Sunlight Exposure, Work Hours, Caffeine Consumption, and Sleep Duration in the Naval Environment

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BACKGROUND: Sailors in the U.S. Navy are habitual shiftworkers, often experiencing circadian misalignment due to their irregular work/rest schedules. This study assessed the effect of sunlight exposure, work hours, and caffeinated beverage consumption on the daily sleep duration of crewmembers of a U.S. Navy ship during a 2-wk underway period.

METHODS: Working in an artificially lit area with no access to sunlight during work hours, U.S. Navy crew members ($N = 91$) used daily logs to report their daily activity, caffeinated beverage consumption, and exposure to sunlight while off-duty; sleep was assessed by wrist-worn actigraphy.

RESULTS: Hours of sunlight exposure, work duration, and the amount of coffee/tea/soft drinks were statistically significant predictors of sleep duration. On average, crewmembers who reported more than one half-hour of sunlight each day slept on average ~40 min (10%) less than their peers working the same shifts who received less than one half-hour of sunlight (on average 6.05 ± 0.90 h vs. 6.71 ± 0.91 h, respectively).

DISCUSSION: Exposure to sunlight, work hours, and consumption of caffeinated beverages are important factors when planning watchstanding schedules at sea. Even though further research is needed, our results suggest that even brief exposure to sunlight may contribute to circadian misalignment that negatively affects sleep in the operational environment. Educating crewmembers about sleep hygiene, especially the important roles played by sunlight and caffeine, could potentially improve the sleep and fatigue levels of this population of maritime shiftworkers.

KEYWORDS: sleep, circadian misalignment, sunlight exposure, caffeine consumption, long work hours.

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Shipboard life while underway at sea has a continuous rhythm of work, characterized by long workdays, commencing when the ship pulls away from the pier and ending when the ship pulls back into port. Depending on their duties, some crewmembers may begin this pattern of extended workdays before the ship gets underway and continue even after the ship returns to port. At sea, the typical sailor's workday is divided into two distinct activities: standing watch and performing various off-watch duties such as maintenance, drills, and training. These watch and off-watch work duties often result in 12- to 15-h workdays with little or no time for recovery.[18] Given these work patterns, it is no surprise that maritime operations are notorious for inducing fatigue and sleep deprivation.[11] In an attempt to maintain alertness, crewmembers frequently consume caffeinated beverages and energy drinks.[17] When consumed in large quantities at inopportune times, though, caffeine degrades sleep.[17,21]

Patterns of shiftwork in U.S. Navy sailors have been documented in a series of studies conducted at the Naval Postgraduate School over the last two decades.[11,20] One significant problem with the shiftwork observed in this naval population is that their work schedules, unlike work schedules common in the civilian community, frequently rotate such that individuals are not on a 24-h day. That is, work commences and ends at different times on ensuing days and opportunities for sleep also occur at irregular times of the day and night. The conflict between external patterns (e.g., light conditions, mealtimes, social, and work commitments) and internal circadian rhythms can lead to circadian misalignment, with significant physiological and psychological consequences.[22]

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The human biological clock controls many physiological and psychological processes based on a circadian (i.e., 24-h) pattern.[2] In natural conditions, human sleep periods are closely aligned with this 24-h rhythm.[5] However, this internal oscillator can be reset or "entrained" by retinal exposure to photic stimuli such as sunlight or artificial light.[16] However, exposure to light in the late biological day and early biological night leads to a phase delay (i.e., later bedtime and awakening) while exposure in the late biological night and early biological morning leads to a phase advance (i.e., earlier bedtime and awakening).[14] From a human performance perspective, circadian misalignment can have severe consequences, particularly in continuous operations. The optimal arrangement of shifts is one in which each worker's shift coincides with their biological "daytime." If circadian rhythms are not aligned with the workday schedule, crewmembers may have to stand watch during their biological "night,"[1] resulting in degraded alertness and setting them up for higher accident rates and reduced performance. Chronic circadian misalignment due to irregular work/rest schedules may also lead to shift work disorders.[13]

