Author(s)	Shattuck, Nita Lewis; Matsangas, Panagiotis
Title	Work and rest patterns and psychomotor vigilance performance of crewmembers of the USS Jason Dunham: a comparison of the 3/9 and 6/6 watchstanding schedules
Publisher	
Issue Date	2014-12
URL	http://hdl.handle.net/10945/44348

NPS-OR-14-004

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

WORK AND REST PATTERNS AND PSYCHOMOTOR VIGILANCE PERFORMANCE OF CREWMEMBERS OF THE USS JASON DUNHAM: A COMPARISON OF THE 3/9 AND 6/6 WATCHSTANDING SCHEDULES

by

Nita Lewis Shattuck, Ph.D. and Panagiotis Matsangas, Ph.D.

December 2014

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Prepared for: United States Navy, N171, 21st Century Sailor Office and the Naval Medical Research Center, Advanced Medical Development Office, 503 Robert Ave., Bldg. 500, Silver Spring, MD 20910

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YYYY)***	**2. REPORT TYPE**	**3. DATES COVERED** ***(From-To)***
31-12-2014	Technical Report	October 2013 – September 2014

4. TITLE AND SUBTITLE
WORK AND REST PATTERNS AND PSYCHOMOTOR VIGILANCE PERFORMANCE OF CREWMEMBERS OF THE USS JASON DUNHAM: A COMPARISON OF THE 3/9 AND 6/6 WATCHSTANDING SCHEDULES

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Nita Lewis Shattuck, Ph.D. and Panagiotis Matsangas, Ph.D.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)
Operations Research Department
Naval Postgraduate School
Monterey, CA 93943

8. PERFORMING ORGANIZATION REPORT NUMBER
NPS-OR-14-004

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
United States Navy, N171, 21st Century Sailor Office, Naval Medical Research Center Advanced Medical Development Office, 503 Robert Ave Bldg. 500, Silver Spring, MD 20910

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
The views expressed in this report are those of the author(s) and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

14. ABSTRACT
This study compares the patterns of crew rest and sleep, psychomotor vigilance performance, and work demands/rest opportunities afforded by two different schedules, the 3-hour on/9-hour off ("3/9") and the 6-hour on/6-hour off ("6/6") watchstanding schedules. The study was conducted aboard the USS Jason Dunham, a U.S. Navy destroyer operating in the vicinity of the Persian Gulf during the months of November and December 2012. Of the 122 participants in the overall study, 52 were shift workers using either the 3/9 (n=41) or the 6/6 (n=11) schedules. These 52 individuals are the focus of the current analysis. Although sleep deprivation was evident in both watch schedules, results show that crewmembers on the 3/9 received more sleep than their peers on the 6/6, with 6.46 ±0.77 hours versus 5.89 ±0.87 hours, respectively. The 3/9 schedule, compared to the 6/6, was also better in terms of the distribution of sleep episodes across the day. Specifically, crewmembers on the 3/9 received more sleep during nighttime hours, whereas crewmembers on the 6/6 had to sleep during the day to compensate for their lack of sleep during nighttime hours. In terms of work demands, crewmembers on the 6/6 schedule have considerably long workdays, with, on average, 15 hours on duty, which corresponds to approximately 30% more time on duty than allocated in the Navy Standard Work Week criterion (on average, 105 hours compared to 81 hours weekly).

The two schedules differed significantly in the variability of psychomotor vigilance performance; specifically, crewmembers on the 6/6 schedule had larger variability than those on the 3/9 in 11 of the 13 Psychomotor Vigilance Task (PVT) metrics analyzed ($p<0.05$). The average value of the PVT scores was better on the 3/9 compared to the 6/6, but not at statistically significant levels. The findings of this study show that the 3/9 is better than the 6/6 in affording rest and sleep opportunities, sleep hygiene, fatigue levels, psychomotor vigilance performance, work demands, and acceptance from the participants.

15. SUBJECT TERMS
Watch schedules, sleep, psychomotor vigilance performance

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			
Unclassified	Unclassified	Unclassified	UU	61	Nita Lewis Shattuck
					19b. TELEPHONE NUMBER ***(include area code)*** (831) 656-2281

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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NAVAL POSTGRADUATE SCHOOL
Monterey, California 93943-5000

Ronald A. Route
President

Douglas A. Hensler
Provost

The report entitled *"Work and Rest Patterns and Psychomotor Vigilance Performance of Crewmembers of the USS Jason Dunham: A Comparison of the 3/9 and 6/6 Watchstanding Schedules"* was prepared for and funded by United States Navy, N171, 21st Century Sailor Office and the U.S. Navy Bureau of Medicine Advanced Medical Devices.

Further distribution of all or part of this report is authorized.

This report was prepared by:

Nita Lewis Shattuck, Ph.D.
Associate Professor of
Operations Research

Panagiotis Matsangas, Ph.D.
National Research Council
Postdoctoral Associate

Reviewed by:

Robert F. Dell, Chairman
Chairman
Department of Operations Research

Johannes O. Royset
Associate Chairman for Research
Department of Operations Research

Released by:

Jeffrey D. Paduan
Dean of Research

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ABSTRACT

This study compares the patterns of crew rest and sleep, psychomotor vigilance performance, and work demands/rest opportunities afforded by two different schedules, the 3-hour on/9-hour off ("3/9") and the 6-hour on/6-hour off ("6/6") watchstanding schedules. The study was conducted aboard the USS Jason Dunham, a U.S. Navy destroyer operating in the vicinity of the Persian Gulf during the months of November and December 2012. Of the 122 participants in the overall study, 52 were shift workers using either the 3/9 (n=41) or the 6/6 (n=11) schedules. These 52 individuals are the focus of the current analysis. Although sleep deprivation was evident in both watch schedules, results show that crewmembers on the 3/9 received more sleep than their peers on the 6/6, with 6.46 ± 0.77 hours versus 5.89 ± 0.87 hours, respectively. The 3/9 schedule, compared to the 6/6, was also better in terms of the distribution of sleep episodes across the day. Specifically, crewmembers on the 3/9 received more sleep during nighttime hours, whereas crewmembers on the 6/6 had to sleep during the day to compensate for their lack of sleep during nighttime hours. In terms of work demands, crewmembers on the 6/6 schedule have considerably long workdays, with, on average, 15 hours on duty, which corresponds to approximately 30% more time on duty than allocated in the Navy Standard Work Week (NSWW) criterion (on average, 105 hours compared to 81 hours weekly).

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I. INTRODUCTION

Even though shift work is an integral part of modern societies, it remains an abnormal behavior for humans. Many human physiological functions are controlled by the circadian clock; for example, sleep and its associated functions are promoted during the biological night, whereas wakefulness is more common during the biological day (Dijk & Czeisler, 1995; Dijk & Edgar, 1999; Drake & Wright, 2011). Research findings suggest that shift work, that is, working hours other than the typical daytime work hours of 8:00 am to 5:00 pm, affects physiological function and performance through circadian desynchrony. This disruption of the internal circadian rhythm (Colquhon, Blake, & Edwards, 1969b) is accompanied by an alteration of melatonin production (Burch, Yost, Johnson, & Allen, 2005) and disturbance of the sleep-wakefulness cycle (Åkerstedt, 2003). The brain undergoes long-term changes when subjected to chronic sleep restriction (Belenky et al., 2003) altering neural function in a manner that precludes rapid recovery to baseline levels of alertness and performance, even after sleep durations return to baseline levels. The time needed to adjust to a nocturnal rhythm is at least a week (Monk, 1986), although 12 days or more have also been reported (Colquhon, Blake, & Edwards, 1969a; Hockey, 1983). Workers often experience sleep disturbance and sleepiness after months or years of shift work (Drake & Wright, 2011). Research findings suggest that prior exposure to shift work is related to sleep problems during retirement (Monk et al., 2013). Irrespective of the shift system, night and early-morning shifts are associated with short sleep and increases in sleepiness (Sallinen & Kecklund, 2010). Compared to non-watchstanders or day workers, shift work results in more sleep deprivation, shorter sleep episodes, greater sleep fragmentation, and increased levels of fatigue (Arendt, Middleton, Williams, Francis, & Luke, 2006).

Long duration shifts—that is, shifts greater than 12 hours in length—lead to increased sleepiness due to reduced sleep opportunities afforded to shift workers (Åkerstedt & Wright, 2009). Short sleep and increased sleepiness are also evident in individuals working long shifts (i.e., >16 hours) and extended weekly working hours (i.e., >55 hours) (Sallinen & Kecklund, 2010).

In general, researchers agree that forward-rotating shifts are better for alertness and sleep (Hockey, 1983; Sallinen & Kecklund, 2010; Viitasalo, Kuosma, Laitinen, & Härmä, 2008), even though some studies do not fully support the argument that rotating clockwise is better than rotating counterclockwise (Cruz, Boquet, Detwiller, & Nesthus, 2003). Many studies show that rotating watch systems have a detrimental impact on the sleep/wake cycle (Colquhoun & Folkard, 1985; Goh, Tong, Lim, Low, & Lee, 2000; Hakola & Härmä, 2001); however, there are conflicting results regarding the utility of fixed-shift systems compared to rotating systems (Åkerstedt, 2003; Folkard, 1992; Wedderburn, 1992; Wilkinson, 1992). Supporters of fixed systems suggest that, given adequate time, the human circadian pacemaker will adjust to night shift work, whereas other researchers argue that humans can never fully adjust their sleep/wake patterns to night shift work because of social or other factors (Colquhoun & Folkard, 1985; Cruz et al., 2003; Monk, 1990). Studies show that shift work can lead to considerable performance degradation (as measured by sustained attention, vigilance, and simulated driving tasks) caused by sleepiness at levels equivalent to 0.04 to 0.05 g% blood alcohol concentration (Arnedt, Owens, Crouch, Stahl, & Carskadon, 2005).

Shift work is also associated with elevated levels of physiological fatigue in manual tasks involving the upper extremities (Rosa, Bonnet, & Cole, 1998). Specifically, longer shifts (12 hours compared to 8 hours) and night shifts lead to increased fatigue. Shiftwork, however, not only leads to circadian desyncrony, sleep deprivation, and performance impairment, but it also has considerable negative social consequences on balancing work and home life. Scientific evidence suggests that shift work has a negative influence on children's well-being and on marital satisfaction (Albertsen, Rafnsdóttir, Grimsmo, Tómasson, & Kauppinen, 2008). Shift work is also associated with weight gain and various morbidities. A study assessed the health effects of implementing a 12-hour shift in place of the traditional 8-hour shift in factory workers in Japan (Yamada, Tachibana, & Kuriyama, 1988). Compared to the workers on the 8-hour shift, the workers changing to a 12-hour shift had significant increases in psychological symptoms related to fatigue and experienced, on average, a weight gain of one kilogram. Research findings also suggest that shift workers are more prone to developing other disorders, e.g., obesity, gastrointestinal disorders, cardiovascular heart disease, compromised pregnancy outcome, breast cancer, prostate cancer, metabolic syndrome, and diabetes (Drake & Wright, 2011; Folkard & Tucker, 2003; Harrington, 2001; Knutsson, 2003; Wang, Armstrong, Cairns, Key, & Travis, 2011). The International Agency for Research on Cancer has classified "shift work that involves circadian disruption" as a probable human carcinogen (Stevens et al., 2011, p. 764).

Shift work can have a significant impact on organizational risk and safety rates. Epidemiological studies have shown that the relative risk of workplace accidents increases by approximately 15% during afternoon shifts and by 30% for night shifts compared to morning shifts (Folkard, Lombardi, & Spencer, 2006). Long work hours and shift work increase the risk of workplace accidents (Åkerstedt & Wright, 2009), with accident rates increasing between 50% and 100% (Wagstaff & Sigstad Lie, 2011). Work periods of more than 8 hours carry an increased risk of accidents that cumulates, so that the increased risk of accidents at around 12 hours is twice the risk at 8 hours. The authors noted, however, that "pure" night work may bring some protection against the detrimental effects of shift work (Wagstaff & Sigstad Lie, 2011).

