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A COMPARISON OF SLEEP AND PERFORMANCE OF SAILORS ON AN OPERATIONALLY DEPLOYED U.S. NAVY WARSHIP

by

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September 2013

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The crew's mission on a deployed warship is inherently dangerous. The nature of the job means navigating restricted waters, conducting underway replenishments with less than 200 feet of lateral separation from another ship, and various other operations—all of which require a high level of training, alertness, and attention to detail. Performing these tasks when sailors are sleep deprived creates the potential for catastrophic incidents that can cost millions of dollars and possibly result in injury or loss of life.

This study compared the sleep and performance of sailors standing either the 3/9 or 6/6 watch rotation on a deployed warship. Results showed that not only did sailors standing the 6/6 rotation receive less sleep, but their response speeds were significantly slower than their 3/9 counterparts. Although the 3/9 participants stood half as much watch, with twice as much time off watch, they still received only 391 minutes of sleep per night, on average. Even more concerning was that the 6/6 participants received only 330 minutes of sleep per night (less than six hours per day), on average, accruing over 2.5 hours of sleep debt per night. Sleep provides a combat edge to today's warfighters. Leaders neglect it at their peril.

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A COMPARISON OF SLEEP AND PERFORMANCE OF SAILORS ON AN OPERATIONALLY DEPLOYED U.S. NAVY WARSHIP

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ABSTRACT

The crew's mission on a deployed warship is inherently dangerous. The nature of the job means navigating restricted waters, conducting underway replenishments with less than 200 feet of lateral separation from another ship, and various other operations—all of which require a high level of training, alertness, and attention to detail. Performing these tasks when sailors are sleep deprived creates the potential for catastrophic incidents that can cost millions of dollars and possibly result in injury or loss of life.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

AMI	Ambulatory Monitoring, Inc.
AOR	Area of Responsibility
FAST	fatigue avoidance scheduling tool
gm	grams
ID	identification
IRB	Internal Review Board
ISI	inter stimulus interval
LED	light emitting diode
ms	milliseconds
NA	not available
NPS	Naval Postgraduate School
NREM	non rapid eye movement
NSWW	Navy standard work week
OIC	officer in charge
OPNAVINST	Office of the Chief of Naval Operations Instruction
PSG	polysomnography
PSQI	Pittsburg Sleep Quality Index
PVT	psychomotor vigilance test
REM	rapid eye movement
RT	reaction time
s	seconds
sd	standard deviation
se	standard error
SORM	Standard Organization Regulation Manual
TST	total sleep time
TOD	time of day
USS	United States Ship

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EXECUTIVE SUMMARY

The United States Navy never stops working. "A Global Force for Good," the Navy is forward-deployed in almost every major body of water on the planet. Congressional budget cuts have reduced ship numbers and crew size, while the length of naval deployments is increasing from a traditional 6 months to as much as 10 months' duration. Not only are deployments growing longer, but the reduced crew size means that those sailors who are left work longer hours. Since the Navy operates continuously, many of its sailors are required to work in shifts to man systems around the clock. Shift work on a deployed surface combatant is unique, because when sailors are through with their watch, they do not get to punch out and head home. In fact, when sailors are off watch, there are many other requirements that are time consuming and prevent them from sleeping. These additional requirements can be training, maintenance, qualifications, and/or collateral duties. In short, deployed sailors are either at work or on call around the clock.

With smaller crews, the number of qualified personnel to stand watch is also reduced. Although crew sizes are smaller, the required number of manned watches is often not reduced. A typical workday for most crewmembers is significantly longer and the opportunity for sleep is limited. Thesis research at the Naval Postgraduate School by Haynes (2007), Mason (2009), and Green (2009) showed that most sailors are working more and sleeping less than the eight-hour per-night standard for sleep set by the Navy Standard Work Week. These studies focused on the work and rest patterns of crewmembers on several ships; however, an objective measure of performance for the crewmembers was not attempted.

This study takes the works done by these previous NPS students one step further and evaluates both the sleep and performance of a U.S. Navy surface combatant crew on an operational deployment, while the crew was working various watch-standing schedules, specifically the 3/9 and 6/6 schedules. The USS Jason Dunham (DDG 109) graciously volunteered to allow a team of researchers to come aboard for three weeks while they were forward deployed to the 5th Fleet Area of Responsibility. Participants of

this observational study wore wrist activity monitors for two weeks. They also filled out daily activity logs for every 30-minute period of each day and they completed psychomotor vigilance tests to assess alertness levels before and after standing watch.

Results showed that not only did sailors standing the 6/6 rotation receive less sleep, but their response speeds were significantly slower than their 3/9 counterparts. Although the 3/9 participants stood half as much watch with twice as much time off watch, they still received only 391 minutes of sleep per night, on average. Even more concerning was that the 6/6 participants received only 330 minutes of sleep per night (less than six hours per day), on average, accruing over 2.5 hours of sleep debt per night. Sleep provides a combat edge to today's warfighters. Leaders neglect it at their peril.

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This data collection was only made possible because of the grace and support of the leadership and crew of USS Jason Dunham (DDG-109). The willingness of the ship's leadership to allow a team to meet them halfway around the world and accompany them for three weeks to collect sleep and performance data made this experience possible.

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I. INTRODUCTION

The mission of the crew on a deployed warship is inherently dangerous. The mere nature of the job means navigating restricted waters, conducting underway replenishments with less than 200 feet of separation alongside another ship, launching and recovering aircraft, and various other operations—all of which require a high level of training, alertness, and attention to detail. The Navy estimated the cost of ship operations, support, and training to be over $700 million in 2012 (Department of the Navy, 2012); yet, despite this huge expenditure, in that same year three U.S. Navy ships collided at sea, costing millions in taxpayer dollars. With all of this training and technology available, it would seem that these collisions could have been avoided with vigilant and alert watchstanding, procedure compliance, and situational awareness. How is it possible that billion-dollar warships with advanced technology and highly trained personnel continue to see instances of collisions, groundings, and various other mishaps? The focus of this study is on the relationship between sleep, watch standers and performance of a sailor on a surface combatant that is operationally deployed.

The United States Navy never stops working. "A Global Force for Good," the Navy is forward-deployed in almost every major body of water. With congressional budget cuts and reduction in ship numbers, the length of time for naval deployments is increasing from a traditional 6 months to as much as 10 months' duration. Since the Navy operates continuously, many of its sailors are exposed to shift work. Shift work on a deployed surface combatant is unique, because when sailors are through with their watch they do not get to punch out and head home. In fact when sailors are off watch there are still a number of other requirements that are time consuming and that can prevent them from sleeping. These additional requirements can be training, maintenance, qualifications and/or collateral duties. Deployed sailors are either at work or on call around the clock.

The Navy Standard Work Week (NSSW) is broken down into various categories: messing, Sunday free, sleep time, service diversion, training, watchstanding, and maintenance (OPNAVINST 1000.16k, 2007). The NSWW calculations allot sailors 81 hours of work and 56 hours of sleep per week. Thesis research at the Naval Postgraduate

School (NPS) by Haynes (2007), Mason (2009), and Green (2009) showed that most sailors are working more than and sleeping less than is specified in the NSWW. All three if these studies point out that USN sailors are chronically fatigued.

While there have been many studies covering shift work in the civilian sector (several are discussed in Chapter II), there have been few efforts to study the effects of watch rotation on sailors who are forward-deployed. Controlled studies in sleep laboratories can provide insight into the effects of shiftwork on sleep and performance, but they may not capture the same issues faced by participants in operational environments.

Additionally, there is little guidance for how commanders should establish their watchbills to ensure that sailors receive adequate sleep. While enlisted sailors are allotted eight hours of sleep, according to the NSWW, it does not define the construction of the watchbill or management of personnel to guarantee that sailors actually receive their eight hours of sleep per night. The Standard Organization Regulation Manual (SORM), also known as Office of the Chief of Naval Operations Instruction (OPNAVINST) 3120.32d, states,

> The length of time for continuous watches is normally four hours. However, the length of assignment to a watch should be based on the conditions under which the watch is stood. The officer in charge (OIC) of the watch station shall ensure that watch standers are rotated frequently enough to stand an effective watch. (OPNAVINST 3120.32D, 2012, pp. 4–6)

Table 1 lists the standard watches for Navy units according to the SORM.

Table 1. Standard Watches in Navy Units (After OPNAVINST 3120.32D, 2012).

Time	**Watch**
0000–0400	Mid Watch
0400–0800	Morning Watch
0800–1200	Forenoon Watch
1200–1600	Afternoon Watch
1600–1800	First Dog Watch
1800–2000	Second Dog Watch
2000–0000	Evening Watch

While this information provides some guidance to commanders, it is ambiguous and leaves the responsibility with commanders to ensure that watches are rotated frequently and that the watch standers are alert and vigilant. The guidance from the SORM does not indicate whether the watch rotation in Table 1 is for a two-, three-, four-, or more section watchbill. Commanding officers are required to establish the necessary watches for safety, security, and proper operation of the command (OPNAVINST 3120.32D, 2012).

The most common factors that constrain commanders in creating watch bills are manning levels and qualifications. Unfortunately, there are times when the level of manning does not support anything more than a two-section watchbill. Some watch stations, however, have the manning and qualifications to allow for a three or four section watchbill. If manning does not support multiple sections of a watchbill, the SORM provides no guidance for how to run the ship.

When crew sizes are reduced, the number of qualified personnel to stand watch is also reduced; however, the number of manned watches is often not reduced. In order to properly man the required watch, commanders have had to become innovative and step outside the traditional watch schedules. With fewer sailors, Navy commanders have tried various alternative watch rotations in order to minimize fatigue, while maximizing crew readiness and watch-standing vigilance.

There have been several strategies and attempts to minimize fatigue-related issues in the military. In 2011, the USS San Jacinto tested a four-section watch rotation that allowed its sailors to stand watch for three hours and then have nine hours off also called the 3/9. The Naval Postgraduate School was asked to help the USS San Jacinto commander assess the effects of this 3/9 watch-standing schedule. In an NPS thesis by Roberts (2012), a survey of over 100 sailors on the USS San Jacinto assessed the alternative 3/9 watch rotation. The objective was to determine what the crew thought about the alternative watch rotation, comparing it to more traditional watch rotations such as

- five hours on/ten hours off (5/10)
- five hours on/fifteen hours off (5/15)

- four hours on/eight hours off (4/8)
- six hours on/six hours off (6/6), and
- twelve hours on/twelve hours off (12/12).

From the survey responses, Roberts concluded that the USS San Jacinto's crew preferred the 3/9 watch rotation when compared to conventional watch rotations. Roberts analyzed the predicted effectiveness of sailors for the alternative and traditional watch rotations using the Fatigue Avoidance Scheduling Tool (FAST). FAST is used to predict fatigue in transportation operations and Air Force aviation based on the quantity and quality of sleep received. He concluded that the 3/9 watch rotation provided the best predicted effectiveness for a four-section watch, that the 4/8 schedule was best for a three-section watch, and that the 12/12 schedule was best for a two-section watch (Roberts, 2012).

Yokeley (2102) took Roberts' findings and conducted a study on another surface combatant, the USS Jason Dunham, in an attempt to empirically assess differences in the sleep and alertness of crew members working the alternative 3/9 watch rotation compared to a traditional 5/15 watch rotation. Like Roberts, Yokeley also concluded that the sailors preferred the 3/9 rotation. Yokeley's results also supported Roberts' findings on alertness, concluding that there were measurable performance benefits to the 3/9 when compared to the 5/15 (Yokeley, 2012).

This study takes the works done by previous NPS students one step further and evaluates the sleep and performance of a U.S. Navy surface combatant crew on an operational deployment, while operating on various watch-standing schedules, specifically the 3/9 and 6/6. Chapter II reviews the scientific literature related to the study. Chapter III describes the methods used in this study, while Chapter IV has the results of the analysis. Chapter V discusses the results and concludes with recommendations for future work.

II. LITERATURE REVIEW

A. SLEEP

Sleep is an essential part of life for humans. While there are many definitions, there is a common understanding of what is meant by the term “sleep.” According to The Free Dictionary online (2009), sleep is defined as

> a period of rest for the body and mind, during which volition and consciousness are in abeyance and bodily functions are partially suspended; also described as a behavioral state, with characteristic immobile posture and diminished but readily reversible sensitivity to external stimuli.

The average person requires an average of eight hours of sleep per night. An eight-hour sleep period consists of approximately four to six 90-minute cycles (see Figure 1). There are two types or “states” of sleep: non rapid eye movement (NREM) and rapid eye movement (REM). NREM can be further broken down into five distinct stages: stage 0 (awake) and stages 1 through 4, which represent increasingly deeper levels of sleep (Miller & Firehammer, 2007).

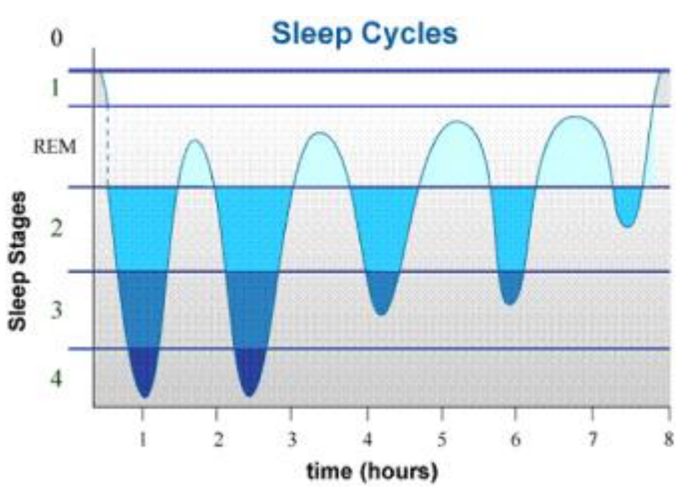

Figure 1. Sleep in the normal adult human (From Miller, Matsangas, & Shattuck, 2008).

The NREM stages of sleep can be described as progressively deeper levels of sleep. The REM stage can be easily recognized as the stage where the eyes dart back and forth rapidly and in which dreams commonly occur. Both REM and NREM stages are important and serve unique purposes.

B. CIRCADIAN RHYTHMS

A person's physiological processes fluctuate over time. This fluctuation is referred to as a biological rhythm. The "oscillations" of activity over a 24-hour period are known as circadian (circa = about and dian = day) rhythms (see Figure 2). Every individual has a unique biological rhythm, although the general pattern conforms to a 24-hour period (Anch, Browman, Mitler, & Walsh, 1988).

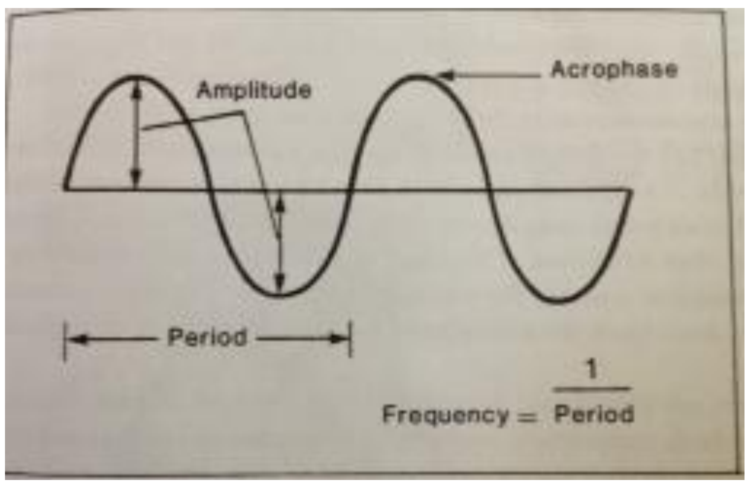

Figure 2. A hypothetical biological rhythm (From Anch et al., 1988).

