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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

ASSESSMENT OF THE FIXED 3-SECTION 4HRS-ON/8HRS-OFF WATCHSTANDING SCHEDULE IN SAILORS OF THE SWEDISH ROYAL NAVY COMPARED TO SAILORS OF THE UNITED STATES NAVY

by

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May 2021

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14. ABSTRACT
This prospective longitudinal quasi-experimental study assessed the utility of the 3-section, fixed, 4hrs-on/8hrs-off watchstanding schedule on a ship of the Swedish Royal Navy (HSwMS ORION). Sailor (n = 19) state was assessed in terms of sleep attributes, fatigue, insomnia symptoms, mood, psychomotor vigilance performance, and workload. Data from the HSwMS ORION were compared with data from sailors from three surface vessels of the USN (n = 22).
Compared to their USN peers, sailors on the HSwMS ORION were more alert, reported better sleep quality, less severe insomnia symptoms, and better mood in terms of total mood disturbance, depression, fatigue, and vigor. The same pattern was evident in psychomotor vigilance performance, i.e., sailors on the HSwMS ORION were faster and made fewer errors as assessed by lapses or lapses combined with false starts. Sailors in the two samples did not differ in terms of daily sleep duration and the number of sleep episodes per day. Also, daily work duration did not differ substantively between the two groups. We postulate that one factor that explains why Swedish sailors felt and performed better is the fact that sailors in night shifts were allowed to wake up later in the day, and, consequently some work duties occurred later in the day.
In conclusion, our findings suggest the sailor well-being when standing watch on the fixed 4/8 can be improved when sailors are allowed flexible wake-up times in the morning after a night shift. Given the small number of participants, however, further research is needed to understand better the advantages and disadvantages of the 4/8 in the naval operational environment, and how to improve the utility of the watchbill.

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The report was entitled "Assessment of the fixed 3-section 4hrs-on/8hrs-off watchstanding schedule in sailors of the Swedish Royal Navy compared to sailors of the United States Navy".

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ABSTRACT

This prospective longitudinal quasi-experimental study assessed the utility of the 3-section, fixed, 4hrs-on/8hrs-off watchstanding schedule on a ship of the Swedish Royal Navy (HSwMS ORION). Sailor (n = 19) state was assessed in terms of sleep attributes, reported fatigue, insomnia symptoms, mood, psychomotor vigilance performance, and workload. Data from the HSwMS ORION were compared with data from sailors (n = 22) from three surface vessels of the USN working a similar 3-section 4hrs-on/8hrs-off schedule.

Compared to their USN peers, sailors on the HSwMS ORION were more alert, reported better sleep quality, less severe insomnia symptoms, and better mood in terms of total mood disturbance, depression, fatigue, and vigor. The same pattern was evident in psychomotor vigilance performance; i.e., sailors on the HSwMS ORION were faster and made fewer errors as assessed by lapses or lapses combined with false starts. Sailors in the two samples did not differ in terms of daily sleep duration and the number of sleep episodes per day. Also, daily work duration did not differ substantively between the two groups. We postulate that one factor that explains why Swedish sailors felt and performed better is the fact that Swedish sailors working night shifts were allowed to wake up later in the day with some of their work duties occurring later in the day.

In conclusion, our findings suggest that sailor well-being when standing watch on the fixed 4/8 can be improved when sailors are allowed flexible wake times in the morning after a night shift. Given the small number of participants, however, further research is needed to better understand the advantages and disadvantages of the 4/8 in the naval operational environment and explore ways to improve the usefulness of the watchbill.

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TABLE OF CONTENTS

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LIST OF FIGURES

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LIST OF TABLES

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I. INTRODUCTION

A. BACKGROUND

In 2001, as part of an effort to improve operational performance in the US Navy (USN), the Crew Endurance Team at the Naval Postgraduate School (NPS) began documenting sailor well-being on surface vessels. Twenty years and more than 30 studies later, we have assessed hundreds of sailors' sleep, sleepiness, insomnia, sleep quality, psychomotor vigilance task performance, reported factors that disrupt sleep in their berthing compartments, and other occupational stressors. Results from these studies consistently highlighted two points of interest. First, sailors worked on a variety of watchstanding schedules ("watchbills"), some of which had fixed shifts, i.e., sailors stood watch at the same times every day, whereas other watchbills had rotating shifts (Shattuck, Matsangas, & Dahlman, 2018; Shattuck, Matsangas, Mysliwiec, & Creamer, 2019). Second, fixed watchbills were associated with less tired and more alert sailors compared to their peers working on rotating watchbills (Shattuck & Matsangas, 2019; Shattuck, Matsangas, & Brown, 2015; Shattuck, Matsangas, & Powley, 2015).

Based on these results, the Naval Advanced Medical Development (NAMD) program funded a 3-year project in 2016 to systematically assess the utility of circadian-based watchbills, to determine which watchstanding and work schedules are most effective while ships are underway, and to provide actionable recommendations to the US Navy leadership.

The study we present herein is focused on the fixed 4-hour on/8-hour off ("4/8") schedule, also known as the traditional maritime schedule (Colquhoun, 1985; Miller, 2006). Initially, we intended to collect data from surface ships of the USN. To our surprise, however, the 4/8 schedule was rarely used in the USN surface ships before the fleet-wide directive to implement "circadian-based watchbills" onboard all US Navy surface ships (COMNAVSURFOR, 2017; Department of the Navy, 2017). Specifically, in the studies conducted at the NPS, fewer than 30 sailors out of approximately 1500 stood watch on the 4/8. To fill in this gap, we used an opportunity to conduct a field study on a ship of the Swedish Royal Navy to compare results between sailors on the Swedish Royal Navy and this small sample of pre-collected data from USN sailors.

Miller provided a detailed historical perspective of the origins of the 4/8 in the maritime domain and the research conducted on the variants of the 4/8 (Miller, 2006, 2013, 2015). Based on his review of earlier research and his assessments of the 4/8, Miller (2006) concluded that the main problems with the traditional maritime 4/8 are reduced total sleep time and fragmented sleep, i.e., splitting sleep into multiple episodes during the day. The latter is the direct result when only 8 hours is off between consecutive shifts.

B. STUDY GOALS

The specific goals of the study are:

- To assess the state of crewmembers in terms of sleep attributes, fatigue, insomnia symptoms, mood, and psychomotor vigilance performance.
- To assess daily workload as described in the Navy Availability Factor (NAF) model.
- To compare sailor well-being and workload between the Swedish sample and a sample of USN sailors working on the same watchbill on three USN ships.

II. METHODS

A. EXPERIMENTAL DESIGN

The study protocol is based on a prospective, longitudinal, quasi-experimental design. Using this naturalistic approach, sailors were observed while they performed their normal underway duties.

B. PARTICIPANTS

Swedish sailor participants (N = 19) were volunteers from the two crews manning the HSwMS Orion (A-201), a signals intelligence-gathering vessel of the Swedish Royal Navy (Figure 1). Participation rate was approximately 50% of the total crew.

The study protocol was approved by the Naval Postgraduate School Institutional Review Board (NPS.2017.0071), the Department of the Navy (DON) Human Research Protection Program (HRPP), and the Swedish Royal Navy.

Figure 1. HSwMS Orion (A-201)

C. EQUIPMENT AND INSTRUMENTS

1. Questionnaires

The Pre-study Questionnaire included in the Sleep Study protocol included demographic items and five standardized questionnaires. Demographic questions included age, gender, rate/rank, department, years on active duty, factors affecting sleep, type and frequency of caffeinated beverage use (e.g., tea, coffee, soft drinks, energy drinks), type and frequency of tobacco product use (e.g., cigarettes, chewing tobacco, nicotine gum or patches, electronic smoke), use of medication (prescribed or over-the-counter), and the type and frequency of exercise routine. The five standardized questionnaires included in the Pre-study Questionnaire are described in detail below.

The self-administered morningness-eveningness questionnaire (MEQ-SA) (Terman, Rifkin, Jacobs, & White, 2001) was used to assess participants' chronotype, an attribute of human beings related to their preference for waking earlier or later in the day. The scale includes 19 multiple-choice questions. Scores range from 16 to 86, with scores less than 42 corresponding to evening chronotypes and scores higher than 58 indicating morning chronotypes. Although based on the Horne and Östberg (1976) original MEQ scale, the MQE-SA has some stem questions and item choices rephrased to conform with spoken American English. Discrete item choices have been substituted for continuous graphic scales.

The Pittsburgh Sleep Quality Index PSQI was used to determine sleep quality (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). Individuals with a PSQI total score of 5 or less are characterized as good sleepers, whereas scores of more than 5 are associated with poor sleep quality. The Epworth Sleepiness Scale (ESS) was used to assess average daytime sleepiness (Johns, 1991). The individual used a 4-item Likert scale to rate the chance of dozing off or falling asleep in eight different everyday situations. Scoring of the answers was 0 to 3, with 0 being "would never doze," 1 being "slight chance of dozing," 2 being "moderate chance of dozing," and 3 denoting a "high chance of dozing." Respondents were instructed to rate each item according to his/her usual way of life in recent times. Responses were summed to the total score. A sum of more than 10 reflects above normal daytime sleepiness and a need for further evaluation (Johns, 1992). The ESS questionnaire has a high level of internal consistency, as measured by Cronbach's alpha, ranging from 0.73 to 0.88 (Johns, 1992). The 7-item Insomnia Severity Index (ISI) was used to assess the severity of both nighttime and daytime components of insomnia (Bastien, Vallieres, & Morin, 2001; Morin, Belleville, Bélanger, & Ivers, 2011).

To measure mood states and assess mood changes, participants filled out the POMS (McNair, Lorr, & Droppelman, 1971). The POMS is a standardized, 65-item inventory originally developed to assess mood states in psychiatric populations. The questionnaire assesses the dimensions of the mood construct using six subscales: anger - hostility (12 items; range 0-48), confusion - bewilderment (7 items; range 0-28), depression (15 items; range 0-60), fatigue (7 items; range 0-28), tension - anxiety (9 items; range 0-36) and vigor - activity (8 items; range 0-32). Vigor is subtracted and the Total Mood Disturbance (TMD) score is derived by adding the subscales (range 0-200). Normalized scores (T-scores) are based on norms for adults (Nyenhuis, Yamamoto, Luchetta, Terrien, & Parmentier, 1999). The POMS was administered using the instruction set: "Describe how you felt during the past week." Positive mood has been associated with better within-team communication behaviors and enhanced team awareness (Pfaff, 2012).

The Post-study Questionnaire included in the protocol included the ESS, ISI, PSQI, and POMS. Participants were asked to indicate their watchstanding schedule, the adequacy of their own and their peers' sleep (5-point Likert scale: "Much less than needed"; "Less than needed"; "About right"; "More than needed"; "Much more than needed"), and to compare their workload during the data collection period with their normal workload underway (5-point Likert scale: "Much less than usual," "Less than usual"; "About the same"; "More than usual"; "Much more than usual"). The post-study survey also included two open-ended questions ("What did you like most about your current watch schedule?" and "What did you like least about your current watch schedule?")

