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Sleep and performance in simulated Navy watch schedules

Elena Skornyakov[a,*], Nita L. Shattuck[b], Michael A. Winser[a], Panagiotis Matsangas[b], Amy R. Sparrow[a], Matthew E. Layton[a], Rylie J. Gabehart[a], Hans P.A. Van Dongen[a]

[a] Sleep and Performance Research Center and Elson S. Floyd College of Medicine, Washington State University, PO Box 1495, Spokane, WA 99210-1495, USA
[b] Naval Postgraduate School, 1411 Cunningham Road, Monterey, CA 93943, USA

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ABSTRACT

To operate Navy ships 24 h per day, watchstanding is needed around the clock, with watch periods reflecting a variety of rotating or fixed shift schedules. The 5/15 watch schedule cycles through watch periods with 5 h on, 15 h off watch, such that watches occur 4 h earlier on the clock each day – that is, the watches rotate backward. The timing of sleep varies over 4-day cycles, and sleep is split on some days to accommodate nighttime watchstanding. The 3/9 watch schedule cycles through watch periods with 3 h on, 9 h off watch, allowing for consistent sleep timing over days. In some sections of the 3/9 watch schedule, sleep may need to be split to accommodate nighttime watchstanding. In both the 5/15 and 3/9 watch schedules, four watch sections alternate to cover the 24 h of the day. Here we compared sleep duration, psychomotor vigilance and subjective sleepiness in simulated sections of the 5/15 and 3/9 watch schedules. Fifteen healthy male subjects spent 6 consecutive days (5 nights) in the laboratory. Sleep opportunities were restricted to an average of 6.5 h daily. Actigraphically estimated sleep duration was 5.6 h per watch day on average, with no significant difference between watch sections. Sleep duration was not reduced when sleep opportunities were split. Psychomotor vigilance degraded over watch days, and tended to be more variable in the 5/15 than in the 3/9 watch sections. These laboratory-based findings suggest that Navy watch schedules are associated with cumulative sleep loss and a build-up of fatigue across days. The fixed watch periods of the 3/9 watch schedule appear to yield more stable performance than the backward rotating watch periods of the 5/15 watch schedule. Optimal performance may require longer and more consistent daily opportunities for sleep than are typically obtained in Navy operations.

1. Introduction

Navy surface operations involve watchstanding 24 h per day to be able to operate around the clock. Watchstanding duties include a variety of tasks essential to the operation of the ship. To operate around the clock, these duties are distributed among different crews, which work alternating schedules called watch sections. Usually, there are three or four such watch sections in order to cover all hours of the day.

In most traditional watch schedules, the alternation of watch sections is not aligned with the 24 h cycle of day and night. Various commonly used watch schedules rotate backward, causing desynchronization of circadian rhythms (Sallinen and Kecklund, 2010). Furthermore, in addition to watchstanding duties, Naval personnel are assigned many other tasks. As a consequence, sleep opportunities on board tend to be restricted (Shattuck and Matsangas, 2015a, 2015b).

The combination of around-the-clock operations with insufficient sleep has the potential to induce significant levels of fatigue (Åkerstedt, 2007) due to the effects of two key biological processes of sleep/wake regulation (Van Dongen and Dinges, 2005). The circadian process, which keeps track of time of day, produces a drive for wakefulness during the day, but withdraws this drive during the night and early morning, thereby promoting fatigue. The homeostatic process, which keeps track of sleep and wakefulness, produces an elevated drive for sleep in the face of sleep loss, which also promotes fatigue.

In this pilot study, we considered sleep and fatigue in two specific Naval watch schedules: the traditional 5/15 watch schedule and the more recently introduced 3/9 watch schedule. The 5/15 watch schedule rotates through periods with 5 h on watch followed by 15 h off watch, creating a 20 h watch day. Through the inclusion

* Corresponding author.
E-mail addresses: elenaskorn@gmail.com (E. Skornyakov), nlshattu@nps.edu (N.L. Shattuck), mike.winser@wsu.edu (M.A. Winser), pmatsang@nps.edu (P. Matsangas), amy.sparrow@wsu.edu (A.R. Sparrow), layton@wsu.edu (M.E. Layton), rylie.gabehart@wsu.edu (R.J. Gabehart), hvd@wsu.edu (H.P.A. Van Dongen).