"Homeostasis" is defined as the ability or tendency of an organism or cell to maintain internal equilibrium by adjusting its physiological processes ("Homeostasis," 2009). The body maintains internal conditions such as body temperature, blood pressure, and amount of sleep received in the last_24 hours. The homeostatic process and circadian process combine to determine the onset and offset of sleep. The homeostatic process controls the drive for sleep. As time awake increases and the "homeostat" is above a certain level, sleep is triggered. When it drops below a certain level, wakefulness is triggered. The circadian process represents the daily oscillatory component in the drive for sleep and wakefulness (Van Dongen & Dinges, 2005).

"Zeitgebers" (German for time-givers) are environmental influences that help align an individual's biological rhythm to the earth's 24-hour, day-night cycle. Examples of zeitgebers can be things like light, temperature, social interactions, pharmacological manipulation, exercise, and eating/drinking patterns. The prevailing zeitgebers, along with continuous rotating watch rotations, can make it difficult for sailors to properly adjust and establish a biological rhythm. Anch et al. (1988) writes:

> The range within which this can occur, known as the 'range of entrainment,' is approximately 22 to 26 hours, depending upon the zeitgeber strength. Beyond this range the individual will be out of synchrony with the demands of the environment. (pp. 66–67)

Rapid time shifts also create changes in the biological rhythm, referred to as jetlag or phase shifting. It has been discovered that phase shifts occur more rapidly when traveling from east to west (also known as "phase delay"), than after a "phase advance," traveling from west to east. Resynchronization can take a day for every one to two time zones crossed, with resynchronization being 50% faster for westward flights (Anch et al., 1988).

C. FATIGUE

"Fatigue" is easily defined for physical materials since failure due to physical fatigue can be measured or observed through dislocations and deformations (Ackerman, Calderwood, & Conklin, 2012). Humans, however, often suffer from two different types of fatigue: physical fatigue, similar to that which physical materials deal with, and cognitive fatigue. Cognitive fatigue can be very difficult to define. Partially because of the difficulties in defining cognitive fatigue, it is difficult to measure. Hancock, Desmond, and Matthews (2012) define fatigue "as a lack of sufficient steady state energy to power physical and/or cognitive work" (p. 67).

Measuring an individual's level of fatigue can be as difficult as defining fatigue, in part, due to differences in individuals and the task they are performing. In fact, an individual's level of interest in the task they are performing can play a very important role in the amount of time they are able to remain on task, known as “time on task.” Individuals are able to play various games and read for pleasure for hours on end without any obvious fatigue, but when similar tasks are given by authority figures and there is a lack of interest, then fatigue will often follow (Ackerman et al., 2012).

If adequate sleep is not obtained, then human performance suffers from the effects of sleep deprivation. Cognitive performance is seriously hindered by sleep deprivation and multiple studies have linked cognitive performance to the amount of sleep received (Belenky et al., 2003;Van Dongen, Maislin, Mullington, & Dinges, 2003). Studies have shown that even one to three hours of sleep deprivation per night for a seven-night period required more than three days of eight hours’ time in bed to restore performance to base levels (Belenky et al., 2003).

Dawson and Reid (1997) conducted a counterbalanced experiment of alcohol intoxication and sleep deprivation of 40 participants. In the sleep deprivation condition, participants were asked to remain awake for a period of 28 hours. In the other condition, they were to consume 10-15 grams (gm) of alcohol every 30 minutes until they reached a blood alcohol level of 0.10%. Every 30 minutes, psychomotor performance was measured in both conditions. Linear regression analysis showed a significant correlation between performance and hours of wakefulness, accounting for about 90% of the variance. The results of the study showed a significant correlation between mean blood alcohol level and performance, accounting for about 70% of the variance. Comparing the rate of performance decline between wakefulness and alcohol consumption, respectfully, the researchers concluded that each hour of wakefulness between 10 and 26 hours was equivalent to the performance decrement observed with a 0.004% rise in blood alcohol concentration. At this rate, in just 17 hours of wakefulness, an individual’s psychomotor performance decrement would be equivalent to that of an individual with a blood alcohol level of 0.05% (see Figure 3) (Dawson & Reid, 1997).

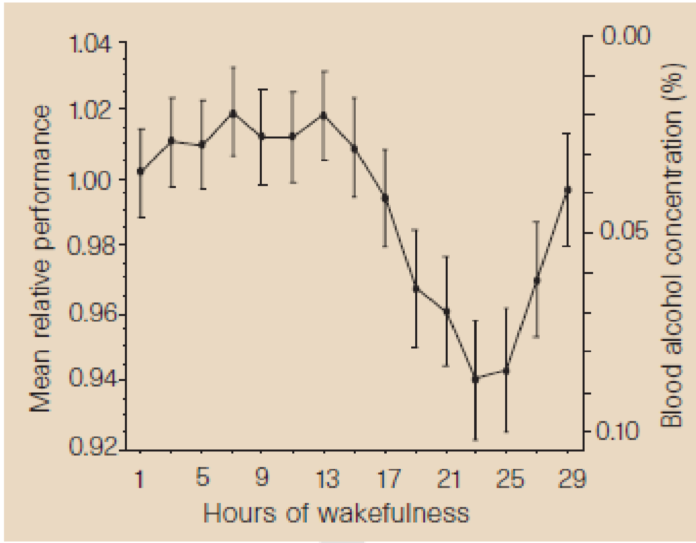

Figure 3. Performance in the sustained wakefulness condition expressed as mean relative performance and the percentage blood alcohol concentration equivalent. Error bars ± s.e. (From Dawson & Reid, 1997).

D. SHIFT WORK

Shift work is a way of scheduling work so that workers can continually provide services or production, usually 24 hours a day. Millions of Americans are working full time on evening shift, night shift, rotating shift, or some other irregular shift.

In addition, another shift-work consideration is that workers can either be on a rotating shift or a nonrotating shift. A rotating shift is one in which their work hours change from working days to nights, days to evenings, evenings to days, etc. A nonrotating or permanent schedule is one in which a person works the same shift each work day (e.g., they only work evenings or nights). Wilkinson (1992) categorizes shiftwork into four speeds of rotation:

- Rapidly rotating, where people never spend more than one, two, or three successive days on the night shift before they rotate and spend equal amounts of time either off, on morning shift, or on afternoon shift, before returning to work.
- Weekly rotating shift, where the rotation adheres to the work week. An example would be working week days with the weekend off, cycling morning, evening, and night shifts every week.

- Prolonged night shift, which requires weeks or even months on the night shift, with intervening days off throughout and with the whole interleaved with correspondingly longer working periods of continuous day shifts.
- Fixed shift, where a portion of the workforce spends all of their working time on the night shift.

As an alternative to weekly rotations, Wilkinson (1992) reported that permanent or slowly rotating night shift systems are better than rapidly rotating schedules in terms of sleep duration, performance, health and absenteeism, and personal satisfaction. The issue Wedderburn (1992) has with Wilkinson's (1992) findings is the lack of support and implementation. If, in fact, permanent night shifts are the preferred method, then why is there still an abundance of rotating shifts in the workforce—on the order of three times as many rotating shifts compared to permanent shifts (Wedderburn, 1992). Wedderburn suggests, "An alternative and equally plausible inference is that it is extremely difficult, and perhaps impossible, to reproduce in the laboratory the motivation, teamwork, practice and realistic consequences or work in a factory" (1992, p. 1448).

It has also been argued that permanent night shifts are better than rotating night shifts (Folkard, 2008). The thought is that permanent night shifts will allow the body's circadian rhythm to adjust. If a permanent night shift worker can adjust their circadian rhythm, then the health and safety issues that come with rotating night shift work are minimized (Folkard, 2008). In 2008, Folkard conducted a review of real-life studies that concentrated on the adjustments of the circadian rhythm in melatonin in permanent night workers. Folkard (2008) explains:

> It follows that if a night worker's melatonin level is completely adjusted to his/her work schedule, then melatonin should remain at baseline levels during the entire course of the night shift, and the peak in melatonin should occur about 2–3 h after daytime sleep onset. (p. 218)

A search through various databases allowed Folkard to narrow his findings to six relevant studies, which are listed in Table 2.

Table 2. Summary of the Results of the Studies Pertaining to the Adjustment of the Melatonin Rhythm to Permanent Night Work (After Folkard, 2008).

Study	Lighting Conditions	Male	Female	Substantial	Completed
Waldhauser et al. (1986)	Normal	2	0	1	0
Sack et al. (1992)	Dim	2	8	3	0
Roden et al. (1993)	Normal	9	0	1	0
Koller et al. (1994)	Normal	14	0	2	1
Weibel et al. (1997)	Dim	11	0	4	0
Dumont et al. (2001)	Dim	3	27	5	1
Total		41	35	16	2

Folkard's (2008) review pertaining to the adjustment of the circadian rhythm in the secretion of melatonin to permanent night work concluded with these findings:

- "Only a small minority (<3%) of permanent night workers show evidence of 'complete' adjustment" (p. 215).
- "Less than a quarter (21.1%) of permanent night workers shows evidence of sufficiently substantial adjustment to derive any real benefit from it" (p. 215).
- "There is no evidence of a gender difference in the adjustment to permanent night work" (p. 215).

In summary, the studies and data did not support the idea that the use of permanent night shifts results in a complete circadian adjustment for the majority of individuals (Folkard, 2008).

In 2005, Rouch, Wild, Ansiau, and Marquié (2005) conducted a study of 3,237 workers (1,660 males, 1,577 females), who were either 32, 42, 52, or 62 years old, to examine the relationship between shift work and cognitive efficiency and to assess the hypothetical mediating role of sleep quality in this relationship (Rouch et al., 2005). The study's aim was to answer three questions:

- "Do current shift workers show lower cognitive functioning as compared with workers who never worked on shift and former shift workers?" (p. 1284)
- "Do the effects of shift work depend on exposure duration and worker's age?" (p. 1284)

- “Are these hypothetical cognitive decrements reversible? In other words, is cognitive performance influenced by the length of the time since former shift workers have returned to a normal schedule?” (p. 1284)

Participants completed questionnaires on their shift work and sleep histories and took cognitive tests. The shift-work questionnaires contained questions regarding how often participants went to sleep after midnight, how often they rose prior to 5:00 am due to shift work, and any issues they may have in sleeping through the night. On a four-point scale, participants were asked to list the frequency in the last month of the following: difficulty initiating sleep, difficulty staying asleep, difficulty getting back to sleep, early morning awakening, and hypnotic medication use. Tests of memory, digit-symbol substitution and selective attention were used for the cognitive portion of the study.

Using linear regression and adjusting for age, Rouch et al. (2005) were able to assess the relationship between exposure to shift work and sleep. They concluded that males currently on shift work had a lower cognitive performance than workers who have never been on shift work and, as the duration of the shift work increased, performance decreased (Rouch et al., 2005). There was, however, no such relationship observed for women. Both men and women who had stopped working shifts for more than four years showed higher memory test scores than those who had stopped shift work within four years of the study (Rouch et al., 2005).

Rouch et al. go on to discuss how the study shows evidence that shift work adversely affects cognitive functioning, especially for men who are currently on shift work and have been practicing shift work for 10 to 20 years. Their study suggests that there is a link between cognitive functioning and chronic exposure to shift work. While there is evidence in their study to support this idea, the evidence is inconclusive. Due to limitations in their study, the authors suggest that one must be cautious when drawing such conclusions (Rouch et al., 2005).

In 2005, Shen, Botly, Chung, Gibbs, Sabanadzoviz & Shapiro conducted a study of 489 workers from a major Ontario, Canada employer through a series of subjective, self-reported questionnaires, including the Fatigue Severity Scale and the Epworth Sleepiness Scale, in an attempt to determine whether shift work differentially affects fatigue and sleepiness (Shen et al., 2006). Shen et al. (2006) argue, "There is no 'gold standard' test for fatigue and a consensus has yet to be achieved in the literature with regard to an adequate definition" (p. 1). Their study found a low correlation between workers' subjective fatigue and sleepiness scores. This finding supports the idea that sleepiness and fatigue are distinct and independent phenomena (Shen et al., 2006).

Shen et al. (2006) concluded that the frequency of shift work had a significant effect on fatigue. There is no one single schedule or watch rotation that is recommended for all shift workers in civilian or military environments. There are several different watch rotations used on deployed surface combatants. The type of rotation can be dictated by issues such as the number of qualified personnel, the amount of work required to be accomplished. It is important to understand, however, the effects that shift work can have on personnel so that it can be monitored and properly managed by supervisors. A schedule that is prepared without knowledge or consideration of its effects can lead to fatigued workers with acute and/or chronic sleep deprivation.

It is ironic that while many night shifts have fewer and less experienced workers than day shifts, the potential risk for serious error and accidents or injuries on the night shift may actually be higher and should not be underestimated (Folkard & Lombardi, 2009). Fatigue has served as a major contributor to many industrial mishaps such as the Three Mile Island, Pennsylvania; the Bhopal, India chemical spill; Chernobyl, Ukraine; and Exxon Valdez disasters, all of which occurred during the night. Folkard argues that the nature of the job being performed, level of supervision, and number of workers can vary throughout the 24-hour day and, therefore, cannot be compared across different shifts, since fewer accidents would be expected for the night shift (Folkard, 2008). Folkard believes that if current models are to be refined, there should be three factors: a nonlinear relationship between fatigue and relative risk, a cumulative fatigue effect, and the time of day in which sleep occurs (Folkard, 2008).

With shifts spanning a 24-hour day, it is not uncommon to find personnel who are just ending a night shift, with little or no sleep, driving home from work in the early morning. In 2004, Akerstedt et al. (2005) conducted a driving simulator study of five male and five female shift workers to measure impaired alertness and performance while driving home from the night shift. In their study, driving performance was measured in this way: if two wheels crossed left or right of the line defining the lane, it was classified as an incident; but, if all four wheels crossed left or right of the lines defining the lane, then it was classified as an accident. To establish a baseline, each person would drive in the simulator once after a night of sleep and once after a night at work, with three days between the two simulated drives. The study showed that participants driving after a night shift were sleepier, had longer blink durations, and more accidents when compared to the base case. While it is possible that the simulator itself could have a larger effect on the fatigued participants than actual driving, Akerstedt et al. (2005) conclude that the night shift does have an impact on impairment of alertness and performance.

