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**Original Article**

## Original Article

# Steps toward developing a comprehensive fatigue monitoring and mitigation solution: perspectives from a cohort of United States Naval Surface Force officers

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## Abstract

**Study Objectives:** This study analyzed fatigue and its management in US Naval Surface Force warships, focusing on understanding current practices and barriers, and examining the influence of organizational and individual factors on managing chronic fatigue. Furthermore, this study explored the impact of organizational and individual factors on fatigue management.

**Methods:** As part of a larger study, 154 naval officers (mean ± standard deviation; 31.5 ± 7.0 years; 8.8 ± 6.8 years of service; 125 male, and 29 female) completed a fatigue survey. The survey addressed (1) self-reported fatigue, (2) fatigue observed in others, (3) fatigue monitoring strategies, (4) fatigue mitigation strategies, and (5) barriers to fatigue mitigation. Logistic and ordinal regressions were performed to examine the effect of individual (i.e. sleep quality and years in military service) and organizational (i.e. ship-class) factors on fatigue outcomes.

**Results:** Fatigue was frequently experienced and observed by 23% and 54% of officers, respectively. Of note, officers often monitored fatigue reactively (i.e. 65% observed others nodding off and 55% observed behavioral impairments). Still, officers did not frequently implement fatigue mitigation strategies, citing few operationally feasible mitigation strategies (62.3%), being too busy (61.7%), and not having clear thresholds for action (48.7%). Fatigue management varies across organizational factors, which must be considered when further developing fatigue management strategies.

**Conclusions:** Fatigue remains a critical concern aboard surface force ships and it may be better addressed through development of objective sleep and fatigue monitoring tools that could inform leadership decision-making.

*This paper is part of the Sleep and Circadian Rhythms: Management of Fatigue in Occupational Settings Collection.*

**Key words:** fatigue management; fatigue risk; Navy; sleep; ship-class

### Statement of Significance

Characterization of current fatigue management strategies used in high-risk occupations in which fatigue is prevalent is needed to identify barriers to fatigue mitigation and opportunities for improvement. As such, this study characterized current fatigue management practices aboard US Naval Surface Force warships from the perspective of officers. This study found that fatigue remains a critical issue aboard Surface Force warships and it is currently monitored and identified *after* behavioral deficits are apparent. Furthermore, current fatigue mitigation solutions have not been frequently implemented primarily because available solutions are often not feasible within operational environments. Objective and proactive fatigue management solutions that account for job- and setting-specific constraints are needed for high-risk occupations.

## Introduction

Poor sleep (e.g. short sleep and poor sleep quality) is a widespread issue, affecting the health and productivity of populations across different cultures and societies due to factors like technological distractions, rising stress levels, and changing lifestyle patterns [1]. Such concerns especially hold true for those employed in

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high-risk occupations (e.g. aviation, first responders, and military), where such sleep deficiencies and chronic fatigue are pervasive. In addition to negatively impacting workforce health and well-being, sleep deficiencies and fatigue in high-risk industries present concerns regarding operational safety outcomes [2–4]. High-risk occupations are characterized by multiple factors that can contribute to chronic fatigue, such as high workloads, nontraditional or irregular work schedules (e.g. nightshifts, extended shifts, and dynamic scheduling), and inadequate sleep (e.g. short duration and fragmented) [2, 5, 6]. Such factors can disrupt sleep and alertness if individuals' daily schedules become misaligned with the timing signals generated by their internal circadian rhythms [7, 8]. As a case in point, short sleep has consistently been observed aboard US Navy (USN) warships, whether measured using self-report surveys (mean ± standard deviation; 5.26 ± 1.23 hours) [6] or actigraphy (6.60 ± 1.01 hours) [9] and fatigue has been associated with several deadly and costly at-sea mishaps [10–13]. These prominent threats to safety, among other consequences of fatigue, underscore the need for an effective fatigue management system (i.e. fatigue monitoring and mitigation) for high-risk occupations.

In response to these challenges in high-risk occupations, the number of efforts to implement effective fatigue mitigation policies and programs across these occupations has increased in recent years [14, 15]. These initiatives have included improving education (e.g. sleep health), work scheduling (e.g. shortening shifts or increasing time between shifts), and increasing staffing [5, 16]. For example, the US Naval Surface Force (SURFOR; i.e. warships excluding submarines and aircraft carriers) has mandated 7.5 hours of protected sleep time and the use of circadian-aligned watchbill scheduling [17]. Additionally, SURFOR—as part of a larger fatigue management strategy—has recently undertaken efforts to objectively track fatigue using physiological monitoring devices (aka and wearables) and to manage fatigue risk using biomathematical models [18]. Biomathematical models used to predict fatigue have been developed based on the two-process model of sleep regulation and can incorporate multiple parameters (e.g. time of day, time awake, and sleep history) to predict fatigue risk and performance degradation [19, 20]. These models have been used in fatigue risk management systems across select high-risk occupations (e.g. aviation) [21]. Importantly, these models often make assumptions regarding sleep–wake periods based on work schedules due to difficulty obtaining objective sleep data in operational settings—a gap that wearables may address [19, 22]. Biomathematical models that integrate operational work schedules with real-time wearable-based sleep data hold promise for mitigating operational risk by providing leaders with a comprehensive program to monitor and mitigate fatigue-related risks [23].

Despite SURFOR's efforts to alleviate fatigue, the desired outcomes are rarely achieved due to a number of factors, such as operational schedules, workloads, and personnel shortages [18, 24, 25]. As a result, there is a critical need to characterize and evaluate current fatigue management practices. To date, much of the SURFOR-focused research has centered on characterizing sleep and fatigue realities onboard ships. However, research characterizing the current strategies used to address sleep and fatigue issues is lacking.

Any effort to address this gap in understanding must also consider contextual factors at the organizational (e.g. ship-class and leadership) and individual (e.g. military experience and sleep quality) levels. For example, SURFOR is composed of different ship-classes, which vary in size/equipment, staffing levels, operational responsibilities, and leadership, thus reflecting distinct work environments and occupational stressors that must be accounted for in development fatigue mitigation efforts. These factors could plausibly influence sleep opportunities and an organization's efforts to implement fatigue mitigation strategies. Small organizations may lack the resources to tailor strategies to individual personnel or to monitor the effectiveness of solutions. Additionally, staffing limitations may hinder an organization's ability to add personnel with the specialized expertise required to implement and guide the development of fatigue mitigation solutions. Individual characteristics, such as sleep quality and duration, military experience, or beliefs about the real-world impact of fatigue and the importance of managing it, could also compromise efforts to implement fatigue mitigation practices. For example, there is evidence that military officers who experience less fatigue as a result of good sleep habits encourage healthier sleep practices in their subordinates [26]. Therefore, the sleep quality of officers and the fatigue management strategies they implement may be related. However, this phenomenon could have a negative effect as well, as in the case of an individual who believes fatigue to be irrevocable part of military life and may therefore undercut intervention efforts. Understanding the influence of context on fatigue management practices could thus provide additional insights regarding operationally relevant barriers to fatigue mitigation in naval settings.

