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ANALYSIS OF SLEEP, MOOD, AND WORKLOAD OF ENGINEERING SAILORS ONBOARD USS GONZALEZ

by

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U.S. Navy Sailors assigned to surface ship engineering departments operate, maintain, and repair many systems that provide critical services such as propulsion, damage control, air conditioning, potable water, electricity, and sewage. These engineering Sailors are expected to stand watch vigilantly and train constantly amid demanding work conditions and marginal manning levels. These issues potentially drive higher individual workload, restrict sleep opportunities, and erode crew morale. These challenges may be especially prevalent while ships are in the Basic Phase and may have been further exacerbated during the COVID-19 pandemic. Therefore, the objectives of this thesis are a) to assess the well-being, sleep attributes, and workload of engineering Sailors onboard USS Gonzalez (DDG 66), and b) to explore how the spread of COVID-19 affected the readiness of the department during the Basic Phase.

Sailors were assessed using questionnaires, actigraphy, and self-report activity logs. Underway 1—dominated by 5/10 watch rotation and higher OPTEMPO—reflected worse mood compared to Underway 2, which was characterized by more 3/9 watch rotations and lower OPTEMPO (Underway 1 TMD: 68 ± 36.5; Underway 2 TMD: 53.1 ± 30.8; Wilcoxon signed rank test, $n = 26$, $S = -103$, $p = 0.006$). Mood, sleep quality, daytime sleepiness, insomnia symptoms, and proclivity to nap during Underway 1 and Underway 2 were worse compared to data collected from engineering departments across 14 other ships.

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ANALYSIS OF SLEEP, MOOD, AND WORKLOAD OF ENGINEERING SAILORS ONBOARD USS GONZALEZ

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

AASM	American Academy of Sleep Medicine
ARG	amphibious ready group
AWP	availability work package
BA	Billets Authorized
BH-FDR	Benjamini–Hochberg False Discovery Rate
BUPERS	Bureau of Naval Personnel
CNO	Chief of Naval Operations
COVID-19	Coronavirus Disease 2019
CR	Comprehensive Review
CSG	carrier strike group
DOD	Department of Defense
DON	Department of the Navy
ESG	expeditionary strike group
HADR	humanitarian assistance and disaster relief
ICAV	inspections, certifications, assessments, and visits
JCIDS	Joint Capabilities Integration and Development System
MPN	Military Personnel, Navy
MPT&E	Manpower, Personnel, Training, and Education
NAF	Navy Availability Factor
NASA	National Aeronautics and Space Administration
NAVMAC	Navy Manpower Analysis Center
NEC	Navy Enlisted Classification
NHHC	Naval History and Heritage Command
NINDS	National Institute of Neurological Disorders and Stroke
NRC	National Research Council
NREM	non-rapid eye movement
OMB	Office of the Management and Budget
OPNAV	Office of the Chief of Naval Operations
OFRP	Optimized Fleet Response Plan
OPHOLD	operational hold

PAF	Productive Availability Factor
PACFLT	United States Pacific Fleet
PESTO	personnel, equipment, supply, training, and ordnance
POE	Projected Operational Environment
PPBE	Planning, Programming, Budgeting, and Execution
REM	rapid eye movement
RCN	Rating Control Number
ROC	Required Operational Capabilities
SRS	Sleep Research Society
SMD	Ship Manpower Documents
SURFLANT	United States Naval Surface Forces, Atlantic
SURFOR	United States Naval Surface Forces
SURFPAC	United States Naval Surface Forces, Pacific
SWAT	Subjective Workload Assessment Technique
SWS	slow-wave sleep
TLX	Task Load Index
USFF	United States Fleet Forces Command
WW1	World War 1

EXECUTIVE SUMMARY

The responsibilities of the Engineering Department onboard U.S. Navy destroyers are inherently demanding. Sailors assigned to the Engineering Department operate, maintain and repair many of the systems throughout the ship in order to provide various critical services such as propulsion, damage control, air conditioning, potable water, electricity, and sewage. Engineering Sailors deliver round-the-clock support to all evolutions onboard while continuously subjected to demanding work conditions, to include long work hours, extreme heat, high stress, and inadequate rest. In this grueling environment—coupled with marginal manning levels—engineering Sailors are not only expected to stand watch vigilantly, but also to train constantly, gain new skills and expand their knowledge.

Anecdotal reports suggest that these impediments to higher performance may be widespread during the Basic Phase of the OFRP cycle and may even be further aggravated at the height of the COVID-19 pandemic. Therefore, this thesis aimed to a) assess the sleep attributes, mood, and workload of engineering Sailors onboard USS Gonzalez, and b) explore how the spread of COVID-19 affected the readiness of the Engineering Department during the Basic Phase.

Participants (N = 57) were evaluated using standardized questionnaires—Profile of Mood Scales (POMS), Insomnia Severity Index (ISI), Epworth Sleepiness Scale (ESS), Pittsburgh Sleep Quality Index (PSQI)—actigraphy, and self-reported activity logs. Data collection took place during the Basic Phase over two underway periods of 15 days each. Underway 1 was characterized by the prevalence of non-circadian-based watch rotations and higher OPTEMPO, as indicated by the Engineering Department's MOB-D certification. Underway 2 was characterized by the dominance of the "3/9" and "4/8" watch rotations and lower OPTEMPO when the Engineering Department transitioned to a supporting role to the other departments' training events.

The results suggest positive effects of lower OPTEMPO and the use of circadian watchbills; however, this study is unable to distinguish the effects between the two factors.

All participants received less than 8 hours of sleep a day during Underway 2, but fewer Sailors responded that their sleep was less than adequate compared to Underway 1 (Underway 1: 74.1%, Underway 2: 51.9%; McNemar's test, n = 27, $\chi^2 = 4.5$, p = 0.034). Underway 2 mood was also better than Underway 1 (Underway 1 TMD: 68 ± 36.5, Underway 2 TMD: 53.1 ± 30.8; Wilcoxon signed rank test, n = 26, S = -103, p = 0.006).

Lower OPTEMPO does not signify zero OPTEMPO, which may explain the lack of differences identified in some of the metrics. Between Underway 1 and 2, no differences were recognized in sleep quality (post-Underway 1 PSQI: 9.1 ± 3.6; post-Underway 2 PSQI: 9.3 ± 3.4; Wilcoxon signed rank test, S = -19, n = 23, p = 0.574), daytime sleepiness (post-Underway 1 ESS: 16; post-Underway 2 ESS: 18; McNemar's test, $\chi 2 = 0.5$, n = 27, p = 0.479), insomnia symptoms (post-Underway 1 ISI: 14.1 ± 6.04; post-Underway 2 ISI: 13.23 ± 6.2; Wilcoxon signed rank test, S = -18.5, n = 25, p = 0.627), sleep duration (Underway 1: 6.3[0.9] hrs,; Underway 2: 6.3[1.2] hrs.; Wilcoxon signed rank test, S = -9, n = 16, p = 0.669), and the number of sleep episodes per day (Underway 1: 1.8 ± 0.4 sleep episodes per day; Underway 2: 1.9 ± 0.4 sleep episodes per day; Wilcoxon signed rank test, S = 14.5, n = 16, p = 0.472).

The results also hint at the difficulty of the Basic Phase and the adverse effects of COVID on the Engineering Department of USS Gonzalez; however, this study cannot differentiate between the two. Compared to pre-COVID data collected from engineering departments across 14 other ships, Underway 1 was worse in terms of mood (post-Underway 1 TMD: 68[60], 14 other ships TMD: 29.5[45]; one-sample median test, T(42) = 358, p < 0.001), sleep quality (Underway 1 PSQI: 9[6], 14 other ships PSQI: 7[5]; one-sample median test, T(34) = 201, p = 0.0004), daytime sleepiness (Underway 1 ESS: 11.5[10], 14 other ships ESS: 9.5[6]; one-sample median test, T(43) = 204.5, p = 0.015), insomnia symptoms (Underway 1 ISI: 13.5[10.8], 14 other ships ISI: 10[7]; one-sample median test, T(43) = 251.5, p = 0.002), and proclivity to nap (Underway 1: 1.7[0.6] sleep episodes per day; 14 other ships: 1.4[0.5] sleep episodes per day; one-sample median test, T(23) = 106.5, p = 0.0009) .

Similarly, Underway 2 was worse than 14 other ships in terms of mood (post-Underway 2 TMD: 46.1[46.4], 14 other ships TMD: 29.5[45]; one-sample median test, T(35) = 192.5, $p = 0.002$), sleep quality (Underway 2 PSQI: 9[4.5], 14 other ships PSQI: 7[5]; one-sample median test, T(37) = 222.5, $p = 0.001$), daytime sleepiness (Underway 2 ESS: 11[6], 14 other ships ESS: 9.5[6]; one-sample median test, T(37) = 148, $p = 0.029$), insomnia symptoms (Underway 2 ISI: 12.5[8], 14 other ships ISI: 10[7]; one-sample median test, T(35) = 157.5, $p = 0.011$), and the propensity to nap (post-Underway 2: 1.8[0.6] sleep episodes per day; 14 other ships: 1.4[0.5] sleep episodes per day; one-sample median test, T(36) = 279.5, $p < 0.0001$).

Workload during Underway 1 was not statistically significant from the Productive Availability Factor (PAF) allotted in the Navy Availability Factor (NAF; Underway 1 = 76[36.9] hours, PAF = 67 hours; one-sample median test, T(13) = 21.5, $p = 0.194$), but was disproportionately distributed among the Sailors. Workload during Underway 2 was greater than the PAF (Underway 2 = 74.1[12.1] hours, PAF = 67 hours, one-sample median test, T(21) = 75.5, $p = 0.011$), and was more evenly distributed among Sailors—21 out of the 22 Sailors reported 72.2 ± 10.2 hours of workload per week.

This thesis was originally intended to evaluate whether increasing the manning levels of the Engineering Department results in improved well-being and performance. However, the manning goals were not met in order to conclusively identify the positive effects of enhancing manning. While this thesis offers promising insights, the presence of actual Sailors is required to conduct a more thorough comparison between a control ship with typical manning levels and a test ship with higher-than-normal manning levels.

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I am asked for very little compared to how much I am being given.

—St. Josemaria Escriva (Furrow, 1986, p. 1)

For my family—my parents BGEN Mariano and Navie Veloria, Philippine Army (Retired); my siblings LCDR Maria Josefa Veloria Bainco, LCDR Maria Cristina Veloria Diaz, EMC(SW) Michael Veloria, LT Maria Luzviminda Veloria, Rafael 1 & 2, and Maria Angela Isabel Veloria; my brothers-in-law LT Nestor Diaz and LSCS(SW/AW) Vhon Bainco; my sister-in-law Christine Veloria; my nieces Mirjana, Tabitha, Olivia and Hiraya; my nephew Jeremiah; and my fiancée LT Arleen Estabillo—I thank every single one of you for your unwavering support.

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This is dedicated to the Sailors of the Engineering Department on the USS Gonzalez (DDG 66) who volunteered their time for this study. I also dedicate this thesis to all the snipes I had the honor of serving alongside, especially the Sailors assigned to the Main Propulsion Division onboard USS Benfold (DDG 65) circa 2015–2017.

May God bless us all.

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I. INTRODUCTION

A. BACKGROUND

In 2017, successive surface ship mishaps that led to the death of 17 Sailors prompted a Comprehensive Review (CR) of surface force accidents from the past decade. From the Comprehensive Review, a recommendation identified as CR53 called for a study to assess whether increasing DDG manning levels during the Basic Phase results in reductions in sailor workload (Davidson, 2017). Garbacz (2019) and Murph (2019) attempted to address CR53, despite facing manning challenges that prevented the exact comparison directed by it. Garbacz's (2019) and Murph's (2019) theses provided promising insights on the positive effects of enhancing manning on sailor well-being, but also ironically highlighted the challenge of increasing ship-wide manning.

Building on the foundations laid by Garbacz (2019) and Mansfield (2019), the initial aim of this thesis was to compare two Arleigh Burke-type destroyers in the Basic Phase to explore the effects of increased manning on the well-being and work hours of Sailors assigned to the Engineering Department. The Engineering Department on the control ship was intended to be manned at typical levels, while the Engineering Department on the test ship was projected to be manned with higher fit and fill rates. Administratively, the necessary manning was provided. However, various factors—to include the spread of the Coronavirus Disease 2019 (COVID-19)—greatly reduced the number of fit-for-duty Sailors onboard the test ship. Given that the assumption of augmented manning in the test ship was not realized, the overarching aim of this thesis was adjusted to assess the conditions that potentially impede engineering Sailors from conducting their duties at peak performance.

The responsibilities of the Engineering Department onboard U.S. Navy destroyers are inherently demanding. Engineering Sailors operate, maintain, and repair many of the systems on the ship providing critical services such as propulsion, damage control, air conditioning, potable water, electricity, and sewage. The Engineering Department Sailors deliver 24-hour support to all activities onboard while continuously subjected to demanding work conditions, to include long work hours, extreme heat, high stress, and inadequate rest. Amidst these difficulties, Sailors in the Engineering Department are not only expected to stand watch vigilantly, but also to constantly train, gain new skills, and expand their knowledge. Anecdotal reports indicate that these challenges are especially prevalent while the ship is in the Basic Phase.

During the Basic Phase of the Optimized Fleet Response Plan (OFRP) cycle, each ship and crew undergo certification events to demonstrate proficiency in activities such as getting underway, combating major casualties, proper operation of combat systems, and safe navigation (Chief of Naval Operations [CNO], 2014). All of these activities rely on the readiness and performance of crewmembers in the Engineering Department. In order to progress to the more complex events of the Integrated and Advanced Phases required for deployment certification, the ship must first successfully pass the Basic Phase (CNO, 2014).

The challenges that accompany Engineering Department operations may jeopardize the overall safety and operational effectiveness of the ship. These challenges are already recognized, albeit anecdotally: lower manning levels across the fleet, higher individual workload, restricted sleep opportunities, eroding crew morale, and now the emergence of the invisible coronavirus are all factors that increase mission risk. This thesis aims to explore these issues to better inform decision-makers of the risks impacting our Navy.

B. SCOPE

The overarching aim of this thesis is to assess the work conditions of sailors assigned to the Engineering Department on the USS Gonzalez (DDG 66) during two underway periods in the Basic Phase.

C. STUDY OBJECTIVES

This study has the following objectives:

1. Assess mood, sleep attributes, and workload of engineering Sailors.

2. Assess whether mood, sleep attributes, and workload of Sailors on the Engineering Department of USS Gonzalez are comparable to the data collected by NPS on Sailors on other ships.
3. Explore how the spread of COVID-19 on the USS Gonzalez affected the readiness levels and performance of the Engineering Department.

D. THESIS OUTLINE

The remainder of this thesis is organized as follows: Chapter II reviews the process of manning ships in the U.S. Navy and reviews the literature related to sleep, workload, mood, and the challenges brought about by COVID-19. Chapter III discusses the procedures used in the collection, preparation, and analysis of the data. Chapter IV presents the results. Chapter V provides the corresponding findings and the limitations of the study. Finally, Chapter VI offers the conclusions and recommendations of the study.

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II. LITERATURE REVIEW

This chapter has two goals. First, it provides an overview of the Navy's Manpower, Personnel, Training and Education (MPT&E) Process and the readiness-generation plan as they relate to the surface fleet. Second, this chapter explores the existing literature related to sleep, workload, mood, and the disruption of operations caused by infectious diseases, including COVID-19.

A. MANPOWER, PERSONNEL, TRAINING, AND EDUCATION

Manpower, Personnel, Training, and Education (MPT&E) refers to the process in which the Navy determines the manpower requirements of the force and obtains the personnel necessary to meet those requirements (Rodney, 2017). It is a complex process that involves the input of multiple organizations within the Navy and is characterized by four major steps shown in Figure 1: manpower requirements, manpower programming, personnel planning, and personnel execution (Rodney, 2017). The National Defense Strategy stimulates the progression by providing "a strategic demand signal to the Navy" (Rodney, 2017, p. 3). Figure 1 shows the flow of the MPT&E process.

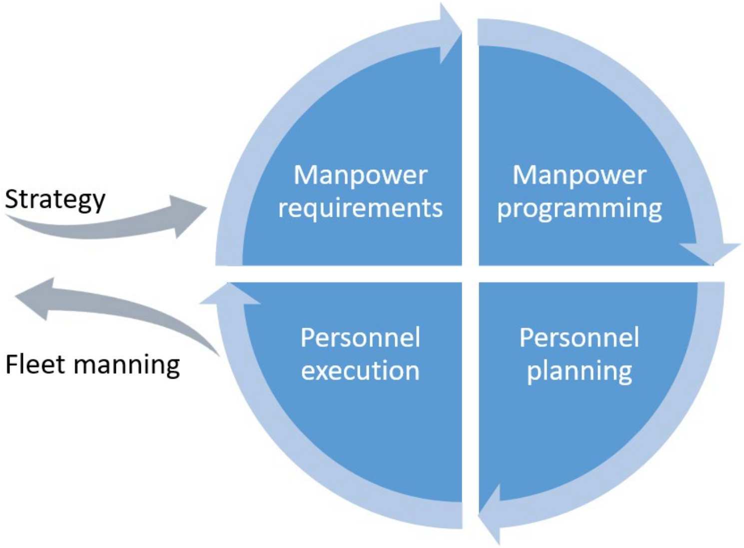

Figure 1. DON MPT&E process. Adapted from Rodney (2017).