The costs saved by companies through the implementation of shiftwork may very well be paid at the expense of their employees' health (Tucker & Folkard, 2012). Regardless of the attempt to maximize sleep and reduce fatigue, workers who are working on the night shift will suffer from more fatigue than typical day workers. Shift workers are not afforded the same opportunities for sleep, rest, and recovery as their counterparts who are not shift workers. The inability of shift workers to properly rest and recover may be very detrimental to their performance and increase the chance of making a mistake, which can result in an accident. Furthermore, prolonged exposure to these conditions may impact an individual's physical and psychological well-being (Tucker & Folkard, 2012). Tucker and Folkard (2012) conclude that individuals engaged in shift work, particularly night work, experience greater fatigue than daytime workers. While many issues with shift work cannot be eliminated, it is possible, with the help of research, that a shift-work system can be designed that will minimize the issues of fatigue, rest, and recovery time. Tucker and Folkard (2012) state, "There can be no such thing as a 'good' shift system, but better shift systems are those which minimize the build-up of fatigue, maximize the dissipation of fatigue through rest, and minimize sleep and circadian disruption" (p. 464).

Shift work affects individuals outside the actual shift-work period through their sleep habits. A recent study by Monk et al. (2013a) explored how shift-work exposure during one's working life carried over to sleep quality and quantity during retirement.

This study consisted of 1,113 subjects, whose ages ranged from 65 to 94 years old, who participated in a telephone survey of 20-30 minutes. The participants were broken down into three sections based on their shift-work exposure in years [0 years (n=387), 1-15 years (n=371), and >15 years (n=355)]. Shift work was the major independent variable in the study, while the Pittsburg Sleep Quality Index (PSQI) was the primary dependent variable. PSQI is a questionnaire that assesses the quality of sleep and sleep disturbances over a one month period. The PSQI results can range anywhere from 0-21, with poorer sleep associated with higher numbers. Any number over five was considered as an indication of possible sleep issues. The participants were asked questions regarding their exposure to shift work, the duration of their shift work, and general health questions. Participants also answered questions about their current sleep habits. One interesting finding was that there was a significant effect of shift-work exposure on PSQI; the 0 year group had lower PSQI scores than the 1-15 years group. Ironically, the study supported a smaller shift-work exposure effect in the > 15 years group. This finding supports the theory of "survivor effect." That is, those participants who were able to stay on shift work for greater than 15 years without any day shifts may make up a special group of personnel that are less affected by their sleep in retirement, explaining their slightly lower PSQI scores compared to the 1-15 years group. The study concluded that shift-work exposure was associated with poorer sleep when compared to retired senior day workers (65+ years) (Monk et al., 2013a). Researchers believe this difference may be due to a change in the relationship between habitual sleep timing and the phase of the circadian pacemaker (Monk et al., 2013a).

Curious to see if the finding would hold up when using polysomnographic (PSG) measures of sleep, Monk invited all personnel who completed the phone interview to participate in a 36-hour laboratory study. The study involved continuous core body temperature measurements and two nights of PSG to determine if the retirees' circadian temperature rhythms differed as a function of shift-work exposure. After the study, the participants were divided into four shift work exposure groups: 0 years (i.e., no exposure to shift work), 1 to 7 years, 7 to 20 years, and 20+ years. Sample sizes were 11, 16, 15, and 15, respectively. As the shift-work exposure increased, so did the percentage of participants who received less than 80% sleep efficiency. In fact, total sleep time (TST) < six hours were 36%, 56%, 53%, and 73%, respectively (P, 0.01). This study confirmed the telephone survey results, concluding that is likely that shift work may be related to a scarring of sleep and circadian rhythms (Monk et al., 2013b).

E. ACTIGRAPHY

Actigraphy is a noninvasive way of quantifying human movements that help researchers to differentiate between rest and wake states. For three decades, wrist-worn monitors that record actigraphy have allowed researchers to study sleep/wake patterns. With advances in technology, actigraphs have become small, wearable devices able to record actigraphy for extended periods of time. Some devices can record actigraphy for as long as six months. The actigraphs have small accelerometers that are able to detect the number of movements in a given amount of time. This movement can be stored on the actigraphs and then downloaded to computers. The actigraphy can be displayed in an actigram, which shows the amount of activity over a period of time. Since the body is less active when sleeping, the level of activity can then be used to determine rest and wake periods. While actigraphy is not as accurate as PSG, which is known as the "gold standard" for measuring sleep, it has been proven to provide a noninvasive and cost-effective method to accurately estimate durations of sleep (Mullaney, Kripke, & Messin, 1980). While actigraphs often overestimate sleep, they are still more reliable than self-reported sleep logs, which are dependent on the participant's recollection of their sleep periods (Ancoli-Israel et al., 2003).

F. PSYCHOMOTOR VIGILANCE TEST (PVT)

From the above literature, it is obvious how important sleep is and that acute and chronic sleep debt can affect one's ability to maintain focus or conduct detail oriented tasks. Reaction time (RT) provides one way to show the impact of sleep loss on performance during sustained work. In 1985, Dinges and Powell set out to see if the PVT could be used as an indicator for sleep tendencies and overall performance capacity during sustained operations. The stimulus was a four-digit clock in milliseconds displayed on a small light emitting diode (LED). Participants would respond by depressing a button as soon as they noticed the stimulus. The system would record their RT in milliseconds (ms). Dinges and Powell (1985) concluded:

> Rather simple portable RT devices, such as those devised by Wilkinson and Houghton (1982), hold considerable promise for providing an index of sleep tendency, if the data are analyzed to yield the maximum information. Automation of appropriate analyses further enhances the practicality of these devices. (p. 654)

Like the VRT, the psychomotor vigilance test (PVT) is a sustained-attention, RT task that measures the speed with which subjects respond to a visual stimulus.

Studies have shown that restricted sleep periods result in deficits in cognitive performance on tasks such as the PVT (Van Dongen, Maislin, Mullington, & Dinges, 2003). In 2003, Belenky et al. conducted a sleep dose-response study of 66 volunteers who received three, five, seven, or nine hours' time in bed daily for a one-week period. The week of restricted sleep was followed by three days of recovery where the participants received eight hours of time in bed. Not only was there a noticeable difference in the mean RT based on the levels of sleep, but even with three days of recovery, the five-hour and seven-hour levels did not completely recover to the baseline, while the nine-hour group remained the same and the three-hour doses showed dramatic improvement after only one day of recovery sleep (see Figure 4) (Belenky et al., 2003). Similar results were observed when sleep doses of four, six, and eight hours were given for a period of 14 days, with three days of baseline and three days of recovery sleep (Van Dongen et al., 2003).

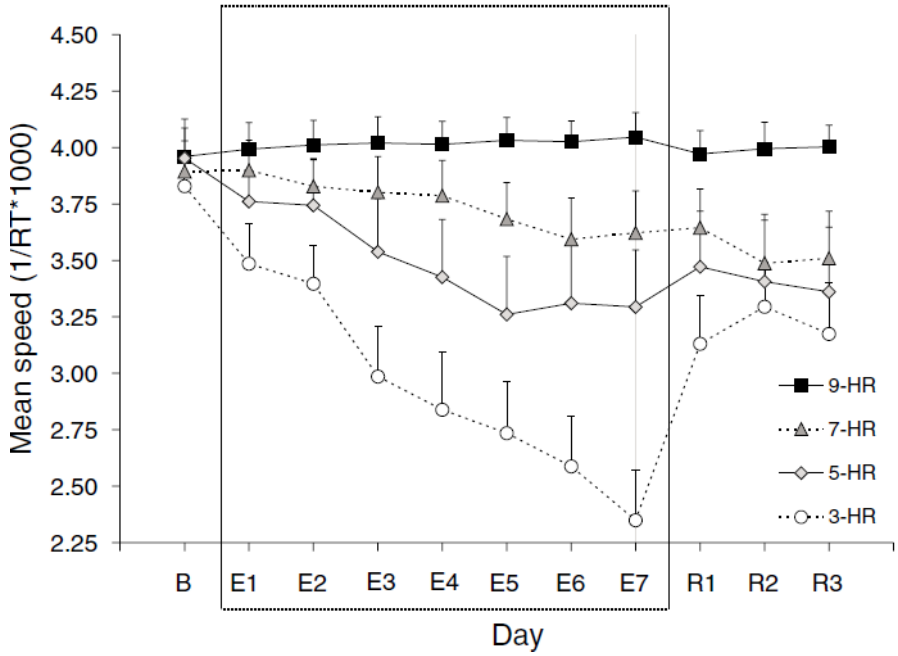

Figure 4. Mean psychomotor vigilance task speed (and standard error) across days as a function of time in bed group (From Belenky et al., 2003).

While the PVT offers an inexpensive way to measure cognitive performance with time on task, one issue is that a 10-minute PVT can be quiet burdensome, especially for sailors who are deployed and cannot always dedicate a full 10 minutes in a quiet, nondistracting environment to conduct a PVT. Advances in technology have allowed the devices that house and conduct the PVT to become smaller and more portable—in some cases, even wearable—such as the Ambulatory Monitoring, Inc. (AMI) motionlogger watch.

Understanding the difficulties and constraints of a 10-minute PVT in 2005, Lamond, Dawson, and Roach (2005) conducted a study of 15 participants to see if options like the AMI motionlogger PVT-192 are a viable option instead of the 10-minute PVT. Lamond et al. (2005) concluded that a shorter PVT not only minimizes the impact on the day-to-day lives of the individuals participating in the studies, but it is a useful substitute to the 10-minute PVT under the following conditions:

- "a shorter test is required due to time restraints, or to increase the number of tests that can be performed" (p. 489)

- “a small, convenient device (i.e., that is easy to transport and carry around) is required” (p. 489)
- “a large number of devices are needed” (p. 489)
- The results of this study allow researchers to use the PVT in the field and conduct sleep studies on individuals in their natural setting.

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III. METHODS

A. STUDY DESIGN

1. Overview

While other sleep studies and surveys have been conducted aboard surface combatants, rarely have these studies captured sleep data of individuals while in a deployed status. Work-ups and mini-underways involve activities similar to actual underways and prepare the crew for what may be seen while forward deployed; however, they often involve simulated activities, do not have the same real-world effects, and are usually much shorter in duration. In order for this study to successfully describe performance and sleep in actual deployed conditions, it was essential to find a surface combatant that was forward-deployed. Building on the relationship that NPS had established with the crew of the USS Jason Dunham, their leadership and crew allowed a team of researchers to come onboard while they were forward deployed to the 5th Fleet Area of Responsibility (AOR). The team was onboard for a three-week period in November-December 2012.

Due to the ship's schedule, manning requirements, and the timing of the study, it was not possible to make this data collection a controlled experiment. Instead, it provided an opportunity to observe sailors while operationally deployed. The team of researchers was unable to establish a baseline for sleep or PVT performance for any of the participants. While it would have been beneficial to have a controlled environment where baselines could be established, the unique opportunity of collecting data underway could not be passed up.

The underway period followed a short port visit to Dubai and lasted from November 30, 2012 to December 19, 2012. The first few days of the underway were used to brief the leadership of the ship, ensuring them that the study would take a backseat to any and all operational commitments and, to the extent possible, would not be obtrusive to the crew or the ship. The last few days of the underway were used to collect the sleep devices, upload the data on laptop computers, and then put together a summary brief with initial findings for the leadership of the Jason Dunham.

2. Variables

This study was observational in method, and involves human subjects. Knowing the important role of the human into system effectiveness, careful consideration was given to the selection of the variables for the current study. The dependent variables for this study were sleep duration and PVT performance. The independent variables for this study were watch rotation, watch section, day of the week and pay grade. Other variables of interest included gender and rank.

3. Institutional Review Board (IRB)

The study was submitted to the NPS Institutional Review Board (IRB) for review and approval. The IRB determined that the study and its methods posed little risk or inconvenience to the individual participants and the approval for the study was subsequently granted.

Prior to beginning the study, prospective study participants were recruited with a presentation given by Dr. Nita Lewis Shattuck. This briefing included a detailed description of the requirements of the study participants, the data collection methods, and potential inconveniences or discomforts that participants might experience. Participants were also told that participation was completely voluntary and that no reprisal would be given for declining to participate. All participants signed consent forms indicating their intention to participate in the study. A copy of the NPS Consent to Research Form can be seen in Appendix B.

B. PARTICIPANTS

The study included 122 participants standing 3/9, 6/6, 12/12, 4/8, and 6/18 watch rotations in various locations onboard the USS Jason Dunham, an operationally deployed U.S. Navy surface combatant. This thesis compares the sleep and PVT performance of those sailors standing the 6/6 and 3/9 watch rotation who were wearing AMI motionloggers to record sleep and PVT performance. Initially, there were 13 participants standing the 6/6 watch rotation and 37 participants standing the 3/9 watch rotation, for a total of 50 participants for this individual study. Participants 3098 and 3015 voluntarily withdrew from the study. Due to equipment malfunction, participants 3037 and 3074 were not included. A lack of participation and insufficient PVT or actigraphy data from participants 3008 and 3014 did not allow the inclusion of their data; therefore they were excluded from the study. Participants 3021, 3032, 3066, 3067, 3073 and 3082 were excluded since they switched watch sections or watch rotations during the middle of the study. Two participants, 3004 and 3050 were not standing a traditional 6/6 watch and were on call during their watch times; therefore, they do not accurately represent the traditional 6/6 watch rotation and were excluded. Participants 3024, 3028 and 3048 removed their watches during sleep episodes and an accurate account of their sleep was not able to be calculated, so they were excluded from this study. After removing the participants from this study for the above reasons, only 33 participants (23 males, 10 females; average age 28.56 years, standard deviation [sd] = 4.911 years) remained. Of these 33 participants 3016 and 3022 failed to complete at least one PVT per day and their data were excluded from PVT analysis. Participants stood watch in one of two watch rotations: 3/9 (24 participants) or 6/6 (9 participants). The watch rotations were broken down into four sections for 3/9: 0000-0300 (4 participants), 0300-0600 (5 participants), 0600-0900(6 participants) and 0900-1200 (9 participants) and two sections for 6/6: 0000-0600 (5 participants) and 0600-1200 (4 participants). The participants varied in rank from E-4 to O-3: officers (13 participants) and enlisted (20 participants). See Appendix A for a complete list of data by participant identification (ID).

1. Demographics

With the ship's company and attached air department, the USS Jason Dunham had a crew size of approximately 300. The 33 participants of this study, all of whom were ship's company, made up about 11% of the total Jason Dunham crew. Approximately 70% of the participants were male, while 60% were enlisted (see Figure 5). Just over 70% of the participants were standing the 3/9 watch rotation, while the remaining participants were standing the 6/6 watch rotation. See Figure 6 for a breakdown of participants by watch section, with their respective watch rotations.

