantity decrease, performance on the obstacle course is expected to decrease. The metric used to determine obstacle course performance was time to complete the obstacle course with longer obstacle course times indicating worse performance.

Cognitive Test Battery: In order for healthy adults to achieve full cognitive functioning they require approximately eight hours of sleep each night (Anch, Browman, Mitler, & Walsh, 1988). There is, however, considerable variability among individual sleep requirements, with some people necessitating more and others needing less than eight hours of sleep per night (Van Dongen & Dinges, 2000). As sleep quantity and quality decreases, performance on the cognitive test battery is expected to decrease. Metrics used to determine cognitive performance are mean response time and cognitive throughput for the ANAM Switching Test.

B. DEMOGRAPHICS

Initially, 64 enlisted Marine volunteers were recruited for the study. Of the 64 Marines, 61 completed the training and were considered study participants. These 61 participants completed a Sleep and Activity Log and wore a WAM for the duration of the study. Participants were between the ranks of Private First Class (E-2) and Sergeant (E-5), pooled from various commands. The 61 participants were grouped into four squads. Squads A, B, and C consisted of 15 Marines in each squad, while Squad D consisted of 16 Marines. Participants included 5 E-2s, 27 E-3s, 26 E-4s, and 3 E-5s. Figure 22 shows the distribution of rank among the participants.

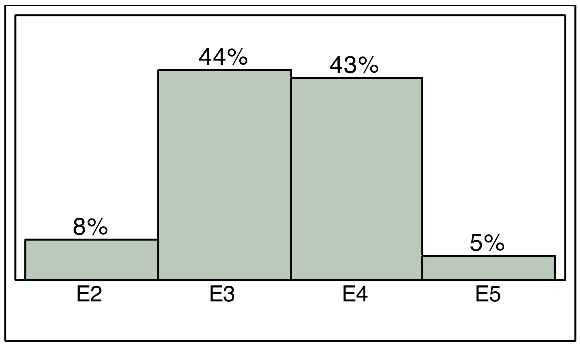

Figure 22. Participant Rank Distribution (*n* = 61).

The average age of the participants was 22.30 years (*SD* = 1.97). Figure 23 shows the distribution of age among the participants.

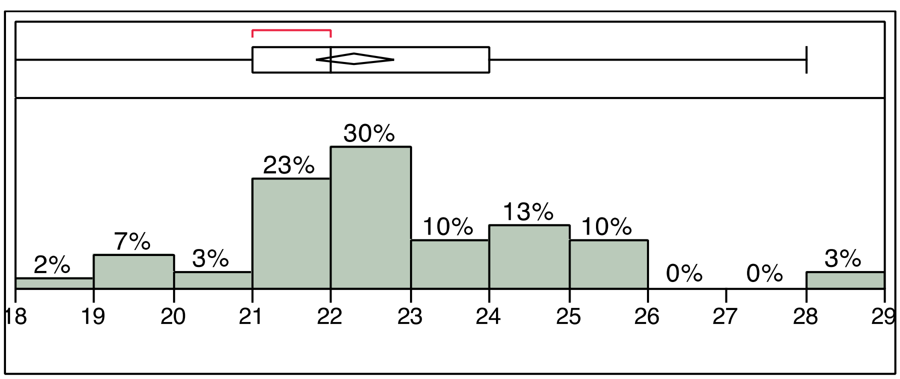

Figure 23. Distribution of Age (*n* = 61).

The participants had an average of 3.51 years (*SD* = 1.79) of military service. Figure 24 shows the distribution of years in service for all of the participants.

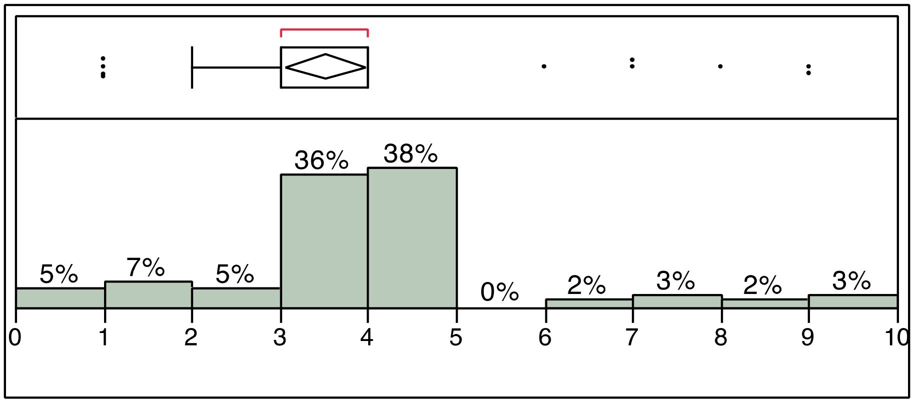

Figure 24. Years of Service (*n* = 61).

Participants came from 14 different MOSs. The average time in MOS was 3.45 years (*SD* = 1.77). Figure 25 shows the distribution of MOSs among the participants. MOSs with similar functions are condensed into occupational fields. In this case, those MOSs beginning with the field number 03 – Infantry, 06 – Communications, 11 – Utilities, 13 – Engineer, Construction, Facilities and Equipment, 30 – Supply Administration and Operations, 35 – Motor Transport, and 58 – Military Police and Corrections.

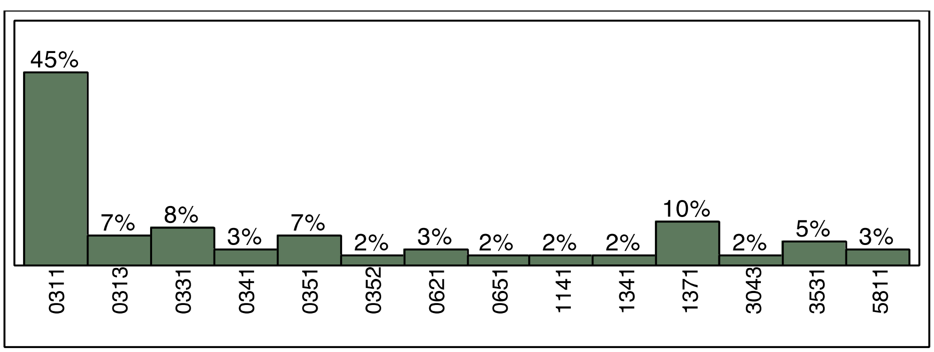

Figure 25. Participants' MOS (*n* = 60).

Participants were asked to report their most recent rifle marksmanship qualification scores. An expert qualification was reported by over half (55%) of the participants. Figure 26 shows the distribution of reported marksmanship qualification scores.

