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# NAVAL POSTGRADUATE SCHOOL

**MONTEREY, CALIFORNIA**

**SAILOR WELL-BEING AND RACK CURTAINS**

by

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**14. ABSTRACT**
Studies conducted by the Naval Postgraduate School Crew Endurance Team on United States Navy (USN) ships have shown that ambient light is a major habitability-related factor in berthing compartments. Even though the US Navy rack curtains are intended only for privacy, we postulated that they could also be used to improve sleeping conditions by blocking the light entering the rack space while the sailor is sleeping. Along these lines, we conducted a longitudinal quasi-experimental study on a Navy ship, comparing an enhanced rack curtain with the standard rack curtain in terms of sailor well-being, acceptance, and habitability conditions.
Data were collected in December 2018 from 71 fit-for-duty crewmembers while the ship was underway in cold waters off the Pacific Northwest coast. Results showed that, overall, sailors approved of the enhanced curtain rating it positively in terms of light and noise reduction inside the rack. Also, regardless of the type of rack curtain, temperature inside the rack space was consistently lower than outside the rack. Compared to the standard curtain, the enhanced curtain was associated with an even larger temperature differential between the spaces inside and outside the rack. That is, in the cold environmental operating conditions in which the ship sailed, the inside of the racks with the enhanced curtain was colder than racks with the standard curtain. These findings can be explained if we consider that temperature in the rack is affected by the supply of air from the central ventilation system. When the curtains are closed (as it is oftentimes the case when sailors sleep in their racks), airflow is obstructed and the inside temperature cannot equalize to the external one. Therefore, our results suggest that the enhanced curtain obstructs airflow in the rack more than the standard curtain design.
Overall, this study cannot provide conclusive results regarding the use of enhanced curtain designs to improve sleep in the berthing compartments. Future studies should further assess the effect of rack curtains on sleep habitability conditions in various environmental conditions, e.g., when sailing in warmer waters.

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# ABSTRACT

Studies conducted by the Naval Postgraduate School Crew Endurance Team on United States Navy (USN) ships have shown that ambient light is a major habitability-related factor in berthing compartments. Even though the US Navy rack curtains are intended only for privacy, we postulated that they could also be used to improve sleeping conditions by blocking the light entering the rack space while the sailor is sleeping. Along these lines, we conducted a longitudinal quasi-experimental study on a Navy ship, comparing an enhanced rack curtain with the standard rack curtain in terms of sailor well-being, acceptance, and habitability conditions.

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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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# ACKNOWLEDGEMENTS

The data presented herein were collected by LT Megan Mittleider, USN and Dr. Heather Clifton. Parts of these data were used in LT Mittleider's thesis (Mittleider, 2020). The authors wish to thank the crew of the USS MOMSEN (DDG 92) for participating in the study.

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# I. INTRODUCTION

## A. BACKGROUND

Studies conducted by the Naval Postgraduate School (NPS) Crew Endurance Team have shown that several habitability-related issues in berthing compartments are affecting sailor well-being (Matsangas & Shattuck, 2017, 2020). Specifically, our studies have shown that inside the berthing spaces, noise, ambient temperature, poor bedding conditions, and ambient light were the most frequently reported factors of concern (Matsangas & Shattuck, 2020). Unlike USN officers, almost all enlisted sailors share berthing compartments with other sailors. In these situations, light and noise can be major sleep disruptions.

Habitability in manned spaces on ships of the United States Navy is outlined in the instruction for the Shipboard Habitability Program (NAVSEA, 2016) and includes habitability of berthing compartments. According to this instruction, rack curtains are intended only to provide privacy to the sailors when in their rack. We believe, however, that the utility of a rack curtain can extend beyond privacy. Specifically, we postulate that the rack curtain could also be used to improve sleeping conditions by preventing light and noise from entering the rack space while the sailor is sleeping.

## B. STUDY GOAL

The goal of this study is to compare the enhanced rack curtain to the standard curtain in terms of sailor well-being, acceptance, and habitability in the rack.

# II. METHODS

## A. EXPERIMENTAL DESIGN

This naturalistic study was designed to be prospective, longitudinal, quasi-experimental, and between-subjects. In the study, sailors were observed as they performed their normal underway duties.

## B. PARTICIPANTS

Study participants (N = 71) were volunteers from the ship's company assigned to the USS MOMSEN (DDG-92), an Arleigh Burke Flight IIA destroyer of the United States Navy (Figure 1). Participation rate was approximately 26%. The study protocol was approved by the Naval Postgraduate School Institutional Review Board (NPS.2019.0010).


Figure 1. USS MOMSEN (DDG 92).

## C. EQUIPMENT AND INSTRUMENTS

### 1. Questionnaires

The Pre-study Questionnaire included demographic items (age and gender), items on occupational characteristics (rate/rank, department, years on active duty, how many times the sailor had deployed, total number of months deployed). It also asked about the current watch schedule, other schedules the sailor had experienced previously, berthing compartment, rack number, bunk location, 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, Nicorette gum or patches, electronic smoke). In addition, questions about the use of medication (prescribed or over-the-counter), and the type and frequency of exercise routine were included. The Pre-study Questionnaire included the Profile of Mood States (POMS) (McNair, Lorr, & Droppelman, 1971), a standardized, 65-item inventory originally developed to assess mood states in psychiatric populations. The POMS 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). The Total Mood Disturbance (TMD) score is derived by adding the five subscales and subtracting the score for Vigor (range -32 to 200). Normalized 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 on POMS has been associated with better within-team communication behaviors and enhanced team awareness (Pfaff, 2012).

The Post-study Questionnaire included items regarding sailors' 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"), their own and their peers' work hours compared to a normal underway (5-point Likert scale: "Much less than usual," "Less than usual"; "About the same"; "More than usual"; "Much more than usual"). It also asked sailors about the methods used to help them sleep or to minimize disturbances of sleep (wear earplugs, wear eyeshades, listen to music, other), whether they look at light-emitting devices before bed and what type (TV, tablet, smartphone, computer, other), and the type of curtains they had in their rack. Sailors also rated their level of agreement with five statements regarding whether the curtain affected their ability to sleep (blocks light, temperature, ventilation, noise, other) using a 5-point Likert scale ("Disagree -2"; "-1"; "Neutral 0"; "1"; "Agree 2"). Sailors rated how much 25 factors interfered with or promoted sleep in their rack (5-point Likert scale: "Interferes -2"; "-1"; "No effect 0"; "1"; "Promotes 2").

Lastly, the Post-test Questionnaire included four standardized questionnaires, i.e., the Epworth Sleepiness Scale (ESS), Insomnia Sleep Index (ISI), Pittsburgh Sleep Quality Index (PSQI), and the POMS. The ESS was used to assess average daytime sleepiness (Johns, 1991). Participants used a 4-item Likert scale to rate the chance of dozing off or falling asleep in eight different everyday situations. Answers for the 8 items ranged from 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 obtain the total Epworth score. A sum of more than 10 reflects above normal daytime sleepiness and a need for further evaluation (Johns, 1992). The 7-item ISI was used to assess the severity of both nighttime and daytime components of insomnia (Bastien, Vallieres, & Morin, 2001; Morin, Belleville, Bélanger, & Ivers, 2011). The 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 >5 are associated with poor sleep quality.

### 2. Sleep assessment

Sleep was assessed by wrist-worn actigraphy (Spectrum Plus actigraph; Philips-Respironics; Bend, Oregon) assisted by activity logs, which represent 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 and scored with the Actiware software version 6.0.0 (Phillips Respironics; Bend, Oregon). The medium sensitivity threshold (40 counts per epoch) was used with 10 immobile minutes as the criterion for sleep onset and sleep end (all were default values for this software).

### 3. Activity Logs

All participants were asked to complete an activity log, documenting their daily routine (meetings, maintenance, other work, service diversion, training, watch, eating/messing, sleeping/napping, personal/free time, removed actigraph). The activity logs covered a 24-hour period in 15-minute intervals. Participants were asked to document in the log whether they were exposed to sunlight (along with the duration and timing), consumption of caffeinated beverages and energy drinks, and whether they worked out (including time and duration of workout).