In the first stage of the MPT&E process, the manpower requirements are determined (Rodney, 2017). The Navy Manpower Analysis Center (NAVMAC) leads the development of the billets by coordinating with various entities such as the warfare sponsors, U.S. Fleet Forces Command (USFFC), and the Office of the Chief of Naval Operations (OPNAV) N13M (NAVMAC, 2013). The factors that drive the manpower requirements include the parameters defined in the Required Operational Capabilities (ROC) and Projected Operational Environment (POE), the workload allowances proposed in the Navy Availability Factor (NAF), system maintenance demands, and the assignment of special billets such as command master chief or career counselor (CNO, 2019). Ultimately, the end products of the Manpower Requirements stage of MPT&E are the Ship Manpower Documents (SMD). Each SMD specifies the minimum quantity and quality of Sailors required to man a specific type of ship (CNO, 2019).

The second stage of the MPT&E process—Manpower Programming—refers to the procurement of funding. Manpower programming occurs within the Department of Defense's (DOD) Planning, Programming, Budgeting, and Execution (PPBE) Process (CNO, 2019). PPBE, shown in Figure 2, is a calendar-driven process that enables the funding of the Joint Capabilities Integration and Development System (JCIDS) and the Defense Acquisition System (Blickstein et al., 2016).

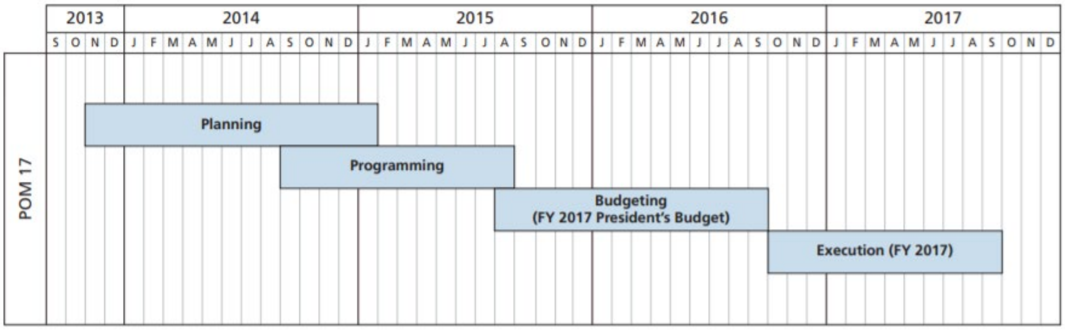

Figure 2. DOD PPBE process. Source: Blickstein et al. (2016).

In the Planning stage of the PPBE, strategic priorities are established, and the corresponding capabilities required to achieve them are identified (DOD, 2017). In the programming stage, a top-down approach determines how future resources are to be allocated between competing requirements (DOD, 2017). In the Budgeting stage, a bottom-up process identifies the proper pricing of programs (DOD, 2017). In the Execution stage, the approved plan is executed and monitored (DOD, 2017). The PPBE process starts from within the Navy and Marine Corps, moves up to the bigger Department of the Navy (DON), then proceeds to the Office of the Secretary of Defense (OSD), and continues to the Office of Management and Budget (OMB) (Rodney, 2017).

The end result of the manpower programming stage of the MPT&E process is the Billets Authorized (BA) funded by Congress (Rodney, 2017). While Congress sets the maximum size of the military's active duty component for each fiscal year ("end strength"), resource sponsors—such as OPNAV N2/N6/N4—and Budget Submitting Offices (BSO)—such as the Bureau of Naval Personnel (BUPERS) and the United States Pacific Fleet (PACFLT)—decide the composition of the authorized end strength (Rodney, 2017).

In the third stage of MPT&E, Personnel Planning, plans are developed to acquire personnel ("bodies") that match up to the quantities and qualities authorized (Rodney, 2017). This process considers the many aspects of personnel management, to include strength planning, community management, accession planning, recruiting, training and education, advancement or promotion, retention, and compensation (Rodney, 2017). Because much of the Navy operates with a closed labor market, multiple issues necessitate the consideration of trends and decisions over many years. For example, a goal of having 500 Sailors with five years of service and certain qualities in the next year requires having at least 500 Sailors with four years of service and opportunities for development (e.g., technical, professional, tactical, and educational) in the current year.

In the final stage of MPT&E, Personnel Execution, the plans for matching the bodies with the billets are implemented toward meeting congressional end strength while keeping the Navy within the Military Personnel, Navy (MPN) appropriation (Rodney, 2017). This step includes the movement of personnel through training pipelines, the assignment of personnel to billets onboard ships, and the assessment of the personnel plans being executed. In the end, fleet manning is evaluated using the Rating Control Number (RCN) Fit, RCN Fill, and Navy Enlisted Classification (NEC) Fit. Fill refers to the percentage of total personnel onboard against the total number of billets authorized, while Fit refers to the alignment of sailor skills and experience to the billets.

Despite the robust process of the MPT&E, manning issues always exist in the fleet. Past Commander, Naval Surface Forces (SURFOR) and Commander, Naval Surface Forces, Pacific (SURFPAC) VADM Brown (2018) expressed, “Our goals are for ships to deploy 92 percent fit, 95 percent fill” (p. 2), alluding to the barriers to meet 100% fit and fill levels. At the unit level, commanding officers of ships may request an operational hold (OPHOLD) of personnel, justifying the delay of the sailor’s transfer to their new command is required to “meet the critical and immediate operational needs” of the current command (BUPERS, 2019, p. 2). Similarly, one of the ways SURFOR manages manning concerns is by focusing on the NEC metrics of ships about to deploy (Rodney, 2017). When required, SURFOR considers the drastic approaches of cross-decking or diverting, which involves the temporary or permanent transfer of personnel from one unit to another (Rodney, 2017). Although these remedies improve the manning of one afloat unit, they may be disruptive to another command, as well as to the Sailors and the families involved.

B. OPTIMIZED FLEET RESPONSE PLAN

Fleet manning goals are matched to the Optimized Fleet Response Plan (OFRP) cycle: manning target levels are reduced when the ship is in the maintenance phase (Rodney, 2017). The OFRP is the overarching policy for the management of the fleet and is “designed to optimize the return on training and maintenance investments, maintain Sailor quality of service, and ensure units and forces are certified in defined, progressive levels of employable and deployable capability” (CNO, 2014, p. 1-2). It is a framework for force generation that integrates other processes in the Navy such as manning and individual training, unit and advanced training, maintenance, modernization, and logistics (CNO, 2014). Figure 3 illustrates the four phases of the OFRP cycle.

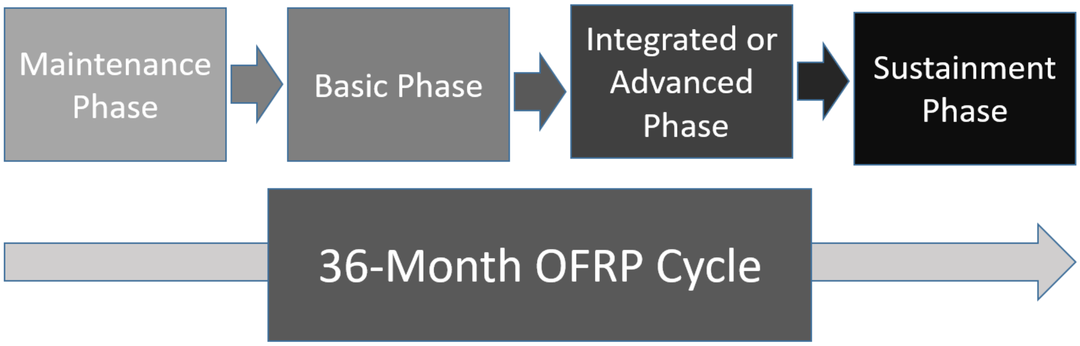

Figure 3. OFRP cycle. Adapted from DOD Office of Inspector General (2020).

The OFRP cycle begins at the maintenance phase, then progresses to the basic phase, the integrated or advanced phase, and finally to the sustainment phase. The maintenance phase provides the optimal opportunity for major shipyard or depot-level repairs, platform modernization, or upgrades (CNO, 2014), in addition to the opportunity for Sailors to complete the required schoolhouse training to support the subsequent phases of the OFRP (SURFPAC & Naval Surface Forces, Atlantic [SURFLANT], 2018). The goals of this period are the timely completion of the maintenance package, the successful completion of Inspections, Certifications, Assessments, and Visits (ICAV), and continued emphasis on individual and team readiness (CNO, 2014).

In the basic phase of the OFRP cycle, ships concentrate on developing unit core capabilities (CNO, 2014). These milestones are assessed through the completion of corresponding ICAV across the pillars of personnel, equipment, supply, training, and ordnance (PESTO) (SURFLANT & SUFPAC, 2018). At the conclusion of the basic phase, ships may be tasked as an independent unit to conduct focused operations such as humanitarian assistance and disaster relief (HADR), homeland security, and support of phase zero operations (CNO, 2014).

The next phase of the OFRP, the integrated or advanced phase, is tied to the employment of the units. The integrated phase develops the warfare skill sets of individual ships into a synchronized carrier strike group (CSG), expeditionary strike group (ESG), or amphibious ready group (ARG) (SURFLANT & SURFPAC, 2018). The advanced phase, on the other hand, applies to ships that deploy separately from a CSG, ESG, or ARG but nonetheless operate with other units (CNO, 2014). In order to certify for deployment, forces are required to meet the acceptable levels of proficiency in all required mission areas delineated in the integrated or advanced phases of the OFRP (CNO, 2014).

Finally, during the sustainment period, ships maintain their warfighting readiness beyond their deployment period (CNO, 2014). While sustaining deployable readiness, the ship's force and outside entities conduct material assessments to develop the availability work package (AWP) for the upcoming maintenance phase (SURFLANT & SURFPAC, 2018). Altogether, the four phases of the OFRP sum up to 36 months and aim for a more stable deployment cycle—a cycle that offers predictability to Sailors and their families, improves manning, enables better preparation for maintenance, and facilitates the timely delivery of ships back to sea.

Accomplishing these goals may require more consideration of the Basic Phase. The Basic phase is intended for the formation and training of cohesive warfighting teams, as well as building the rest of the foundations for a successful deployment; but there is a mismatch with manning. VADM Brown, former Commander, Naval Surface Forces, attested that most ships do not receive 92% fit and 95% fill—the Navy's metrics for a "fully manned" ship—until the start of the Advanced Phase (Larter, 2020). The Basic Phase depicts a period of lower manning levels amid higher levels of workload. Accordingly, exploring the associated risks and challenges to sailor performance and well-being may be worthwhile.

C. SLEEP

Sleep can be defined as the "reversible condition of reduced responsiveness usually associated with immobility" (Cirelli & Tononi, 2008, p. 1605). This reversibility discriminates sleep from a coma, while the decreased reactions to stimuli differentiate sleep from consciousness (Cirelli & Tononi, 2008).

While the biological purpose of sleep remains somewhat of a mystery, various research efforts highlight the role of sleep in many processes of the body. Sleep facilitates critical functions of the brain such as neuronal connectivity that assist in concentration and learning (National Institute of Neurological Disorders and Stroke [NINDS], n.d.). Sleep also affects metabolism, immune function, disease resistance, and mood (Zielinski et al., 2016). Furthermore, sleep minimizes caloric expenditure, restores brain energy, facilitates the removal of the toxic byproducts of wakefulness, and offers a reset for degrading performance as a result of cumulative wakefulness (Krueger et al., 2016)

The American Academy of Sleep Medicine (AASM) and Sleep Research Society (SRS) developed consensus recommendations for the duration of sleep required on a regular basis for optimal health: 7 or more hours per night for adults (18-60 years old; Watson et al., 2015a; 2015b) and 8–10 hours per night for teenagers up to 18 years old (Paruthi et al., 2016). More than 9 hours of sleep per night may be suitable for adults recuperating from illness or sleep debt. According to Watson and colleagues (2015b), "Sleeping less than 7 hours per night on a regular basis is associated with adverse health outcomes, including weight gain and obesity, diabetes, hypertension, heart disease and stroke, depression, and increased risk of death" (p. 843). Beyond adverse health outcomes, chronic lack of sleep is associated with an increased risk of accidents, reduced performance, and more errors (Watson et al., 2015a; 2015b). Factors required of healthy sleep include acceptable duration, regularity, adequate quality, and lack of disturbances (Paruthi et al., 2016).

1. Architecture of Sleep

Two broad stages—rapid eye movement (REM) and non-REM (NREM)—are used to classify sleep cycles based on physiology and recognizable brain activity (Zielinski et al., 2016). Individuals cycle alternately between the NREM and REM over the course of a sleep episode, although the function of the rotations is still not fully understood (Colten & Altevogt, 2006). Nevertheless, irregular sequencing of the NREM-REM cycle is associated with sleep disorders (Colten & Altevogt, 2006). Figure 4 shows the typical progression of sleep states for a young adult over a single night.

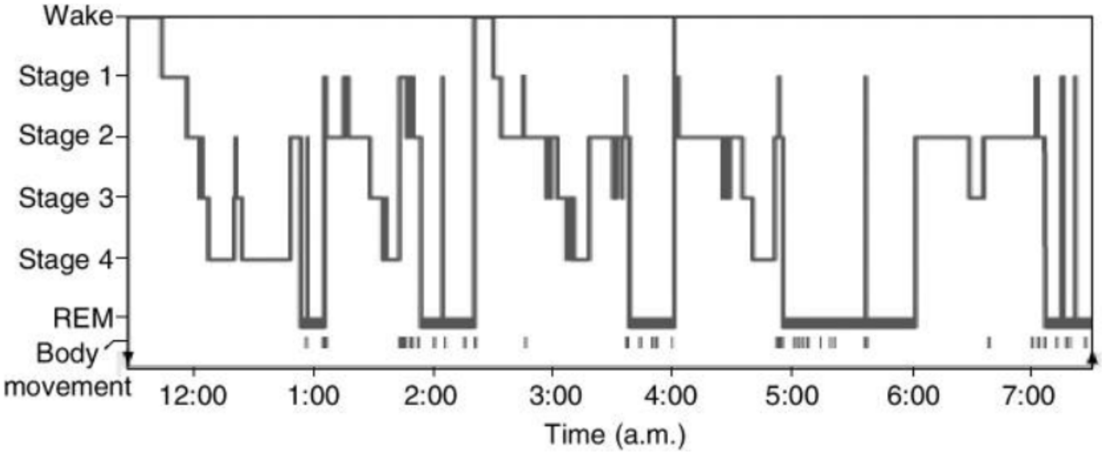

Figure 4. Progression of sleep states across a single night in young adults. Source: Carskadon and Dement (2017).

Transitioning from a period of wakefulness, the body first goes through the four stages of NREM. In the first stage of NREM, the heartbeat, breathing, eye movement, and brain waves slow down (NINDS, n.d.). NREM stage one makes up 2–5% of total sleep, and can easily be disrupted by outside factors such as noise (Colten & Altevogt, 2006). In the second stage of NREM, the previously mentioned functions slow down and a more intense stimulus is required to interrupt sleep (Colten & Altevogt, 2006). An individual spends most of their sleep at stage two NREM, accounting for 45–55% of the total sleep episode (Colten & Altevogt, 2006). The third and fourth stages of NREM make up slow-wave sleep (SWS), which is characterized by the lowest heart rate and breathing levels (NINDS, n.d.), and is considered the deepest phase of NREM (Colten & Altevogt, 2006).

During REM sleep, the eyes rapidly move side-to-side while brainwave activity, heart rate, and blood pressure increase close to waking levels (NINDS, n.d.). While the majority of dreaming occurs during the REM cycle, a temporary loss of muscle tone and reflexes prevents an individual from acting out dreams (Colten & Altevogt, 2006).

Two internal biological mechanisms control periods of sleep or wakefulness: circadian rhythms and sleep-wake homeostasis (Acherman & Borbely, 2003). Circadian rhythms regulate the timing of sleep, synchronized with environmental cues such as light (NINDS, n.d.). Sleep-wake homeostasis tracks an individual's need for sleep, generating an increasing drive for sleep throughout the day until adequate rest is achieved (Colten & Altevogt, 2006).

2. Sleep in the Military

Substantial scientific research findings have pointed out that military service members across the different branches continue to be sleep-deprived despite evidence of the destructive effects of sleep deprivation on training and performance (Miller et al., 2011). More recent studies have concluded the same and carry on the exploration of sleep to enhance performance. A study onboard underway U.S. Navy ships determined Sailors receive an average of 6.60 ± 1.01 hours a day, with 86.9% of the participants splitting sleep into more than one episode per day (Matsangas & Shattuck, 2020). Myers (2020) found that Sailors continue to receive less than the recommended amount of sleep and that Sailors on varying watch schedules to include night watchstanders receive the least amount of sleep. Young (2013) compared two watch rotations—six hours on, six hours off ("6/6") and three hours on, nine hours off ("3/9")—and observed that Sailors on the 3/9 rotation had better psychomotor vigilance performance than Sailors on the 6/6 rotation. Nonetheless, Sailors on the 3/9 rotation received less than the recommended amount of sleep. Shattuck and Matsangas (2016) delivered the same conclusions, in addition to showing that 3/9 watchstanders were less fatigued compared to Sailors on the 6/6 rotation.