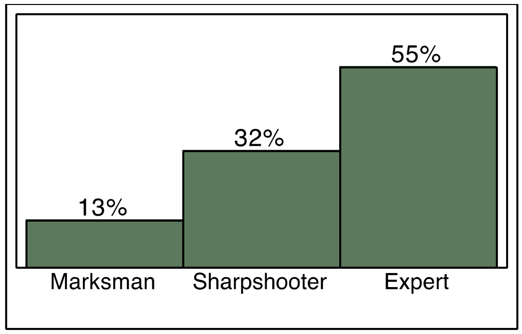

Figure 26. Marksmanship Qualification (*n* = 56).

The MSSQ was used in this study to stratify the participants for squad assignments in order to ensure that those participants with higher scores on the MSSQ (i.e., those more likely to get sick) were evenly distributed across all squads. The average MSSQ score was 17.70 (*SD* = 27.19). The distribution of these scores is shown in Figure 27.

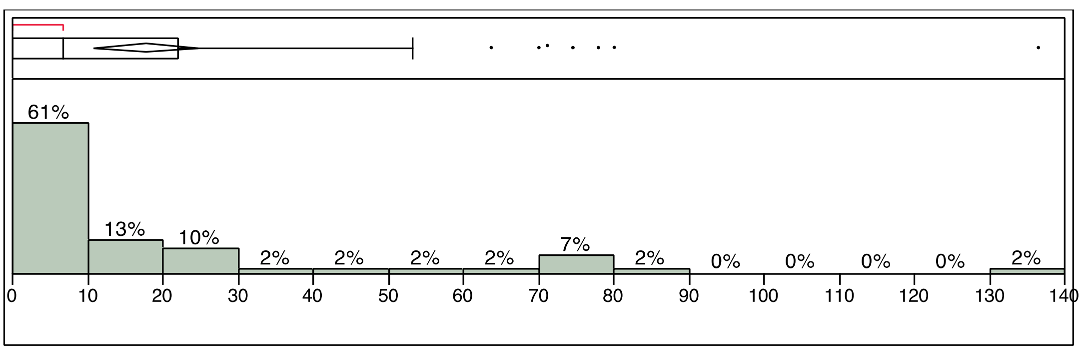

Figure 27. MSSQ Score Frequency Plot (*n* = 61).

Fourteen, or 23.3%, of the participants reported that they had any “landing experience with AAVs.” On average, these participants reported having participated in 21.4 landings (*SD* = 15.2).

Various factors affect human performance. When discussing sleep effects on performance, those factors that may affect sleep quality, as well as those factors that enhance performance, should be taken into account. These factors include caffeine intake and tobacco use, as well as the use of seasickness medication for those individuals embarked on the amphibious vehicles exposed to motion. Thirty-eight of the 61 participants (63%) reported daily use of caffeinated beverages, while 35 participants (58%) reported using tobacco products. One participant reported taking over-the-counter motion sickness medication.

Participants were administered the MSAQ twice daily throughout the testing period. The MSAQ captured participant symptoms immediately after each exposure (0, 1, 2, and 3 hours) as well as after a one-hour recovery period.

C. SLEEP DATA

Actigraphic data were collected on 61 participants. Actigraphic data for five of the participants were not available due to device malfunctions. Therefore, analysis was conducted on actigraphic data for 56 participants. This analysis used 892 days of sleep data for 56 Marines, collected over a 16-day period between 8 and 24 August 2011. Of the 892 days of sleep data, 15 days of data were excluded from the study because participants did not wear their WAMs. On average, 15.6 sleep days were collected per participant, with a standard deviation of 1.3. Figure 28 shows the distribution of sleep days among the 56 participants.

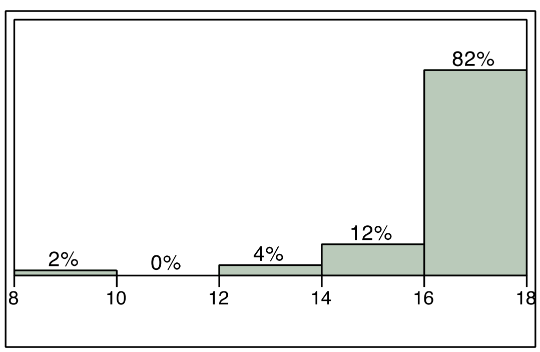

Figure 28. Distribution Sleep Days per Participant (*n* = 56).

Sleep analysis for this study was based on daily sleep amount, night sleep amount, and sleep efficiency. Daily sleep amount was determined by combining the major night sleep episode and any naps taken that day. The longest sleep episode that occurred during the night (from 2200 to 0630) was considered the night sleep. Sleep episodes starting during the nighttime period and extending into the next morning were considered part of the previous night's sleep episode. Table 1 shows the results of the sleep analysis. The difference in sample size between daily sleep amount and night sleep amount is because some participants did not sleep during the time set forth as nighttime (2200–0630), but did sleep during the daytime.

Metric	*n*	Mean	Standard Deviation	Minimum	Maximum
Daily Sleep Amount (min) (Night+Naps)	877	486.67	141.21	114	1,022
Night Sleep Amount (min)	875	363.47	113.97	30	790
Sleep Efficiency (%)	875	85.71	6.40	44.37	98.53

Table 1. Sleep Summary Statistics.

During the study, the average daily sleep that each participant obtained during the 16-day data collection period was calculated. Results indicated that participants received an average of 482.86 minutes of daily sleep (*SD* = 145.97), just over eight hours per day, during the testing period. The daily sleep per participant ranged from 15 to 1,022 minutes.

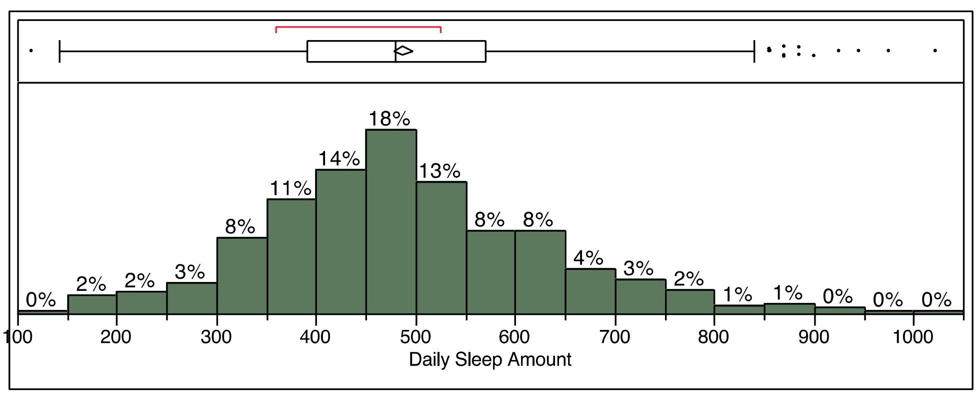

Figure 29. Daily Sleep Amount in Minutes (*n* = 877, *M* = 486.56, *SD* = 141.21).