### 4. Temperature and light measurements

Ambient light intensity and ambient temperature data were collected with the HOBO pendant ® temperature/light data logger. The sensor logged readings aggregated in 5-minute intervals. Two sensors were installed in the rack of each participant, one outside and one inside the rack. Specifically, the sensor inside the rack was positioned at a location corresponding to the position of the occupant's eyes ("B" in Figure 2), whereas the second sensor was positioned immediately exterior to the rack ("A" in Figure 2).


Figure 2. Placement of sensors in racks. Photo was taken from Mittleider (2020).

### 5. Rack curtains

Two types of curtains were used in this study. The first type is the standard-issue Navy rack curtain ("standard") which all ships of the USN use for sailor privacy (NAVSEA, 2016). Manufactured under government contract in specific dimensions, the standard curtain is made from a single layer of blue, polyester-cotton blend fabric. The second type was a commercial-off-the-shelf (COTS) rack curtain ("enhanced") made from blue polyester fabric backed with thin white plastic and personal storage pockets on the internal side. The size of the enhanced curtains is provided to the manufacturer to accommodate various rack opening dimensions.

## D. PROCEDURES

Data collection was conducted during an underway 9-20 December 2018, with the ship sailing off the coast of the Pacific Northwest area. 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 actigraphs and activity logbooks. All participants were instructed to fill out their activity logs daily. Upon completion of the study, the participants returned their equipment and filled out a Post-study Questionnaire. There were no changes to rack curtains or berthing arrangements throughout the study.

## E. ANALYTICAL APPROACH

### 1. Actigraphy Data Cleaning and Data Reduction Procedures

The actigraphic data were prepared 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 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 was based on 60 participants. Sleep data were aggregated to get an average score of daily sleep duration and an average number of sleep episodes per day for each individual over the entire study period.

### 2. Sleep Log Data Cleaning and Data 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. Interpolation was applied to 742 missing 15-minute intervals (1.78%). Analysis of workload with the activity logs was based on 435 days of data.

### 3. Analysis Roadmap

Initially, the analysis was focused on the entire data set. All variables underwent descriptive statistical analysis to identify anomalous entries and to describe our sample in terms of demographic characteristics, average daytime sleepiness, insomnia symptoms, mood, sleep attributes (daily sleep duration, number of sleep episodes per day), adequacy of sleep, and sleep-related habitability factors in the berthing compartments. Next, our analysis focused on the main goal of this study, i.e., to compare the enhanced and the standard rack curtains.

Statistical analysis was conducted with JMP statistical software (JMP Pro 15; SAS Institute; Cary, NC). Data normality was assessed with the Shapiro-Wilk W test. Summary data are reported as mean ± standard deviation (M ± SD) or median—MD (interquartile range—IQR) as appropriately needed. An alpha level of 0.05 was used to determine statistical significance. Post-hoc statistical significance was assessed using the Benjamini–Hochberg False Discovery Rate (BH-FDR) controlling procedure with $q = 0.20$ (Benjamini & Hochberg, 1995). The Wilcoxon Rank Sum test and the t-test were used for pairwise comparisons between independent samples, whereas Signed Rank tests were used for dependent pairwise comparisons. The binomial test was used to compare

POMS scores with adult norms. Multivariate analysis was based on general linear models adjusting for confounding variables.

The Bland–Altman method was used to assess differences in temperature between inside and outside the rack (Altman & Bland, 1983; Bland & Altman, 1986, 1999). The basic Bland–Altman method was used if the mean and standard deviation of the differences between devices were the same throughout the range of measurement (Altman & Bland, 1983). The regression approach for non-uniform differences was used if the difference between devices was associated with the magnitude of the measurements (Bland & Altman, 1999).

To assess temperature conditions in the berthing compartments, we used the habitability design criteria in technical publication T9640-AC-DSP-010/HAB (NAVSEA, 2016). Specifically, ambient temperature was assumed to be within limits if was between 65°F and 78°F (the minimum in the heating season and the maximum in the cooling season) (NAVSEA, 2016).

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# III. RESULTS

## A. ENTIRE DATASET (N = 70)

From the initial population of 71 consented sailors, 70 were used for analysis (one was omitted due to missing data).

### 1. Demographic and occupational information

As shown in Table 1, participants were predominantly male (n=57, 81.4%) with a median age of 24 (8.25) years (range: 19 – 43 years). Of the 70 sailors who participated in the study, 48 were watchstanders (all on fixed watchbills) and 22 non-watchstanders. Most of the watchstanders (39 sailors) were working on the 3hrs-on/9hrs-off, while nine stood watch on other watchbills. From the non-watchstanders, seven sailors worked when needed, six were working on 12hrs-on/12hrs-off shifts, six were galley workers, and three were day workers.

Table 1. Demographic and occupational characteristics.

| | |
|---|---|
| Age (years), MD (IQR) | 24 (8.25) |
| Gender, Males, # (%) | 57 (81.4%) |
| Rank, # (%) | |
| Officers | 11 (15.7%) |
| Enlisted | 59 (84.3%) |
| Active duty (years), MD (IQR) | 4 (6.5) |
| Times deployed, MD (IQR) | 1 (3.25) |
| Total number of months deployed, MD (IQR) | 7 (19.5) |
| Department, # (%) | |
| Engineering | 15 (21.4%) |
| Supply | 12 (17.1%) |
| Weapons | 11 (15.7%) |
| Combat Systems | 9 (12.9%) |
| Plans and tactics | 8 (11.4%) |
| Operations | 7 (10.0%) |
| Executive/admin | 3 (4.29%) |
| Medical | 3 (4.29%) |
| Navigation | 2 (2.86%) |
| Watchstanding status, # (%) | |
| Watchstanders | 48 (68.6%) |
| Non-watchstanders | 22 (31.4%) |

### 2. Sleep-related practices and habitability in the berthing compartments

Sailors were asked what they do to help them get to sleep or to minimize disturbances of sleep. Most sailors (21, 30.0%) responded that they listen to music. Detailed results are shown in Figure 2.

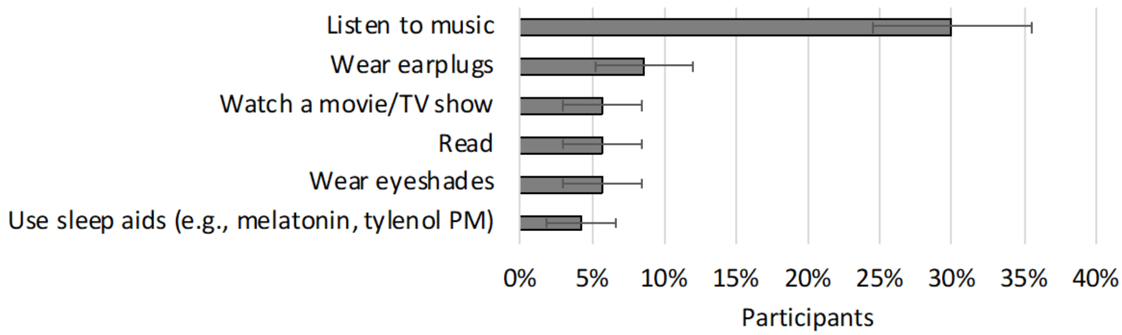


Figure 3. What sailors do to help get to sleep or to minimize disturbances of sleep. Horizontal lines denote the Standard Error.

Most sailors (54, 77.1%) reported looking at devices with screens before going to bed. Specifically, 50 (71.4%) reported using their smartphones; the use of computers, tablets, TV, and game consoles was less prevalent. Detailed results are shown in Figure 3.

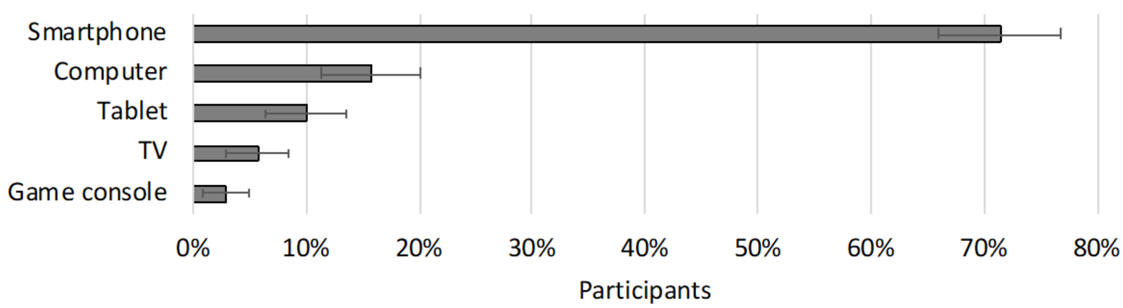


Figure 4. Use of devices before going to sleep. Horizontal lines denote the Standard Error.