2. Sleep assessment

Sleep was assessed by wrist-worn actigraphy (Motionlogger Watch by Ambulatory Monitoring, Inc.) assisted by activity logs, a validated method to collect objective sleep data in field studies (Meltzer, Walsh, Traylor, & Westin, 2012; Rupp & Balkin, 2011). The use of actigraphy followed existing recommendations (Ancoli-Israel et al., 2015; Morgenthaler et al., 2007). Data were collected in 1-minute epochs using the Zero-Crossing Mode. Data were scored using Action W version 2.7.3045 software. The Cole-Kripke algorithm with rescoring rules was used. The criterion for sleep and wake episodes was five minutes. The sleep latency criterion was no more than one minute awake in a 20-minute period (all values are the default for this software).

3. Activity Logs

All participants were asked to complete an activity log, documenting their daily routine in accordance with the Navy Availability Factor (NAF) categories (OPNAV, 2015) used in the US Navy. The activity logs covered a 24-hour period in 15-minute intervals. Participants were asked to document whether they were exposed to sunlight (duration and timing), consumption of caffeinated beverages and energy drinks, and whether they worked out (including time and duration of workout).

4. Psychomotor Vigilance Test (PVT)

Performance data were collected using a 3-minute version of the original 10-minute Psychomotor Vigilance Task—PVT (Dinges & Powell, 1985) which was embedded in the AMI actigraphs (Matsangas & Shattuck, 2018b; Matsangas, Shattuck, & Brown, 2017; Matsangas, Shattuck, Mortimore, Paghasian, & Greene, 2019). PVT performance is not only affected by sleep loss, but has also been shown to be sensitive to circadian rhythmicity (Dinges et al., 1997; Doran, Van Dongen, & Dinges, 2001; Durmer & Dinges, 2005; Jewett, Dijk, Kronauer, & Dinges, 1999; Wyatt et al., 1997). The PVT is a simple reaction time test in which participants press a button in response to a visual stimulus. Because of its simplicity, the PVT has very minor learning effects, which can be reached in one to three trials (Dinges et al., 1997; Jewett et al., 1999; Kribbs & Dinges, 1994; Rosekind et al., 1994). The PVT nominal inter-stimulus interval (ISI), defined as the period between the last response and the appearance of the next stimulus, randomly ranges from 2 to 10 seconds. The original version of the PVT has a duration of 10 minutes (Loh, Lamond, Dorrian, Roach, & Dawson, 2004); however, shortened versions have also recently been validated to assess sleep deprivation effects (Basner & Dinges, 2011; Loh et al., 2004; Matsangas & Shattuck, 2018a; Matsangas et al., 2017). Operational demands precluded the use of the 10-minute version in this study. Consequently, we used a 3-minute version of the PVT included on the AMI actigraphs, with ISI ranging from 2 to 10 seconds. A red backlight appeared for one second and the letters “PUSH” were used as visual stimuli; the response time was then displayed in milliseconds.

5. Fatigue Avoidance Scheduling Tool (FAST)

The utility of the 4/8 was further explored using the Fatigue Avoidance Scheduling Tool (FAST) (version 3.3.01T by Fatigue Science). FAST is based on the Sleep and Fatigue, Task Effectiveness (SAFTE™ © 2000-2008 Fatigue Science) model, which was initially developed for the Department of Defense (DOD). It is the official DOD-sanctioned model for predicting fatigue-related performance degradation. The Naval Safety Center requires that SAFTE/FAST be applied to all mishap investigations (Department of the Navy, 2014). SAFTE-FAST has been validated using actual performance in aircrew and provides a means for assessing and mitigating fatigue in shiftwork environments and aviation duty schedules.

The SAFTE/FAST model has been used to assess predicted effectiveness, a measure of cognitive performance, ranging from 100% (best) to 0% (worst) (Hursh et al., 2004). According to the FAST manual, an eight-hour period of excellent sleep at night results in normal daytime predicted effectiveness that ranges between 90% and 100%, the green horizontal band on the FAST graph. Predicted effectiveness between 65% and 90%, the yellow band on the FAST graph, is the range of performance observed during the 24-hour period after missing one night of sleep. Predicted effectiveness below 65%, the red band on the FAST graph, indicates performance that is well below the level acceptable for operations. The red band represents predicted effectiveness resulting from staying awake for two full days and one night. Reaction times for individuals in the red band are greatly slowed, more than twice the normal level. Figure 3 shows a screenshot of SAFTE/FAST output.

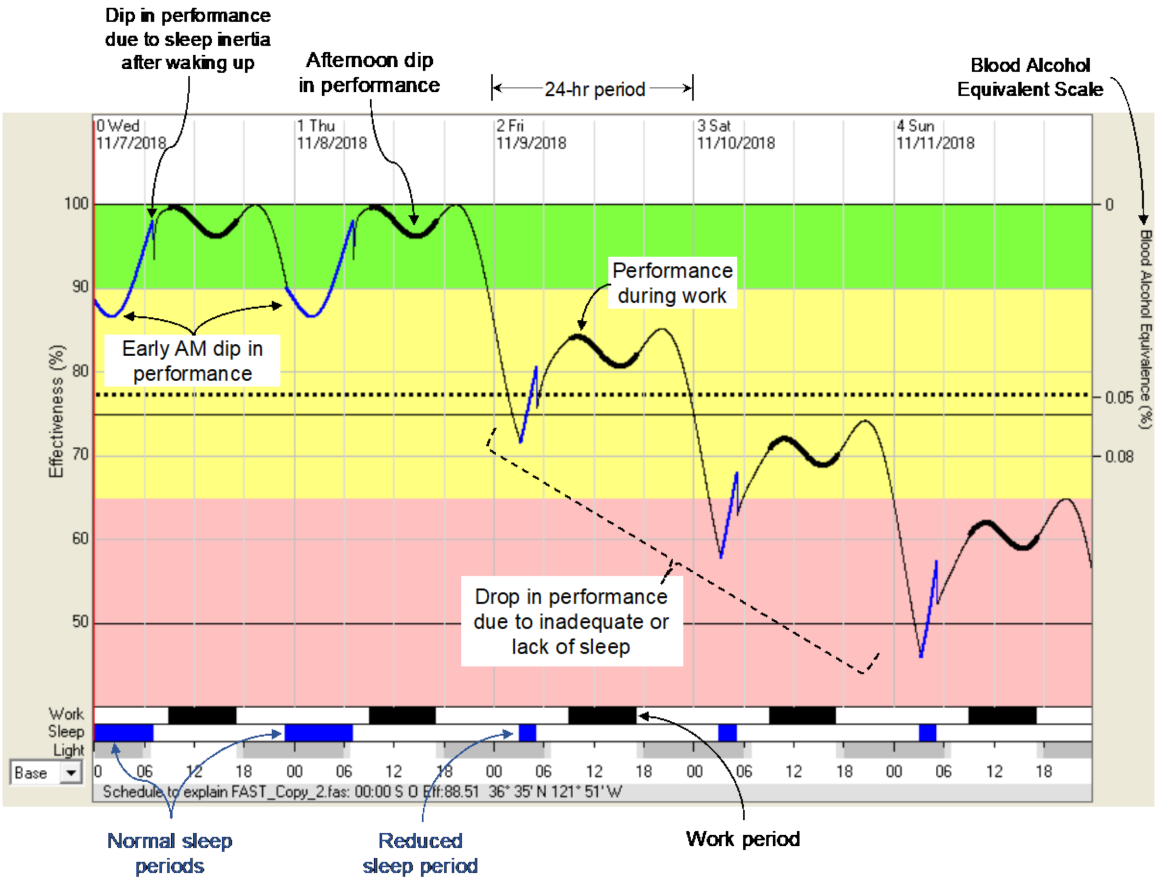

Figure 1. SAFTE/FAST screenshot

D. PROCEDURES

Data collection was conducted in two underway phases in April 2018, 4 to 14, and 17 to 28. Initially, sailors were briefed on the research protocol and study procedures. Individuals who agreed to participate in the study signed informed consent forms and received further training before being issued study equipment. Participants completed the Pre-study Questionnaire and received their actiwatches and activity logbooks. All participants were instructed to fill out their activity logs daily. Participants were instructed to perform the PVT in their actiwatch before and after their watchstanding period. Upon completion of the study, the participants returned their equipment and filled out an end-of-study survey.

E. ANALYTICAL APPROACH

1. Actigraphy Data Cleaning and Reduction Procedures

The preparation of the actigraphy data for analysis included three steps. First, we evaluated the number of days of data available for each participant. Participants with fewer than seven days of data (n = 3) were excluded from sleep analysis.

Next, we prepared the actigraphic data for analysis based on a procedure we have developed and used in all our field sleep studies at NPS. Specifically, the primary source for the sleep analysis was the actigraphy data, but sleep logs assisted in the determination of the start and end times of sleep intervals. Based on this comparison, we manually identified the start and end times of sleep episodes in the actigraphy data. The criteria used to determine whether we could use the data or whether imputation was required included the quality of the actigraphy data, the consistency of activity patterns over consecutive days, the amount of missing data, whether the participant was a watch-stander, and the accuracy of the sleep log. According to this procedure imputation is applied only when: (a) there is a gap in actigraphy data within which the sleep log showed a sleep interval, and (b) the pattern of actigraphy data, assisted by the activity logs, is such to assure confidence in the interpolation of the sleep interval.

Overall, the preparation of actigraphic data for analysis led to the development of the database of sleep episodes. Imputation was not applied to actigraphic data. Due to missing data, sleep analysis is based on nine participants of HSwMS ORION, i.e., 4 sailors working in the 0001-0400/1200-1600 section, three in the 0400-0800/1600-2000, and two in the 0800-1200/2000-2359 section.

2. PVT Data Cleaning and Reduction Procedures

Psychomotor vigilance performance data were collected using the PVT version included in the AMI Motionloggers. The duration of each PVT trial was three minutes, with a minimum interstimulus interval of two seconds, and a maximum interstimulus interval of 10 seconds. Responses without a stimulus or with RTs < 100 milliseconds (ms) were identified as false starts. Lapses were defined as RTs equal to, or greater than, 355 ms and 500 ms. PVT responses were aggregated; first by trial and then by participant. Reaction time, response speed, fastest 10% reaction times, slowest 10% response speeds, percentage of false starts (FS), percentage of 355 ms lapses, percentage of 500 ms lapses, percentage of 355 ms lapses combined with false starts, and percentage of 500 ms lapses combined with false starts were the PVT metric used in our analysis. No imputation was used with the PVT data.

3. Sleep Log Data Cleaning and Reduction Procedures

Activity logs were used to analyze work and rest patterns in the actigraphy data. Sleep log data were entered into a spreadsheet and screened for completeness and accuracy. Specifically, we looked for any instances with missing activity or instances of noncompliance with the sleep log instructions (e.g., adding activity codes not included in the instruction set).