Military officers and senior enlisted leaders play an integral role in personnel management and are ideally positioned to provide insights into service member fatigue and fatigue management practices. Officers are in a position to understand the severity of the fatigue problem and to provide essential feedback on the most effective methods of addressing the problem. As such, it is important to develop a profile of officer views to aid in the development of fatigue management policies and programs. The current study sampled SURFOR officers to characterize their beliefs about their own personal fatigue, crew fatigue, fatigue monitoring strategies, efforts to implement fatigue mitigation practices, and barriers to these implementation efforts (aim 1). This study also explored individual (i.e. sleep quality and length of military service) and organizational factors (i.e. ship-class) relating to these beliefs (aim 2). For aim 2, it was hypothesized that both individual and organizational factors would influence fatigue-related beliefs and efforts to mitigate fatigue.

## Materials and Methods

### Participants

As part of a larger SURFOR study [27], 187 active-duty officers serving across three different ship classes (guided missile destroyer [DDG], amphibious landing helicopter dock ship [LHD], and littoral combat ship [LCS]) participated in this study. Additionally, participants assigned to a marine expeditionary unit (MEU) embarked on one of the LHDs were included in analyses as a distinct cohort. The number of cohorts enrolled from each unit varied: 1 DDG, 2 LHDs, 5 LCSs, and 1 MEU.

Study approval was acquired from both Commander, Naval Surface Forces and the commanding officer of each ship. Recruitment briefs were conducted aboard each ship and those who opted into the voluntary study signed an informed consent document. Participants completed an anonymous survey assessing demographic characteristics, military experience, sleep quality, and fatigue. Descriptive measures included age, height, weight, racial and Hispanic/Latino identity, military pay grade (analogous to rank), and years of military service. Height and weight were used to calculate body mass index as an estimate of body composition.

All study procedures were approved by the Naval Health Research Center Institutional Review Board in adherence with federal regulations governing the protection of human participants (Protocol NHRC.2021.0003).

## Sleep quality

Sleep quality was quantified using the Pittsburgh Sleep Quality Index (PSQI) which provides a composite measure of seven dimensions of sleep quality: duration, efficiency, disturbances, latency, daytime dysfunction, quality, and medication use. PSQI scores range from 0 to 21, with higher scores reflecting worse sleep quality [28]. Scores above 5 reflect clinically meaningful levels of sleep disturbance. A modified version of the PSQI that asks about sleep over the past 7 days [29] instead of the standard past 30 days, was used for all except one ship of participants ($n = 42$). There was no evidence of a substantial difference between the two PSQI versions ($t = 1.51$, $p = .13$, $g = 0.26$), so all PSQI total scores were collapsed over this variable.

## Officer fatigue survey

Participants completed a survey that asked about perceptions of fatigue during underway operations. The survey is detailed in Supplementary Figure S1). In brief, the survey assessed: (1) the frequency of fatigue and of job-related factors contributing to fatigue in themselves and their crew, (2) factors contributing to fatigue underreporting, (3) strategies used to monitor fatigue (e.g. crewmember self-report, objective sleep data to identify insufficient sleep, alertness assessments such as the psychomotor vigilance task), identify overtasked crew members (e.g. schedule conflicts), and mitigate fatigue (e.g. protected sleep periods), and (4) reasons fatigue mitigation strategies were not used (e.g. they were infeasible).

Survey questions were a mix of Likert-type scales and yes/no responses. A Likert-type frequency scale (response anchors: *never, rarely, sometimes, frequently, and always*) assessed frequency of fatigue in themselves and their crew, specific factors contributing to fatigue, and fatigue mitigation strategy use. Yes/no items examined methods used to identify fatigued or overtasked crewmembers, reasons fatigue mitigation strategies were not implemented, and reasons for fatigue underreporting. Subject matter experts developed the survey items to ensure their operational relevance. Fatigue was defined as occurring when alertness had become unreliable and there was an elevated risk of task failure, injury, or equipment casualty (Supplementary Figure S1).

## Statistical analysis

All analyses were conducted using R within the RStudio platform (version 2022.02; R: The R Project for Statistical Computing, Vienna, Austria). To address aim 1, fatigue survey response frequencies were summarized. To aid interpretation, Likert-type scale outcomes were collapsed into three response categories: infrequently (*never* and *rarely*), sometimes, and frequently (*frequently* and *always*).

To address aim 2, ordinal (*polr* function) and logistic (*glm* function) regression methods were applied to the fatigue survey responses to model the relationships among PSQI scores, service length, and ship class. PSQI scores and years of service were included as continuous independent variables. For ship class, LHD was used as the reference group. Sex was controlled for in all models. Adjusted odds ratios (aOR) and 95% confidence intervals (CI) were presented. Statistical significance ($p < .05$) was examined and corroborated by CI that did not overlap with 1.0. Crosstabulation tables were examined to confirm sufficient sample size ($n > 0$ in all cells, $n > 5$ across at least 80% of cells) [30]. For ordinal regressions, Brant tests (*brant* function) were used to assess the assumption of proportional odds.

# Results

Only participants with complete data were included in analyses, resulting in a final sample of 154 officers (82% of the original sample). To guard against sampling bias due to excluding some participants, demographic variables and fatigue outcomes were examined across the sample used for the main analysis and the subset of excluded participants; these results are provided in Supplementary Tables S1–S6). Participants excluded from analysis due to incomplete data did not differ substantially across demographic variables from participants included in the main analysis (Supplementary Table S1).

Participants were predominantly male, white, and not Hispanic/Latino. Most participants were stationed aboard an LHD and most were junior officers (paygrade O1–O3). Additional participant characteristics are provided in Table 1.

## Self-reported fatigue

Among participants, 35 (23%) reported frequently feeling fatigued while 61 (40%) reported infrequently feeling fatigued. Operational needs most frequently contributed to self-reported fatigue, followed by administrative duties, watchstanding (i.e. additional duties to ensure continuous shipboard operations and security), meetings, and special evolutions (i.e. tasks outside of routine shipboard events) (Figure 1A). Conversely, preventative and corrective maintenance tasks were the least frequently reported contributors to self-reported fatigue.

Self-reported fatigue varied based on PSQI scores, service length, and ship class (Table 2). Officers with higher odds of frequently being fatigued included those with higher PSQI scores (i.e. more disturbed sleep; aOR = 1.11, 95% CI [1.01, 1.22]) and those who were aboard a DDG (aOR = 3.15, 95% CI [1.35, 7.50]) or LCS (aOR = 3.33, 95% CI [1.55, 7.32]) compared with an LHD (reference group). Furthermore, the odds that different job-related factors contributed frequently to fatigue varied based on PSQI scores, service length, and ship class. Officers with higher PSQI scores had higher odds of last-minute schedule changes contributing frequently to fatigue (aOR = 1.15, 95% CI [1.05, 1.26]).

