Research Report

Effects of sleep and fatigue on teams in a submarine environment

Sarah Chabal, PhD [1]; Rebecca Welles, BA [1,2]; Lt.Cmdr. F. Jay Haran, PhD [1]; Rachel Markwald, PhD [3]

[1] Naval Submarine Medical Research Laboratory, Groton, Connecticut
[2] Leidos, Inc., Reston, Virginia
[3] Naval Health Research Center, San Diego, California

CORRESPONDING AUTHOR: Sarah Chabal – *sarah.a.chabal.civ@mail.mil*

ABSTRACT

Successful submarine operations rely on the performance of tactical teams who must work under conditions of physiological and cognitive fatigue. Sleep loss and circadian disruption contribute to fatigue in this setting and, although the effects of this fatigue have been studied extensively in individuals, little is understood about how fatigue impacts team performance – especially in a submarine environment. The present review provides an overview of the fatigue on submarine teams and is divided into four main sections:

1) A discussion of factors that should be considered in team fatigue research.
2) An outline of how sleep and circadian rhythms of submariners are impacted by submarine-specific factors.
3) A discussion of the known effects of fatigue from sleep loss and circadian disruption on individual performance.
4) A consideration of how this fatigue impacts team performance.

As the submarine force has recognized the need to protect submariner sleep and improve team dynamics, it is vital that future research accounts for the interplay between these two factors.

INTRODUCTION

Although submarine teams share many characteristics with teams across other domains (e.g., aviation, business), the submarine environment presents a number of unique challenges that set the teams apart. On submarines, team members must work together to make sound decisions based on incomplete, discontinuous, and often ambiguous data. For example, while navigating congested water space, the crew in a submarine control room must combine data from sound signals picked up by the sonar operators, plots developed and maintained by the quartermaster, and a tactical picture compiled by the contact management team to decide whether it is safe to come to periscope depth. The ship control team must then bring the submarine up to depth, while being prepared to quickly dive the boat if periscope safety sweeps conducted by the Officer of the Deck reveal any unanticipated hazard. Although the Officer of the Deck makes the final calls regarding maneuvering of the submarine, this process could not be carried out without full participation from the team.

. . . it is vital that we gain an understanding of the interplay between fatigue and team dynamics.

However, this team decision-making is challenged by the physiological and cognitive fatigue often experienced by submarine crews. Therefore, it is vital that we gain an understanding of the interplay between fatigue and team dynamics. Although an abundance of literature exists on team performance and on how fatigue affects individual performance, the two research areas are seldom combined.

The present review provides an overview of fatigue from sleep loss and/or circadian disruption and their potential impact on submarine teams. We begin with a discussion of factors that should be considered for team fatigue research. We then provide an outline of sleep and circadian rhythms within the submarine environment. Particular emphasis is given to how fatigue may be affected by watchbill structure, the submarine's lack of natural light, and the constant motion of the boat.

KEYWORDS: submariner; fatigue; circadian rhythms

Next, we discuss the known effects of fatigue on performance in laboratory and operational settings, and consider how fatigue might impact team performance. Unlike the abundant research on the effects of fatigue on individual performance, there is a striking lack of research on how fatigue impacts group performance, and the limited findings are mixed. Knowledge of how fatigue affects individuals, combined with general knowledge of teams, allow us to posit that fatigue may degrade team performance, as it leads to communication difficulties, social loafing, distractibility and shared negative emotions. Finally, we end with a discussion of how teams have been shown to overcome some of the negative effects of fatigue. For this review, research was compiled from searches of Google Scholar, the Defense Technical Information Center (DTIC), PubMed, and the archive of Technical Reports from the Naval Submarine Medical Research Laboratory (NSMRL). Due to the different ways that researchers throughout the literature define "teams" (as discussed below), we chose to consider any research involving two or more individuals working toward a common goal.

FACTORS TO CONSIDER WHEN STUDYING TEAM FATIGUE

The literature on team fatigue is relatively sparse [1-4], and it is often contradictory. As we will discuss throughout this review, fatigue sometimes brings out the worst qualities in a team (e.g., social loafing, communication difficulties, distractions, shared negative emotions), leading to poorer overall performance. However, team membership sometimes protects against certain negative aspects of fatigue, leading to overall better performance. This apparent contradiction highlights the importance of careful control of a number of factors when conducting and interpreting studies. As noted by Barnes and Hollenbeck [5], the influence of fatigue on a team *"is determined by the task structure, the team's structure, and social processes. Thus, in some contexts the influence of sleep deprivation will not significantly influence team decision accuracy, and in others it will have disastrous effects."*

Before we consider how fatigue may impact the performance of submarine teams, we will begin with a discussion of the factors that should be taken into account when designing and interpreting team fatigue studies; it should be recognized that many of these factors may interact with one another.

Defining teams

In team fatigue literature, studies often differ in terms of how "teams" are defined. For example, Frings defines a team as a *"group of people who share common goals, have a history of working together, and who have knowledge of various members' strengths and weaknesses"* [2]. Whitmore and colleagues do not require that team members have a history of prior experience and knowledge of one another, requiring *"two or more individuals working together toward a common goal in an interdependent fashion"* [6]. Other researchers (e.g., [7]) choose not to explicitly define teams at all, opting to simply juxtapose group and individual performance.

These differing definitions make it difficult to interpret findings across research studies. For example, consider the difference between teams whose members come from the same organization and have a history of working together previously (e.g., [2,8]), and teams whose members had not met prior to participation (e.g., [3,9]). Researchers examining surgical teams have noted that *"Factors that promote team effectiveness such as cohesiveness and the team member's ability to anticipate may be more critical to attend to among ad hoc teams because they lack the frequency and consistency of working together that advantage intact teams in this way"* [10].

