IMPROVED SLEEP HYGIENE AND PSYCHOMOTOR VIGILANCE PERFORMANCE FOLLOWING CREW SHIFT TO A CIRCADIAN-BASED WATCH SCHEDULE

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In the military, any degradation in performance may have serious implications, potentially resulting in loss of life or affecting mission accomplishment. The maritime environment imposes the additional unique challenges of waterborne motion on the shipboard crew. Additionally, the U.S. Navy's 24/7 operational requirements mandate rigorous equipment monitoring and shiftwork. This study assesses how crewmember sleep hygiene and psychomotor vigilance performance is affected by a shift from traditional work schedules to an alternative circadian-based schedule. Twenty-eight sailors were assessed while working two watch schedules, a conventional 5-hours on/10-hours off (5/10) rapidly rotating schedule, and an alternative 3-hours on/9-hours off (3/9) fixed schedule. Average daily sleep duration was the same for both watch schedules. However, compared to their scores on the 5/10, sailors on the 3/9 had significantly less daytime sleepiness, improved mood, 30% faster reaction times, and had 40% to 50% fewer errors (i.e., lapses combined with false starts). The significant improvements in performance, mood, and sleep hygiene observed in this within-subjects study suggest that circadian watch schedules should be chosen rather than non-circadian aligned schedules.

INTRODUCTION

To remain operational and mission ready 24 hours a day, 7 days a week, crews on U.S. Navy ships work on shifts. The watch schedule selected depends on factors like the number of personnel qualified to stand watch, the type of watch, and the overall daily activities of the ship. Some schedules require crewmembers to stand watch at the same time each day, whereas in other schedules, watch times change on subsequent days.

Although routinely used in the operational environment, shiftwork has been associated with elevated levels of fatigue, sleep deprivation, and reduced sleep quality (Arendt, Middleton, Williams, Francis, & Luke, 2006). Additionally, rapidly rotating schedules exacerbate these issues due to circadian desynchrony, resulting in poor quality of life and mental health consequences (Åkerstedt, 1990, 2003; Colquhoun & Folkard, 1985; Monk, 2000; Sack et al., 2007).

Over the past 15 years at the Naval Postgraduate School, we have studied the work and rest patterns of Sailors and Marines in a variety of operational environments, primarily shipboard (refer to Miller, Matsangas, & Kenney, 2012). During this multiyear effort, we noted a number of fixed and rotating watch schedules that are used by the U.S. Navy. Fixed schedules include the 4-hour on/8-hour off, 6-hour on/6-hour off, the 6-hour on/12-hour off (commonly used in the submarine commmunity), the 6-hour on/18-hour off, and the 3-hour on/9-hour off ("3/9"). Other rotating schedules result in days that are other than 24 hours in length. For example, the 5-hour on/10-hour off ("5/10") results in a day that is either 15 or 30 hours in length, and the 5-hour on/15-hour off schedule results in a 20-hour day. However, working other than a 24-hour day, especially shorter days that impose a type of chronic jetlag, is not compatible with human circadian cycles. In recent studies, we have found that, compared to circadian-aligned watch schedules, schedules which are non circadian-aligned or do not take into account human sleep physiology are worse in terms sleep hygiene, mood, psychomotor vigilance performance, and work distribution (Shattuck & Matsangas, 2014; Shattuck, Matsangas, & Waggoner, 2014; Shattuck, Waggoner, Young, Smith, & Matsangas, 2014).

In light of the previous research findings, we conducted a two-phase longitudinal study on the USS NIMITZ (CVN-68). The study was designed to compare the fatigue levels, mood states and psychomotor vigilance performance of crewmembers when working the 5/10 schedule with their performance when working the new 3/9 schedule. This paper describes the preliminary results of that study focusing on those crewmembers who participated in both data collection periods. Detailed results for the entire sample of crewmembers working on the 5/10 is included elsewhere (Shattuck, Matsangas, & Powley, 2015).