Having more years of military service was related to higher odds that corrective maintenance (aOR = 1.08, 95% CI [1.02, 1.14]) contributed frequently to fatigue and lower odds of administrative duties (aOR = 0.93, 95% CI [0.88, 0.98]) or standing watch doing so (aOR = 0.93, 95% CI [0.88, 0.98]). Regarding ship class, DDG (aOR = 6.49, 95% CI [2.69, 16.27]) and LCS officers (aOR = 3.77, 95% CI [1.74, 8.37]) had higher odds of frequently experiencing fatigue due to last-minute schedule changes compared with LHD officers. DDG officers also had higher odds of corrective maintenance (aOR = 3.17, 95% CI [1.07, 9.42]) and meetings (aOR = 2.77, 95% CI [1.14, 7.02]) frequently contributing to fatigue. Furthermore, LCS officers had higher odds of special evolutions (aOR = 3.13, 95% CI [1.48, 6.78]), operational needs (aOR = 2.81, 95% CI [1.22, 6.78]), and watchstanding duties (aOR = 4.08, 95% CI [1.83, 9.46]) contributing frequently to fatigue than LHD officers.

**Table 1.** Descriptive Characteristics of Study Participants

| | Mean | SD | Range |
|---|---|---|---|
| Age (years) | 31.5 | 7.0 | 22–52 |
| Years of service | 8.8 | 6.8 | 0.5–28 |
| BMI (kg/m$^2$) | 26.64 | 3.14 | 20.5–39.5 |
| PSQI | 6.2 | 3.4 | 0–18 |
| | | **Count** | **%** |
| Sex | | | |
| Male | | 125 | 81.2 |
| Female | | 29 | 18.8 |
| Racial identity | | | |
| African American/black | | 9 | 5.8 |
| Asian American/Pacific Islander | | 15 | 9.7 |
| Hawaiian | | 2 | 1.3 |
| White | | 113 | 73.4 |
| Multiple selected | | 11 | 7.1 |
| No response | | 4 | 2.6 |
| Hispanic/Latino | | | |
| Yes | | 21 | 13.7 |
| No | | 131 | 85.6 |
| No response | | 2 | 1.3 |
| Pay grade | | | |
| O1–O3 | | 106 | 68.8 |
| O4 | | 23 | 14.9 |
| O5+ | | 16 | 10.4 |
| W1–W3 | | 9 | 5.8 |
| Command class | | | |
| LHD | | 67 | 43.5 |
| DDG | | 27 | 17.5 |
| LCS | | 32 | 25.3 |
| MEU | | 21 | 13.6 |

SD, standard deviation; BMI, body mass index; PSQI, Pittsburgh Sleep Quality Index; O, officer; W, warrant officer; LHD, amphibious landing helicopter dock ship; DDG, guided missile destroyer; LCS, littoral combat ship; MEU, Marine Expeditionary Unit.

Preventative maintenance and covering shifts for others were not explored due to inadequate frequencies (Table 2).

## Crewmember fatigue

Officers reported observing fatigue more frequently in crewmembers than experiencing it themselves. Eighty-three officers (54%) reported frequently observing fatigue in others, while 18 officers (12%) reported infrequently observing fatigue in others. Fatigue in others was most frequently attributed to operational needs, followed by special evolutions, and watchstanding responsibilities (Figure 1B). Officers excluded from the main analyses less frequently reported that special evolutions contributed to fatigue observed in others, but the use of the complete sample would not have altered the ranking of special evolutions as a contributor to fatigue (Supplementary Table S3).

Due to small cell sizes, the influence of sleep quality, length of service, and ship class on fatigue observed in others could not be examined. The odds of different job-related factors contributing to fatigue varied across PSQI scores and ship class (Table 3). Higher PSQI scores were related to higher odds that last-minute schedule changes frequently contributed to fatigue observed in others (aOR = 1.10, 95% CI [1.01, 1.20]). For ship class, DDG officers exhibited higher odds of fatigue being frequently attributed to corrective maintenance (aOR = 3.41, 95% CI [1.43, 8.29]), preventative maintenance (aOR = 2.92, 95% CI [1.20, 7.20]), special evolutions (aOR = 2.65, 95% CI [1.04, 7.16]), last-minute schedule changes (aOR = 7.00, 95% CI [2.81, 18.17]), and covering others' shifts (aOR = 2.83, 95% CI [1.18, 6.88]) relative to LHD officers. Furthermore, compared with LHD officers, LCS officers had higher odds of frequently attributing fatigue observed in others to corrective maintenance (aOR = 4.96, 95% CI [2.33, 10.85]), preventative maintenance (aOR = 2.66, 95% CI [1.26, 5.70]), last-minute schedule changes (aOR = 3.41, 95% CI [1.58, 7.47]) covering others' shifts (aOR = 3.28, 95% CI [1.53, 7.20]), and watch duties (aOR = 3.08, 95% CI [1.33, 7.58]). Lastly, MEU officers had lower odds of attributing fatigue observed in others to watch duties compared with LHD officers (aOR = 0.28, 95% CI [0.11, 0.71]), a finding that was expected because MEU personnel do not have watch responsibilities aboard ships.

## Fatigue monitoring

To identify fatigue in others, officers predominately relied on crewmember self-reports (*n* = 106, 69%), observing crewmembers falling asleep (*n* = 100, 65%), and observing neurobehavioral impairment in crewmembers (*n* = 84, 55%; e.g. slumped posture, slurred speech). Conversely, officers reported that methods that relied on objective data were less likely to be used to monitor and identify fatigue, such as the use of objective sleep data (*n* = 28, 18.2%), an alertness assessment (*n* = 22, 14%), and a biomathematical model (*n* = 4, 3%).

Methods of corroborating fatigue differed based on service length and ship class (Table 4). Officers with more years of service had lower odds of using objective sleep data to identify fatigue in crewmembers (aOR = 0.90, 95% CI [0.81, 0.98]). MEU officers had lower odds than LHD officers of identifying fatigue by observing neurobehavioral impairment (aOR = 0.22, 95% CI [0.07, 0.65]). Furthermore, DDG officers were less likely than LHD officers to identify fatigued crewmembers from self-reports (aOR = 5.39, 95% CI [1.62, 24.75]) and objective sleep data (aOR = 7.13, 95% CI [2.33, 23.64]). The odds of using different fatigue monitoring strategies did not vary based on PSQI scores.