When deemed appropriate, 15-minute bins with missing activity were interpolated. The criteria for interpolation were the accuracy of the sleep log, the pattern of activities over consecutive days, the length of missing data, whether the participant was a watchstander, and the existence of actigraphy data. The pattern of activities was a critical criterion; if the participant did not have a consistent daily pattern of activities, then it was difficult to infer activities for missing days. Actigraphy assisted in evaluating the actual sleep and wake periods; hence, we were able to deduce the watch period when integrating information from the posttest questionnaire where participants reported their predominant watch schedule. Overall, we attempted to interpolate as little as possible given the utility and accuracy of the available information sources. Analysis of workload with the activity logs was based on 185 days of data. Interpolation was applied to 207 missing 15-minute intervals (1.17%).

4. Analysis Roadmap

Sleep and PVT metrics were aggregated to get an average score for each individual over the entire study period. Therefore, both sleep and PVT metrics provided an overall estimate of sailor alertness and performance during the data collection period.

The analysis focused first on the entire data set of 19 sailors. All variables underwent descriptive statistical analysis to identify anomalous entries and to describe our population in terms of demographic characteristics, alertness, insomnia symptoms, sleep attributes (daily sleep duration, number of sleep episodes per day, sleep quality), adequacy of sleep, mood states, and sleep-related habitability factors in the berthing compartments. Next, the analysis focused on the main goal of this study, i.e., the assessment of sailor well-being when working on the fixed 4/8 watchbill. Due to the small number of participating sailors, we used a descriptive approach for the entire 4/8 sample (n = 12) without assessing differences among the three sections of the 4/8 watchbill with an analytical comparison. We also compared the data we collected on HSwMS ORION with the data of 22 USN sailors working on the fixed 4/8 on three surface ships (n = 22; 17 [77.3%] males; median age = 23.5 years [range 19 to 37]; 20 [90.0%] enlisted personnel). These data are from two Arleigh Burke-class destroyers and one Ticonderoga class cruiser and are described elsewhere (Shattuck & Matsangas, 2014, 2019).

Statistical analysis was conducted with JMP statistical software (JMP Pro 14; SAS Institute; Cary, NC). Data normality was assessed with the Shapiro-Wilk W test. The Wilcoxon Rank Sum test was used for pairwise comparisons between independent samples, whereas the Signed Rank and the McNemar's tests were used for dependent pairwise comparisons. The Likelihood Ratio test was used to compare POMS scores with adult norms. An alpha level of .05 was used to determine statistical significance. Post-hoc statistical significance was assessed using the Benjamini–Hochberg False Discovery Rate (BH-FDR) controlling procedure(Benjamini & Hochberg, 1995) with q=0.20. Effect size r was calculated for statistically significant differences. Cohen (1988) considered effect sizes of less than 0.20 small, between 0.20 and 0.50 moderate, and effects sizes greater than 0.50 large. Summary data are reported as mean ± standard deviation (M ± SD) or median—MD (interquartile range—IQR) as appropriately needed.

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III. RESULTS

A. ENTIRE DATASET (N = 19)

As shown in Table 1 participants were predominantly male (18, 94%) with an average age of 37.9 ± 14.9 years (range: 21 – 59 years). Of the 19 sailors who participated in the study, 12 stood watch on the fixed 4hrs-on/8hrs-off schedule, five did not stand watches, and two sailors stood in for other sailors when needed.

Table 1. Demographic information.

Age (years), M ± SD	37.9 ± 14.9
Gender, Males, # (%)	18 (94.7%)
Rank, # (%)	
Officers	5 (26.3%)
O1-O3	4 (21.1%)
O4-O6	1 (5.26%))
Enlisted	14 (73.7%)
E1-E3	8 (42.1%)
E4-E6	3 (15.8%)
E7-E9	3 (15.8%)
Active duty (years), M ± SD	17.1 ± 17.3
ME Preference [1]	
ME Score, M ± SD	55.4 ± 7.40
ME type, # (%)	
Definitely morning	0
Moderately morning	7 (36.8%)
Intermediate	11 (57.9%)
Moderately evening	1 (5.79%)
Definitely evening	0

[1] ME denotes morningness-eveningness

Overall, 18 (94.7%) sailors indicated drinking caffeinated beverages, i.e., coffee (17, 89.5%) and caffeine pills (2, 10.5%). Nicotine products were used by 6 (31.6%) participants, i.e., chewing tobacco/snuff.

All participants reported having an exercise routine working out on average 4 (2) times per week, with a median duration of 1 (0.25) hour. The workout routines reported by the sailors were mainly weightlifting and aerobic exercise. None of the participants reported taking prescribed or over-the-counter medications.

1. Sleep-related attributes

Actigraphic data from 16 sailors were used in the sleep analysis. Crewmembers slept on average 6.60 ± 0.798 hours on a daily basis split in 1.67 ± 0.392 sleep episodes. Overall, 12 (75.0%) sailors slept on average less than 7 hours per day, whereas 4 (25.0%) slept on average less than 6 hours per day.

Sailors reported being satisfied with the sleep they received during the underway with approximately 78% noting that the sleep they received was about right. The same trend was identified in the responses regarding the adequacy of sleep of other sailors (see Figure 2).

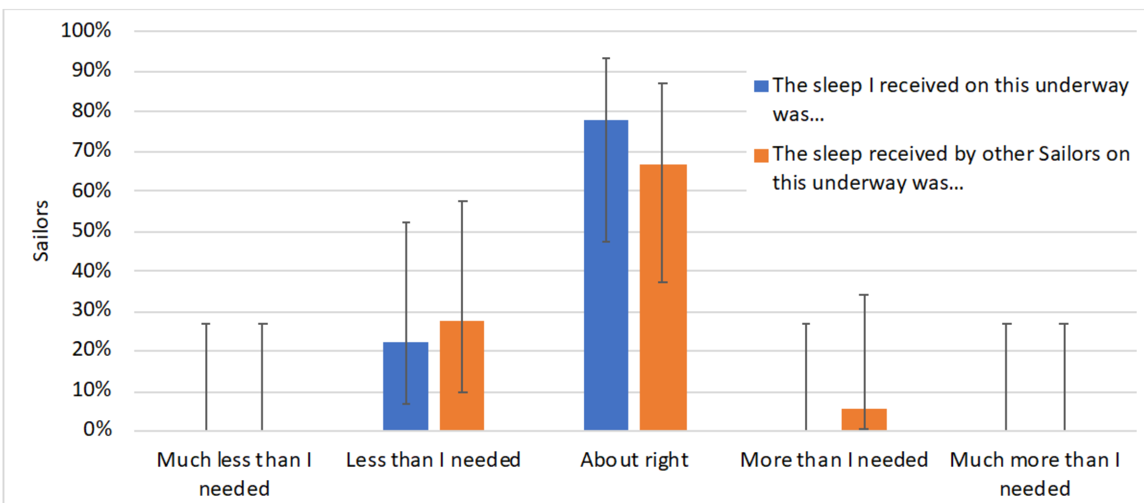


Figure 2. Responses to the statement "The sleep I received on this underway was . . . ." and to the statement "The sleep received by other sailors on this underway was . . . ."

The average ESS score at the beginning of the study was 6.11 ± 2.42 with none of the sailors reporting elevated daytime sleepiness (ESS score > 10), whereas the average ESS score at the end of the study was 4.72 ± 3.20 with 1 (5.56%) sailor reporting elevated daytime sleepiness (ESS score > 10). The change in ESS was not statistically significant (Wilcoxon Signed Rank test, S = 38, p = 0.101).

As assessed by the PSQI global score, sleep quality did not change during the data collection period (beginning of the study: PSQI score = 5.05 ± 2.78; end of the study: PSQI score = 5.78 ± 2.82; Wilcoxon Signed Rank test, S=16, p=0.529). The percentage of sailors classified as poor sleepers was 42.1% in the beginning and 55.6% at the end of the study (McNemar's test, $X^2(2) = 0.667$, p = 0.414).

The average ISI score at the beginning of the study was 6.26 ± 4.36 with one of the sailors (5.26%) reporting elevated severity of insomnia symptoms (ISI score > 15). At the end of the study, the average ISI score was 6.11 ± 3.43 with none of the sailors reporting elevated insomnia symptoms. ISI scores did not change during the study (Wilcoxon Signed Rank test, S=8.50, p=0.716).

In terms of mood at the end of the study, the average POMS TMD score was 14.8 ± 21.7 (POMS T: 7.31 ± 3.03; POMS D: 4.50 [10.8]; POMS A: 4.50 [9.50]; POMS V: 16.4 ± 4.70; POMS F: 5.44 ± 3.41; POMS C: 6.31 ± 3.28). POMS scores did not change at a statistically significant level during the study (Wilcoxon Signed Rank test, all p > 0.15). Lastly, sailor POMS scores at the end of the study did not differ from adult norms (Likelihood Ratio, all p > 0.30). These results are shown in Figure 4.

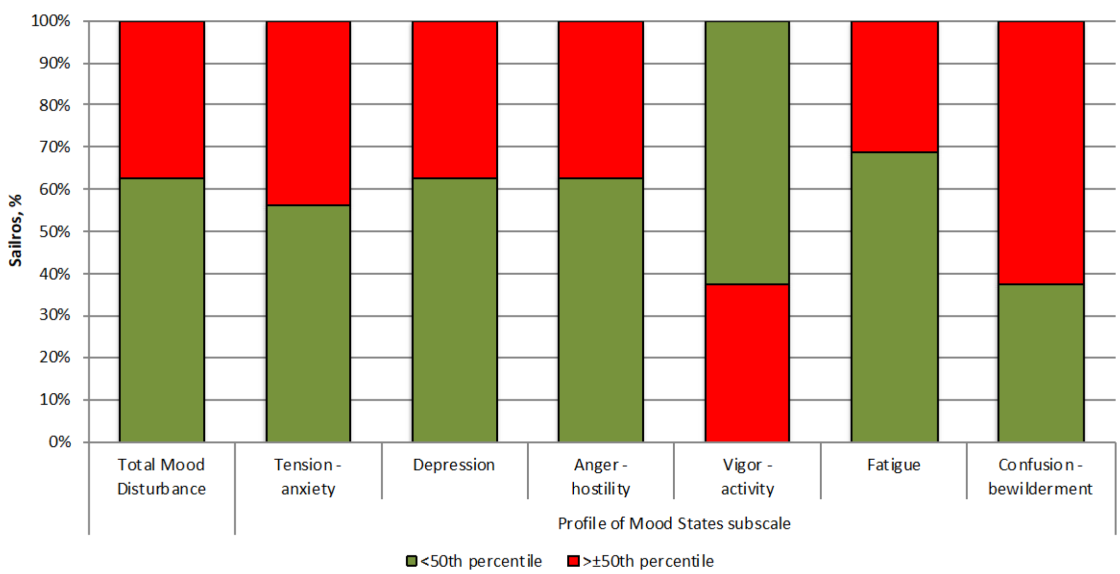


Figure 3. Percentage of sailors with POMS scores worse than the 50^{th} percentile of adult norms at the end of the study

2. Habitability in the berthing compartments

Focusing on habitability in the berthing compartments, temperature (17, 89.5%) and noise (16, 82.4%) were the most frequent factors affecting sailor sleep, followed by ship motion (14, 73.7%), and bedding conditions (12, 63.2%). The most frequently reported source of noise was by other people in the space (14, 73.7%) followed by noise from inside the berthing compartment (12, 68.4%). In terms of bedding conditions, mattress and pillow were reported by 9 (43.4%) sailors followed by bed size (4, 21.1%). These results are shown in Figures 4 to 6. "1 Main Circuit" (1MC) is the term for the shipboard public address system.