Given the ever-increasing prevalence of shiftwork in modern society, there is a growing need to understand how various shiftwork schedules affect the workers and the quality of work they perform. However, few operational studies have focused on the effect of sunlight on the sleep of shift workers in naturalistic conditions. In their review of light treatment for sleep disorders, Eastman et al.[7] identified a series of studies conducted by the National Aeronautics and Space Administration (NASA). In these studies, exposure to bright light was used to shift the circadian phase of astronauts during the week-long prelaunch quarantine period and during space missions. Light was also used to shift the circadian phase of members of the payload support crew working in NASA control rooms. To our knowledge, the only study assessing the effect of sunlight during maritime operations was conducted aboard the USS *Stennis* during Operation Enduring Freedom.[12] To accommodate flight sorties during night combat operations, the work schedule of the entire ship (~5000 crewmembers) was shifted from days to nights. This schedule required the crew to awaken at 18:00 for breakfast (reveille) and other daily routines, then work throughout the night and early morning hours until approximately 10:00, when they were allowed to go to bed. The demanding pace of combat operations in support of Operation Enduring Freedom resulted in extremely long workdays. The study used wrist-worn actigraphy, sleep diaries, and standardized sleep and mood questionnaires to assess the crew. Results showed that crewmembers working "topside" and exposed to morning sunlight before retiring to bed slept approximately 5.32 h per 24-h period (median value) as compared to crewmembers working "below decks" who received 7.47 h per 24-h period. In addition, crewmembers working topside also experienced more fragmented sleep compared to their counterparts working below decks. Exposure to sunlight before bedtime was the major difference between these two groups of sailors.

The current study assessed the effect of sunlight, working long hours, and caffeinated beverage consumption on the average daily sleep duration of a sample of crewmembers aboard the USS *Nimitz* in their naturalistic work setting, i.e., working below decks without access to sunlight during their work shifts. This study is part of a larger ergonomic intervention to optimize the watchstanding and sleep patterns of crewmembers of the Nuclear Reactor Department of the USS *Nimitz*.[18]

METHODS

Subjects

There were 91 crewmembers who volunteered to participate in the study. Due to missing sleep data, this paper will be based on 82 volunteers from the Reactor Department of the aircraft carrier USS *Nimitz* performing their normal underway duties. In a typical day at sea, crewmembers spend their on-duty time in activities related to the ship mission, i.e., standing watch, and performing other work duties assigned to them during off-watch periods. Crewmembers also participate in meetings, drills, and training evolutions, and respond to emergencies as needed. During their off-duty hours, crewmembers sleep, eat, or spend their personal time engaged in various social and personal activities such as hygiene. The study volunteers worked on a 3 h on/9 h off (3/9) watchstanding schedule. In a 24-h day, a crewmember on the 3/9 stands watch for two 3-h shifts. The 3/9 is a four-section schedule, i.e., the 3/9 requires four groups or watch sections (WS) of crewmembers to cover the entire 24-h day since each section stands 6 h of watch per day split in two 3-h shifts. The 3/9 is a fixed schedule so that crewmembers stand the same watch periods each day. In the study, 27 crewmembers were in WS 1 (standing watch from 03:00 to 06:00 and from 15:00 to 18:00), 20 were in WS 2 (standing watch from 06:00 to 09:00 and from 18:00 to 21:00), 18 were in WS 3 (standing watch from 09:00 to 12:00 and from 21:00 to 00:00), and 17 were in WS 4 (standing watch from 00:00 to 03:00 and from 12:00 to 15:00). Before the underway study period, personnel in the Reactor Department had been working in a simulated underway environment for approximately 3 d. More detailed information about the 3/9 watchbill is included in a technical report.[19] The study protocol was approved by the Naval Postgraduate School Institutional Review Board.