Figures 30 and 31 show the distribution of nighttime sleep amount and sleep efficiency throughout the study. Results indicated that participants received an average of 363.47 minutes of nighttime sleep (*SD* = 113.97), about six hours per day, during the testing period. The nighttime sleep per participant ranged from 30 to 790 minutes.

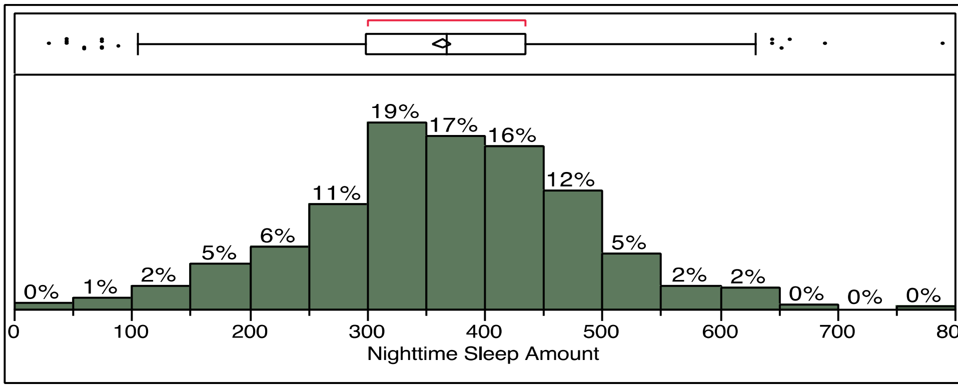

Figure 30. Distribution of Night Sleep Amount in Minutes (*n* = 875, *M* = 363.47, *SD* = 113.97).

Results indicated that participants achieved an average of 85.71% of sleep efficiency (*SD* = 6.40) per day during the testing period. The sleep efficiency per participant ranged from 44.37% to 98.53%.

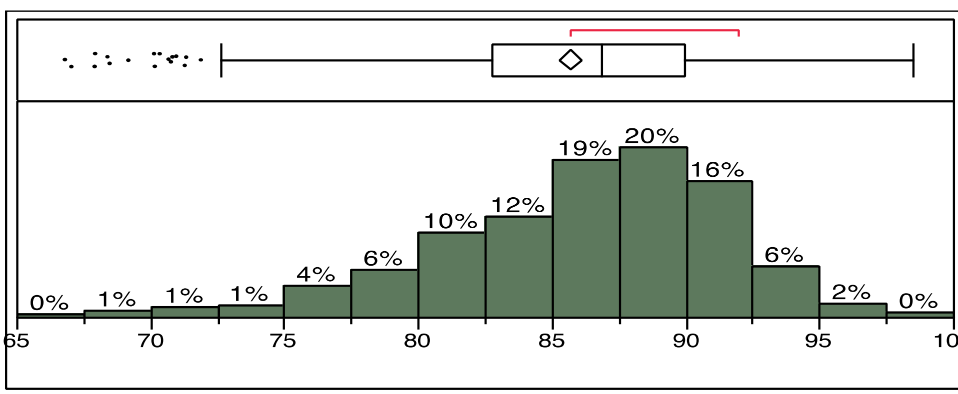

Figure 31. Distribution of Sleep Efficiency in Percent (*n* = 875, *M* = 85.71, *SD* = 6.40).

Both daily sleep amount and night sleep amount varied greatly by day. Figure 32 shows the variability between daily sleep and nighttime sleep over the course of the study. The error bars represent one standard deviation from the mean.

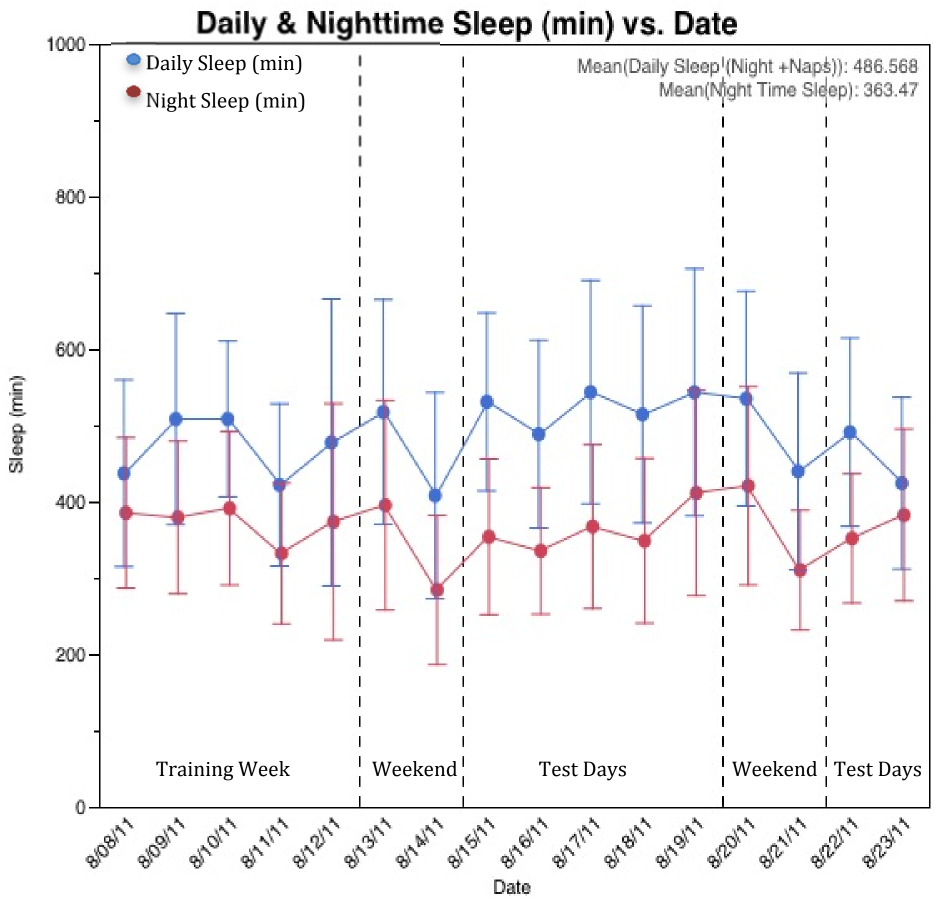

Figure 32. Daily and Nighttime Sleep per Day in Minutes (n = 877 / n = 875).

Figure 33 shows the variability in sleep efficiency throughout the course of the study. There is more variability in sleep efficiency on the weekend nights than during the weekdays for the first two weeks of the study. The error bars represent one standard deviation from the mean.