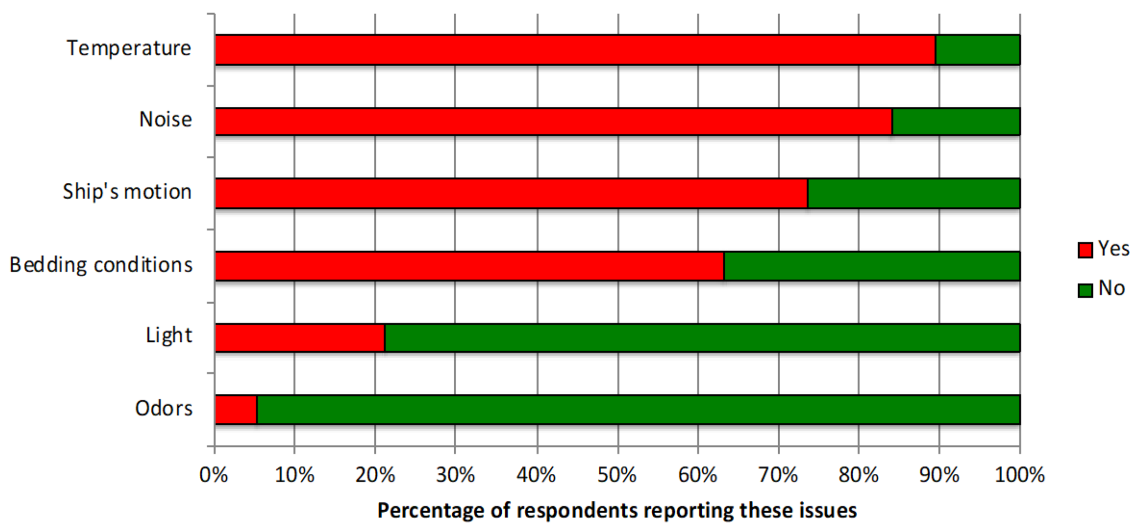


Figure 4. Factors affecting sleep.

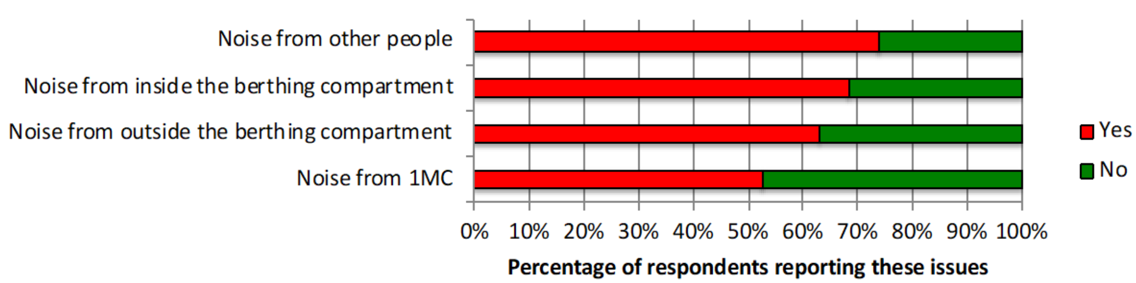


Figure 5. Sources of noise affecting sleep.

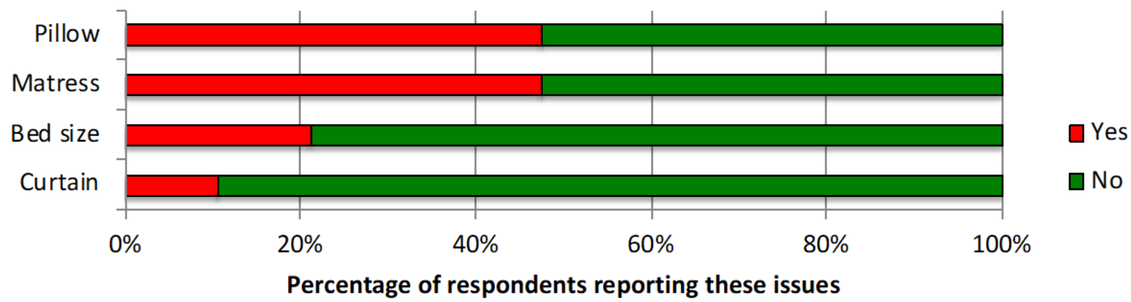


Figure 6. Sources of complaints about berthing/bedding conditions.

B. 4HRS-ON/8HRS-OFF ASSESSMENT

Next, we focused on the main objective of this project: to assess the 4/8 in terms of sleep-related attributes and psychomotor vigilance performance. From the 19 crewmembers of HSwMS ORION, 12 worked on the 4hrs-on/8hrs-off (4/8) watch schedule. These 4/8 sailors stood watch between 00:01-04:00/12:00-16:00 (n = 5), 04:00-08:00/16:00-20:00 (n = 5), and 08:00-12:00/20:00-23:59 (n = 2). We also compared Orion data with the data from 22 USN sailors working on the fixed 4/8. Five of these 4/8 sailors stood watch in the 00:01-04:00/12:00-16:00 section, seven in the 04:00-08:00/16:00-20:00, and 10 sailors in the 08:00-12:00/20:00-23:59 section.

Focusing on the HSwMS ORION sailors, the median ESS score at the end of the study was 5.0 (4.0) with 10 (90.9%) sailors reporting normal daytime sleepiness. The median ISI score was 7.0 (3.0) with none of the sailors reporting elevated severity of insomnia symptoms. The median PSQI score was 6.0 ± 5.0 with 7 (63.6%) sailors classified as poor sleepers (PSQI score > 5). In terms of POMS scores, the median POMS TMD score was 10.0 (34.0) (POMS T: 7.0 [8.0]; POMS D: 3.0 [11.0]; POMS A: 4.0 [6.0]; POMS V: 18.0 [8.0]; POMS F: 6.0 [6.0]; POMS C: 6.0 [5.0]). Compared to the USN sample, sailors on the HSwMS ORION were more alert (p = 0.003), reported better sleep quality (p = 0.044), less severe insomnia symptoms (p = 0.002), and better mood (POMS TMD score: p = 0.053). The same pattern was evident in psychomotor vigilance performance, i.e., sailors on the HSwMS ORION were faster and made fewer errors as assessed by lapses or lapses combined with false starts.

In terms of sleep attributes, the median daily sleep duration on HSwMS ORION was 6.11 ± 0.67 hours with 8 (88.9%) sailors sleeping on average less than 7 hours per day (4 [44.4%] slept on average less than 6 hours per day). Sailors split their sleep into 2.0 ± 0.19 episodes per day (MD ± IQR) with all of them napping. The two groups of sailors did not differ in terms of daily sleep duration or number of sleep episodes per day (both $p > 0.20$).

Lastly, ORION sailors standing watch on the 4/8 worked (on duty time) 12 hours per day (median value), approximately 0.6 hours more than their USN peers ($p = 0.097$). Of note, sailors on the ORION had on average 2.3 hours of personal time on a daily basis, that is, 1.7 hours less than the sailors in the USN sample ($p = 0.002$).

Detailed results regarding sailor well-being, mood, sleep attributes, and psychomotor vigilance performance are shown in Table 2 and Figures 7 to 9. Due to the small number of participants, we did not compare variables of interest among the 4/8 sections. Figures 7 to 9, however, show information regarding the 4/8 sections.

Table 2. Differences between sailor groups.

	Orion	USN ships	p-value [A]	Effect size r
ESS score	5.00 (4.00)	10.0 (5.25)	0.003 [B]	0.520
PSQI	6.00 (5.00)	8.00 (4.50)	0.044 [B]	0.357
ISI	7.00 (3.00)	14.5 (7.75)	0.002 [B]	0.687
POMS TMD	10.0 (34.0)	30.0 (57.8)	0.053 [B]	0.423
Tension-anxiety	7.00 (8.00)	6.00 (9.75)	0.671	-
Anger-Hostility	4.00 (6.00)	10.5 (16.0)	0.191	-
Depression	3.00 (11.0)	9.50 (10.8)	0.052 [B]	0.426
Vigor	18.0 (8.00)	8.00 (6.50)	0.020 [B]	0.509
Fatigue	6.00 (6.00)	9.00 (12.5)	0.077 [B]	0.385
Confusion-Bewilderment	6.00 (5.00)	7.00 (9.25)	0.395	-
Sleep attributes (actigraphy)				
Daily sleep duration	6.11 (0.67)	6.55 (0.70)	0.214	-
Sleep episodes/day	2.00 (0.19)	1.87 (0.71)	0.254	-
PVT metrics				
Reaction time, ms	292 (57.9)	327 (373)	0.061 [B]	0.391
Response speed, sec^{-1}	4.09 (0.56)	3.50 (1.11)	0.046 [B]	0.417
Fastest 10% reaction times, ms	190 (30.8)	221 (63.5)	0.061 [B]	0.391
Slowest 10% response speeds, sec^{-1}	2.52 (0.61)	2.23 (1.40)	0.166	-
False starts (FS), %	1.28 (14.8)	1.50 (1.16)	0.926	-
355 ms lapses, %	11.3 (6.33)	16.4 (30.3)	0.021 [B]	0.481
500 ms lapses, %	4.32 (3.73)	7.39 (20.2)	0.091 [B]	0.353
355 ms lapses combined with FS, %	13.3 (6.45)	18.3 (31.1)	0.029 [B]	0.456
500 ms lapses combined with FS, %	5.40 (4.32)	8.55 (21.4)	0.103 [B]	0.340
Workload, hrs/day (logs)				
Training	0.33 (0.66)	0.50 (0.99)	0.328	-
Work/Maintenance	2.94 (2.25)	2.00 (2.12)	0.231	-
Service diversion	0.58 (1.63)	0.50 (0.78)	0.558	-
Productive Work	10.9 (2.02)	8.81 (3.07)	0.203	-
On Duty	12.0 (1.22)	11.4 (2.57)	0.097 [B]	0.371
Personal time	2.30 (0.84)	4.00 (1.90)	0.002 [B]	0.681
Messing	1.61 (0.79)	1.17 (0.92)	0.164	-

Results presented as MD (IQR)

[A] Unadjusted p-values based on the Wilcoxon Rank Sum test

[B] Statistically significant based on post hoc analysis with the BH-FDR controlling procedure

