Comparison of the 3/9 and 6/6 Watchstanding Schedules for Crewmembers of a U.S. Navy destroyer

Nita Lewis Shattuck, and Panagiotis Matsangas
Operations Research Department, Naval Postgraduate School, Monterey, CA

This naturalistic study of 52 sailors on the USS Jason Dunham (DDG-109) compared actigraphic sleep and psychomotor vigilance performance of crewmembers working a 3hours-on/9hours-off ("3/9") with the performance of their counterparts who worked a 6hours-on/6hours-off ("6/6") watchstanding schedule. Crewmembers on the 3/9 slept more (6.46±0.77 hours) and reported less daytime sleepiness (Epworth Sleepiness Scale (ESS) score = 10.7±3.70) than their peers on the 6/6 schedule (sleep 5.89±0.87 hours; ESS = 13.1±3.45). The length of the workday for participants on the 6/6 schedule was 15 hours compared to 12.2 hours for crewmembers on the 3/9. Based on 11 of 13 Psychomotor Vigilance Task metrics, performance of crewmembers on the 6/6 schedule had significantly greater variability than the 3/9 sailors ($p<0.05$). Overall, participants evaluated the 6/6 as being worse and the 3/9 as the better schedule. Results showed that the 3/9 outperformed the 6/6 in terms of daily sleep duration, fatigue levels, psychomotor vigilance performance, and acceptance from the participants.

INTRODUCTION

The maritime environment is characterized by sleep problems, sleep deprivation, and high levels of fatigue (Miller, Matsangas, & Kenney, 2012). Shiftwork is a major contributor to sleep problems and sleep insufficiency in sailors. Crewmembers working in shifts often have to stand watch when their sleep propensity is high; additionally, their opportunity to sleep may occur when their sleep propensity is low, making it harder to sleep. Sleep, like many other human physiological functions, is controlled by the body's internal circadian rhythm. Working at times not aligned with this internal biologial clock disrupts the internal circadian rhythm and leads to circadian desynchrony (Åkerstedt, 2003). Irrespective of the shift system, night and early morning shifts are associated with short sleep and increased sleepiness (Sallinen & Kecklund, 2010). Short sleep and increased sleepiness are evident in individuals working long shifts (e.g., >16 hours in length) or extended weekly working hours (e.g., >55 hours per week) (Sallinen & Kecklund, 2010).

Shiftwork can also lead to considerable degradation in performance as measured by tasks requiring sustained attention, vigilance, and simulated driving. These performance decrements are caused by excessive sleepiness and are equivalent to the performance of individuals with a 0.04 to 0.05 g% blood alcohol concentration (Arnedt, Owens, Crouch, Stahl, & Carskadon, 2005). Research findings also suggest that shift workers are more prone to developing medical disorders, e.g., obesity, gastrointestinal problems, cardiovascular heart disease, and diabetes (Knutsson, 2003). The International Agency for Research on Cancer has classified "shiftwork that involves circadian disruption" as a probable human carcinogen (IARC Monographs Working Group on the Evaluation of Carcinogenic Risks to Humans, 2010). Shiftwork can significantly impact organizational risk and safety rates (Wagstaff & Sigstad Lie, 2011).

It is no surprise, therefore, that optimizing shiftwork 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 watchstanding schedules traditionally used at sea often 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, e.g., the 6hours-on/6hours-off ("6/6"), or the 3hours-on/9hours-off ("3/9").

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

METHOD

Participants

Participants were crewmembers of the USS Jason Dunham (DDG-109), an Arleigh Burke class destroyer. Approximately 40% (n=122) of the crew volunteered for a

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study of their work/rest and performance patterns. This analysis will focus on 52 crewmembers who were standing watch in the two schedules of interest: 41 participants on the 3/9 schedule and 11 participants on the 6/6 schedule. All 6/6 participants were in the operations (OPS) department, while the 3/9 participants were spread across the weapons (WEPS, n=2), OPS (n=5), engineering (ENG, n=24), and combat systems (n=10) departments. Table 1 provides detailed information on the demographics of the two groups.

