Submarine watch schedules: Underway evaluation of rotating (contemporary) and compressed (alternative) schedules.

C. A. DUPLESSIS¹, J.C. MILLER², L. J. CREPEAU¹, C. M. OSBORN³, J. DYCHE¹,⁴

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¹Naval Submarine Medical Research Laboratory, Groton CT; ²Air Force Research Laboratory, Brooks City-Base TX; ³Naval Postgraduate School, Monterey CA; ⁴United States Air Force Academy, Colorado Springs CO

INTRODUCTION

With a desire to increase health, cognitive performance effectiveness, and quality of life for submarine watch-standers underway, we performed an evaluation comparing an alternative, compressed-work (ALT) schedule, designed to enhance circadian rhythm entrainment and sleep hygiene, to the contemporary submarine (SUB) forward rotating schedule, aboard the ballistic-missile submarine, USS Henry M. Jackson (SSBN-730 Gold). METHODS We assessed a compressed close-6 watch-schedule (“ALT”) relative to the existing backward rotating 6-hr on, 12-hr off 18-hr watch schedule (“SUB”) employed underway aboard submarines. We monitored 40 subjects’ sleep, and temperature and salivary cortisol from 10 of the 40 for approximately two weeks on each respective schedule underway. RESULTS The cortisol cosinor mesors, and amplitudes did not differ significantly between conditions. The temperature cosinor mesors, and the cosinor amplitude were not significantly different, while the cosine curve fit accounted for significantly more variance in the ALT condition than in the SUB condition. The SUB schedule garnered significantly more sleep (7.1 +/- 0.2 hours) than that of the ALTMID schedule (6.3 +/- 0.3 hours). Surveys revealed that 52% of respondents preferred the SUB schedule, 15% preferred the ALT, and 33% were either indifferent or submitted uninterpretable surveys. CONCLUSIONS The ALT schedule was not superior to the existing SUB schedule by physiological or subjective measures and was incompatible to accommodating operational constraints.

INTRODUCTION

The submarine environment is unique, imposing numerous physiological and psychological stressors, including confinement, sunlight deprivation, hypercarbia (5), reduced access to fresh food, micronutrient alterations stemming from distilled water supplies, inaccessibility to weight-bearing exercise and circadian desynchronization from adherence to a rotating watch schedule.

Submariners must continuously navigate the boat, requiring them to function effectively with atypical work-sleep schedules against a back-drop of substantial information processing and sustained alertness demands. The submarine service employs three watch sections, each six hours in duration, based on work required and limited crew accommodations (19). Thus, submarine watch-standers follow a 6-hr-on, 12-hr-off (6/12) watch-standing (SUB) schedule, yoking them to an 18-hr wake-sleep cycle that conflicts with the human body’s normal biological wake-sleep cycle. The SUB schedule, which has been employed for about 40 years, was originally conceived as the most viable means to facilitate 24/7 operations with three watch sections aboard the spatially-
confined, limited-crew-complement of the submarine, and the operational constraints underway including training, qualifications, and drills imposed by the advent of nuclear power. Additionally, the SUB schedule was favored by the nuclear submarine community over the traditional Maritime watch schedule involving three watch sections, each performing 4 hour watch sections (with 8 hours off) because if afforded at least one night of sacrosanct, uninterrupted, unfragmented sleep every third night. Submariners obtained more sleep on the SUB versus the 4/8 Maritime schedule, which typically accommodated only 5-6 hours/day of sleep due to the aforementioned collateral duties, which consumed one of the other 8-hr periods.

Unfortunately, the SUB watch-schedule coupled with an absence of the powerful light-dark cycle Zeitgeber underway causes circadian desynchronization (free running rhythms averaging 24.3 hours), and chronic sleep deprivation, both known to reduce cognitive performance, health and quality of life (25).