Efforts by the Navy to combat the accumulating sleep debt are plentiful, but there is still room for other innovative methods to increase the quality and quantity of sleep. The use of circadian-based watch bills was mandated across the fleet in 2017 (LaCrosse, 2017), and the Navy Availability Factors (NAF) model was developed to replace the legacy Navy Standard Workweek (NSWW) as a more accurate basis for workload and other manpower decisions (CNO, 2019). The Navy also revised the OFRP deployment scheme (Eckstein, 2020).

D. WORKLOAD

Many definitions exist for the term workload. A simple description of workload is the ratio of time required to complete a task and the time available to the worker (National Research Council [NRC], 1995). A case in which more time is required than what is available is considered workload overload; less time required than what is available is regarded as workload underload (NRC, 1995). A drawback of this time-based approach is its inadequacy to apply to individuals performing more than two tasks at once (NRC, 1995). Additionally, a time-based approach may be insufficient for tasks that require long periods of attention without overt movements (e.g., monitoring equipment readings on a console). Such situations seemingly characterize workload underload but can actually be stressful and result in overload. Wickens and Tsang (2015) extend the simple definition above by describing workload as the relationship between an individual's supply and demand of resources to accomplish a task. These resources include mental, physical, or temporal (i.e., based on time) dimensions (Webb et al., 2010).

Since there is no consensus regarding the definition of the term workload, the construct is measured in various ways. The three main categories of workload measurement are divided into physiological assessments, subjective assessments, and task performance (Webb et al., 2010). Physiological measurements include brain activity, heart rate, blink rate, and breathing. These methods are objective and mostly non-intrusive (NRC, 1995). However, these methods typically require equipment that makes them impractical for field testing (Webb et al., 2010).

Most subjective metrics solicit a response from individuals upon the completion of a task and produce scores on uni- or multi-dimensional scales (Webb et al., 2010). Subjective metrics are the most widely used due to convenience, cost-effectiveness, and less obtrusion (Webb et al., 2010). Subjective metrics also exhibit high face validity (NRC, 2015). However, they are not designed to capture intermediate measurements that physiological monitoring provides (Webb et al., 2010). An example of a multi-dimensional subjective metric is the National Aeronautics and Space Administration (NASA) Task Load Index (TLX), which produces scores for mental, physical, and temporal demands; performance; effort; and frustration (Hart & Staveland, 1988). Another subjective workload assessment is the Subjective Workload Assessment Technique (SWAT), which incorporates time load, mental effort load, and psychological stress load (Webb et al., 2010).

Secondary task performance measures require the participant to perform another task concurrently with the main task (Webb et al., 2015). Assessing secondary task performance measures the leftover resources not necessary for the primary task (Wickens & Tsang, 2015). The more resources the main task requires, the fewer resources become available in the reserve capacity for performing the secondary task, and the poorer the performance becomes (Webb et al., 2010). Although secondary task performance measures are sensitive and have good diagnosticity (NRC, 2015), they are intrusive (Webb et al., 2015).

Aside from a variety of factors—poor lighting, excessive noise, or unclear instructions, for example—declining performance may also be attributed to workload overload (Wickens & Tsang, 2015). When the threshold for workload overload is crossed, individuals take several approaches. Higher objectives may be prioritized, while the lower ones are given less importance or even neglected (Wickens & Tsang, 2015). When tasks in the queue are of equal significance, individuals tend to select the easiest first (Wickens & Tsang, 2015). Individuals may also modify the task at hand to reduce their demands on resources (Wickens & Tsang, 2015). To manage workload overload, Wickens and Tsang (2015) offer four strategies: (a) training personnel on techniques to reduce demands on resources, (b) redistributing work from an overloaded individual to other operators, (c) redesigning the task to reduce demand on resources, and (d) implementing automation.

E. MOOD IN THE MILITARY

Lane and Terry (2000) define mood as “a set of feelings, ephemeral in nature, varying in intensity and duration, and usually involving more than one emotion” (p. 7). Findings from a recent series of studies on Navy ships suggest that poor sleeping conditions while underway are consistently associated with poor mood, increased levels of fatigue, slower reaction times, and more errors (Shattuck & Matsangas, 2015; Brown et al., 2016; Shattuck et al., 2019).

Nonetheless, results from earlier studies provide promising insights for the military. Burr and colleagues (1993) explored the psychological effects of extended periods of general quarters (GQ; i.e., battle readiness conditions) on Sailors onboard a guided-missile cruiser (CG) and a frigate (FFG). Some of their findings showed the Sailors' average mood scale scores were not significantly different from college students and that the crew of the FFG exhibited higher levels of psychological fatigue than the crew of the CG—likely due to a smaller crew or from being less adjusted to sustained operations. They also observed a decline in negative mood scores across time, suggesting the Sailors were adapting to the demands of prolonged operations.

Lieberman et al. (2014) found similar results ashore. At the end of 9–10 weeks of Army basic Combat Training (BCT), the mood scores of young adult females improved (Lieberman et al., 2014). Potential factors responsible for the improvements include participation in the structured BCT, which was designed to develop physical fitness, work ethic, coping skills, cohesion, and unit pride (Lieberman et al., 2014).

F. INFECTIOUS DISEASES IN THE MILITARY

While the U.S. Navy's combat casualties during World War 1 (WW1) totaled over 1,200 personnel, deaths due to the Spanish Flu exceeded 5,000 (Leuci, 2020). In 1918 alone, of the 121,225 patients admitted to Navy medical facilities due to the disease, over 4,000 died (Naval History and Heritage Command [NHHC], 2015). The worst outbreak on all U.S. Navy ships took place in October 1918 on the USS Pittsburgh (ACR 4), where 80% of the crew contracted the flu, and the ship was unable to perform any missions for over a month (NHHC, 2020). Ashore, many U.S. Navy installations also were hit hard. By the fall of 1918, 31,000 Sailors in Boston and Great Lakes had fallen ill—1,100 of which died (Cox, 2018).

Among those who died during the epidemic between 1918 and 1919 were the medical professionals providing care for the patients. The Navy Cross was posthumously awarded to Hospital Apprentice First Class Carey Miller (Gillingham, 2020) and three nurses who unfortunately contracted the illness while performing their duties (NHHC, 2015). The Navy implemented quarantine or infectious disease stations because treatment was nonexistent and antibiotics had not yet been discovered (NHHC, 2015; Cox, 2018). Because the world was at war, the United States, along with other combatant nations, intentionally tried to hide the gravity of the Spanish Flu from the adversaries (Cox, 2018).

Consequently, this subterfuge contributed to the slow and inadequate response against the epidemic (Cox, 2018). Nonetheless, the Spanish Flu pandemic is ripe with lessons learned to aid the preparation for the next pandemic.

Presently, the Navy and the rest of the world are battling another pandemic. USS Theodore Roosevelt (CVN 71) was sidelined in Guam for two months after a COVID-19 outbreak at the beginning of their deployment in the Indo-Pacific (Fuentes, 2020). Major military exercises were either reduced, suspended, or canceled entirely (Cancian et al., 2020). U.S. Navy ships have conducted fewer port calls and longer deployments to keep the virus from infecting crews while maintaining readiness (McLeary, 2020). The Secretary of Defense issued a 60-day stop movement order to forces overseas and required a 14-day quarantine for ships before deployments (Cancian et al., 2020).

At the unit level, various safety measures are adopted to combat contagious infections while at sea. Onboard USS Nimitz (CVN 68), newly reporting Sailors are first placed in a 14-day quarantine period off-ship (Mason, 2020). Upon testing negative for COVID after the quarantine period, the Sailors join the rest of the crew onboard (Mason, 2020). Other practices across the fleet include mandating the use of face coverings, staggering mealtimes, and limiting access to gyms (McLeary, 2020). While the spread of the virus is managed through the implementation of controls, anxiety about COVID-19 transmission and mortality rates might have detrimental effects on sailor workload, sleep, and well-being.

The spread of infectious diseases on Navy ships can be highly disruptive for the entire command and individual Sailors. The safety measures translate to additional responsibilities to the pre-existing roles of each sailor; the workload originally distributed across many crew members become assigned to the remaining few that have not yet contracted the disease. These higher workload levels potentially translate to fewer opportunities for sleep. The customary procedures that once offered Sailors a routine, and the leisure activities that previously carried Sailors through their demanding workdays, are put on hold—potentially adversely affecting their well-being.

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III. METHODS

This chapter covers the methods used in the collection, preparation, and analysis of the data. The methods utilized in this study were adapted from previous research conducted by the NPS Crew Endurance team.

A. STUDY DESIGN

As stated in Chapter I, the original intent of the study was to compare two U.S. Navy destroyers in the Basic Phase of the OFRP cycle to assess the impact and potential benefits of increasing the manning of the Engineering Department. The test ship's Engineering Department was intended to be manned with higher fit and fill rates, while the control ship's Engineering Department was planned to have typical manning levels. Drawing from the lessons learned from research by Garbacz (2019) and Murph (2019), Naval Surface Force Atlantic (SURFLANT) transferred additional engineering Sailors permanently to the ship—vice "cross-decking" or temporary assignments. While the increased manning onboard the test ship was administratively fulfilled, the actual number of Sailors fit for duty prevented a successful comparison. Hence, the study objective was refocused on an empirical assessment of the factors that potentially impede the peak performance of engineering Sailors in the Basic Phase. This thesis is a combination of cross-sectional and longitudinal studies across two underway periods onboard USS Gonzalez (DDG 66), an Arleigh Burke-class Flight I guided-missile destroyer homeported in Norfolk, Virginia.

Each data collection period took place during the Basic Phase and spanned two weeks. Underway 1 was characterized by the high operational tempo dictated by the Engineering Department's primary role in the Mobility Damage Control Warfare (MOB-D) assessment. Underway 2, on the other hand, portrayed a lower operational tempo as the Engineering Department transitioned to a supporting role for the Weapons and Combat Systems Departments' intermediate-level training events. Underway 2 also took place at the end of the ship's holiday stand-down period.

B. PARTICIPANTS

Volunteers were recruited from both the officer and enlisted populations of the Engineering Department. Damage Control Petty Officers (DCPOs)—Sailors with non-engineering ratings who assist in the maintenance of damage control equipment—were not considered. Overall, the total number of study participants was 57 Sailors; 31 Sailors participated in both underway periods. Of the 56 Sailors eligible to participate during the Underway 1, 45 (80.4%) volunteered. Of the 58 Sailors eligible to participate in Underway 2, 43 (74.1%) volunteered. Engineering Department fit and fill numbers for Underway 1 and 2 were 89%/74% and 103%/80% (author's calculations using Billet Based Distribution [BBD]), respectively. The study protocol was approved by the NPS Institutional Review Board (IRB) (NPS.2020.0073-IR-EP4_7-A).

C. EQUIPMENT

This study solicited from participants a variety of information ranging from sleep-related behaviors and history, cognitive readiness, and mood. These data were obtained with objective and self-report methods. Sleep attributes and sleep/wakes patterns were assessed objectively with actigraphy. Self-report measures consisted of the activity logs, as well as the pre- and post-underway questionnaires, which included the validated scales of Epworth Sleepiness Scale (ESS), Insomnia Severity Index (ISI), Profile of Mood States (POMS), and Pittsburg Sleep Quality Index (PSQI).

(1) Philips Respironics Spectrum Actiwatch

The Philips Actiwatch is an activity monitor designed for continuous wear and has low levels of intrusion. The wrist-worn device uses an accelerometer to record the movement of the user and provides objective actigraphy data. It also utilizes a light sensor to assess ambient light levels.

Present technology allows the measurement of sleep based on muscle activity obtained in electromyogram (EMG) and electric brain signals captured in electroencephalogram (EEG) (Zielinski et al., 2016). In situations where laboratory-based polysomnography (PSG) is impractical or not possible, wrist activity monitors provide an alternative method to measuring sleep attributes and sleep/wake patterns (Caldwell & Caldwell, 1993; Quante et al., 2018). Wrist-worn actigraphy units assisted by activity logs were utilized to assess the sleep of Sailors across various platforms of ships (Garbacz, 2019; Murph, 2019; Myers, 2020; Shattuck & Matsangas, 2015).

(2) Activity Logs

The purpose of the Activity Logs is twofold: to calculate workload, and to obtain subjective data to supplement the objective data collected from the actiwatches. Participants were asked to log their activities daily according to the following categories: "W" for watchstanding; "T" for both all-hands and individual training; "D" for meetings; "M" for maintenance; "SD" for service diversion, which are the activities required by regulation or by the nature of the profession (e.g., quarters and inspections); "O" for or other work; "E" for eating/messing; "S" for sleeping/napping; "P" for personal/free time; and "R" for removing the actiwatch for any reason. The logs covered each 24-hour period underway in 15-minute intervals.

(3) Pre- and Post-underway Questionnaires

A combination of open-ended and fixed-alternative questions made up the pre- and post-underway questionnaires. The questions were designed to capture participant demographics, watch schedule, exercise routine, tobacco/nicotine use, caffeine consumption, and the factors that affect sleep. The questionnaires also sought self-reported evaluations on the adequacy of sleep and amount of workload for each underway.

(4) Epworth Sleepiness Scale

The Epworth Sleepiness Scale is a self-report questionnaire that measures the participant's general level of daytime sleepiness (Johns, 1991). Johns (1991) demonstrated that ESS can significantly distinguish normal participants from those with excessive daytime sleepiness. The ESS presents participants with eight common situations in daily life such as watching television and sitting in the car as a passenger. For each situation, participants are asked to assess their likelihood of falling asleep on a four-point scale. The individual scores are summed to produce the participant's ESS score, which is then used to assess their level of daytime sleepiness. ESS scores above 10 suggest excessive daytime sleepiness (Johns, 1991).

(5) Insomnia Severity Index

Morin and colleagues (2011) demonstrated that ISI is a reliable and valid tool for identifying cases of insomnia, despite not being a formal evaluation of the condition. Insomnia is a sleep disorder that makes initiating or maintaining sleep difficult (Roth & Roehrs, 2003). It is widespread yet commonly unrecognized and untreated because clinical evaluations of insomnia require thorough medical, psychological, and psychiatric assessments (Sateia e. al., 2000).

The ISI asks participants to rate the severity of their insomnia symptoms across seven items. The first three questions ask for an assessment of their difficulty in falling asleep, staying asleep, and waking up too early. The following four questions ask their perceptions about the quality of the sleep they receive. The response for each question is fixed to a five-point scale, and the sum of the individual scores ranges from 0 to 28. Total ISI scores less than 8 are classified as no insomnia, 8–14 as sub-threshold insomnia, 15–21 as moderate insomnia, and 22–28 as severe insomnia (Morin et al., 2011).

(6) Profile of Mood States

The POMS Standard Form is a 65-item questionnaire that measures the brief, temporary mood state of the participants (McNair et al., 1971; Spielberger, 1978). The questionnaire consists of a list of adjectives describing feelings, with a corresponding five-point Likert scale for each item. For each adjective, respondents are instructed to select the degree that best describes how they are feeling. Six mood dimensions—tension-anxiety, depression-rejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment—are calculated by a subset of 7–15 adjectives each (McNair et al., 1971). The Total Mood Disturbance score is obtained by subtracting Vigor from the sum of the remaining five mood dimensions (McNair et al., 1971).

(7) Pittsburgh Sleep Quality Index

PSQI was designed to assess the patterns and quality of sleep over a period of one month (Buysse et al., 1989; Smith, 2008); however, PSQI has also been used for shorter time intervals (Smith, 2008). PSQI consists of 19 items broken down into five open-ended and fourteen fixed-alternative questions. Responses to the questionnaire questions consolidate into the seven component scores for sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, sleep medication, and daytime dysfunction (Buysse et al., 1989). The sum of the component scores, which ranges from 0 to 21, produces the PSQI Global Score. This study considers PSQI Global Scores above 5 as indicative of poor sleep quality (Morin et al., 2011), despite evidence that higher thresholds may be more suitable for military personnel (Matsangas & Mysliwiec, 2018; Matsangas & Shattuck, 2020).

D. PROCEDURES

The research team arrived onboard USS Gonzalez on 7 October 2020 to begin the recruitment process for Underway 1. After providing an in-brief to the chain-of-command, the team presented a recruitment brief to the engineering Sailors. At the brief, the Sailors were informed of the research protocol and study procedures. Sailors were encouraged to participate to the fullest extent possible, although participation was completely voluntary.

Sailors with signed consent forms were administered a pre-underway questionnaire to complete and were provided an actiwatch and an activity log. Sailors were instructed to wear the actiwatch throughout the day, only removing it when showering or engaging in activities that could damage the unit. During Underway 1, members of the research team were onboard to address questions from participants, encourage them to diligently log their daily activities, and troubleshoot faulty or broken actiwatches, as necessary. The research team was also onboard to understand the context of the data being collected.

On 28 October 2020, at the end of Underway 1, the post-underway questionnaires were administered to the participants. Upon completion of the post-underway questionnaires, the participants returned them to the research team, along with their completed activity logs and actiwatches.