Knutsson (1989, 2003) proposed a conceptual model to explain mechanisms of disease in shift workers by integrating relevant research findings. Although the initial model focused only on disease, it can be extended to include the effect on human performance as well as on organizational health and resilience (Rutenfranz, Colquhoun, Knauth, & Ghata, 1977). Figure 1 demonstrates a revision to the initial model.

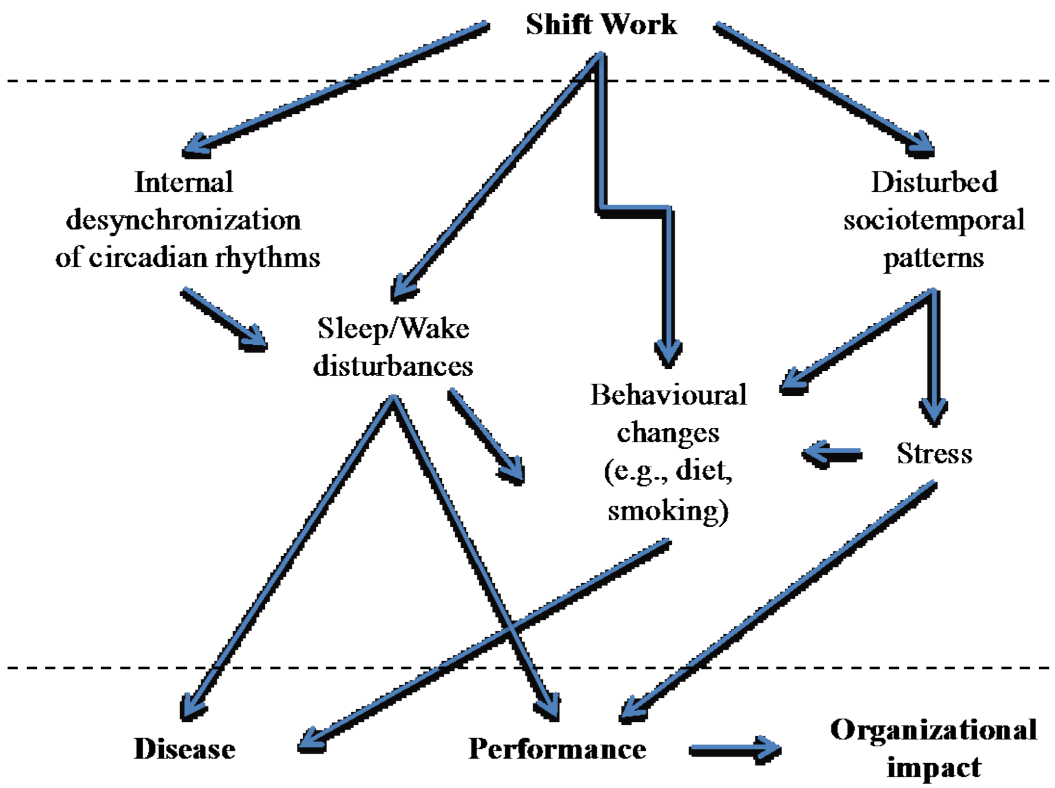

Figure 1. Effects of shift work on individuals and organizations.

Overall, optimizing a shift schedule for a specific work environment is not an easy task; a large number of parameters must be considered. Given the complexity in assessing the utility of a watch system, Miller (2006) proposed nine "principles" of shift-work scheduling, in the sense that these "principles" describe essential qualities of shift systems. These nine principle were classified into three groups: circadian stability, principle of chronohygiene (short shift length, minimum number of consecutive night shifts, recovery after each night shift, maximum number of free days on weekends, at least 104 days off per year), and principles of satisfaction (equity among shift workers for types of work dates and free days, predictability of specific work and free days, and quality of time off).

A. SHIFT WORK IN THE NAVAL ENVIRONMENT

The naval environment is characterized by sleep problems, sleep deprivation, and increased levels of fatigue (Howarth, Pratt, & Tepas, 1999). Shift work is considered one of the major factors leading to sleep problems. It is not surprising, therefore, that optimizing shift work practices is a matter of concern for many navies and has long been a topic of investigation. While at sea, watches must be manned around the clock; consequently, watches are either fixed (i.e., crewmembers work the same time each day), rapidly rotating (i.e., crewmembers work different times every day), or irregular. The watch system to be used depends on the organizational culture, the prior experience of the command leadership, and the number of crewmembers available to stand watch. This final factor is a critical consideration on ships with limited crew size. Studies on naval vessels have shown that watch schedules traditionally used at sea lead to sleep deprivation, sleep fragmentation, suboptimal performance, and worrisome levels of alertness (Paul, Ebisuzaki, McHarg, Hursh, & Miller, 2012; Rutenfranz et al., 1988).

In the U.S. Navy, it is the responsibility of the officer of the watch to ensure that watchstanders are able to stand an effective watch (Department of the Navy, 2012). Given the availability of personnel, the watch itself, and other daily activities, a number of fixed and rotating watch systems are used like the 4-hour on/8-hour off, 6-hour on/ 6-hour off ("6/6"), the 12-hour on/12-hour off ("12/12"), the 6-hour on/18-hour off ("6/18"), or the 3-hour on/9-hour off ("3/9"). Some of these schedules result in days that are other than 24 hours in length. For example the 5-hour on/10-hour off ("5/10") is either 15 or 30 hours in length, and the 5-hour on/15-hour off ("5/15") results in a 20-hour day. Following a 1969 Naval Postgraduate School master's thesis by Stolgitis (1969), U.S. Navy submarine crews adopted a 6-hour on/12-hour off ("6/12"), three-section watchstanding schedule that results in an 18-hour day.

Several studies have modeled the effects of specific watch schedules by using the Fatigue Avoidance Scheduling Tool (FAST) (Hursh et al., 2004; Kronauer & Stone, 2004). A study in the Royal Canadian Navy (RCN) compared the predicted psychomotor performance of crewmembers on four watch schedules: the 3-section 8-hour on/16-hour off, the 3-section 4-hour on/8-hour off, and the 2-section 8-hour on/4-hour off/4-hour on/8-hour off ("8/4/4/8"), and the 2-section 6/6 schedule used by RCN submarines (Paul, Hursh, & Miller, 2010). The results showed that the 8-hour on/16-hour off, 4-hour on/ 8- hour off, and the 8/4/4/8 resulted in better performance as compared to the 6/6.

A number of studies have been conducted at the Naval Postgraduate School to assess the effect of shift work on sleep hygiene and the performance of U.S. Navy crews.

Osborn (2004) compared the 6-hour on/12-hour off used in submarines with a 6-hour watch schedule rotating every three days. Although his results showed that the schedule under investigation did not allow the crew to get more sleep, he noted that further research should identify a watch schedule that would provide more sleep, while still accommodating the constraints of submarine operations. Yokeley (2012), in a within-subjects study of sleep and performance of crewmembers onboard a U.S. Navy destroyer, compared performance of crewmembers while working the 3/9 compared to their performance while working the 5/15. The results, based on actigraphic data, showed that crewmembers on the 3/9 (6.11 ± 0.852) got 0.14 hours more sleep ($p=0.062$) on a daily basis than while on the 5/15 (5.56 ± 0.788). In terms of variability, psychomotor vigilance performance of crewmembers in the 3/9 was more consistent (decreased standard deviation of reaction time) compared to the 5/15.

B. NAVY STANDARD WORK WEEK (NSWW) MODEL

The NSWW model is part of the United States Navy Total Force Manpower Policies Procedures and is described in Naval Operations (OPNAV) Instruction 1000.16K (Department of the Navy, 2007). The NSWW represents a standardized version of one week of work performed by a single enlisted Sailor while at sea, and is used to calculate manning levels, which are a theoretical reflection of the minimum manpower resources necessary to accomplish the ship's mission. The workweek for sea duty is a guideline for sustained personnel utilization based on the operational requirements under projected wartime conditions with units in Condition III steaming, as described in OPNAV Instruction 1000.16K, page C-1 (Department of the Navy, 2007). Although not prescriptive, the instruction notes that extending work hours on a routine basis could adversely affect morale, retention, safety, etc., and, as a policy, habitually extending work hours should be avoided (Department of the Navy, 2007).

The NSWW provides guidelines for the time available per person to accomplish the required workload, including watches expressed in average hours per week. The week is divided into two categories, On Duty (or Available) time (81 hours) and Nonavailable time (87 hours). On Duty time refers to the time periods where personnel are occupied by their required duties: watchstanding (56 hours), work (14 hours), training (7 hours), and service diversion (4 hours). Training contributes to combat readiness and includes activities such as general drills and engineering casualty damage control. Service diversion includes quarters, inspections, sick call, and administrative requirements. Productive Work time (70 hours) includes watchstanding and work. Nonavailable time is comprised of all personal time that is allotted to sleep (56 hours), messing (14 hours), personal needs (14 hours), and free time (3 hours).

Multiple studies conducted at the Naval Postgraduate School have shown that crewmembers work longer hours and sleep less than what is allocated in the NSWW model, suffering from significant sleep deprivation (Green, 2009; Haynes, 2007; Mason, 2009). Specifically, Haynes (2007) found that crewmembers worked approximately 14 hours per day, with 85% of them exceeding the 81 hours allotted by the NSWW, whereas Green (2009) identified that sailors worked 12.5 hours per day, with 61% of her participants exceeding the NSWW model. Mason (2009) found that Senior Chief Petty Officers and Chief Petty Officers averaged 6.26 hours of sleep, while senior officers (Lieutenant Commanders and above) slept approximately 6.4 hours per day.

C. SCOPE

This report compares the 3-hour on/9-hour off and the 6-hour on/6-hour off watch schedules in terms of crew rest and sleep patterns, psychomotor vigilance performance, and work demands/rest opportunities. This work is part of a multiyear effort at the Naval Postgraduate School designed to systematically and empirically assess the wide range of watch schedules used on U.S. Navy ships to provide insight and guidance for future naval operations.

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II. METHODOLOGY

A. EXPERIMENTAL DESIGN

This study used a quasi-experimental approach in which volunteers from various ship departments were recruited to participate in a study of sleep and performance on a U.S. Navy warship.

B. PARTICIPANTS

Participants were volunteers from the USS JASON DUNHAM (DDG 109), an Arleigh Burke class destroyer, Flight IIA (9,300 tons). Initially, 122 crewmembers volunteered to participate in this study. Crewmembers had been working the same schedule for several weeks before the data collection commenced.

C. EQUIPMENT AND INSTRUMENTS

1. Actiwatches

Two types of actigraphs were used, the Ambulatory Monitoring, Inc. (AMI) Motionlogger Watch and the Philips Respironics (PR) Spectrum actiwatch. Data for both devices were collected in 1-minute epochs. AMI data (collected in the Zero-Crossing Mode) were scored using Action W version 2.7.2155 software. The Cole-Kripke algorithm, with rescoring rules, was used. Sleep statistics criteria for long sleep and long wake episodes was five minutes. The sleep latency criterion was no more than 1-minute wake in 20 minutes period (all values are default for this software). PR data were scored using Actiware software version 6.0.0 (Phillips Respironics, Bend, Oregon). The medium sensitivity threshold (40 counts per epoch) was used, with 10 immobile minutes as the criterion for sleep onset and sleep end (all values are default for this software). Previous research has shown that AMI data analyzed with Cole-Kripke and PR data analyzed with medium sensitivity parameters assess total sleep time for an approximately 8-hour night sleep episode with three minutes precision (average results compared to polysomnography derived 436 minutes of sleep) (Meltzer, Walsh, Traylor, & Westin, 2012). A comparison failed to identify any significant differences between AMI and PR actiwatches in 3/9 daily rest, daily total sleep time, occurring within watch periods (Wilcoxon Rank Sum test, for all differences $p > 0.180$).