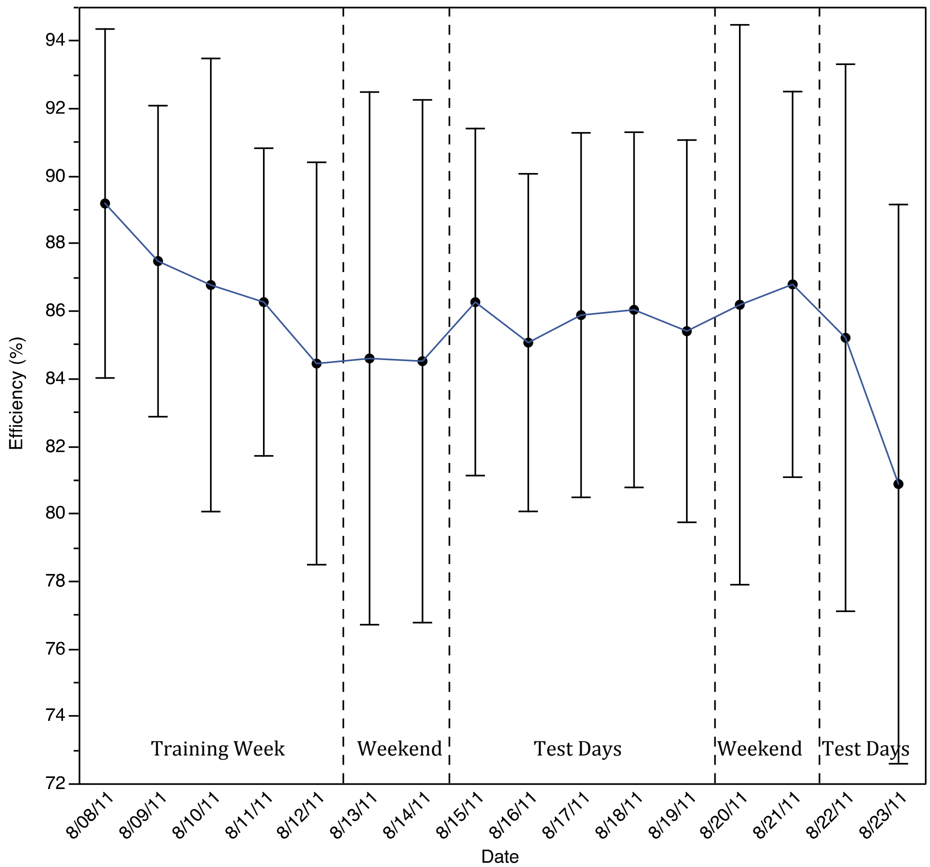

Figure 33. Sleep Efficiency per Day in Percent (*n* = 875).

The Morningness-Eveningness Questionnaire (MEQ), a standardized test used to assess an individual's morningness-eveningness (M-E) preference (or "chronotype") was administered to the participants in order to determine when participants preferred to be more active. The questionnaire consists of multiple-choice questions, which provide scores ranging from 16 to 86. Lower values correspond to evening chronotypes, while higher values indicate morning chronotypes. Analysis of the M-E scores showed that the mean M-E score was 48.04 (SD = 8.34). The highest M-E score was 70, while the lowest was 31. Figures 34 and 35 show the frequency of M-E scores and M-E types. Most participants fell into the "Intermediate" category although 22% scored as having a moderate eveningness preference.

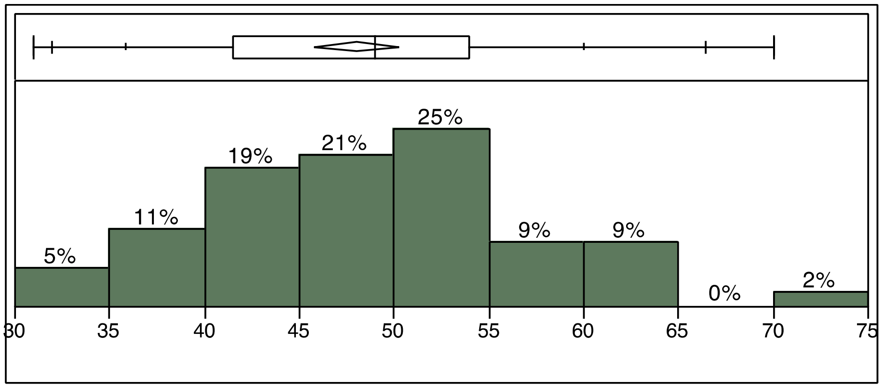

Figure 34. MEQ Scores (n = 57).

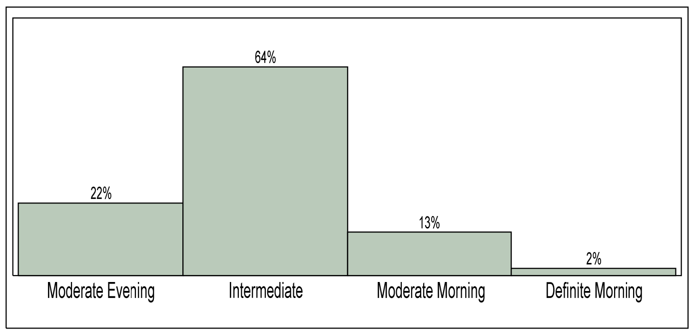

Figure 35. M-E Types (n = 57).

D. TRAINING WEEK

Data collection for the test of record was preceded by a week of training, 8–14 August 2011, which was devoted to training the study participants and the data collection team. It is common for individuals to improve over successive exposures to novel tests, such as those used in the measurement battery. This effect, called the "learning curve" or practice effect, can be partially accounted for by giving participants multiple trials to reach "asymptotic" or level performance. In order to ensure that any changes in the dependent measures were not a result of learning, the first week was dedicated to ensuring that participants were familiar with each of the tests.

Figure 36 shows the data from the marksmanship test, obstacle course, and cognitive battery for the entire study period. The first six sessions occurred during the training week, while the remaining five were from the actual test of record. This data indicates that the training week was necessary for participants to become familiar with the test. The figure shows that participants demonstrated significant improvement during the first six sessions and then stabilized after reaching near asymptotic performance. Although there continues to be slight improvement in the cognitive scores through the testing, these results lead to the conclusion that training, for both the participants and the data collection team, was both necessary and adequate.