METHOD

Watch schedules

Traditionally used in the U.S. Navy (Stavridis & Girrier, 2007), the 5/10 is a 3-section watchstanding schedule in which a crewmember stands watch for five hours followed by 10 hours off watch. These five-hour watches commence at 0200, 0700, 1200, 1700, with the 2200 watch period lasting only four hours in duration. This rotating pattern iterates every three days. Figure 1 shows two 3-day cycles of the 5/10 watchstanding schedule. "WS" refers to watch sections. This continual rotation of the 5/10 results in work and rest periods occurring at different times each day and has long been associated with sleep problems and circadian desyncrony

(Colquhoun & Folkard, 1985; Goh, Tong, Lim, Low, & Lee, 2000; Hakola & Härmä, 2001).

Day	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day 1	WS 3		WS 1					WS 2					WS 3					WS 1					WS 2	
Day 2	WS 2		WS 3					WS 1					WS 2					WS 3					WS 1	
Day 3	WS 1		WS 2					WS 3					WS 1					WS 2					WS 3	
Day 4	WS 3		WS 1					WS 2					WS 3					WS 1					WS 2	
Day 5	WS 2		WS 3					WS 1					WS 2					WS 3					WS 1	
Day 6	WS 1		WS 2					WS 3					WS 1					WS 2					WS 3	

Figure 1. 5/10 watchstanding schedule

During the 3-day cycle of the 5/10 schedule, a crewmember sleeps at three distinctly different time periods each day. On the first day of the cycle, the sailor typically receives a short 4-hour daily sleep opportunity followed by two periods of sustained wakefulness, 22 and 20 hours in length (Shattuck et al., 2015).

In contrast, crewmembers on the 3/9 stand watch on one of four watch sections (WS) of the 3/9 schedule; WS 1 (watch from 0300 to 0600 and from 1500 to 1800), WS 2 (0600-0900, 1800-2100), WS 3 (0900-1200, 2100-0000), and WS 4 (0000-0300, 1200-1500). The daily watch schedule is fixed and crewmembers stand the same two 3-hour shifts each day (Figure 2) and have opportunites to sleep at the same time each day.

Day	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Day 1	WS 4			WS 1			WS 2			WS 3			WS 4			WS 1			WS 2			WS 3		
Day 2	WS 4			WS 1			WS 2			WS 3			WS 4			WS 1			WS 2			WS 3		
Day 3	WS 4			WS 1			WS 2			WS 3			WS 4			WS 1			WS 2			WS 3		
Day 4	WS 4			WS 1			WS 2			WS 3			WS 4			WS 1			WS 2			WS 3		
Day 5	WS 4			WS 1			WS 2			WS 3			WS 4			WS 1			WS 2			WS 3		
Day 6	WS 4			WS 1			WS 2			WS 3			WS 4			WS 1			WS 2			WS 3		

Figure 2. 3/9 watchstanding schedule

Equipment and Instruments

The pre-test survey included demographic questions and two standardized survey tools. Daytime sleepiness was assessed with the Epworth Sleepiness Scale (ESS), using the threshold of 10 or greater as an indication of above normal daytime sleepiness (Johns, 1991, 1992). The Profile of Mood States (POMS) was used to assess mood states (McNair, Lorr, & Droppelman, 1971). The questionnaire assesses six dimensions of mood: anger - hostility, confusion - bewilderment, depression, fatigue, tension - anxiety and vigor - activity. Total Mood Disturbance (TMD) score is derived by summing five of the subscales and subtracting Vigor. The post-test survey included the ESS, the POMS, the Pittsburgh Sleep Quality Index (PSQI) to assess sleep history (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989), and a morningness-eveningness questionnaire (MEQ-SA) to assess preference for early waking or later sleeping (Terman, Rifkin, Jacobs, & White, 2001).

The Motionlogger Watch was used to collect 1-minute epoch actigraphy data and assess individual sleep patterns over each collection period (Ambulatory Monitoring, Inc.-AMI; Ardsley, NY). The Cole-Kripke algorithm with rescoring rules was also used, with a 5-minute threshold for determining sleep and wake episodes. Participants also completed an activity log that documented their daily routines. These logs were used to verify the sleep scoring in the actigraphy data.