2. Epworth Sleepiness Scale (ESS)

The ESS is a widely used instrument to assess average daytime sleepiness (Johns, 1991). Using a 4-point Likert scale, the individual indicates the chance of dozing off or falling asleep in eight different everyday situations. Scoring of the answers is 0 to 3, with 0 being "would never doze," 1 is "slight chance of dozing," 2 is "moderate chance of dozing," and 3 denotes "high chance of dozing." Participants are instructed to rate each question according to his/her usual way of life in recent times. Responses are summed to obtain a total score. A sum of 10 or more reflects above-average daytime sleepiness and the need for further evaluation (Johns, 1992). The questionnaire has a high level of internal consistency, as measured by Cronbach's alpha, ranging from 0.73 to 0.88 (Johns, 1992).

3. Morningness-Eveningness (ME) Preference

The Morningness-Eveningness Scale (Horne & Östberg, 1976) was used to assess participants' chronotype; an individual human attribute related to whether there is a preference for waking earlier or later in the day. The scale includes 19 multiple-choice questions. Scores range from 16 to 86, with scores less than 42 corresponding to evening chronotypes and scores higher than 58 indicating morning chronotypes.

4. Pittsburgh Sleep Quality Index (PSQI)

The evaluation of the participants' sleep pattern quality was assessed with the PSQI scores (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). The PSQI has 18 questions that yield seven component scores (sleep quality, sleep latency, duration, sleep efficiency, sleep disturbances, sleep medication use, and daytime dysfunction) rated from 0 (better) to 3 (worse). The total score, ranging from 0 (better) to 21 (worse), is the summation of all the component scores. Individuals with a PSQI total score ≤ 5 are characterized as good sleepers, whereas scores > 5 are associated with poor sleep quality. According to its developers, the PSQI has a sensitivity of 89.6% and a specificity of 86.5% ($\kappa = 0.75$, $p < 0.001$), and an internal consistency $\alpha = 0.83$ (Buysse et al., 1989).

5. Psychomotor Vigilance Test (PVT)

Performance data were collected using the 3-minute PVT (Dinges & Powell, 1985) available on the AMI Motionloggers. PVT performance is not only affected by sleep loss, but it is also sensitive to circadian rhythmicity (Dinges et al., 1997; Doran, Van Dongen, & Dinges, 2001; Durmer & Dinges, 2005; Jewett, Dijk, Kronauer, & Dinges, 1999; Wyatt et al., 1997). The PVT is a simple reaction time test, where participants are required to press a response button as soon as the stimulus appears on the screen. The PVT has minor learning effects that can be reached in one to three trials (Dinges et al., 1997; Jewett et al., 1999; Kribbs & Dinges, 1994; Rosekind et al., 1994). The PVT interstimulus interval (ISI), defined as the period between the last response and the appearance of the next stimulus, ranges randomly from 2 to 10 seconds. The standard version of the PVT has a duration of 10 minutes (Loh, Lamond, Dorrian, Roach, & Dawson, 2004); however, shortened versions have also been used effectively to demonstrate sleep deprivation effects (Basner & Dinges, 2011; Loh et al., 2004). Since operational demands prevented the use of the 10-minute version, we used the 3-minute version of the PVT, which is included on the AMI Motionlogger actigraphs. The ISI ranged from 2 to 10 seconds, a red backlight appeared for one second and the word "PUSH" was the visual stimuli; the response time in milliseconds was then displayed to the participant.

6. Activity Logs

All participants were asked to complete a daily activity log, documenting their daily routine in accordance with NSWW categories. The logs covered 24-hour periods in 30-minute intervals.

D. PROCEDURES

The study was approved by the Naval Postgraduate School Institutional Review Board. Personnel were briefed on the research protocol and study procedures. Those wishing to volunteer signed informed consent forms at the beginning of the study and received further training prior to being issued equipment for the study. Participants filled out the prestudy surveys upon receipt of their sleep watches and activity logs. All participants were instructed to fill out their activity logs daily and, at a minimum, complete a PVT prior to and after their watchstanding period. Upon completion of the study, the participants returned their equipment and filled out an end-of-study survey.

E. VARIABLES

Two independent variables, watch schedule and watch section, were used to compare the 3-hour on/9-hour off and 6-hour on/6-hour off watch schedules in terms of crew rest, sleep, and psychomotor vigilance performance. Dependent variables were daily rest and sleep amount (with and without naps within watch periods), number of sleep episodes per day, ESS scores, and PVT performance (as measured using mean reaction time [RT], mean response speed [1/RT], fastest 10% RT [i.e., 10^{th} percentile of RT], slowest 10% of 1/RT [i.e., 10^{th} percentile of 1/RT], percentage of 750ms, 600ms, 500ms and 355ms lapses, percentage of lapses and false starts, and percentage of false starts [FS]).

To assess work demands and rest opportunities, we compared the weekly amount of reported time with the time criteria of the NSWW model activities (sleep, messing, personal time, free time, watch, work, training, service diversion, nonavailable time, productive work, and time on duty).

F. ANALYSIS

1. Actigraphic Data Cleaning and Reduction Procedures

The preparation of the actigraphic data for analysis included three steps. First, we determined the number of days of data available for each participant to examine the occurrence of gaps. Seventeen participants (13.8%) had fewer than five days of data and were omitted from the analysis. Then, we assessed the activity logs completed by each participant and verified the actigraphic data by using these logs. However, the main source of information for the sleep analysis was the actigraphic data, although sleep logs assisted in the determination of start and finish time of the sleep intervals. Based on this comparison, we manually identified the start and end times of sleep episodes in the actigraphic data. Imputation was applied only when: (a) there was a gap in actigraphic data within which the sleep log showed a sleep interval, or (b) the pattern of actigraphic data, verified by the activity logs, was such to assure a confidence in the interpolation of a sleep interval. The criteria when considering imputation were the utility of the actigraphic data, the consistency in the pattern of activities over consecutive days, the amount of missing data, whether the participant was a watchstander, and the accuracy of the sleep log. Two crewmembers on the 3/9 schedule shifted their watch schedule for two or three days in the middle of the data collection period. We did not use their data from those days or from the day following their shift in schedule in the analysis. A large amount of data was missing on the first day of the study (3 December 2012); thus, our analysis used 4 December 2012 as the actual first day of the study.

Due to an operational commitment occurring on/about 15 December 2012, the ship was required to travel at high speeds, for a prolonged time, through rough seas. During this period, the motion of the ship was clearly evident in the actigraphic data, thereby contaminating the data for that time period. Therefore, all intervals after 15 December 2012 were omitted from the analysis. No observable interference due to ship motion was identified during the other days of the data collection period, although it should be noted that there is currently no objective method for isolating ship motion in actigraphic output. Using the methods described, an initial Excel spreadsheet of sleep intervals was developed that included data between 4 and 14 December 2012.

We focused on the rest/in-bed intervals (identified as DOWN intervals in the AMI software, and REST intervals in the Respironics software). The software provided the "Rest" time for each interval (also called time in-bed [TIB] in the literature); however, we did not use this naming convention, since some of the rest was obtained during watch. The software also provided the actigraphically evaluated Sleep amount within each Rest interval (also called Total Sleep Time [TST] in the literature). It should be noted that none of the participants reported a nap during watch periods, which was expected. For this reason, any naps within a watch period were based strictly on the pattern of activity that each participant demonstrated.

Of the 1,864 rest intervals, 80 (4.3%) were imputed, while 82 (4.4%) were naps identified during watch periods. The amount of rest and sleep for each day was calculated from 00:00 to 23:59.

2. PVT Data Cleaning and Reduction Procedures

Psychomotor vigilance performance data were collected using the version of the PVT included on the AMI Motionloggers. The duration of each PVT trial was 3 minutes, with a minimum interstimulus interval (ISIMin) of 2 seconds and maximum interstimulus interval (ISIMax) of 10 seconds. As with the sleep analysis, tests taken on 3 December and after 15 December were omitted from the analysis. No imputation was applied in the PVT data.

PVT data were analyzed based on the metrics described by Basner and Dinges (2011) for individuals with chronic sleep deprivation. Specifically, a PVT response was scored as valid if RT was ≥ 100 milliseconds (ms). Responses without a stimulus or with RTs < 100 ms were identified as false starts. Four categories of lapses were defined as RTs: equal to or greater than 355 ms, 500 ms, 600 ms, and 750 ms.

This data set, however, included some extraordinarily long reaction times of 10 seconds or more. Given that the PVT was not performed in controlled conditions, we postulate that these responses can be attributed predominantly to environmental factors acting as distractors (e.g., environmental noise, crewmembers in the same area, resumption of duties, etc.). For this reason, we omitted those responses with RTs ≥ 10 seconds from RT calculations, although we still denoted them as lapses and included them in the calculation of lapses (n = 78 responses). With the ISI settings used, approximately 18 to 24 responses were expected in the 3-minute PVT. Therefore, trials with less than 10 responses were omitted from the analysis.

All PVT responses were aggregated by trial and then by participant. PVT performance metrics were analyzed between participants. No imputation was applied in the PVT data. PVT analysis was based on 959 trials.

3. Sleep Log Data Cleaning and Reduction Procedures for Workload Analysis

Data from all sleep logs were screened for completeness and accuracy and were input into an Excel spreadsheet. Specifically, we assessed missing activity information or information that did not comply with the instructions for completing the sleep logs (e.g., adding activity codes not included in the instructions provided). Due to excessive missing data, logs from 3 and 17 December were omitted from the analysis, which included data between 4 and 16 December 2012.

In some cases, participants included two activity codes in the same 30-minute interval (n = 102; 0.18% of the 55,824 intervals). We interpreted these inputs as meaning that the participant spent time in both activities within the same 30-minute period. Without altering the amount of activity time within that day, we deleted the second activity from one cell and added it, as appropriate, to another cell with the same activity code. Two days of data were omitted from participant 3018 because of illness.

When deemed appropriate, data for days with missing activity were interpolated. The criteria for interpolation were (a) the accuracy of the sleep log, (b) the pattern of activities over consecutive days, (c) the length of missing data, (d) whether the participant was a watchstander, and (e) the existence of actigraphy data. Some logs were classified as inappropriate for interpolation because they did not correlate well with the actigraphic data. The pattern of activities was a critical criterion; that is, if the participants did not have a consistent daily pattern of activities, it was difficult to infer activities for missing days. Lastly, watchstanders had daily schedules that were more consistent and predictable. This consistency in activity patterns was not observed in nonwatchstanders; hence, we did not interpolate missing days of nonwatchstanders. Overall, we attempted to interpolate as needed, given the utility and accuracy of the available information sources, but we kept the interpolation rate as low as possible.

Entire day interpolation was applied to 59 days (5% of the 1,163), whereas partial interpolation was applied to five days that were missing, on average, 2.5 hours each. Overall, interpolation was applied to 2,344 30-minute intervals (4.2%).

4. Analysis Roadmap

Statistical analysis was conducted with the JMP Pro 9 statistical software package (SAS Institute; Cary, North Carolina). Descriptive statistical analysis was used to describe demographic characteristics of the population. Correlation analysis was conducted using nonparametric Spearman’s rho. Levene’s test was used for testing for equality of variances. Nonparametric methods were used for comparisons. These included the Wilcoxon Rank Sum test and, for multiple comparisons, the Dunn method (for joint ranks accounting for group error rate).

Data are presented as mean (M) ± standard deviation (SD) or median (MD) as appropriate. Significance level was set at $p < 0.05$. The nonparametric Wilcoxon Rank Sum test was used for comparisons. Correlation analysis was performed using the nonparametric Spearman's rho.

We initially performed a descriptive analysis of the entire data set, focusing on sleep intervals and daily rest/sleep amounts. Next, analysis was focused on the comparison between the 3/9 and 6/6 schedules.