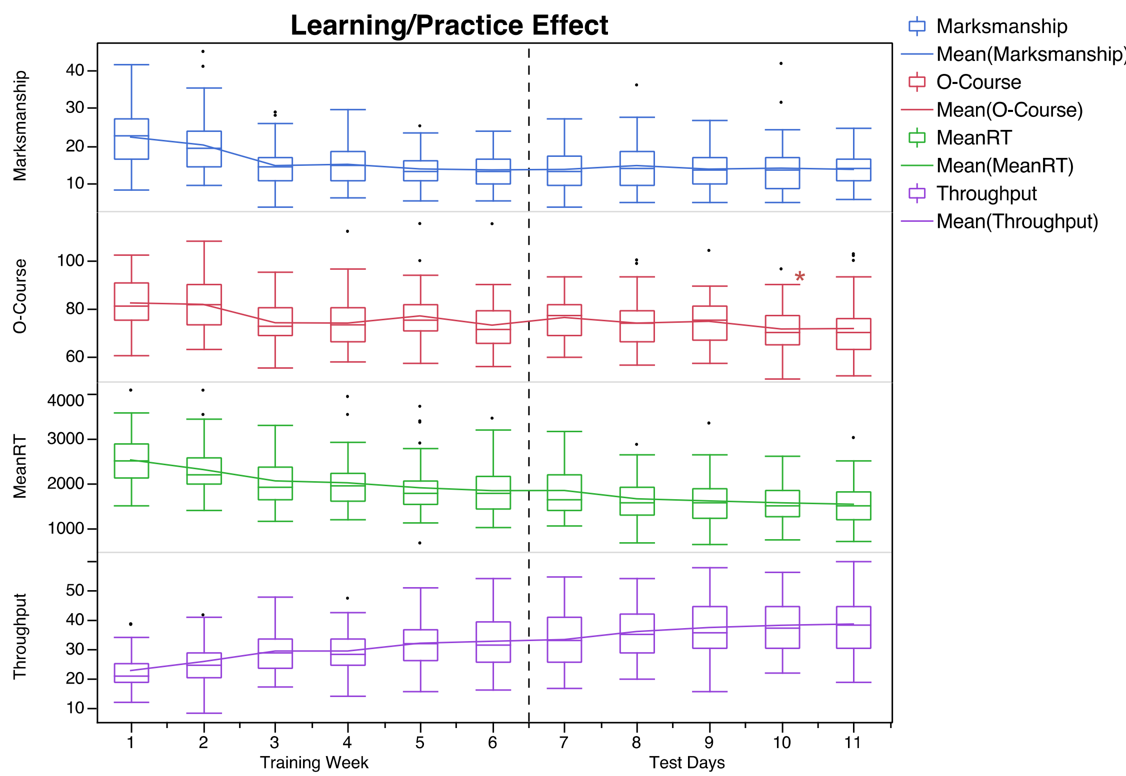

Figure 36. HAT Learning Curve.

Note: Between test days 9 and 10, there is a dip in learning in the Obstacle Course data that can be attributed to the shift in testing location from Pelican Point to Red Beach.

E. CIRCADIAN EFFECT

Testing throughout the course of the study started each day in the early morning, from 0700 to 0830, and continued throughout the course of the day. This circadian trend in the rise and decline in performance follows the natural tendencies of the neural processes controlling alertness and sleep (Mitler et al., 1988). Since the pre-treatment tests were conducted in the morning and the posttests were generally conducted in the afternoons, we found that it was important to analyze the time of day effect. In order to do so we used the data from the control condition to analyze this effect. Scores from the pre-exposure test battery were compared to scores from the post-exposure test battery.

Throughout the testing period, participants were required to report to the testing site no later than 0700, a time that is associated with an increased propensity to sleep and diminished capacity to function. Results from the HAT control condition were analyzed using three different tests: the one-sample t-test, the one-sample Wilcoxon test, and the sign test. These tests were conducted on each of the measures collected: marksmanship, obstacle course, and cognitive test battery. For all of the measures being tested, the null hypothesis for the one-sample t-test and the one-sample Wilcoxon (signed rank) test is that the average of the population from which the changes were derived should be zero, with the alternative being that the average population is something other than zero. Table 2 shows the results for each test.

Measure	***n***	**One-Sample t-test**	**Wilcoxon Signed Rank**	**Sign Test**
Marksmanship	61	$t(60) = -0.72$ $p = 0.4772$	$t(60) = -123.00$ $p = 0.3696$	$t(60) = -4.00$ $p = 0.3663$
Obstacle Course	59	$t(58) = -1.89$ $p = 0.0630$	$t(58) = -233.50$ $p = 0.0318$	$t(58) = -7.00$ $p = 0.0704$
Mean RT	60	$t(60) = -3.36$ $p = 0.0014$	$t(60) = -505.00$ $p < 0.0001$	$t(60) = -13.00$ $p = 0.0011$
Throughput	60	$t(59) = 3.66$ $p = 0.0005$	$t(59) = 473.50$ $p = 0.0003$	$t(59) = 13.00$ $p = 0.0011$

Table 2. Results for Time of Day or Circadian Effect.

Based on the data collected and the results of these tests, there is a clear indication of a time of day or circadian effect. Participants did not display a significant circadian effect in marksmanship, but the results for the obstacle course and cognitive battery did yield significant results. The circadian effect on the obstacle course was significant at $\alpha = 0.1$, while the cognitive test was significant at the $\alpha = 0.05$. The obstacle course showed that there was a significant difference between the post-treatment and pre-treatment scores indicating that the participants performed better in the afternoon than in the morning (i.e., they were faster in the afternoon than the morning). Scores for the cognitive battery were analyzed based on mean response time and throughput. There was a significant difference between the post-treatment and pre-treatment scores indicating that participants performed better in the afternoon than in the morning (i.e., the mean response time was faster and the participants got more correct responses later in the morning than in the early morning testing.

F. MOTION SICKNESS ASSESSMENT QUESTIONNAIRE (MSAQ)

Participants were administered the MSAQ twice daily throughout the testing period. The MSAQ captured participants' symptoms immediately after each exposure (0, 1, 2, and 3 hours), as well as after a one-hour recovery period. The MSAQ consists of 16 questions that the participant can answer with a score from 1 to 9, with 1 being mild or no symptoms and 9 being severe symptoms. The total MSAQ score was calculated using the following formula:

$$MSAQ\ Total = \frac{Sum\ of\ Scores}{144} * 100$$

Table 3 shows the descriptive statistics for the MSAQ data.

Test	*n*	Mean	Std Dev	Min	Max
Post-Treatment MSAQ	226	18.02	9.49	11.11	79.86
Recovery MSAQ	225	14.20	4.59	11.11	36.11

Table 3. MSAQ Descriptive Statistics.

Figures 37 and 38 display the distribution of MSAQ scores among the participants for the entire testing period.

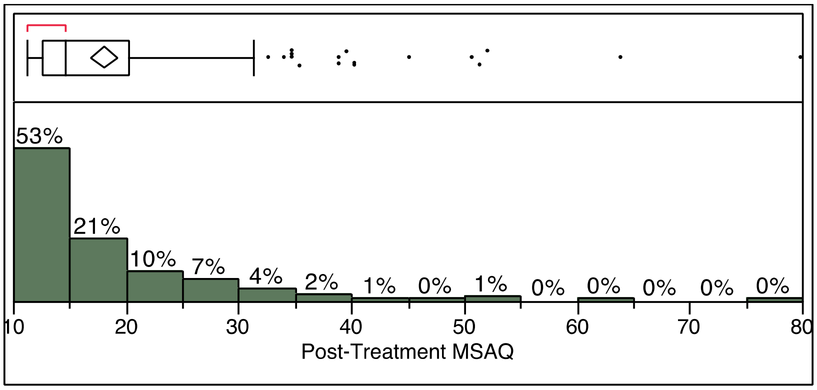

Figure 37. Distribution of Post-treatment MSAQ Scores (*n* = 226).