Table 1. Demographics.

Variable	3/9 n = 41	6/6 n = 11
Age, years, M ± SD	29.8 ± 6.48	26.6 ± 3.83
Gender, # males (%)	33 (80.5%)	7 (63.6%)
Officers %/ Enlisted %	34.2%/ 65.8%	0/100%
Service, years, M ± SD	7.45 ± 5.83	6.07 ± 4.78
ME score, M ± SD	46.5 ± 8.54	50.1 ± 6.02

Participants on the 3/9 stood watch in four watch sections (WS1-4). WS 4 stood watch from 0000 (midnight) to 0300 and from 1200 to 1500, WS 1 from 0300 to 0600 and from 1500 to 1800, WS 2 from 0600 to 0900 and from 1800 to 2100, and WS 3 from 0900 to 1200 and from 2100 to 2359. Participants on the 6/6 stood watch in two watch sections (0000 (midnight) to 0600 and 1200 to 1800, 0600 to 1200 and 1800 to 2359). Crewmembers had been working the same schedule for several weeks before the data collection commenced.

Equipment and Instruments

Sleep was assessed with actigraphy supplemented with activity logs. 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 to score sleep; the criterion for sleep and wake episode length was set at five minutes. The sleep latency criterion was no more than 1-minute wake in 20 minutes period. All values are the defaults for the Action W software. PR data were scored using Actiware software version 6.0.0 (Philips 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. Again, all values are defaults for the Actiware 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 minute precision (average results compared to polysomnography-derived 436 minutes of sleep) (Meltzer, Walsh, Traylor, & Westin, 2012).

Performance data were collected using a 3-minute version of PVT which was available on the AMI Motionloggers (PVT-192). The PVT is a simple visual reaction time test where participants are required to press a response button as soon as the stimulus appears on the screen (Dinges & Powell, 1985). The PVT interstimulus interval (ISI), defined as the period between the last response and the appearance of the next stimulus, ranged randomly from 2 to 10 seconds.

Procedures

The study protocol was approved by the Naval Postgraduate School Institutional Review Board. Crewmembers were briefed on the research protocol and study procedures. Those wishing to participate provided written informed consent to enroll in the study. The data collection occurred from December 3 to 18, 2012 while the ship was underway in a forward-deployed area of operations. Sea state was relatively benign during the data collection period. Participants had been in their underway routine for a period of approximately five months before the study commenced. After enrolling, participants completed a series of questionnaires including the Epworth Sleepiness Scale (Johns, 1991). Participants were issued actigraphic devices and were instructed to take the PVT prior to and after their watchstanding periods. They were also asked to fill out daily activity logs divided into 30-minute increments to indicate how they spent each day. Upon completion of the study, the participants returned their equipment and filled out an end-of-study survey. Using a 6-point 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"), participants were asked to rate seven different watchstanding schedules (5/10, 5/15, 6/6, 3/9, 12/12, 6/12, and 6/18) by responding to the question "Compared to my current schedule, the [watch schedule] is …"

Analysis

The data used for this analysis was an eleven-day period from December 4 to 14, 2012 when seas were relatively calm and crew activities were not out of the ordinary. Of the 1,864 rest/sleep intervals, 80 (4.3%) were missing and imputation was used to calculate their values; 82 of the rest/sleep intervals (4.4%) were identified as naps occurring during watch periods. The amount of rest and sleep for each day was calculated from 0000 (midnight) to 2359. Average time in bed and sleep amounts were calculated from actigraphic data by day and averaged by participant. PVT analysis was based on 959 trials (42% compliance rate). PVT metrics were calculated by trial and averaged by participant. No imputation was applied to the PVT data. For more information on data reduction, please refer to the technical report (Shattuck & Matsangas, 2014).