III. RESULTS

A. DEMOGRAPHICS

From the 122 crewmembers that initially volunteered, 52 were included in the watch schedule analysis, 41 (43.2%) in the 3/9 and 11 (11.6%) in the 6/6 watch schedules. Participants in the 3/9 stood watch between 00:01-03:00/12:00-15:00 (n = 6), 03:00-06:00/15:00-18:00 (n = 9), 06:00-09:00/18:00-21:00 (n = 8), and 09:00-12:00/ 21:00-23:59 (n = 18). Participants in the 6/6 stood watch between 00:01-06:00/ 12:00-18:00 (n = 7) and 06:00-12:00/18:00-23:59 (n = 4). All 6/6 participants were in the Operations (OPS) department, while the 3/9 participants were spread across the Weapons (WEPS), OPS, Engineering (ENG), and Supply departments. Appendix A provides a detailed description of participants by watch schedule, watch section, and actiwatch type. Table 1 shows the demographic information.

Table 1. Demographics.

Variable	Entire Data Set N = 122	Used for Analysis N = 52
Age, years, M ± SD	28 ± 5.96	29.1 ± 6.12
Gender, # males (%)	98 (80.3%)	40 (76.9%)
Pay grade, #		
Officers	28 (WO2-3, O1-5)	14 (WO2-3, O1-3)
Enlisted	94 (E2-8)	73 (E3-8)
Department, # All (Off.)		
CO – XO (not in a department)	2	–
Air Department	15 (6 officers)	–
Combat Systems	21 (3)	6 (4)
Engineering	32 (6)	19 (5)
Executive/Administration	3 (0)	–
Navigation	1 (0)	–
Operations	22 (5)	12 (4)
Supply	5 (1)	–
Weapons	20 (4)	1 (1)
Service, years, M ± SD	6.94 ± 5.55	7.15 ± 5.61
ME score, M ± SD	49.3 ± 8.05	47.3 ± 8.15
ME types, # (%)		
Definitely morning type	13 (10.7%)	–
Moderately morning type	1 (0.83%)	6 (11.5%)
Neither type	88 (72.70%)	34 (65.4%)
Moderately evening type	18 (14.90%)	12 (23.1%)
Definitely evening type	1 (0.83%)	–

B. DESCRIPTIVE RESULTS FOR THE ENTIRE DATA SET

The average PSQI Global score for the entire data set was 8.51 ± 3.29 (MD=8) ranging from 1 to 18. PSQI scores indicate that 91% of the participants were "poor sleepers" (PSQI score ≥ 5).

Actigraphic data were available from 95 participants over 1,864 sleep episodes. On average, each participant provided 20.2 ± 6.68 sleep episodes (MD = 20), ranging from 9 to 44 sleep episodes per person. Analysis showed that participants slept, on average, 1.77 ± 0.598 (MD = 1.75) episodes per day, ranging from 0.909 to 3.67 episodes. The average daily rest and sleep amount by participant is shown in Table 2.

Table 2. Daily rest and sleep amount by participant.

Sleep Intervals		Duration (hours)				
		Mean	Standard Deviation	Median	Minimum	Maximum
All	Rest	7.27	0.883	7.24	5.42	9.65
	Sleep	6.58	0.856	6.62	4.81	8.78
Only off-watch	Rest	7.20	0.903	7.17	4.65	9.65
	Sleep	6.53	0.873	6.60	4.07	8.78

Figures 2 and 3 show the frequency plots of daily rest and sleep amount in hours (all intervals included).

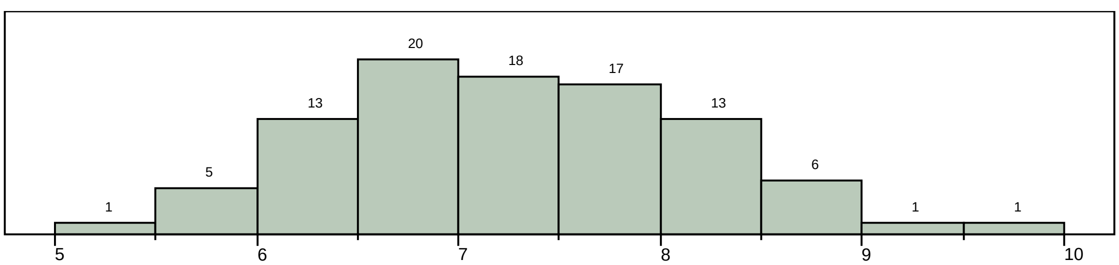

Figure 2. Daily rest amount in hours. Numbers on vertical bars represent the corresponding number of participants.

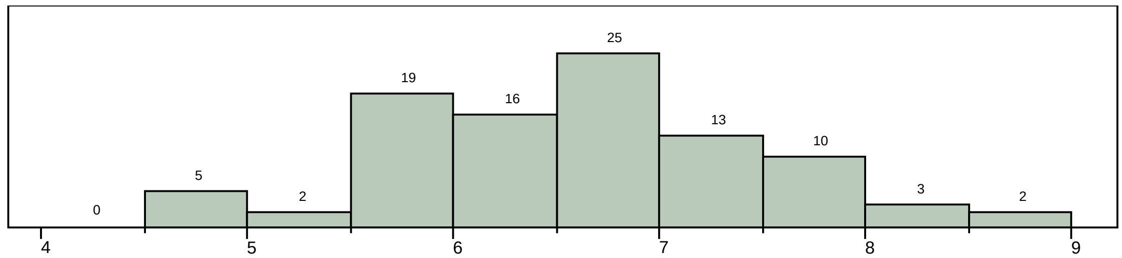

Figure 3. Daily sleep amount in hours. Numbers on vertical bars represent the corresponding number of participants.

It is notable that 95% of the participants received, on average, less than eight hours of sleep daily; 27% of the participants slept less than six hours per night. On average, participants experienced approximately 1.5 hours of sleep debt daily. Over the 11-day period of the research study, crewmembers accumulated an average of approximately 16 hours of sleep deficit. The average ESS score was 10.6 ± 3.70 (MD = 10) ranging from 2 to 22. ESS scores indicate that 52 participants (42.6%) have excessive daytime sleepiness (i.e., ESS score > 10) (Johns, 1991).

C. PRIMARY ANALYSIS

First, we assessed daily rest and sleep duration and compared them between schedules. From the actigraphic data, we determined that 10 (24.4%) participants on the 3/9 and 5 (45.5%) on the 6/6 schedules napped during watch. Analysis showed that the participants on the 6/6 schedule received less rest and sleep daily than participants on the 3/9 schedule, either when including all rest/sleep episodes or only those periods when sleep occurred during off-watch periods ($p < 0.05$). When looking only at the off-watch sleep intervals, crewmembers on the 3/9 slept, on average, 6.43 ± 0.77 hours, compared to 5.66±0.79 hours for those on the 6/6 schedule. When all sleep intervals included, crewmembers on the 3/9 slept, on average, 6.46 ± 0.77 hours, compared to 5.89 ± 0.87 hours for those on the 6/6 schedule. In short, the difference of approximately 46 minutes in daily sleep during off-watch periods was reduced to 34 minutes when including all rest/sleep intervals. Although napping during watch was identified in the actigraphic recordings of both watch schedules, napping on watch was more common on the 6/6 schedule. Consequently, crewmembers on the 6/6 partially compensated for their sleep debt by napping more during watch periods.

Including all sleep intervals, we assessed whether participants on the 6/6 schedule had more sleep episodes per day compared to those on the 3/9. Table 3 shows these results and indicates that there were significant differences between the 3/9 and 6/6 in mean values for all metrics. Figure 4 depicts daily sleep and sleep episodes per day.

Table 3. Daily rest/sleep amount in hours and number of sleep episodes per day by watch schedule.

Daily amount (hours)	3/9 M ± SD	6/6 M ± SD	Mean values Δ%	Sig. p val.[A]	Standard Deviation Δ%	Sig. p val.[B]
Daily Rest – all intervals	7.20 ± 0.71	6.49 ± 0.90	10.9%	0.007	–17.90%	0.622
Daily Rest – off-watch	7.17 ± 0.72	6.21 ± 0.78	16.5%	0.001	–4.88%	0.900
Daily Sleep – all intervals	6.46 ± 0.77	5.89 ± 0.87	11.2%	0.043	–11.10%	0.754
Daily Sleep – off-watch	6.43 ± 0.78	5.66 ± 0.79	15.8%	0.011	–2.44%	0.799
Sleep episodes per day	1.95 ± 0.50	2.39 ± 0.64	–18.4%	0.026	–21.90%	0.160

[A] Wilcoxon Rank Sum Test. [B] Levene's test for equality of variances.

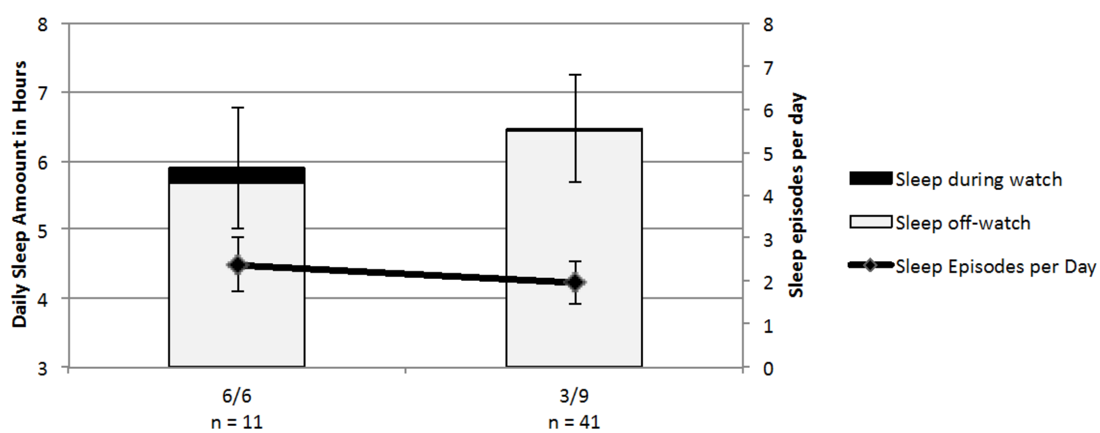

Figure 4. Daily sleep and number of sleep episodes per day by watch schedule.

Compared to participants on the 3/9 (10.7 ± 3.70), those watchstanders on the 6/6 had worse (i.e., larger) ESS scores (13.1 ± 3.45; Wilcoxon Rank Sum test: $X^2(1) = 4.36$, $p = 0.038$). Figure 5 depicts ESS scores by watch schedule.

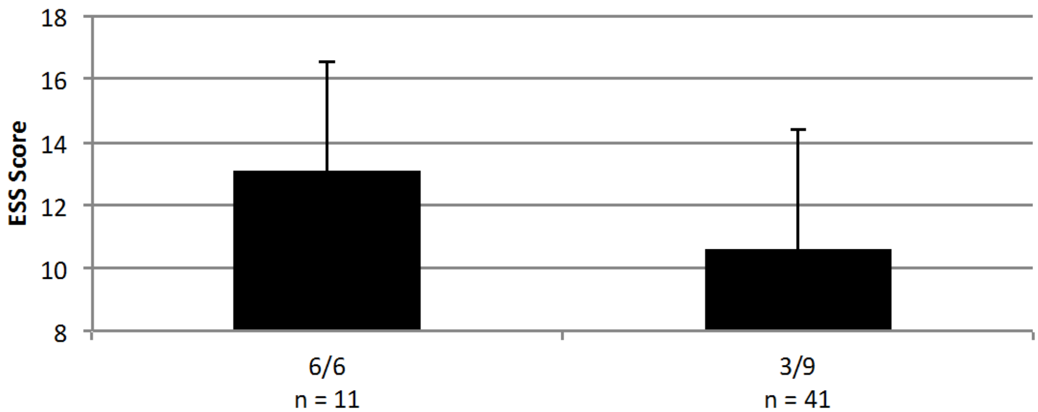

Figure 5. Epworth Sleepiness Scale scores by watch schedule.