Differences in how teams are defined can manifest in seemingly conflicting experimental results (e.g., [9,11]), as we will discuss below. Such differences may be attributed to whether team definitions require interdependent work (e.g., [6,11]) or allow for members to work independently toward a common goal (e.g., [9]). It is therefore important that researchers explicitly define their use of the term "team," to ensure that meaningful comparisons can be made across studies.

Defining fatigue

Equally as important as defining the type of team is defining the type of fatigue. Fatigue research typically divides into chronic fatigue (fatigue that accumulates over time, such as weeks or months receiving five to six hours of sleep per night) and acute fatigue (fatigue resulting from short-term sleep loss, such as one night of sleep deprivation). In team fatigue research, most work has focused on acute fatigue. However, even then, studies are based on inconsistent severity levels of fatigue. Research has ranged from one night of total sleep deprivation (e.g., [1,12]) to sleep deprivation lasting in the range of 20 to 30 or more hours (e.g., [3,6,9,11]). These differences in the amount of restricted sleep can dramatically alter the conclusions drawn from research studies. For example, Whitmore and colleagues [6] measured performance on a synthetic command and control task (Command, Control and Communication Simulation Training and Research System; C3STARS) and found that individual, but not team, performance was degraded after 36 hours of sleep deprivation. Using the identical C3STARS task, Chaiken and colleagues [7] also found that a fatigue effect was not evident for teams after 36 hours; however, after 48 hours of sustained wakefulness, fatigue actually had a larger impact on teams than it did on individuals.

Further complicating the way that researchers define fatigue is that some studies compound sleep-based fatigue with other sources of fatigue. For example, sleep deprivation has been combined with vigorous exercise (e.g., [2,8]), which can impact cognitive performance in and of itself [13,14]. Sleep-based fatigue can also interact with time-on-task fatigue, as illustrated in a recent study examining on-road driving performance [15]. As research has not explored the effects of time-on-task fatigue on team performance, it is not possible to know how time-on-task and sleep-based fatigue might interact to impact teams. Similarly, although it is known that changes in the normal 24-hour (circadian) sleep cycle may lead to cognitive decrements, both alone and when compounded with sleep-based fatigue [16-18], the impact of circadian-based fatigue on teams is unstudied.

Choosing tasks

In addition to variations in how teams and fatigue are conceptualized, many studies employ different types of tasks to assess performance. One of the major distinctions between task types is independent versus interdependent tasks. In independent tasks, each team member is theoretically capable of fulfilling his or her role regardless of how other team members are performing. An example of this is a mathematical problem-solving task in which small groups work together to solve critical-thinking puzzles [8]. In contrast, interdependent tasks require unique contributions from each group member. For example, Baranski and colleagues [11] required teams to assess the threat levels of radar contacts, with each team member responsible for the analysis of three unique information items. The interdependency of tasks is important because it changes the degree to which team members feel accountable, thereby potentially changing outcomes.

The interdependency of tasks is important because it changes the degree to which team members feel accountable, thereby potentially changing outcomes.

The cognitive processes underlying chosen tasks can also impact the outcomes of team fatigue studies. Barnes and Hollenbeck [5] propose that sleep deprivation will have a larger negative impact on team problem-solving than on team decision-making. In individuals, Barnes and Hollenbeck point out that problem-solving is affected more by fatigue because it relies more on pre-frontal cortex brain regions, which are highly sensitive to fatigue effects. They suggest that this will interact with team dynamics to magnify the differences in performance between task processes. Specifically, past research has demonstrated differences in how teams respond to tasks with different levels of demonstrability [5]. When tasks are high in demonstrability, a single group member can arrive at the correct answer and easily convince the group to adopt the solution; in contrast, for tasks with low demonstrability, multiple team members must independently reach the correct solution before it is adopted by the team [19]. Therefore, Barnes and Hollenbeck [5] propose that the strongest effects of fatigue on team performance will emerge on divergent problem-solving tasks with low demonstrability. In this case, each individual will struggle at the task due to effects of fatigue on the pre-frontal cortex. In the event that an individual reaches a correct solution, he or she may struggle to convince the team; moreover, any individual who reaches an incorrect solution may not be convinced of a correct solution offered by a teammate.

Finally, in military settings, it is important to choose tasks that are operationally relevant and suited to assess military team performance. In a recent systematic review, Lawson and colleagues [20] examined 54 computerized metrics of team performance and selected seven that they believed to be the most relevant for military research needs. To our knowledge, only one of the assessments (Duo Wondrous Original Method of Basic Airmanship/Awareness Testing; DuoWOMBAT) has been used in fatigue-based experiments, and only data from individual performance has been presented [21]. Nevertheless, many of these assessments are likely to be of great utility to team fatigue research.

Choosing baselines

A final consideration for team fatigue research is the baseline measure used to assess performance. In the literature, fatigued teams have been compared to fatigued individuals (e.g., [7,9,11]) and to rested teams (e.g., [2,8]). Team performance has also been explored over time, as fatigue sets in (e.g., [1,3,12]). Each of these comparisons will limit the conclusions that can be drawn from the research, and should be carefully designed to optimally answer the research question being addressed.