Two independent variables, watchstanding schedule and watch section, were used to compare the 3-hours on/9-hours off and 6-hours on/6-hours off watchstanding schedules in terms of crewmember sleep and psychomotor vigilance performance. Sleep analysis was based on two metrics, the average daily sleep amount per participant (with and without naps within watch periods), and the number of sleep episodes per day. ESS scores were used to assess daytime sleepiness. Based on the recommendations by Basner and Dinges (2011), PVT performance was assessed using nine different metrics:

mean reaction time (RT), mean response speed (1/RT), fastest 10% RT (i.e., 10th percentile of RT), slowest 10% of 1/RT (i.e., 10th percentile of 1/RT), percentage of lapses, percentage of false starts, and the percentage of lapses plus false starts (combined). Responses with a reaction time greater than or equal to the 500 ms (standard) and 355 ms were identified as lapses (Basner & Rubinstein, 2011).

Statistical analysis was conducted with JMP statistical software (JMP Pro 10; SAS Institute; Cary, NC). All variables underwent descriptive statistical analysis to identify anomalous entries and to determine demographic characteristics. After first assessing and then rejecting the data for normality with the Shapiro-Wilk W test, further comparisons were based on nonparametric methods. The criterion for statistical significance was p = 0.05. For multiple comparisons, statistical significance was assessed using the Benjamini–Hochberg False Discovery Rate (BH-FDR) controlling procedure (Benjamini & Hochberg, 1995). Correlational analysis was conducted using Spearman's rho. Levene's test was used for testing for equality of variances. Comparisons were based on the Wilcoxon Rank Sum test and, for multiple comparisons, the Dunn method (for joint ranks accounting for group error rate) was used. Data are presented as mean (M) ± standard deviation (SD).

RESULTS

Sleep

We compared the daily sleep duration between schedules. Although napping is not permitted while standing watch, from the actigraphic data, we determined that 10 (24.4%, from all section) participants on the 3/9 and 5 (45.5%, mainly from the section standing watch from midnight to 0600) on the 6/6 schedules napped at some time during watch. Analysis showed that the participants on the 6/6 schedule received less sleep daily than participants on the 3/9 schedule, either when including all sleep episodes or only those periods when sleep occurred during off-watch periods. 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 (p=0.011). When all sleep intervals were 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 (p=0.043). The 46 minutes per day difference between the two groups in daily sleep during off-watch periods was reduced to only 34 minutes per day when all sleep intervals were included. Although napping while on watch was identified in the actigraphic recordings of both watch schedules, napping was more common for crewmembers on the 6/6 schedule. In effect, crewmembers on the 6/6 partially compensated for their chronic sleep debt by napping more during watch periods. Furthermore, sleep of participants on the 3/9 was distributed in 1.95 ± 0.50 episodes across the 24-hour day, whereas participants on the 6/6 slept on average 2.39 ± 0.64 episodes daily (p=0.026. In effect, sleep on the 3/9 was less fragmented when compared to the 6/6. It is not surprising that watchstanders on the 6/6 had more highly elevated daytime sleepiness (ESS scores: 13.1 ± 3.45) when compared to participants on the 3/9 (10.7 ± 3.70; p=0.038).

We assessed the differences in daily sleep between various sections of the two watchstanding schedules. Figure 1 shows daily sleep by watchstanding schedule and watch section. Vertical lines represent one standard deviation of daily sleep, including all sleep intervals. Statistical results cannot not be reported because of the small number of participants on the two sections of the 6/6. However, Figure 1 shows two trends of interest. Participants on the 3/9 schedule working the section with night watches from midnight to 0300 and 0300 to 0600 sleep more than their 3/9 peers working in sections without night watches. The same trend is evident in the 6/6 schedule. Furthermore, napping on watches is clearly evident for participants on the 6/6, with most naps occurring during the 00:00-06:00 watch when sleep propensity is highest.