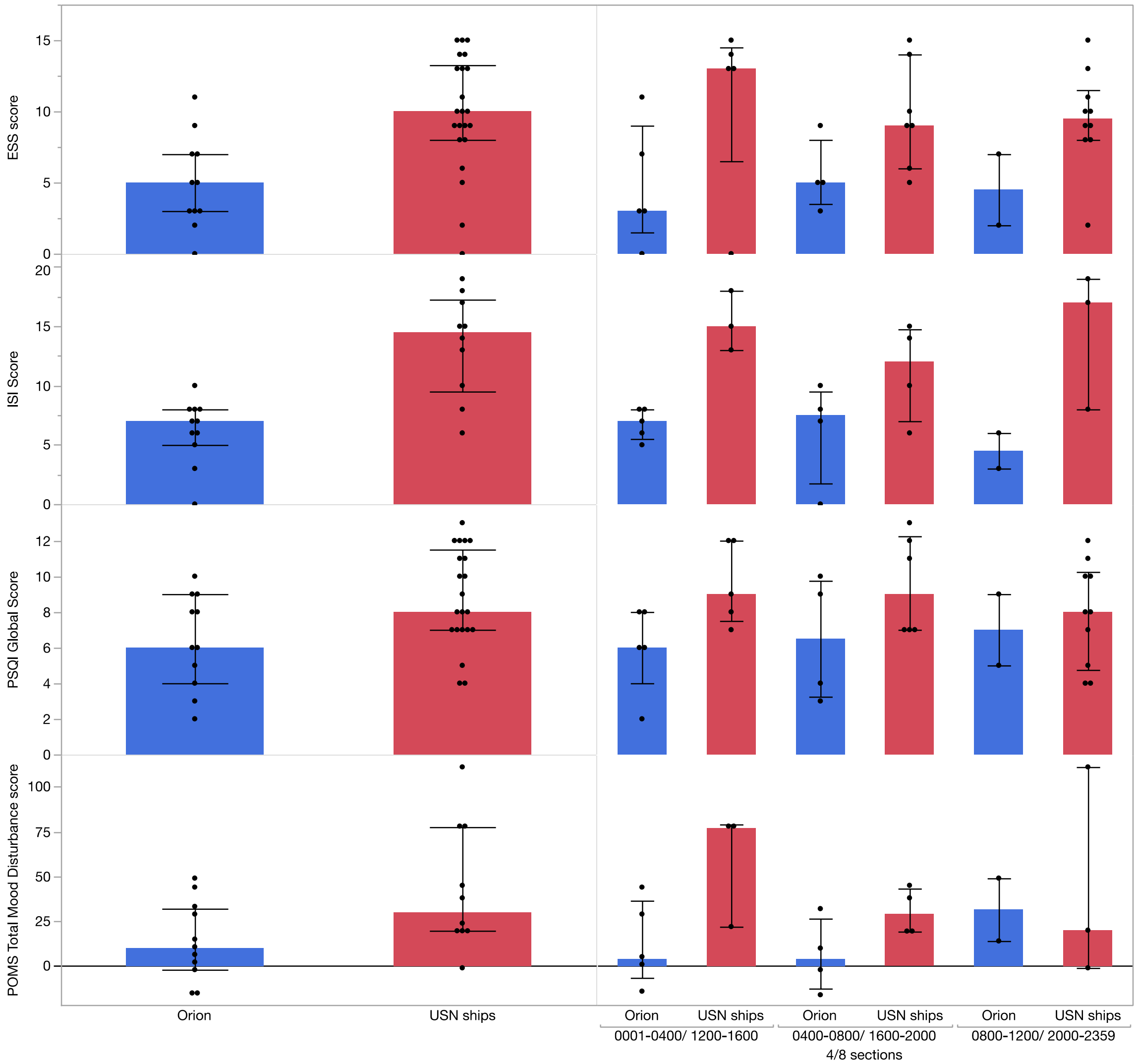


Figure 7. ESS, ISI, PSQI, and POMS TMD median scores. Vertical lines denote the interquartile range (IQR).

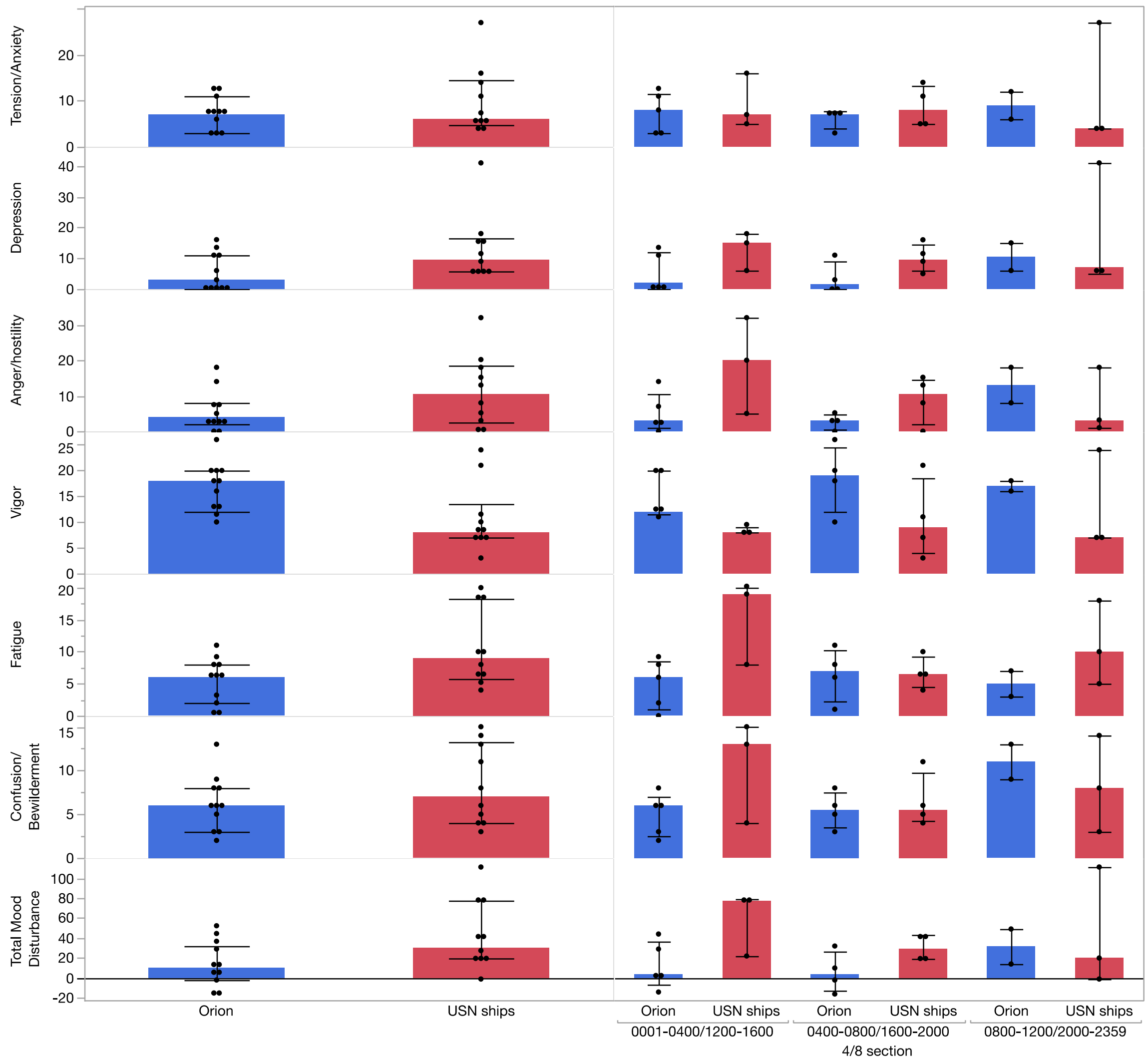


Figure 8. POMS median scores. Vertical lines denote the interquartile range (IQR).

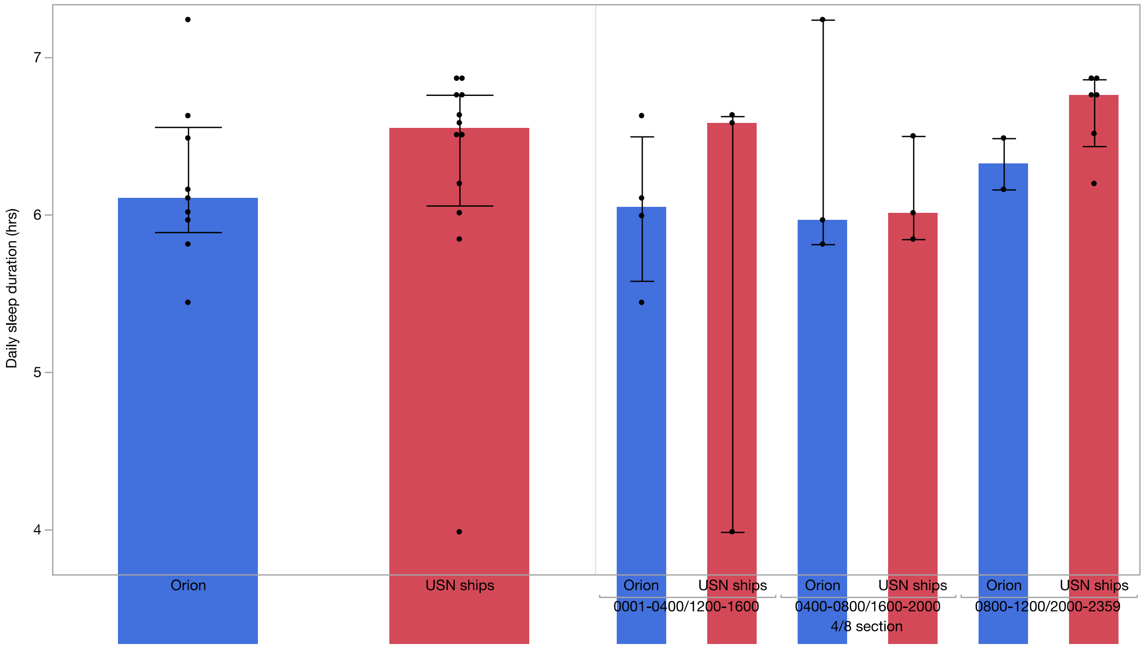


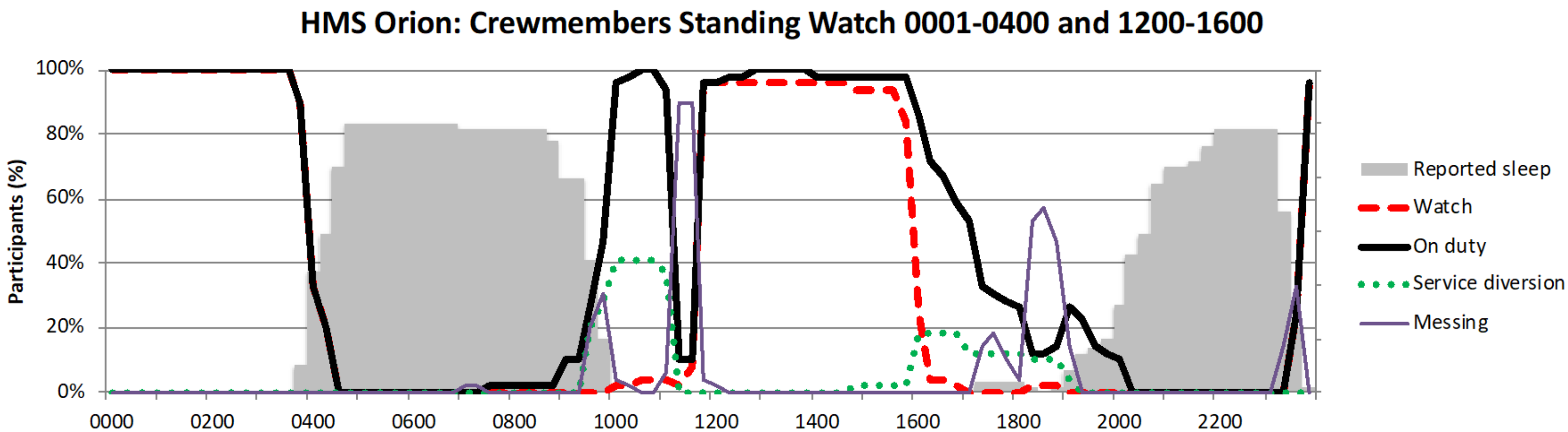
Figure 9. Median daily sleep duration. Vertical lines denote the interquartile range (IQR).