FACTORS CONTRIBUTING TO FATIGUE IN A SUBMARINE ENVIRONMENT

There are a number of factors that likely contribute to fatigue onboard a submarine. In addition to normal physiological and schedule-based stressors that may lead to feelings of tiredness in an individual's daily life, the unique environment and high-tempo operational schedule of a submarine affect the sleep and circadian rhythms of submariners. As a result, submariners report experiencing high levels of subjective fatigue. In a survey of 143 enlisted submariners with at least one full year of submarine service, more than 45% of sailors reported feeling physically or mentally tired during at-sea watches either "often," "frequently," or "always." Relatedly, more than 60% reported "rarely" or "never" feeling rested while at sea, in contrast to less than 15% reporting such negative sleep while on leave [22].

Barnes and Hollenbeck propose that sleep deprivation will have a larger negative impact on team problem-solving than on team decision-making.

Watchbills

Since the 1960s, United States (U.S.) submarine crews have operated on a watchbill schedule that consists of an 18-hour work-rest cycle; for every six hours spent on watch, submariners are given 12 hours off. This "6/12" schedule was originally designed to optimize the number of crew sleep opportunities [23], though knowledge gained since its inception has shown that the 6/12 schedule likely does not contribute to optimal rest for three reasons.

First, the 6/12 schedule was largely based on two underlying assumptions that have since been found inaccurate. It was believed that *"A minimum of 5 hours sleep is required to enable the individual to maintain an acceptable level of consistent and reliable performance"* [23]. However, more recent research has reported that even modest chronic sleep restriction (e.g., six hours of sleep) can adversely affect neurobehavioral performance [24-26]. It was also believed that *"Physical and psychological recovery from sleep loss is accomplished by the acquisition of a normal uninterrupted sleep period"* [23]. It is now understood, however, that at least two days of unrestricted (eight-hour) sleep is required to recover from the effects of restricted sleep, with some neurocognitive functions taking much longer to return to baseline levels [26-29].

Second, the analytical metrics used to justify the 6/12 schedule were not optimal. Stolgitis used a metric called "sleep cycle efficiency (SCE)," defined as the ratio of the average potential daily sleep periods (i.e., sleep available) to the average daily rest/recreation periods allotted to a crew member. The SCE for a 6/12 watchbill (18-hour day) was found to be higher (8.66/9.67=0.895) than the SCE for a 4/8 watchbill (24-hour day; 5.83/8.67=0.673). However, this statistic was calculated across four available sleep periods (5-hour, 4.5-hour, 6-hour, and 10.5-hour) over a 72-hour period. While the average was 8.66 hours of sleep, this was largely driven by the single 10.5-hour sleep session (the median sleep obtained was only 5.25 hours). As noted above, a single sleep session is insufficient to restore accrued sleep debt.

Finally, the 18-hour schedule fails to account for the human circadian clock, which coordinates the timing of physiological processes and behavior (including the timing of the sleep/wake cycle) with daily environmental changes in the day-night cycle. The human circadian clock is approximately 24 hours, with an average duration of 24.2 hours [30-33]. Alertness, performance, sleep, and sleepiness are all regulated by the circadian clock, and all demonstrate distinct circadian variation across the 24-hour day [34].

When imposed work/rest schedules do not align with the internal clock's near 24-hour period, sleep disruption can occur. This is because complex and coordinated patterns of activity among brain regions are under the control of two distinct biological processes that regulate sleep [35-37]: The internal circadian clock coordinates the timing of sleep onset and offset, and a homeostatic process coordinates the pressure to sleep [38]. When the circadian and homeostatic processes are synchronized, the circadian system actively promotes sleep while homeostatic sleep levels are high, allowing for non-disrupted, high-quality, restorative sleep. When these two processes are not synchronized, however, the clock may inappropriately signal sleep while an individual is required to be awake and alert; it may conversely promote alertness when an individual has the opportunity to sleep. The misalignment between the homeostatic sleep drive and the internal circadian clock results in circadian disruption and less restorative sleep, both of which are associated with increased sleepiness/fatigue levels; reduced performance on tasks of alertness/vigilance, learning, and memory; and poorer health outcomes [16-18]. Over time, the resulting sleep loss, both acute and chronic, can adversely affect physiological well-being [4,18,39], and neurobehavioral and cognitive functioning [24,40-42].

The 18-hour schedule onboard submarines does not align with the near 24-hour circadian clock, and thus results in rotating periods of scheduled sleep and wake that occur at different clock hours throughout the day-night cycle. The daily six-hour change in the timing of sleep from the night before is equivalent to traveling across six time zones each day, leading to sustained operational jet lag [43].

In order to protect sailors' sleep and allow for eight hours of continuous sleep per night [44], the U.S. submarine force recently made a 24-hour day the expected standard under normal operational situations [45]. It is important to note, however, that even a 24-hour-based schedule may not ensure that submariners receive optimal levels of sleep. In an at-sea trial of a compressed-work 24-hour schedule (six hours on/six off; six hours on/12 off; six hours on/six off; six hours on/24 off), submariners received about 51 minutes of sleep per day less than they did on the 18-hour-based schedule, due to the need to complete collateral work in the intended 12- and 24-hour sleep periods [46]. Even though this schedule was shown to be physiologically superior to the 18-hour schedule when tested in a laboratory setting [47], operational constraints limited its utility at sea. This points to the need for careful research both in the lab and at sea before new schedules are implemented, and also highlights the importance of mimicking operational constraints in the laboratory to the greatest extent possible in order to expedite the at-sea utility of findings. Recent at-sea research has provided preliminary evidence that two 24-hour schedules ("straight eights": three rotating watch sections consisting of eight hours on watch, eight hours of training and other duties, and eight hours for sleep; and all-hands awake: three watch sections with staggered sleep periods permitting the entire crew to be awake during a single eight-hour period for drills and training evolutions) provided submariners with more sleep (and were subjectively preferred) relative to an 18-hour schedule [43], but further research is needed to determine which 24-hour schedule best accommodates the needs of submarine crews.