Performance data were collected with the Psychomotor Vigilance Task (PVT) (Dinges & Powell, 1985). The PVT is a simple reaction time test that is sensitive to sleep loss and circadian rhythmicity, and has minor learning effects (Dinges et al., 1997; Doran, Van Dongen, & Dinges, 2001; Jewett, Dijk, Kronauer, & Dinges, 1999; Kribbs & Dinges, 1994; Rosekind et al., 1994). This study used the PVT variant which is embedded in the Motionlogger watch (Ambulatory Monitoring, Inc. – AMI; Ardsley, NY). This wrist-worn version of the PVT has the advantage that it can be administered in the participant's individual working environment. The PVT was programmed to use an inter-stimulus interval (ISI), or period between the last response and the appearance of the next stimulus, of 2 to 10 seconds. A red backlight appeared on the actigraphy display for one second and the letters "PUSH" were used as visual stimuli; the response time was then displayed in milliseconds.

Due to operational demands, we used a 3-minute version of the PVT instead of the original 10-minute duration of the task (Loh, Lamond, Dorrian, Roach, & Dawson, 2004). Shortened versions have also been validated to assess sleep deprivation effects (Basner & Dinges, 2011; Loh et al., 2004). Participants were instructed to take the PVT approximately 4 times a day, typically at the beginning and end of their watch standing periods, upon awakening and before bedtime.

Participants

For the two-phased study, participants were volunteers from the Reactor Department (RX) of USS NIMITZ (CNV-68), a US Navy aircraft carrier. Seventy-seven individual crewmembers volunteered to participate in the 5/10 study with 117 volunteering for the 3/9 data collection period. However, only 28 crewmembers participated in both phases and could be used for this within-subject analysis. Participating crewmembers were 25.7±3.01 years old, 23 were males, one was an officer and 27 were enlisted. When on the 3/9 schedule, 6 of the 28 participants worked in WS 4, 8 in WS 1, 8 in WS 2, and 6 in WS 3. Participants had served on active duty for an average of 4.95±2.0 years.

The average PSQI scores did not differ between the two schedules (3/9: 8.53±3.08; 5/10: 9.33±2.80; matched pairs Wilcoxon Signed Rank test, p>0.40). For both schedules, PSQI scores suggest that approximately 96% of the participants were "poor sleepers" with PSQI scores greater than or equal to 5. The average Morningness-Eveningness Preference score was approximately 49 without differences between data collections (p>0.60).

Procedures

The protocol for this quasi-experimental study was approved by the Naval Postgraduate School Institutional Review Board. Data were collected on USS Nimitz in two phases. From 10-27 June 2014 participants worked the 5/10 schedule, whereas participants worked the 3/9 schedule from 3-14 November 2014.

Initially, Reactor Department personnel were briefed on the research protocol and study procedures. Crewmembers who volunteered to participate in the study signed informed consent forms and received further training prior to being issued equipment for the study. Participants filled out the pre-study surveys, ESS, POMS, and received their sleep watches and activity logbooks. All participants were instructed to fill out their activity logs daily and at a minimum, take the 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 that included ESS and POMS.

Analysis

Statistical analysis was conducted with a statistical software package (JMP Pro 10; SAS Institute; Cary, NC). Data normality was assessed with the Shapiro-Wilk test. Given that some of our data violated the assumption of normality, statistical analysis was based on parametric and non-parametric methods as appropriately needed. The statistical analysis was conducted using within-subjects repeated measures analysis of variance (ANOVAs) and matched pairs Wilcoxon Signed Rank tests. Confidence intervals were set at 95% (alpha = .05). Data is presented as mean (M) ± standard deviation (SD). Statistical significance for these multiple comparisons was assessed using the Benjamini–Hochberg False Discovery Rate (BH-FDR) controlling procedure (Benjamini & Hochberg, 1995).

The primary source of sleep data was the actigraphic recordings from the individual participants. The sleep logs also assisted in the determination of start and end time of the sleep intervals. Based on this comparison, we adjusted the start and end of sleep episodes in the actigraphy data. PVT data analysis was based on the metrics proposed by Basner and Dinges (2011) for individuals with chronic sleep deprivation, i.e., 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 500ms and 355ms lapses, percentage of lapses and false starts, and percentage of false starts (FS). All PVT responses were aggregated per participant.