Circadian desynchronization causes a host of acute and chronic detrimental influences on health and performance including increased risks of gastrointestinal illness, coronary artery disease, depression, and malignancies; and reduced memory, psychomotor function, alertness, vigilance, concentration, and cognitive performance (6,13,19,25). These problems are compounded by the additional stressors of chronic social crowding, and confinement of submarine life (6,16,19,25,28). The SUB schedule was implemented universally as a superior watch schedule, before appreciation for the deleterious health effects of circadian desynchronization became widespread.

Significantly, sleep deprivation and circadian desynchronization accentuate the normal nadir in cognitive performance (13), of import for the submarine environment wherein watch-standers may be performing watch at their cognitive “nadir” within their free-running circadian rhythms. Thus, submariners are prone to the same health detriments as shift workers, who are also known to incur a greater risk of accidents (6,19). Indeed, circadian desynchronization and sleep deprivation are becoming increasingly-recognized public health issues. This awareness—and the mandates to remedy the problem—is clearly exemplified by the precedence-setting policy change that shortens medical interns’ work schedule (6,33).

With a desire to increase health, cognitive performance effectiveness, and quality of life for submarine watch-standers underway, essential for retention, we performed an evaluation comparing an alternative, compressed-work (ALT) schedule, designed to enhance circadian rhythm entrainment and sleep hygiene, to the contemporary 6/12 submarine (SUB) schedule, aboard the ballistic-missile submarine, USS Henry M. Jackson (SSBN-730 Gold). The ALT schedule was a close-6, 3-section watch-schedule calling for 6-hr-on--6-hr-off--6-hr-on, 12-hr-off, 6-hr-on--6-hr-off--6-hr-on, 24-hr-off. The schedule was reminiscent of the close-4 schedule designed by Kleitman, and included 24 hr of watch-standing time per 72 hr, equal to the watch-standing demand of the SUB schedule and the classical Maritime schedule (14,15,19,21,30). On the basis of simulations and a laboratory experiment (19), we hypothesized that the ALT schedule would improve circadian rhythm, physiological function and performance, and that submariner watch-standers would prefer it to the SUB schedule. The ALT schedule was designed to allow entrainment to the 24-hr clock, to provide a long, uninterrupted, nocturnal sleep period, and to exploit the coveted work compression and expansion of time off, often preferred by shift-workers. The ALT schedule also accommodated the “familiar” watch period of six hours, which had been
considered to be the longest palatable watch duration that was sustainable while underway, and thus the longest watch period that would be accepted for consideration in any novel schedule implementation. This schedule had achieved superior physiological performance in simulations and a laboratory experiment when compared to the contemporary 6/12 SUB and the 4/8 Maritime watch-schedules (19). See Figure 1, opposite. Legend below:

**METHODS**

Human testing was approved by the internal review boards at the Naval Submarine Medical Research Laboratory (NSMRL), the Naval Health Research Center (NHRC), and the Bureau of Medicine and Surgery (BUMED). Each subject provided documented, informed consent before participating. Setting: A ballistic-missile submarine, the USS Henry M. Jackson (SSBN-730 Gold). Study design: The experiment used a single-factor (Schedule), 3-level design with repeated measures. Subjects: Forty male 20-37 year-old subjects were recruited from a submarine’s crew during a scheduled deployment (US submarines have no female crew members). These subjects were randomly selected, stratified by rate, age, and race from the ship’s crew who volunteered to participate in the study. Few submariners declined participation in the study. This sampling is generalized to the submarine community as the ships complement underway is conserved, with deployment contingent upon staffing of requisite ratings. Two subjects were
African-American; four were Hispanic, two Asian American, and the balance Caucasian (reflective of the submarine community). Respective values for the group’s height, weight, and BMI were 180.1 ± 8.1 cm, (70.9 ± 3.2 in); 89.5 ± 19 kg, (197 ± 41.9 lb) and 25.7 ± 6.5. A sample size of 40 yields a power of 0.98 to identify an effect size of one standard deviation unit, which we assume to be an operationally significant effect.