Over time, resulting sleep loss, both acute and chronic, can adversely affect physiological well-being, and neurobehavioral and cognitive functioning.

Lack of natural light

Submariners onboard U.S. Navy submarines are exposed to artificial lighting for up to 12 weeks at a time. In contrast to the bright light experienced in natural settings, submarine crews are continually exposed to dim lighting levels [48], well below those required to affect circadian rhythms [49]. This may be problematic, as exposure to daily bright light allows for small adjustments in the circadian clock and entrainment to the environmental light/dark cycle (for a review, see [50]). When bright light is received during the daytime, especially in the morning upon awakening, it helps anchor the internal clock and reinforces the appropriate timing of alertness and sleepiness. Conversely, lack of bright light stimulation during the day can decrease alertness. Furthermore, when exposure to light occurs during an individual's biological night (when the circadian clock is actively promoting sleep), the clock begins to adjust to this perceived change in the environmental light/dark cycle. In either case, or in combination, the result is circadian misalignment. Onboard a submarine, lighting levels are held constant and are not synchronized with work schedules, leading to difficulties stabilizing alertness cycles [48].

This lack of optimal light intensity is compounded by the spectrum of light to which crew members are exposed. Submarines are currently equipped with long-wavelength (yellow and red) light sources that lack short-wavelength (blue) light [51]. As short-wavelength blue light is most effective at affecting circadian rhythms (e.g., [52,53]), the lighting environment on submarines likely fails to promote full alertness, thereby contributing to the fatigue experienced by crew members. Preliminary research suggests that a shift to high correlated color temperature lighting (that includes short-wavelength light), in combination with 24-hour watch schedules, might improve submariners' behavioral alignment with work and sleep schedules [51].

Motion

A final factor contributing to fatigue in submariners is the physical motion of the boat. On a submarine, sailors are in constant movement as the boat travels (particularly when transiting on the surface or at periscope depth), which can affect the physical and cognitive well-being of those onboard. In addition to the gastrointestinal distress and dizziness associated with motion sickness [54], sailors may experience sopite syndrome, characterized by symptoms of fatigue, drowsiness, and mood changes in response to periods of prolonged motion [55]. Sopite syndrome can occur independently, with or without motion sickness [55,56], and may result in drowsiness accompanied by quick shifts from alertness to deep sleep, regardless of the time of day [55-58]. Because sleep deprivation can exacerbate the effects of motion on the body [59], sopite syndrome may be of particular concern on submarines where irregular lighting and watch schedules contribute to sleep loss.

On a neuroanatomical level, sleep deprivation leads to decreases of brain activity in both cortical (prefrontal) and subcortical (thalamic) regions responsible for alertness, attention and higher-order cognitive processing.

EFFECTS OF FATIGUE ON INDIVIDUAL PERFORMANCE

Sleep loss and circadian misalignment, like that experienced onboard a submarine, can disrupt physiological processes and health, including decreased immunological function [60,61], increased obesity and metabolic disorders (see [62] for a review), and changes to autonomic and endocrine function [63]. While these factors are clearly important to understand in order to ensure the well-being of sailors, the effects of sleep loss and circadian misalignment on cognitive processing are the most relevant for ensuring that operational missions are completed safely and successfully.

In laboratory settings, sleep deprivation and/or circadian disruption can degrade decision-making and judgment [64,65], visuospatial attention [66], working memory [67], and logical reasoning [68] (for a review of fatigue effects see [4,69]). In an operational context, lack of adequate sleep contributes to errors in automobile driving (as indexed by crashes; for a review see [70]), marksmanship [71], and accuracy of flight maneuvers [72], among others.

Fatigue from sleep loss

The driving factor of fatigue due to sleep loss is a build-up of homeostatic sleep pressure that is hypothesized to occur from the accumulation of sleepiness-inducing metabolic byproducts, such as adenosine [37]. During prolonged wakefulness, adenosine accumulates in extracellular regions of the basal forebrain, inhibiting neurons that promote wakefulness [73]. When sleep of sufficient duration (recommended seven to nine hours for adults [74]) is received, adenosine levels are reduced [73] and sleep pressure is relieved. However, when adequate sleep is not received, residual adenosine accumulation leads to feelings of grogginess and fatigue. On a neuroanatomical level, sleep deprivation leads to decreases of brain activity in both cortical (prefrontal) and subcortical (thalamic) regions responsible for alertness, attention, and higher-order cognitive processing [75,76].

One of the most widely studied impacts of fatigue due to sleep loss has been on vigilance and attentional stability. In the laboratory, total sleep deprivation (usually involving 24 hours or more of sustained wakefulness) and chronic sleep restriction (sleeping less than the recommended amount for several days or more) both produce deficits in neurobehavioral performance. Studies using the psychomotor vigilance task (PVT) consistently demonstrate slower response times and increased lapses in attention [24,26,77,78] compared to a well-rested baseline.