RESULTS

No change was observed in average daily sleep duration and daily rest duration after the switch in watch schedule from the 5/10 to the 3/9 watch schedule (ANOVA, $p>0.05$). However, there are indications that sleep quality improved as seen by the significant reduction in sleepiness levels as measured by ESS. ESS scores did not differ between schedules at the beginning of the underway periods (n=27, $F(1,26) = 0.204$, $p=0.655$). However, when working the 5/10, the Sailors had elevated daytime sleepiness at the end of the underway as compared to the 3/9 (5/10: 10.6±4.47; 3/9: 7.70±4.32; n=27, $F(1,26)=16.6$, $p<0.001$). Furthermore, the pattern of ESS scores differ between schedules when assessing changes between the beginning and the end of the underway. Specifically, ESS scores increased when working the 5/10 (1-side matched pairs Wilcoxon Signed Rank test, S=49.5, $p=0.092$), whereas ESS scores decreased on the 3/9 (1-side matched pairs Wilcoxon Signed Rank test, S=57.5, $p=0.060$). These findings suggest that daytime sleepiness increased when working the 5/10, whereas working the 3/9 led to a decrease in ESS during the underway. These results are shown in Figure 3. Vertical lines denote one standard deviation.

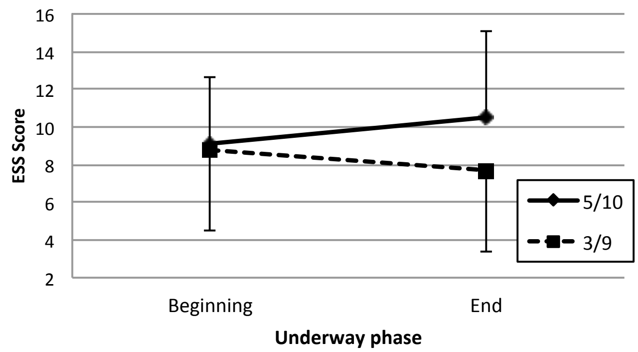

Figure 3. ESS scores at the beginning and end of the underway

Additionally, the pattern of change in Total Mood Disturbance (TMD) scores differed between watch schedules, $F(1,23)=4.81$, $p=0.039$. On the 3/9, TMD scores did not change between the beginning and the end of the underway period (Δ=-1.42±24.7). In contrast, TMD scores on the 5/10 became worse, increasing an average of 12.79±18.8 points. These results are shown in Figure 4. Vertical lines denote one standard deviation.

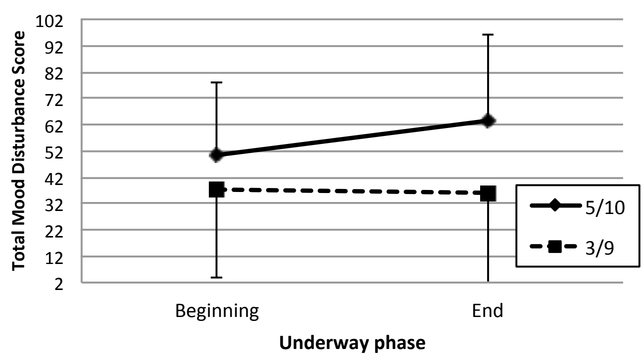

Figure 4. Total mood disturbance score at beginning and end of the two data collection periods.

As assessed by PVT metrics, psychomotor vigilance performance also differed between watch schedules. Specifically, psychomotor vigilance performance was significantly better when crewmembers were working the 3/9 compared to the 5/10 in eight of the nine PVT metrics. It is interesting that crewmembers on the 3/9 were approximately 30% faster, and had 40% to 50% fewer errors (lapses combined with false starts). These results are shown in Table 1 and Figures 5 through 7 below. Due to missing data, this analysis is based on only 13 participants.

Table 1. PVT metrics by watch schedule

Variable	5/10	3/9	Comparison
Mean RT, [ms]	395±80.0	287±48.5	$F(1,12)=30.18$, $p<0.001$
Mean 1/RT	3.15±0.44	4.14±0.81	$F(1,12)=42.41$, $p<0.001$
Fastest 10% RT, [ms]	252±40.5	194±38.8	$F(1,12)=105$, $p<0.001$
Slowest 10% 1/RT	2.12±0.73	2.61±0.50	$F(1,12)=5.54$, $p=0.0365$
False starts (FS), %	1.04±0.95	2.36±4.03	$S=18$, $p=0.176$ [A]
Lapses 355ms, %	33.9±20.5	14.8±9.74	$S=45.5$, $p<0.001$ [A]
Lapses 500ms, %	14.1±8.24	5.31±2.49	$S=44.5$, $p<0.001$ [A]
Lapses 355ms+FS, %	13.6±6.74	7.67±4.04	$S=37.5$, $p=0.006$ [A]
Lapses 500ms+FS, %	36.2±19.3	17.1±8.85	$S=45.5$, $p<0.001$ [A]