Officers also provided information about methods used to identify overtasked crewmembers (i.e. those who may be at high risk of fatigue). Officers again relied heavily on crewmember self-reports (*n* = 107, 70%). Other methods that officers reported using to identify/monitor crewmembers included mental calculation of task saturation (*n* = 78, 51%) and identification of scheduling conflicts (*n* = 81, 53%). Additionally, 36 (23%) officers reported that there were not any procedures in place to identify overtasked crewmembers. Sleep quality and service length did not influence these methods, but LCS officers had higher odds of identifying overtasked crewmembers through scheduling conflicts than did LHD officers (Table 4; aOR = 3.33, 95% CI [1.45, 7.99]).

## Underreporting of fatigue

Despite the high rates of crewmember self-report being endorsed as a method to monitor fatigue and overtasked crewmembers, 143 officers (93%) believe that fatigue is underreported. The most endorsed reason for underreporting fatigue was that "there is no solution available, so there is no point in identifying the problem"

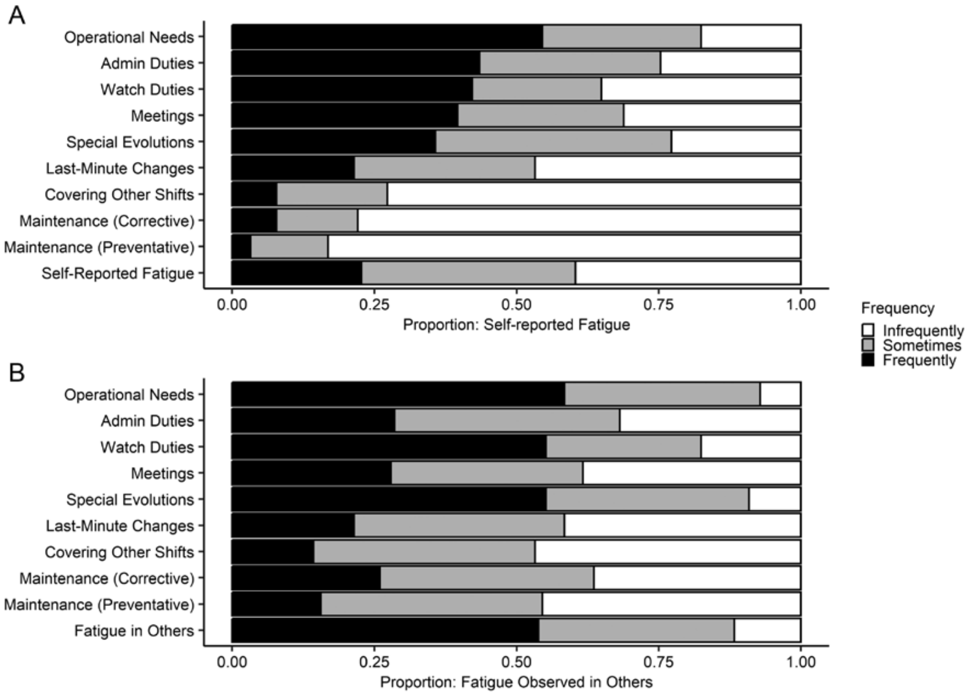

**Figure 1.** Proportion of respondents who endorsed different job-related factors as contributors to (A) self-reported fatigue and (B) fatigue observed in others. Bars on the left (dark) represent a frequently contributing factor; middle, a factor that sometimes contributes; and right (light bar), an infrequent contributor. Factors sorted based on the proportion of a factor frequently contributed to self-reported fatigue.

**Table 2.** Predictors of Frequency of Self-reported Fatigue and Job-related Factors Endorsed as Contributing to Self-reported Fatigue

| | Sex | PSQI | Service length | Command type | | |
|---|---|---|---|---|---|---|
| | | | | DDG | LCS | MEU |
| | OR [95% CI] | OR [95% CI] | OR [95% CI] | OR [95% CI] | OR [95% CI] | OR [95% CI] |
| Self-reported fatigue | 0.68 [0.29, 1.56] | *1.11 [1.01, 1.22]* | 0.97 [0.92, 1.01] | *3.15 [1.35, 7.50]* | *3.33 [1.55, 7.32]* | 0.96 [0.36, 2.49] |
| Corrective maintenance | 0.86 [0.25, 2.59] | 1.01 [0.89, 1.13] | *1.08 [1.02, 1.14]* | *3.17 [1.07, 9.42]* | 2.02 [0.75, 5.47] | 0.99 [0.20, 3.71] |
| Preventative maintenance | | | | | | |
| Special evolutions | 1.07 [0.48, 2.41] | 0.97 [0.89, 1.06] | 0.98 [0.94, 1.03] | 1.82 [0.78, 4.30] | *3.13 [1.48, 6.78]* | 1.47 [0.57, 3.83] |
| Admin. duties | 1.06 [0.44, 2.62] | 1.08 [0.98, 1.19] | *0.93 [0.88, 0.98]* | 0.93 [0.39, 2.22] | 1.64 [0.75, 3.63] | 0.49 [0.19, 1.24] |
| Operational needs | 2.45 [0.93, 7.08] | 1.10 [0.99, 1.22] | 1.01 [0.96, 1.06] | 2.21 [0.90, 5.71] | *2.81 [1.22, 6.78]* | 0.89 [0.35, 2.28] |
| Last-minute changes | 0.79 [0.33, 1.85] | *1.15 [1.05, 1.26]* | 1.00 [0.96, 1.06] | *6.49 [2.69, 16.27]* | *3.77 [1.74, 8.37]* | 1.00 [0.35, 2.70] |
| Cover other shifts | | | | | | |
| Watch duties | 2.05 [0.83, 5.35] | 1.03 [0.94, 1.14] | *0.93 [0.88, 0.98]* | 2.28 [0.94, 5.71] | *4.08 [1.83, 9.46]* | 0.38 [0.13, 1.02] |
| Meetings | 0.97 [0.41, 2.27] | *1.13 [1.03, 1.25]* | 0.98 [0.94,1.03] | *2.77 [1.14, 7.02]* | 0.96 [0.46, 2.01] | 1.07 [0.42, 2.75] |

Italics, statistically significant. Gray cells, Not have sufficient cell sizes to run models; PSQI, Pittsburgh Sleep Quality Index; DDG, guided missile destroyer; LCS, littoral combat ship; MEU, Marine Expeditionary Unit; OR, odds ratio; CI, confidence interval.

(*n* = 109, 71%). Officers also cited being too busy (*n* = 105, 68%) and inadequate tools to monitor and/or report fatigue (*n* = 87, 57%). Other less frequently endorsed reasons for underreporting fatigue included being “contrary to the Navy fighting spirit” (*n* = 78, 51%), “willful ignorance” (*n* = 60, 39%), and the “lack of training to identify the causes, signs, and symptoms of fatigue” (*n* = 39, 25%).