The four most frequently reported factors affecting sailor sleep was noise from other sailors in the compartment (52, 74.3%), not having enough time to sleep (47, 67.1%), thoughts (45, 64.3%), and noise inside the compartment from machinery and other non-human-related sources (40, 57.1%). Notably, four of the seven factors listed as interfering with their sleep were related to noise. These results are based on aggregating the two negative responses, i.e., "interferes (-2)" and "-1."

The four most frequently reported factors promoting sailor sleep were ship motion (35, 50.0%), ventilation (30, 42.9%), cold temperature in the rack (28, 40.0%), and rack curtains (26, 37.1%). These results are based on aggregating the two positive responses, i.e., "1" and "promotes (2)." Detailed results are shown in Figure 4.

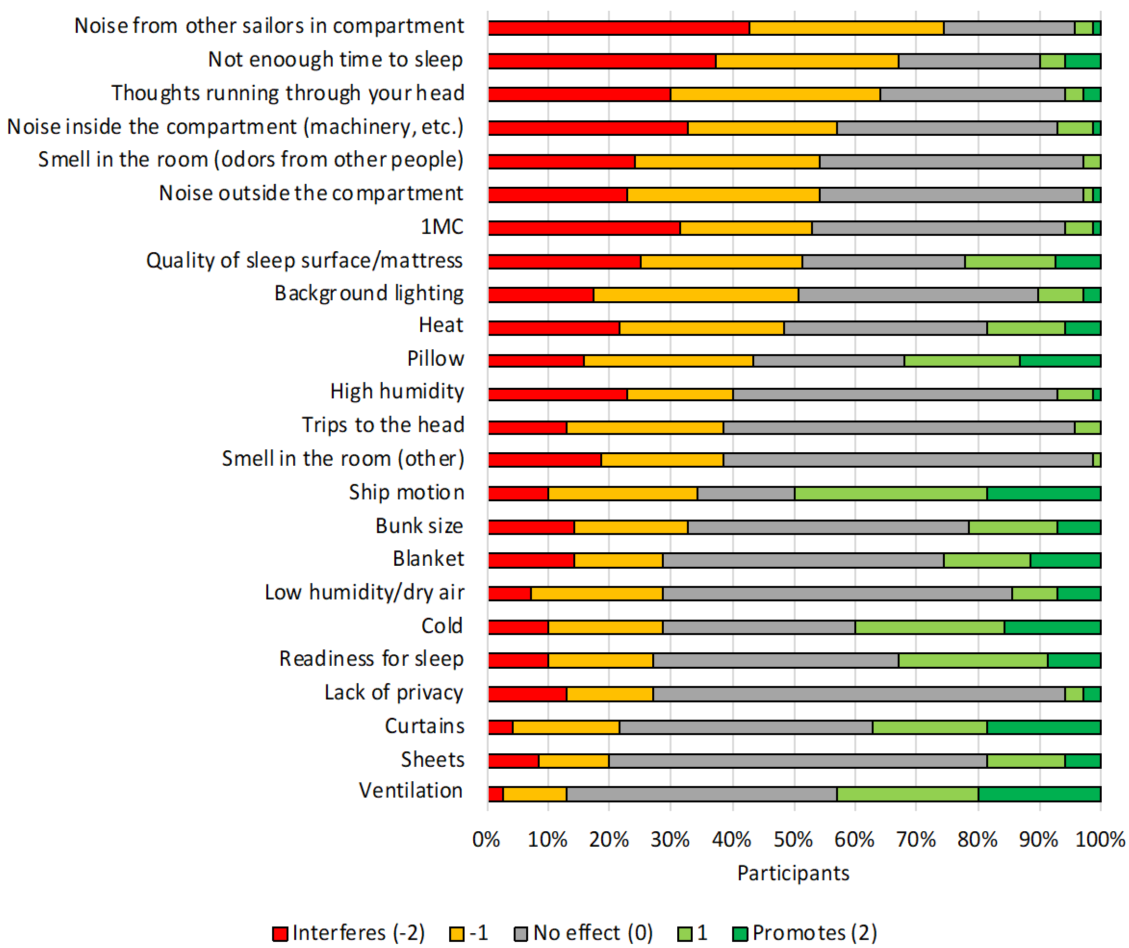


Figure 5. Factors affecting sailor sleep.

### 3. Caffeinated beverages and nicotine products

Sailors reported the type and frequency of caffeinated beverages they consumed (see Figure 5). Of the 70 sailors, 60 (85.7%) indicated drinking some type of caffeinated beverage. The most frequently reported beverage was coffee (34 [48.6%] of the respondents drinking on average 2 cups per day – median value), followed by soft drinks (28 [40.0%] of the respondents drinking on average 1 serving per day – median value), energy drinks (26 [37.1%] of the participants drinking on average 1 serving/cup per day – median value), and tea (14 [20.0%] of the participants drinking on average 1 serving/cup per day – median value).

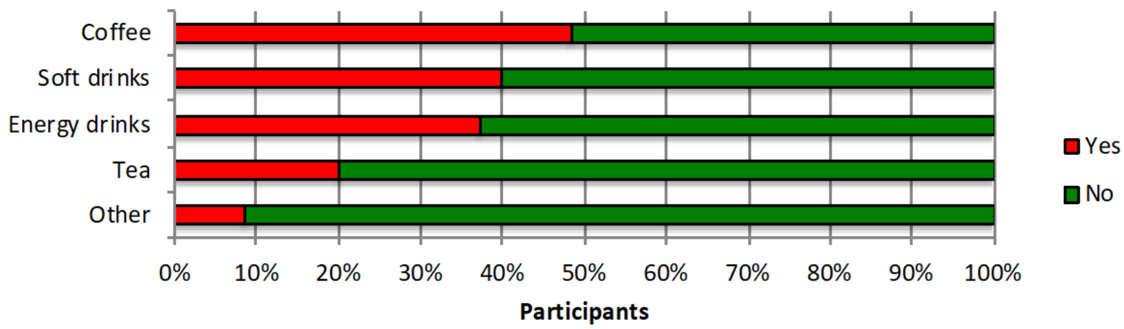


Figure 6. Consumption of caffeinated beverages.

Nicotine products were used by 26 (37.7%) Sailors, i.e., mainly cigarettes (12, 17.4%), chewing tobacco/snuff (9, 12.9%), and electronic smoke (7, 10.0%). Forty-one (58.6%) sailors had an exercise routine, working out on average 3.5 (2) times per week, with a median duration of 1 (0.80) hour. The workout routines reported by the sailors were mainly weight lifting and aerobic exercise. Fifteen participants reported taking prescribed or over-the-counter medications, i.e., sleep aids (3 sailors), antihistamines (3), pain-killers (3), anti-depressants (3), and other (6 sailors).

## 4. Sleep-related attributes

Actigraphic data from 60 sailors were used in the sleep analysis. Crewmembers slept 6.37 ± 1.02 hours on a daily basis split into 1.5 (0.690) sleep episodes. Not surprisingly, sailors were not satisfied with the sleep they received during the underway with approximately 64% noting that the sleep they received was less than needed or worse. The same trend was identified in the responses regarding the adequacy of sleep of other sailors (see Figure 6).