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of a 4 h watch every fourth day, this schedule repeats a backward rotating watch pattern in 4-day cycles. In contrast, the 3/9 watch schedule involves periods with 3 h on watch followed by 9 h off watch, which through two iterations creates a fixed 24 h watch day. Both the 5/15 and the 3/9 schedules are four-section watch schedules, meaning that four different crews alternate to fill the watches of the day.

Using a laboratory simulation of a typical Navy environment, we investigated the effects of circadian misalignment and restricted sleep opportunity on amounts of sleep obtained and levels of fatigue experienced in Navy watch schedules. Controlled laboratory conditions allowed for precise measurements by standardizing or eliminating potential confounds in the measurement of sleep and performance, such as weather conditions, variable workload, and hostile encounters. We compared sleep duration, psychomotor vigilance and subjective sleepiness in individuals working simulated watch sections of the 5/15 and 3/9 schedules, keeping total watch duration and total sleep opportunity equal across schedules.

2. Methods

2.1. Subjects

Fifteen healthy male volunteers (ages 18–29 y) completed a six-day, five-night laboratory study. Subjects were physically and psychologically healthy as assessed by history, questionnaires, and physical examination. They were free of traces of drugs and alcohol as assessed by blood and urine chemistry and history. They reported to be good sleepers, habitually sleeping between 6 and 10 h daily with regular bedtimes and typical wake times between 06:00 and 09:00.

Subjects were instructed to maintain regular sleep-wake schedules during the seven days preceding the study. Compliance was verified with wrist actigraphy, sleep logs, and a time-stamped voice recorder on which subjects reported their bedtimes and rising times. During the seven days before the study, subjects were to avoid napping, caffeine or alcohol consumption, and drugs including tobacco. Compliance was verified with urine and breathalyzer tests.

The study was approved by the Institutional Review Board (IRB) of Washington State University. All subjects gave written, informed consent, and were financially compensated for their time.

2.2. Experimental design

The study took place in the controlled laboratory environment of the Sleep and Performance Research Center at Washington State University Spokane. Subjects were in the laboratory continuously for six days (five nights). The first day was an adaptation day, during which subjects practiced laboratory performance tests. The next four days involved simulated watchstanding schedules, described below. These days are referred to as *watch days 1–4* throughout the rest of this paper (see Fig. 1). The last day in the laboratory included an 11.5 h sleep opportunity for recovery before subjects went home.

Subjects were assigned to one of four watch sections, as shown in Fig. 1:

5/15-A: a 5/15 watch section, backward rotating, with 6.5 h sleep opportunities beginning at 00:30 on watch day 1, 22:30 on