Underway work-demands ultimately determined the order of presentation of watch schedules to the crew. Upon initial deployment, the crew spent 4 days on the SUB schedule. Then the ALT schedule was evaluated for 14 days, starting the close-6 watch cycle at midnight (ALTMID). Subsequently, 6 more days were spent on the ALT schedule, but commencing the close-6 watch cycle at noon (ALTNOON), to determine whether the latter would be received more favorably by the crew. Finally, the SUB schedule was evaluated for 13 days. Most statistical comparisons were limited to the ALTMID and SUB conditions, excluding the first three days of each schedule to allow for some degree of circadian acclimatization.

Unsupervised digital oral temperature readings were acquired by the subjects throughout their waking hours. They were encouraged to take readings as often as possible, but at a minimum, upon awakening; before, halfway through and after each watch period; and prior to retiring to sleep. This sample rate was more than twice the Nyquist rate for a circadian rhythm, but did not preclude aliasing by cortisol pulsatile release and/or ultradian rhythms faster than 2 cycles/day. The samples were collected using Sali-Saver ™ Saliva collection tubes (ALPCO, Windham, NH), and were immediately stored in the submarine freezer with a temperature maintained at approximately –20 °C, until they were shipped on dry ice to the Naval Institute for Dental and Biomedical Research facility where they were stored at –80 °C until analysis.

We collected salivary samples at each of four meal periods from ten of the 40 subjects to measure cortisol as an index of stress, and a biomarker from which to establish circadian rhythm (number based on limited funding) (24). The subjects were selected randomly from specific ratings, and therefore watch-standing positions. Samples were collected at 0530, 1130, 1730, and 2330. This 4-sample/day rate was twice the Nyquist rate for a circadian rhythm, but did not preclude aliasing by cortisol pulsatile release and/or ultradian rhythms faster than 2 cycles/day. The samples were collected using Sali-Saver ™ Saliva collection tubes (ALPCO, Windham, NH), and were immediately stored in the submarine freezer with a temperature maintained at approximately –20 °C, until they were shipped on dry ice to the Naval Institute for Dental and Biomedical Research facility where they were stored at –80 °C until analysis.

Upon thawing of the saliva samples, aliquots of 250 µl were prepared for replicate analysis utilizing the ALPCO Diagnostics (Windham, NH) Salivary Cortisol Kit. The lowest detectable level of cortisol distinguishable from the zero standard at the 95% confidence limit was 1.14 ng/ml. The intra-assay and inter-assay coefficients of variation were 5.14 and 5.88 respectively.

We assessed the subjects’ wake-sleep patterns with wrist activity monitors (WAM; Precision Control Design, Ft. Walton Beach, FL) data reduced by the Cole-Kripke algorithm3 (ACT Millenium© software version beta 3.5.13.2 and Action-W 2© software version 2.4.20, Ambulatory Monitoring Inc., Ardsley, NY). Usable data were available from 29 subjects. Inter-schedule comparisons were made by slope comparisons after mixed-effects, linear-regression modeling of the cumulative data distribution of subject daily sleep length means within each condition25.

The Department of Defense Sleep,
Activity, Fatigue, and Task Effectiveness (SAFTE) simulation, implemented in a Windows program, the Fatigue Avoidance Scheduling Tool (FAST™), was used to estimate cognitive performance effectiveness (7,12). The input to the simulation was the timing of wake and sleep periods, acquired from the WAM data. SAFTE’s cognitive performance effectiveness estimates were based upon throughput on relatively simple cognitive tasks, such as mental arithmetic and logical reasoning. These tasks engage some of the cognitive functions required to perform safety-sensitive jobs. SAFTE presumed that cognitive performance effectiveness is influenced by the interactions of a circadian process, a homeostatic sleep regulation and sleep inertia. The following estimates provide context for SAFTE estimates: for day workers who slept regularly from 2200 to 0600, the simulation estimated a typical effectiveness level of 90% at 2200, 75% for 24 hr of continuous wakefulness, and 50% for 48 hr of continuous wakefulness. At the 90% level, some commercial airline pilots admit to being only moderately competent to fly (19).