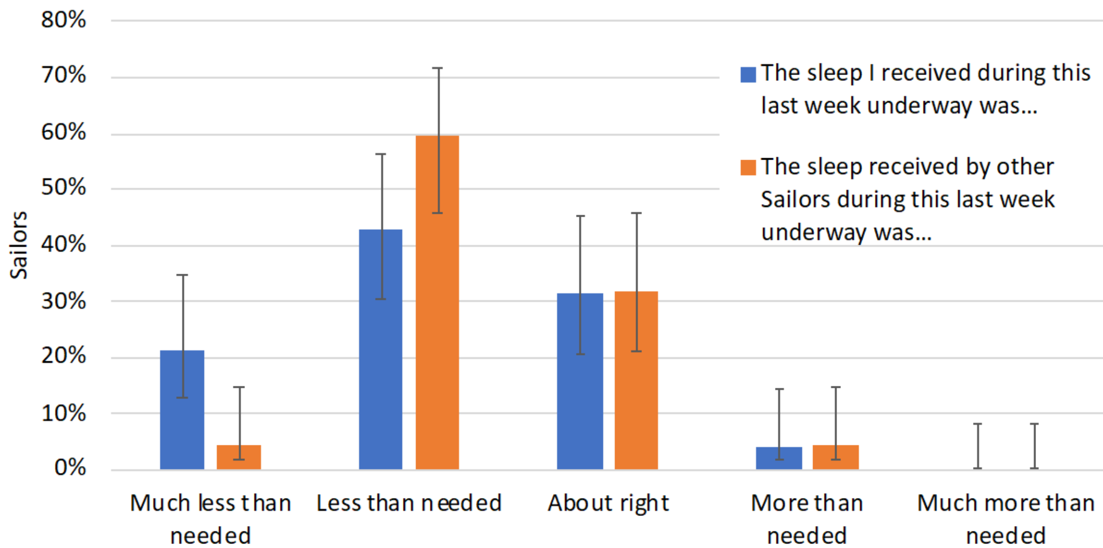


Figure 7. Responses to the statement "The sleep I received on this underway was…" and to the statement "The sleep received by other sailors on this underway was…" Vertical lines denote the Standard Error.

The average ESS score at the end of the study was 10.9 ± 5.06 with 34 (49.3%) of the sailors classified as showing elevated daytime sleepiness (ESS score > 10). The average PSQI global score at the end of the study was 5.71 ± 2.55 with 33 (48.5%) of the sailors classified as poor sleepers. The average ISI score at the end of the study was 11.6 ± 5.62 with 21 (32.3%) of the sailors reporting elevated severity of insomnia symptoms (ISI score > 15). Further analysis showed that 16 (24.6%) sailors had elevated daytime sleepiness (ESS score > 10) and elevated severity of insomnia symptoms (ISI score > 15). From these sailors, six were watchstanders in the 0000-0300/1200-1500 section of the 3/9. Fourteen (20.0%) sailors used caffeinated beverages and nicotine products and did not have an exercise routine. From these sailors, five were watchstanders in the 0000-0300/1200-1500 section of the 3/9 and four in the 0300-0600/1500-1800 section.

POMS scores at the beginning of the study showed that, compared to adult norms, more sailors had worse mood (with scores above the 50$^{th}$ percentile) in terms of TMD scores (81.2%, Binomial test: $p < 0.001$), tension-anxiety (78.3%, $p < 0.001$), Anger-hostility (68.1%, p = 0.002), vigor-activity (78.3%, p < 0.001), fatigue (76.8%, p < 0.001), and confusion-bewilderment (73.9%, p < 0.001). Comparison of the POMS scores between the beginning and end of the study showed that vigor scores worsened (decreased; p < 0.001) but depression scores improved (decreased; p = 0.027). Detailed results of POMS scores and pre-/post-study comparisons are shown in Table 2; Figure 7 shows the percentage of sailors with POMS scores worse than the 50th percentile of adult norms.

Table 2. POMS scores. Results presented as MD (IQR).

| POMS scales | Pre-study | Post-study | p-value [A] |
|---|---|---|---|
| Tension-Anxiety | 11.0 (7.0) | 11.0 (9.0) | 0.059 |
| Depression | 12.0 (14.0) | 6.0 (10.0) | 0.027 [B] |
| Anger-Hostility | 13.0 (20.0) | 11.0 (14.0) | 0.137 |
| Vigor-Activity | 14.0 (8.0) | 10.0 (7.0) | <0.001 [B] |
| Fatigue | 11.0 (10.0) | 12.0 (12.0) | 0.790 |
| Confusion-Bewilderment | 8.0 (7.5) | 7.0 (7.0) | 0.056 |
| Total Mood Disturbance | 38.0 (52.0) | 37.0 (47.0) | 0.538 |

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

[B] Statistically significant based on the BH-FDR controlling procedure

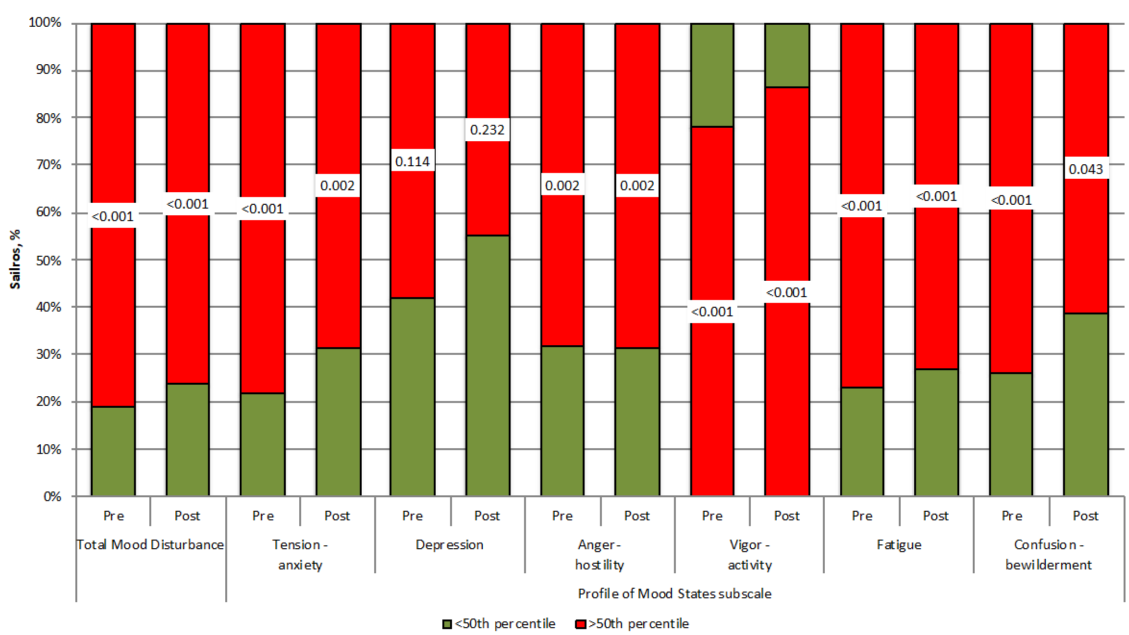

Figure 8. Percentage of sailors with POMS scores worse than the 50th percentile of adult norms.

### 5. Work hours

Based on their activity log data, we assessed the hours that sailors (n = 44) worked and compared them with the criteria of the Naval Availability Factor (NAF) model as revised by Change 2 (OPNAV, 2020). Results showed on average, sailors spent 10.5 hours per day (median value) in productive work, i.e., approximately one hour more than the NAF criterion (Wilcoxon Signed Rank test, p < 0.001). Overall, sailors worked 12.8 hours per day (median value), i.e., approximately 1.2 hours more than the NAF criterion (Wilcoxon Signed Rank test, p = 0.002). Detailed results are shown in Table 3.

Table 3. Sailor daily activity

| Activity | Hours per day | NAF criterion | Average daily criterion | p-value |
|---|---|---|---|---|
| Watch, M ± SD [A] | 6.51 ± 1.27 | 56 hrs/week | 8 hrs/day | < 0.001 [B] |
| Training, MD (IQR) | 0 (0.293) | 8 hrs/week | 1.14 hrs/day | <0.001 [C] |
| Service diversion, MD (IQR) | 0.392 (2.13) | 6 hrs/week | 0.857 hrs/day | 0.100 [C] |
| Productive availability factor, MD (IQR) | 10.5 (3.15) | 67 hrs/week | 9.57 hrs/day | <0.001 [C] |
| Navy availability factor, MD (IQR) | 12.8 (3.20) | 81 hrs/week | 11.6 hrs/day | 0.002 [C] |

[A] Only for watchstanders with activity log data (n = 33)

[B] Unadjusted p-values based on a t-test

[C] Unadjusted p-values based on the Wilcoxon Signed Rank test

## B. CURTAINS ASSESSMENT

Initially, all sailors had the standard curtain in their rack. Before the commencement of the study the ship's leadership replaced the standard curtains in half of the ship racks with the enhanced ones. This analysis focused on comparing the two types of curtains and was conducted on a subset of sailors who had a curtain in their rack (n = 51; 31 with the standard curtain and 20 with the enhanced curtain). All sailors were enlisted personnel (8 E-1 to E-3; 43 E-4 to E-6), from all departments, sleeping in berthing compartments 1 to 5. In terms of their bunk location, sailors were approximately equally distributed (15 in the lower bunk, 18 in the middle, and 18 in the upper bunk).