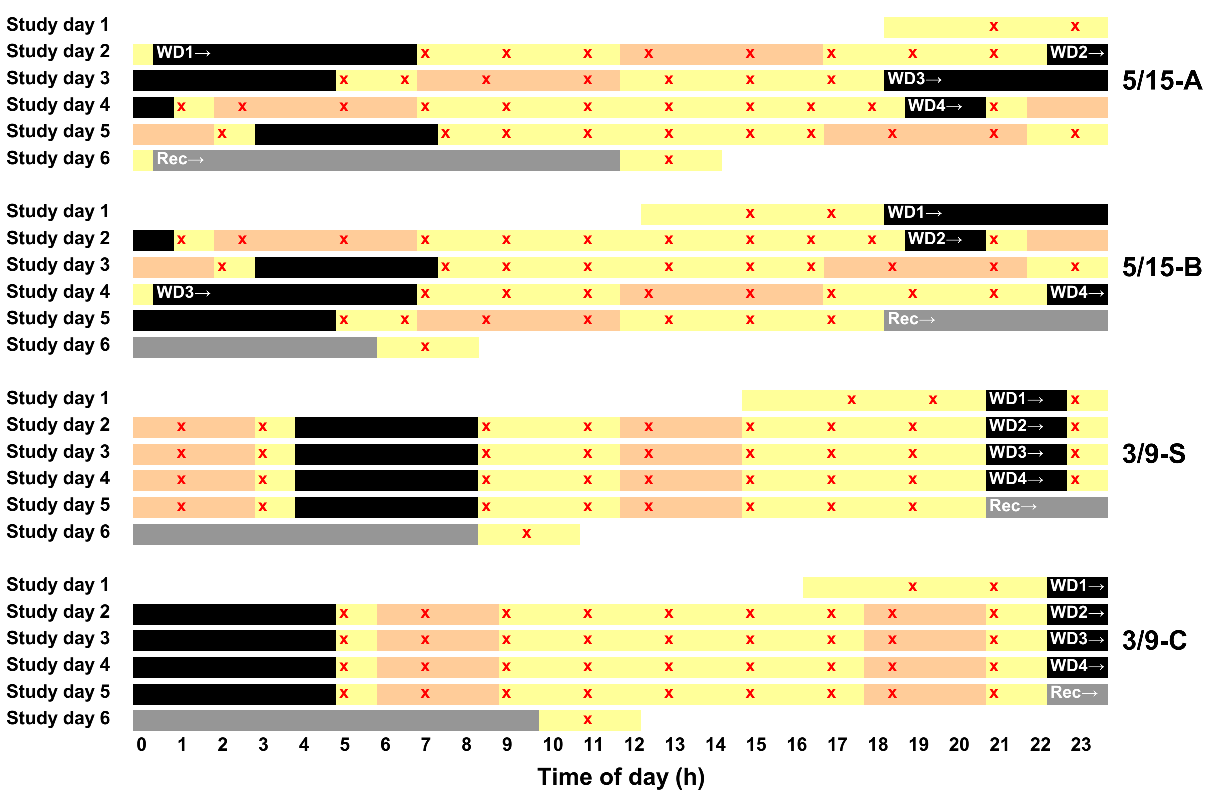

Fig. 1. Schematic of the study design showing each of the four watch sections simulated in the laboratory. Within each watch section, days progress from top to bottom and time of day progresses from left to right. All watch sections began with an adaptation day, included four watch days, and concluded with a recovery day. The beginning of each watch day is indicated with a white marker with an arrow; WD1→ indicates the beginning of watch day 1, etc. The beginning of the recovery day is indicated with Rec→. Black bars represent scheduled sleep opportunities (time in bed), and gray bars indicate scheduled recovery sleep. Orange bars represent scheduled watchstanding periods. Yellow bars represent all other periods of wakefulness. The red cross marks indicate the times when psychomotor vigilance and subjective sleepiness were measured (approximately every 2 h during scheduled wakefulness).

watch day 2, 18:30 on watch day 3, and split sleep at 19:00 (2 h) and 03:00 (4.5 h) on watch day 4;

5/15-B: a 5/15 watch section equivalent to the 5/15-A watch section, but shifted by 2 watch days in the four-day rotation cycle;

3/9-S: a 3/9 watch section, not rotating, with 6.5 h *split* sleep opportunities beginning at 21:00 (2 h) and 04:00 (4.5 h) each watch day;

3/9-C: a 3/9 watch section, not rotating, with 6.5 h *consolidated* sleep opportunities beginning at 22:30 each watch day.

There were four subjects assigned to each watch section, except for the 3/9-S watch section, which had three subjects.

Subjects assigned to the 5/15-A and 5/15-B watch sections were in the laboratory at the same time, sharing laboratory space and sleeping quarters like they would on a ship. Likewise, subjects assigned to the 3/9-S and 3/9-C watch sections were also in the laboratory at the same time. The sleeping quarters were in a single area of the laboratory outfitted with bunk beds. Subjects were instructed to try to sleep during scheduled sleep opportunities. When sleep opportunities of the 5/15-A and 5/15-B watch sections overlapped, subjects were asked to minimize disturbance of the other watch section's sleep. The same applied to the 3/9-S and 3/9-C watch sections (see Fig. 1). The rationale for this arrangement was that any sleep disturbance that nonetheless occurred could be reasonably expected to occur in shared sleeping quarters in real-world Naval operations as well.

Subjects were scheduled to stand simulated watch duties for an average of 6 h per watch day (see Fig. 1). During simulated watches, subjects were assigned to continuous, cognitively demanding tasks (which are beyond the scope of this paper). Relevant for the present study, Navy personnel are expected to be operationally active at all hours of the day except when sleeping. Therefore, psychomotor vigilance and subjective sleepiness were measured approximately every 2 h during all scheduled periods of wakefulness.

Subjects received three standardized meals and one snack per watch day on average. Caffeine, alcohol, and tobacco were not allowed. Light exposure was less than 100 lux during scheduled wakefulness, and lights were off during scheduled sleep. Subjects were supervised 24 h per day by trained research assistants and kept awake during scheduled wake times.