Although most research supports the finding of decreased cognitive performance (e.g., decision-making, working memory) under conditions of sleep loss (for a review see [79]), much of this work has been conducted in laboratory settings. Stringent experimental control ensures that effects can be meaningfully compared across studies and provides researchers with the greatest probability of observing effects when they are present; however, laboratory experimentation may fail to account for how fatigue affects performance in operational settings. A review of sleep in the military [80] noted a reluctance to generalize from laboratory-based findings to military settings, as it is thought that motivation and determination will allow operators to overcome fatigue and continue to perform their required jobs [81]. It is important to understand, however, that motivation does not appear sufficient to overcome the deleterious effects of fatigue. As fatigue sets in, high levels of subjective effort are required to maintain task performance [21]; in other words, tired people feel as if they must work harder to obtain the same outcome. Moreover, in spite of high subjective effort, sleep-deprived individuals still underperform their well-rested peers on cognitive tasks [82,83]. This likely reflects that sleep loss results in a reduced capacity to perform, not a loss of willingness to perform [84]. As a result, an individual's self-assessment of "fitness for duty" often does not accurately reflect performance ability [85]. This is shown in performance decreases due to fatigue, even in military populations. A survey of deployed U.S. Forces in Afghanistan found a significant negative relationship between soldiers' reported hours of sleep per day and the likelihood of making a mistake or having an accident during deployment [86]. Other research shows that field-based tasks requiring consistent, sustained alertness are the most susceptible to effects of fatigue [87].

> As fatigue sets in, high levels of subjective effort are required to maintain task performance. Moreover, in spite of high subjective effort, sleep-deprived individuals still underperform their well-rested peers on cognitive task. This likely reflects that sleep loss results in a reduced capacity to perform, not a loss of willingness to perform

Fatigue from circadian rhythm disruption

In addition to fatigue caused by sleep deprivation or restriction, fatigue can also result from disruption to the body's circadian rhythms. Circadian rhythms are the physiological processes that maintain the body's 24-hour sleep/wake cycle. Human circadian rhythms are diurnal, which leads to being awake during the day and asleep at night. Notably, the circadian rhythm in alertness reaches its nadir in the early morning, approximately two hours before habitual wake time [34]. When work and wakefulness are attempted outside of this diurnal rhythm (such as standing watch overnight around the circadian nadir in alertness), the situation may lead to decreased performance [88] and increased impulsivity [89]. Even shifts in wakefulness as small as two hours can negatively affect performance [90], as demonstrated by studies in which sleep time is shifted but the duration of sleep is preserved. For example, when a regular eight-hour sleep period (e.g., 2400-0800) was shifted forward (0300-1100) or backward (2100-0500) by three hours, decrements in mood and vigilance performance were quantitatively similar to those observed when total sleep time was decreased by three hours [91].

Time-on-task fatigue

Even when circadian rhythms are maintained and optimal sleep levels are achieved, fatigue can result from long-lasting involvement on a cognitive task. This phenomenon is often referred to as "mental fatigue" or "time-on-task fatigue," and emerges when individuals perform a task requiring sustained vigilance over an extended period of time. Though time-on-task fatigue is thought to be distinct from sleep-based fatigue, effects stemming from the two are qualitatively similar [92], and time-on-task performance decrements are greatly exacerbated during sleep deprivation. Like sleep-based fatigue, time-on-task fatigue can result in both laboratory-based vigilance and executive control errors [93, 94], and operational errors in areas such as driving [95, 96], aviation and air traffic control [97,98], and threat detection [99). Specifically, time-on-task fatigue can slow reaction time in response to new stimuli [100,101] and impair operators' ability to prepare for future actions [101]. Critically, these performance decrements are not limited to the task that induces fatigue, but can extend to secondary tasks that simulate emergency scenarios [102].

Time-on-task fatigue is directly relevant for a military environment, where operators conduct sustained and continuous missions with little opportunity for mental rest. Within the submarine force, time-on-task will likely become more pertinent with the switch to the 24-hour watch schedule, as submariners may often stand watches for up to eight consecutive hours. It is important to note that on submarines, as in most military environments, time-on-task demands will interact with fatigue due to sleep schedules (for a review see [103]). In fact, most research on military time-on-task fatigue is conducted within the broader context of concurrent sleep deprivation [104-106]. These potential interactions, as well as how time-on-task effects are impacted by the presence of multiple individuals working together, must all be considered in future research on submarine crews. To our knowledge, the effects of time-on-task have not been explored in a team context.

Individual trait susceptibility

Much as individuals are differently susceptible to allergens, susceptibility to impairment from fatigue can vary from person to person. Van Dongen and colleagues [107] repeatedly exposed participants to 36 hours of sleep deprivation and found substantial differences in how they performed on a variety of computerized neurobehavioral assessments (e.g., PVT). However, despite these individual differences in performance under sleep loss, each person's performance remained stable over time. In other words, a person who performed poorly under the first instance of fatigue experienced similar decrements when exposed to subsequent sleep deprivations (see also [108,109]). This trait susceptibility is so strong that, according to Van Dongen and colleagues [107], variations among individuals can explain up to 92.2% of the variance in neurobehavioral outcomes. Moreover, susceptibility to sleep loss does not manifest only in performance on neurobehavioral measures – subjective alertness also varies among individuals. Interestingly, however, reported levels of sleepiness do not correspond with behavioral performance [108].

In addition to differential vulnerabilities to sleep loss and fatigue, people differ in the amount of sleep required, when optimal sleep occurs (i.e., evenings or mornings), the perceived quality of sleep received, and the susceptibility to sleep disorders (e.g., sleep disturbance, excessive daytime sleepiness, sleep apnea, narcolepsy, parasomnias, insomnia) [110]. These individual trait-like differences have implications for military settings, as they imply that not everyone is capable of adjusting to the demanding sleep-work schedules that are often present (see also [111]). Future research is needed to improve methods for identification of individuals who are most resilient to performance impairments resulting from sleep loss and fatigue [110].