1. Comparison Between Watch Sections

We assessed changes in daily rest, sleep, and number of sleep episodes between various watch sections on the two watchstanding schedules. We identified a difference in daily rest (Dunn method, $Z = 2.57$, $p = 0.061$) and sleep (Dunn method, $Z = 2.41$, $p = 0.096$) between the 03:00-06:00 and the 06:00-09:00 sections on the 3/9 schedule. Figure 6 depicts daily sleep and number of sleep episodes per day, by the 3/9 sections. Vertical lines represent one standard deviation of daily sleep, including all sleep intervals or only those sleep intervals that occurred while participants were off watch.

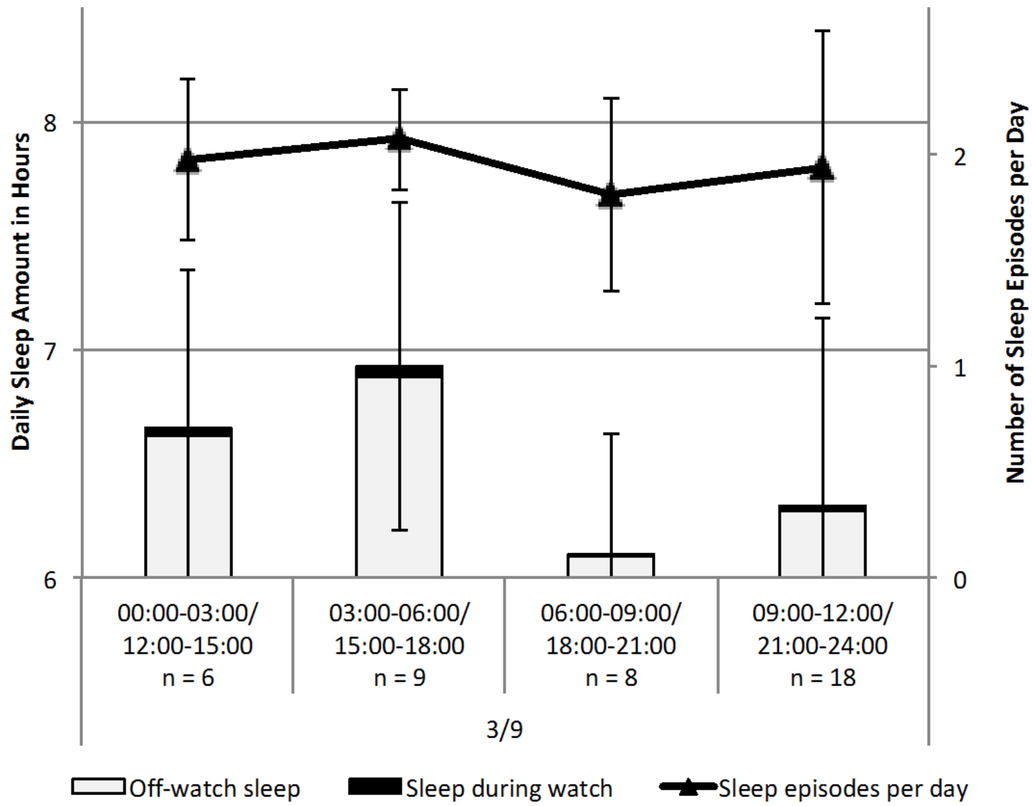

Figure 6. Daily sleep and the number of sleep episodes per day in the 3/9 watch sections.

This diagram shows that the participants on the 3/9 schedule, with shifts occurring from midnight to 06:00 and from noon to 18:00, receive significantly more rest and sleep than their peers on the 06:00 to noon and 18:00 to midnight shifts. The same pattern is evident in the 6/6, but because of the small number of participants on the two shifts of the 6/6, statistical results are not reported. These results are shown in Table 4. Comparisons are based on Wilcoxon Rank Sum test.

Table 4. Daily rest/sleep amount in hours by watch shift.

Watch Schedule	Daily amount (hours)	1 [A] M ± SD	2 [B] M ± SD	X2(1)	Sig. p val. [A]
3/9	Rest – all intervals	7.48 ± 0.60	7.04 ± 0.73	3.90	0.048
	Rest – off watch	7.43 ± 0.64	7.02 ± 0.73	3.10	0.079
	Sleep – all intervals	6.82 ± 0.70	6.24 ± 0.74	4.69	0.030
	Sleep – off watch	6.78 ± 0.73	6.23 ± 0.74	3.80	0.051
6/6	Rest – all intervals	6.80 ± 1.00	5.95 ± 0.30	–	–
	Rest – off watch	6.37 ± 0.94	5.91 ± 0.27	–	–
	Sleep – all intervals	6.16 ± 1.00	5.43 ± 0.31	–	–
	Sleep – off watch	5.82 ± 0.96	5.41 ± 0.29	–	–

[A] For the 3/9, "1" refers to participants on the 00:00-03:00/12:00-15:00 and 03:00-06:00/15:00-18:00 shifts combined. For the 6/6, "1" refers to participants on the 00:00-06:00/12:00-18:00 shift. [B] For the 3/9, "2" refers to participants on the 06:00-09:00/18:00-21:00 and 09:00-12:00/21:00-24:00 shifts combined. For the 6/6, "2" refers to participants on the 06:00-12:00/18:00-24:00 shift.

Figure 7 shows daily rest and sleep, by watch schedule and section. Napping during watches is clearly evident for participants on the 6/6 watch schedule, with most naps occurring during the 00:00-06:00 watch period.

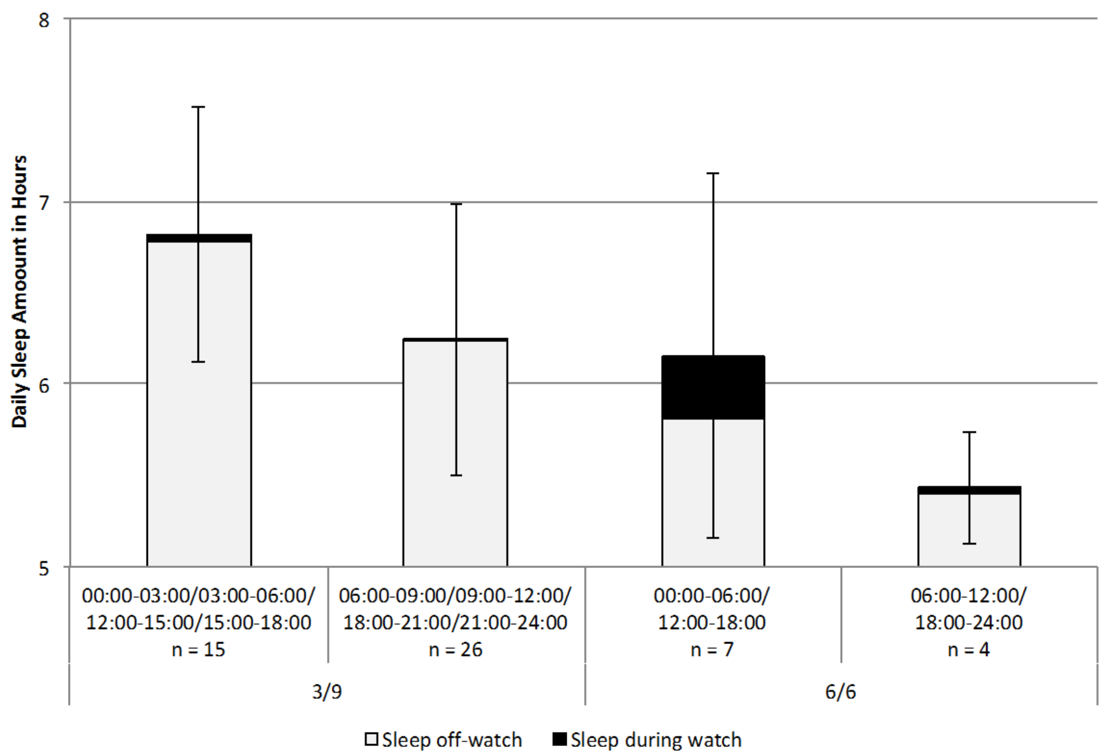

Figure 7. Daily rest and sleep, by watch schedule and shift.

2. Psychomotor Vigilance Performance

We also assessed the effect of watch schedule (3/9 versus 6/6) on PVT performance. Congruent with the rest/sleep results already described, the average values of the PVT were better for participants on the 3/9 compared to those on the 6/6, but not at statistically significant levels. However, the two watch schedules differed significantly in variability; participants on the 6/6 had larger variability than those on the 3/9 for 11 of the 13 PVT metrics used ($p < 0.05$). These results are shown in Table 5.

Table 5. Comparison of PVT metrics between the 3/9 and 6/6 watch schedules.

Variable	3/9 M ± SD	6/6 M ± SD	Mean values Δ%	Sig. p value [A]	Standard Deviation Δ%	Sig. p value [B]
Mean RT, [ms]	323 ± 66.9	372 ± 135	–13.20%	0.407	–50.4%	0.009
Mean 1/RT	3.95 ± 0.524	3.67 ± 0.928	7.63%	0.293	–43.5%	0.016
Fastest 10% RT, [ms]	196 ± 28.0	217 ± 52.7	–9.68%	0.275	–46.9%	0.019
Slowest 10% 1/RT	2.43 ± 0.469	2.18 ± 0.743	11.50%	0.374	–36.9%	0.069
False Starts (FS), %	2.0 ± 1.59	2.23 ± 2.10	–10.30%	0.936	–24.3%	0.474
Lapses 750ms, %	3.74 ± 2.60	5.70 ± 5.38	–35.40%	0.492	–51.7%	0.007
Lapses 600ms, %	5.30 ± 3.06	8.39 ± 7.19	–36.8%	0.518	–57.4%	< 0.001
Lapses 500ms, %	7.54 ± 4.40	11.9 ± 9.57	–36.60%	0.332	–54.0%	< 0.001
Lapses 355ms, %	17.0 ± 9.74	26.8 ± 18.5	–36.60%	0.210	–47.4%	0.005
Lapses 750ms+FS, %	5.74 ± 3.74	7.98 ± 4.86	–28.10%	0.210	–23.1%	0.591
Lapses 600ms+FS, %	7.30 ± 4.03	10.7 ± 6.50	–31.80%	0.258	–38.0%	0.068
Lapses 500ms+FS, %	9.54 ± 5.09	14.2 ± 8.64	–32.80%	0.293	–41.1%	0.014
Lapses 355ms+FS, %	19.0 ± 9.78	29.1 ± 17.2	–34.70%	0.182	–43.1%	0.008

[A] Wilcoxon Rank Sum Test. [B] Levene's test for equality of variances.

Figure 8 shows the aforementioned differences in variability between watch schedules.