Sailors were asked to rate their level of agreement with four statements pertaining to conditions in the bunk. In terms of light, 38.1% more sailors preferred the enhanced curtain (Fisher's Exact test, $p = 0.027$). Specifically, 16 (80.0%) sailors with the enhanced curtain agreed (ratings 1+2) with the statement that the enhanced curtain made the bunk darker compared to 13 (41.9%) sailors with the standard curtain. In terms of noise, 5 (25.0%) sailors with the enhanced curtain disagreed (ratings -2 and -1) with the statement that the enhanced curtain made the bunk quieter compared to 20 (64.5%) sailors with the standard curtain (Fisher's Exact test, $p = 0.023$).

In terms of temperature and ventilation in the rack, however, we did not identify any statistically significant differences between the two types of rack curtains. Specifically, 11 (35.5%) sailors with the enhanced curtain disagreed (ratings -2 and -1) with the statement that the enhanced curtain made the bunk more comfortable compared to 3 (15.0%) sailors with the standard curtain, a 20.5% difference (Fisher's Exact test, $p = 0.641$). In terms of ventilation, 1 (5.0%) sailor with the enhanced curtain agreed (ratings 1 and 2) with the statement that the enhanced curtain made the air better in the bunk compared to 7 (22.6%) sailors with the standard curtain (Fisher's Exact test, $p = 0.504$). Detailed results are shown in Figure 8.

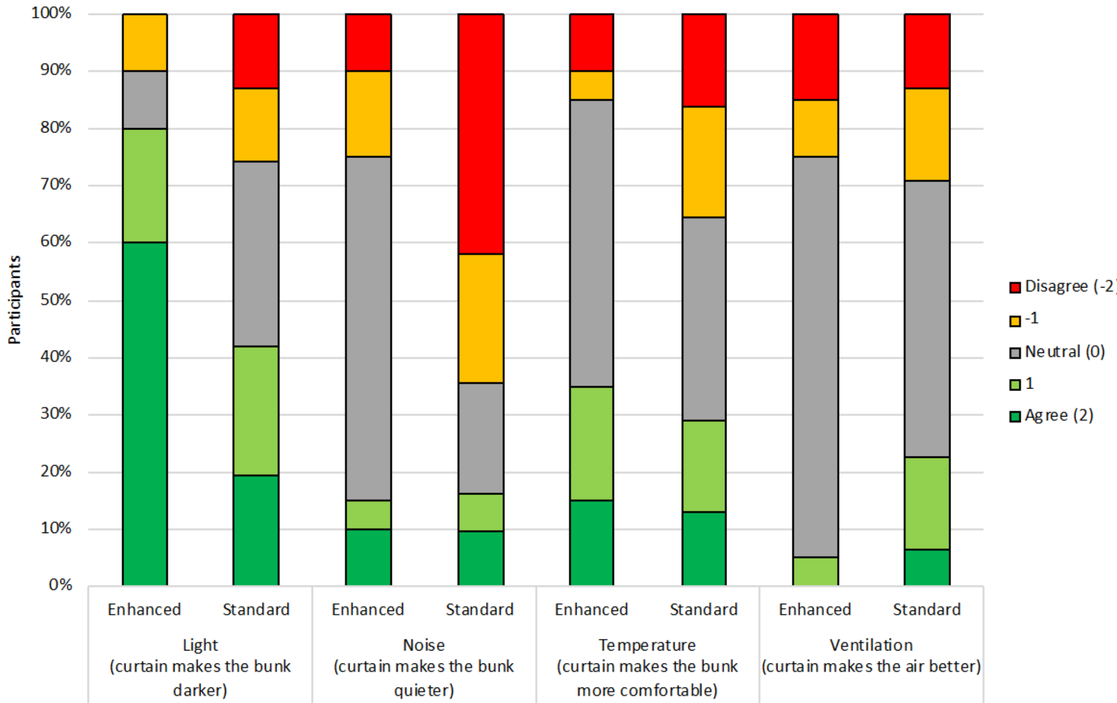


Figure 9. Responses to the question "How do you think your rack curtain affected your ability to sleep?" by curtain type.

Next, sailors were asked to rate several factors in terms of how much they interfere with or promote sleep in the bunk. Results showed that 10 (50.0%) sailors responded that the enhanced curtain they were using promoted (ratings 1 and 2 combined) sleep compared to 7 (22.6%) sailors who used the standard curtain (Fisher's Exact test, $p = 0.061$). Also, 16 (51.6%) sailors with the enhanced curtain responded that cold temperature in their bunk promoted (ratings 1 and 2 combined) sleep compared to 5 (25.0%) sailors who used the standard curtain (Fisher's Exact test, $p = 0.056$). Detailed results are shown in Figure 9.

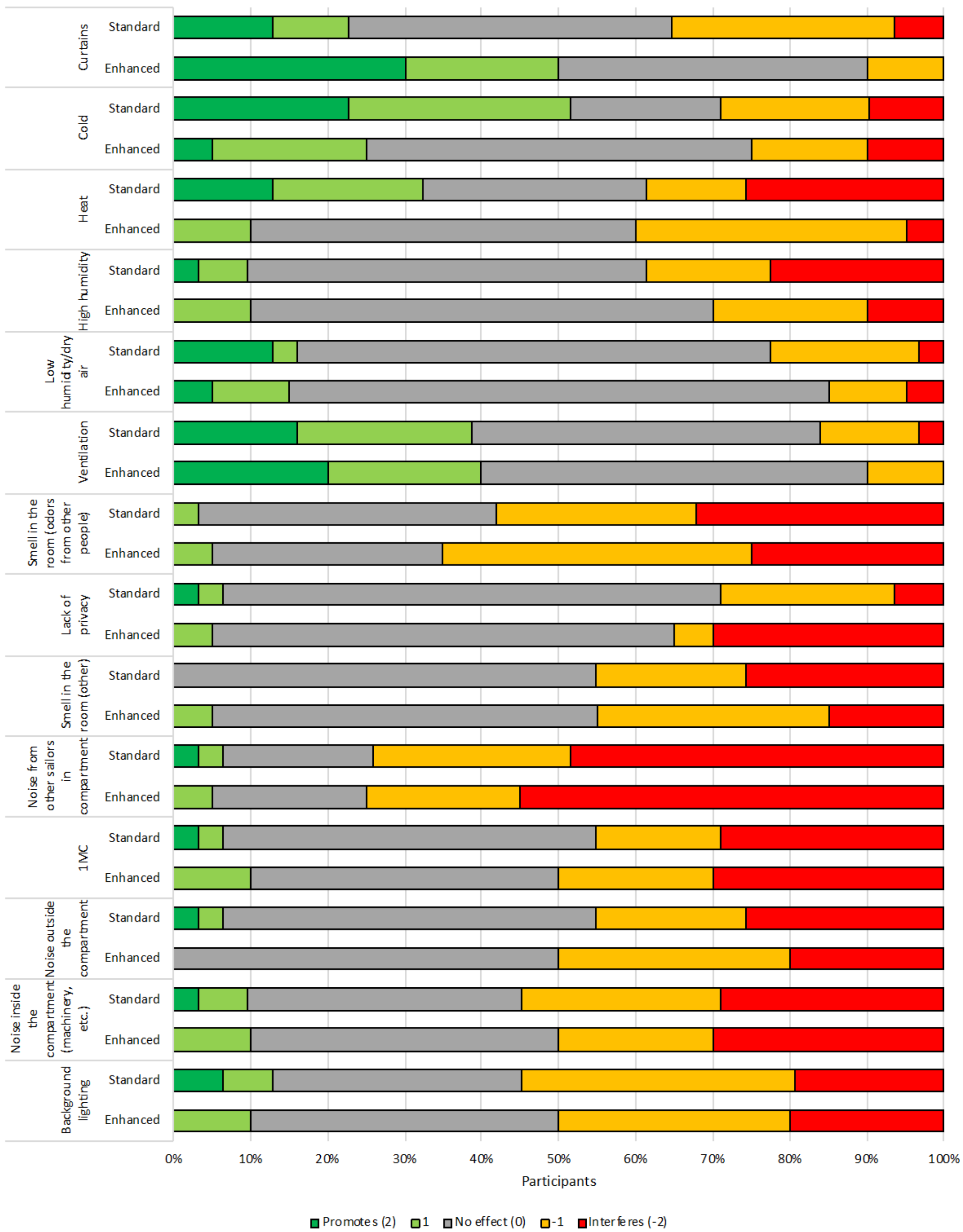


Figure 10. Factors interfering with or promoting sleep in the bunk by curtain type.