Note: Except from FS, all other comparisons statistically significant according to Benjamini–Hochberg procedure for FDR

[A] Matched pairs Wilcoxon Signed Rank test

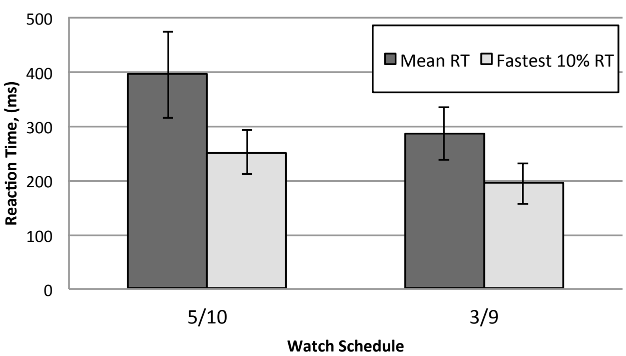

Figure 5. PVT reaction time by watch schedule (lower scores are better)

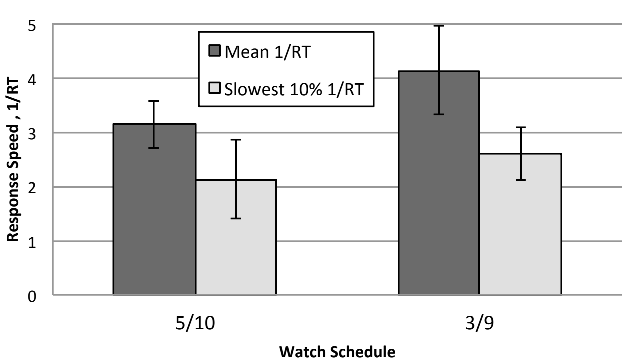

Figure 6. PVT response speed by watch schedule (higher scores are better)

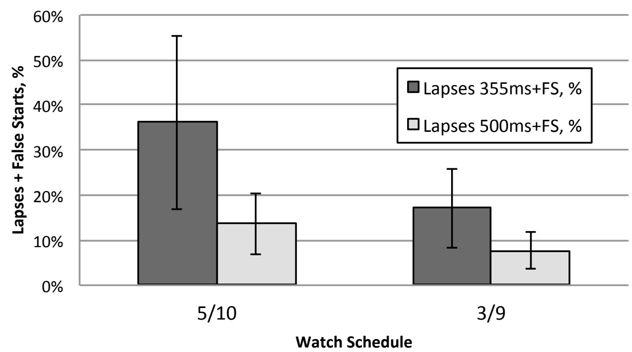

Figure 7. Percentage of lapses combined with false starts by watch schedule (lower scores are better)

DISCUSSION

The preliminary results of this study provide evidence that circadian watch schedules like the 3/9 positively affect sleep hygiene and psychomotor performance. Although there was no change in the duration of average daily sleep received, the results indicate that the 3/9 watch schedule improved sleep quality and outperformed the 5/10 through reduced sleepiness levels, improved mood, faster reaction times and fewer errors (lapses combined with false starts). Order of exposure and external influences (e.g., new commanding officer and leadership, variables in operating schedule tempo, individual work/testing environment, etc.) were factors that could not be controlled. However, despite potential sources of variance from these external influences, ESS and mood were not significantly different between the two groups during the pre-underway periods, indicating a similar steady state prior to the beginning of both phases of the study.

Circadian watch schedules allow for watchstanders to have consistent sleeping periods during the natural 24-hour cycle. This within-subject study has provided evidence of the significant improvements in performance, quality of life, and sleep hygiene resulting from a shift in type of work schedule.

Study limitations

This study has a number of limitations. First, the study was a naturalistic observation rather than an experiment. Participants were volunteers performing their normal daily duties, and therefore randomization in the assignment to watchstanding schedule was not possible. It should also be noted that workload and sleep opportunities on a ship depend greatly on the mission and tasking of the ship's crew. For this reason, analysis of sleep must incorporate mission type as a confounding factor. Future studies should assess the department effect in multiple mission types.

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