On 8 January 2021, the research team returned onboard USS Gonzalez for Underway 2. As before, the chain-of-command was presented an in-brief, and the Engineering Department was given a recruitment brief. The recruitment brief for Underway 2 was presented at the end of the workweek. At the time, a proportion of the department was also on holiday stand-down leave. In an effort to organize the distribution of materials in one day, and to minimize the number of lost or broken watches seen during Underway 1, the watches and the activity logs were not issued immediately following the recruitment brief. Sailors were instructed to pick up the study materials after the weekend, but before the underway, from an assigned research team member stationed in the Engineering Log Room. The active data collection period began on 12 January 2012, but the pickup window was extended to 17 January 2021 to allow maximum participation from eligible Sailors.

On 27 January 2021, post-underway questionnaires were administered to the participants. Once completed, the post-underway questionnaires were turned in, along with the actiwatches and activity logs. Similar to the first underway period, the data collection for the second underway ended once all the materials from the participants were collected and properly inventoried.

E. DATA PREPARATION

All the handwritten information collected was manually entered into Microsoft Excel. The scrubbing and interpolation that followed were specific to each type of data.

(1) Pre- and Post-underway Questionnaires

The questionnaire data were investigated for missing responses. Participants who left the exercise, caffeine, or nicotine questions blank were categorized as not exercising, not consuming caffeine, or not using nicotine, correspondingly. Any other blanks were not interpolated. In total, the data points interpolated were 2/1980 (0.0010%) for Underway 1, and 2/1892 (0.0011%) for Underway 2. From Underway 1, one participant did not turn in the post-underway questionnaire, leaving 44 for analysis. From Underway 2, four participants did not turn in their post-underway questionnaires, leaving 39 available for analysis

(2) Epworth Sleepiness Scale and Insomnia Severity Index

Interpolation was not applied to ESS and ISI data. Participants with missing responses were simply excluded from the analysis. For ESS, one participant from Underway 1 was dropped, leaving 44 available for analysis; five participants in Underway 2 were dropped, leaving 38 for analysis. For ISI, two participants were dropped for analysis from Underway 1, leaving 43 available for analysis; nine participants were dropped from Underway 2, leaving 34 for analysis.

(3) Profile of Mood States

The POMS data was first investigated for missing responses. If only one or two values were missing for a single participant, the blank was replaced with the participant's average, rounded up to one decimal point. The amount of interpolation for each data collection varied: 2/2925 (0.0007%) for pre-Underway 1, 1/2795 (0.0004%) for post-Underway 1, 5/2470 (0.0020%) for pre-Underway 2, and 6/2340 (0.0026%) for post-Underway 2.

If a participant left three or more questions blank, he/she was dropped from the analysis. From Underway 1, two individuals were dropped in the "post" phase, leaving 43 of 45 available for analysis. From the 43 participants in Underway 2, two Sailors were dropped in the "pre" phase and seven from the "post" phase, leaving 35 available for analysis.

(4) Pittsburgh Sleep Quality Index

If participants responded with a range of time, the median value was used. For example, a response of "2100-2300" was interpolated as "2200." Missing PSQI information was filled in with the responses from the activity logs. For each data collection, the amount of interpolation varied: 28/766 (0.0366%) for pre-Underway 1, 22/554 (0.0397%) for post-Underway 1, 18/717 (0.0251%) for pre-Underway 2, and 3/722 (0.0042%) for post-Underway 2.

Participants were excluded from the analysis if they left enough questions blank that could not be interpolated and could not produce a PSQI score. Eleven participants were dropped from Underway 1, leaving 34 available for analysis. Six participants were dropped from Underway 2, leaving 37 available for analysis.

(5) Activity Logs

Days containing two or more hours of missing data were excluded from further analysis. Periods before or after sleep that were indicated by “R” (watch removal) were interpolated to “P” (personal time). Other missing values were interpolated based on the patterns observed from the adjacent days. The amount of interpolation was 147/23040 (0.6380%) for Underway 1, and 192/26838 (0.0072%) for Underway 2.

The number of 24-hour periods of activity log data for each participant was recorded. Participants with fewer than five 24-hour periods were dropped. The daily values for each participant were obtained by taking the sum of each category of activity, dividing by four to obtain the total amount of time in hours, and further dividing by the number of 24-hour periods. The resulting numbers of participant data considered for analysis were 14 for Underway 1, and 22 for Underway 2.

(6) Actigraphy Data

The actigraphy data were first imported to Philips Actiware 6 version 6.0.9 for initial cleaning. Then, the rest intervals determined by the software’s algorithm were discarded. New rest intervals were manually identified by reconciling the periods of low activity with the activity logs, watch schedules, and light sensor information. The number of 24-hour periods of actigraphy data for each participant was recorded, and only the participants with more than five were considered for analysis. To keep the maximum amount of viable data, the assigned start and end times of the 24-hour periods were unique to each participant. Twenty-one participants were dropped from Underway 1, leaving 24 for analysis. Six participants were dropped from Underway 2, leaving 37 available for analysis.

Actigraphic data were exported as comma-separated-values files. Summary tables displaying sleep information for each participant were generated via JMP Pro 15.1.0. The average amount of sleep for each participant was calculated by their total amount of sleep divided by the number of 24-hour periods. The daily averages were multiplied by 7 to get the weekly averages.

F. ANALYTICAL STRATEGY

All analyses were conducted using Microsoft Excel and JMP Pro 15.1.0. Continuous variables were reported as mean and standard deviation (M ± SD), if normally distributed, or as median and interquartile range (MD[IQR]) if otherwise. Normality was assessed visually with the normal quantile plot and the Shapiro-Wilk goodness-of-fit test. The statistical significance level was set to 0.05.

The first study objective—assess mood, sleep attributes, and workload of engineering Sailors—was achieved by describing our participants in terms of their demographic characteristics, well-being, and sleep-related behaviors. Demographic data of interest were participant age, sex, rank, rate, body mass index, and length of active-duty service. Participant well-being and sleep-related behaviors included exercise routines, nicotine use, caffeine consumption, perceptions of the amount of sleep and workload, sleep quality, average daytime sleepiness, insomnia symptoms, and mood. Descriptive statistics were provided for the entire data sample. Comparisons between the two data collection periods were based only on those Sailors who participated in both data collections. The Wilcoxon Signed Rank test was used to assess statistical differences between dependent continuous variables, whereas the McNemar's test was used for nominal dependent variables.

For the second objective—assess whether the mood, sleep attributes, and workload of engineering Sailors onboard USS Gonzalez are comparable to other populations— we used data collected from 14 other USN ships, normative POMS data on the normal adult population, and the Navy Availability Factor (NAF) workload criteria. The methods used to compare USS Gonzalez data to known values depended on the distribution of the data: one-sample t-test for normally distributed data, and one-sample median test for non-normally distributed data. The Benjamini–Hochberg False Discovery Rate (BH-FDR) controlling procedure with q = 0.20 was used to assess post-hoc statistical significance (Benjamini & Hochberg, 1995).

The third objective—explore how the spread of COVID-19 on USS Gonzalez affected the readiness levels and performance of the Engineering Department—required the collection, organization, and evaluation of qualitative data. Material examined includes the responses from the open-ended questions of the pre- and post-underway questionnaires, the measures implemented on the ship in response to COVID-19, and the circumstances that surrounded each underway period. Gaps identified in the quantitative data findings of the first three research objectives drove the investigation for recurring themes in the qualitative data.

IV. RESULTS

A. PARTICIPANTS

A total of 57 volunteers participated in the study. Forty-five Sailors participated in Underway 1, 43 Sailors participated in Underway 2, and 31 Sailors participated in both data collections. Table 1 describes the participant attributes according to the groupings utilized in the analysis.

Table 1. Demographics of study participants

	All (N=57)	**Underway 1 (n=45)**	**Underway 2 (n=43)**	**Both underway periods (n=31)**
Age ***Median (min-max)***	26 (19-42)	26 (19-42)	27 (20-43)	27.6 ± 6.6
Sex: Female ***Count (%)***	12 (21.1%)	9 (20%)	8 (18.6%)	5 (16.1%)
Sex: Male ***Count (%)***	45 (78.9%)	36 (80%)	35 (81.4%)	26 (83.9%)
BMI ***Median (min-max)***	26 (19.7-41.3)	25.8 (19.7-41.3)	27.4 (19.7-41.3)	26.5 (19.7-41.3)
Years on active duty ***Median (min-max)***	1 (0.8-23)	3 (0.8-23)	3.5 (0.9-23)	3 (1-23)
Number of previous deployments ***Median (min-max)***	1 (0-8)	1 (0-8)	1 (0-8)	1 (0-8)
Length of previous deployments (months) ***Median (min-max)***	7 (0-60)	7 (0-60)	7 (0-60)	7 (0-60)

The participants represented various enlisted occupational ratings: 15 (26%) Gas turbine system technician, Mechanical; 10 (18%) Electrician’s mates; 9 (16%) Gas turbine system technician, Electrical; 7 (12%) Machinist's mates; 7 (12%) Damage controlmen; 2 (4%) Hull maintenance technicians; and 1 (2%) Gas turbine system technician, senior chief petty officer. Among the participants were also 6 (11%) officers.

Rotating watch schedules were predominant during Underway 1 whereas circadian-based watch schedules were predominant during Underway 2. Table 2 shows the distribution of the watchbills implemented on each underway period.

Table 2. Watch rotations during each underway

Watch rotation	**Underway 1 (n=45)** ***Count (percentage)***	**Underway 2 (n=43)** ***Count (percentage)***
5/10	33 (73.3%)	0 (0%)
3/9	3 (6.7%)	23 (53.5%)
4/8	0 (0%)	9 (20.9%)
Other	3 (6.7%)	5 (11.6%)
None	5 (11.1%)	1 (2.3%)
No response	1 (2.2%)	5 (11.5%)

Table 3 shows the distribution of caffeine consumption, nicotine use, and exercise among the participants for each underway period.

Table 3. Number of Sailors who consume caffeine, use nicotine, and exercise for each underway

Item	**Underway 1 (n=45)**	**Underway 2 (n=43)**
Caffeine		
Tea	6 (13.3%)	6 (14%)
Coffee	23 (51.1%)	21 (48.8%)
Soda	14 (31.1%)	10 (23.3%)
Energy drinks	29 (64.4%)	18 (41.9%)
Other	2 (4.4%)	1 (2.3%)
Nicotine		
Cigarettes	15 (33.3%)	9 (20.9%)
Tobacco chew/snuff	4 (8.9%)	3 (7%)
Electronic smoke	10 (22.2%)	7 (16.3%)
Exercise routine	25 (55.6%)	19 (44.2%)

B. PROFILE OF MOOD STATE (POMS)

Participant Total Mood Disturbance scores (TMD) are depicted in Figure 5. Table 4 shows the scores for each POMS subscale across the entire study. Normally distributed data are presented as mean ± standard deviation. Non-normally distributed data are displayed as median (interquartile range).

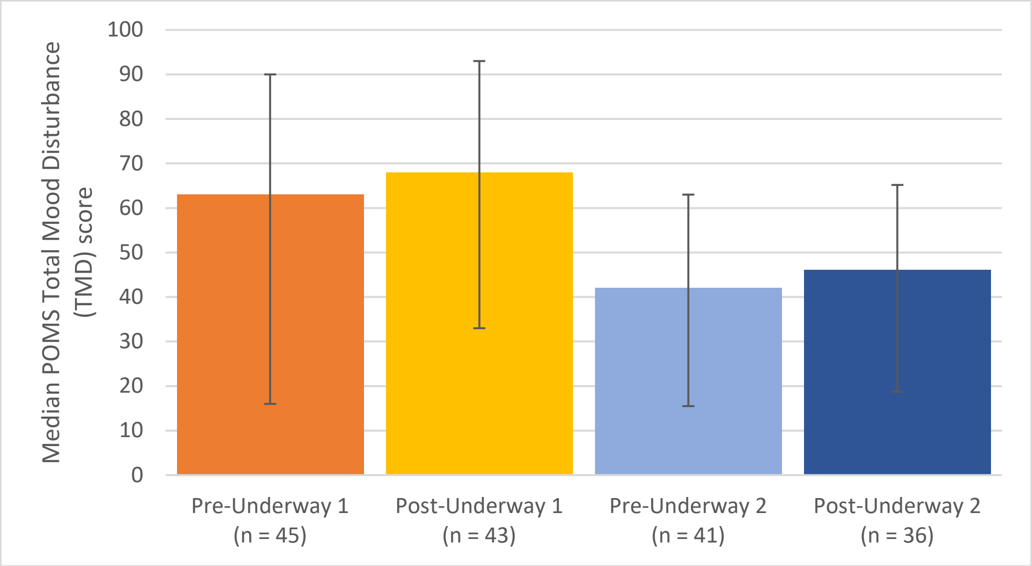

Figure 5. TMD scores of all participants. Vertical lines denote the interquartile range.

Table 4. POMS scores of all participants

POMS scales	Pre-Underway 1	Post-Underway 1	Pre-Underway 2	Post-Underway 2
TMD Score	63 (74)	65 ± 44.3	40.93 ± 32.4	47.7 ± 31.1
Tension-anxiety	13.1 ± 7.1	13.5 ± 8.1	11.1 ± 5.9	9.7 ± 5.8
Depression	14 (21.5)	19 (24)	12 (11.6)	15 (18.5)
Anger-hostility	13 (23.5)	17.1 ± 12.5	9 (10)	12 (15)
Vigor	12.9 ± 5.2	11 ± 5.3	12.02 ± 5.4	8.3 ± 4.7
Fatigue	14.4 ± 7.1	15.6 ± 6.6	10.3 ± 6.7	11.6 ± 5.8
Confusion	10 (11)	11.7 ± 6.2	8 (4.5)	8.3 ± 4.1

Sailor mood at different points of the study was compared. The comparison of POMS scores of Sailors who participated in pre- and post-Underway 1 is shown in Table 5. Table 6 presents the POMS scores of Sailors who participated in both pre- and post-Underway 2. Vigor worsened at the end of both Underway 1 and Underway 2; however, mood during Underway 1 was worse than mood during Underway 2, as shown in Table 7.

Table 5. Comparison of pre- and post-Underway 1 POMS scores

POMS scale	Pre-Underway 1	Post-Underway 1	Wilcoxon signed rank unadjusted p-value (n=43)
Total Mood Disturbance	60.4 ± 43.3	65 ± 44.3	S = 69, p = 0.411
Tension-anxiety	13.6 ± 6.9	13.48 ± 8.1	S = -55, p = 0.510
Depression	16 (22)	19 (24)	S = 86.5, p = 0.300
Anger-hostility	15 (23)	16 (18)	S = -6.5, p = 0.938
Vigor	13.1 ± 5.2	11 ± 5.3	S = -186.5, p = 0.022*
Fatigue	14.8 ± 7.1	15.6 ± 6.6	S = 68.5, p = 0.413
Confusion-bewilderment	11.6 ± 6.2	11.7 ± 6.2	S = 4.5, p = 0.957

* Post-hoc statistically significant based on BH-FDR (q = 0.20)

Table 6. Comparison of pre- and post-Underway 2 POMS

POMS scale	Pre-Underway 2	Post-Underway 2	Wilcoxon signed rank unadjusted p-value (n = 35)
Total Mood Disturbance	42.1 ± 31.1	48.6 ± 31.2	S = 76.5, p = 0.215
Tension-anxiety	11.3 ± 5.9	9.9 ± 5.8	S = -105.5, p = 0.083
Depression	12 (12)	15 (18)	S = 72.5, p = 0.239
Anger-hostility	9 (8)	12 (15)	S = 85, p = 0.166
Vigor	11.9 ± 5.3	8.3 ± 4.8	S = -215.5, p < 0.001*
Fatigue	10.7 ± 6.9	11.5 + 5.9	S = 58, p = 0.348
Confusion	8 (4)	8.3 ± 4.2	S = -55.5, p = 0.369

* Post-hoc statistically significant based on BH-FDR (q = 0.20)

Table 7. Comparison of post-Underway 1 and post-Underway 2 POMS.

POMS scale	Post-Underway 1	Post-Underway 2	Wilcoxon signed rank unadjusted p-value (n=26)
Total Mood Disturbance	68 ± 36.5	53.1 ± 30.8	S = -103, p = 0.006*
Tension-anxiety	13.7 ± 7.6	10.7 ± 5.6	S = -92, p = 0.016*
Depression	19.3 ± 13	15.5 ± 11.4	S =-54.5, p = 0.169
Anger-hostility	17.1 ± 9.9	13.7 ± 10.2	S = -96.5, p = 0.011*
Vigor	9.6 ± 5.5	9 ± 4.7	S = -48.5, p = 0.223*
Fatigue	15.77 ± 5.6	12 (6)	S = -64.5, p = 0.101
Confusion	11.8 ± 5.9	9 ± 3.8	S = -115, p = 0.002*

* Post-hoc statistically significant based on BH-FDR (q = 0.20)

POMS scores collected from USS Gonzalez crewmembers were compared against POMS scores of other USN engineering departments as well as to normative data. Table 8 shows that Vigor during Underway 1 was better than 14 other ships, while all other mood scales from Underway 1 were worse than 14 other ships. Table 9 shows that mood in Underway 2 was worse than 14 other ships.