Next, we assessed whether curtain type was associated with sailor well-being at the end of the study. Analysis was based on general linear models adjusting for watchstanding status (watchstanders or non-watchstanders). Results showed that ESS and ISI scores were not associated with curtain type (ESS entire model: $R^2 = 0.015$, $F(2, 47) = 0.370$, $p = 0.693$; ISI entire model: $R^2 = 0.076$, $F(2, 46) = 1.90$, $p = 0.162$). Analysis of PSQI scores (entire model: $R^2 = 0.235$, $F(2, 46) = 7.06$, $p = 0.002$), however, showed that the enhanced curtains were associated with higher PSQI scores (i.e., worse sleep quality) ($p = 0.015$).

Analysis of POMS TMD scores was based on a general linear model adjusting for pre-study POMS TMD scores and watchstanding status (watchstanders or non-watchstanders). Results showed that POMS TMD scores at the end of the study improved (lower scores) for sailors with the enhanced curtain compared with sailors with the standard curtain (entire model: $R^2 = 0.505$, $F(3, 44) = 14.9$, $p < 0.001$; POMS TMD $p = 0.076$).

**1. Temperature inside and outside the rack**

Due to missing data, analysis of the temperatures was based on data retrieved from sensors in the racks of 30 sailors. Temperature outside the racks over the entire study was on average 68.9 ± 3.32°F. Outside temperature was within the acceptable range (65 – 78°F) in 88.5% of the data collection period, exceeding 78°F in less than 1% of the time and being lower than 65°F for 10.9% of the time. Temperature inside the racks during the entire study was on average 66.8 ± 3.18°F. Inside temperature was within the acceptable range (65 – 78 °F) for 70.8% of the data collection period. Of note, temperature inside the racks was lower than the criterion of 65°F for 29.2% of the time, a 3-fold increase compared to the temperature outside the rack. The criterion of 78°F was exceeded 0.06% of the time. Detailed results are shown in Figure 11.

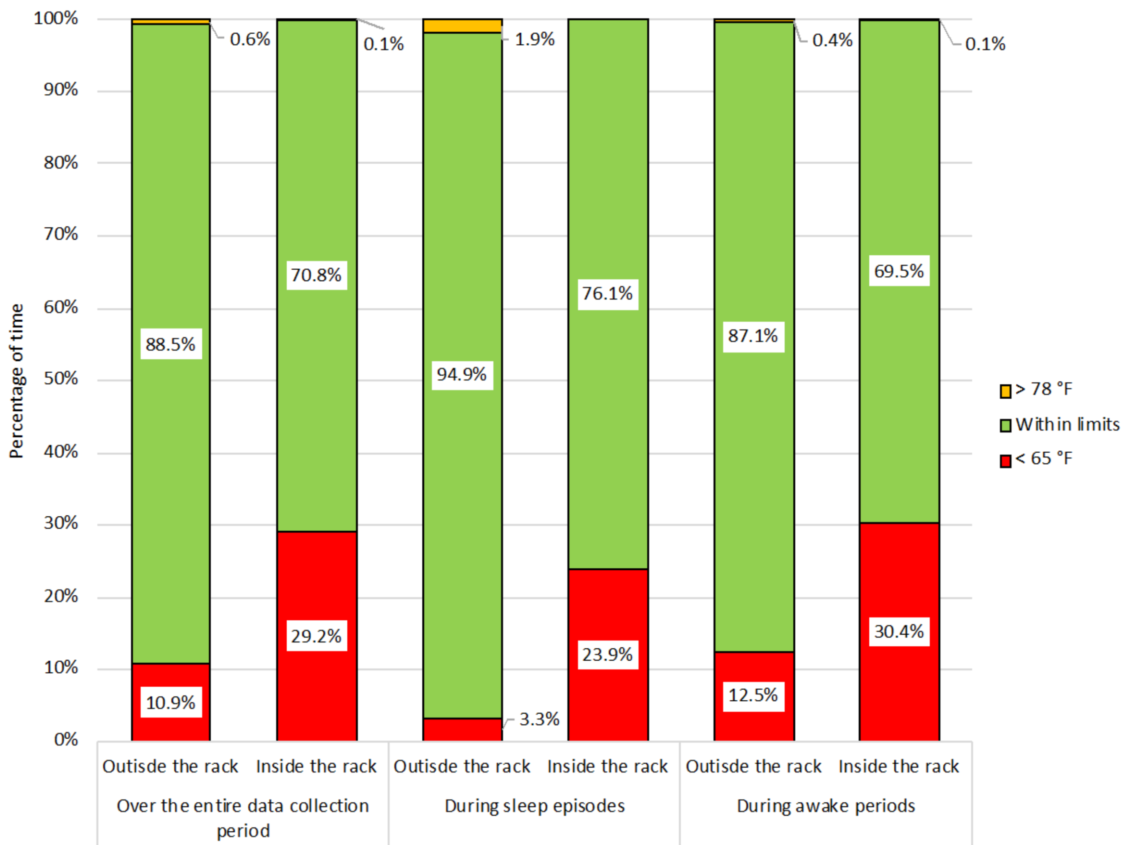


Figure 11. Percentage of time temperature exceeded NAVSEA (2016) criteria.

Temperature, however, was measured primarily to assess whether the temperature inside the rack during sleep differed from the temperature outside the rack. Based on our observations combined with anecdotal data, sailors typically close their curtain when in their rack. On average, the temperature inside the rack was 67.6 ± 2.87°F (ranging from 59.7 to 72.5°F) during sailor sleep episodes, whereas the temperature outside the rack was 71.0 ± 2.9 °F (ranging from 64.4 to 76.1°F) during the same periods. That is, the temperature inside the rack was on average 3.38°F lower compared to outside the rack (Wilcoxon Signed Rank test, $S = 232.5$, $p < 0.001$). The temperature difference during sleep did not differ between bunk locations ($F(2, 27) = 2.73$, $p = 0.083$). Figure 10 shows the scatterplot of temperatures inside and outside the racks both during the sleep episodes and the awake periods. The equivalence line is based on the outside temperature.

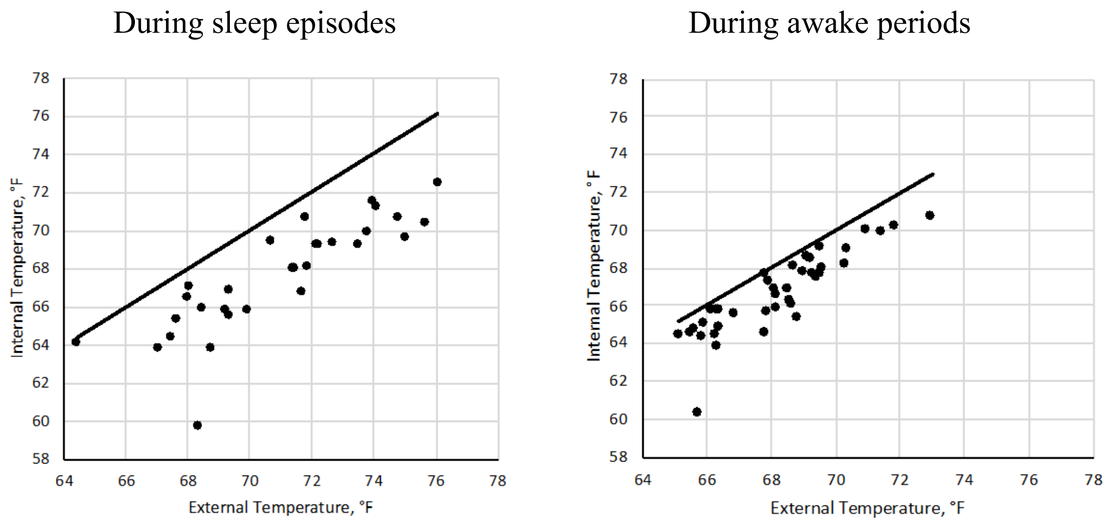


Figure 12. Temperature inside and outside sailor racks. The indicated line of equivalence is based on the data from outside the racks.