Next, we assessed the distribution of sailors' activities based on the data reported in the activity logs. Our observations are summarized as follows:

- Split sleep is clearly evident in the two sections of HSwMS ORION with night shifts.
    - In the 0001-0400/1200-1600 section sailors sleep before and after the 0001-0400 shift (Figure 10). The night sleep episode extends until approximately 0930, suggesting a late wake-up time for sailors working on the night shift. In contrast, not all sailors in the USN sample wake up late. Some (~20%) wake up around 0600 to start working, with the corresponding percentage increasing over time (Figure 10).
    - In the 0400-0800/1600-2000 section, sailors sleep before the 0400-0800 shift and take a short nap after (~70% to 80%) waking up at around 0930 (Figure 11). Also, some sailors (~35%) take a short nap after lunch. In contrast, sailors in the USN sample stand the 0400-0800 shift and then

continue working on their other duties (Figure 11). A small number of sailors (~35%) take a nap between 1430 and 1530.

- HSwMS ORION sailors working in the 0800-1200/2000-2359 section slept in one long night episode with approximately 15% of the sailors taking a short 1-hour nap after dinner and before the 2000-2359 shift (Figure 12). Napping in the USN sample was more evident, however, with approximately 20% of the sailors napping between 1330 and 1530.
- Messing on HSwMS ORION took place at ~0700-0830, ~1100-1300, and ~1700-1900. Sailors standing watch on the 1600-2000 shift were substituted in their duties by other sailors to have dinner. On the 3 USN vessels we collected 4/8 from, breakfast and dinner time was approximately one hour earlier than HSwMS ORION.
- The distribution of maintenance and other work differs between HSwMS ORION and the USN sample. Sailors on HSwMS ORION perform their maintenance/other work tasks between 0930 and 1700, whereas sailors in the USN sample perform their corresponding duties mainly (~65%) in the morning between 0700 and 1100.



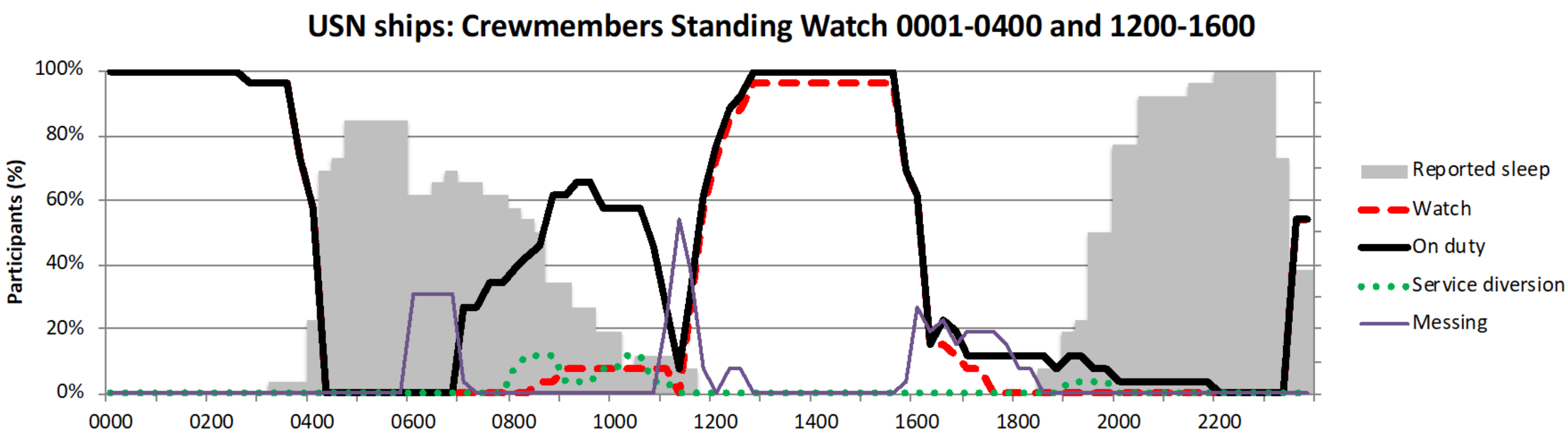


Figure 10. Daily activities of sailors standing watch on the 4/8 0001-0400/1200-1600 shift.

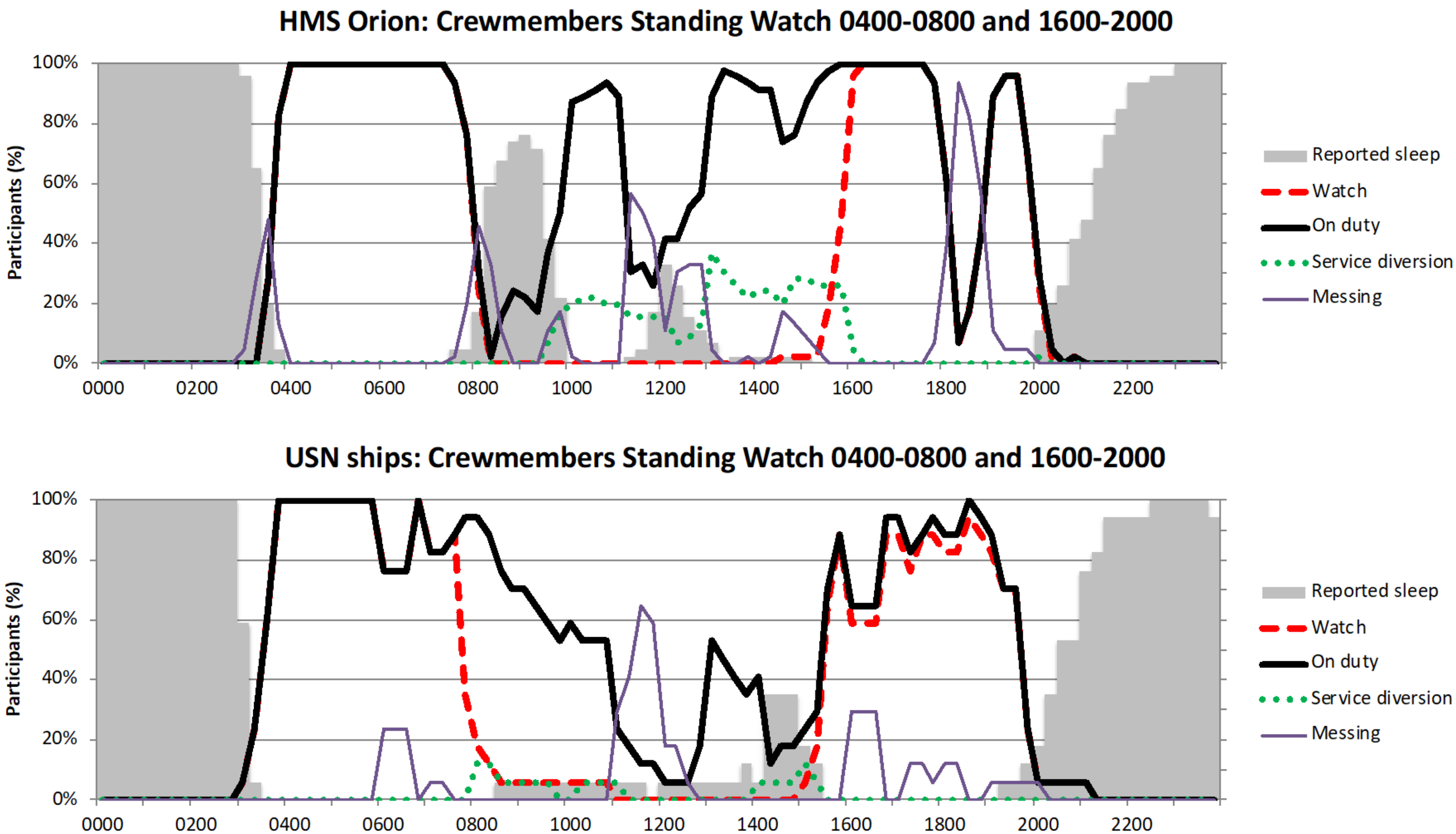


Figure 11. Daily activities of sailors standing watch on the 4/8 0400-0800/1600-2000 shift.