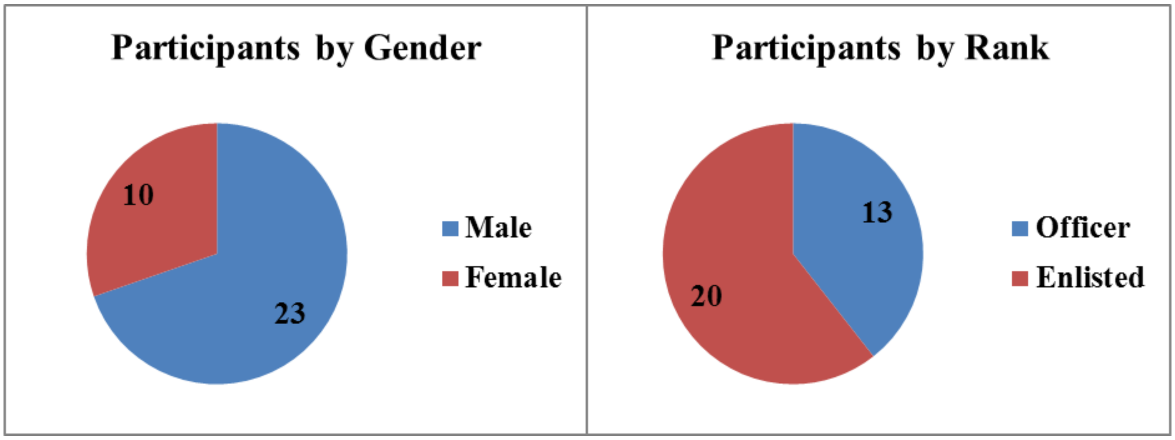

Figure 5. Study Participants by Gender and Rank.

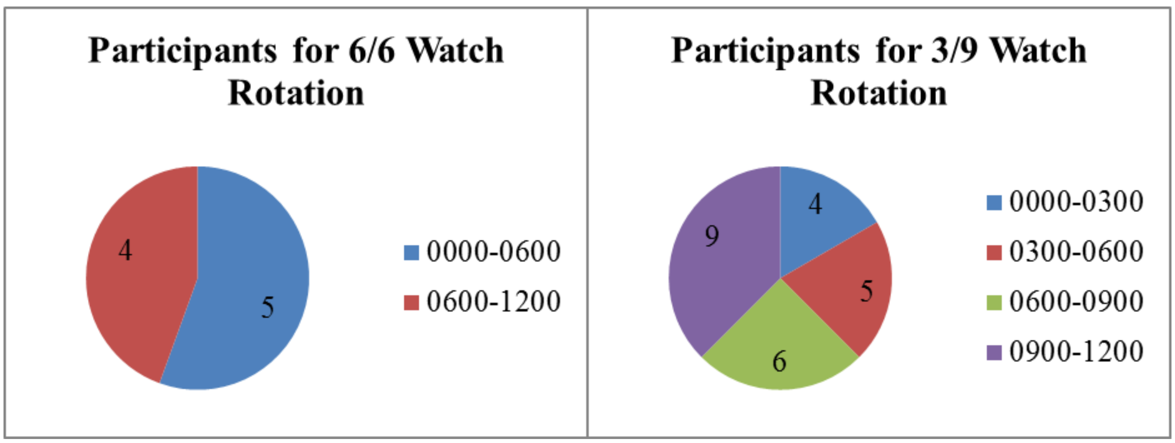

Figure 6. Participants by Watch Rotation and Watch Section.

C. APPARATUS

1. Actigraphy

Actigraphy data were collected using AMI motionlogger actigraph watches. Motionlogger actigraph watches were configured to collect data using zero crossing mode, life measures, events, and PVTs. Watch modes were set to show the date and the backlight feature was activated, with a duration of one second. Activity was recorded in one-minute epochs. The motionlogger recorded the number of movements or activity in one-minute periods; that count was then used in a sleep algorithm to determine if the participant was asleep or awake. The watches were handed out on December 3, 2012. The study lasted for a period of two weeks and all watches were collected on December 17, 2012.

2. PVT

PVT performance data were collected utilizing the PVT-192 feature on the AMI watches. PVT length was set to three minutes and inter stimulus intervals (ISI) varied randomly from 2 to 10 seconds. A red backlight appeared for one second and the letters "PUSH" were used as visual stimuli; the response time was then displayed in ms.

3. Activity Logs

Every participant was handed a daily activity log that corresponded to categories of the NSWW. These logs covered a 24-hour period and were in 30-minute intervals, allowing each participant to document individual activity throughout the study (see Appendix C).

4. Equipment and Programs

Actigraphy and PVT data were downloaded from the watches on one of three Dell laptops using the USB ACT-IR2000UL (ACTiSYS IR wireless interface) and Motionlogger WatchWare Version 1.94.2.0. Three Dell Latitude E6330 computers were time synchronized and loaded with the following software to support the initialization, download, and analysis of the actiwatch data: Respironics Actiware 5.70.1, Motionlogger WatchWare Version 1.94.2.0, REACT-PVT 192 Data Analyzer 1.1.05, Action 4 Version 1.16, Action-W Version 2.7.1150, and FAST Version 2.2.47T.

D. PROCEDURES

1. Actigraphy

The motionlogger devices were handed out after a presentation by Dr. Shattuck to the participants on December 3, 2012 and then collected at the end of the study on December 17, 2013. This allowed for a two-week observation period. After signing the consent form and receiving their watch, participants were given a demonstration on the functions of the watches. Individuals were asked to wear the watch for the duration of the study, although they were permitted to remove the watch for showers and physical fitness activities. If the participants removed the watch, they were asked to annotate the times of the removal on their daily activity logs. All participants were asked to stop by the mess decks daily (either during breakfast, lunch, or dinner) so that a visual inspection could be conducted of their watch to ensure that there was sufficient battery life for the duration of the study. After noticing that the battery life of many of the watches was becoming low, all of the watches were downloaded onto one of the three Dell computers to ensure no data were lost. Batteries were replaced after the download if the battery life was less than two bars (about half the life of a battery) and the watches were reinitialized to the original study settings.

2. PVT

Participants were asked to complete the PVT four times a day, before and after standing each watch. We also stressed the importance of taking four PVTs at the times described above, and for participants to minimize distractions while taking their PVTs.

3. Activity Logs

All participants were asked to complete a daily activity log (see Appendix C), documenting their daily routine in accordance with NSWW categories, their daily caffeine intake, nicotine usage, energy drink consumptions, and the last time they had seen sunlight. Activity logs were collected each day at a central location during breakfast, lunch, or dinner. When activity logs were returned, a visual inspection of the actiwatches and daily activity sheets was conducted.

E. ANALYTICAL APPROACH

1. Actigraphy

Actigraphy data were opened and scrubbed in Action-W Version 2.7.1150. Since many of the watch stations onboard the Jason Dunham required the participants to sit while on watch, participants were sometimes stationary for hours at a time. These reduced activity periods caused many of the participants to be given credit for sleep by the software scoring process when they were actually awake and on watch. The daily activity logs helped the team get a clearer picture of when each individual was actually in bed and when they were performing activities such as standing watch, training, and briefs, any of which could result in reduced activity being incorrectly scored as sleep. With the aid of daily activity logs, down intervals were entered. These down intervals were essentially indications of time in bed. Once the down intervals were entered, we looked at the scored sleep during these intervals to get a more accurate estimate of each individual's sleep.

The study lasted from December 3-17, but only 11 days of actigraphy data for each individual was used. The decision was made to not use the data from December 3, since the equipment was handed out during midday and not at the same time for each individual. This adjustment allowed the study to start at midnight between December 3 and 4 for all individuals. The quantity of sleep for each day and each individual was calculated from 0001 to 2400. Due to an operational commitment toward the end of the data collection period, the ship had to travel at excessive speeds for an extended period of time. This excessive speed caused the ship to vibrate and skewed the readings on almost all watches, making it appear that just about everyone was awake for an extended period of time on December 15. Since it was not feasible to get an accurate sleep count for this period of excessive ship motion and vibration, the decision was made to exclude all data after midnight on December 14, resulting in 11 days of data, from December 4 to 14.

Software programs used for the statistical analysis were Excel 2010, JMP PRO 10, and RStudio version 0.97.449. Sleep was computed for each individual and comparisons were made across watch rotations, allowing comparison of differences in the amount of sleep. The amount of sleep was further broken down by watch sections within watch rotations to detect visual differences in the amount of sleep for a particular watch section.

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IV. RESULTS

A. EXPLORING THE AMOUNT OF SLEEP BY EACH VARIABLE

1. Actigraphy

One objective of this study was to discover if there was a difference in the amount of sleep received by participants who stood different watches. More importantly, this study sought to explore variables that might influence the amount of sleep received between watch-standing groups. In this chapter, summary statistics and a variety of plots are used to help illustrate these relationships.

The average daily (24-hour) sleep for all of the participants was 376 minutes (standard error [se] = 5.3 minutes). Daily sleep was calculated from midnight to midnight. A simple plot of average sleep by participant (with "whiskers" extending one sd above and below the mean) clearly shows there is a wide range in the average amount of sleep among the participants (see Figure 7). For example, participant 3018 received a daily average of 237 minutes of sleep (sd = 26 minutes), while participant 3069 received a daily average of 464 minutes of sleep (sd = 17 minutes). From Figure 7, it is apparent that no individual was getting the recommended average of eight hours of sleep.

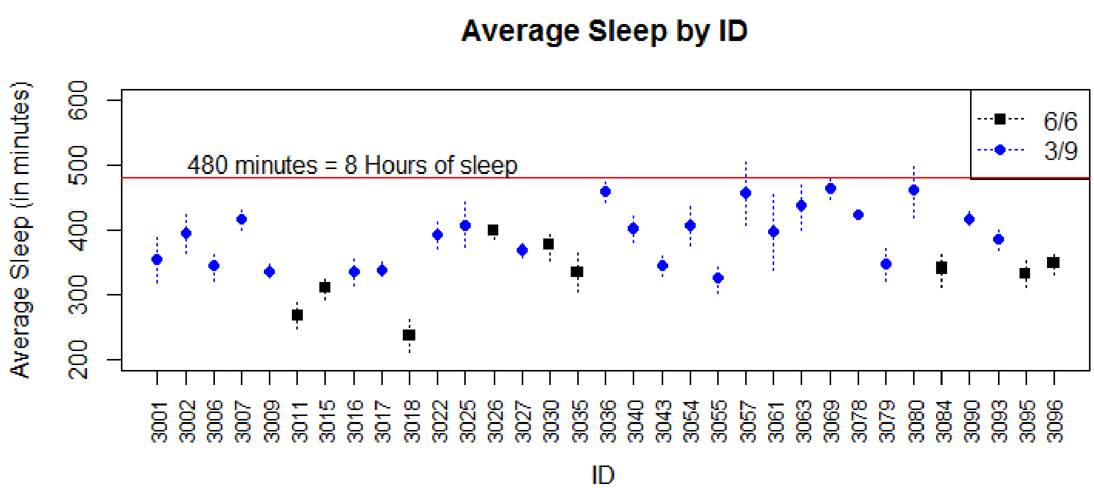

Figure 7. Average sleep (in minutes) by participant ID number, with "whiskers" extending one standard deviation above and below the mean.

The daily average sleep by day for the 33 participants is 378 minutes (se = 10 minutes). From the plot of average sleep versus day (see Figure 8) it appears that more sleep is received on day 7, Sunday, than for any other day. While on operational deployment, Sundays were considered “holiday routine,” meaning that as long as there were no operational commitments, the majority of the sailors could use the spare time to do as they pleased. Within those parameters, many sailors chose to catch up on sleep. One important note was that not a single day had an average sleep greater than the recommended eight hours of sleep, not even Sunday.

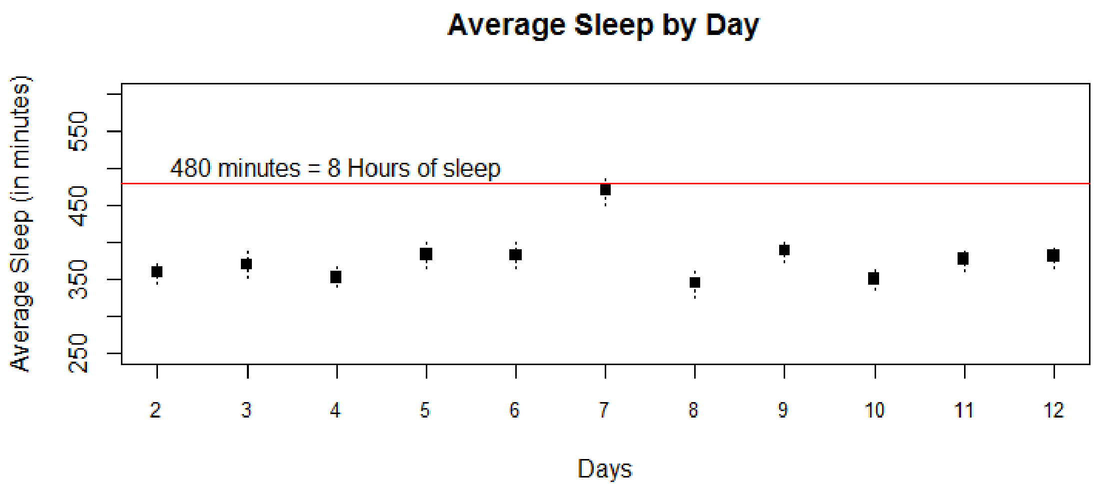

Figure 8. Average sleep (in minutes) by day, with “whiskers” extending one standard error above and below the mean, where days was 11 consecutive days, with day 2 starting on a Tuesday.

Figure 8 suggests that there were differences in the amount of sleep received each day. To allow blocking on participants with missing values, a modification of Friedman’s Test, the Skillings-Mack test, was used to test the null hypothesis that the expected average sleep is the same for every day. The Skillings-Mack test rejected the null hypothesis (p-value < 0.0001), meaning that the average sleep is different in at least one of the days. Adjusting p-values for multiple comparisons using Bonferroni’s inequality, the Wilcoxon signed rank test revealed that only the distribution of average sleep for day 7, Sunday, differs at a 5% family-wise level of confidence from day 2; a Tuesday (p-value = 0.0022)), day 3; a Wednesday (p-value = 0.0078), day 4; a Thursday (p-value = 0.005), day 8; a Monday (p-value = 0.017), day 10; a Wednesday (p-value = 0.0037), day 12; and a Friday (p-value = 0.032).

Another factor that distinguished the participants of this study was their assigned watch rotation. The participants were in one of two watch rotations, 3/9 or 6/6. The 3/9 participants only stood six hours of watches a day, while the 6/6 participants stood a total of 12 hours of watches a day. Even though the 3/9 participants only stood watch for half as many hours as the 6/6 participants, both watch rotations were off watch at least 12 out of 24 hours. The time off watch for each watch rotation is more than eight hours; so theoretically, all of the participants should have had the opportunity to receive eight hours sleep. The average sleep for 3/9 participants was 392 minutes (se = 6.12 minutes), while 6/6 participants received an average of 331 (se = 8.80 minutes) of sleep. This difference was 61 minutes, just over a full hour more of sleep for the 3/9 watch group as compared to the 6/6 group. A graph of average sleep per day by watch rotation illustrates how 6/6 watch standers received less sleep than 3/9 watch standers (see Figure 9). For example, for day 12 in Figure 9 the difference between the 3/9 and 6/6 participants' average sleep is 116 minutes—nearly two full hours. It is important to note that while it appears that 3/9 watch standers are receiving more sleep than 6/6 watch standers, only on one day is the average sleep more than eight hours, and that is only for the 3/9 watch standers. It seems that even with twice the amount of time off, the 3/9 watch standers are still unable to receive eight hours of sleep.