Table 8. POMS: Underway 1 versus 14 other ships

POMS scale	**Post-Underway 1 (n=43)**	**14 Other ships**	**One-sample median test***
Total Mood Disturbance	68 (60)	29.5 (45)	T(42) = 358, p < 0.001**
Tension-anxiety	13 (13)	9 (8.3)	T(42) = 251.5, p = 0.002**
Depression	19(24)	6 (13)	T(42) = 339, p < 0.001**
Anger-hostility	16 (18)	9 (13.3)	T(42) = 292, p = 0.001**
Vigor	12 (8)	13 (8)	T(42) = -173.5, p = 0.034**
Fatigue	17 (11)	11 (8.3)	T(42) = 308, p < 0.001**
Confusion	11 (9)	7 (6.3)	T(42) = 341, p < 0.001**

* Unadjusted p-values

** Post-hoc statistically significant based on BH-FDR (q = 0.20)

Table 9. POMS: Underway 2 vs. 14 other ships

POMS Scale	**Post-Underway 2 (n=36)**	**14 Other ships**	**One-sample median test***
Total Mood Disturbance	46.1 (46.4)	29.5 (45)	T(35) = 192.5, p = 0.002**
Tension-anxiety	9 (8.8)	9 (8.3)	T(35) = 31, p = 0.632
Depression	15 (18.5)	6 (13)	T(35) = 241.5, p < 0.001**
Anger-hostility	12 (15)	9 (13.3)	T(35) = 82.5, p = 0.198
Vigor	7.5 (7)	13 (8)	T(35) = -277, p < 0.001**
Fatigue	11.5 (5.8)	11 (8.3)	T(35) = 30, p = 0.643
Confusion	8 (5.8)	7 (6.3)	T(35) = 113.5, p = 0.073**

* Unadjusted p-values

** Post-hoc statistically significant based on BH-FDR (q = 0.20)

POMS scores collected on the USS Gonzalez were also compared to normative data. The percentages of Sailors whose scores were worse than the 50^{th} percentile of the normal adult population are shown in Table 10 and Figure 6 for Underway 1; in Table 11 and Figure 7 for Underway 2; and in Table 12 and Figure 8 for participants in both underway periods. Underway 1 was worse than the adult norms for all seven of the POMS scales. At the significance level of $\alpha = 0.1$, Sailors who participated in Underway 2 and Sailors who participated in both data collections had worse scores than the normal adult population across all seven of the POMS subscales.

Table 10. POMS: Underway 1 participants vs. normative data

POMS scale	Study phase	<50th percentile	≥50th percentile	Percentage of Sailors ≥ 50th percentile of adult norms	P-value compared to the 50th percentile
Total Mood Disturbance	Pre	9	34	79.1%	<0.001
	Post	9	34	79.1%	<0.001
Tension - anxiety	Pre	8	35	81.4%	<0.001
	Post	13	30	69.8%	0.007
Depression - dejection	Pre	14	29	67.4%	0.016
	Post	12	31	72.1%	0.003
Anger-hostility	Pre	14	29	67.4%	0.016
	Post	12	31	72.1%	0.003
Vigor - activity	Pre	37	6	86.1%	<0.001*
	Post	41	2	95.4%	<0.001*
Fatigue - inertia	Pre	9	34	79.1%	<0.001
	Post	5	38	88.4%	<0.001
Confusion - bewilderment	Pre	10	33	76.7%	0.003
	Post	9	34	79.1%	<0.001

* Compared to < 50^{th} percentile

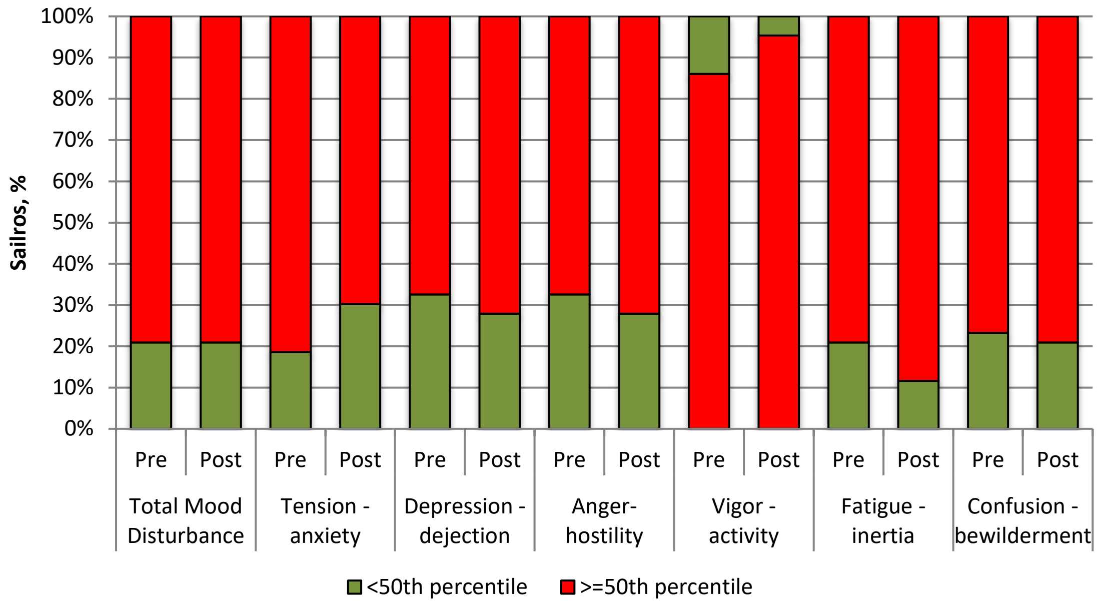

Figure 6. POMS: Underway 1 participants vs. normative data

Table 11. POMS Underway 2 participants vs. normative data

POMS scale	Study phase	<50th percentile	≥50th percentile	Percentage of Sailors ≥ 50th percentile of adult norms	P-value compared to the 50th percentile
Total Mood Disturbance	Pre	8	27	77.1%	<0.001
	Post	7	28	80%	<0.001
Tension - anxiety	Pre	8	27	77.1%	<0.001
	Post	13	22	62.9%	0.088
Depression - dejection	Pre	11	24	68.56%	0.021
	Post	9	26	74.3%	0.003
Anger- hostility	Pre	12	23	65.7%	0.045
	Post	11	24	68.6%	0.021
Vigor - activity	Pre	30	5	85.7%	<0.001*
	Post	34	1	97.1%	<0.001*
Fatigue - inertia	Pre	11	24	68.6%	0.021
	Post	7	28	80%	<0.001
Confusion - bewilderment	Pre	8	27	77.1%	<0.001
	Post	8	27	77.1%	<0.001

* Compared to < 50th percentile

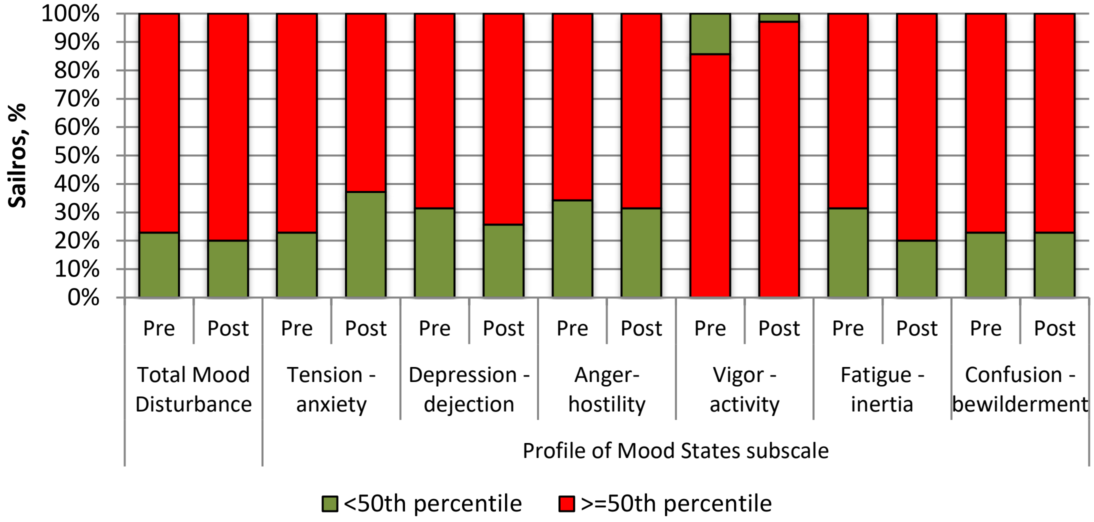

Figure 7. POMS: Underway 2 vs. normative data

Table 12. POMS: Participants from both data collections versus normative data

POMS scale	Study phase	<50th percentile	≥50th percentile	Percentage of Sailors ≥ 50th percentile of adult norms	P-value compared to the 50th percentile
Total Mood Disturbance	Pre	3	23	88.5%	<0.001
	Post	3	23	88.5%	<0.001
Tension - anxiety	Pre	7	19	73.1%	0.015
	Post	9	17	65.4%	0.084
Depression - dejection	Pre	5	21	80.8%	0.001
	Post	7	19	73.1%	0.015
Anger- hostility	Pre	5	21	80.8%	0.001
	Post	7	19	73.1%	0.015
Vigor - activity	Pre	26	0	100%	<0.001*
	Post	25	1	96.2%	<0.001*
Fatigue - inertia	Pre	1	25	96.2%	<0.001
	Post	2	24	92.3%	<0.001
Confusion - bewilderment	Pre	5	21	80.8%	0.001
	Post	4	22	84.6%	<0.001

* Compared to < 50th percentile

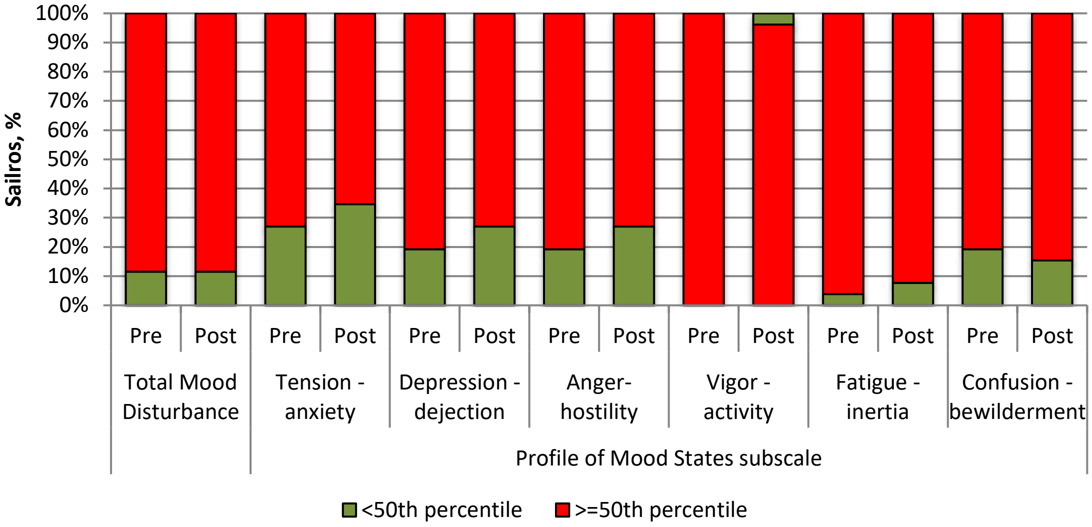

Figure 8. POMS: Participants from both data collections vs. normative data

C. SLEEP ATTRIBUTES

This section presents the results pertaining to sleep duration, sleep episodes per day, sleep quality, average daytime sleepiness, insomnia symptoms, perception of sleep adequacy, and the factors affecting sleep. A comparison of sleep attributes between Underway 1 and Underway 2 is also presented, along with a comparison of the sleep attributes onboard USS Gonzalez against those of the Engineering Departments of 14 other ships.

1. Sleep Duration and Number of Episodes per Day

The sleep duration for all participants is summarized in Figure 9. Table 13 displays the percentages of Sailors that sleep less than eight, seven, or six hours per day.

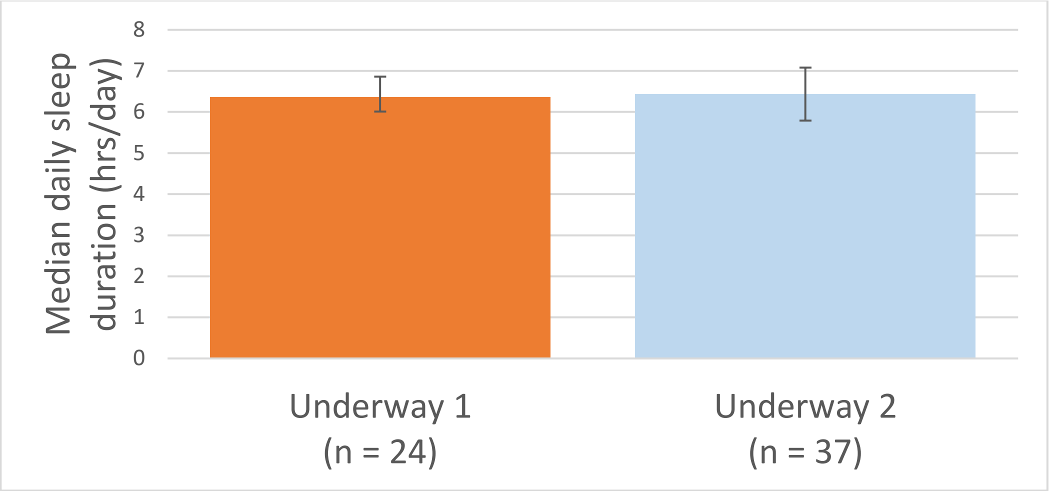

Figure 9. Daily sleep duration: All Sailors. Vertical lines denote the interquartile range.

Table 13. Sleep grouped by duration: All Sailors

	Underway 1 (n = 24)	**Underway 2 (n = 37)**
Daily sleep duration, hrs/day	6.4 (0.9)	6.4 (1.3)
Number of Sailors sleeping <8 hrs/day	21 (87.5%)	37 (100%)
Number of Sailors sleeping <7 hrs/day	19 (79.2%)	27 (72.9%)
Number of Sailors sleeping <6 hrs/day	6 (25%)	13 (35.1%)

A comparison of sleep duration between Underway 1 and Underway 2 is shown in Table 14. No statistically significant differences were found at the α = 0.05 level.

Table 14. Sleep duration of Sailors in both data collections

	Underway 1	**Underway 2**	**Wilcoxon signed rank test (n=16)**	**McNemar's test (n=16)**
Hours per day	6.3 (0.9)	6.3 (1.2)	S = -9 P = 0.669	
Number of Sailors sleeping <8 hrs/day	14 (87.5%)	16 (100%)		N/A*
Number of Sailors sleeping <7 hrs/day	12 (75%)	12 (75%)		$\chi^2 = 0$ p = 0.999
Number of Sailors sleeping <6 hrs/day	4 (25%)	5 (31.3%)		$\chi^2 = 0.2$ p = 0.655

* McNemar's test not applied due to non-dichotomous data

Daily sleep duration in Underway 1 on the USS Gonzalez did not differ from sleep of the crew on 14 other ships (Underway 1: 6.5 ± 0.8 hrs/day; 14 other ships: 6.3 ± 0.9 hrs/day; one-sample t-test, t(26) = 1.5, p = 0.150). Sleep duration during Underway 2 also did not differ from 14 other ships (post-Underway 2: 6.4 ± 0.9; 14 other ships:6.23 ± 0.9; one-sample median test, t(36) = 1.09, p = 0.279).

Split sleep was prevalent during both underway periods. The numbers of sleep episodes per day for all participants were 1.7 ± 0.4 for Underway 1 and 1.8 ± 0.4 for Underway 2. No statistically significant difference was identified in the number of sleep episodes per day between the Sailors who participated in both data collections (Underway 1: 1.8 ± 0.4; Underway 2: 1.9 ± 0.4; Wilcoxon signed rank test, S = 14.5, n = 16, p = 0.472).

Napping was more common during Underway 1 compared to crews of 14 other ships (Underway 1: 1.7 [0.6] sleep episodes per day; 14 other ships: 1.4 [0.5] sleep episodes per day; one-sample median test, T(23) = 106.5, p < 0.001). Napping was also more common during Underway 2 compared to 14 other ships (Underway 2: 1.8 [0.6] sleep episodes per day; 14 other ships: 1.4 [0.5] sleep episodes per day; one-sample median test, T(36) = 279.5, $p < 0.0001$).

2. Sleep Quality

The sleep quality assessed by the PSQI score for all participants is shown in Figure 10. Poor sleepers, as defined by PSQI scores above 5, were identified among the participants: 39 (88.6%) in pre-Underway 1, 29 (82.9%) in post-Underway 1, 36 (85.7%) in pre-Underway 2, and 34 (89.7%) in post-Underway 2.