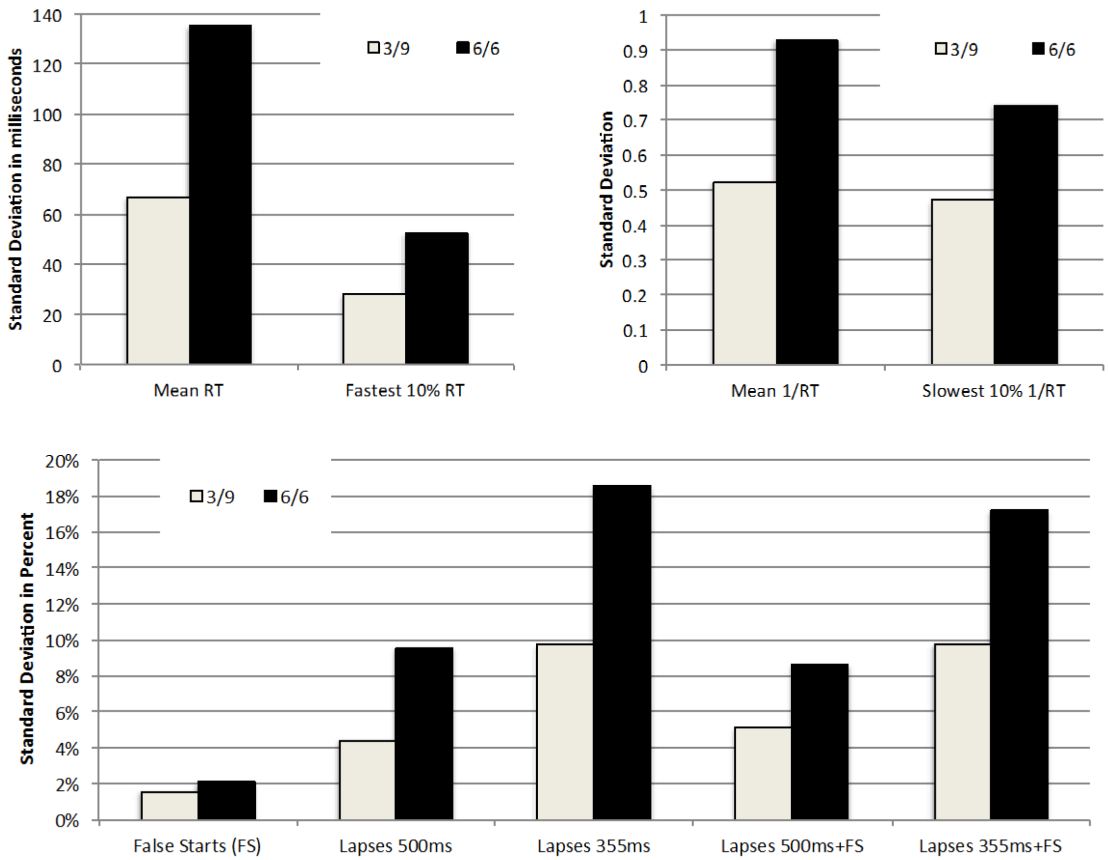

Figure 8. Differences in standard deviations in PVT metrics between the 3/9 and 6/6 watch schedules.

3. Posttest Questionnaires

At the completion of the study, participants (N = 122) rated seven watch schedules (5/10, 5/15, 6/6, 3/9, 12/12, 6/12, and 6/18). They were asked to respond to the question "Compared to my current schedule, the [watch schedule] is …" using a 6-level Likert scale (Worse "1," Same as "2," Better "3," Never stood the [watch schedule] watch before "4," Standing [watch schedule] watch now "5," No answer "6"). Results show that the participants evaluate the 6/6 as being the worst schedule and the 3/9 and 6/18 as the two best. Figure 9 shows the integrated results by watch schedule.

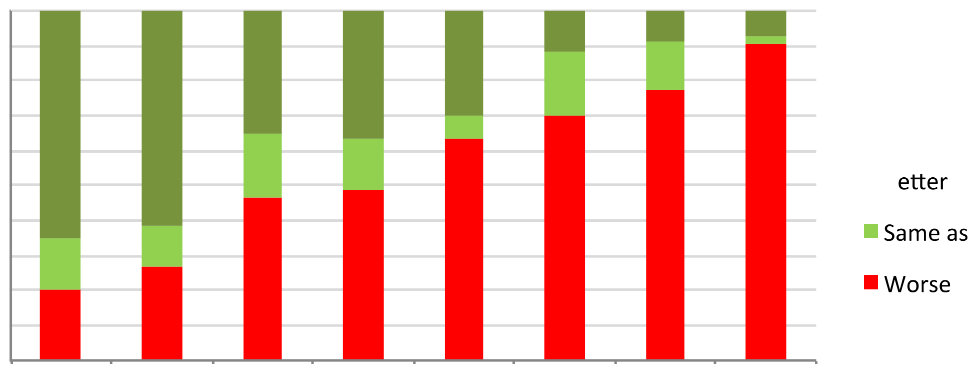

Figure 9. Subjective evaluations of watch schedules.

4. Work Patterns

Next, we assessed work patterns in terms of NSWW compliance and the association between work patterns and watch schedule. Crewmembers on the 6/6 watch schedule work 30% more than the NSWW criterion (105 hours compared to 81 hours) and stand watch 60% more than the criterion (91 hours compared to 56 hours). We found that participants on the 6/6 watch schedule experience a 15-hour workday. Furthermore, crewmembers on the 6/6 schedule indicate spending 460% more time on Service Diversion than the NSWW criterion and over twice as much as participants on the 3/9 (+225%). These results are shown in Table 6.

Table 6. Work patterns by watch schedule.

Activity (criterion)	3/9 (M ± SD)	6/6 (M ± SD)	Watch schedule comparison p-value
Non-available time (87 hours)	82.6 ± 13.6**	63.0 ± 4.84**	< 0.001
Sleep (56 hours)	46.6 ± 7.10***	42.2 ± 8.30**	0.167
Messing (14 hours)	10.4 ± 4.00***	8.24 ± 2.70**	0.157
Personal time (14 hours)	24.4 ± 13.0***	12.5 ± 5.77	< 0.001
Free time (3 hours)	1.26 ± 2.80***	0	
On Duty (81 hours)	85.4 ± 13.6**	105 ± 4.84**	< 0.001
Productive Work (70 hours)	58.2 ± 14.4***	91.4 ± 3.84**	< 0.001
Watch (56 hours)	48.7 ± 8.60***	90.0 ± 2.20**	< 0.001
Work (14 hours)	9.55 ± 12.2**	1.32 ± 4.00**	0.028
Training (7 hours)	4.84 ± 5.10**	0.695 ± 0.900**	0.003
Service diversion (4 hours)	22.4 ± 15.9***	13.0 ± 6.70**	0.102

Note: Different than the criterion: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Service Diversion activities are responsible for dramatically reducing sleep opportunities for participants on the 6/6 watch schedule. This result was further assessed by a stepwise regression analysis. Initially, we included all activity groups as probable factors for consideration. The stepwise analysis showed that only the Service Diversion group was associated with sleep time ($p = 0.05$). Based on this result, the corresponding regression model showed that Service Diversion alone explained 62% of the observed variability in the sleep time of participants on the 6/6, $R^2_{adj}=0.575$, $F(1, 8) = 13.2$, $p = 0.007$. Stepwise analysis of the sleep patterns for participants on the 3/9 did not exclude any of the seven groups of activity. The corresponding multiple regression model explained 86% of the observed variability of sleep time of participants on the 3/9, $R^2_{adj} = 0.832$, $F(7, 36) = 31.4$, $p < 0.001$.

The considerable differences in distributions of duty time, productive work, watch, and sleep between participants on the 3/9 and 6/6 watch schedules are clearly depicted in Figures 10-16. Vertical axes show the percentage of participants on each watch section. Each time bin represents a 30-minute period.

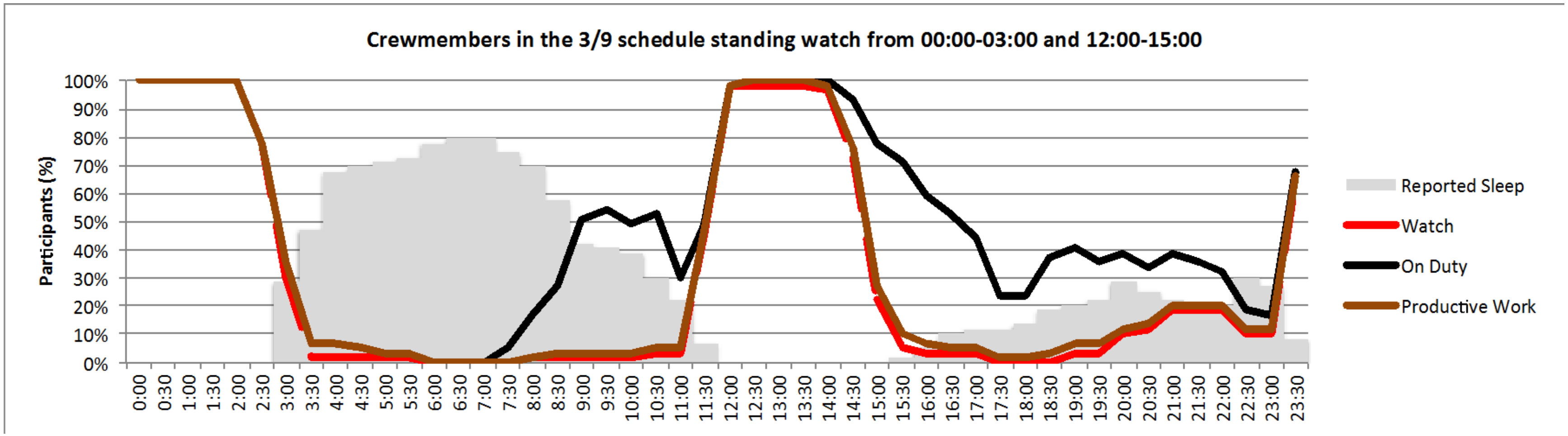

Figure 10. Work and sleep patterns in the 00:00 – 03:00 and 12:00 – 15:00 section of the 3/9 watch schedule.

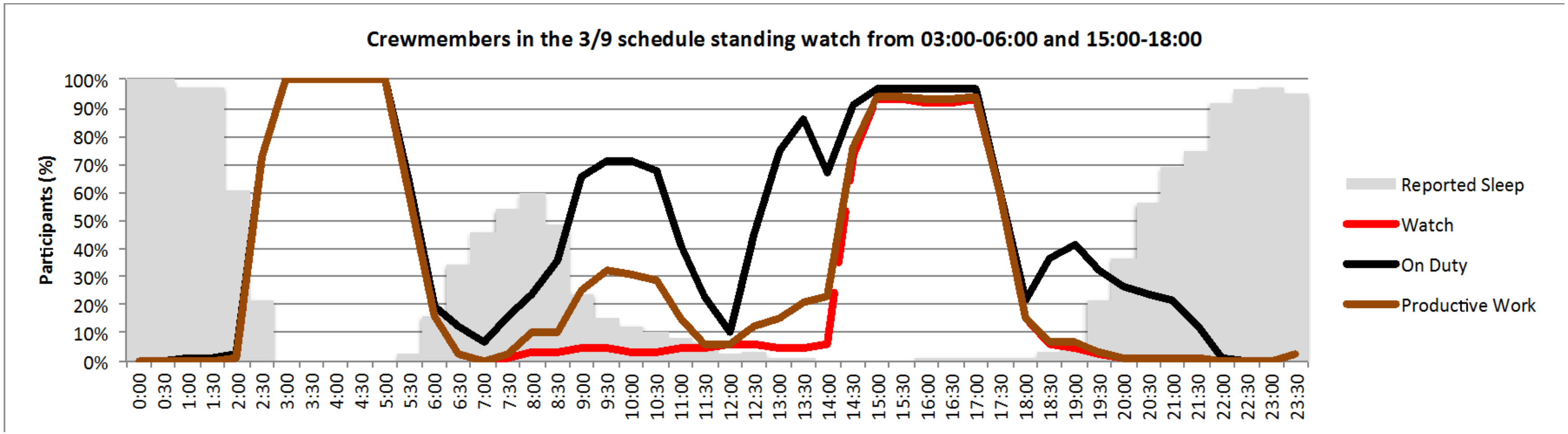

Figure 11. Work and sleep patterns in the 03:00 – 06:00 and 15:00 – 18:00 section of the 3/9 watch schedule.