A survey posted on the submarine’s intranet used 7-point rating scales to (1) assess the submarine crew’s sleep quality and fatigue on each watch-standing schedule, (2) determine whether the ALT schedule was operationally viable, and (3) assess each individual’s overall impression of the crew’s performance and schedule viability (23). This survey was open to the entire ships complement underway, from which we solicited 130 responses.

A cosine curve-fitting approach was used to tease a circadian component out of data collected at irregular intervals over a period of several days (20). The products of the assessment allowed statements about the degree to which a psychophysiological phenomenon of interest expressed both a rectilinear change across days and a sinusoidal variation with a period of 24 hours. The cortisol and temperature data were represented as multi-day time series and subjected to within-subject, within-condition cosine curve fitting, after rectilinear trend was estimated by the least squares method and subtracted from each time series(8,17,23). A ‘measurable’ circadian rhythm in body temperature, and cortisol was one for which the proportion of variance accounted for by the cosine fit was 5% or more and the F statistic for the multiple R was 1.0 or greater. Cosinor analysis was used to characterize circadian rhythmicity in data collected at irregular intervals over a period of several days. The cosinor equations were implemented in a Microsoft® Office Excel 2003 spreadsheet. The spreadsheet’s Solver function was used to minimize the residual sum of squares of the cosine function estimates by manipulating the cosinor midline (mesor) and the amplitude-weighted, 24-hour-period sine and cosine of the relative phase of the estimated function. The products of the cosinor analysis for each time series included mesor, (half-wave) amplitude, relative waveform phase (peak time), standard error of the estimate, Pearson correlation coefficient, F ratio, mean squared error, and degrees of freedom. Comparisons between condition means were made with the 2-tail, paired t-test.

RESULTS

All data are presented as means ± S.D.

Salivary Cortisol

Mean cortisol levels ranged from 1.55 to 4.64 ng/ml across 20 time series from 10 subjects (grand mean 2.6 ± 0.9 ng/ml) and did not differ significantly between conditions (p = 0.60). Linear slopes ranging from -0.56 to 0.43 ng/ml/day (0.00 ± 0.22 ng/ml/day) were removed from the time series. These linear trends accounted for 0.008% to 17.0% (5.9 ± 6.1%) of total variance across the 20 time
series. We detected no measurable circadian rhythm in salivary cortisol level for 3 subjects in the ALTMID condition and 2 subjects in the SUB condition (1 subject was the same in both conditions). Because of the repeated measures design, these 4 subjects were removed from the sample leaving a new sample size of 6.

The cosine curve fits accounted for 9.9% to 47.4% (26.2 ± 10.5%) of the variance across the remaining 12 time series for these 6 subjects. Neither the cosinor mesors nor the cosinor amplitudes differed significantly between conditions (p = 0.88 and 0.94, respectively; Table 1).

**Body temperature**

Mean temperature levels were normal, ranging from 35.9 to 36.7 °C (96.7 to 98.1 °F) across 60 available time series from 30 subjects (grand mean 36.4 ± 0.17 °C (97.51 ± 0.30 °F) and did not differ between conditions (p = 0.68). Linear slopes ranging from -0.10 to 0.12 °F/day (0.00 ± 0.04 deg/day) were removed from the time series. These linear trends accounted for 0.003% to 12.1% (3.3 ± 5.8%) of total variance across 59 time series. In the other time series, 41.5% of variance was accounted for by the linear component, which increased at 0.125 °F/day; however, this series had a measurable circadian rhythm. We detected no measurable circadian rhythm in body temperature for 5 subjects in the ALTMID condition and 10 subjects in the SUB condition (2 subjects were the same in both conditions). Because of the repeated measures design, these 13 subjects were removed from the sample leaving a new sample size of 17.

The cosine curve fit accounted for marginally more variance (p = 0.098) in the ALT condition than in the SUB condition (Table 1). The cosinor mesors did not differ significantly between conditions (p = 0.51). The cosinor amplitudes did not differ (p = 0.18). The mean circadian acrophases occurred in the afternoon and did not differ between conditions ($X^2 = 0.01, p < 0.05, df = 1$).