PSQI scores and length of military service, but not ship class, were associated with officers’ perceptions of fatigue underreporting (Table 4). Officers with higher PSQI scores had higher odds of reporting that a lack of training in fatigue identification contributed to fatigue underreporting (aOR = 1.14, 95% CI [1.02, 1.28]). Officers with more years of service had higher odds of endorsing inadequate fatigue quantification/documentation tools (aOR = 1.06, 95% CI [1.01, 1.13]) and lower odds of endorsing the lack of a solution to address fatigue as reasons for underreporting (aOR = 0.94, 95% CI [0.89, 0.99]).

## Fatigue mitigation strategies

Despite frequent perceptions of fatigue in themselves and others, officers reported that fatigue mitigation strategies were not frequently adopted (Figure 2). Providing protected sleep periods was the most frequently used fatigue mitigation measure (*n* = 37, 24%), while no other strategy was frequently implemented by more than 13% of officers. Officers reported not implementing

**Table 3.** Predictors of the Frequency of Different Job-related Factors Contributed to Fatigue in Others

| | **Sex** | **PSQI** | **Service length** | **Ship-class** | | |
|---|---|---|---|---|---|---|
| | | | | **DDG** | **LCS** | **MEU** |
| | **aOR [95% CI]** | **aOR [95% CI]** | **aOR [95% CI]** | **aOR [95% CI]** | **aOR [95% CI]** | **aOR [95% CI]** |
| Fatigue in others | | | | | | |
| Corrective maintenance | 1.13 [0.49, 2.65] | 1.07 [0.97, 1.17] | 1.02 [0.97, 1.07] | *3.41 [1.43, 8.29]* | *4.96 [2.33, 10.85]* | 1.23 [0.45, 3.30] |
| Preventative maintenance | 1.60 [0.69, 3.70] | 1.04 [0.95, 1.14] | 1.01 [0.96, 1.06] | *2.92 [1.20, 7.20]* | *2.66 [1.26, 5.70]* | 1.77 [0.64, 4.86] |
| Special evolutions | 2.15 [0.85, 5.77] | 1.02 [0.93, 1.13] | 1.03 [0.98, 1.09] | *2.65 [1.04, 7.16]* | 2.17 [0.97, 5.02] | 0.91 [0.36, 2.34] |
| Admin. duties | 1.17 [0.51, 2.69] | 1.09 [1.00, 1.19] | 0.97 [0.93, 1.02] | 1.09 [0.47, 2.52] | 0.84 [0.40, 1.78] | 1.15 [0.45, 2.98] |
| Op. needs | | | | | | |
| Last-minute changes | 0.99 [0.43, 2.29] | *1.10 [1.01, 1.20]* | 0.97 [0.93, 1.02] | *7.00 [2.81, 18.17]* | *3.41 [1.58, 7.47]* | 1.41 [0.54, 3.63] |
| Cover other shifts | 0.90 [0.38, 2.14] | 1.02 [0.93, 1.13] | 1.00 [0.95, 1.05] | *2.83 [1.18, 6.88]* | *3.28 [1.53, 7.20]* | 0.56 [0.18, 1.57] |
| Watch duties | 1.16 [0.47, 3.03] | 1.03 [0.93, 1.13] | 0.97 [0.93, 1.02] | 2.29 [0.91, 6.25] | *3.08 [1.33, 7.58]* | *0.28 [0.11, 0.71]* |
| Meetings | 1.47 [0.65, 3.34] | 1.08 [0.99, 1.18] | 0.97 [0.93, 1.02] | 1.36 [0.58, 3.18] | 0.68 [0.32, 1.42] | 0.91 [0.35, 2.34] |

Italics, statistically significant. Gray cells, Not have sufficient cell sizes to run models; PSQI, Pittsburgh Sleep Quality Index; DDG, guided missile destroyer; LCS, littoral combat ship; MEU, Marine Expeditionary Unit; aOR, adjusted odds ratio; CI, confidence interval.

**Table 4.** Influence of Sex, Sleep Quality, Military Experience, and Ship-Class on Fatigue Identification Methods and Fatigue Underreporting

| | **Sex** | **PSQI** | **Service length** | **Ship-class** | | |
|---|---|---|---|---|---|---|
| | | | | **DDG** | **LCS** | **MEU** |
| | **aOR [95% CI]** | **aOR [95% CI]** | **aOR [95% CI]** | **aOR [95% CI]** | **aOR [95% CI]** | **aOR [95% CI]** |
| *What observations corroborated the identification of fatigue in crewmembers?* | | | | | | |
| Falling asleep | 0.79 [0.30, 2.09] | 1.09 [0.98, 1.22] | 1.02 [0.97, 1.08] | 1.11 [0.43, 2.97] | 1.86 [0.76, 4.87] | 0.53 [0.19, 1.45] |
| Neurobehavioral impairment | 0.61 [0.24, 1.53] | 1.10 [0.99, 1.2] | 0.99 [0.94, 1.04] | 2.31 [0.86, 6.78] | 0.77 [0.34, 1.77] | *0.22 [0.07, 0.65]* |
| Self-report | 1.14 [0.41, 3.42] | 1.09 [0.98, 1.23] | 0.97 [0.91, 1.02] | *5.39 [1.62, 24.75]* | 1.28 [0.55, 3.08] | 2.31 [0.78, 7.89] |
| Sleep data | 0.95 [0.29, 3.01] | 1.09 [0.95, 1.25] | *0.90 [0.81, 0.98]* | *7.13 [2.33, 23.64]* | 0.99 [0.23, 3.68] | 2.30 [0.53, 9.12] |
| Alertness assessment | | | | | | |
| Biomath. model | | | | | | |
| *How do you identify specific crewmembers who are overtasked?* | | | | | | |
| Self-report | 1.26 [0.48, 3.51] | 1.03 [0.92, 1.15] | 1.02 [0.96, 1.08] | 1.49 [0.55, 4.37] | 1.04 [0.44, 2.52] | 1.30 [0.45, 4.09] |
| Mentally calculate task saturation | 0.97 [0.39, 2.40] | 1.09 [0.99, 1.20] | 0.99 [0.94, 1.04] | 0.98 [0.39, 2.48] | 1.29 [0.57, 2.95] | 0.98 [0.36, 2.68] |
| No procedure to monitor fatigue | 0.81 [0.26, 2.30] | 0.99 [0.88, 1.11] | 0.99 [0.93, 1.05] | 1.21 [0.42, 3.30] | 0.67 [0.23, 1.76] | 0.67 [0.17, 2.14] |
| Scheduling conflict | 1.51 [0.59, 3.95] | 1.01 [0.91, 1.12] | 1.02 [0.97, 1.07] | 2.41 [0.95, 6.29] | *3.33 [1.45, 7.99]* | 2.26 [0.83, 6.35] |
| *Do you believe that fatigue is underreported? If yes, to what do you attribute the cause of this underreporting?* | | | | | | |
| Underreport | | | | | | |
| Contrary to Navy fighting spirit | 0.85 [0.35, 2.09] | 1.03 [0.93, 1.13] | 0.99 [0.94, 1.04] | 0.80 [0.32, 2.00] | 1.13 [0.50, 2.56] | 0.43 [0.14, 1.17] |
| Inadequate tools to monitor fatigue | 1.65 [0.66, 4.27] | 1.05 [0.95, 1.17] | *1.06 [1.01, 1.13]* | 1.69 [0.66, 4.48] | 1.32 [0.58, 3.07] | 1.42 [0.51, 4.03] |
| Willful ignorance | 0.51 [0.19, 1.31] | 1.05 [0.95, 1.16] | 0.95 [0.90, 1.00] | 0.91 [0.35, 2.31] | 0.45 [0.18, 1.07] | 0.70 [0.25, 1.92] |
| Lack of training to identify fatigue | 1.35 [0.46, 3.79] | *1.14 [1.02, 1.28]* | 1.04 [0.98, 1.10] | 1.63 [0.58, 4.49] | 0.39 [0.13, 1.09] | 0.91 [0.26, 2.86] |
| No available solution | 1.42 [0.48, 4.82] | 1.01 [0.91, 1.13] | *0.94 [0.89, 0.99]* | 1.20 [0.41, 3.79] | 1.18 [0.47, 3.06] | 0.53 [0.19, 1.53] |
| Too busy | 0.61 [0.23, 1.68] | 1.11 [0.99, 1.24] | 0.96 [0.91, 1.01] | 0.98 [0.37, 2.70] | 1.73 [0.69, 4.61] | 0.63 [0.23, 1.80] |