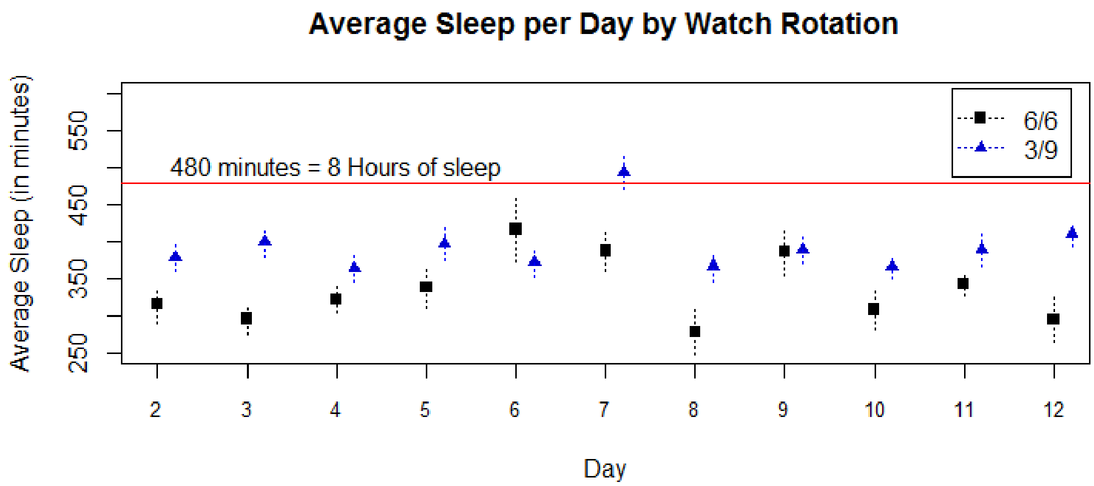

Figure 9. Average sleep (in minutes) per day by 6/6 and 3/9 watch rotations, with "whiskers" that extend one standard error above and below the mean, for 11 consecutive days, with day 2 starting on a Tuesday.

Figure 9 suggests that there was a difference in the average sleep received between the 3/9 and 6/6 watch rotations. The Wilcoxon test rejected the null hypothesis that the expected average sleep is the same for the two watch rotations, concluding there was a statistical difference in the amount of sleep received between the two watch rotations (p-value < 0.0001).

Watch rotations are partitioned into separate sections. The 3/9 watch rotation contains four sections (0000-0300, 0300-0600, 0600-0900, and 0900-1200) and the 6/6 watch rotation contains two sections (0000-0600 and 0600-1200). Table 3 lists the average sleep for each watch rotation. There is quite a difference in the amount of sleep received in the four separate watch sections of the 3/9 watch rotation (see Table 3). On the other hand, there is only a five-minute difference between the average sleep for the two watch sections in the 6/6 rotation.

Table 3. List of average sleep and standard error (in minutes) received by the various watch sections within the 3/9 and 6/6 watch rotation.

Watch	Average Sleep (Minutes)	Standard Error (Minutes)
3/9		
0000-0300	408	20.1
0300-0600	426	13.5
0600-0900	366	8.0
0900-1200	385	9.6
6/6		
0000-0600	330	13.0
0600-1200	333	11.4

Table 4 shows a small difference in the average sleep received between the 0000-0600 and 0600-1200 watch section; but, when the day is accounted for, the story seems quite different (see Figure 10). It appears as if the amount of sleep received between the two watch sections differs by day. For example, on day 6, a Saturday, the difference in the average sleep between the two watch sections is 122 minutes, or more than two hours. On the other hand, on day 10, a Wednesday, there is only a difference of 6.5 minutes between the 0000-0600 and 0600-1200 watch sections. The Wilcoxon test concluded there was not a significant difference in the average sleep received between the 0000-0600 and 0600-1200 watch sections (p-value = 0.8478).

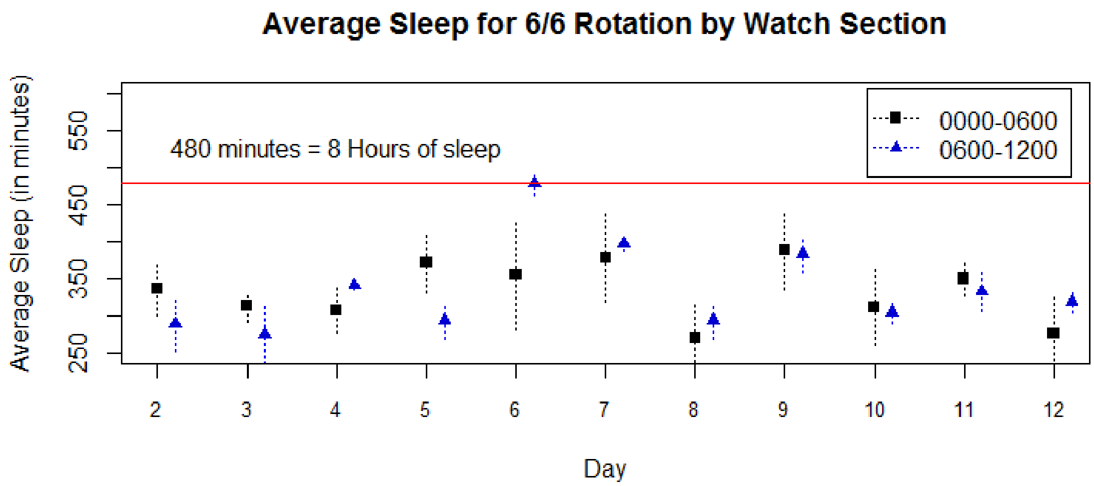

Figure 10. Average sleep (in minutes) per day by participants of the 0000-0600 and 0600-1200 watch sections of the 6/6 watch rotation, with "whiskers" extending one standard error above and below the mean, for 11 consecutive days, with day 2 starting on a Tuesday.

When the 3/9 watch sections' average sleep were plotted by day, the average sleep also differed and fluctuated among the watch sections (see Figure 11). One interesting note was that on four days—3, 5, 7, and 12—more than the recommended average of eight hours of sleep was received, but only for participants standing the 0000-0300 and 0300-0600 watch sections. Figure 11 and Table 4 give credibility to the suggestion that watch standers standing the 0000-0300 and 0000-0600 watches received more sleep.

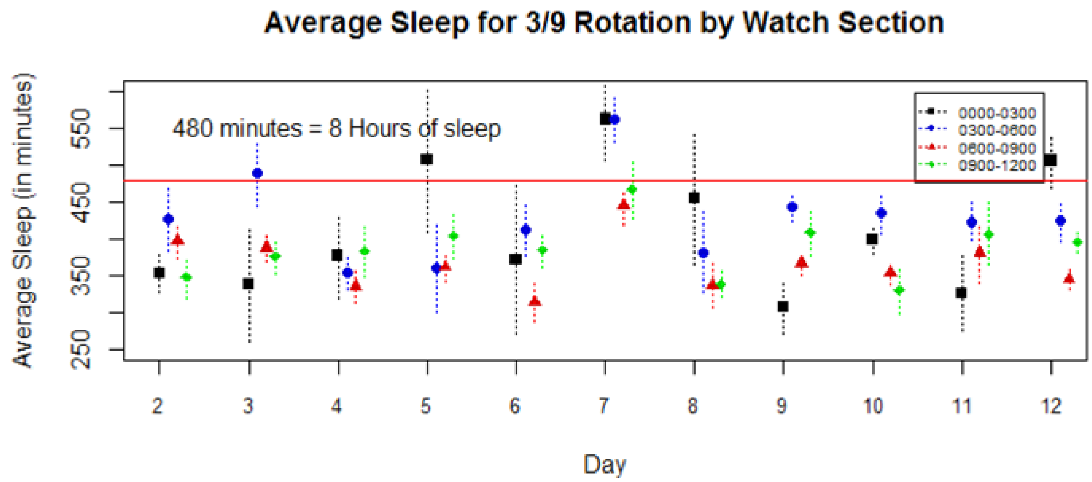

Figure 11. Average sleep (in minutes) per day by participants of the 0000-0300, 0300-0600, 0600-0900, and 0900-1200 watch sections of the 3/9 watch rotation, with "whiskers" extending one standard error above and below the mean, for 11 consecutive days, with day 2 starting on a Tuesday.

A Kruskal-Wallis test was used to test the null hypothesis that there was no difference in the average amount of sleep received between the 0000-0300, 0300-0600, 0600-0900, and 0900-1200 watch sections (all within the 3/9 watch rotation) against the alternative hypothesis that there *was* a difference in the averages of sleep in at least one of the watch sections. The Kruskal-Wallis test concluded that there were differences in the average amount of sleep received in at least one of the watch sections (p-value = 0.0033). The Dunn multiple comparison tests showed that there was only a difference in average sleep received between sections 0900-1200 and 0300-0600 and between sections 0600-0900 and 0300-0600, at a 5% family-wise level of significance.

With only 33 participants, participant rank was divided into two sub categories, officers and enlisted. A graph of average sleep per day by rank is given in Figure 12. The average amount of sleep received by officers was 403 minutes (se = 7.7 minutes), while enlisted participants received an average of 359 minutes (se = 6.9 minutes). In this plot, it is clear that the recommended average eight hours of sleep was received on only one day of the 11-day study, and it was only received by officers on day 7, Sunday.

Another interesting observation is that it appears that officers were receiving more sleep than enlisted sailors for all but one of the days—day 5.

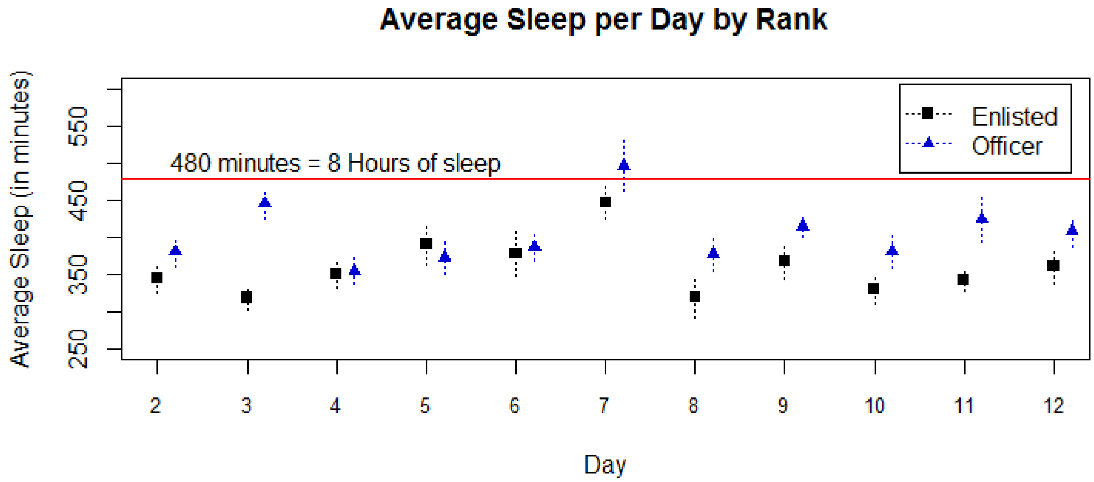

Figure 12. Average sleep (in minutes) per day by rank (enlisted or officer), with “whiskers” extending one standard error above and below the mean, for 11 consecutive days, with day 2 starting on a Tuesday.

Figure 12 provided a compelling visual argument that the average sleep received was different for officer and enlisted participants. The Wilcoxon test rejected the null hypothesis that the expected average sleep was the same for officers and enlisted participants (p-value < 0.0001), meaning there was a statistical significance in the different amount of sleep received between officers and enlisted sailors.

All of the officers in this study only stood the 3/9 watch rotation. Since there was a significant difference in the amount of sleep received between the 3/9 and 6/6 watch rotations, it was possible that the difference in average sleep by rank was confounded with watch rotation. Officers received in the 3/9 watch rotation, on average, 403 minutes (se = 8.3 minutes) of sleep, while enlisted participants received an average of 380 minutes (se = 8.9 minutes) of sleep. A Wilcoxon rank sum test comparing the average sleep received of officers and enlisted who stood watch in the 3/9 watch rotation rejects the null hypothesis, concluding there was a statistically significant difference in the average sleep received based on rank within the 3/9 watch rotation (p-value = 0.0067). The average sleep of enlisted participants standing the 3/9 watch was 21 minutes more than the average sleep of all enlisted participants. Enlisted participants standing watch in the 6/6 rotation received, on average, 331 minutes (se = 8.8 minutes), almost 50 minutes less than the average sleep received by enlisted participants standing watch in the 3/9 rotation. This finding provided evidence to the theory of confounding between ranks and watch rotations.

The average sleep per day for males was 373 minutes (se = 9.8 minutes), while females received an average of 389 minutes of sleep (se = 14.0 minutes) per day. A plot of sleep per day by gender showed that females routinely received more sleep than their male counterparts. On only two days, days 2 and 7, did males received more sleep than females (see Figure 13). Assuming independence, a quick computation using the binomial distribution gives only a 3% chance that females would receive more sleep on two or fewer days more sleep than males given that the distribution of sleep time was the same for males and females, and that the amount of sleep was independent over days. This suggests that there may have been a difference in the average amount of sleep received, based on gender. a Wilcoxon test which did not account for the day of the week effect failed to reject the null hypothesis, however, concluding there was not a difference in the average sleep received between males and their female counterparts (p-value = 0.43).

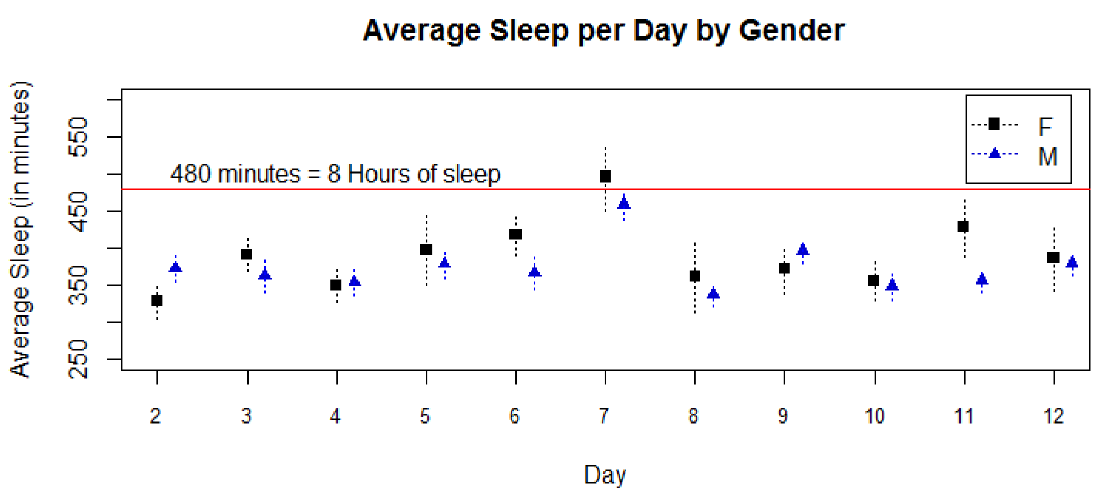

Figure 13. Average sleep (in minutes) per day gender (male or female), with "whiskers" extending one standard error above and below the mean, for 11 consecutive days, with day 2 starting on a Tuesday.