Materials

The pre-study questionnaire included demographic questions about age and gender. The Epworth Sleepiness Scale (ESS) was used to assess average daytime sleepiness at the outset of the study.[10] A total score of 10 or more reflected above normal daytime sleepiness. Morningness-eveningness (ME) tendency was assessed with a self-administered ME questionnaire.[23]

Sleep was assessed with actigraphy using the Motionlogger Watch (Ambulatory Monitoring, Inc. - AMI; Ardsley, NY). Data were collected in 1-min epochs. AMI data (collected in the Zero-Crossing Mode) were scored using Action W version 2.7.2155 software. The Cole-Kripke algorithm with rescoring rules was used. Criterion for sleep and wake episodes was 5 min. The sleep latency criterion was no more than 1 min awake in a

20-min period (all values are default for this software). Crewmembers also completed an activity log, documenting in 15-min intervals their daily routine. The activity log was also used to report intake of caffeinated beverages, i.e., coffee/tea/sodas, and energy drinks. Lastly, participating crewmembers were asked whether they had been exposed to sunlight in the last 24 h and, if so, the amount of time they spent in the sunlight.

Procedure

Data collection for this portion of the study commenced on November 3 and ended on November 14, 2014. During the data collection period, the ship was on Pacific Standard Time (GMT-8), with local sunrise at ~06:13 and local sunset at ~16:52. Personnel from the Reactor Department were briefed on the research protocol and study procedures. Volunteers gave written informed consent and were briefed prior to being issued equipment for the study. Crewmembers filled out the pre-study questionnaires and received sleep watches and activity logbooks to be filled out daily. Upon completion of the study, participating crewmembers returned their equipment and completed an end-of-study questionnaire.

Statistical Analyses

Statistical analysis was conducted with a statistical software package (JMP Pro 10; SAS Institute; Cary, NC). Data are presented as mean ± SD or median, as appropriate. Significance level was set at $P < 0.05$. We performed descriptive statistical analyses of age, gender, ESS scores, ME preference scores, daily consumption of coffee/tea/sodas, daily consumption of energy drinks, duration of sunlight exposure, and duration of work. Next, a hierarchical regression analysis was used to explore predictors of daily sleep duration. The exploratory variables were daily intake of coffee/tea/soft drinks, daily intake of energy drinks, daily duration of sunlight exposure, and daily duration of work. Logarithmic transformation was used for those data fields that were not normally distributed. Statistical significance of the multiple regression results was based on post hoc analysis using the Benjamini–Hochberg False Discovery Rate controlling procedure.[3] To further explore the association between daily sleep duration and sunlight exposure, a classification tree was constructed using recursive partitioning analysis. Crewmembers were divided into two groups based on the results of the recursive partitioning analysis; daily sleep duration was compared between the groups. The Wilcoxon Rank Sum test was used for pairwise comparisons and Spearman's rho was used for correlation analysis.

RESULTS

Participating crewmembers ($N = 82$) were on average 25.0 ± 4.33 yr of age; 65 were men. The four watch sections had similar demographic characteristics. Prescription and/or over-the-counter medications were used by 12 individuals (14.6%). One crewmember reported taking sleep-promoting medication (melatonin and sleep aids). The average ME score was 50.5 ± 8.50. Based on their ME score, subjects were classified as Moderately Morning type ($N = 15$), Moderately Evening type ($N = 13$), one as Definitely Evening type, and 52 as Intermediate type. The average ESS score at the beginning of the study was 8.59 ± 3.91 with 32.9% of the subjects exhibiting elevated daytime sleepiness (ESS score > 10).[10] As assessed by ESS scores, sleepiness levels did not change during the study (Wilcoxon Signed Rank test, S = 153, $P = 0.475$). ESS scores at the beginning of the study and their change during the study did not differ by watch section (Dunn method for joint ranking, for all comparisons $P > 0.60$).