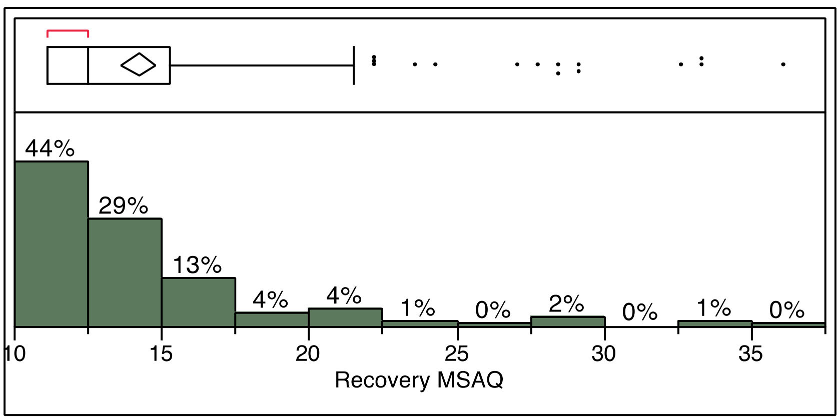

Figure 38. Distribution of Recovery MSAQ Scores (*n* = 225).

G. MARKSMANSHIP

Every day, four separate marksmanship tests were conducted for each participant. Participants took a pre-treatment test battery that included a marksmanship test before the obstacle course and the second marksmanship test after the cognitive test battery. After the participants were exposed to their treatment or control condition, they were given the same test battery. The one exception in the second battery was that participants took the MSAQ prior to their third marksmanship test. After exiting the vehicles, participants lined up in pairs to complete their third marksmanship test of the day. Since some of the participants had been out of the vehicle for several minutes before commencing the marksmanship test, we were concerned that the delay from this queuing procedure may have added variability to the marksmanship test performance.

Table 4 shows the descriptive statistics for the marksmanship data. The standard deviation for the third marksmanship test is larger than for the other tests. Marksmanship 3 was the first post-treatment test taken by the participants and any changes resulting from motion exposure would have been expected to appear in this third marksmanship test.

Test	Test Period	*n*	Mean	Std Dev	Min	Max
Marksmanship 1	0700–1000	228	13.80	5.01	3.60	36.13
Marksmanship 2	0700–1000	227	13.61	5.32	2.73	35.67
Marksmanship 3	0930–1330	217	14.63	11.31	0.48	109.89
Marksmanship 4	0930–1330	227	13.53	6.66	3.70	54.86

Table 4. Marksmanship Descriptive Statistics for All Participants on Test Days.

H. OBSTACLE COURSE

The obstacle course test was conducted twice each test day, once before treatment and again after treatment. Pre-treatment tests were conducted in the early morning, 0700–0830, while post-treatment testing was conducted in early to midafternoon. As discussed previously, the circadian effect due to the time of day that the tests occurred is a significant confound in the results.

Table 5 shows the descriptive statistics for the obstacle course data listed in minutes.

O-Course	*n*	Mean	Std Dev	Min	Max
Pre-treatment (min)	226	1.24	0.16	0.87	1.73
Post-treatment (min)	227	1.20	0.16	0.88	1.77

Table 5. Obstacle Course Descriptive Statistics for All Participants During Test Days.

I. COGNITIVE BATTERY

The cognitive battery used for this study was a subset of the ANAM. The results analyzed for this thesis were Response Time, defined as number of milliseconds before response was entered, and Throughput, defined as the rate of correct responses per minute. As shown in Figure 21 the cognitive battery was administered three times throughout the day: pre-treatment, post-treatment, and recovery one-hour after treatment.

Table 6 shows the descriptive statistics from the cognitive battery. Mean Response Time (MeanRT) was measured in msec, while throughput was measured in correct responses per minute.

Cognitive Metric	*n*	Mean	Std Dev	Min	Max
Pre_MeanRT	228	1683.92	492.17	660.33	3355.83
Post_MeanRT	227	1644.63	462.00	644.59	3200.73
Rec_MeanRT	227	1669.38	506.43	528.26	3651.59
Pre_Throughput	228	36.02	9.60	15.45	60.06
Post_Throughput	227	36.73	9.93	17.57	67.09
Rec_Throughput	227	36.18	10.04	15.25	67.78

Table 6. Cognitive Battery Descriptive Statistics for All Participants During Test Days.

J. PERFORMANCE MEASURE MODELING

Using JMP 10, the participants' performance for each test was modeled using a univariate repeated measures model. Participant numbers were included as a random effect to control for variation within subjects. Fixed effects were added to control for exposure times, MSAQ scores, daily sleep, nighttime sleep, sleep efficiency, and MEQ rating. A manual stepwise approach was used to identify significant factor effects. Using this approach, a univariate repeated measures model, with all possible covariates, was fit where covariates that were not significant were iteratively removed and added until the model with the best fit was found. When motion was included in the model, JMP treated the three-hour case as the baseline; therefore the results for the other exposure times are presented relative to the three-hour case. Also, due to the repetition of the marksmanship test both pre- and post-treatment the average of marksmanship 1 and 2 and the average of marksmanship 3 and 4 were used for analysis. The best fit was determined by the coefficient of determination and the number of significant factors.

- **Post-treatment MSAQ:** This analysis revealed that Sea Exposure Time (in hours) was significant, $R^2 = 0.50$, $F(3.171) = 10.8761$, $p < 0.0001$, with participant as a random effect making up 32.8% of the total variance. In an attempt to determine which of the conditions differed from the others, a Least Squares Means Differences Tukey Honestly Significant Differences (HSD) was conducted to analyze the different exposure times. This analysis revealed that the 0- and 1-hour exposures, while similar to one another, were significantly different from the 2- and 3-hour exposures. Table 7 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	18.18	21.71	<.0001
Sea Exposure Time (hrs)[0]	–3.87	–4.56	<.0001
Sea Exposure Time (hrs)[1]	–1.64	–1.94	0.05
Sea Exposure Time (hrs)[2]	2.65	2.97	0.00

Table 7. Parameter Estimates for Post-treatment MSAQ.