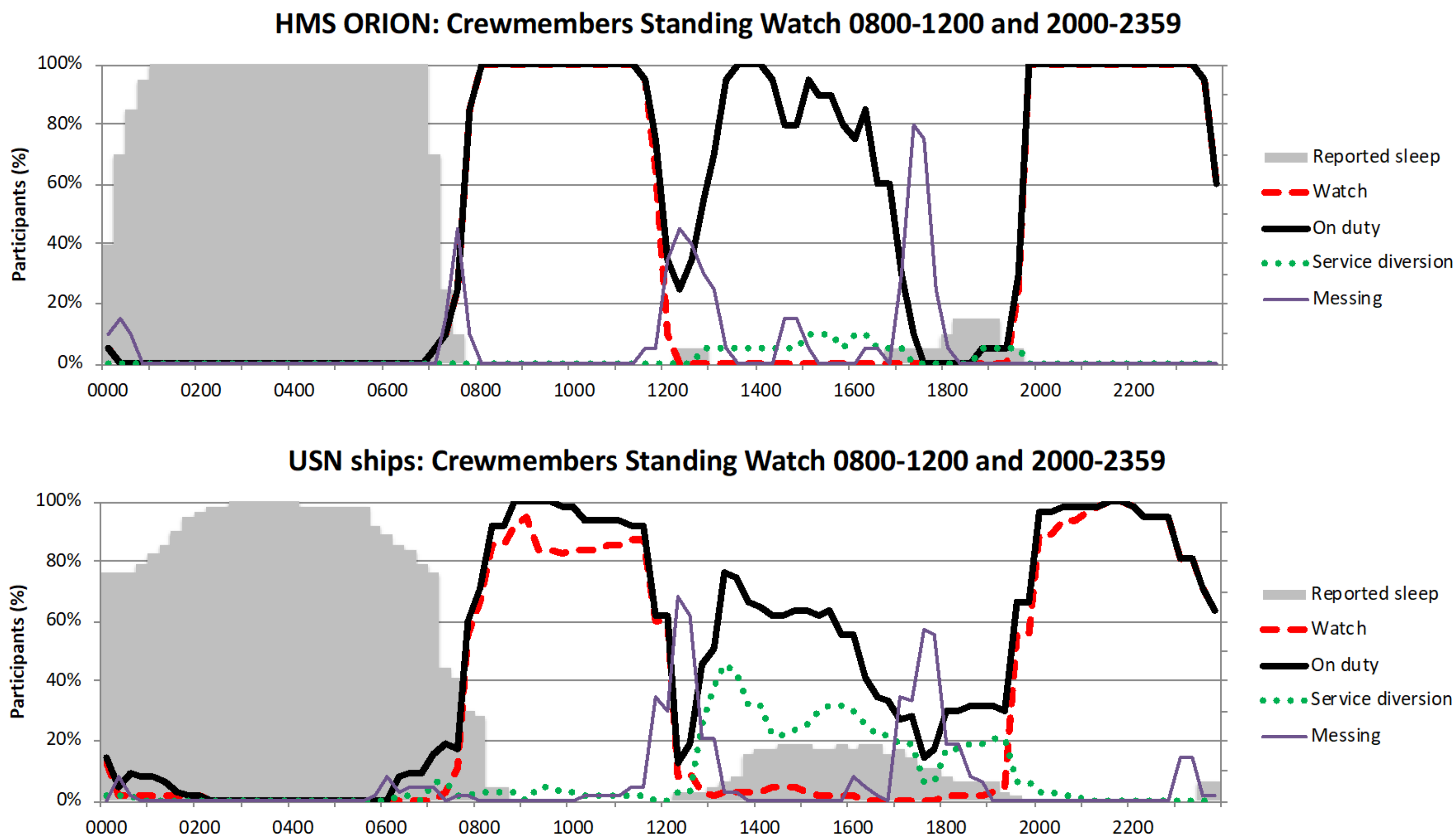
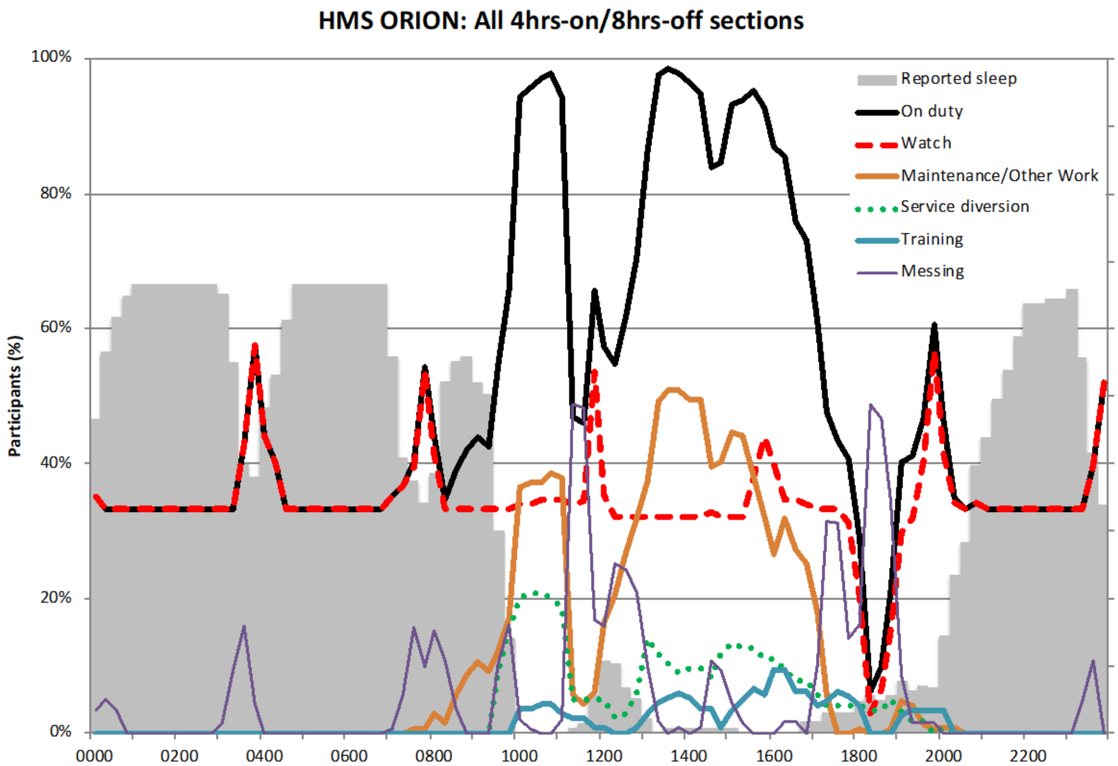


Figure 12. Daily activities of sailors standing watch on the 4/8 0800-1200/2000-2359 shift.



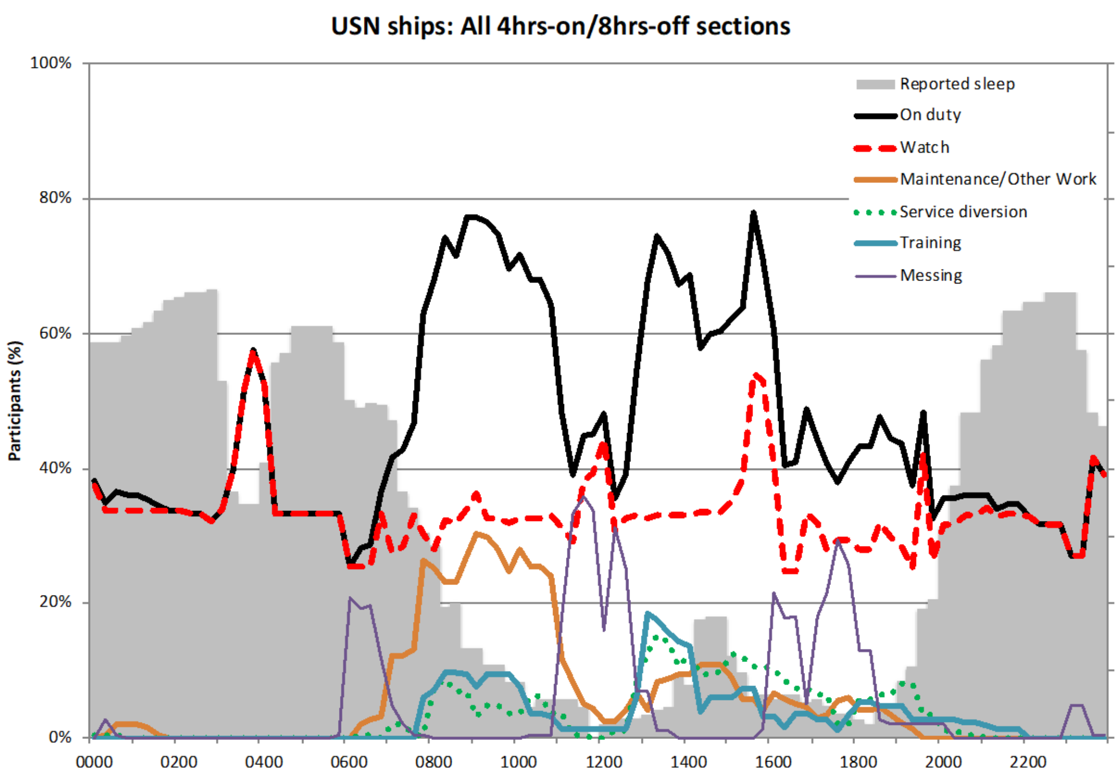


Figure 13. Daily activities of sailors standing watch on the 4/8 schedule.

1. SAFTE/FAST predicted effectiveness

Lastly, we used the SAFTE/FAST model to predict sailor effectiveness in the 4/8 sections. Based on the actigraphic data we collected on HSwMS ORION, we used the following model parameters:

- Sleep quality: Good
- 0001-0400/1200-1600 section
  - Daily sleep duration: 6 hours split into two episodes, 0445-0900 and 2115-2300
- 0400-0800/1600-2000 section
  - Daily sleep duration: 6 hours split into two episodes, 2200-0300 and 0830-0930
- 0800-1200/2000-2359 section
  - Daily sleep duration: 6.5 hours in one episode from 0030 to 0700

Figures 14 to 16 show the FAST output of predicted effectiveness for the three watch sections of the 4/8. Work and sleep intervals are color-coded: black intervals indicate watch periods and blue intervals indicate sleep periods. The black line represents the predicted effectiveness of a person with average sensitivity to sleep loss. The dotted line represents the predicted effectiveness of a person with high sensitivity to sleep loss (10^{th} percentile). The FAST outputs shown refer to individuals who are initially adjusted to normal daylight conditions before starting work on the schedule of their watch section. Each diagram shows predicted effectiveness during a 3-week period.

First, we assessed the effectiveness of sailors working on the 0001-0400/1200-1600 section. SAFTE/FAST output suggests that predicted effectiveness in this section shows a decreasing trend stabilizing after the second week (Figure 14). During the third week, the average predicted effectiveness during shifts was approximately 76%, ~77% in the night and ~75% in the afternoon shift. During the entire 3-week period, predicted effectiveness dropped below 77.5% in approximately 49% of the time during night shifts and ~100% of the time during the afternoon shifts. Predicted effectiveness of 77.5% is equivalent to the predicted effectiveness of an individual with a Blood Alcohol Concentration (BAC) of 0.05%.

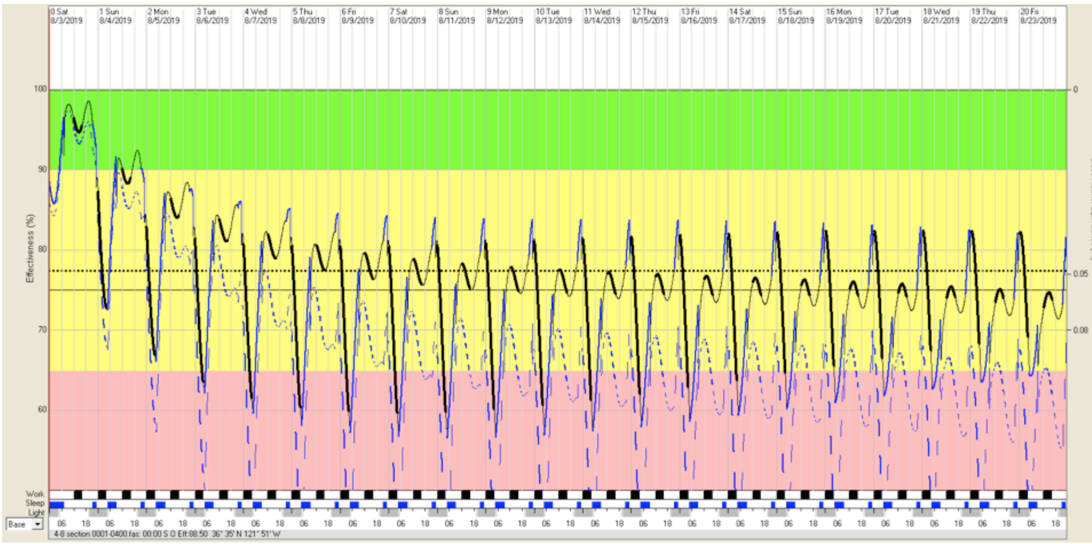


Figure 14. FAST predicted effectiveness on the 0001-0400/1200-1600 section.