Actigraphy data showed that crewmembers slept an average of 6.64 ± 0.95 h/d. Some exposure to sunlight (on average 21 min/d) was reported by 54 crewmembers (61.8%). There were 78 crewmembers who reported drinking some type of caffeinated beverage, i.e., 24 reported using only coffee, tea, or caffeinated soft drinks, 4 used only energy drinks, 49 reported using both categories of caffeinated beverage, and 4 reported never using caffeinated drinks, while this information was missing for 1 crewmember. Data from the activity logs indicated that crewmembers worked on average 11.1 ± 1.95 h/d. This time included watchstanding, training, meetings, and performing administrative and other duties. **Table I** provides a detailed picture of these results.

Next, we examined the activities in which our subjects reportedly engaged during their waking hours. We focused specifically on the time on duty (which includes standing watch) and personal or free time. Since all work activities were performed in the nuclear reactor spaces below decks, our study subjects had no access to sunlight during their duty periods; that is, crewmembers had access to sunlight only during their personal or free time. **Fig. 1** shows the corresponding distribution of daily activities by watch section. Approximately

Table I. Behavioral Patterns.

	MEAN	SD	MEDIAN	MINIMUM	MAXIMUM
Sleep, hours	6.61	0.94	6.54	4.08	8.92
Number of sleep episodes per day	1.49	0.43	1.35	1	2.9
Sunlight exposure*, hours	0.344	0.59	0.129	0.019	3.56
Daily consumption of coffee/tea/sodas†, number of cups/cans	1.62	1.28	1.28	0.1	6.5
Daily consumption of energy drinks†, amount	0.61	0.54	0.546	0.1	3.44
Daily work time, hours	11.1	1.95	11.0	7.38	15.9

* For the 57 crewmembers who reported sunlight exposure > 0 h at least once during the study.
† For those crewmembers who reported drinking caffeinated beverages at least once during the study.