2.3. Measurements

Subjects wore Actiwatch-2 wrist actigraphs (Respironics, Bend, OR) continuously to record rest/activity patterns. Two actigraphs were worn, one on each arm, to protect against critical data loss due to equipment failure. Actigraph data were analyzed in 1 min epochs to estimate sleep, using the Actiware 6 software (Respironics, Bend, OR) and constrained by the timing of the scheduled sleep opportunities (see Fig. 1). For each sleep opportunity, sleep onset and sleep offset were manually determined by finding the first and last epochs with consistent (>3 min) lack of movement. Intermittent wakefulness was calculated by an automated algorithm implemented in the Actiware 6 software. Sleep duration was calculated as the interval between sleep onset and sleep offset minus intermittent wakefulness.

Approximately every 2 h during scheduled wakefulness, a psychomotor vigilance test (PVT) and the Karolinska Sleepiness Scale (KSS) were administered (see Fig. 1). The PVT is a 10 min simple reaction time test requiring subjects to respond as quickly as possible to a visual stimulus appearing on a computer screen at random intervals of 2–10 s (Dinges and Powell, 1985). The PVT measures the ability to sustain attention in a stable manner (Doran et al., 2001) and is a sensitive assay of fatigue due to sleep deprivation and circadian misalignment (Lim and Dinges, 2008). The number of lapses of attention (response times ≥500 ms) was used to quantify PVT performance. The KSS is a subjective scale of sleepiness in which subjects rate how sleepy they feel (Åkerstedt and Gillberg, 1990). Responses range from 1 (extremely alert) to 9 (extremely sleepy – fighting sleep).

2.4. Statistical analysis

Statistical analyses focused on sleep duration, psychomotor vigilance and subjective sleepiness during the four watch days in the different watch sections. Analyses of sleep duration compared each of the watch sections against each other to investigate the effects of the different ways of scheduling sleep (see Fig. 1). Analyses of performance and sleepiness compared the combined 5/15 watch sections with the combined 3/9 watch sections in order to investigate performance of all subjects that were in the laboratory simultaneously as part of the simulated Navy surface operation. Analyses were performed with mixed-effects analysis of variance (ANOVA) with a random effect on the intercept (Van Dongen et al., 2004), using SAS version 9.2 statistical software (SAS Institute Inc., Cary, NC).

Actigraphically assessed sleep duration was analyzed by means of mixed-effects ANOVA with a between-subjects fixed effect for watch section (5/15-A, 5/15-B, 3/9-S, 3/9-C), a within-subjects fixed effect for watch day (1–4), and their interaction. Data from both actigraphs worn by each subject were included in the analysis, and to account for any differences between the two actigraphs, a within-subjects covariate for arm (on which the actigraph was worn) was included. A secondary analysis was performed to compare split sleep periods with consolidated sleep periods, using mixed-effects ANOVA with a mixed between- and within-subjects fixed effect for sleep period (consolidated versus split), and a within-subjects covariate for arm.

PVT lapses of attention and KSS sleepiness scores were analyzed with mixed-effects ANOVA with a between-subjects fixed effect for watch schedule (5/15 versus 3/9), a within-subjects fixed effect for watch day (1–4), and their interaction. Furthermore, PVT and KSS administrations were binned into 3 h time intervals covering the 24 h of the day, and then analyzed with ANOVA with a between-subjects fixed effect for watch schedule (5/15 versus 3/9), a within-subjects fixed effect for time of day (00:00–03:00, 03:00–06:00, . . ., 21:00–24:00), and their interaction.

3. Results

Fig. 2 shows the actigraphically assessed sleep durations across watch days in each of the four watch sections. Overall sleep

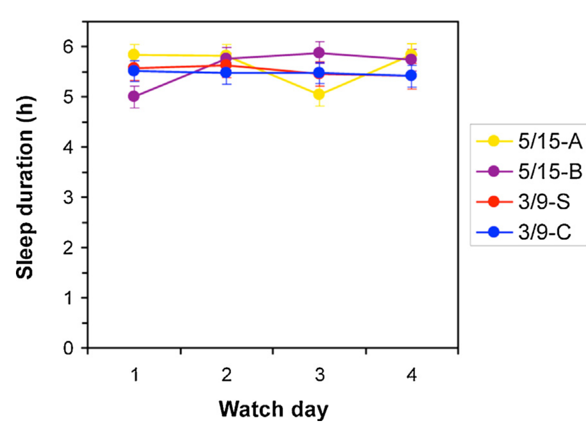

Fig. 2. Actigraphically assessed total sleep duration on watch days 1–4 in each of the four simulated watch sections. Dots indicate means; error bars reflect standard errors.