Analysis also showed that temperature differential increased as temperature outside the rack increased ($R^2 = 0.290$, $F(1, 27) = 11.0$, $p = 0.003$). For this reason, the association and differences in temperature were further assessed with the Bland-Altman method. Figure 11 shows the Bland-Altman plots for the absolute (diagrams A, B) and percentage-wise (diagrams C, D) differences in temperature. The dotted lines are the 95% agreement limits, whereas the continuous black lines are the regression lines. The slope of the regression line between the difference (absolute and percentage-wise) and the mean temperature showed a consistent downward trend during sleep episodes (as shown in diagrams A and C). In contrast, the difference in temperature between outside and inside the racks remains constant when sailors are awake.

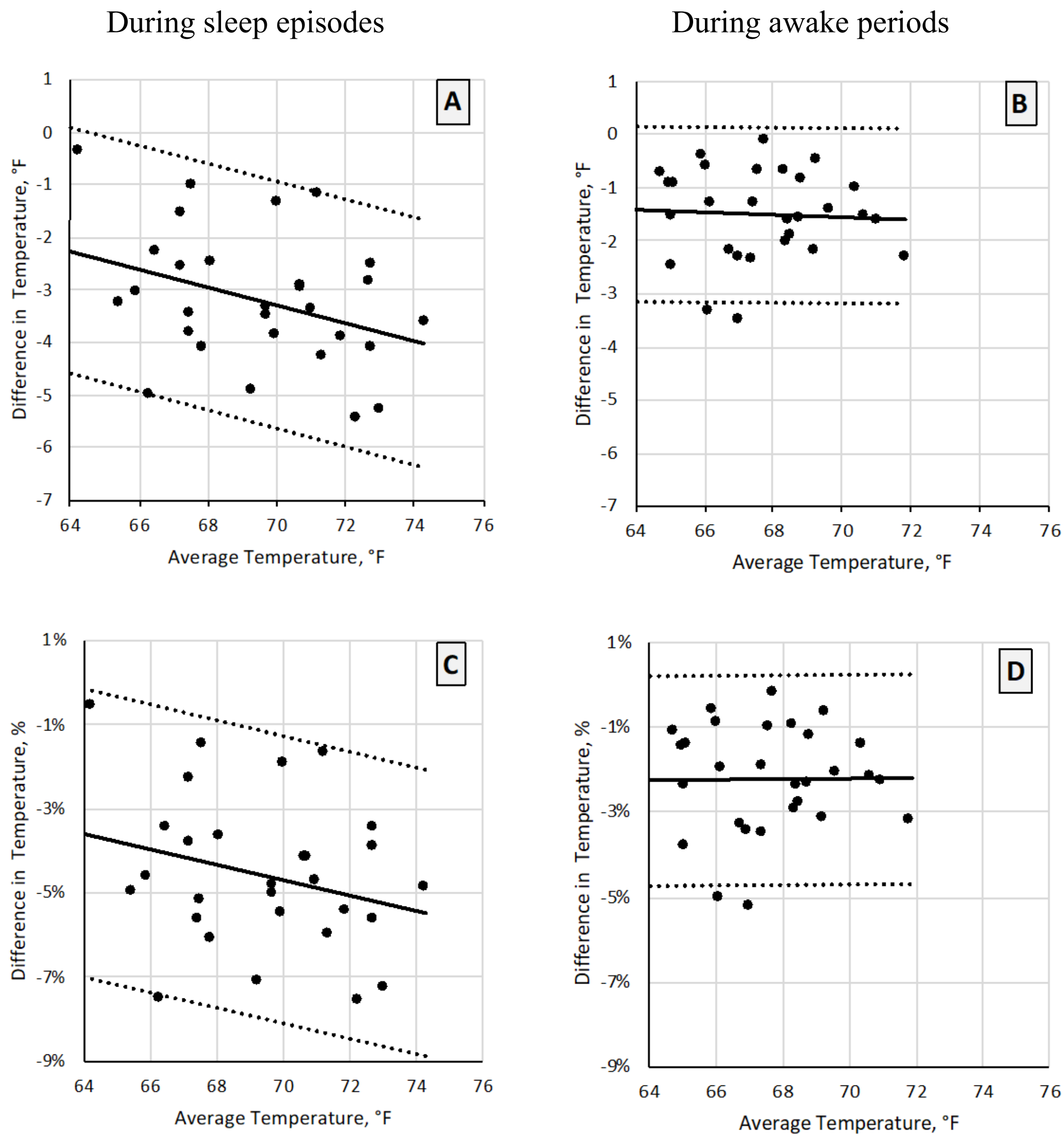


Figure 13. Temperature differences during sleep episodes and awake periods.

We also assessed whether the temperature inside the rack during sleep differed between curtain types. Adjusting for external temperature, we did not identify any statistically significant differences in rack ambient temperature between the enhanced and the standard curtain (entire model: adjusted $R^2 = 0.798$, $F(2, 26) = 56.4$, $p < 0.001$; curtain type $p = 0.634$). The same pattern of results was evident even after adjusting for bunk location (lower, middle, upper).

Given that we did not assess whether sailors closed their curtains while in the rack sleeping, we calculated the temperature difference between the inside and outside of the rack when sailors were sleeping (based on their actigraphy data) in the rack and when they were awake. Our analysis showed that during sleep episodes, the average temperature difference was 2.82 °F (Wilcoxon Signed Rank test, $S = 214.5$, $p < 0.001$), while when sailors were awake, the temperature difference was on average 0.99 °F (Wilcoxon Signed Rank test, $S = 180.5$, $p < 0.001$).

**2. Light inside and outside the rack**

We measured light inside and outside the racks to assess the efficacy of curtains as an external light barrier. Analysis was based on data retrieved from sensors in the racks of 30 sailors. Data included 18,544 5-minute light intervals collected during sleep episodes. Based on the light conditions outside and inside the rack, the 5-minute intervals were classified into four groups. In 17,682 (95.4%) intervals, there was dark outside and inside the rack (0 $lm/ft^2$). Dark outside and light inside the rack was identified in 110 (0.59%) intervals. There were 186 (1.03%) intervals during which light was detected outside and inside the rack but light intensity inside the rack was higher than outside, suggesting that the rack light was on. Lastly, there were 566 (3.05%) intervals in which there was light was detected outside and inside, but light intensity inside the rack was lower than outside.

Aggregated by sailor, we used these last 566 intervals to assess how well the curtains stopped outside light from entering the rack space during sailor sleep. Analysis showed that the median light intensity inside the rack was 0 (2.67) $lm/ft^2$ (ranging from 0 to 3.17 $lm/ft^2$), whereas the corresponding median light intensity outside the rack was 5.06 (3.60 $lm/ft^2$) (ranging from 3.83 to 8.62 $lm/ft^2$). That is, the median difference in light intensity between outside and inside of the rack was 5.46 $lm/ft^2$ (Wilcoxon Signed Rank test, $S = 95.0$, $p < 0.001$). Comparison between curtains could not be performed due to missing data (only five sailors with the enhanced curtain and 13 with the standard curtain were represented in the 566 intervals that this analysis could be based on).

### 3. Example diagram

Figure 12 shows the temperature and light intensity data of Participant 65. Working on the 0600-0900/1800-2100 section of the 3/9 watchbill, the enlisted sailor had a middle rack in berthing compartment 5. The grey areas in Figure 12 denote sleep episodes. Because his watchstanding schedule accommodated it, the sailor slept predominantly at night. Also, he does not seem to be a habitual napper.

In terms of light conditions, most of the time the areas outside and inside the rack were dark, a condition expressed in the "dark outside, dark inside the rack" data. During daytime, there are periods during which the area outside the rack is dark but there is light inside the rack ("dark inside, light inside the rack") and periods during which the area outside the rack is lit but light intensity inside the rack is higher ("light outside, more light inside the rack"). These light conditions may denote periods that the sailor is in the rack but not sleeping or periods during which the rack light was just on without the sailor being present. Lastly, there is a fourth light condition with light in the area outside the rack and less intense light inside the rack. Such a condition is not identified during sleep episodes in Participant 65's data, but it is evident in other sailors.