Italics, statistically significant. Gray cells = Not have sufficient cell sizes to run models; PSQI, Pittsburgh Sleep Quality Index; DDG, guided missile destroyer; LCS, littoral combat ship; MEU, Marine Expeditionary Unit; aOR, adjusted odds ratio; CI, confidence interval.

fatigue mitigation strategies as they were not feasible within operational constraints (*n* = 96, 62%), not having enough time to stop and rest (*n* = 95, 62%), and unclear thresholds for action to be taken (*n* = 75, 49%).

The frequency which fatigue mitigation strategies were used varied based on service length and ship class (Table 5). Officers with more years of service had higher odds of frequently providing a recovery opportunity when they observed fatigued crewmembers (aOR = 1.07, 95% CI [1.02, 1.13]). Relative to LHD officers, LCS officers had higher odds of having crewmembers swap watchbills (aOR = 5.12, 95% CI [2.31, 11.81]). Further, LCS (aOR = 7.17, 95% CI [3.32, 15.99]) and MEU officers (aOR = 7.31, 95% CI [2.89, 18.96])

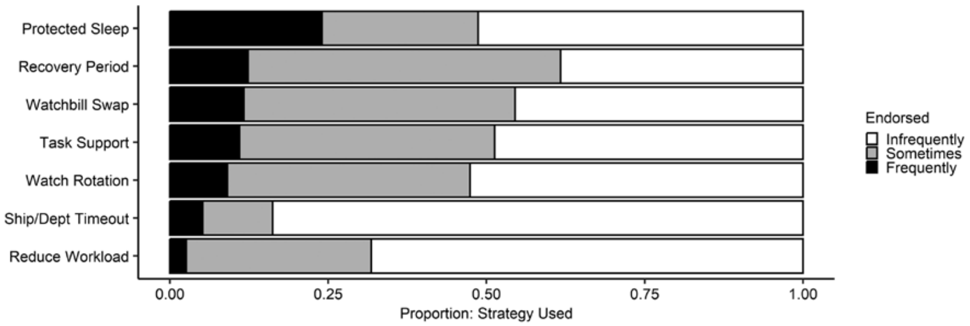

**Figure 2.** Implementation frequency of different fatigue mitigation strategies. Strategies were sorted based on the proportion they were endorsed as frequently implemented. Bars on the left (dark) represent a frequently contributing factor; middle, a factor that sometimes contributes; and right (light bar), an infrequent contributor.

**Table 5.** Influence of Sex, PSQI Scores, Service Length, and Ship-Class on Fatigue Mitigation Strategy Implementation

| Fatigue mitigation strategy | Sex | PSQI | Service length | Ship-class | | |
|---|---|---|---|---|---|---|
| | | | | DDG | LCS | MEU |
| | aOR [95% CI] | aOR [95% CI] | aOR [95% CI] | aOR [95% CI] | aOR [95% CI] | aOR [95% CI] |
| Recovery opportunity | 1.04 [0.44, 2.45] | 0.97 [0.89, 1.07] | *1.07 [1.02, 1.13]* | 0.61 [0.25, 1.47] | 1.81 [0.83, 3.97] | 1.06 [0.41, 2.72] |
| Watchbill swap | 0.81 [0.35, 1.88] | 1.01 [0.92, 1.11] | 1.03 [0.98, 1.08] | 1.48 [0.64, 3.47] | 5.12 *[2.31, 11.81]* | 1.26 [0.51, 3.15] |
| Watch rotation | | | | | | |
| Task support | 0.89 [0.39, 2.07] | 1.07 [0.98, 1.17] | 1.04 [0.99, 1.09] | 1.20 [0.53, 2.74] | 1.94 [0.92, 4.15] | 1.77 [0.70, 4.51] |
| Protected sleep period | 0.90 [0.39, 2.07] | 1.03 [0.95, 1.13] | 1.01 [0.97, 1.06] | 0.61 [0.26, 1.42] | *7.17 [3.32, 15.99]* | *7.31 [2.89, 18.96]* |
| Ship or dept. timeout | | | | | | |
| Reduce workload | | | | | | |

Italics, statistically significant. Gray cells, Not have sufficient cell sizes to run models; PSQI, Pittsburgh Sleep Quality Index; DDG, guided missile destroyer; LCS, littoral combat ship; MEU, Marine Expeditionary Unit; aOR, adjusted odds ratio; CI, confidence interval.