- **Recovery MSAQ:** This analysis revealed that Sea Exposure Time (hours) was significant, $R^2 = 0.68$, $F(3,166) = 5.5988$, $p = 0.0011$, with participant as a random effect making up 57.3% of the total variance. In an attempt to determine which of the conditions differed from the others, a Least Squares Means Differences Tukey HSD was conducted to analyze the different exposure times. This analysis revealed that the 0-, 1-, and 2-hour exposures were similar and the 2 and 3-hour exposures were similar, but the 3-hour exposure was significantly different from the 0- and 1-hour exposures. Table 8 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	14.25	29.46	<.0001
Sea Exposure Time (hrs)[0]	–1.06	–3.13	0.00
Sea Exposure Time (hrs)[1]	–0.46	–1.36	0.18
Sea Exposure Time (hrs)[2]	0.26	0.73	0.47

Table 8. Parameter Estimates for Recovery MSAQ.

- **Pre-treatment Marksmanship:** This analysis revealed that Daily Sleep (min) was significant, R^2 = 0.67, $F(1,185)$ = 5.9053, p = 0.0160, with participant as a random effect making up 55.8% of the total variance. This finding indicates that daily sleep predicted marksmanship performance on this test. Table 9 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	15.70	16.24	<.0001
Daily Sleep (min)	–0.00	–2.43	0.016

Table 9. Parameter Estimates for Pre-treatment Marksmanship.

- **Post-treatment Marksmanship:** This analysis revealed that Sea Exposure Time (hrs) was significant, R^2 = 0.40, $F(3,175)$ = 2.3613, p = 0.0731, with participant as a random effect making up 24.3% of the total variance. In an attempt to determine which of the conditions differed from the others, a Least Squares Means Differences Tukey HSD was conducted to analyze the different exposure times. This analysis revealed Table 10 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	13.67	23.07	<.0001
Sea Exposure Time (hrs)[0]	-0.72	-1.07	0.29
Sea Exposure Time (hrs)[1]	-1.33	-1.98	0.05
Sea Exposure Time (hrs)[2]	0.59	0.85	0.40

Table 10. Parameter Estimates for Post-treatment Marksmanship.

- **Pre-treatment Obstacle Course:** This analysis revealed that Daily Sleep (min) was significant, R^2 = 0.73, $F(1,175)$ = 7.8799, p = 0.0056, with participant as a random effect making up 64.2% of the total variance. Table 11 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	1.31	41.80	<.0001
Daily Sleep (min)	0.00	–2.81	0.01

Table 11. Parameter Estimates for Pre-treatment Obstacle Course.

- **Post-treatment Obstacle Course:** This analysis revealed that MEQ Rating was significant, R^2 = 0.75, $F(3,177)$ = 2.8997, p = 0.0365, with participant as a random effect making up 66.1% of total variance. In an attempt to determine which of the conditions differed from the others, a Least Squares Means Differences Tukey HSD was conducted to analyze the different MEQ ratings. This analysis revealed that there were no significant differences between those participants who were definite morning, moderate morning, and intermediate chronotypes. There were also no significant differences between those participants who were moderate morning, and intermediate and moderate evening chronotypes. There was, however, a significant difference between those participants who were definite morning and moderate evening chronotypes. Table 12 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	1.26	42.91	<.0001
Rating[Definite Morning]	0.16	2.37	0.02
Rating[Intermediate]	–0.07	–2.39	0.02
Rating[Moderate Evening]	–0.07	–2.61	0.01

Table 12. Parameter Estimates for Post-treatment Obstacle Course.

- **Pre-treatment Mean Response Time:** This analysis revealed that Daily Sleep (min) was significant, R^2 = 0.83, $F(1,169)$ = 4.8572, p = 0.0289, with participant as a random effect making up 76.5% of the total variance. Table 13 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	1842.20	19.53	<.0001
Daily Sleep (min)	–0.34	–2.20	0.03

Table 13. Parameter Estimates for Pre-treatment Mean Response Time.

- **Pre-treatment Throughput:** This analysis revealed that there were no significant effects and participant as a random effect makes up 80.8% of the total variance. Table 14 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	33.63	19.25	<.0001
Daily Sleep (min)	0.01	1.84	0.07

Table 14. Parameter Estimates for Pre-treatment Throughput.

- **Post-treatment Mean Response Time:** This analysis revealed that Sea Exposure Time was significant at α = 0.10, R^2 = 0.80, $F(3,166)$ = 2.5239, p = 0.0595, with participant as a random effect making up 73.2% of total variance. In an attempt to determine which of the conditions differed from the others, a Least Squares Means Differences Tukey HSD was conducted to analyze the different Sea Exposure Times. This analysis revealed that there were no significant differences between the 0-, 1-, and 2-hour exposures or the 1-, 2-, and 3-hour exposures, but there was a significant difference between the 0-hour and the 3-hour exposures. Table 15 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	1643.16	31.14	<.0001
Sea Exposure Time (hrs)[0]	–60.13	–2.23	0.03
Sea Exposure Time (hrs)[1]	–17.40	–0.65	0.52
Sea Exposure Time (hrs)[2]	11.17	0.38	0.70

Table 15. Parameter Estimates for Post-treatment Mean Response Time.

- **Post-treatment Throughput:** This analysis revealed that Sea Exposure Time was significant, R^2 = 0.84, F(3,165) = 4.3777, p = 0.0054, with participant as a random effect making up 78.6% of total variance. In an attempt to determine which of the conditions differed from the others, a Least Squares Means Differences Tukey HSD was conducted to analyze the different Sea Exposure Times. This analysis revealed that there were no significant differences between the 0-, 1-, and 2-hour exposures or the 2- and 3-hour exposures, but there was a significant difference between the 0- and 1-hour when compared to the 3-hour exposure. Table 16 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	36.75	31.63	<.0001
Sea Exposure Time (hrs)[0]	1.23	2.38	0.02
Sea Exposure Time (hrs)[1]	0.90	1.74	0.08
Sea Exposure Time (hrs)[2]	–0.45	–0.80	0.43

Table 16. Parameter Estimates for Post-treatment Throughput.

- **Recovery Mean Response Time:** This analysis revealed that MEQ Rating of Moderate Evening was significant, $t(204) = 2.11$, $p = 0.0363$, yet the MEQ Rating itself was not significant, $R^2 = 0.81$, $F(3,197) = 1.5596$, $p = 0.2005$. Participant as a random effect made up 75.1% of the total variance. In an attempt to determine which of the conditions differed from the others, a Least Squares Means Differences Tukey HSD was conducted to analyze the different MEQ ratings. This analysis revealed that there were no significant differences between participants. Table 17 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	1553.78	18.32	<.0001
Rating[Definite Morning]	–308.35	–1.66	0.10
Rating[Intermediate]	113.10	1.33	0.18
Rating[Moderate Evening]	162.91	2.11	0.04

Table 17. Parameter Estimates for Recovery Mean Response Time.