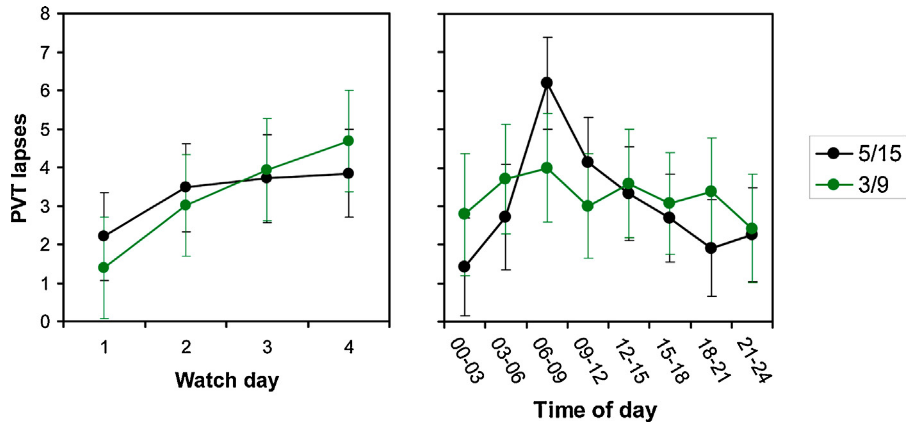

Fig. 3. Number of lapses (response times ≥500 ms) on the 10 min psychomotor vigilance test (PVT) on watch days 1–4 (left) and as a function of 3 h intervals across the 24 h day (right) in the 5/15 and 3/9 watch schedules. Dots indicate means; error bars reflect standard errors.

duration was 5.6 ± 0.1 h (grand mean ± standard error) per watch day. There was no significant main effect of watch section ($F_{3,84} = 0.18$, $p = 0.91$) and no significant main effect of watch day ($F_{3,84} = 1.51$, $p = 0.22$). However, there was a significant interaction of watch section by watch day ($F_{9,84} = 3.82$, $p < 0.001$). Both 5/15 watch sections exhibited less sleep when the sleep opportunity was scheduled to begin early in the evening (at 18:30), i.e., on watch day 3 in the 5/15-A watch section and on watch day 1 in the 5/15-B watch section (see Fig. 1). Watch days with split sleep did not show reduced total sleep duration ($F_{1,95} = 2.19$, $p = 0.14$).

Fig. 3 shows the number of lapses of attention on the PVT across watch days (left panel) and as a function of time of day (right panel) in the 5/15 watch schedule (8 subjects) and the 3/9 watch schedule (7 subjects). Because of a number of technical problems and occasional compliance issues, 48 of the 540 PVT data points were a priori excluded from analysis. In the analysis focusing on watch days, there was no significant main effect of watch schedule ($F_{1,472} < 0.01$, $p = 0.98$), and no significant interaction of watch schedule by watch day ($F_{3,472} = 1.43$, $p = 0.23$). However, there was a main effect of watch day ($F_{3,472} = 12.12$, $p < 0.001$), indicating a progressive increase in PVT performance impairment across watch days in both schedules (see Fig. 3, left panel). In the analysis of the same data focusing on time of day, there was a significant main effect of time of day ($F_{7,464} = 4.11$, $p < 0.001$) and a trend for an interaction of watch schedule by time of day ($F_{7,464} = 1.89$, $p = 0.069$). In both schedules performance was most impaired during the late night/early morning hours of the 24 h day, and the variability in performance as a function of time of day was greatest in the 5/15 watch schedule (see Fig. 3, right panel).

For subjective sleepiness scores on the KSS, in the analysis focusing on watch days, there was no significant main effect of watch schedule ($F_{1,519} = 0.48$, $p = 0.49$), and no significant interaction of watch schedule by watch day ($F_{3,519} = 0.59$, $p = 0.62$). However, there was a main effect of watch day ($F_{3,519} = 5.70$, $p < 0.001$). This effect involved an increase in sleepiness from the first to the second watch day, with no further increase in sleepiness on the third and fourth watch days. In the analysis of the subjective sleepiness data focusing on time of day, there was a significant main effect of time of day ($F_{7,511} = 17.14$, $p < 0.001$), but no significant interaction of watch schedule by time of day ($F_{7,511} = 1.06$, $p = 0.39$). In both schedules, subjective sleepiness was highest from the late evening until the late morning and lowest during the afternoon. In general, the temporal profiles of performance impairment observed on the PVT were not reflected in subjective sleepiness scores on the KSS.