<table>
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<th>Cosinor Metric</th>
<th>SUB</th>
<th>ALTMID</th>
<th>Grand</th>
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<tr>
<td><strong>Salivary Cortisol Level (n = 6)</strong></td>
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<td>Mesor (ng/ml)</td>
<td>2.39 (1.02)</td>
<td>2.43 (0.89)</td>
<td>2.41 (0.91)</td>
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<tr>
<td>Amplitude (ng/ml)</td>
<td>0.91 (1.08)</td>
<td>0.94 (0.10)</td>
<td>0.92 (1.00)</td>
</tr>
<tr>
<td>%Variance</td>
<td>28.2% (12.1%)</td>
<td>24.3% (9.2%)</td>
<td>26.2% (10.5%)</td>
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<tr>
<td><strong>Body Temperature (n = 17)</strong></td>
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<tr>
<td>Mesor (deg F)</td>
<td>97.63 (0.29)</td>
<td>97.58 (0.32)</td>
<td>97.61 (0.30)</td>
</tr>
<tr>
<td>Amplitude (deg F)</td>
<td>0.30 (0.10)</td>
<td>0.35 (0.14)</td>
<td>0.32 (0.12)</td>
</tr>
<tr>
<td>%Variance</td>
<td>15.1% (6.4%)</td>
<td>20.6% (11.3%)</td>
<td>p = 0.098</td>
</tr>
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</table>

Table 1. Cosinor analysis metrics (mean and sd) for plasma cortisol, and body temperature in the SUB and ALTMID conditions and either the p value for significant differences between conditions or the grand means and standard deviations.

**Sleep length**

According to the WAM data, the subjects slept an average of 6.3 ± .3 hr/day during the ALTMID schedule (n = 25, df = 48). During the ALTNOON and SUB schedules, this amount increased to 6.6 ± 0.2 and 7.1 ± 0.2 hr/day, respectively (Table 2). The difference between ALTMID and ALTNOON was not significant (t = 1.52, p = 0.14). The differences between ALTMID and SUB and between ALTNOON and SUB were significant (t = 4.48, p < 0.0001; t = 2.08, p = 0.043; respectively).

**Estimated cognitive performance effectiveness**

According to the SAFTE model, using the wake-sleep patterns produced by the WAM data, a mean daily effectiveness of 77.7 ± 1.7% was reached during the ALTMID schedule (n = 27, df = 52). During the ALTNOON and SUB schedules, estimated mean daily
effectiveness increased to 80.1 ± 1.0% and 80.0 ± 1.2%, respectively. The difference between ALTMID and ALTNOON was statistically significant \((t = 2.49, p = 0.016)\). The difference between ALTMID and SUB levels approached statistic significance \((t = 1.97, p = 0.054)\). The difference between ALTNOON and SUB was not statistically significant \((t = 0.13, p = 0.89)\).

<table>
<thead>
<tr>
<th>Mean ± SD</th>
<th>ALTMID</th>
<th>ALTNOON</th>
<th>SUB</th>
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<tbody>
<tr>
<td>Sleep (min/day)</td>
<td>375.3 (16.0)</td>
<td>395.4 (13.2)</td>
<td>424.7 (11.0)</td>
</tr>
<tr>
<td>p vs. ALTMID</td>
<td>0.14</td>
<td>&lt;0.0001</td>
<td></td>
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<tr>
<td>p vs. ALTNOON</td>
<td></td>
<td>0.043</td>
<td></td>
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<tr>
<td>Effectiveness (%)</td>
<td>77.7 (1.68)</td>
<td>80.1 (1.0)</td>
<td>80.0 (1.2)</td>
</tr>
<tr>
<td>p vs. ALTMID</td>
<td>0.016</td>
<td>0.054</td>
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<tr>
<td>p vs. ALTNOON</td>
<td></td>
<td>0.89</td>
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**Table 2.** Mean daily minutes of sleep estimated from activity monitor data. Cognitive performance effectiveness estimated from activity monitor data and the SAFTE simulation and respective p values. Standard errors in parentheses.