While the above plots in this section provided insight and offer suggestions about the relationships of various factors and the quantity of sleep received, the distribution of times during the day when participants were sleeping was also be investigated. During the study period, one of the standing policies on the ship was that the hours of 0900 and 1500 were considered working hours and, unless a sailor had a “day sleeper’s chit,” they were not allowed in their racks. This potentially could make it difficult for 0000-0600 watch standers to get much time in the rack since 25% of their off watch time was considered “working hours” and, unless they had a chit, they would not be permitted to sleep.

To gain insight into what times of the day sailors were sleeping, the percentage of participants asleep (out of 33) was computed for each minute of each day. Figure 14 plots the average percentage of sleep (averaged over 11 days) by minute for 24-hours. From Figure 14 it appears that sailors were sleeping around the clock with the majority of the sleep occurring between the hours of 2200 and 0900. As expected, there appeared to be a decrease in the number of sailors sleeping from 0900 to 1500, when the ship’s official duty day occurs, followed by an increase of sailors sleeping after 1500. This gives credibility to the idea that sailors who were not allowed to sleep from 0900 to 1500 may have been trying to get some sleep in prior to their watch beginning at 1800. An overlay of the average percentage of sailors sleeping by each watch section allows for more detail and insight (see Figures 15 and 16). These plots show that sleep is bimodal. Participants standing the 0000-0600 and 0600-1200 watches received split sleep. There was also evidence that participants standing the 0300-0600 watches received split sleep. These plots seem to confirm the fact that the participants are shift workers.

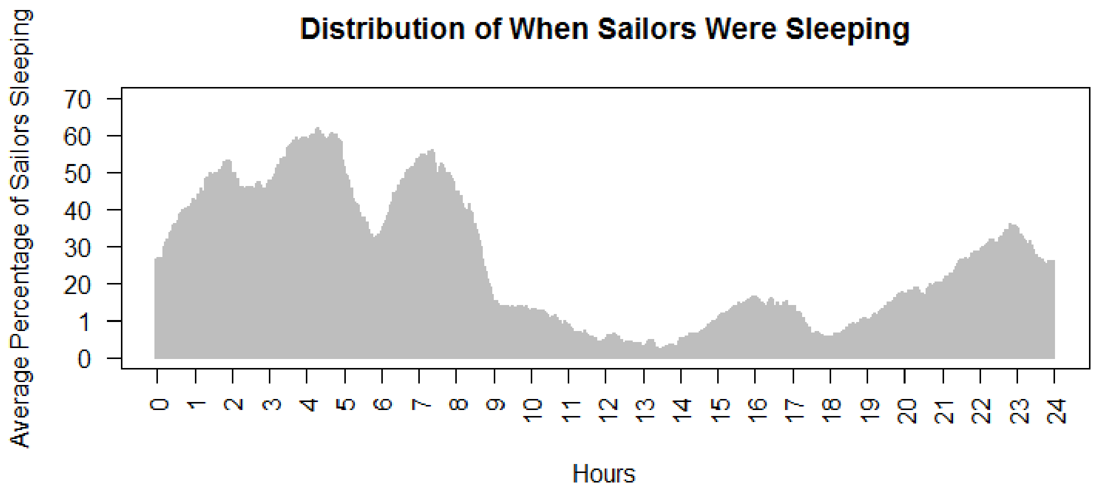

Figure 14. Average percentage of sailors sleeping (averaged over 11 days) by minute for 24 hours.

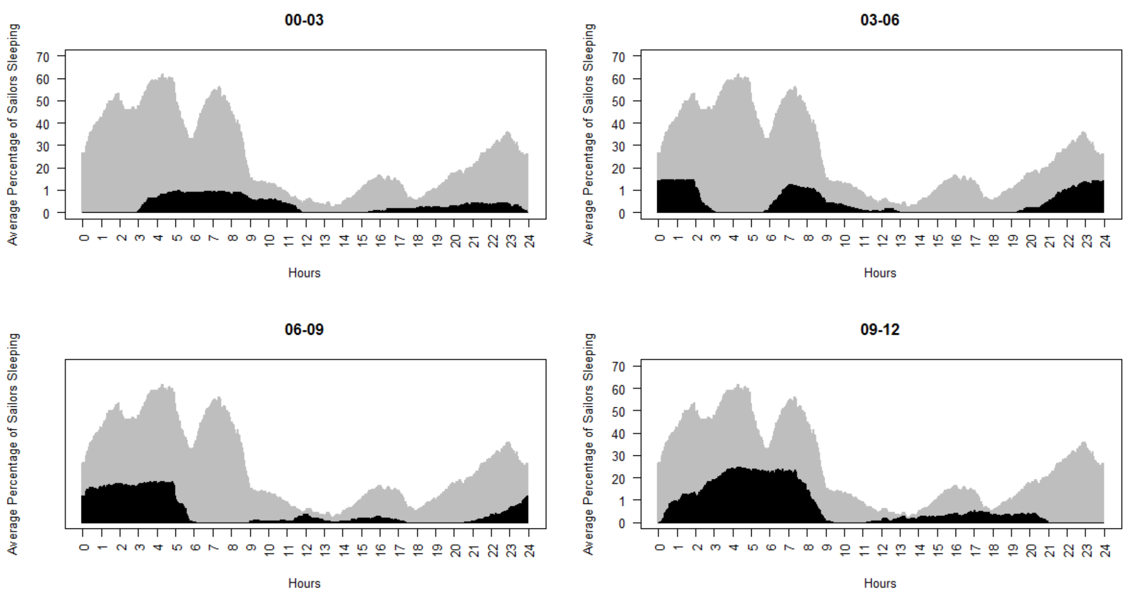

Figure 15. Average percentage of sailors sleeping (averaged over 11 days) by minute for 24 hours, with an overlay of the average percentage of sailors sleeping by each watch section in the 3/9 watch rotation.

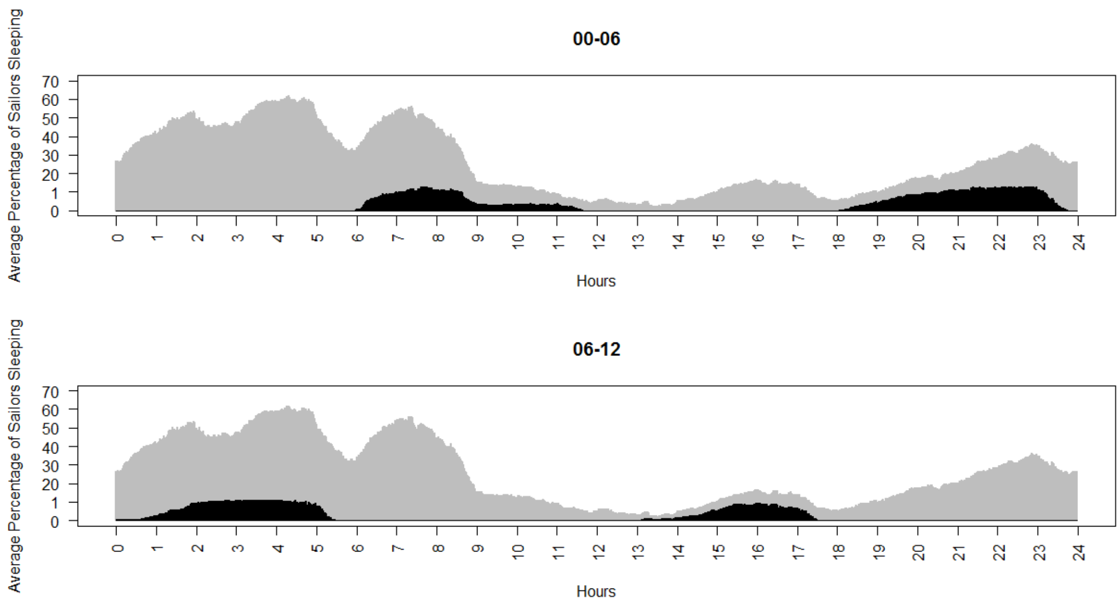

Figure 16. Average percentage of sailors sleeping (averaged over 11 days) by minute for 24 hours, with an overlay of the average percentage of sailors sleeping by each watch section in the 6/6 watch rotation.

B. MIXED EFFECTS MODEL FOR SLEEP

Through a series of plots and statistical tests it has been shown that rank, watch rotation, watch section (which is a biproduct of watch rotations), and day were related to the amount of sleep received by participants. One thing that is not clear is how the variables affect sleep in the presence of one another. In order to account for individual variability and variability between subjects, a linear mixed effect model with repeated measures was used (Faraway, 2006). The fixed effects for the participants in this study were gender, rank, day, and watch section within watch rotation. The random effect variable was participant ID. The random effects model assumed that the participants' (or ID) effects were independent and normally distributed with the same variance. The first model fit included all effects. Due to the limited sample size and the confounding between rank and watch rotation, no interactions were included. The model fit was followed by a backwards elimination to remove unneeded fixed effects. This procedure yielded a model with two fixed effects: watch rotation and day (see Table 4).

There are three possible explanations about why the variables of rank, gender, and watch section were not included in the mixed effects model in the presence of watch rotation and day. It is possible that these variables are not related to sleep. In light of the analysis and plots in the previous section, however, it is more plausible that the confounding between these variables and watch rotation made them appear unimportant in the presence of watch rotation and day. This is particularly true of the effects for rank because all officers stood a 3/9 watch; we cannot completely unravel the effects due to rank. It is also plausible that with the small sample size of only 33 participants observed over 11 days, there was insufficient evidence to detect differences with these variables. It was rather surprising that watch sections did not show up in the mixed effects model. We suspect that a future study, with more observations, may reveal differences between watch sections in the same watch rotation.

Table 4. Summary of mixed effects model fit, with average sleep per day as the response variable.

ID (Intercept)	1469.5	38.33	4	
Residual	6511.8	80.6	96	
Number of obs:	334, groups: ID, 33			
Fixed effects:				
	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	315.177	20.639	15.271	< 2e-16
WatchRotationTN	61.302	18.121	3.383	0.00192
Day3	10.881	20.348	0.535	0.59323
Day4	-6.713	20.348	-0.33	0.74172
Day5	19.876	20.708	0.96	0.33793
Day6	17.982	21.305	0.844	0.39934
Day7	105.907	21.331	4.965	1.17E-06
Day8	-16.849	20.382	-0.827	0.40908
Day9	26.651	20.382	1.308	0.19204
Day10	-9.329	20.379	-0.458	0.64746
Day11	16.702	20.554	0.813	0.41712
Day12	19.538	21.139	0.924	0.35611

C. EXPLORING PVT PERFORMANCE BY EACH VARIABLE

As with sleep, PVT performance was also compared to see if there were differences in performance between the participants standing different watches. Since PVT was a subjective test, it was postulated that there were differences based on individual results. Specifically, the inverse of RT in seconds (s), also known as response speed, was the dependent variable investigated with regard to the PVT test and results. Response speed was the average number of responses per second. In order for a participant to be included in the PVT analysis, they needed to complete a minimum of 10 PVTs throughout the study. Participants 3015 and 3022 were excluded from the PVT analysis since they did not complete the required minimum number of PVTs. The goal was to see if there were noticeable differences in various variables between the different watches. In this section, descriptive statistics and a variety of plots were used to help illustrate these relationships.

The average response speed for all the participants was 3.9 (1/s) (se = 0.12). A plot of average response speed by ID (with "whiskers" extending one se above and below the mean); Figure 17 shows there was a wide range in average response speed among the 31 participants. For example, participant 3035 has an average response speed of 5.15 (1/s) (sd = 0.49), while participant 3018's average response speed was 2.46 (1/s) (sd = 0.49). Not depicted in this plot are differences in other underlying factors that may have accounted for differences in individual performance such as gender, rank, watch section, watch rotation, time of day (TOD), or amount of sleep received in the previous 24 or 72 hours.

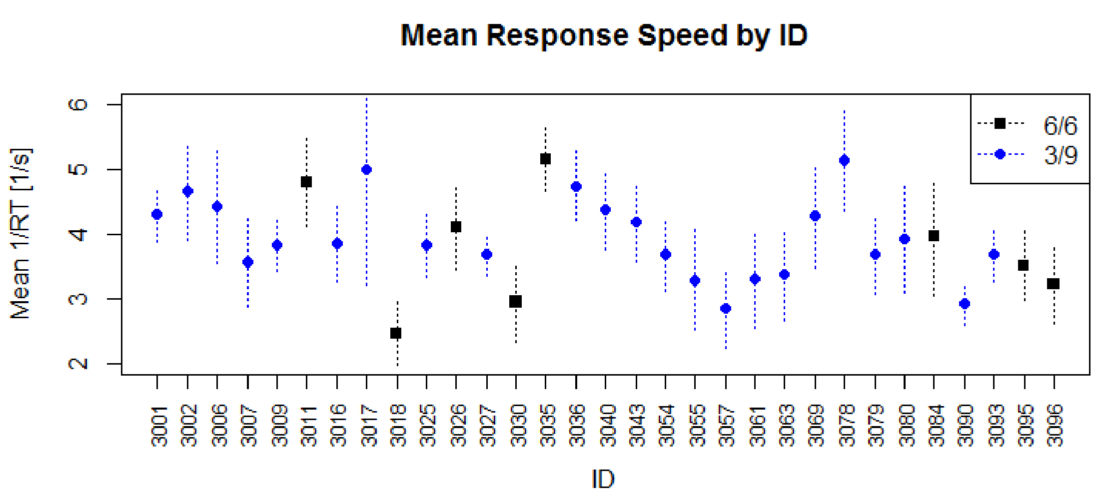

Figure 17. Mean 1/RT (1/s) by participant ID number, with "whiskers" extending one standard deviation above and below the mean.

The average response speed by day was 3.87 (1/s) (se = 0.026). A plot of response speed by day gave clear evidence that response speed did not appear different between the 11 days for the 31 participants (see Figure 18).

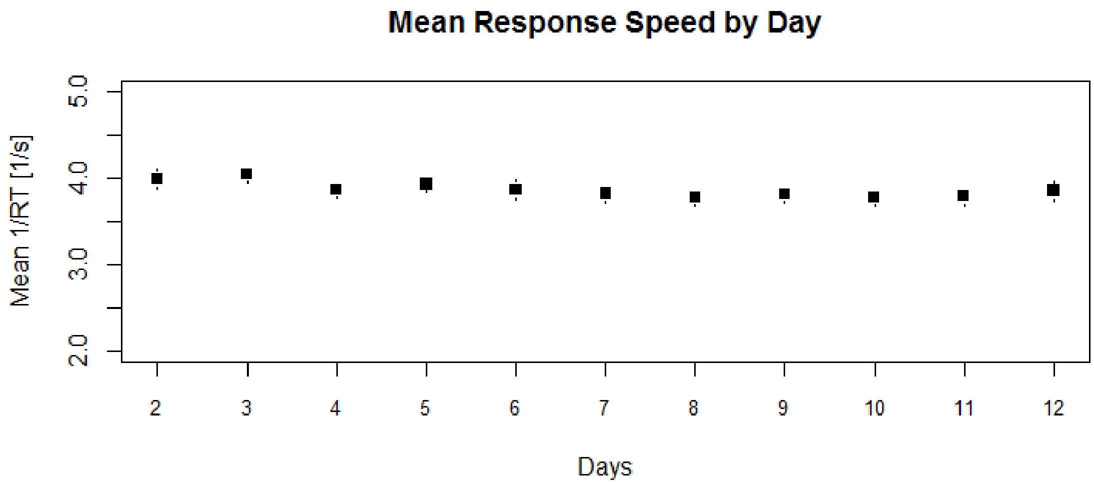

Figure 18. Mean 1/RT (1/s) by day, with "whiskers" extending one standard error above and below the mean, for 11 consecutive days, with day 2 starting on a Tuesday.