Temperature-wise, it is in general evident that both the outside temperature and the temperature inside his rack are increasing during his sleep episodes. There is, however, a consistent lag between the two temperatures, i.e., it is always cooler inside the rack than outside with this difference increasing over the course of the night.

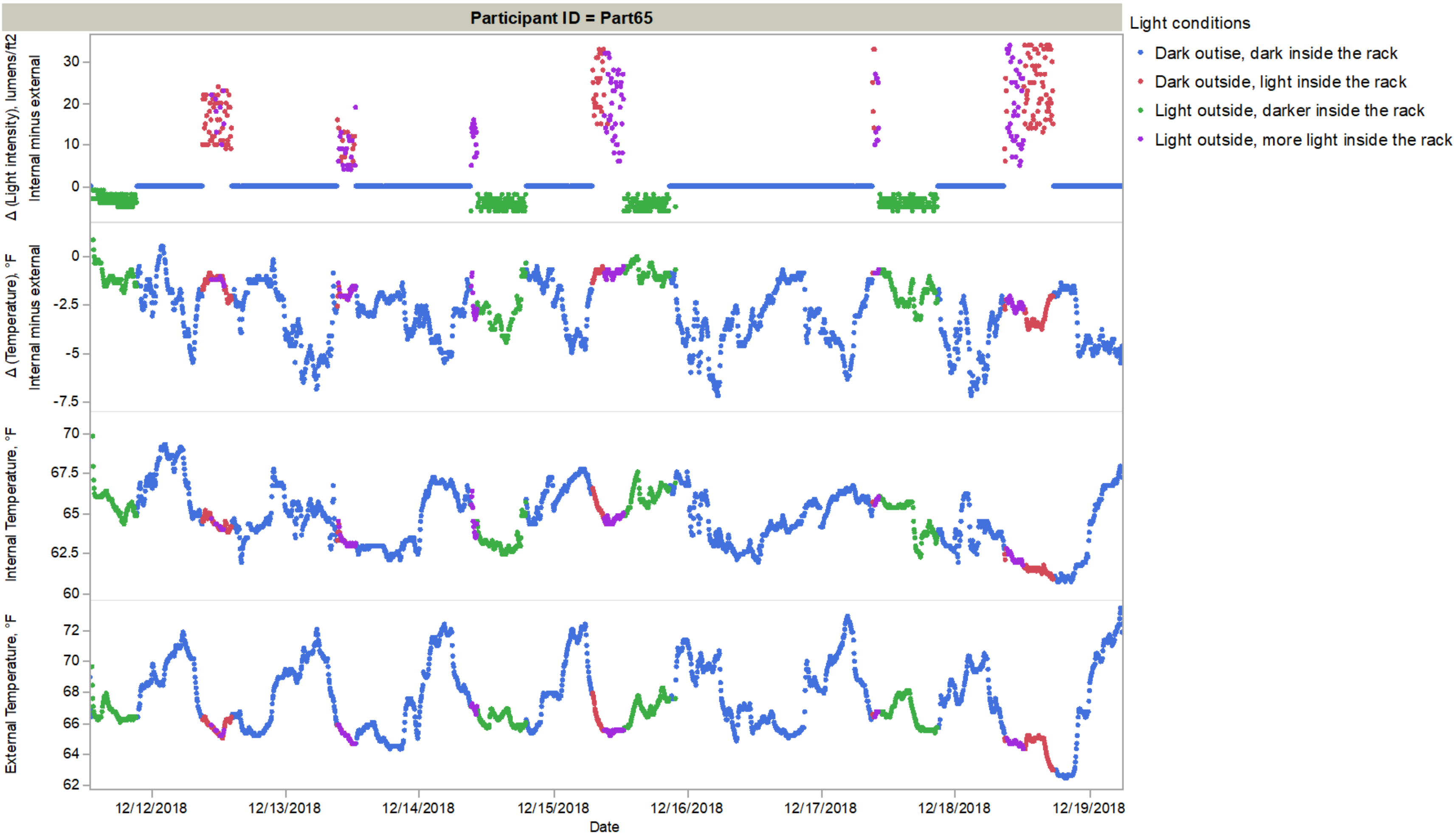


Figure 14. Temperature and light patterns in the rack of Participant65.

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# IV. DISCUSSION

Our study goal was to compare the enhanced rack curtain to the standard curtain in terms of sailor well-being, acceptance, and habitability in the rack. In general, sailor opinions indicated that the enhanced curtain promoted sleep compared to the standard curtain ($p = 0.061$). Specifically, sailors preferred the enhanced curtain because it made the bunk darker ($p = 0.027$) and quieter ($p = 0.023$). The two curtains were equivalent temperature-wise ($p = 0.641$), but the enhanced curtain received 20.5% fewer negative responses compared to the standard curtain. Of note, temperature measurements during sleep did not identify any statistically significant differences in rack ambient temperature between the enhanced and the standard curtains ($p = 0.634$). The two curtains received equivalent responses regarding ventilation in the rack ($p = 0.504$), but the standard curtain received 17.6% more positive responses compared to the enhanced curtain. Also, analysis led to mixed results in terms of sailor well-being. We did not identify any differences in average daytime sleepiness and insomnia symptoms, but sailors reported worse sleep quality with the enhanced curtains ($p = 0.015$). In contrast, mood seemed to be better with the enhanced curtain ($p = 0.076$).

Another interesting finding of our study was that the temperature inside the rack was on average 3.38°F lower compared to the temperature outside the rack ($p < 0.001$), a trend consistent for both rack curtains and sleep/wake conditions. During sleep episodes, the temperature difference was higher (i.e., colder inside the rack) compared to non-sleep periods. This finding can be explained if we consider that sailors tend to close their rack curtain when sleeping. Furthermore, the temperature difference did not remain constant but increased as the temperature outside the rack increased. The fact that the ambient temperature inside the rack was lower than the outside of the rack during sleep can be explained if we consider the important role of the ventilation system in a berthing compartment and how the curtain acts as an airflow barrier. In berthing compartments, the ventilation system supplies air at central locations outside the space of the racks. Consequently, when rack curtains are closed, airflow from outside towards the rack is obstructed and ambient temperature in the rack lags and cannot equalize rapidly with the ambient temperature outside the rack. We postulate that the direction of this lag depends on the environmental temperature outside the hull of the ship (the temperature of the ocean if the location of the berthing compartment is below the water level). Specifically, during this study, the ship was sailing off the coast of the Pacific Northwest with average ocean temperatures of approximately 46°F. This fact may explain why temperature inside the rack space is consistently lower than outside the rack.

Another interesting finding from our study was that the temperature inside the racks during the entire study was on average 66.8 ± 3.18°F, lower than the criterion of 65°F (NAVSEA, 2016) for 29.2% of the time. Even though these measurements cannot be used to characterize the performance of the heating/ventilation/air conditioning (HVAC) system, they show how much temperature inside the racks may deviate from nominal levels.

In conclusion, our findings suggest that the enhanced rack curtain had positive results in terms of light and noise reduction in the rack, and sailors were generally favorable about the design. The enhanced curtain, however, seemed to obstruct airflow in the rack more than the standard design. Hence, the enhanced curtain was associated with even larger temperature differences between the spaces inside and outside the rack compared to the standard curtain (i.e., even colder rack spaces).

## A. STUDY LIMITATIONS

This study has several limitations. First, we were not able to systematically assess whether sailors closed their curtains while sleeping in their rack. Our observations combined with anecdotal data suggest that sailors typically close their curtain when in their rack. Future efforts, however, should assess when the curtains are closed, especially during sleep episodes. Secondly, we did not assess when the sailors had their rack light on. To overcome this issue, light analysis was based on the postulation that the rack light was on when light intensity inside the rack was higher than light intensity outside the rack. Also, we did not assess airflow inside the racks. Lastly, we could not compare the light-blocking properties of the enhanced curtains to the standard curtains due to the lack of appropriate data.

# V. RECOMMENDATIONS

Based on the findings from this study we recommend the following:

- Improve the standard curtain used in racks on USN ships.
- Further assess the utility and acceptance of new curtain designs.
- Assess the effect of rack curtains on habitability conditions in the rack with ships sailing in warmer climates.

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