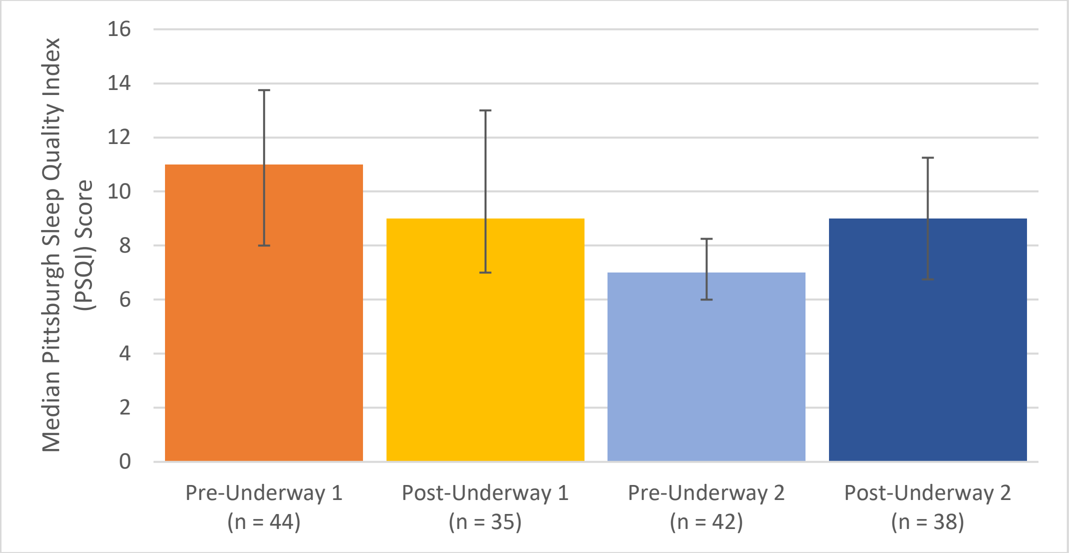

Figure 10. PSQI scores: All participants.Vertical lines denote the interquartile range.

PSQI scores decreased (sleep quality improved) at the end of Underway 1 (pre-Underway 1: 10.9 ± 3.5; post-Underway 1: 9.7 ± 4.2.; Wilcoxon signed rank test, S = -141.5, n = 34, p = 0.013). The number of poor sleepers before and after Underway 1 did not differ (pre-Underway 1: 31 [91.2%] Sailors; post-Underway 1: 28 [82.4%] Sailors; McNemar's test, $\chi 2 = 1.8$, n = 34, p = 0.180).

At the end of Underway 2, sleep quality worsened (pre-Underway 2: 7 [2.5]; post-Underway 1: 9 [4.5].; Wilcoxon signed rank test, S = 222.5, n = 37, $p < 0.001$). The number of poor sleepers before and after Underway 2 did not differ (pre-Underway 2: 33 [89.9%] Sailors; post-Underway 2: 33 [89.9%] Sailors; McNemar's test, $\chi 2 = 0$, n = 37, p = 0.999).

The two underway periods began with different PSQI scores (Sailors who participated in both phases of the study; pre-Underway 1: 10.9 ± 3.3; pre-Underway 2: 6.9 ± 1.7; Wilcoxon signed rank test, S = -130, n = 23, $p < 0.001$). At the end of both underway periods, PSQI scores did not differ (post-Underway 1: 9.1 ± 3.6; post-Underway 2: 9.3 ± 3.4; Wilcoxon signed rank test, S = -19, n = 23, p = 0.574). The number of poor sleepers at the end of Underway 1 and Underway 2 did not differ either (post-Underway 1: 20 [87%] Sailors; post-Underway 2: 21 [91.3%] Sailors; McNemar's test, $\chi 2 = 0.2$, n = 23, p = 0.655).

PSQI scores at the end of Underway 1 were worse compared to 14 other ships (post-Underway 1: 9 [6]; 14 other ships: 7 [5]; one-sample median test, T(34) = 201, $p < 0.001$). PSQI scores at the end of Underway 2 were also worse compared to 14 other ships (post-Underway 2: 9 [4.5]; 14 other ships: 7 [5]; one-sample median test, T(37) = 222.5, $p < 0.001$).

3. Average Daytime Sleepiness from Epworth Sleepiness Scale (ESS)

The median ESS score for all participants is shown in Figure 11. Sailors with elevated daytime sleepiness (EDS), as defined by ESS scores above 10, were identified among the participants: 27 (60%) in pre-Underway 1, 26 (59.1%) in post-Underway 1, 21 (48.8%) in pre-Underway 2, and 22 (57.9%) in post-Underway 2.

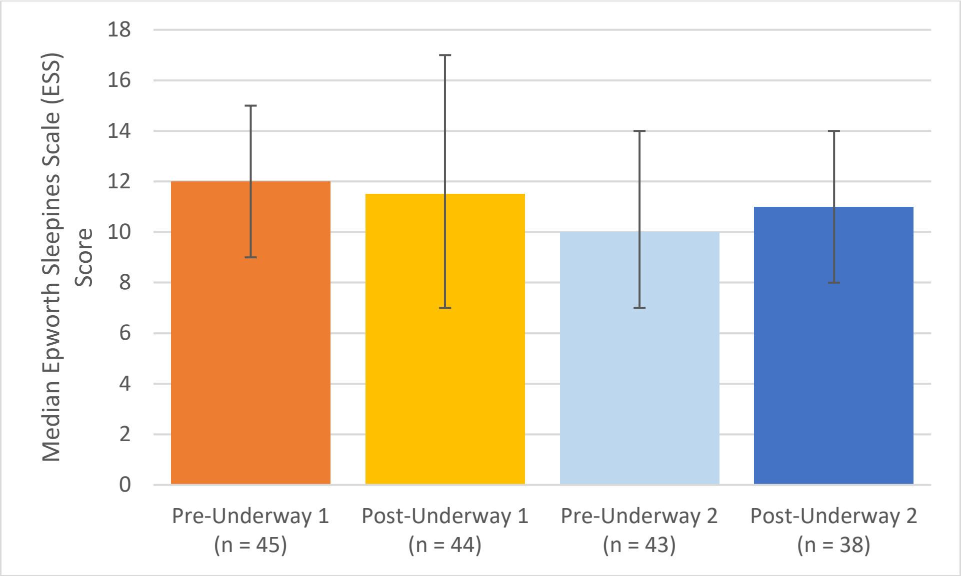

Figure 11. ESS score: All participants. Vertical lines denote the interquartile range.

Daytime sleepiness before and after Underway 1 did not differ (pre-Underway 1: 12(6); post-Underway 1: 11.5(10); Wilcoxon signed rank test, S = -88.5, n = 44, p = 0.306). The number of Sailors with elevated daytime sleepiness (EDS) before and after Underway 1 did not differ either (pre-Underway 1: 26 [59.1%] Sailors; post-Underway 1: 26 [59.1%] Sailors; McNemar's test, χ2 = 0, n = 44, p = 0.999).

Similar results were identified during Underway 2. Average daytime sleepiness before and after Underway 2 did not differ (pre-Underway 2: 10.5 ± 4.4; post-Underway 1: 11.2 ± 4.9; Wilcoxon signed rank test, S = 75.5, n = 38, p = 0.277). The number of Sailors with EDS before and after Underway 2 also did not differ (pre-Underway 2: 19 [55.9%] Sailors; post-Underway 2: 22 [64.7%] Sailors; McNemar's test, χ2 = 0.82, , n = 34, p = 0.366).

ESS scores did not differ among Sailors who participated in both data collections (post-Underway 1: 12.5 ± 5.5; post-Underway 2: 11.5 ± 4.9.; Wilcoxon signed rank test, S = -62, n = 27, p = 0.138). The number of Sailors with EDS from both data collections also did not differ (post-Underway 1: 16; post-Underway 2: 18.; McNemar's test, χ2 = 0.5, n = 27, p = 0.48).

ESS scores at the end of Underway 1 were worse (higher) compared to 14 other ships (post-Underway 1: 11.5 [10]; 14 other ships: 9.5 [6]; one-sample median test, T(43) = 204.5, p = 0.015). Also, ESS scores at the end of Underway 2 were worse compared to 14 other ships (post-Underway 2: 11 [6]; 14 other ships: 9.5 [6]; one-sample median test, T(37) = 148, p = 0.029).

4. Insomnia from Insomnia Severity Index (ISI)

The severity of insomnia symptoms, as measured by ISI, for all participants is shown in Figure 12.

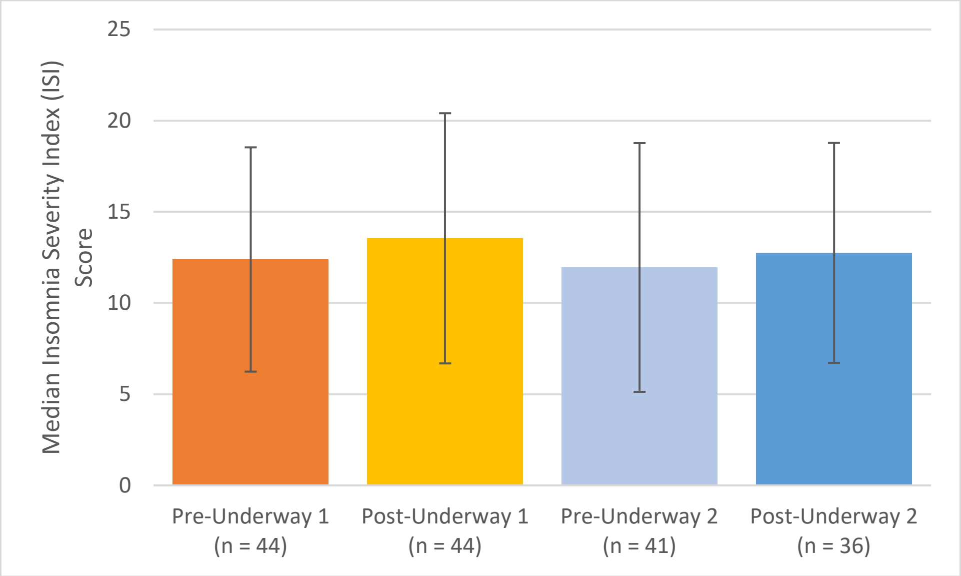

Figure 12. Average ISI scores: All participants. Vertical lines denote the interquartile range.

Sailors with elevated insomnia symptoms, as indicated by ISI scores of 15 and above, were identified among the participants: 16 (36.4%) in pre-Underway 1, 21 (47.7%) in post-Underway 1, 15 (36.6%) in pre-Underway 2, and 12 (33.3%) in post-Underway 2.

The severity of insomnia symptoms before and after Underway 1 did not differ (pre-Underway 1: 12.5 ± 6.2; post-Underway 1: 13.7 ± 6.9; Wilcoxon signed rank test, S = 140, n = 43, p = 0.090). The number of Sailors with elevated insomnia symptoms seemed to increase during Underway 1 (pre-Underway 1: 16 [37.2%] Sailors; post-Underway 1: 21 [48.8%] Sailors; McNemar's test, $\chi 2 = 2.78$, n = 43, p = 0.096).

ISI scores did not differ before and after Underway 2 (pre-Underway 2: 12.4 ± 6.8 post-Underway 2: 12.7 ± 6.2; Wilcoxon signed rank test, S = 76.5, n = 34, p = 0.194). Also, the number of Sailors with elevated insomnia symptoms did not differ before and after Underway 2 (pre-Underway 1: 13 [38.2%] Sailors; post-Underway 1: 11 [32.4%] Sailors; McNemar's test, $\chi 2 = 0.5$, n = 34, p = 0.480).

Among the Sailors who participated in both data collections, ISI scores did not differ between underway periods (post-Underway 1: 14.1 ± 6; post-Underway 2: 13.2 ± 6.2; Wilcoxon signed rank test, S = -18.5, n = 25, p = 0.627). However, the number of Sailors with elevated insomnia symptoms was less during Underway 2 compared to Underway 1 (post-Underway 1: 12 [48%] Sailors ; post-Underway 2: 9 [36%] Sailors; McNemar's test, $\chi 2 = 3$, n = 25, p = 0.083).

Severity of insomnia symptoms during Underway 1 was worse compared to 14 other ships (post-Underway 1: 13.5 [10.75]; 14 other ships: 10 [7]; one-sample median test, T(43) = 251.5, p = 0.002). Severity of insomnia symptoms during Underway 2 was also worse compared to 14 other ships (post-Underway 2: 12.5 [5.8]; 14 other ships: 10 [7]; one-sample median test, T(35) = 157.5 p = 0.011).

5. Adequacy of Sleep

Summarized in Figures 13 and 14 are the responses from all participants for each underway period regarding the amounts of sleep they received and the amounts of sleep other Sailors received.

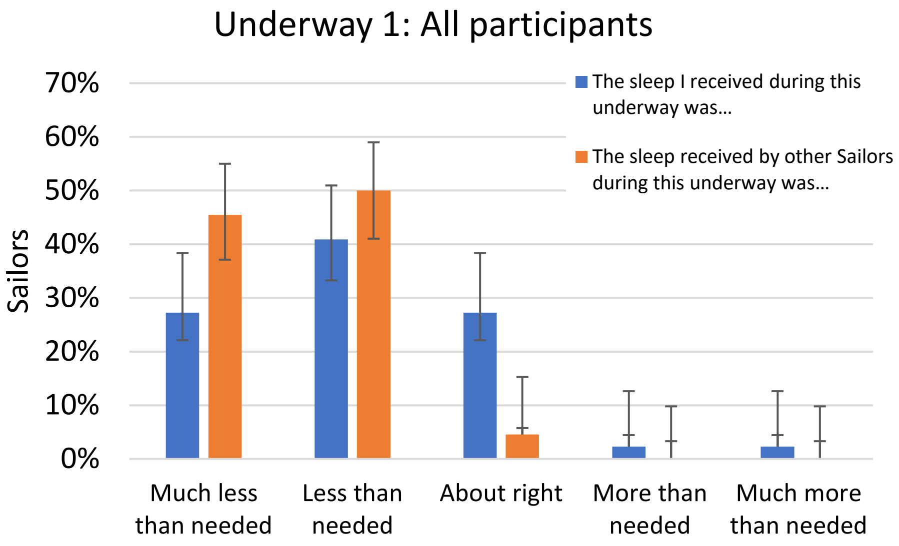

Figure 13. Opinion of adequacy of sleep during Underway 1: All participants

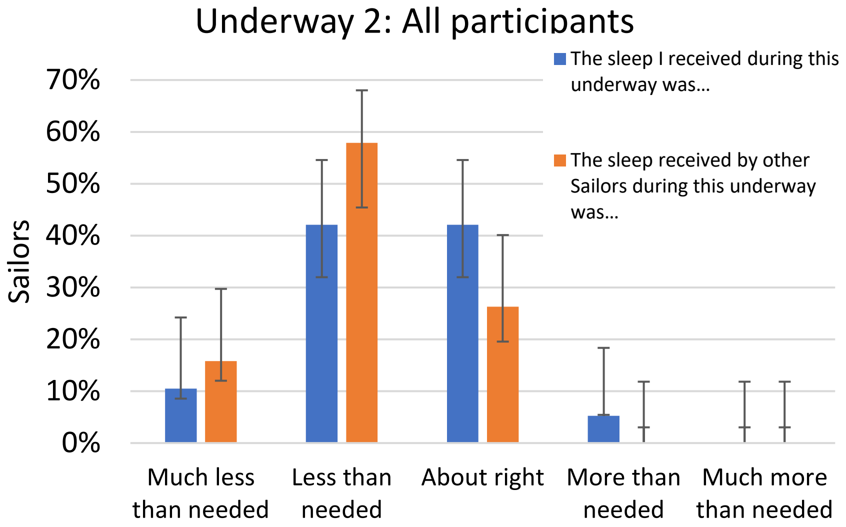

Figure 14. Opinion of sleep adequacy during Underway 2: All participants

Presented in Figures 15 and 16 are the responses from Sailors who participated in both data collections regarding the amounts of sleep they received and the amounts of sleep other Sailors received. Fewer Sailors from Underway 2 responded that their sleep was less or much less than needed (Underway 1: 20 [74.1%], Underway 2: 14 [51.9%]; McNemar's test, $n = 27$, $\chi^2 = 4.5$, $p = 0.034$). Additionally, fewer Sailors from Underway 2 responded that other Sailors received less or much less than the sleep needed (Underway 1: 27 [100%], Underway 2: 19 [70.4%]).