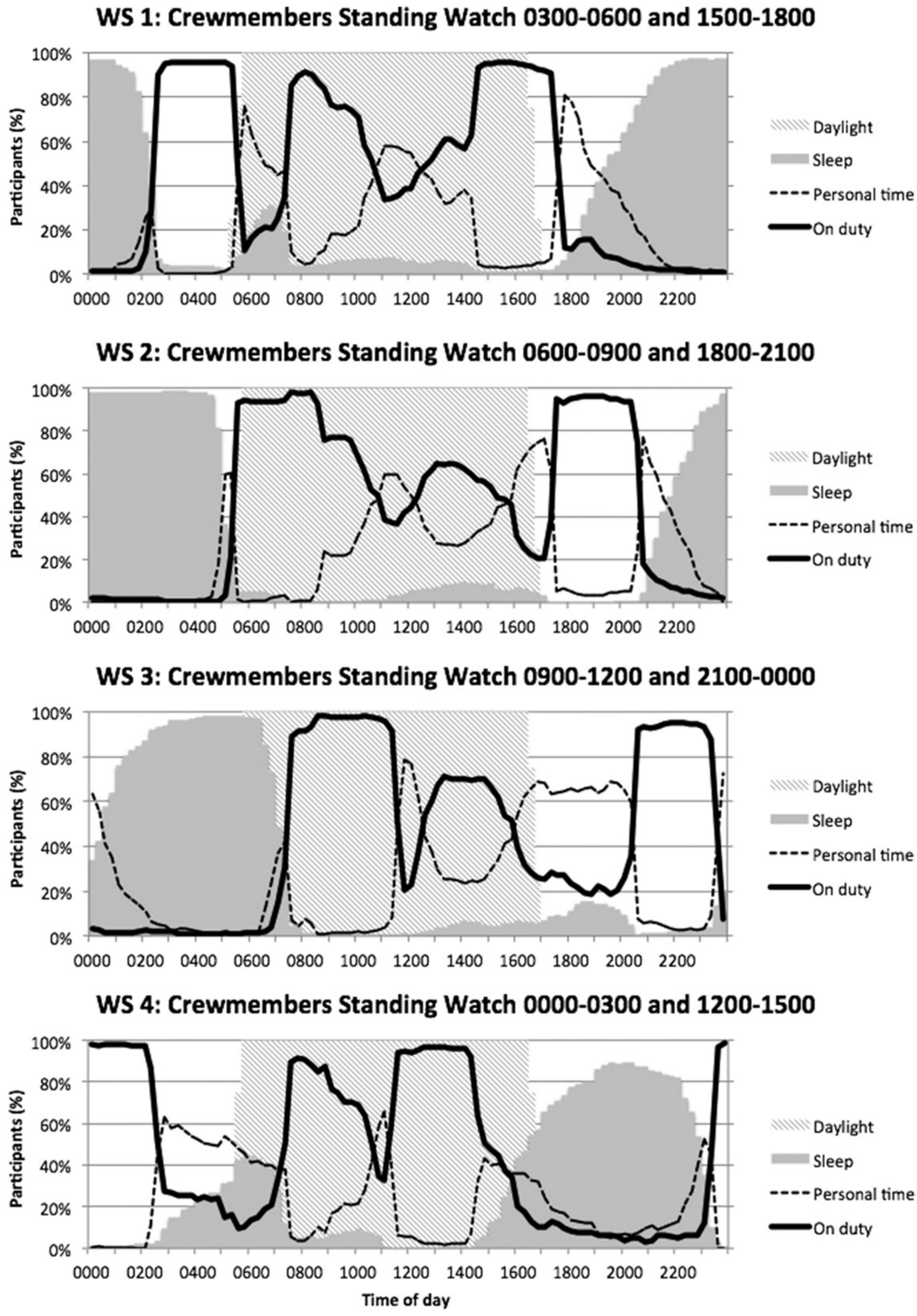

Fig. 1. Daily activities by watch section.

40% of the crewmembers in WS 4 (i.e., from 00:00 to 03:00 and from 12:00 to 15:00) had personal time in the early morning and late afternoon, whereas more than 40% of the crewmembers in WS 2 (standing watch from 06:00 to 09:00 and from 18:00 to 21:00) had personal time in the late afternoon. Analysis showed that these two sections had the highest number of crewmembers exposed to more than 30 min of sunlight per day: four crewmembers in WS 4 and five in WS 2. In WS 1 (i.e., standing watch from 03:00 to 06:00 and from 15:00 to 18:00), approximately 40% of the crewmembers had personal time in the early morning and afternoon, whereas approximately 70% of the crewmembers in WS 3 (i.e., standing watch from 09:00 to 12:00 and from 21:00 to 00:00) had personal time in the late afternoon. Analysis showed that these two watch sections had the lowest number of crewmembers exposed to more than 30 min of sunlight per day: two crewmembers in WS 1 and one crewmember in WS 3. Diagrams in Fig. 1 also include the approximate sunlight period (local sunrise at ~06:13 and local sunset at ~16:52).

Nonparametric correlation analysis among the study variables (age, sunlight exposure, number of coffee/tea/sodas, number of energy drinks, and daily work duration) showed that sleep duration was negatively correlated with the number of coffee/tea/soft drinks (rho = −0.326, $P = 0.003$) and with length of work hours (rho = −0.383, $P < 0.001$). Furthermore, length of workday was also positively correlated with intake of coffee/tea/soft drinks (rho = 0.248, $P = 0.025$); that is, those who spent more time working also consumed more caffeinated beverages.

The multiple regression model [$R^2 = 0.265$, $F(4,76) = 6.83$, $P < 0.001$] with all the exploratory variables included is shown in **Table II**. Three of the predictors, sunlight exposure, daily work duration, and number of coffee/tea/soft drinks, were statistically significant. All three were negatively associated with daily sleep duration. The patterns of results did not change after omitting four multivariate outliers using Mahalanobis' distance method.