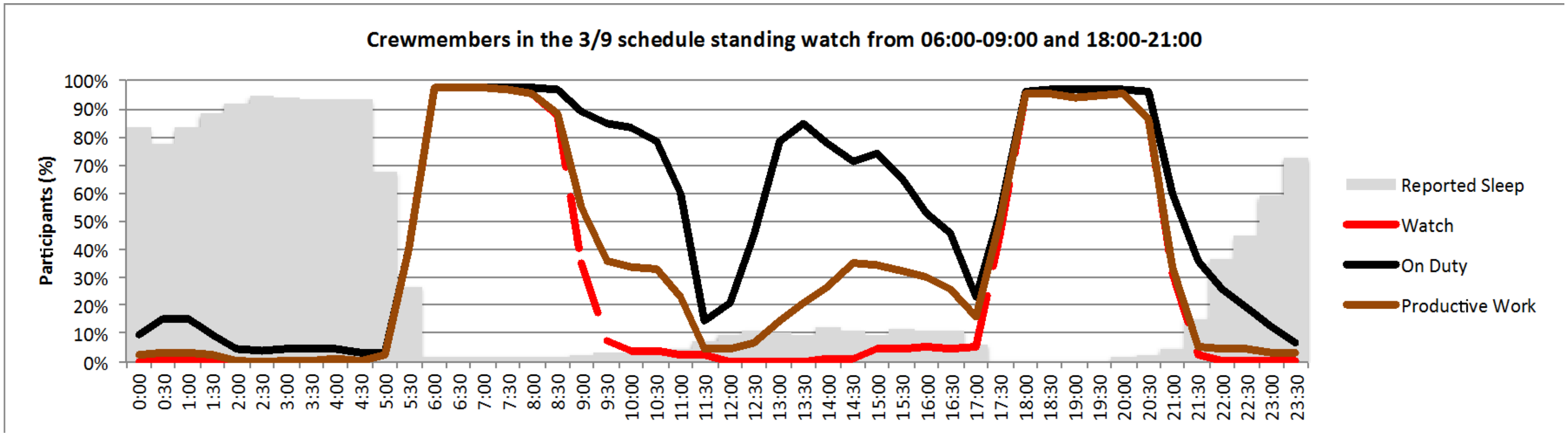

Figure 12. Work and sleep patterns in the 06:00 – 09:00 and 18:00 – 21:00 section of the 3/9 watch schedule.

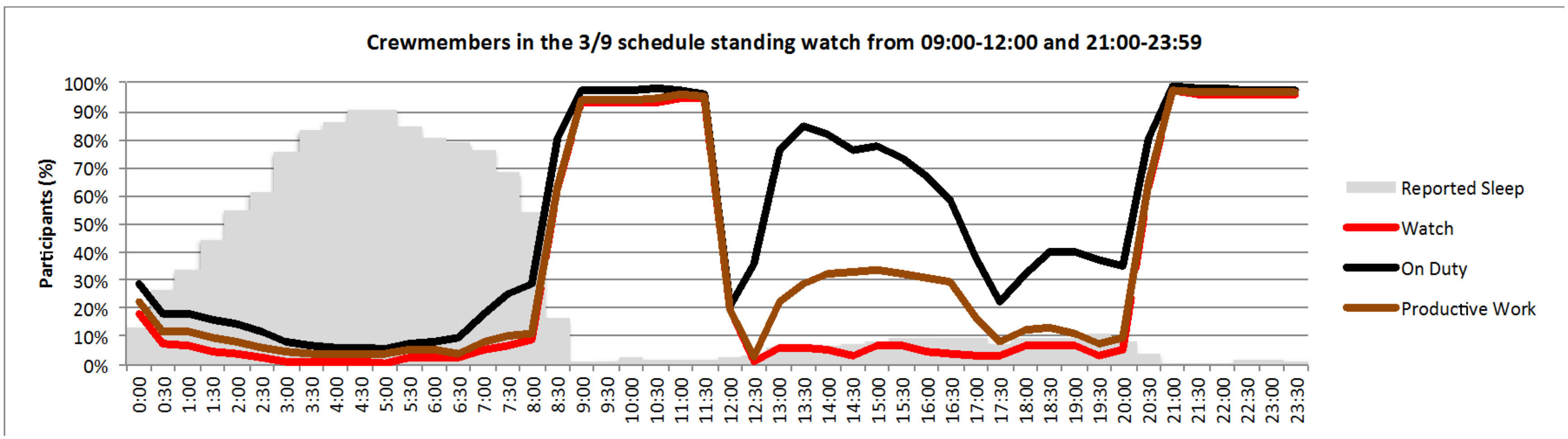

Figure 13. Work and sleep patterns in the 09:00 – 12:00 and 21:00 – 23:59 section of the 3/9 watch schedule.

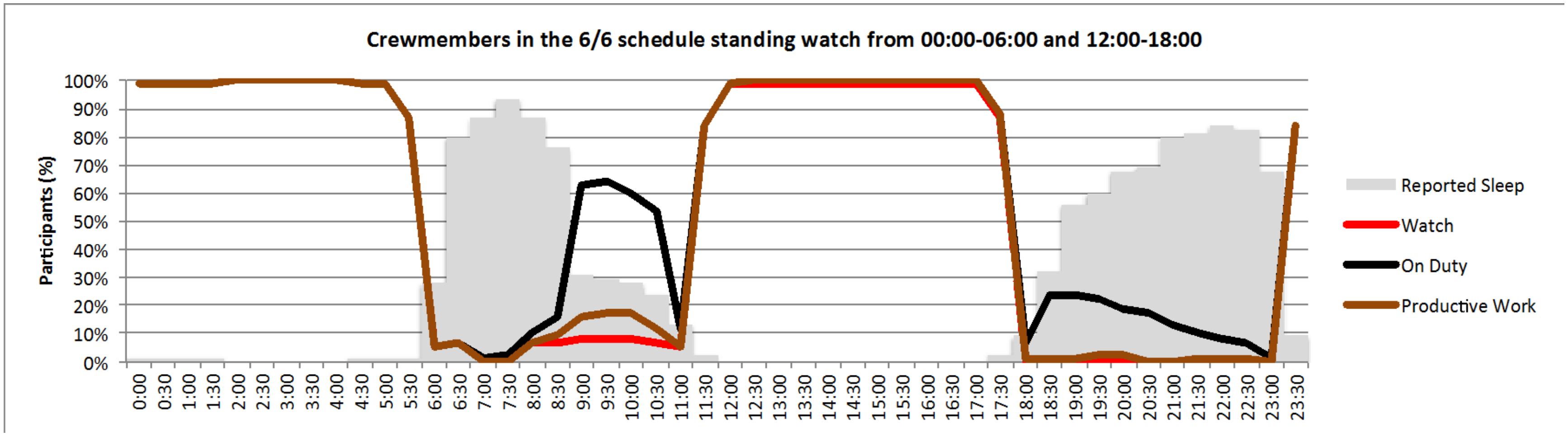

Figure 14. Work and sleep patterns in the 00:00 – 06:00 and 12:00 – 18:00 section of the 6/6 watch schedule.

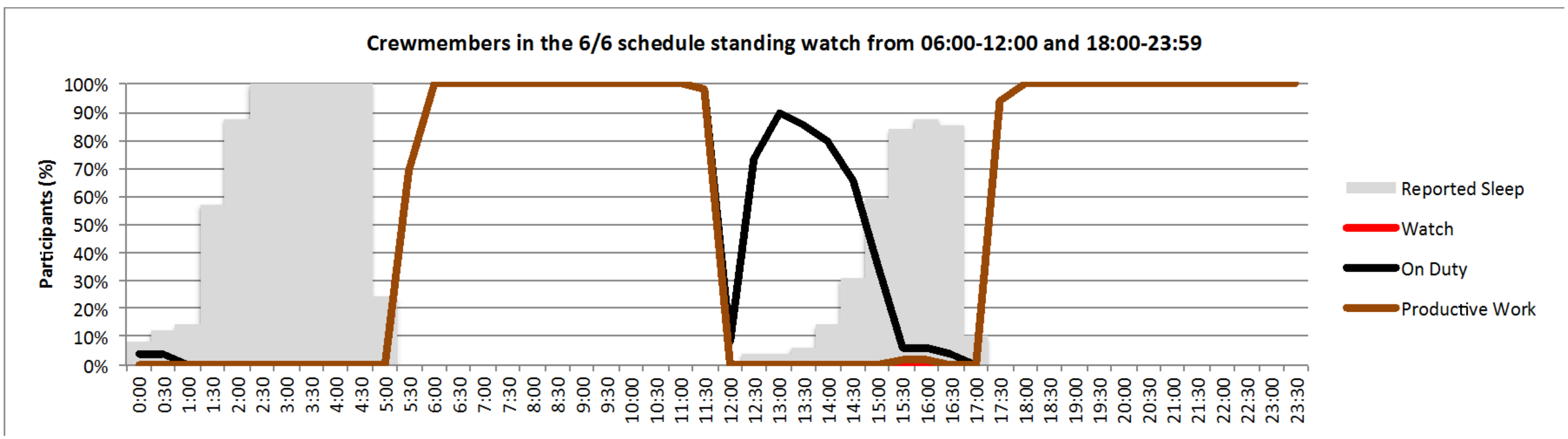

Figure 15. Work and sleep patterns in the 06:00 – 12:00 and 18:00 – 23:59 section of the 6/6 watch schedule.

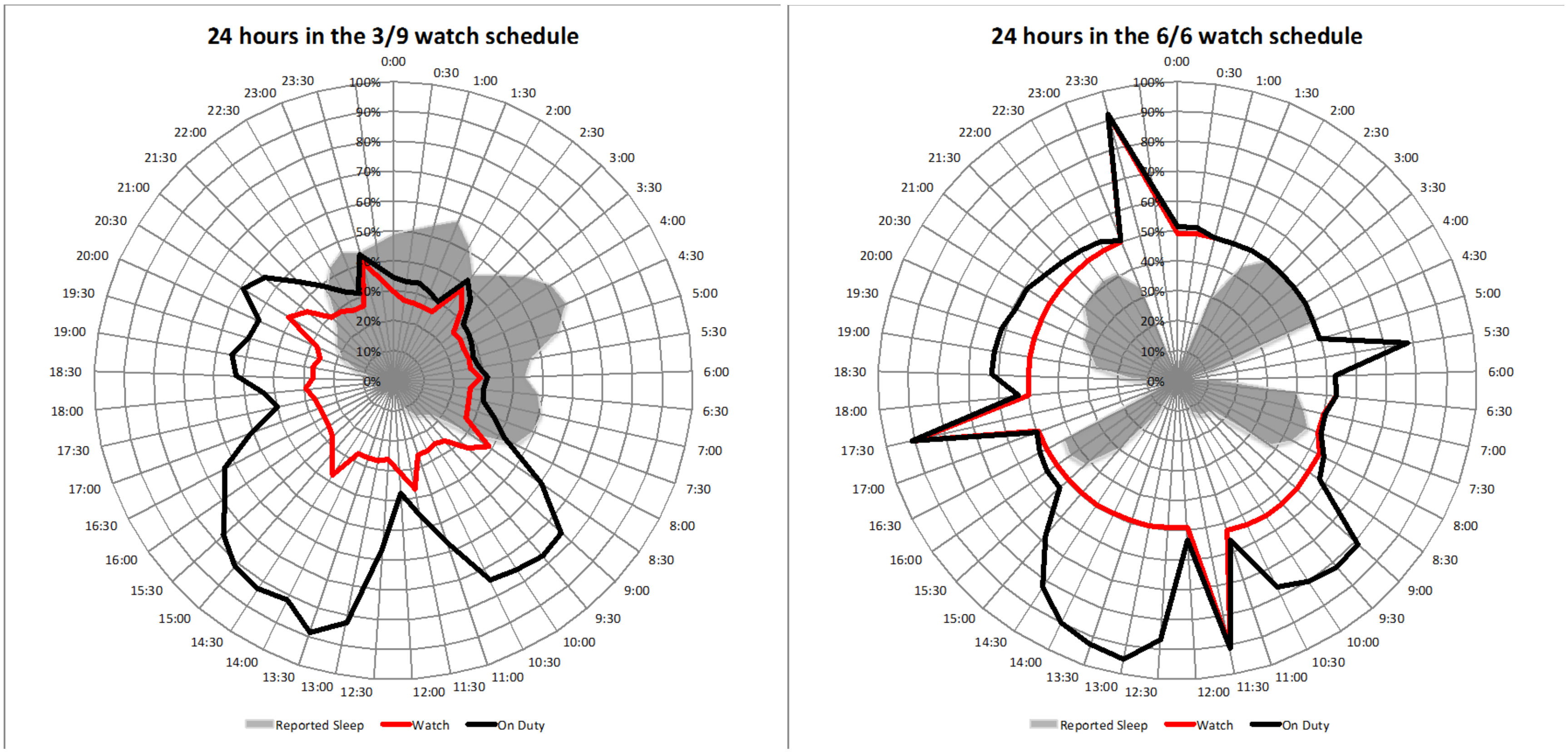

Figure 16. Polar diagrams of typical 24-hour days in the 3/9 (left diagram) and 6/6 watch schedules (right diagram).