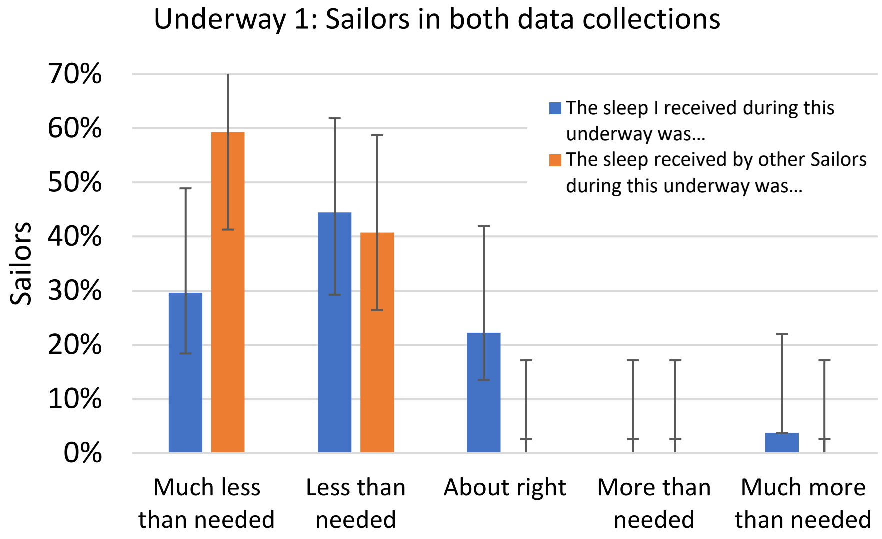

Figure 15. Opinion of sleep by participants from both underway periods: Underway 1

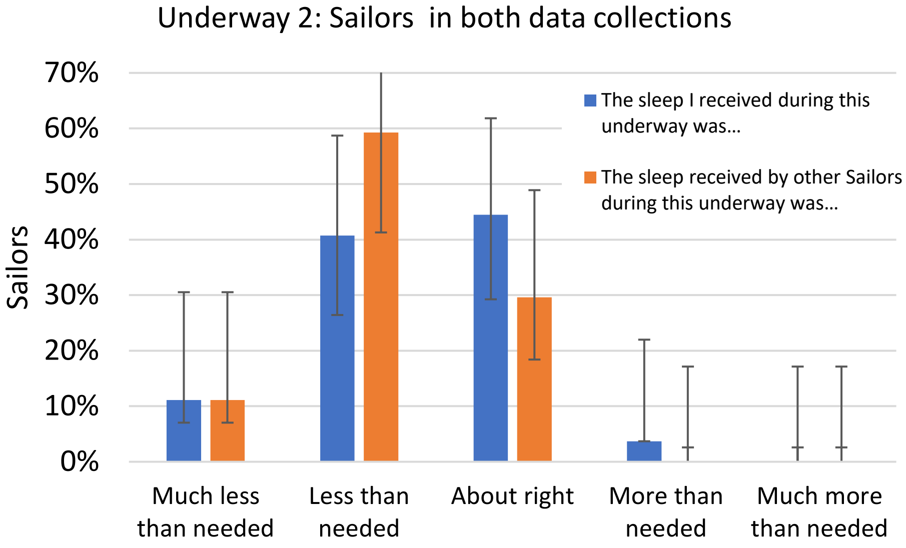

Figure 16. Opinion of sleep by participants from both underway periods: Underway 2

6. Factors Affecting Sleep

Figure 17 shows Sailor responses from Sailors in both data collections regarding the factors affecting their sleep. Table 15 shows the results of tests conducted to identify statistically significant differences between the factors affecting sleep. Results suggested that fewer Sailors reported not having enough time to sleep during Underway 2.

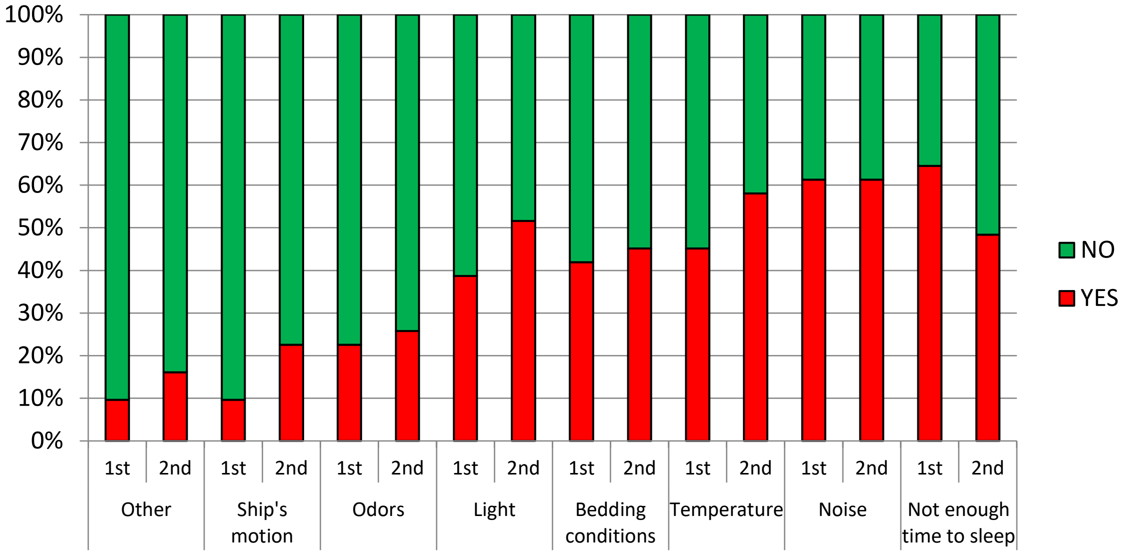

Figure 17. Factors affecting sleep: Sailors in both underway periods

Table 15. Factors affecting sleep: Underway 1 vs. Underway 2

Factors	Post-Underway 1	Post-Underway 2	McNemar's Test (n = 30)
Not enough time to sleep	20 (64.5%)	15 (48.4%)	$\chi^2 = 3.6$, $p = 0.058$
Noise	19 (61.3%)	19 (61.3%)	$\chi^2 = 0$, $p = 0.999$
Temperature	14 (45.2%)	18 (58.1%)	$\chi^2 = 1.6$, $p = 0.206$
Bedding conditions	13 (41.9%)	14 (45.2%)	$\chi^2 = 0.14$, $p = 0.706$
Light	12 (38.7%)	16 (51.6%)	$\chi^2 = 2.67$, $p = 0.103$
Odors	7 (22.6%)	8 (25.8%)	$\chi^2 = 0.33$, $p = 0.564$
Ship's motion	3 (9.7%)	7 (22.6%)	$\chi^2 = 2$, $p = 0.157$
Other	3 (9.7%)	5 (16.1%)	$\chi^2 = 0.5$, $p = 0.480$

Shown in Figure 18 are the Noise factors affecting sleep, as reported by Sailors from both data collections. As shown in Table 16, no statistically significant differences were identified in the prevalence of the noise factors between the two underway periods.

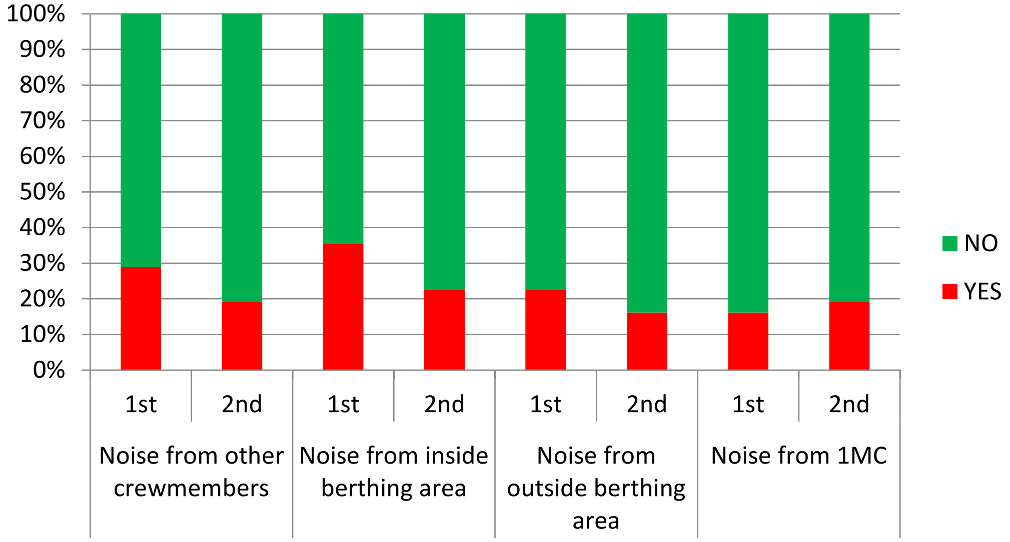

Figure 18. Noise factors affecting sleep: Sailors in both underway periods

Table 16. Noise factors affecting sleep: Underway 1 vs. Underway 2

Factors	Post-Underway 1	Post-Underway 2	McNemar's Test (n = 30)
Noise from other crewmembers	9 (29%)	6 (19.4%)	$\chi^2 = 1.8$, p = 0.180
Noise from inside berthing	11 (35.5%)	7 (22.6%)	$\chi^2 = 2$, p = 0.157
Noise from outside berthing	7 (22.6%)	5 (16.2%)	$\chi^2 = 0.67$, p = 0.414
Noise from 1MC	5 (16.1%)	6 (19.4%)	$\chi^2 = 0.33$, p = 0.564

The temperature factors affecting sleep, as reported by Sailors in both data collections, are depicted in Figure 19. No statistically significant differences between the two underway periods were identified: too hot (Post-Underway 1: 9 [30%] Sailors; post-Underway 2: 6 [20%] Sailors; McNemar's test, $\chi^2 = 2.27$, n = 30, p = 0.132); too cold (post-Underway 1: 11 [36.7%] Sailors; post-Underway 2: 7 [23.3%] Sailors; McNemar's test, $\chi^2 = 0.33$, n = 30, p = 0.5637).

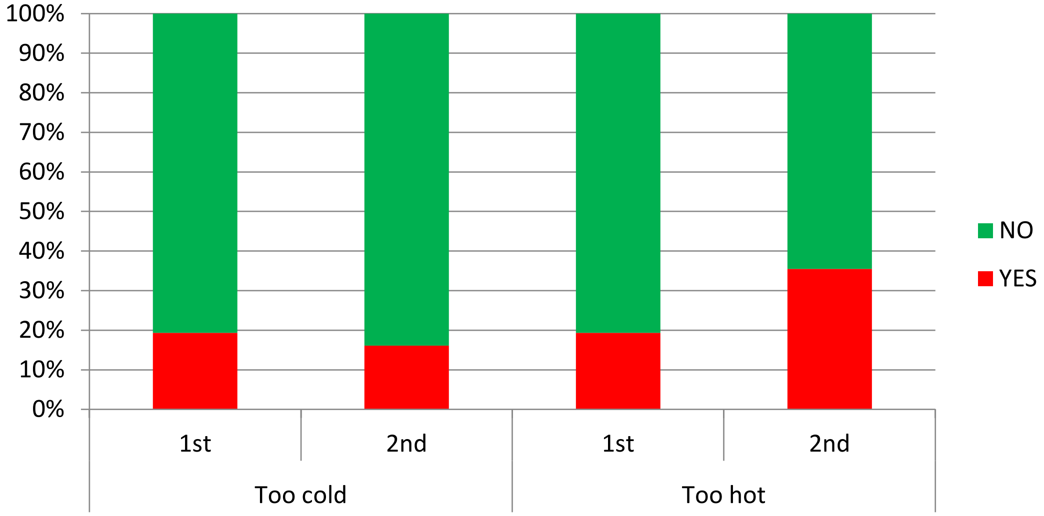

Figure 19. Temperature factors affecting sleep: Underway 1 vs. Underway 2

Bedding conditions affecting sleep between the two underway periods are shown in Figure 20. No statistically significant differences between the two underway periods were identified, as shown in Table 17.

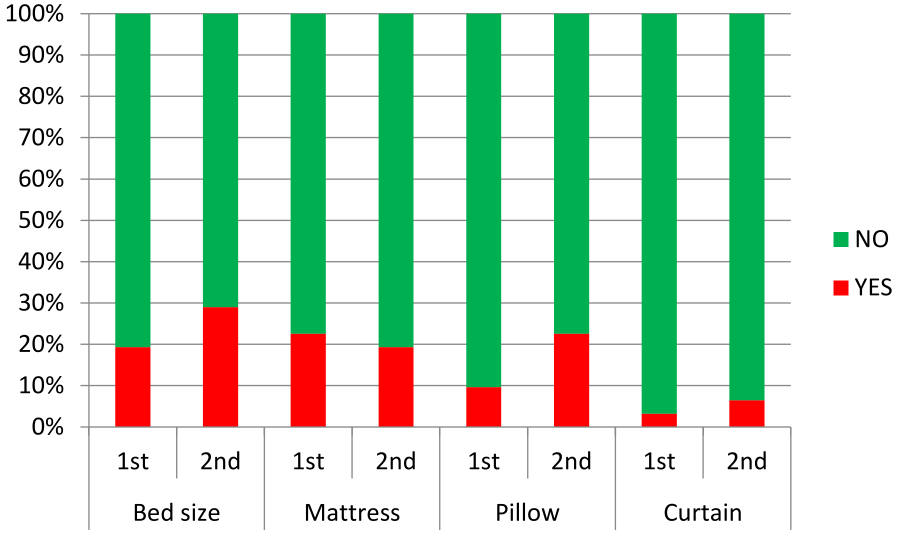

Figure 20. Bedding conditions affecting sleep: Sailors in both data collections

Table 17. Bedding conditions affecting sleep: Underway 1 vs. Underway 2

Factors	**Post-Underway 1**	**Post-Underway 2**	**McNemar's Test (n = 30)**
Bed size	9 (29%)	6 (19.4%)	$\chi^2 = 1.29$, $p = 0.257$
Mattress	11 (35.48%)	7 (22.6%)	$\chi^2 = 0.2$, $p = 0.655$
Pillow	7 (22.56%)	5 (16.1%)	$\chi^2 = 2.67$, $p = 0.103$
Curtain	5 (16.1%)	6 (19.4%)	$\chi^2 = 1$, $p = 0.317$

D. WORKLOAD

Depicted in Table 18 are the median hours of work of all participants, as well as the calculated Productive Availability Factor (PAF). The PAF is the cumulative amount of time spent on work, maintenance, watch, training, and service diversions in a week that is allotted in the Navy Availability Factor (NAF; CNO, 2019). Workload during Underway 1 was similar to the workload of 14 other ships (Underway 1 = 10.89 [5.3] hours; 14 other ships = 12.2 [2.7]; one-sample median test, $T(13) = -23.5$, $p = 0.153$). In contrast, Sailors during Underway 2 worked fewer hours per day than Sailors on 14 other ships (Underway 2 = 10.6 [2.2] hours; 14 other ships = 12.12 [2.7] hours; one-sample median test, $T(21) = -103.5$, $p < 0.001$).

Table 18. Workload: All Sailors

	Underway 1 (n = 14)	**Underway 2 (n = 22)**
Workload (hrs/day)	10.9(5.3)	10.6(2.2)
Mean / Median Productive Availability Factor* (hrs/week)	76(36.9)	74.1(15.1)
Sailors working >15 hrs/ day	1 (7.1%)	1 (4.5%)
Sailors working >12 hrs/ day	4 (28.6%)	3 (13.6%)

Work hours of all participants during Underway 1 and Underway 2 were compared to the PAF. No statistically significant difference was identified between the workload from Underway 1 and PAF (Underway 1 = 76 [36.9] hours, PAF = 67 hours, one-sample median test, $T(13) = 21.5$, $p = 0.194$). However, the workload during Underway 1 was not evenly distributed among the sailors, as evidenced by the large interquartile range (IQR = 36.9 hours).

Sailors in Underway 2 worked more hours than the PAF (Underway 2 = 74.1 [12.1] hours, PAF = 67 hours, one-sample median test, T(21) = 75.5, p = 0.011). During Underway 2, workload was more evenly distributed among the Sailors—21 out of the 22 Sailors reported 72.2 ± 10.2 hours of workload per week.

The workloads of Sailors who participated in both data collections are displayed in Table 19. Due to the small number of available data points (n = 9), statistical comparisons are not appropriate.

Table 19. Workload: Sailors in both data collections

	Underway 1	**Underway 2**
Workload (hrs/day)	10.8 ± 2.2	9.9 ± 1.5
Mean Productive Availability Factor (hrs/week)	75.6 ± 15.6	69.5 ± 10.4
Sailors working >15 hrs/day	0 (0%)	0 (0%)
Sailors working >12 hrs/day	2 (22.2%)	0 (0%)

Sailor opinion regarding the workload of all participants is presented in Figures 21 to 24. Fewer Sailors from Underway 2 responded that their workload was more or much more than usual (Underway 1: 19 [70.4%], Underway 2: 12 [44.4%]; McNemar's test, n = 27, $\chi^2 = 3.3$, p = 0.071). Moreover, fewer Sailors from Underway 2 responded that other Sailors' workload were more or much more than usual (Underway 1: 22 [81.5%], Underway 2: 11 [40.7%], n = 27, $\chi^2 = 9.3$, p = 0.002).