Next, a partition analysis was performed to explore the association between daily sleep duration and sunlight exposure. There were 12 crewmembers who received more than one half-hour of sunlight daily and slept an average of ~40 min (10%) less than their peers working the same shifts who received less than one half-hour of sunlight (on average 6.05 ± 0.90 h vs. 6.71 ± 0.91 h, respectively; Wilcoxon Rank Sum test, Z = 1.98, $P = 0.048$; effect size r = 0.218). These results are shown in **Fig. 2**. It is notable that even though sleep duration differed between light exposure groups, daily rest duration and number of sleep episodes per day were statistically equivalent (daily rest duration: Wilcoxon Rank Sums test, Z = 1.48, $P = 0.140$; number of sleep episodes per day: Wilcoxon Rank Sums test, Z = 0.263, $P = 0.793$). Of the 12 crewmembers with reported exposure to sunlight of more than 30 min daily, 2 did not nap, whereas 8 of the 70 crewmembers with reported exposure to sunlight of less than 30 min daily did not nap.

DISCUSSION

This study assessed the effect of work hours, use of caffeinated beverages, and sunlight exposure on the daily sleep duration of a sample of USS *Nimitz* crewmembers working below decks in the Reactor Department during a 2-wk underway while working a 3/9 watchstanding schedule. As expected from earlier research, our study identified that work hours and use of caffeinated beverages are statistically significant predictors of sleep duration.[6,17] Specifically, our results show that the use of caffeinated beverages in our sample of active duty crewmembers is associated with decreased average daily sleep duration. This finding may be explained if we consider that in general, sailors are habitual caffeine drinkers, a habit that has been associated with disturbed sleep.[15,17] Long work hours leading to extended periods of wakefulness are also associated with disturbed sleep patterns.[1]

As our results suggest, the most interesting finding in our study is that sunlight exposure in this population of shiftworkers may result in less sleep. Crewmembers exposed to sunlight for more than one half-hour per day slept 10%, or approximately 40 min, less than their peers working the same shifts who were exposed to sunlight less than one half-hour per day (average sleep 6.05 ± 0.90 h vs. average 6.71 ± 0.91 h). The difference in daily duration that we observed may be explained if we consider that some crewmembers go topside instead of using this time to nap. By going topside, the crewmembers were exposed to sunlight, but in doing so, they also lost an opportunity to sleep. Our analysis showed that the two exposure groups did not differ significantly in terms of rest duration or number of sleep episodes per day (i.e., both groups were equivalent in terms of napping). Therefore, we suggest that the difference in sleep duration between these two groups can be better explained by considering the timing of the crewmembers' sunlight exposure. Based on activity patterns, most of our study participants had access to sunlight either early in the morning or late in the afternoon. Research has shown, however, that exposure to light in the late biological day and early biological night leads to a phase delay (i.e., later bedtime and awakening), while exposure in the late biological night and early biological morning leads to a phase advance (i.e., earlier bedtime and awakening).[14] The problem of light exposure may be further exacerbated by the fact that many crewmembers are napping during the late afternoon or early evening. Therefore, some of these crewmembers may be exposed to sunlight prior to naptime. Research has shown that light

Table II. Multiple Regression Model for the Duration of Daily Sleep.

PREDICTOR VARIABLE	STANDARDIZED REGRESSION COEFFICIENT	95% CONFIDENCE INTERVAL	*P*-VALUE	PROPORTION OF VARIANCE EXPLAINED
Work duration, hours	−0.165	−0.264, -0.066	0.001†	0.11
Sunlight exposure, hours*	−2.42	−4.20, -0.646	0.008†	0.07
Use of coffee/tea/sodas, number of cups/cans*	−0.953	−1.85, -0.055	0.038†	0.04
Use of energy drinks, amount*	0.708	−0.852, 2.27	0.369	0.01

* Logarithmic transformation.