4. Discussion

4.1. Sleep findings

In this laboratory-based pilot study of two simulated Navy watch schedules – the 5/15 backward rotating schedule and the 3/9 non-rotating schedule – sleep was systematically restricted (see Fig. 2). Average daily sleep duration during the simulated watch days was 5.6 h out of 6.5 h sleep opportunity. There was no significant overall difference in sleep duration between the watch sections. Nonetheless, both 5/15 watch sections exhibited less sleep when the sleep opportunity was scheduled to begin at 18:30 (see Fig. 2). This early bedtime falls in the "wake maintenance zone", which is the period in the early evening when the circadian drive for wakefulness is so high that it interferes with sleep (Lavie, 1986; Strogatz et al., 1987). On the other hand, the splitting of sleep opportunities in the 5/15 watch sections and in one of the two 3/9 watch sections (see Fig. 1) did not adversely affect total sleep duration. In another simulated shift work study, split sleep was associated with reduced sleep efficiency as compared to consolidated sleep (Jackson et al., 2014). However, this effect becomes negligible under conditions of sustained sleep restriction (Mollicone et al., 2007), as is more typical in operational settings.

In the simulated watch schedules, sleep opportunity was standardized to a fixed 6.5 h per watch day in order to be able to compare the two schedules on an equal footing. Although the average daily sleep duration obtained by the subjects was similar to that reported for real-world military environments (Miller et al., 2010), field research has found that the total amount of sleep obtained by Naval personnel is greater on the 3/9 schedule than on the 5/15 schedule (Yokeley, 2012). In our laboratory study, subjects were instructed to try to sleep during scheduled sleep opportunities, yet not to take any naps beside those specifically scheduled on split sleep days (see Fig. 1). In real-world military settings, the pressure for sleep tends to be very high. Military personnel are inclined to sleep whenever the opportunity arises, and they often nap to compensate for chronic sleep loss (Miller et al., 2010). It is possible that in a field setting, the 5/15 schedule allows less time for napping than the 3/9 schedule due to the shorter, 20 h watch days of the 5/15 schedule.

4.2. Performance results

The systematic restriction of sleep in the simulated Navy watch schedules resulted in a build-up of psychomotor vigilance impairment across watch days in both schedules (see Fig. 3, left panel). This is in agreement with earlier laboratory studies demonstrating cumulative performance impairment due to sustained sleep restriction (Belenky et al., 2003; Van Dongen et al., 2003, 2011; Mollicone et al., 2008). Furthermore, there was more variability in psychomotor impairment across the 24 h of the day in the 5/15 watch schedule than in the 3/9 watch schedule (see Fig. 3, right panel). This is consistent with findings from forced desynchrony experiments, which show large fluctuations in performance due to circadian misalignment (Lee et al., 2009; Cohen et al., 2010; Zhou et al., 2011; Kosmadopoulos et al., 2014).

These findings indicate that Navy watch schedules have the potential to induce considerable levels of fatigue. This fatigue may be mitigated, to some extent, by regularity in the schedule, as achieved in the 3/9 schedule through its consistent alignment relative to circadian rhythmicity. Field observations comparing the 3/9 watch schedule to the 5/15 watch schedule confirm this (Yokeley, 2012). Other field research comparing the 3/9 watch schedule to a 6/6 watch schedule (Shattuck and Matsangas, 2014) or a 5/10 watch schedule (Shattuck et al., 2015) also identifies the 3/9 watch schedule as more effective for maintaining psychomotor vigilance. That said, even non-rotating watch schedules are associated with performance impairment, depending on the time of day, as was recently demonstrated in a simulated 4/8 watch schedule (van Leeuwen et al., 2013).

It should be noted that none of these studies, including the present one, have specifically investigated the issue of sleep inertia – the performance impairment, disorientation and grogginess experienced immediately after awakening (Dinges et al., 1981; Balkin and Badia, 1988). Additionally, the extent to which the use of caffeine, which is ubiquitous on board Navy ships (Brown, 2012), is effective as a fatigue countermeasure has not been assessed, either under laboratory-simulated conditions or in the real-world operational environment.