EFFECTS OF FATIGUE ON TEAM PERFORMANCE

It is important to recognize that most tasks performed in operational settings are not performed by individuals in isolation. On U.S. Navy submarines, for example, a team made up of five groups and one individual (or a "team of teams" [112]) is responsible for successfully navigating the boat and carrying out tactical operations. In many situations *"Teams have the potential to offer greater adaptability, productivity, and creativity than any one individual can offer (e.g., [113,114])"* [115], and as a result have the ability to enhance performance outcomes. When teams are fatigued, however, history has demonstrated that there can be dire consequences. For example, the meltdown of nuclear power plants including Chernobyl and Three Mile Island have been associated with groups of people working under conditions of reduced sleep [4], as has the space shuttle Challenger disaster [4,116].

In spite of the importance of teamwork, little is known about how team performance is affected by fatigue [1-3]. It has been noted that even when studies of fatigue involve groups of individuals, there is often little discussion of interactions among group members [4]. Therefore, in the present review, we combine knowledge of how fatigue affects individuals with general knowledge of teams in order to draw conclusions about what might be most relevant in a fatigued-team environment.

Negative effects of fatigue on teams

Communication breakdowns. One area in which fatigue may be particularly relevant for team dynamics is communication. Under conditions of sleep deprivation, verbal communications are degraded as voice tone is flattened [117], spontaneous dialogue is decreased [118], word retrieval abilities are impaired [119], speech is slowed [120], and interlocutors become less aware of conversation partners' ignorance [4]. As Harrison and Horne [4] note: *"All this can impair the accurate transmission of ideas between colleagues and impact conversational flow."* This is important to consider, as open communication and dialogue are vital for successful teams [115], and the submarine force has prioritized dialogue in the evaluation of submarine watch team resilience [121]. On an individual level, fatigue has also been shown to negatively impact mood [122] and interpersonal behavior [123]. This may lead to irritability, impatience, and a lack of regard for social conventions, contributing to task and relationship conflict [5]. Task and relationship conflict lead to decrements in team performance [124].

Changes in communication as a result of fatigue have been observed in Air Force command and control personnel [12]. In a simulated sustained command operations task, increased fatigue was associated with decreases in the number of communications regarding assets and strategy. Expressions of encouragement among team members also declined, though this change did not reach statistical significance. These changes in communication structure appeared to reduce mission effectiveness, as correlations between communication variables and objective mission outcomes (e.g., friendly assets killed by hostile assets) reached significance only under conditions of fatigue.

> Onboard a submarine, negative emotions arising from fatigue may be compounded by emotional negativity stemming from other sources including working in an isolated environment, overcrowding and lack of personal space, and even the constant motion of the boat.

Negative emotions

Closely related to communication breakdowns are decreases in emotional states as a result of fatigue. As noted previously, fatigue impacts frontocortical brain regions associated with higher-level cognitive processing [75,76]. Importantly, many of these regions also subserve emotional processing and emotionally based decision-making [125]. For example, the medial prefrontal and anterior cingulate cortices are involved with emotional processing and expression [126]; and the dorsolateral prefrontal cortex is involved with emotional self-regulation [127] (for a review of the neural substrates of emotion, see [128]). Therefore, fatigue and sleep deprivation are associated with emotional effects that can impact interpersonal relationships.

When individuals are fatigued, they have lower emotional intelligence (emotional quotient; EQ) scores, with specific decrements emerging in levels of empathy and interpersonal functioning [125]. Optimism and desire to socialize decrease, which can be accompanied by increases in anger and aggression (see [129] for a review). Fatigued individuals may also display more emotional responses to negativity compared to those who have received sufficient sleep [130]. Onboard a submarine, negative emotions arising from fatigue may be compounded by emotional negativity stemming from other sources including working in an isolated environment [131], overcrowding and lack of personal space [132], and even the constant motion of the boat (sopite syndrome: [55,56]).

The negative emotional state of even one individual can affect interactions within a team environment through emotional contagion. Emotional contagion is *"a process in which a person or group influences the emotions or behavior of another person or group through the conscious or unconscious induction of emotion states and behavioral attitude"* [133]. When negative emotional contagion is present in a group environment, there can be adverse ramifications for group dynamics [134], such as strained leader-member relationships that result in cynicism and distrust toward the leader [135]. Therefore, fatigue's negative effect on an individual's emotions could have far-reaching implications for the overall performance and well-being of the team.

Social loafing

Another potential negative effect of fatigue in a team environment is the tendency of group members to engage in social loafing. Social loafing is the phenomenon of observed decreases in individual effort while in the social presence of others [136]. For example, the amount of noise that is made by a group clapping or shouting in unison does not grow in proportion to the group [136]. In other words, when acting as a group member, an individual creates less noise than he or she would create if acting alone. Social loafing is not limited to physical efforts, but has also been observed in cognitive tasks including brainstorming uses for objects [137] and visual vigilance [138]. Team members are more likely to engage in social loafing if individual efforts are not identifiable [139].

Fatigue may magnify the propensity for social loafing [9] and may undermine some of the usual social loafing countermeasures. For instance, although social loafing is less likely in cohesive groups [140] as are often seen on submarine teams, team cohesiveness is no longer a good buffer against social loafing when members are fatigued [9]. Such findings emphasize the need to recognize how the negative effects of fatigue and social loafing interact, in order to ensure that fatigued teams perform at optimum levels.