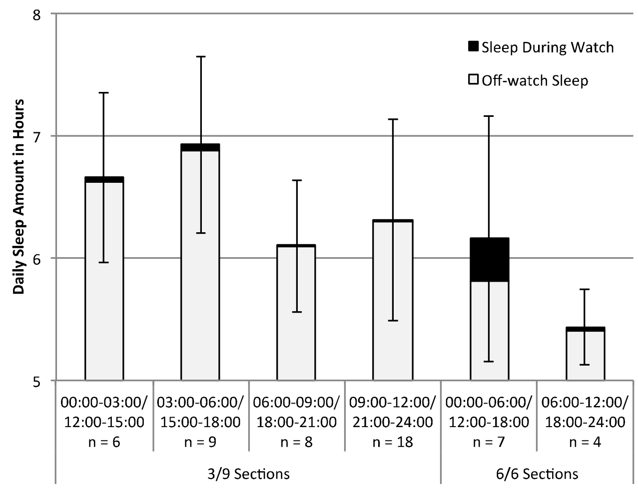

Figure 1. Daily rest and sleep, by watch schedule and shift.

Psychomotor Vigilance Performance

Consistent with the 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 1.

Table 2. Comparison of PVT metrics between the 3/9 and 6/6 watch schedules.

Variable	3/9 M±SD	6/6 M±SD	P value [A]
Mean RT, [ms]	323±66.9	372±135	0.009 *
Mean 1/RT	3.95±0.524	3.67±0.928	0.016 *
Fastest 10% RT, [ms]	196 ±28.0	217±52.7	0.019 *
Slowest 10% 1/RT	2.43±0.469	2.18±0.743	0.069
False Starts (FS), %	2.0±1.59	2.23±2.10	0.474
Lapses 500ms, %	7.54±4.40	11.9±9.57	< 0.001 *
Lapses 355ms, %	17.0±9.74	26.8±18.5	0.005 *
Lapses 500ms+FS, %	9.54±5.09	14.2±8.64	0.014 *
Lapses 355ms+FS, %	19.0±9.78	29.1±17.2	0.008 *

[A] Levene's test for equality of variances.
[*] Statistically significant according to the BH-FDR

Posttest Questionnaires

Results from the port-test questionnaires (Figure 2) also show that the participants rated the 6/6 as being the worst schedule and the 3/9 as the best.

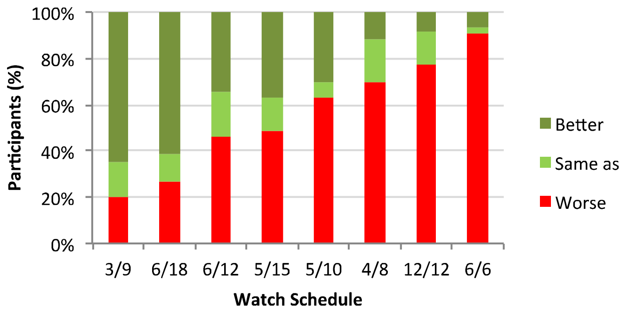

Figure 2. Subjective evaluations of watchstanding schedules.

Work Patterns

Based on the activity logs, we also assessed work patterns (time on duty) between schedules. Crewmembers on the 6/6 work 23% more than counterparts on the 3/9 (6/6: 105 ± 4.84 hours of work on a weekly basis; 3/9: 85.4 ± 13.6 hours; Wilcoxon Rank sum test, $p < 0.001$), i.e., participants on the 6/6 watch schedule experience a 15-hour workday compared to 12.2 hours on the 3/9. These results highlight how standing watch is only part of the duties when working at sea. Specifically, watch standing in the 3/9 comprises 57% of the workday (7 of their 12.2 hour workday) compared to 87% in the 6/6 (13 of their 15 hour workday). Figures 3 and 4 show the daily distribution of time on duty for the two watch standing schedules.