IV. DISCUSSION

Our results show that from a human-centered perspective, the 3/9 watch schedule is better than the 6/6 schedule in terms of patterns of work, rest and sleep, subjective levels of fatigue, psychomotor vigilance performance, and acceptance by the participants. Although crewmembers were sleep deprived on both watch schedules, crewmembers on the 3/9 received more sleep than their peers in the 6/6, 6.46 ± 0.77 hours and 5.89 ± 0.87 hours, respectively. The 3/9 schedule was also better than the 6/6 in terms of the distribution of sleep episodes. Specifically, crewmembers on the 3/9 received more night sleep, whereas the crewmembers on the 6/6 had to sleep during the day to compensate for their sleep loss at night.

Actigraphic analysis also showed that 24.4% participants on the 3/9 schedule and 45.5% on the 6/6 schedule napped occasionally during their watch. Napping was more pronounced in crewmembers on the 6/6 schedule during the night watches, which fits with earlier research showing that involuntary sleep is more commonly experienced on night shifts, with 7% to 20% of the personnel reporting falling asleep during night work (Åkerstedt et al., 2002; Åkerstedt & Wright, 2009). However, whether a specific watch location affords involuntary napping depends on the type of watch duties assigned. Therefore, while severe sleep debt and its concomitant need for napping almost certainly exist in other watch stations, it is not feasible for personnel to nap because of their assigned duties. The issue of falling asleep while on watch is critical because it indicates how, in extreme sleep debt, the individual uses every possible opportunity to compensate for the accumulated sleep debt. Future efforts should investigate whether napping during watch is a viable operational measure to ameliorate sleep deprivation, in conjunction with the specific duties of each watch location. We should note that the identification of naps was based solely on actigraphic activity patterns. None of the activity logs reported a nap within a watch period, probably due to the controversial nature of such a statement from a military member. Yet, our approach for identifying periods of low activity as naps was conservative; we identified naps only when the activity change was clear and distinct.

These results clearly show that the 3/9 schedule is better than the 6/6 from a sleep hygiene perspective. Not surprisingly, the impact of watch schedule on sleep hygiene is evident in the ESS scores with participants on the 3/9 showing decreased daytime sleepiness compared to their peers on the 6/6.

In terms of work demands, crewmembers on the 6/6 have considerably long workdays (on average, 15 hours on duty), which corresponds to approximately 30% more time on duty than the NSWW criterion (105 hours compared to 81 on a weekly basis). These results are generally congruent with earlier research on U.S. Navy ships in which over 50% of the participants worked more than 95 hours per week, approximately 13.6 hours per day (Haynes, 2007). This amount of daily work far exceeds the recommended work hours, especially when considering that work hours in excess of 8 to 12 hours daily could threaten crew members' ability to perform safe operations (Comperatore, Kingsley, Kirby, & Rivera, 2001). Our findings should also be considered in light of the work hour regulations specified in Title 46 of the United States Code, 2006 Edition, Supplement 5, Section 8104, which states that except in an emergency, licensed individuals cannot be required to work more than 12 of 24 hours at sea ("United States Code," 2006). It further states that on oil tankers, licensed individuals or seamen may not be permitted to work more than 15 hours in any 24-hour period, or more than 36 hours in any 72-hour period—except in an emergency or a drill. It should be noted that the term "work" in the U.S. Code corresponds to the NSWW "time on duty," which includes any administrative duties.

Given the differences in sleep hygiene and work demands between the two watch schedules, the psychomotor vigilance performance results are not surprising. The two schedules differed significantly in variability. Compared to their 3/9 counterparts, personnel on the 6/6 schedule showed greater variability in 11 of the 13 PVT metrics we used ($p < 0.05$). Furthermore, the average values of the PVT metrics were better for personnel on the 3/9 compared to the 6/6, although not at statistically significant levels. The fact that the personnel on the 6/6 schedule had significantly increased variability in psychomotor performance is a major concern in the operational environment. Miller (2006) highlighted performance variability as a primary hallmark of human fatigue, even though performance variability, in itself, has received little attention as a measure of performance impairment (J. C. Miller, 2013a). He attributed this variability in performance to large amplitude, moment-to-moment fluctuations in attention associated with fatigue.

The findings of this study are integrated in Table 7, which assesses the overall utility of the two watch schedules under focus (3/9, 6/6) based on their ranking. A score of 1 is considered the best rank (e.g., more sleep, more rest, fewer sleep episodes per day yielding less fragmented sleep, lower ESS score, etc.). Sleeping on watch is a negative phenomenon; thus, a ranking of 1 refers to the schedule with less napping, whereas the lower rank denotes the schedule with the largest percentage of individuals sleeping on watch. The overall ranking is based on the comparison between 3/9 and 6/6 schedules. The ranking assigned for each factor shows a general pattern of differences between schedules that support any inferential statistics already presented.

Table 7. Comparison ranks between watch schedules.

Watch Schedule	3/9 n = 45	6/6 n = 11
Daily Rest amount – All intervals	1	2
Daily Sleep amount – All intervals	1	2
Affordability of sleep in off-watch periods	1	2
Napping in watches	1	2
Sleep episodes per day	Inconclusive	
ESS	1	2
PVT performance	1	2
Subjective assessment of the watch schedule	1	2
Work patterns	1	2
Overall	1	2

From a human-centered perspective, the pattern of differences between 3/9 and 6/6, combined with the overall ranking, show clearly that the 3/9 is a better watch schedule compared to the 6/6 in terms of rest and sleep, subjective levels of fatigue, psychomotor performance, and acceptance from the participants. This conclusion aligns with previous research (Paul et al., 2010), which showed that the FAST predicted effectiveness of the 6/6 is worse compared to the 8/16, the 4/8, and the 8on-4off-4on-8off watch schedules. The 6/6 schedule should be avoided when alternative circadian-aligned watch schedules can be used.

A critical constraint when addressing optimization of watch schedules, however, is the availability of qualified watchstanders. The two watch-standing schedules we compared have vastly different characteristics in terms of personnel needed to implement them. The 3/9 schedule is a 4-section watchbill in which individuals stand watch for only six hours per day; the 6/6 has only two sections with individuals standing watch for 12 hours each day; the 6/6 theoretically takes only half the crewmembers needed by the 3/9 schedule. This perspective, though, oversimplifies the problem of optimized shiftwork to a simple enumeration of the minimum number of people needed. Such approaches have been used in the past and inevitably lead to watch systems with increased sleep deprivation, fatigue, and circadian desynchrony (Miller, 2013a, 2013b).

A. SOME THOUGHTS ON WORK DEMANDS AND REST AFFORDABILITY

Our results show that while underway, personnel receive much less sleep than the eight hours per day that is widely accepted as normal. This result agrees with earlier research findings conducted on Navy ships (Green, 2009; Haynes, 2007; Mason, 2009; Miller, Matsangas, & Kenney, 2012); however, we have also found that personnel spend a considerable amount of time for their personal needs. The question raised is why don't crewmembers spend more of their personal time sleeping in order to ameliorate their accumulated sleep debt?

One plausible explanation lies in the characteristics of the naval environment and life at sea for extended periods of time. A crew onboard a ship works in a confined environment, with limited opportunities for privacy; their daily schedule continues around the clock and they continue to work without weekends and holidays, away from family and friends until the ship returns to port. Especially evident under these grueling work conditions, is that organizational structure plays a critical role in the psychological health of the crew members (e.g., by providing coworker support and the social interactions that are vital for good morale and mental health) (Maslow, 1943; Taormina, 1997). Although this study was not focused on this issue *per se*, future efforts should investigate how psychological health is affected by increased workload combined with the unique stresses presented by the shipboard environment.

Educating crewmembers on healthy sleep habits is also essential. If personnel were more attuned to the consequences of sleep deprivation on their performance and safety, it is likely that they would try to manage their schedules more wisely. Hence, sleep hygiene training could be beneficial as a fatigue countermeasure.

Another issue of interest is the considerable amount of time spent in Service Diversion activities. Reducing the demand for these activities may free up time for other needs. Some researchers have noted that reducing administrative tasks is a necessary and effective measure for reducing fatigue on naval vessels (Houtman et al., 2005). However, some of the Service Diversion activities may be based on organizational regulations, and thus, may not fall under the command authority of the commanding officer of the ship.

Lastly, the NSWW model should be revised to include adequate time for rest, part of which is the actual time set aside for sleep. Rest time involves more than just the time dedicated for sleep since it takes some time to decompress, fall asleep and awaken. The International Maritime Organization (IMO) has proposed a minimum of 10 hours of **rest** during any 24-hour period and 77 hours of rest for any 7-day period (International Maritime Organization, 2010).

B. CAVEATS

This study has a number of caveats. First, the participants were volunteers, performing their normal daily duties; there was no randomization in the assignment to watch schedule and hence the study is quasi-experimental in nature. Second, all the participants on the 6/6 watch schedule were from the Operations Department. Third, some groups in this analysis had fewer participants than originally planned, resulting in unequal cell sizes and making analysis challenging.

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APPENDIX. PARTICIPANT INFORMATION

Table 8 shows participants by watch schedule, watch section, and actiwatch type.

Table 8. Participants by watch schedule, watch section, and actiwatch type.

Watch Schedule	Watch Section	AMI	PR
3/9 (n = 41)	00:00 - 03:00	n = 5: 3001, 3007, 3025, 3032, 3057	n = 1: 3122
	03:00 - 06:00	n = 5: 3036, 3040, 3054, 3061, 3069	n = 4: 3102, 3110, 3112, 3113
	06:00 - 09:00	n = 6: 3006, 3009, 3016, 3022, 3027, 3090	n = 2: 3101, 3109
	09:00 - 12:00	n = 11: 3002, 3017, 3021, 3043, 3055, 3063, 3074, 3078, 3079, 3080, 3093	n = 7: 3104, 3108, 3111, 3117, 3118, 3119, 3131
4/8 (n = 8)	00:00 - 04:00	n = 2: 3013, 3146	
	04:00 - 08:00	n = 1: 3082	
	08:00 - 12:00	n = 5: 3056, 3064, 3067, 3073, 3092	
6/6 (n = 11)	00:00 - 06:00	n = 6: 3011, 3018, 3026, 3028, 3030, 3084	n = 1: 3134
	06:00 - 12:00	n = 4: 3015, 3035, 3095, 3096	
6/12 (n = 3)	Shifting schedule, no fixed sections	n = 3: 3045, 3089, 3100	
6/18 (n = 4)	06:00 - 12:00	–	
	12:00 - 18:00	n = 2: 3083, 3085	
	18:00 - 23:59	n = 2: 3020, 3047	
12/12 (n = 5)	00:00 - 12:00	n = 2: 3031, 3097	
	12:00 - 23:59	n = 3: 3023, 3058, 3077	
Nonwatch standers (NWS) (n = 23)		n = 16: 3005, 3008, 3033, 3034, 3041, 3042, 3051, 3059, 3060, 3062, 3065, 3070, 3071, 3076, 3087, 3091	n = 7: 3120, 3124, 3125, 3127, 3128, 3129, 3153

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   Graduate School of Operational and Information Sciences (GSOIS)
   Naval Postgraduate School
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