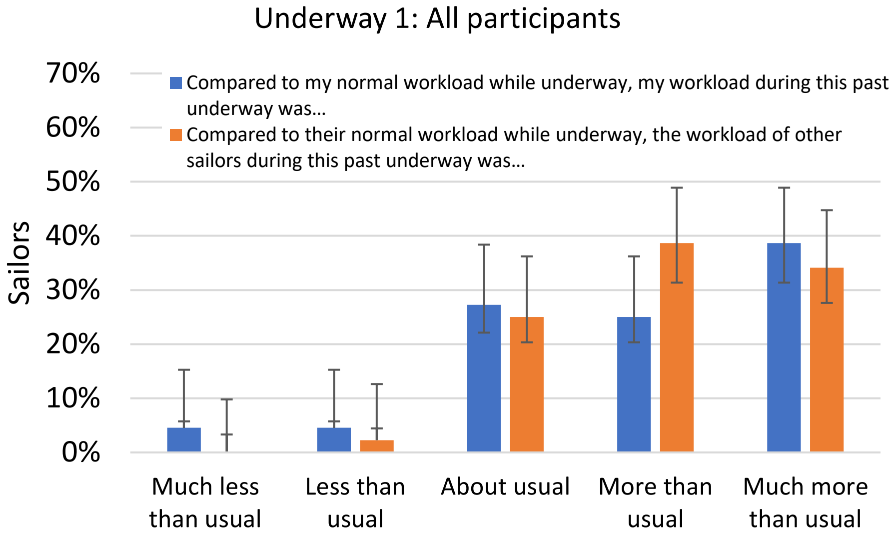

Figure 21. Opinion of Underway 1 workload: All participants

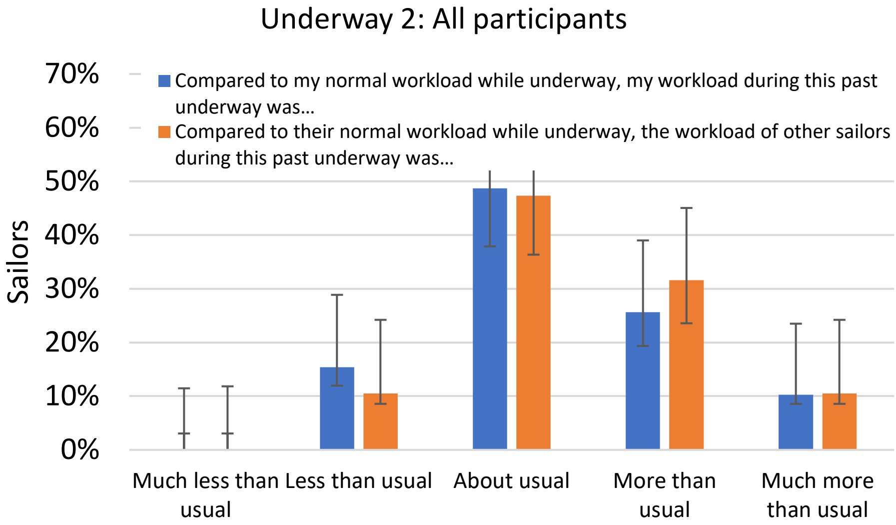

Figure 22. Opinion of Underway 2 workload: All participants

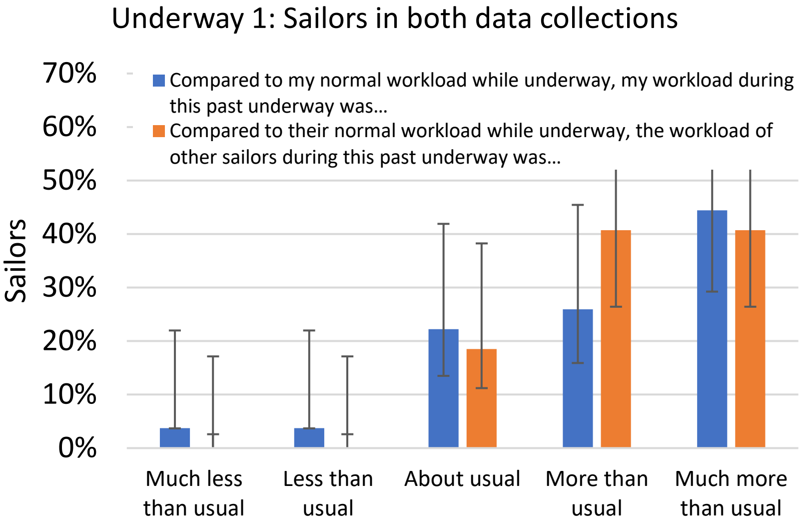

Figure 23. Opinion of Underway 1 workload: Sailors in both data collections

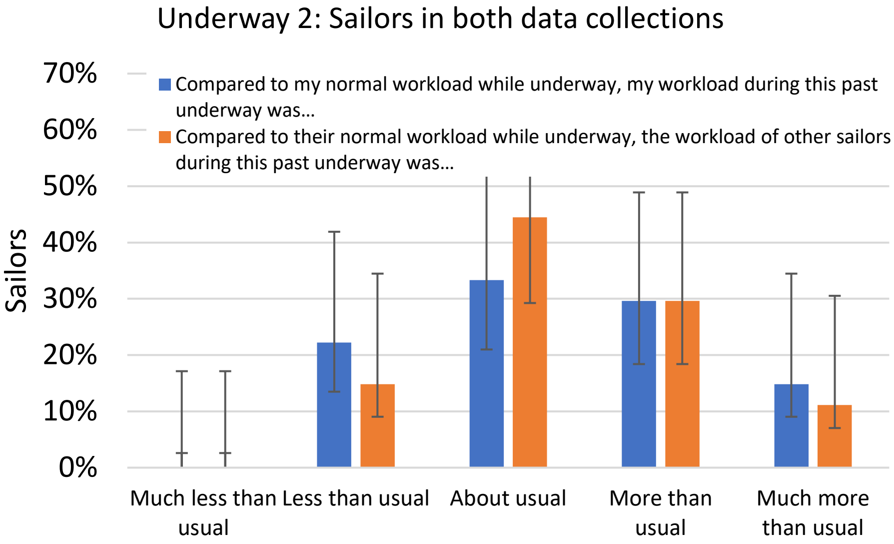

Figure 24. Opinion of Underway 2 workload: Sailors in both data collections

V. DISCUSSION

The results of this study suggest that Sailor well-being—measured by sleep attributes, mood, and workload—improves when OPTEMPO is lower and circadian-based watchbills are implemented. However, this study is unable to discriminate the effects of OPTEMPO from the effects of circadian watchbills.

A. BASIC PHASE AND COVID

Pre-COVID data of engineering departments across 14 other ships reflect better measurements than the data collected from the Engineering Department of USS Gonzalez. The worse measurements for mood, sleep quality, daytime sleepiness, insomnia symptoms, and sleep episodes per day may indicate the difficulty of the Basic Phase and suggest the presence of adverse effects of COVID onboard USS Gonzalez. However, this study is unable to differentiate the effects of the Basic Phase from the effects due to the spread of COVID-19. Also, there were other contemporaneous factors that made the recognition difficult, such as command climate and the death of a non-engineering Sailor due to reasons other than COVID.

The crew employed a variety of approaches against COVID: clear plastic panels were installed on the tables of the ship's galley; routine "cleaning stations" were augmented with antiseptic cleaning supplies; the sleeping accommodations of every department were spread out across multiple berthings ("battle berthings"; Mason, 2020). These initiatives were in addition to the use of masks, contact tracing, cross training, staggered mealtimes, and isolation of Sailors who exhibited COVID symptoms.

Unfortunately, amid the measures against COVID, cases emerged from both participants and non-participants of this study—particularly for those in leadership positions. Of the participants from Underway 1, one division chief petty officer contracted COVID. Of the participants from Underway 2, three contracted COVID: an E-6, the Top Snipe, and the E-7 covering for the Top Snipe.

B. SLEEP ATTRIBUTES

All Sailors during Underway 2 received less than 8 hours of sleep per day, in contrast to 87.5% of Sailors in Underway 1. However, fewer Sailors reported not having enough time to sleep and mood was better during Underway 2 compared to Underway 1. The execution of circadian watchbills provides a likely explanation: 8 hours was the maximum sleep window offered by the "3/9" and "4/8" circadian watchbills in Underway 2, but Sailors found more satisfaction due to the consistency of sleep opportunities. The reduction of OPTEMPO also offers an interpretation: the lower OPTEMPO during Underway 2 may have provided Sailors with less stress and more opportunities to engage in preferred activities other than work or sleep. These two factors also lend an interpretation for Underway 1: fewer Sailors received short amounts of sleep during Underway 1 because the Sailors were prioritizing sleep amid the irregular sleep opportunities and the higher OPTEMPO.

Sleep quality improved during Underway 1. This change can potentially be explained by contrasting routines based on the ship's employment. The battle rhythm during periods of underway may be more consistent than in-port, thereby providing Sailors a more structured routine. Sleep quality worsened at the end of Underway 2; however, Sailors were previously on holiday stand-down, which potentially offered better sleep quality than Underway 2.

Comparable workloads may explain the lack of differences between the sleep durations of (a) Underway 1 and Underway 2, as well as (b) between the engineering Sailors onboard USS Gonzalez and those of 14 other ships. Whether ships are in the Basic Phase or not, engineering Sailors have substantial amounts of work. The high level of workload across the various phases of a ship's life cycle potentially dominates the factors influencing the amount of sleep engineering Sailors receive.

Shipboard culture may also explain the lack of differences between the sleep measurements obtained. Sailors onboard USS Gonzalez and those of 14 other ships. Individual Sailors may encounter motivation or experience pressure to engage in additional work or training for the next higher qualification—at the expense of adequate rest—in order to alleviate some of the burdens of the crew.

Although the average sleep duration of the engineering Sailors onboard Gonzalez was not different from 14 other ships, the participants of this study received less than the amount of sleep recommended by Watson and colleagues (2015b) from the American Academy of Sleep Medicine and Sleep Research Society. If not addressed, the acute sleep debt observed could evolve into chronic sleep debt (Van Dongen et al., 2003) and continuously deteriorate Sailor performance (Lombardi et al., 2010; Miller et al., 2007; Olsen et al., 2013).

C. MOOD

Vigor worsened during Underway 1 and Underway 2, hinting at the demanding nature of underway periods. Various factors that may affect mood are inherent in underway periods, to include components not specifically addressed in this study: separation from family (Landa et al., 2020) and restricted diet (Arab et al., 2019).

Mood during Underway 1 and Underway 2 was worse compared to mood of Sailors on 14 other ships. Along with the additional operational demands of the Basic Phase, perhaps the restrictions implemented onboard the ship to control the spread of COVID-19 affected the mood of the participants. For example, the safety measures may have reduced Sailors' interest in cultivating their well-being through working out: sign-ups were required to use the gym onboard, and some equipment was taped off to facilitate social distancing.

D. WORKLOAD

No differences were identified between the underway with higher OPTEMPO and the underway characterized by lower OPTEMPO. One potential explanation is that lower OPTEMPO does not indicate zero OPTEMPO. Lower-priority tasks during the period of higher OPTEMPO may have simply been postponed to the period of lower OPTEMPO.

The workloads identified for the Engineering Department of USS Gonzalez did not align with the PAF allotted in the NAF. During Underway 1, when the Engineering Department was conducting drills as part of the Basic Phase, workload did not differ significantly from the PAF. However, Underway 1 workload was disproportionately distributed among the Sailors, with a median that represented a higher value than the PAF. During Underway 2—when the Engineering Department transitioned to a supporting role for the other departments—workload was more evenly distributed among the Sailors; however, workload was still higher than the PAF.

The Basic Phase is recognized as a demanding evolution that may be considered more intense than the deployed cruising readiness described in the NAF. While the Basic Phase entails manning watch stations that support deployed cruising readiness, it also entails additional manpower to fill the responsibilities of the engineering training team and the extra capacity to ensure engineering spaces are safe to operate prior to evolutions. These additional requirements beyond the demands of normal underway steaming are necessary to ensure the ship advances toward deployment certification (CNO, 2014). Due to operational requirements, exclusively minimizing workload while not increasing the number of Sailors may not be appropriate. Increasing manning to minimize workload may be a more promising approach to explore.

E. STUDY LIMITATIONS

The interpretation of results from this study requires the consideration of several limitations. The original manning goals were not achieved; consequently, this research could not appropriately explore the effects of increasing the manning of the Engineering Department.

(1) Scope and Participants

The data captured may not be representative of the engineering departments across the fleet. From the single ship observed in this study, only a portion of the crew volunteered and only a percentage of those volunteers participated in the entire data collection. Potential reasons for Sailors not participating may include busyness, disengagement from the command, or doubt about the purpose of the study. Missing data from those who participated required some interpolation, as discussed in Chapter III.

This study neither captures the entire duration of the Basic Phase nor assesses the participants' pre-existing conditions of sleep and mood. Furthermore, this study only explores three components of well-being—sleep, mood, and workload. Among the other constructs that may be of interest is crew morale.

Additionally, the Hawthorne effect (Adair, 1984) could have been active in this study. Because the participants were aware they were under observation, it may have influenced their actions and responses to the questionnaires issued. Rather than reporting their actual thoughts, feelings, and behavior, the Sailors may have reacted to the constructs being measured or responded according to social norms.

(2) Methods

Sleep duration and the number of sleep episodes per day were assessed using actigraphy instead of the gold standard procedure of polysomnography. Highlighting the limitations of actigraphy, Sadeh and Acebo (2002) discuss that "(1) Validity has not been established for all scoring algorithms or devices, or for all clinical groups; (2) actigraphy is not sufficient for diagnosis of sleep disorders in individuals with a motor disorder or high motility during sleep; (3) the use of computer scoring algorithms without controlling for potential artifacts can lead to inaccurate and misleading results" (p. 113).

The use of questionnaires also presents limitations. Open-ended questions may be subject to different interpretations by the respondents. Fixed-alternative questions, on the other hand, may not capture the full range of responses from the participants.

Time spent at work, watch, training, and service diversions were all self-reported, making the measurement for workload subject to biases or distractions. The same limitations of subjective data apply to the assessment of mood, sleep quality, daytime sleepiness, and insomnia symptoms conducted in this study.

Despite the application of standardized procedures, this study may be subject to disparities due to differences in the individual characteristics of the research team members. The same questionnaires were administered at each underway period of this study, as well as onboard the 14 other ships considered for the meta-analysis; however, the interactions between the researchers and the participants may not have been necessarily consistent. Across the archival studies and this study onboard USS Gonzalez, different members of the research team were involved in the recruitment of participants, as well as the collection, preparation, analysis, and interpretation of data.

VI. CONCLUSIONS AND RECOMMENDATIONS

The responsibilities of the Engineering Department onboard U.S. Navy destroyers are inherently demanding. Sailors assigned to the Engineering Department operate, maintain and repair many of the systems throughout the ship in order to provide various critical services such as propulsion, damage control, air conditioning, potable water, electricity, and sewage. Engineering Sailors deliver round-the-clock support to all evolutions onboard while continuously being subjected to demanding work conditions, including long work hours, extreme heat, high stress, and inadequate rest. In this grueling environment, engineering Sailors are not only expected to stand watch vigilantly, but also to train constantly, gain new skills and expand their knowledge.

Anecdotal reports suggest that these impediments to higher performance may be widespread during the Basic Phase of the OFRP cycle and may even be further aggravated at the height of the COVID-19 pandemic. Therefore, this thesis aimed to a) assess the sleep attributes, mood, and workload of engineering Sailors onboard USS Gonzalez, and b) explore how the spread of COVID-19 affected the readiness of the Engineering Department during the Basic Phase.

Participants were evaluated using standardized questionnaires, actigraphy, and self-reported activity logs. Data collection took place during the Basic Phase over two underway periods of 15 days each. Underway 1 was characterized by the prevalence of non-circadian-based watch rotations and higher OPTEMPO, as indicated by the Engineering Department's MOB-D certification. Underway 2 was characterized by the dominance of the "3/9" and "4/8" watch rotations and lower OPTEMPO when the Engineering Department transitioned to a supporting role to the other departments' training events.

The results suggest positive effects of lower OPTEMPO and the use of circadian watchbills; however, this study is unable to distinguish the effects between the two factors. All participants received less than 8 hours of sleep a day during Underway 2, but fewer

Sailors responded that their sleep was less than adequate compared to Underway 1. Mood was also better during Underway 2 than during Underway 1.

Lower OPTEMPO does not signify zero OPTEMPO, which may explain the lack of differences identified in some of the metrics. No differences were recognized in sleep quality, daytime sleepiness, insomnia symptoms, sleep duration, and the number of sleep episodes per day between Underway 1 and Underway 2.

The results also hint at the difficulty of the Basic Phase and the adverse effects of COVID on the Engineering Department of USS Gonzalez; however, this study cannot differentiate between the two. Mood, sleep quality, daytime sleepiness, insomnia symptoms, and proclivity to nap during Underway 1 and Underway 2 were worse compared to pre-COVID data collected from engineering departments across 14 other ships. Even though workload during Underway 1 was equivalent to the PAF allotted in the NAF, it was disproportionately distributed among the Sailors. Workload during Underway 2 was more evenly distributed among Sailors but was higher than the PAF.

This thesis was originally intended to evaluate whether increasing the manning levels of the Engineering Department results in improved well-being and performance. However, the manning goals were not met in order to conclusively identify the positive effects of enhancing manning.

A recommendation from this study is to increase manning in order to properly explore the effects of increased manning for the Engineering Department. When the manning onboard USS Gonzalez was higher (i.e., Underway 2)—albeit only administratively—the Engineering Department onboard the USS Gonzalez managed to keep Sailors behind to attend required schools and continued to provide critical services for the entire ship despite the adverse effects of COVID-19. While this thesis offers promising insights, the presence of actual Sailors is required to conduct a more thorough comparison between a control ship with typical manning levels and a test ship with higher-than-normal manning levels.

The additional manning required for testing a research effort like the current one should be provided deliberately before the start of the Basic Phase. The increase in crew size and this thesis both commenced when the Engineering Department’s heavy role in the Basic Phase began to wane; the Engineering Department’s more difficult sub-phases were likely overlooked.

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