- **Recovery Throughput:** This analysis revealed that Sea Exposure Time was significant, $R^2 = 0.83$, $F(3,165) = 3.9237$, $p = 0.0097$, with participant as a random effect making up 76.5% of total variance. In an attempt to determine which of the conditions differed from the others, a Least Squares Means Differences Tukey HSD was conducted to analyze the different Sea Exposure Times. This analysis revealed that there were no significant differences between the 0-, 1-, and 2-hour exposures or the 1-, 2-, and 3-hour exposures, but there was a significant difference between the 0-hour and the 3-hour exposures. Table 18 shows the parameter estimates.

Term	Estimate	t Ratio	Prob>|t|
Intercept	36.19	31.07	<.0001
Sea Exposure Time (hrs)[0]	1.80	3.28	0.00
Sea Exposure Time (hrs)[1]	–0.19	–0.35	0.73
Sea Exposure Time (hrs)[2]	–0.30	–0.50	0.62

Table 18. Parameter Estimates for Recovery Throughput.

V. DISCUSSION AND RECOMMENDATIONS

A. DISCUSSION

The purpose of this thesis was to determine whether sleep, in addition to motion, is related to the performance of Marines embarked on amphibious vehicles. Assault landings require the transport of Marines in amphibious vehicles in potentially rough seas. Previous operational experiences and anecdotal reports during training exercises have shown how seasickness can be disabling to troops taking part in such landings (Hill & Guest, 1945). Understanding the effect of sleep on performance allows for the separation of sleep history in the evaluation of how motion affects Marines embarked on amphibious vehicles.

In order to evaluate the effect of sleep on performance, 16 days of sleep and activity data were collected from 57 Marines. Sleep history for each participant varied. As seen in the results, sleep history did have an impact on performance. A circadian effect was also observed throughout the testing period. As sleep quantity and quality increased, performance also increased. Many variables other than sleep, however, could account for changes in performance that were not analyzed during this study. These factors include caffeine intake, pharmaceutical agents, and various environmental factors.

The training week, which was designed into the experiment, allowed for near asymptotic performance on each of the tests by the participants. By the end of the week, data collectors and observers were also proficient in their tasks. This near-asymptotic performance reduced the effect of learning on the data collected.

Analysis of the data led to the building of regression models in order to determine if sleep and/or motion correlated with performance. Analysis of each model was conducted in order to answer two questions. For pre-treatment or before exposure models we sought to determine if sleep was correlated with performance. For post-treatment models we sought to determine if either sleep or motion or both was correlated with performance. A third question we sought to answer was whether or not there was a circadian effect on the performance of the participants. The answers to the first two questions are outlined in Table 19.

Model	Was sleep a significant predictor?	Was motion a significant predictor?
Post-treatment MSAQ	No	Yes
Recovery MSAQ	No	Yes
Pre-treatment Marksmanship	Yes	No
Post-treatment Marksmanship	No	Yes
Pre-treatment Obstacle Course	Yes	No
Post-treatment Obstacle Course	No	No
Pre-treatment Mean Response Time	Yes	No
Pre-treatment Throughput	No	No
Post-treatment Mean Response Time	No	Yes
Post-treatment Throughput	No	Yes
Recovery Mean Response Time	No	No
Recovery Throughput	No	Yes

Table 19. Summary of Results.

Once the sleep of the participants' was analyzed, we were able to test whether or not sleep affected participant performance on marksmanship, obstacle course, and in the cognitive battery. Analysis of the data collected and model fitting for the measures of performance suggests that daily sleep (min) predicted the participants performance on multiple tests to include: Pre-treatment Marksmanship, Pre-treatment Obstacle Course, and Pre-treatment Mean Response Time. Performance on some of the measures was predicted by MEQ rating indicating that the M-E preferences of the participants impacted their performance. MEQ rating predicted performance on Post-treatment Obstacle Course and Recovery Mean Response Time. Results indicated that there was a significant difference between those participants who were definite morning and moderate evening chronotypes in obstacle course performance. These findings indicate that sleep as well as chronotype affects the overall performance of Marines. The results also suggest that as participants received more sleep their performance increased on the various measures of performance.

Although there was an increase in performance as sleep amount increased, there was also a circadian effect that was present in the data. Unfortunately, there was no real baseline; however, analyzing performance during the control condition allowed for the identification of a circadian effect. The various statistical tests conducted revealed a definite circadian effect on three of the four measures of performance.

B. LIMITATIONS

There were many limiting factors in the study that hampered the analysis of the data. Originally, a block design was considered for this study; however, implementation of this block design was never achieved. Also, as with any field study, many external factors could not be controlled. Environmental factors, such as sea state, temperature, and sun exposure, could not be controlled. Additionally, the participants were not constantly monitored and, therefore, acted on their own accord while on liberty. This liberty allowed for inconsistency in their recreational activities and in the wearing of the activity monitors, thereby causing gaps in the data and possible differences due to activities such as drinking alcoholic beverages.

The WAM devices were also limiting factors, in that some of the devices failed and other testing devices were hampered by certain environmental factors. At least five of the WAMs failed throughout the course of the study. Due to these failures, sleep data for four of the participants were lost. Additionally, certain aspects of the performance test measurements were lost due to other faulty devices. Marksmanship scores for an entire squad were lost on one day due to glare from the sun. Obstacle course data was lost due to failed RFID Tags and some cognitive data was lost due to technological issues.

C. RECOMMENDATIONS

Based on the results of this study, it is apparent that there were various factors that were not controlled, which may have had a significant effect on performance. The importance of understanding the effects of waterborne motion on the combat performance of infantry personnel embarked aboard amphibious vehicles remains of utmost importance when fulfilling the mission of power projection. Attempting to separate the effects of sleep and motion on performance is essential to understanding the effects of waterborne motion on combat performance. For future studies, it is imperative that those external factors that were not controlled during this study be at the forefront in the development of the study design.

Based on the ages of the participants, future studies should account for the unique shift in sleeping patterns for adolescents and young adults through their mid-20s. As depicted in Figure 2, adolescents and young adults, which accounts for the majority of junior enlisted personnel, require 0.50 to 1.25 hours more sleep than their adult counterparts, and their natural waking cycle occurs during the midmorning hours (0800–0900). By adjusting the testing times to accommodate for this shift, the circadian effect experienced during this study can be mitigated.

External factors are often difficult to control; yet, for future studies, participants should be bivouacked, or placed in a temporary encampment, in which access to alcohol, pharmaceutical agents, caffeine, and tobacco can be limited. Also, by placing them in an encampment, their sleep may also be controlled in order to provide for a true baseline from which analysis could be drawn.

Although various measures of sleep were taken throughout the study, there was a lack of background data on participants in order to understand their sleeping habits as well as their sleep health. Future studies should incorporate the use of the Pittsburgh Sleep Quality Index (PSQI), as well as the Epworth Sleepiness Scale (ESS), in order to assess the participants’ sleep quality and their level of daytime sleepiness prior to beginning the study. These tests have been shown to be useful when analyzing sleep data.

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