**Table 6.** Barriers to Fatigue Mitigation Based on Sex, PSQI Scores, Service Length, and Ship-Class

| Barriers | Sex | PSQI | Service length | Ship-class | | |
|---|---|---|---|---|---|---|
| | | | | DDG | LCS | MEU |
| | aOR [95% CI] | aOR [95% CI] | aOR [95% CI] | aOR [95% CI] | aOR [95% CI] | aOR [95% CI] |
| Unclear action thresholds | 0.53 [0.21, 1.31] | 1.08 [0.98, 1.19] | 1.00 [0.95, 1.05] | 1.25 [0.49, 3.18] | 0.84 [0.37, 1.90] | 1.13 [0.41, 3.09] |
| No time | 2.00 [0.73, 6.13] | 0.99 [0.90, 1.10] | 0.95 [0.90, 1.00] | 2.17 [0.80, 6.36] | 1.95 [0.83, 4.76] | 1.51 [0.55, 4.36] |
| No practical strategies | 0.78 [0.31, 2.05] | 1.02 [0.92, 1.13] | 0.97 [0.92, 1.02] | 1.18 [0.45, 3.19] | 1.68 [0.71, 4.13] | 0.45 [0.16, 1.23] |

PSQI, Pittsburgh Sleep Quality Index; DDG, guided missile destroyer; LCS, littoral combat ship; MEU, Marine Expeditionary Unit; aOR, adjusted odds ratio; CI, confidence interval.

had higher odds of protecting sleep assignments after observing fatigue. PSQI scores, service length, and ship class were not related to the endorsed barriers to fatigue mitigation (Table 6).

## Discussion

This study provides further evidence that fatigue is a pervasive stressor in high-risk occupations and identifies a critical need to improve fatigue monitoring and mitigation strategies in naval environments (Figure 3). Across three ship classes and a MEU, ~25% of officers reported frequently feeling fatigued and ~50% reported frequently observing fatigue in fellow crewmembers. Furthermore, over 90% felt that fatigue was underreported. These findings are consistent with the high rates of fatigue observed across other military and maritime settings [31, 32]. Importantly, fatigue in the current study was defined by behavioral changes, which reflect moderate-high levels of fatigue and therefore may underestimate actual fatigue risk.

Given the high rates of self-reported and observed fatigue, ensuring that leaders can monitor and mitigate fatigue in their subordinates is essential for enhancing operational readiness and safety in high-risk occupations. This study's findings demonstrate that fatigue monitoring practices heavily rely on crewmember self-report and subjective officer perceptions. Approximately 70% of officers used crewmember self-report to identify overtasked crewmembers (i.e. those who may be at high risk of fatigue) or already fatigued crewmembers. The current reliance on self-report may underrepresent the significance of the findings due to the propensity of individuals to underestimate their fatigue. Prior work has found that

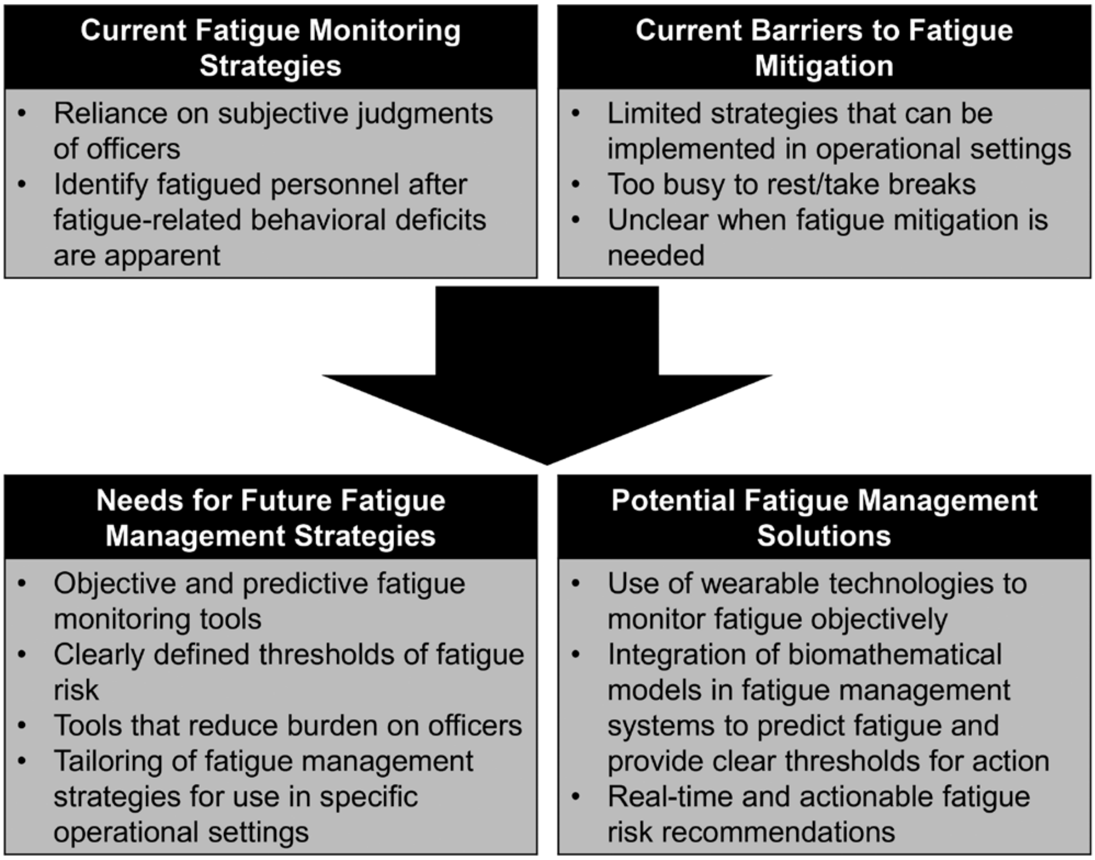

**Figure 3.** Summary of limitations to current fatigue management strategies, future needs, and target characteristics of potential solutions.

individuals underreport self-reported fatigue when compared with behavioral measures of alertness [33]. This underestimation of self-reported fatigue was further suggested in the current study by the discrepancy between self-reported fatigue and fatigue observed in other crewmembers. Notably, the combination of reliance on self-report, potential for underestimation of self-reported fatigue, and perceived underreporting of fatigue creates a troubling scenario whereby fatigue management strategies that rely on self-report are at risk of systematically underestimating fatigue and fatigue-related risk.

In addition to self-report, over 50% of officers relied on their own judgment regarding task saturation and scheduling conflicts to identify overtasked crewmembers. Similarly, over 50% of officers relied on personal observation of behavioral deficits (e.g. falling asleep and neurobehavioral impairments) to identify fatigued crewmembers. In other words, officers monitored fatigue reactively, identifying fatigued personnel after fatigue was observable and accident risk would have already increased. Collectively, these findings highlight a critical need for objective fatigue monitoring and prediction tools that reduce the burden on officers who would otherwise be forced to rely on self-reports and subjective judgments of crew fatigue. Of further concern, 57% of officers reported not having adequate tools to monitor fatigue and 25% reported that there were not any procedures for identifying overtasked crewmembers. These troubling percentages underscore the need to develop and implement standardized fatigue monitoring strategies for shipboard environments.