Distractions

Finally, fatigue may interact with the distraction inherent with being part of a team. Research has shown that having others present during a task creates distraction (distraction-conflict theory; [141]), which can either diminish performance by dividing attention between the task and others, or it can improve performance by facilitating increased effort [2]. Because distraction can lead to either positive or negative outcomes, the result may be dependent on additional factors such as fatigue. In fact, research suggests that fatigue leads to attentional problems (rather than increased drive and effort) when distractions are present. For instance, under conditions of fatigue, the distraction generated by others in a face recognition task led to poorer individual performance, as indexed by a higher rate of false alarms [2].

Using teams to combat negative effects of fatigue

In spite of the negative outcomes that may arise from interactions between fatigue and team dynamics, there are also cases in which team membership may mitigate some detrimental effects of fatigue. For instance, when a team member is fatigued, rested members may be able to compensate for that person's performance [5]. This effect is particularly strong when team members perceive that the cause of an individual's poor performance is outside his or her control [142,143], as is likely the case for fatigue due to set watchstanding schedules.

Even when all team members are fatigued, team membership may be beneficial to performance. In a study of surveillance threat assessments [11], military and civilian participants were asked to identify and classify the threat level of contacts on a radar screen while acting either individually or in teams of four. While individuals and teams did not differ in performance when well-rested, fatigue had more of a negative effect when individuals performed alone compared to when they performed the same task as part of a team. Similar results were found in a study of cognitive flexibility during mathematical problem-solving [8]: Fatigued individuals experienced lower levels of cognitive flexibility, whereas no detriments due to fatigue were experienced by teams.

Baranski, et al. [11] and Frings [8] acknowledge that their findings contradict findings of social loafing under fatigue [9]. Baranski and colleagues [11] provide two explanations for this. First, team members felt accountable for their own performance to their team. Second, because team members were acutely aware of the fatigue experienced by their cohort, individuals may have exerted *"additional effort on the task in order to ensure group success"* [11].

Indeed, it seems that in some cases being part of a team may help *"stabilise performance on a task that normally would show detriments in performance if completed alone under sleep deprivation conditions"* [3]. In their study of vigilance-based tracking performance, Pilcher and colleagues [3] found that teams' performances remained stable throughout 30 hours of sleep deprivation. This is in contrast to performance decrements typically observed in individuals' vigilance under conditions of fatigue (e.g., [77,144]).

SUMMARY AND CONCLUSIONS

The present paper has provided an overview of how sleep and fatigue can impact a submarine team environment. Fatigue is of particular concern for submariners due to the structure of watchstanding schedules that conflict with natural circadian rhythms, the submarine's lack of natural lighting, and constant boat motion. These factors can all interact and lead to fatigue due to circadian misalignment, lack of sleep, and extended time on task. Onboard a submarine, where crew members must work together to safely and successfully execute mission-critical tasks, this fatigue can have a meaningful impact on teams' performance. However, there has not been much historical precedence for studying fatigue in team environments, making it difficult for military researchers to understand what factors might challenge operational teams such as submarine crews. As the submarine force has recognized the need to protect submariner sleep and improve team dynamics [145,146], it is vital that researchers understand the gaps in current literature so that future studies can account for the interplay between the two factors. This is particularly important, as a review of submarine mishap reports by the Naval Submarine Medical Research Laboratory found that many incidents could be directly attributed to failures of teams.

As a whole, team fatigue research findings have been mixed. Some studies outline the negative impacts that fatigue has on team performance; other studies show how team settings may mitigate negative effects of fatigue. This highlights the need for well-designed and controlled research that accounts for factors including the type of fatigue studied, the types of tasks investigated, and what measurements are used as benchmarks for comparisons. Future research should consider these factors and their implications for submarine teams.

In spite of the negative outcomes that may arise from interactions between fatigue and team dynamics, there are also cases in which team membership may mitigate some detrimental effects of fatigue.

For example, an immediate research need is to understand how the recently-adopted 24-hour schedule impacts the sleep and fatigue of submariners. While a shift from 18- to 24-hour days will likely lessen some fatigue concerns due to circadian factors, the necessity of standing eight-hour watches (as opposed to six hours on the 18-hour schedule) may exacerbate fatigue due to extended time on task. It remains unknown which areas of submarine operations will be most affected by this change, though the present review suggests that various team-based tasks will be differentially impacted. For instance, fatigue will likely have a different effect on control room crewmembers, who work interdependently to compile a tactical picture, than it will on submariners completing independent (but related) jobs while conducting machinery room maintenance. Laboratory and field-based research are needed to determine which teams and tasks onboard the submarine are most sensitive to the effects of fatigue, so that performance outcomes can be optimized.

■

DISCLAIMER AND ACKNOWLEDGMENTS

The views expressed in this report are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, nor the U.S. Government. I am an employee of the U.S. Government. This work was prepared as part of my official duties. Title 17 U.S.C. §105 provides that 'Copyright protection under this title is not available for any work of the United States Government.' Title 17 U.S.C. §101 defines a U.S. Government work as a work prepared by a military service member or employee of the U.S. Government as part of that person's official duties.
This work was supported by the Naval Sea Systems Command Deep Submergence Biomedical Development program under work unit number F1503.

REFERENCES

1. Barnes C, Coovert M, Harville D, Elliott L. Effects of fatigue on simulation-based team decision making performance [AFRL-HE-BR-TR-2004-0020]. Ft. Benning, GA: United States Air Force Research Laboratory, 2004.

2. Frings D. The effects of low levels of fatigue on face recognition among individuals and team members. J App Soc Psychol. 2015; 45:461-470.

3. Pilcher JJ, Vander Wood MA, O'Connell KL. The effects of extended work under sleep deprivation conditions on team-based performance. Ergonomics. 2011;54(7):587-596.