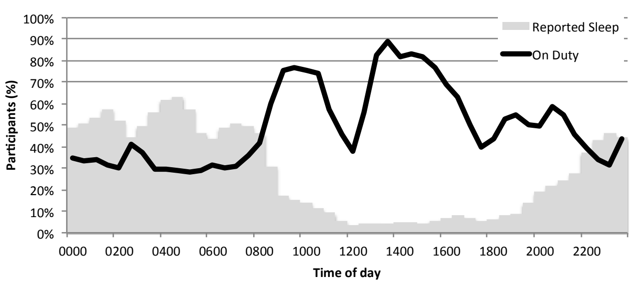

Figure 3. Daily pattern of work and sleep on the 3/9 schedule.

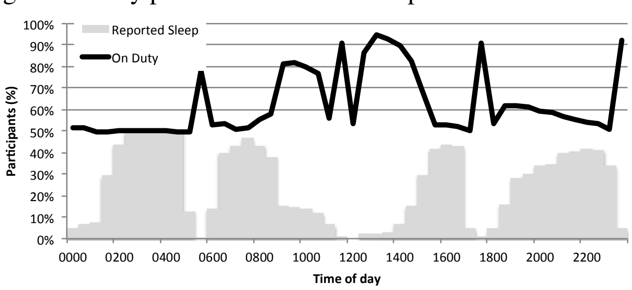

Figure 4. Daily pattern of work and sleep on the 6/6 schedule.

DISCUSSION

Our results show that from a human-centered perspective, the 3/9 watchstanding schedule is better than the 6/6 schedule in terms of daily sleep duration, subjective levels of fatigue, psychomotor vigilance performance, and acceptance by the participants. Although crewmembers were sleep-deprived on both watchstanding schedules, crewmembers on the 3/9 received more sleep than their peers on the 6/6, 6.46 ± 0.77 hours and 5.89 ± 0.87 hours, respectively.

Actigraphic analysis also showed that 24.4% participants on the 3/9 schedule and 45.5% on the 6/6 schedule napped occasionally during watch. Napping was more evident for 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 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 may not be 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 cases of extreme sleep debt, individuals will avail themselves of 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 individuals reported taking a nap within a watch period on their activity logs, probably due to the controversial nature of such a statement from a military member. Yet, our approach for classifying such periods of low activity as naps was conservative; we identified naps only when the change in activity was clear and distinct.

In terms of work demands, crewmembers on the 6/6 have excessively long workdays (time on duty) -- 15 hours on average. 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 a crewmember's 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.

The two schedules also differed in psychomotor vigilance performance variability. Compared to their 3/9 counterparts, personnel on the 6/6 schedule showed greater variability in seven of the nine PVT metrics ($p < 0.05$). 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 greater 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 (Miller, 2013a). He attributed this variability in performance to large amplitude, moment-to-moment fluctuations in attention associated with fatigue.

From a human-centered perspective, the pattern of differences shows clearly that the 3/9 is a better watchstanding schedule compared to the 6/6 in terms of sleep, subjective levels of fatigue, psychomotor vigilance performance, and acceptance from the participants. Therefore, the 6/6 schedule should be avoided when alternative circadian-aligned watch schedules can be used.

A critical constraint when addressing optimization of watchstanding schedules, however, is the availability of qualified watchstanders. The two watchstanding schedules we compared have vastly different characteristics in terms of the number 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 tally of people needed without taking into account sleep deprivation, fatigue, and circadian desynchrony (Miller, 2013a, 2013b).

Caveats

This operational study has a number of caveats. First, the study was a naturalistic observation rather than an experiment. All participants were volunteers performing their normal daily duties; there was no randomization in the assignment to watchstanding schedule. All the participants on the 6/6 watchstanding schedule were from the operations department while multiple departments, including the operations department, were represented in the 3/9 group. Furthermore, the 6/6 group was small and did not include any officers in contrast to approximately 30% in the 3/9.

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