Some high-risk occupations, like aviation and transportation, have adopted fatigue risk management systems to proactively monitor and mitigate fatigue risk. These systems use biomathematical models, developed using sleep–wake or work schedules, to predict and monitor fatigue risk [19, 23]. Such models clearly define thresholds regarding when to mitigate fatigue, which allows for early intervention and prevention of fatigue-related performance deficits [34]. Further development and adoption of these models across other occupations could potentially address the limitations of current subjective fatigue monitoring strategies that are apparent from the current study. Still, less than 3% of officers reported using such models to monitor fatigue. Similarly, few officers (<20%) used objective sleep data to inform fatigue management. Many (but not all) wearables available on the market provide accurate, objective measures of sleep and daytime activity and may further provide effective real-time markers of fatigue [35]. Adding objective sleep–wake outcomes from wearables to biomathematical fatigue predictive models may increase the accuracy of fatigue predictions by removing model assumptions for the timing, duration, and history of sleep. This integration would also support real-time fatigue monitoring, provided these tools can be incorporated seamlessly into existing workflows (subject to multiple operational constraints) and that training/education be provided regarding the interpretation of model outputs and related decision-making [36].

Similar considerations are needed for fatigue mitigation strategies. Officers did not frequently implement fatigue mitigation strategies, despite high rates of fatigue, which is consistent with prior findings [25, 37]. Officers reported that being too busy and impractical mitigation strategies limited their ability to address fatigue. If current strategies do not account for operational realities and work demands, then high rates of fatigue will persist until these strategies can be better tailored for the specific environment in which they are intended for use. In the naval context, this includes consideration of organizational differences across commands, such as ship class and leadership.

In the current study, fatigue and fatigue management practices varied across ship class and individual factors. Admittedly, the effects of individual factors were small (ORs: 0.90–1.15) and must be interpreted with care due to the multitude of comparisons examined. Military experience was related to fatigue management, which may reflect experience-related differences in responsibilities or attitudes regarding fatigue management. For example, that more experienced officers were more likely to frequently provide recovery periods when fatigue was identified may have been related to a greater understanding of the ability or need to prioritize rest in different situations based on operational needs. Furthermore, consistent with previous studies of military service members, worse sleep quality predicted more fatigue [6, 10].

Here, fatigue was also associated with job-related factors and ship class. Notably, relationships between ship class and fatigue were stronger (i.e. had larger effect sizes) than the relationships between sleep and fatigue. Therefore, while interventions to improve sleep may attenuate fatigue, these interventions alone, without consideration of additional operational factors, may not completely address fatigue. Ship classes differ in operational realities (e.g. crew sizes and work responsibilities) and sleeping environments (e.g. noise and ship motion). It should be noted, however, that the number of units in each ship class varied, with only one DDG and one MEU being represented. As a result, observed differences across ship classes may reflect idiosyncratic qualities of specific units (e.g. leadership, staffing shortages, and operational schedules) rather than those of all units in that type. Any general conclusions should be made with caution until additional data can bolster them. However, certain characteristics of different ship classes could help explain these results. For example, DDGs and LCSs are smaller than LHDs, which may result in more disrupted sleep due to more ship motion. Furthermore, DDG and LCS personnel may experience higher workloads due to smaller crew sizes and different organizational structures. These factors may have contributed to the higher observed fatigue in DDG and LCS officers and may have affected fatigue mitigation efforts across ships. Interestingly, MEU and LHD officers who were stationed aboard the same ship differed little in fatigue and fatigue management. Such similarity between MEU and LHD officers was unexpected given the distinct organizational structure, culture, and operational responsibilities of the groups. MEU officers are responsible for maintaining battle readiness in preparation for ashore military operations, while LHD officers oversee ship operations. Ship-class differences in fatigue and fatigue mitigation practices—and the strong effect sizes of these differences—further highlight the need to consider contextual and environmental factors when addressing fatigue in high-risk occupations.

This study has some additional limitations of note. First, it was not possible to exhaustively examine other relevant operational factors (e.g. operational tempo, previous number of deployments, ship motion, organizational performance outcomes, and staffing shortages) on fatigue. Understanding the implications of these factors on fatigue would provide valuable information that would likely inform effective fatigue mitigation practices. In particular, staffing shortages, which are widespread across SURFOR, may limit the ability of personnel to take breaks and of ships to implement comprehensive fatigue mitigation efforts. Second, this study was cross-sectional and thus could not examine the protective (or destructive) influences of fatigue management behaviors on fatigue within the same individuals over time. Future longitudinal studies should extend this work to do so. Third, this study focused on the perspectives of officers, but additional insights may have been gained by surveying senior enlisted personnel who also assist with managing fatigue. Fourth, while this work offers initial insight into the importance of considering ship class in developing and implementing fatigue management solutions, it does not provide a comprehensive characterization of fatigue across all USN ship classes. Future work should include additional ship classes and examine more ships per class. Lastly, the current study did not adjust for multiple comparisons, therefore care must be taken when interpreting these results, particularly ORs close to 1.0.

In conclusion, the current study provides further support that fatigue is a widespread threat to operational efficiency and personnel safety, and that leaders in high-risk industries may benefit from being vigilant in their efforts to develop fatigue monitoring and mitigation solutions. There appears to be substantial benefit from fatigue monitoring tools and mitigation practices that (1) are objective, to reduce reliance on subjective practices and burden on leadership; (2) are predictive and preventative rather than reactive, to mitigate fatigue risk; (3) provide clear and actionable information to help guide decision making; and (4) are tailored to fit the unique demands and characteristics of different operational settings. With recent advances in wearable technologies and the continued refinement of fatigue risk management systems, there are reasons to be optimistic that effective solutions are within reach. Still the successful implementation of these solutions within high-risk occupations will require continuous and iterative adaptation of fatigue risk management systems to account for ever-changing operational needs, constraints, and environments. Following a baseline monitoring period, future research could examine the implementation effectiveness of interventions and countermeasures and assist SURFOR with fatigue risk management system policy development.

## Supplementary Material

Supplementary material is available at *SLEEP Advances* online.

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## Author Contributions

Alice LaGoy (Conceptualization [Equal], Data curation [Equal], Formal analysis [Equal], Writing—original draft [Equal], Writing—review & editing [Equal]), Andrew Kubala (Conceptualization

[Equal], Data curation [Equal], Project administration [Equal], Writing—review & editing [Equal]), Jason Jameson (Writing—review & editing [Equal]), Todd Seech (Writing—review & editing [Equal]), Rachel Markwald (Conceptualization [Equal], Funding acquisition [Equal], Project administration [Equal], Supervision [Equal], Writing—review & editing [Equal]), and Dale Russell (Conceptualization [Equal], Funding acquisition [Equal], Writing—review & editing [Equal]).

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## Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to security protocols and privacy regulations, but they may be made available on reasonable request by the Naval Health Research Center Institutional Review Board (contact phone + 1 619 553 8400).

## Disclaimer

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