† Statistically significant based on post hoc analysis using the Benjamini–Hochberg False Discovery Rate controlling procedure.[3]

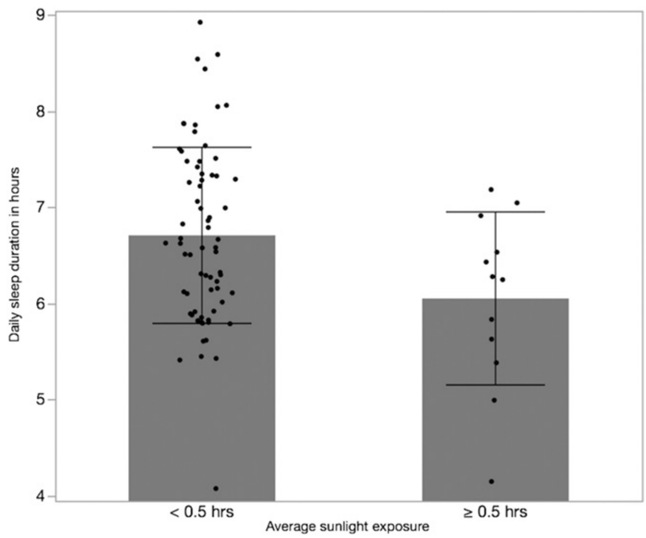

Fig. 2. Daily sleep duration by sunlight exposure. Vertical bars denote 1 SD.

exposure, even room light, before bedtime affects sleep by suppressing melatonin levels.[8]

From an organizational perspective, the effect of sunlight on crewmembers' sleep is important since it illustrates the challenges of optimizing shift schedules in the maritime operational environment. In the civilian workplace, sunlight is generally associated with better mood and increased vitality.[4] However, in maritime operations, going "topside" to see the sun may actually interfere with the circadian clock, further disrupting the circadian re-entrainment needed to sleep during the daytime hours. This disruption and subsequent inability to sleep can result in extreme fatigue during work periods.

Combined with the use of caffeinated beverages and working long hours, our results demonstrate the detrimental effect of sunlight exposure on sleep. Our findings suggest that researchers optimizing shiftwork in operational environments should also address crewmember behaviors that might counteract the beneficial aspects of a circadian-aligned watchstanding schedule. These findings also highlight the need to properly educate crewmembers about "sleep hygiene," i.e., a set of behavioral practices promoting good sleep.[9] In their review, Eastman et al.[7] concluded that the timing of light exposure can be used in part to overcome problems of shiftwork. For crewmembers on Navy ships, sleep hygiene education should address the circadian-alignment of the specific watch schedules on which the crewmembers are working and the consequences of sunlight exposure at inopportune times on the quality and quantity of their sleep. Informing crewmembers of appropriate times for their individual sunlight exposure is essential so that they do not unwittingly reset their circadian rhythms. Such education will be operationally beneficial and result in better rested and alert crewmembers. Our results suggest that the timing of sunlight exposure is an important factor that must be considered when optimizing watchstanding schedules at sea. Sunlight exposure at the wrong time of day may result in circadian misalignment that could further degrade the sleep of shiftworkers.

This study had a number of limitations. The study sample included crewmembers from a single department on a single ship. Future efforts should include a wider sample represented by more ship departments. Crewmembers reported sunlight exposure by filling out a daily log without specifying the precise timing or intensity of the sunlight exposure. Although some actigraphic devices collect light data, earlier efforts by this research team to collect light data in the operational environment using actigraphy were unsuccessful because crewmembers often wear clothing that covers their arms and the light sensor. Since this was a naturalistic study with crewmembers performing their typical naval duties, it was not possible to assess a subject's baseline need for sleep or the phase of their biological clock at the beginning and the end of the data collection period. Future studies should also assess the intensity of artificial lighting in the work environment.

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