Next, we assessed the predicted effectiveness of sailors working on the 0400-0800/1600-2000 section. SAFTE/FAST output suggests that predicted effectiveness in this section shows a decreasing trend, stabilizing after the first five days. After effectiveness is stabilized, the average predicted effectiveness during shifts was approximately 76%, ~72% in the early morning shift and ~79% in the afternoon shift. After the fifth day, predicted effectiveness dropped below 77.5% during the entire time of the early morning shifts but never during the afternoon shifts. These results are shown in Figure 15.

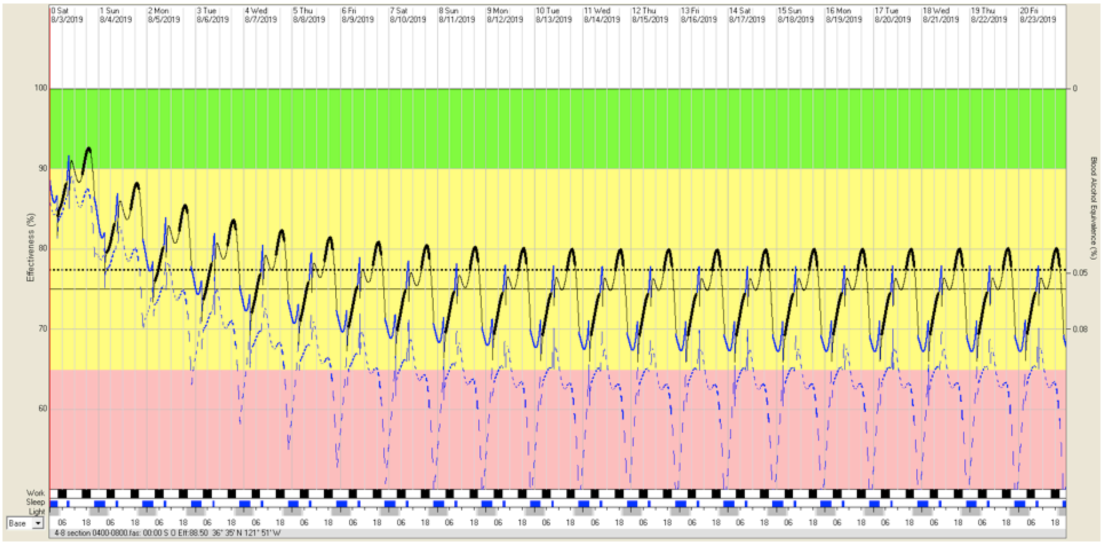


Figure 15. FAST predicted effectiveness on 0400-0800/1600-2000 section.

Lastly, we assessed effectiveness in the 0800-1200/2000-2359 section. Predicted effectiveness stabilized after the first five days (Figure 16). Thereafter, predicted effectiveness during shifts was ~86% (~88% in the morning and ~85% in the late evening shift) and it never dropped below 77.5%.

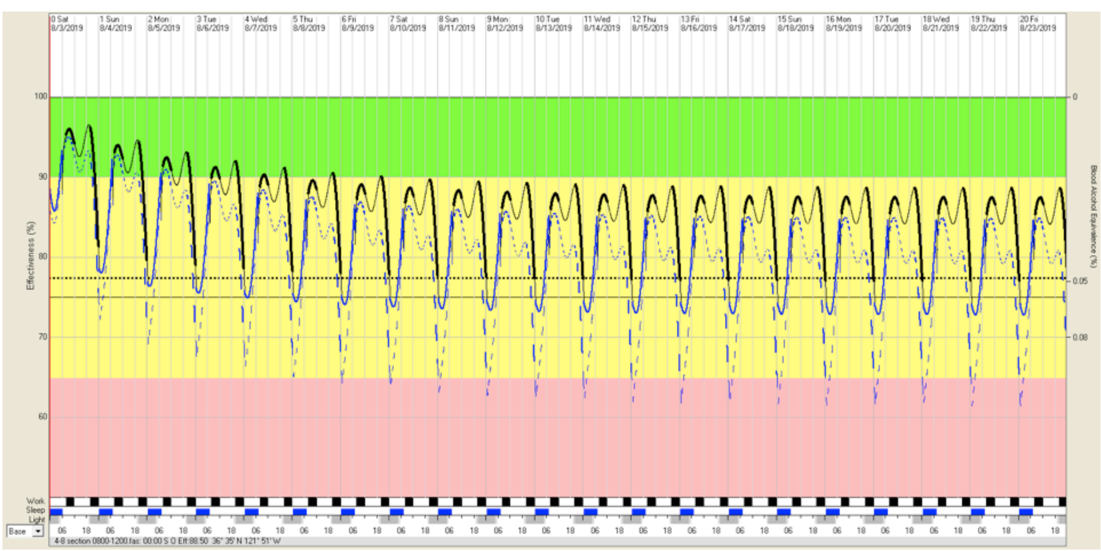


Figure 16. FAST predicted effectiveness in the 0800-1200/2000-2359 section.

IV. DISCUSSION

This prospective, longitudinal, quasi-experimental study assessed the utility of the 3-section, fixed, 4hrs-on/8hrs-off watchstanding schedule on a ship of the Swedish Royal Navy (HSwMS ORION). Sailors (n = 19) were assessed in terms of sleep attributes, fatigue, insomnia symptoms, mood, psychomotor vigilance performance, and workload. Data from the HSwMS ORION were compared with data from sailors from three surface vessels of the USN (n = 22).

Compared to their USN peers, sailors on the HSwMS ORION were more alert, reported better sleep quality, less severe insomnia symptoms, and better mood in terms of total mood disturbance, depression, fatigue, and vigor. The same pattern was evident in psychomotor vigilance performance, i.e., sailors on the HSwMS ORION were faster and made fewer errors as assessed by lapses or lapses combined with false starts. Sailors in the two samples did not differ in terms of daily sleep duration and the number of sleep episodes per day. Also, daily work duration did not differ substantively between the two groups.

We postulate, though, that the differences in sleep following the night shift may provide a possible explanation for the differences between the two samples. Specifically, Sailors on the HSwMS ORION sleep after their night shifts with their sleep extending until approximately 0930. Consequently, maintenance and other work tasks are performed between 0930 and 1700. In contrast, most sailors in the USN sample do not sleep after their night shift but continue working on other work duties. Therefore, it is not a surprise approximately 65% of the maintenance/other work tasks are performed in the morning between 0700 and 1100.

Our finding that all sailors on the 4/8 were nappers agreed with earlier research that one of the major issues with the 4/8 is that sleep is split into multiple episodes during the day (Colquhoun, 1985; Kleitman, 1949; Miller, 2006). The latter is an inherent characteristic of the 4/8 because of the 8 hours off between consecutive shifts. Some researchers have criticized the 4/8, even the fixed version of the watchbill, because of this attribute. The argument against the 4/8 was that the eight-hour period between shifts does not allow for a long sleep episode with a duration of approximately 8 hours, i.e., the physiologically acceptable duration of daily sleep for full cognitive functioning (Anch, Browman, Mitler, & Walsh, 1988). Even though the above mentioned limitation is structural in the 4/8, our field studies have shown that split sleep at sea is the norm. Specifically, in a sample of approximately 1300 sailors from 10 surface vessels of the USN, 80% of the watchstanders (77% in fixed watchbills; 84% in rotating watchbills) and 57% of the non-watchstanders split their sleep into more than 1.2 episodes per day (average value during the data collection period denoting one nap in at least 20% of the days underway). Moreover, the median daily sleep duration is ~6.5 hours for sailors in either fixed or rotating watchbills, and 6.9 hours for non-watchstanders. The reason behind these findings is that work at sea includes standing watches and various other duties. Hence, the opportunity to sleep (in terms of the duration of this window) is affected predominantly by factors other than the time off between consecutive shifts in the watchbill sailors are working on.

In conclusion, our findings suggest that sailor well-being when standing watch on the fixed 4/8 can be improved when sailors are allowed flexible wakeup times in the morning after a night shift. Given the small number of participants, however, further research is needed to understand better the advantages and disadvantages of the 4/8 in the naval operational environment, and how to improve the utility of the watchbill.

A. STUDY LIMITATIONS

This study has several limitations. Participants on the HSwMS ORION were, on average, older than the sailors in the USN sample, but also older than the average sailor in the USN. Therefore, there may a selection bias in favor of the sailors still serving on the Swedish ship.

Sailors on the HSwMS ORION were underway for a short mission compared to the long 6-month deployment the USN sailors were facing. Also, the mission of the Swedish vessel is specialized (collecting intelligence signals) and not comparable with the missions of destroyers and cruisers on which the sailors in the USN sample served. Therefore, sailor duties may differ substantively between the two groups.

Lastly, due to the small number of participating sailors, we could not assess differences among watch sections. Future efforts should include larger numbers of participants in all sections. Even though our findings are based on small samples, the pattern of results should be further investigated with larger, and, therefore, more representative samples.

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V. RECOMMENDATIONS

Based on the findings from this study and the expressed need for guidance regarding the efficient application of circadian watchbills we recommend the following:

- Assess further the utility and problems of the fixed 3-section 4/8 and its variants. The utility of the 4/8 should be assessed on various vessels of different types to investigate the effect of ship type and the acceptance of the watchbill.
- For example, one point of interest is the depression of performance in the night shifts of the fixed 4/8; especially in the beginning of the 0400-0800 shift in conjunction with the deleterious effect of recent awakenings from sleep due to sleep inertia (Burke, Scheer, Ronda, Czeisler, & Wright, 2015; Condon, Colquhoun, Plett, De Vol, & Fletcher, 1988; Sheer, Shea, Hilton, & Shea, 2008; Trotti, 2017).
- Continue collecting underway data from multiple types of ships, during different phases (e.g., basic phase, intermediate phase, advanced phase). This will allow for more thorough comparisons of the various watchstanding schedules and will increase the operation validity of our recommendations. The empirical data will assist in understanding the mid- to long-term effects of working at sea in various watchstanding schedules. Future efforts should assess further whether the importance of circadian watchbills increases under limited manning.
- Collaborate with allied Navies in collecting underway data and exchange of information regarding the utility of various watchbills and shiftwork practices.

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