**Surveys**

The survey revealed that 52% of respondents preferred the SUB schedule, 15% preferred an ALT schedule, and 33% were either indifferent or submitted surveys that could not be interpreted due to experimental-procedural errors. Pair-wise Pearson product-moment correlations among survey responses were computed between preference and specific scheduling issues. The moderate to strong correlations for those respondents who reported that they did NOT prefer either of the ALT schedules suggested the main reasons why they did not like them. They reported less time for:

- Physical training \((r = 0.551, p < 0.001, n = 130)\),
- Free time \((r = 0.550, p < 0.001, n = 130)\), and
- Performing collateral duties \((r = 0.533, p = 0.004, n = 130)\).

And more difficulty in:

- Scheduling training periods \((r = 0.430, p < 0.001, n = 112)\),
- Scheduling maintenance periods \((r = 0.425, p < 0.001, n = 114)\),
- Performing administrative duties \((r = 0.352, p < 0.001, n = 116)\), and
- Getting adequate rest \((r = 0.647, p < 0.001, n = 130)\).

**DISCUSSION**

Originally, the ALT schedule was to commence at noon as it had during the laboratory trial (19). However, the underway work demand compelled us to commence the ALT schedule at midnight. We had planned to use a counterbalanced design by evaluating the two schedules in reverse order aboard another submarine underway. However, once the ALT schedule was found to be unacceptable by the crew, the protocol was halted. Subsequent to the field test described here, a project working group decided to abandon the underway assessment of the ALT schedule in favor of an assessment of an alternative fixed watch-schedule (discussed below).

The submarine crew viewed the ALT schedule as unacceptable. It was not conducive to supporting operational requirements imposed underway (drills, training, maintenance, clean-up, administration, exercise, qualifications). The ALT schedule attempted to compress watch periods, to facilitate an extended period of contiguous sleep. However, little collateral work was completed in the 6 hours between compressed watch periods, necessitating the allocation of this work to the 12- and 24-h
“sleep periods”, undermining the intent of the schedule’s design. Thus, this alternative schedule proved incompatible with this operational submarine environment. Similarly, and probably for similar reasons, Kleitman’s close-4 schedule was never adopted for submarine operations. However, the other results of our field study may enlighten the research community about the operational constraints imposed on any candidate schedule that must be reconciled prior to attempting implementation, and its effects upon submariner performance and physiology.

Overall, we observed normal levels of salivary cortisol and body temperature. Cortisol release above the homeostatic baseline may be mediated by the accumulation of a sleep debt (1,19,24), in addition to the presence of both physiological and psychological stressors. The pooled averages of cortisol across the collection period suggested a flattened, uniform secretion, as opposed to the normal diurnal pattern (norm of 4-10 ng/ml at 0800 AM and 0.7-1.5 ng/ml in the evening: Alpco Diagnostics), ostensibly due to circadian phase shifting. This is consistent with investigations into shift work noting elevated cortisol levels during sleep periods and reductions during the waking periods (1).

In support of schedule comparisons, we found measurable circadian rhythms in plasma cortisol in 6 of 10 subjects across both conditions, and measurable circadian rhythms in body temperature in 17 of 30 subjects across both conditions. Our inability to detect physiological rhythms in 40 to 45% of subjects was likely due to (1) the inherent variability of the oral temperature data acquisition method; (2) the effects of the different cycle lengths of the ALTMID and SUB conditions (24 and 18 h, respectively) on circadian entrainment of the circadian pacemaker, causing phase drift across the measurement days; (3) the schedule irregularities inherent within the two watch schedules; and (4) the absence of daylight and darkness cues while the submarine was underway. Aliasing of ultradian frequencies specifically as a 24-hr cycle length was unlikely. Unfortunately, baseline levels of cortisol levels were not obtained pre- or post deployment to determine “control” circadian variability in the subjects. This was due in part to an inability to logistically schedule sampling from the study participants at either time frame. This is a deficiency that will be remedied in subsequent investigations. Cortisol was analyzed because we believed it would provide a more accurate depiction of circadian rhythm than melatonin. Given the inability to control the lighting intensity levels underway, and concomitantly, the acute masking effects of light on melatonin, the acquisition of dim light melatonin onset (DLMO) seemed impractical. Logistically, it appeared untenable to mandate time in a dim light environment. Interestingly, post hoc evaluation of the lighting levels aboard the submarine revealed intensities in the vicinity of 100 lux, a relatively low figure for typical ambient lighting.