The average response speed for participants standing the 6/6 watch rotation was 3.66 (1/s) (se = 0.06), while 3/9 participants had an average response speed of 3.94 (1/s) (se = 0.12). A plot of response speed by day for the two different watch rotations showed that on every day, with the exception of day 7, Sunday, participants that were standing the 3/9 watch rotation had a higher average response speed. While the average response speed for participants standing watch in the 3/9 watch rotation was faster, the difference in the average response speed by the participants standing the 6/6 watch rotation did not appear to be great (see Figure 19). The Wilcoxon test, however, rejected the null hypothesis that the average response speed was equal for 3/9 and 6/6 watch rotations, meaning there was a significant difference in average response speed between the two watch rotations (p-value 0.0001).

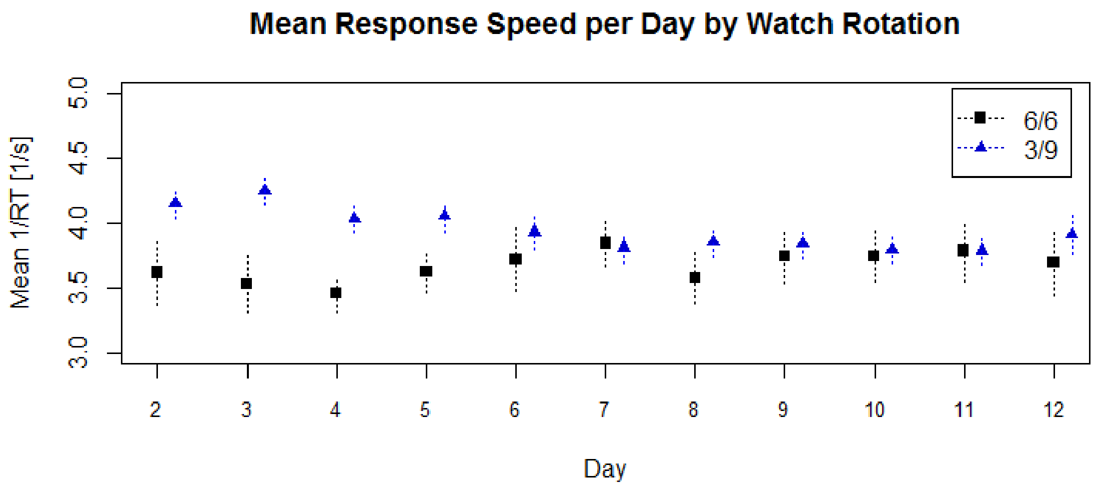

Figure 19. Mean 1/RT (1/s) per day by 6/6 and 3/9 watch rotation, with "whiskers" that extend one standard error above and below the mean, for 11 consecutive days, with day 2 starting on a Tuesday.

A plot of the 6/6 watch sections (0000-0600 and 0600-1200) mean response times by day gave the impression there was a difference in the average response speeds (see Figure 12). For example, the average response for the 0000-0600 watch section on day 9, Tuesday, was 3.49 (1/s) (se = 0.27), while the average response speed for the 0600-1200 watch section on day 9 was 4.27 (1/s) (se = 0.18); on day 8 for watch section 0000-0600, the average response speed was 3.58 (1/s) (se = 0.25), while the average response speed for the 0600-1200 watch section was 3.59 (1/s) (se =0.32).

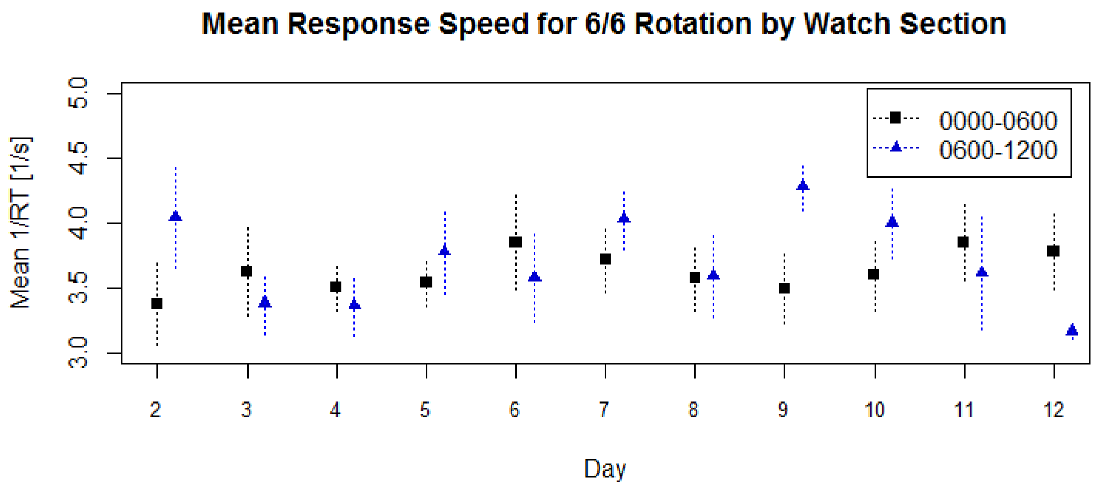

Figure 20. Mean 1/RT (1/s) per day by participants of the 0000-0600 and 0600-1200 watch sections of the 6/6 watch rotation, with "whiskers" extending one standard error above and below the mean, for 11 consecutive days, with day 2 starting on a Tuesday.

Since there were only two sections, 0000-0600 and 0600-1200, in the 6/6 rotation, a simple Kruskal-Wallis test was used to test the null hypothesis that the average response speeds of the 0000-0600 and 0600-1200 watch sections were not equal. The results of the Kruskal-Wallis test failed to reject the null hypothesis, that there was not a significant difference between the two sections (p-value = 0.36).

A plot of average response speed for the four watch sections (0000-0300, 0300-0600, 0600-0900, and 0900-1200) by day, within the 3/9 watch rotation, illustrates a difference in the average response speed between the watch sections (see Figure 21). Multiple comparisons for all pairs of watch sections using the Dunn Method test showed significant differences in the average response speed between the 0300-0600 and 0000-0300 watch sections (p-value < 0.0001), between the 0900-1200 and 0000-0300 watch sections (p-value = 0.0007), between the 0900-1200 and 0600-0900 watch sections (p-value = 0.0452), and between the 0600-0900 and 0300-0600 watch sections (p-value = 0.0015).

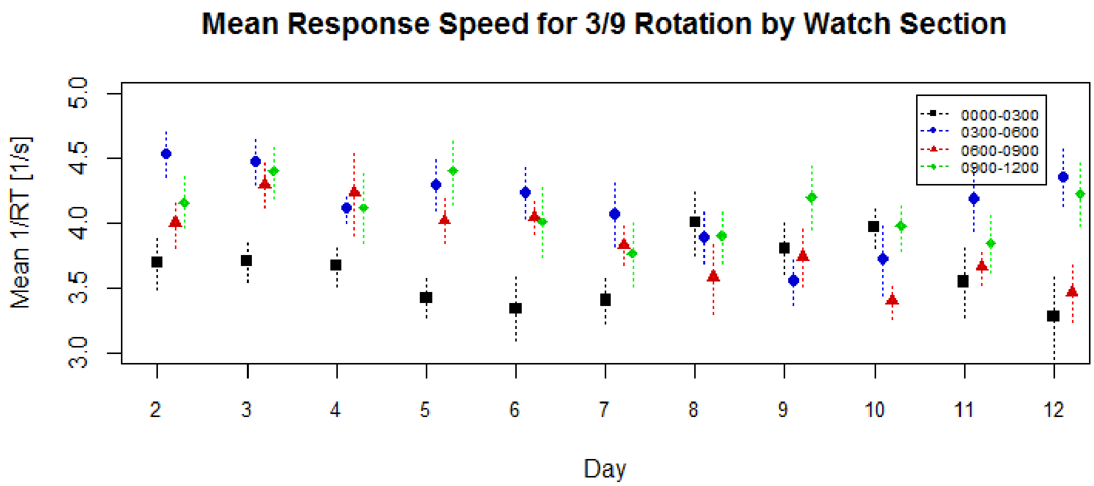

Figure 21. Mean 1/RT (1/s) per day by participants of the 0000-0300, 0300-0600, 0600-0900, and 0900-1200 watch sections of the 3/9 watch rotation, with "whiskers" extending one standard error above and below the mean, for 11 consecutive days, with day 2 starting on a Tuesday.

As with the sleep analysis, participant rank was divided into two sub categories, officers and enlisted, and then the average response speed per day, by rank, was plotted (see Figure 22). From Figure 22 it appears there may have been a difference in average response speed, by rank, for the first few days, but after that, the response speeds seem very similar. The average response speed for officers was 3.93 (1/s) (se = 0.15), while the enlisted participants had an average response speed of 3.81 (1/s) (se = 0.15). The Wilcoxon test, however, failed to show a significant difference in the average response speed between officers and enlisted at a 5% level of significance (p-value = 0.08).

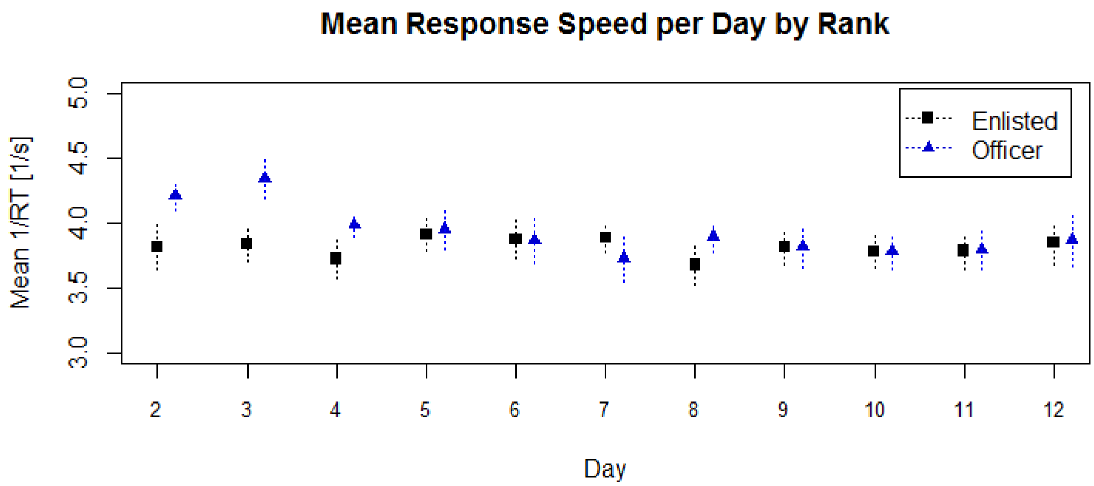

Figure 22. Mean 1/RT (1/s) per day by rank (enlisted or officer), with "whiskers" extending one standard error above and below the mean, for 11 consecutive days, with day 2 starting on a Tuesday.

The average response speed for males was 4.19 (1/s) (se = 0.12), while their female counterparts had an average response speed of 3.27 (1/s) (se = 0.13). A plot of average response speed per day, by gender, shows that on every day, males have faster average responses than their female counterparts (see Figure 23).

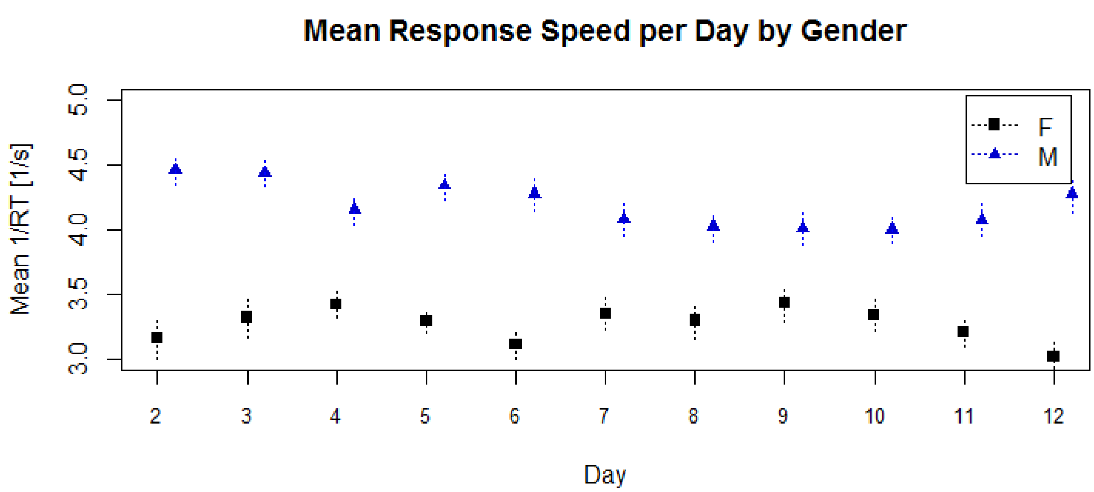

Figure 23. Mean 1/RT (1/s) per day by gender (male or female), with "whiskers" extending one standard error above and below the mean, for 11 consecutive days, with day 2 starting on a Tuesday.

It is apparent from Figure 23 that PVT performance differs by gender. A Wilcoxon test showed that the expected average response speed differed by gender (p-value < 0.0001).

D. MIXED EFFECTS MODEL FOR PVT PERFORMANCE

In addition, we attempted to fit a mixed effects model similar to that model fit with sleep. The dependent variable was PVT response speed (1/RT) and the random effect was participant ID. Among the fixed effects variables considered were participant rank, gender, day, and watch rotation, as in the sleep model. Also considered were the amount of sleep received in the last 24 hours and the last 72 hours, and a time of day variable. The time of day variable was a sine function of the actual time of day, so that the time of day variable decreased during the day and increased at night. No one model fit was satisfactory, in part due to the small sample size and also due to the confounding of so many independent variables. Of the many models that appear to fit equally well, however, the independent variable, "sleep in the last 24 hours," was often included in place of the variable watch rotation, and there also appeared to be a time of day effect in most of the models. We do not report these results explicitly, however, because the models that were fit are not satisfactory since no one model emerged as being superior.

V. CONCLUSIONS

A. SUMMARY OF FINDINGS

This study used graphs, nonparametric tests, and mixed effects models to compare the difference in sleep and performance between sailors standing the 3/9 and 6/6 watch rotations. Sleep and performance data were collected using the AMI wrist activity monitors with the PVT-192 function enabled on the watch. It is important to keep in mind that this was an observational study. Due to the ship's schedule and time limitations, individual sailors' baselines were not able to be established for either sleep habits or performance. Even with the lack of established baselines for sailors, it is believed that the data collected are an accurate representation of the effects that watch rotation can have on both the amount of sleep received by sailors and their performance.