It is noteworthy that subjective sleepiness did not track objective performance impairment. That is, subjective sleepiness ratings did not differ significantly between the 5/15 and 3/9 watch schedules. Also, whereas there was an acute increase after the first day on watch (regardless of watch schedule), unlike psychomotor vigilance, subjective sleepiness showed no further build-up across watch days. Sleepiness was highest from the late evening until the late morning in both simulated watch schedules, which did not mimic the temporal profiles of impairment observed for psychomotor vigilance. Such discrepancy between subjective and objective measures of fatigue, as has been documented previously (Van Dongen et al., 2003, 2011; Zhou et al., 2012), underlines the potential danger of relying on self-report for the evaluation of different watch scheduling options.

5. Conclusion

Sleep in the simulated Navy watch schedules of this laboratory study was insufficient to maintain psychomotor vigilance across watch days. Furthermore, psychomotor vigilance performance was less stable in the 5/15 watch schedule than in the 3/9 watch schedule. Psychomotor vigilance – or the ability to sustain attention in a stable manner (Doran et al., 2001) – is an essential function of Navy personnel for mission safety and success, and more generally for prevention of work-related errors and accidents.

The sample size of this pilot study was small, and although we found statistically significant differences between the 5/15 and 3/9 watch schedules, these results should be considered preliminary. Even so, our findings suggest that maintaining optimal performance may require longer and more consistent daily opportunities for sleep than is typically obtained in real-world Navy operations.