For body temperature, the cosine curve fit accounted for about 5% more variance in the ALTMID condition than in the SUB condition. Perhaps the 24-h cycle of the ALT schedule provided better circadian entrainment cues for body temperature than did the 18-h cycle of the SUB schedule.

The sleep data from the WAM indicated that the SUB schedule afforded significantly more sleep, about 51 min/day, than the ALTMID schedule. This SUB schedule value was consistent with previously published results on a similar SSBN-platform13. All schedules presented a low average level of cognitive effectiveness. This effect may be attributed partially to the rapid transitioning through three different watch rotation schedules, which was not intended or desirable. However, these low performance levels may also reflect an alarming reduction in crew members’ levels of cognitive

Rubicon Research Repository (http://archive.rubicon-foundation.org)
function. Figure 2 illustrates the simulated cognitive effectiveness when performing watch on the SUB schedule.

Each 18-hr “day” for a submariner is not unlike an eastward travel across six time zones. Submariners, therefore, suffer a chronic jet-lag malaise and sleep deficit (19). Moreover, watch periods within these rotating schedules are repeatedly—and unpredictably—aligned with individuals’ performance nadirs, handicapping situation awareness, and contributing to the risk of accidents (6,19,22,33). A “sobering” statistic is that performance after 20-25 hours of sleep deprivation compares to a blood alcohol content of 0.10%32,33. Research to date has not established an attributable-risk of fatigue, and circadian desynchronization to accidents underway, but we assume that they substantially increase the probability of error. This risk may be heightened by the growing demands for information processing that burden the submariner. Fortunately, the submarine service boasts unparalleled safety records thanks in part to extensive training and the committed dedication of its servicemen.

Shift work scheduling should strive to employ the principles of chronohygiene, including 1) adherence to 24-hour work-rest schedules; 2) adoption of a long, protected period of uninterrupted sleep (1,19); 3) minimization of sleep fragmentation; 4) maximizing time off between shifts; 5) limiting work shifts to 8 hours per 24 hour period; 6) adopting a fixed vice rotating shift, (facilitating adjunctive therapies, including bright light phototherapy, melatonin, modafanil and exercise); and 7) minimizing shift turnover frequency (18). Adequate sleep must be regarded as a required staple, and scheduled appropriately into all operations. The dividends of a normal circadian rhythm and improved sleep hygiene include reduced fatigue, enhanced performance, and improved overall health. These objectives logically lead to increased morale, quality of life and, likely,
enhanced retention.

One shortcoming of the ALT schedule was that it offered only one protected period of sleep every 72 hours, and this was during the final 24 hours. The ALT schedule (ALTNOON) was designed to afford two long protected sleep periods every three days. However, the 12-hr off period, flanked by 6-hr watches, occurred during the day (0600-1800) subsumed by drills, training, etc. Thus, it appears the compressed watches accompanied by increased fatigue were not compensated by the one designated protected sleep period. The present 6/12 watch-schedule already accommodates an essentially sacrosanct 12-hour time off period (between 1800 and 0600) every three days to afford a nocturnal period of long, uninterrupted sleep.