Challenges exist whenever human performance is being measured. It is impossible to completely capture human performance with a single method. Analysis of the actigraphy data showed that the 3/9 watch rotation yields more sleep, on average than the 6/6 rotation. Although there was a difference in average sleep received between the two watch rotations, it is important to note that on a number of occasions at least one individual on the 6/6 rotation received more sleep than did individuals on the 3/9 rotation (see Figure 7).

Figures 8 through 13 illustrate the relationships among the factors that may have contributed to the differences in sleep. Interestingly, rank, watch rotation, and watch section individually showed differences in average sleep. Rank and watch rotation may have been confounded, however, since there were no officers standing the 3/9 watch rotation. Ultimately, a mixed effects model suggests that the differences in sleep could be explained by the watch rotation in which the participant was standing. While these findings suggest that the amount of sleep received was due, in large part, to the watch rotation that the sailor was standing, there were still some areas of concern regarding sleep adequacy. For example, sailors on the 3/9 watch rotation were getting an average of 392 minutes (se = 6.12 minutes) of sleep. While that is a full hour more than participants standing watch in the 6/6 rotation, it is still an hour and a half less than the eight hours of sleep per night that is recommended by sleep experts.

Using response speed (mean 1/RT [1/s]) as the metric of performance for PVT data, the Wilcoxon test showed that there was a difference in performance between the 3/9 and 6/6 watch rotations, with sailors on the 3/9 watch rotation performing better than sailors on the 6/6 watch rotation. For example, 3/9 sailors' average response speed was 3.94 (1/s), which is 20 ms faster than 6/6 sailors. A comparison of the watch sections of the 3/9 rotation using the Dunn Method also showed that there were differences in the performance between some of the watch sections in the 3/9 watch rotation. This finding suggests that certain watch sections within the 3/9 watch experienced better psychomotor vigilance performance.

B. DISCUSSION

The overall amount of sleep received by the participants in this study raises serious concerns for the United States Navy. Aligning with the results of Tucker and Folkard (2012), who concluded that shift workers receive less sleep and suffer from more fatigue than day workers, this study revealed that deployed sailors on shiftwork are not receiving the recommended eight hours of sleep per night. While this situation is not ideal, it is understood that shift workers commonly receive less sleep than nonshift workers. The concern is that with chronic and acute sleep debt increasing over a deployment and evolving into chronic sleep debt, sailors will continually perform at lower levels than if they had received eight hours of sleep each day.

This study shows that sailors standing the 3/9 watch rotation, on average, performed better on the PVT than sailors who were standing the 6/6 rotation and receiving less sleep. This finding is consistent with the dose-response studies of Van Dongen et al. (2003) and Belenky et al. (2003)—studies that found that restricted sleep periods resulted in worse cognitive performance on tasks such as the PVT.

C. IMPACT

Sailors receiving less than the optimum amount of sleep can potentially have a great effect on the Navy's ability to perform its mission at the highest possible level. One concern is that sailors have become so accustomed to sleep deprivation, they are not truly aware of how fatigued they are. This level of fatigue has been compared to a drunken person not understanding their level of impairment and believing they are performing at full cognitive capacity. In order to minimize sleep deprivation, it is recommended that both ship commanders and their subordinates be educated on the importance of sleep and on the negative impacts that are associated with sleep deprivation. Unfortunately, many times the issue of fatigue never gets addressed until a mishap graces the front cover of a newspaper. Near mishaps occur all the time, but are never reported, being brushed off as "close calls." While we do not suggest that adequate sleep will prevent all mishaps, we do suggest that well-rested sailors will offer a combat edge.

Navy sailors are a critical part of our weapons systems. Like all weapons, sailors require preventive maintenance. One daily maintenance requirement for sailors is to get adequate sleep. No commanding officer would knowingly forego required maintenance without a good rationale. Yet, sailors routinely do not receive their minimal requisite sleep. Leaders need to be innovative and forward thinking to ensure that sailors are receiving, on average, eight hours of sleep per day—the amount that is laid out in the Navy standard work week (OPNAVINST 1000.16K, 2007).

Consequences of too little rest for sailors can potentially carry on past their next watch. Sailors standing watch on operationally deployed surface combatants are clearly shift workers. Recent studies have shown that shift work exposure has effects on the sleep habits of former shift workers, even in their retirement years (Monk et al., 2013). This clearly raises reasons to be concerned, not only for the immediate impacts of sleep debt, but also on the long-term effects that have been seen in shift workers in retirement.

There will always be challenges that are out of the control of the leaders of individual commands. These challenges include, but are not limited to, the number of personnel assigned to their command, the qualifications of those sailors, and various

Navy fleet requirements. Some things that leaders do have control over are the ship's plan of the day. Scheduling working hours to accommodate sailors' sleep patterns can be a very effective way to ensure that sailors get enough sleep. For example, if a sailor is standing a 6/6 rotation with watch from 0000 to 0600 and 1200 to 1800, and the ship has mandated working hours from 0900 to 1500 (with no sleeping allowed in that period) then, in the best case scenario, this sailor is only afforded the opportunity to get nine hours in bed—assuming that the sailor does not eat, shower, work on qualifications, or do any other duty outside watch or working hours. If working hours were more flexible, however, and sailors could sleep at those times when they are off watch, the sailor could potentially plan accordingly and get the eight hours of sleep needed each night.

D. RECOMMENDATIONS FOR FUTURE WORK

This study does not answer all the questions with respect to sleep deprivation of deployed sailors and its potential impact on sailor performance. This study was, however, able to shed light on the fact that sailors are still not getting the required eight hours of sleep per night—even through the implementation of alternative watch bills such as the 3/9. While progress is being made in the Fleet, there is still work to be done. It would be interesting to compare the amount of sleep across all the different watch rotations. Future studies should also be conducted on other classes of ships, both smaller and larger, to see if the same results hold true for all ship types.

The validation of the three-minute PVT has allowed a fairly nonintrusive way to test performance on sailors, while minimizing the impact to the sailor and the mission, but its use has not been independently validated on surface combatants. It is recommended that a controlled study on an operational surface combatant be conducted that will allow for the validation of the 3-minute PVT, compared to the 10-minute PVT.

Future studies need to address the reasons that sailors are not receiving eight hours of sleep, since there are many factors that could be contributing t this problem. If sailors are not sleeping eight hours when off watch, then what are they doing with their available time and how does that compare to the Navy standard work week allocations?

Studies on deployed ships are always difficult, even if they are just observational in nature. Allowing a lab to utilize simulators that can closely mimic the watch duties of sailors, while affording the opportunity to control sleep periods based on a number of requirements such as training, qualifications, and maintenance would be a major contribution.

E. CONCLUSIONS

This study had three major objectives: (1) to compare the amount of sleep received between sailors standing the 3/9 and 6/6 watch rotations; (2) to compare the performance (using the PVT-192) of sailors standing the 3/9 and 6/6 watch rotations; and (3) identify factors that may have contributed to the amount of sleep received or to the PVT performance.

This study offers insight into the amount of sleep received and the performance of sailors on operationally deployed surface combatants. While these results only represent a single ship performing a specific mission, it is believed that some of these findings can carry over to other ships of similar size and mission assignments. While progress has been made in ensuring that sailors are receiving more sleep through the introduction of alternative watchbills such as the 3/9, there is still much work that remains to be done. The results suggest that sailors are sleep deprived and a true understanding of the level of sleep deprivation may be challenging to understand. It is imperative that research efforts continue to try to understand the effects that sleep deprivation has on sailors; this question is especially true with deployments increasing in length.

A change in thinking that includes placing an emphasis on sleep in the surface community can spell the difference between a well-rested crew and a crew lacking the basic alertness needed to perform simple, routine tasks. It is crucial that sailors, leaders, and subordinates alike continue to be innovative and never blindly accept the current watch schedules as “good enough.” Through ingenuity and a questioning attitude, leaders must strive to make changes that will allow sailors to get the required sleep they need.

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APPENDIX A. PARTCIPANTS' DATA

ID	Gender	Watch Rotation	Watch Section	Rank	# Sleep_days	# PVTs
3001	M	3/9	0000-0300	Enlisted	11	34
3002	M	3/9	0900-1200	Enlisted	10	13
3006	M	3/9	0600-0900	Enlisted	11	18
3007	F	3/9	0000-0300	Officer	5	29
3009	M	3/9	0600-0900	Enlisted	11	18
3011	M	6/6	0000-0600	Enlisted	10	28
3015	M	6/6	0600-1200	Enlisted	7	NA
3016	M	3/9	0600-0900	Enlisted	9	21
3017	M	3/9	0900-1200	Enlisted	10	11
3018	F	6/6	0000-0600	Enlisted	8	27
3022	M	3/9	0600-0900	Enlisted	11	NA
3025	F	3/9	0000-0300	Officer	11	40
3026	M	6/6	0000-0600	Enlisted	11	34
3027	M	3/9	0600-0900	Officer	11	39
3030	F	6/6	0000-0600	Enlisted	11	43
3035	M	6/6	0600-1200	Enlisted	10	17
3036	M	3/9	0300-0600	Officer	11	44
3040	M	3/9	0300-0600	Enlisted	11	38
3043	M	3/9	0900-1200	Officer	11	17
3054	F	3/9	0300-0600	Officer	11	34
3055	M	3/9	0900-1200	Officer	11	27
3057	F	3/9	0000-0300	Enlisted	11	36
3061	M	3/9	0300-0600	Officer	8	26
3063	F	3/9	0900-1200	Officer	11	20
3069	M	3/9	0300-0600	Officer	9	24
3078	M	3/9	0900-1200	Officer	11	44
3079	M	3/9	0900-1200	Enlisted	11	26
3080	M	3/9	0900-1200	Enlisted	11	27
3084	M	6/6	0000-0600	Enlisted	9	25
3090	F	3/9	0600-0900	Officer	10	11
3093	M	3/9	0900-1200	Officer	11	30
3095	F	6/6	0600-1200	Enlisted	11	40
3096	F	6/6	0600-1200	Enlisted	9	27

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APPENDIX B. IRB CONSENT FORM

Naval Postgraduate School
Consent to Participate in Research

Introduction. You are invited to participate in a research study entitled Comparison of various actigraphy devices for sleep/wake estimation. The purpose of the research is to compare the utility of various wrist worn activity monitors for measuring sleep and wake patterns.

Procedures. As a participant in this study, you will be asked to wear up to seven different activity monitors 24-hours a day for a period of 14 days. In addition, you will be asked to fill out a daily activity log to account for your sleep and wake patterns during the 14 days you will be wearing the activity monitors. Filling out the activity logs should take no more than five minutes a day. This study will involve collecting data on roughly 80 participants.

Location. The experiment will take place at the Naval Postgraduate School.

Cost. There is no cost to participate in this research study.

Voluntary Nature of the Study. Your participation in this study is strictly voluntary. If you choose to participate you can change your mind at any time and withdraw from the study. You will not be penalized in any way or lose any benefits to which you would otherwise be entitled if you choose not to participate in this study or to withdraw. The alternative to participating in the research is to not participate in the research.

Potential Risks and Discomforts. The potential risks of participating in this study are: a minor risk of irritation and/or discomfort from wearing the activity monitors on your wrist for an extended period of time. This irritation/discomfort will be no greater than that experienced when wearing a normal wrist watch. To avoid severe irritation or discomfort, you will be allowed to remove the activity monitor from time to time. There may also be a minor risk of breach of confidentiality. Individual level data will not be disclosed to anyone outside of the research team to protect your privacy and confidentiality. No personal identifying information will be associated with the data from the activity monitors.

Anticipated Benefits. Anticipated benefits from this study are an increased understanding of the utility of consumer developed activity monitors for measuring sleep and wake patterns. This effort is intend to find a cheaper and more accessible alternative method for collecting sleep and performance data in a scientific manner. Knowledge from this study will have directed application for Commanders and mid-level officers hoping to improve their methods for managing fatigue risk. You may also directly benefit from participation in this study through an increased knowledge of your own sleep/wake patterns. Your own data will be available to you at your request by Dr. Nita Shattuck, PhD.

Compensation for Participation. No tangible compensation will be given.

Confidentiality & Privacy Act. Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential but total confidentiality cannot be guaranteed. No personal identifying information will be collected for this study. However, participant names will be associated with device serial numbers and participant identification numbers when devices are issued to you. This is only to ensure that those devices issued to you are returned to us. All name and serial number lists will be destroyed once we have collected all devices at the conclusion of the data collection. All data collected in this study will be stored on a secure server in a secured and locked facility.

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Date:

Points of Contact. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact the Principal Investigator, Dr. Nita Shattuck, 831-656-2281, nlshattu@nps.edu. Questions about your rights as a research subject or any other concerns may be addressed to the Navy Postgraduate School IRB Chair, Dr. Maiah Jaskoski, 831-656-3167, majaskos@nps.edu.

Statement of Consent. I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I have been provided a copy of this form for my records and I agree to participate in this study. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

Participant's Signature ______________________ Date ____________

Researcher's Signature ______________________ Date ____________

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Version #
Date:

APPENDIX C.   DAILY ACTIVITY LOGS

Participant ID _____________________________   **Date** ___________________

P (Personal Time) = reading/listening to music, writing letters, JQR/PQS and studying for advancement
W = Watch/Operational Manning
C (Chow) = Time allocated to eat three (3) meals a day and with an occasional 4th meal at night (Mid-Rats).
SF (Sunday Free) = Time allocated to religious observance and not a reflection of how much time is actually spent participating in religious observances
T (Training) = Divisional/departmental, GQ, GMT, etc.
SD (Service Diversion) = Collateral Duties, Meetings, Quarters, Inspections, Sick Call, Assembles, NJP, etc.
M (Maintenance) = Corrective, Preventive, or OUS
S = Sleeping or naps

Time	**0000**	**0030**	**0100**	**0130**	**0200**	**0230**	**0300**	**0330**	**0400**	**0430**	**0500**	**0530**	**0600**	**0630**	**0700**	**0730**	**0800**	**0830**	**0900**	**0930**	**1000**	**1030**	**1100**	**1130**
Activity																								
Time	**1200**	**1230**	**1300**	**1330**	**1400**	**1430**	**1500**	**1530**	**1600**	**1630**	**1700**	**1730**	**1800**	**1830**	**1900**	**1930**	**2000**	**2030**	**2100**	**2130**	**2200**	**2230**	**2300**	**2330**
Activity																								

Daily **<u>caffeine</u>** use:
Time? _____________ Type of drink? _________________ How many drinks? ________________
Time? _____________ Type of drink? _________________ How many drinks? ________________
Time? _____________ Type of drink? _________________ How many drinks? ________________
Time? _____________ Type of drink? _________________ How many drinks? ________________

Daily **<u>nicotine</u>** use:
Time? _____________ Type? ___________________ How many? ___________________
Time? _____________ Type? ___________________ How many? ___________________
Time? _____________ Type? ___________________ How many? ___________________
Time? _____________ Type? ___________________ How many? ___________________

Any medications?_if so, what? ____

When did you last see daylight and for how long?____

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