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References

Åkerstedt, T., 2007. Altered sleep/wake patterns and mental performance. Physiol. Behav. 90 (2–3), 209–218.
Åkerstedt, T., Gillberg, M., 1990. Subjective and objective sleepiness in the active individual. Int. J. Neurosci. 52 (1–2), 29–37.
Balkin, T.J., Badia, P., 1988. Relationship between sleep inertia and sleepiness: cumulative effects of four nights of sleep disruption/restriction on performance following abrupt nocturnal awakenings. Biol. Psychol. 27 (3), 245–258.
Belenky, G., Wesensten, N.J., Thorne, D.R., Thomas, M.L., Sing, H.C., Redmond, D.P., Russo, M.B., Balkin, T.J., 2003. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose–response study. J. Sleep Res. 12 (1), 1–12.
Brown, S.A., (Master's thesis) 2012. Maritime Platform Sleep and Performance Study: Evaluating the SAFTE Model for Maritime Workplace Application. Naval Postgraduate School, Monterey, CA.
Cohen, D.A., Wang, W., Wyatt, J.K., Kronauer, R.E., Dijk, D.-J., Czeisler, C.A., Klerman, E.B., 2010. Uncovering residual effects of chronic sleep loss on human performance. Sci. Transl. Med. 2 (14), 14ra13.
Dinges, D.F., Orne, E.C., Evans, F.J., Orne, M.T., 1981. Performance after naps in sleep-conducive and alerting environments. In: Johnson, L.C., Tepas, D.I., Colquhoun, W.P., Colligan, M.J. (Eds.), Biological Rhythms: Sleep and Shift Work. Spectrum, New York, pp. 539–552.
Dinges, D.F., Powell, J.W., 1985. Microcomputer analyses of performance on a portable, simple visual RT task during sustained operations. Behav. Res. Methods Instrum. Comput. 17 (6), 652–655.
Doran, S.M., Van Dongen, H.P.A., Dinges, D.F., 2001. Sustained attention performance during sleep deprivation: evidence of state instability. Arch. Ital. Biol. 139 (3), 253–267.
Jackson, M.L., Banks, S., Belenky, G., 2014. Investigation of the effectiveness of a split sleep schedule in sustaining sleep and maintaining performance. Chronobiol. Int. 31 (10), 1218–1230.
Kosmadopoulos, A., Sargent, C., Darwent, D., Zhou, X., Dawson, D., Roach, G.D., 2014. The effects of a split sleep-wake schedule on neurobehavioural performance and predictions of performance under conditions of forced desynchrony. Chronobiol. Int. 31 (10), 1209–1217.
Lavie, P., 1986. Ultrashort sleep-waking schedule. III. 'Gates' and 'forbidden zones' for sleep. Electroencephalogr. Clin. Neurophysiol. 63 (5), 414–425.
Lee, J.H., Wang, W., Silva, E.J., Chang, A.M., Scheuermaier, K.D., Cain, S.W., Duffy, J.F., 2009. Neurobehavioral performance in young adults living on a 28-h day for 6 weeks. Sleep 32 (7), 905–913.
Lim, J., Dinges, D.F., 2008. Sleep deprivation and vigilant attention. Ann. N.Y. Acad. Sci. 1129, 305–322.
Miller, N.L., Shattuck, L.G., Matsangas, P., 2010. Longitudinal study of sleep patterns of United States Military Academy cadets. Sleep 33 (12), 1623–1631.
Mollicone, D.J., Van Dongen, H.P.A., Dinges, D.F., 2007. Optimizing sleep/wake schedules in space: sleep during chronic nocturnal sleep restriction with and without diurnal naps. Acta Astron. 60, 354–361.
Mollicone, D.J., Van Dongen, H.P.A., Rogers, N.L., Dinges, D.F., 2008. Response surface mapping of neurobehavioral performance: testing the feasibility of split sleep schedules for space operations. Acta Astron. 63 (7–10), 833–840.
Sallinen, M., Kecklund, G., 2010. Shift work, sleep, and sleepiness – differences between shift schedules and systems. Scand. J. Work Environ. Health 36 (2), 121–133.
Shattuck, N.L., Matsangas, P., 2014. 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 (report NPS-OR-14-004). Naval Postgraduate School, Monterey, CA.
Shattuck, N.L., Matsangas, P., 2015a. A 6-month assessment of sleep during Naval deployment: a case study of a commanding officer. Aerosp. Med. Hum. Perform. 86 (5), 481–485.
Shattuck, N.L., Matsangas, P., 2015b. Psychomotor vigilance performance predicted by Epworth Sleepiness Scale scores in an operational setting with the United States Navy. J. Sleep Res. 24 (2), 174–180.
Shattuck, M.L., Matsangas, P.M., Brown, S.A., 2015. A comparison between the 3/9 and the 5/15 watchbills (report NPS-OR-15-006). Naval Postgraduate School, Monterey, CA.
Strogatz, S.H., Kronauer, R.E., Czeisler, C.A., 1987. Circadian pacemaker interferes with sleep onset at specific times each day: role in insomnia. Am. J. Physiol. 253 (1 Pt 2), R172–R178.
Van Dongen, H.P.A., Belenky, G., Vila, B.J., 2011. The efficacy of a restart break for recycling with optimal performance depends critically on circadian timing. Sleep 34 (7), 917–929.
Van Dongen, H.P.A., Dinges, D.F., 2005. Sleep, circadian rhythms, and psychomotor vigilance. Clin. Sports Med. 24 (2), 237–249.

Van Dongen, H.P.A., Maislin, G., Mullington, J.M., Dinges, D.F., 2003. The cumulative cost of additional wakefulness: dose–response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep 26 (2), 117–126.
Van Dongen, H.P.A., Olofsen, E., Dinges, D.F., Maislin, G., 2004. Mixed-model regression analysis and dealing with interindividual differences. Methods Enzymol. 384, 139–171.
van Leeuwen, W.M., Kircher, A., Dahlgren, A., Lutzhoft, M., Barnett, M., Kecklund, G., Åkerstedt, T., 2013. Sleep, sleepiness, and neurobehavioral performance while on watch in a simulated 4 hours on/8 hours off maritime watch system. Chronobiol. Int. 30 (9), 1108–1115.
Yokeley, M.T., (Master's thesis) 2012. Effects of sleep deprivation on U.S. Navy surface ship watchstander performance using alternative watch schedules. Naval Postgraduate School, Monterey, CA.
Zhou, X., Ferguson, S.A., Matthews, R.W., Sargent, C., Darwent, D., Kennaway, D.J., Roach, G.D., 2011. Sleep, wake and phase dependent changes in neurobehavioral function under forced desynchrony. Sleep 34 (7), 931–941.
Zhou, X., Ferguson, S.A., Matthews, R.W., Sargent, C., Darwent, D., Kennaway, D.J., Roach, G.D., 2012. Mismatch between subjective alertness and objective performance under sleep restriction is greatest during the biological night. J. Sleep Res. 21 (1), 40–49.