We believe there are compelling data that support implementing a fixed watch-standing schedule to accrue physiological, psychological and performance benefits. Accepting this position, we would recommend investigating the efficacy of instituting a fixed 8-hr watch-schedule underway, with a morning (0700-1500), afternoon (1500-2300), and night (2300-0700) shift. The veteran sailor may perceive this as “heresy,” but this schedule satisfies every aspect of the shift work paradigm mentioned above. Six hours of watch has been considered to be the maximum duration for vigilant watch-standing. However, the potential theoretical improvements in circadian rhythm entrainment, sleep hygiene, overall physiology, health, and well being advanced by employing this schedule may render an increased shift length palatable. Additionally, the fixed-8 schedule has the potential to mitigate the risks of errors, (which increase disproportionately when one extends the work period beyond 8 hours per 24), by decreasing turnover frequency. Preliminary SAFTE/FAST simulation modeling of this scenario suggests an average 98% relative effectiveness on the morning and afternoon shifts, and 92% average effectiveness on the night shift (see Fig. 3), which after an equilibration period, approaches similar cognitive effectiveness values as the morning (top graph) and afternoon (bottom graph) schedules.

This is a substantial potential improvement in performance that warrants further inquiry. Reducing the number of scheduled meals from every six hours to every eight hours may achieve improvements in weight management and economy of pantry space. Implementing such a schedule must address the ability to accommodate drills underway, a topic being pursued actively by NSMRL.

Numerous alternative candidate schedules have been considered, but violate the principles of chronohygiene delineated above. The inherent deficiencies of the Maritime schedule were discussed in the introduction. Additionally, the SAFTE/FAST simulation estimates that the Maritime schedule provides an average relative cognitive effectiveness of 85%, with a range of 78-97%, lower than that estimated for the Submarine watch-schedule19.

“Dogged-schedules” (Table 3) may be designed that allow three watch sections to work one fixed six-hour watch, assigning

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Table 3. Three fixed 6-hr shifts, with one 6-hr shift “dogged” via three 2-hr stints allocated to each of three shifts. The “dogged” shift is arbitrary—here we chose to “dog” the 1200-1800 shift. An “x” delineates when the watch section assumes watch.
three two-hour watch stints to each of the three watch-sections respectively to cover the final 6-hr watch period. The biggest issue confronting this approach concerns the time required for adequate turnover between oncoming and off going watchstanders, which could compromise situation awareness. Notably, shift turnover encompasses a disproportionate percentage of errors in all work environments (19). This is an especially compelling issue within the submarine service, which mandates a comprehensive turnover at many watch-stations. The six-hour watch period appears to be an appropriate minimum standard to facilitate situation awareness, and minimize turnover frequency.

Additional research should investigate the utility of implementing focused interventions, including 1) “rating-specific” and “critical-position” schedules, 2) assigning critical positions only to those possessing circadian adaptability, 3) instituting sleep and chronohygiene education in Submarine School, 4) implementing adjunctive measures to expedite circadian entrainment—especially if employing a fixed schedule—such as bright light therapy, melatonin administration, nutraceuticals, exercise, slow-release caffeine, and modafinil, and 5) using adjunctive measures to facilitate alertness during watch, such as bright light (1).
Our results 1) support the assertion that submariners experience sleep deprivation and circadian desynchronization underway; 2) demonstrate that the ALT compressed close-6-hr watch-standing schedule, though it increased daily sleep length, failed to enhance circadian rhythm entrainment beyond the contemporary backwards rotating 6-hr submarine schedule employed underway; and 3) determine that the ALT compressed close-6-hr watch-standing schedule was incompatible with accommodating operational requirements. Physiological interpretations of the ALT schedule are limited by the lack of a second “counterbalanced” underway evaluation as originally conceived. However, incompatibility with the operational schedule truncated further evaluation. The lack of an obvious improvement in this evaluation suggested that even with another counterbalanced evaluation, any significance would probably be modest. Although unsuccessful in our study, the ALT schedule may hold promise for other communities in which work schedules must be designed for 24-hr operations in geographically-confined, limited-crew-number situations.

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DISCLAIMER

The views expressed in this article are those of the authors, and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government.

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