4. Harrison Y, Horne JA. The impact of sleep deprivation on decision making: A review. J Exp Psychol: Appl. 2000;6(3):236-249.

5. Barnes C, Hollenbeck JR. Sleep deprivation and decision-making teams: Burning the midnight oil or playing with fire? Acad Manag Rev. 2009;34(1):56-66.

6. Whitmore J, Chaiken S, Fischer J, Harrison R, Harville D. Sleep loss and complex team performance [AFRL-RH-BR-TR-2008-0005]. Brooks City-Base, TX: Air Force Material Command, 2008.

7. Chaiken S, Harville D, Harrison R, Fischer J, Fisher D, Whitmore J. Fatigue impact on teams versus individuals during complex tasks. In: Ackerman PL, editor. Cognitive Fatigue: Multi-disciplinary Perspectives on Current Research and Future Directions. Washington, DC: American Psychological Association; 2011.

8. Frings D. The effects of group monitoring on fatigue-related einstellung during mathematical problem solving. J Exp Psychol: Appl. 2011;17(4):371-381.

9. Hoeksema-van Orden CYD, Buunk BP. Social loafing under fatigue. J Pers Soc Psychol. 1998;75(5):1179-1190.

10. Leach LS, Myrtle RC, Weaver FA, Dasu S. Assessing the performance of surgical teams. Health Care Manage Rev. 2009; 34(1):29-41.

11. Baranski JV, Thompson MM, Lichacz FMJ, McCann C, Gil V, Pasto L, et al. Effects of sleep loss on team decision making: Motivational loss or motivational gain? Hum Factors. 2007; 49(4):646-660.

12. Harville D, Lopez N, Elliott L, Barnes C. Team communication and performance during sustained working conditions [AFRL-HE-BR-RT-2005-0085]. Ft. Benning, GA: Army Research Laboratory, 2005.

13. Chang YK, Labban JD, Gapin JI, Etnier JL. The effects of acute exercise on cognitive performance: A meta-analysis. Brain Res. 2012;1453:87-101.

14. Labelle V, Bosquet L, Mekary S, Bherer L. Decline in executive control during acute bouts of exercise as a function of exercise intensity and fitness level. Brain Cogn. 2013;81:10-17.

15. Perrier J, Jongen S, Vuurman E, Bocca M, Ramaekers JG, Vermeeran A. Driving performance and EEG fluctuations during on-the-road driving following sleep deprivation. Biol Psychol. 2016;121:1-11.

16. Akerstedt T. Shift work and disrupted sleep/wakefulness. Occup Med. 2003;53(2):89-94.

17. Kelly TL, Neri DF, Grill JT, Ryman D, Hunt PD, Dijk D, et al. Nonentrained circadian rhythms of melatonin in submariners scheduled to an 18-hour day. J Biol Rhythms. 1999;14(3):190-196.

18. Schaefer KE, Kerr CM, Haus E. Effect of 18-h watch schedules on circadian cycles of physiological functions during submarine patrols. Undersea Biomed Res. 1979;6:81-91.

19. Laughlin PR, Shippy TA. Collective induction. J Pers Soc Psychol. 1983;45(1):94-100.

20. Lawson BD, Kelley AM, Athy JR. A review of computerized team performance measures to identify military-relavant, low-to-medium fidelity tests of small group effectiveness during shared information processing [USAARL 2012-11]. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory, 2012.

21. Odle-Dusseau HN, Bradley JL, Pilcher JJ. Subjective perceptions of the effects of sustained performance under sleep-deprivation conditions. Chronobiol Int. 2010;27(2):318-333.

22. Blassingame SR. Analysis of self-reported sleep patterns in a sample of US Navy submariners using nonparametric statistics [Master's Thesis]. Monterey, CA: Naval Postgraduate School; 2001.

23. Stolgitis WC. The effects of sleep loss and demanding work/rest cycles: An analysis of the traditional Navy watch system and a proposed alternative [Master's Thesis]. Monterey, CA: Naval Postgraduate School; 1969.

24. Van Dongen HP, Maislin G, Mullington JM, Dinges DF. The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep. 2003; 26(2): 117-126.

25. Vgontzas AN, Zoumakis E, Bixler EO, Lin HM, Follett H, Kales A, et al. Adverse effects of modest sleep restriction on sleepiness, performance, and inflammatory cytokines. J Clin Endocrinol Metab. 2004;89(5):2119-2126.

26. Belenky G, Wesensten NJ, Thome DR, Thomas ML, Sing HC, Redmond DP, et al. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: A sleep dose-response study. J Sleep Res. 2003;12(1):1-12.

27. Axelsson J, Kecklund G, Akerstedt T, Donofrio P, Lekander M, Ingre M. Sleepiness and performance in response to repeated sleep restriction and subsequent recovery during semi-laboratory conditions. Chronobiol Int. 2008;25(2):297-308.

28. Banks S, Van Dongen HP, Maislin G, Dinges DF. Neurobehavioral dynamics following chronic sleep restriction: Dose-response effects of one night for recovery. Sleep. 2010;33(8):1013-1026.

29. Rabat A, Gomez-Merino D, Roca-Paixao L, Bougard C, Van Beers P, Dispersyn G, et al. Differential kinetics in alteration and recovery of cognitive processes from a chronic sleep restriction in young healthy men. Front Behav Neurosci. 2016;23:95.

30. Czeisler CA, Duffy JF, Shanahan TL, Brown EN, Mitchell JF, Rimmer DW, et al. Stability, precision, and near-24-hour period of the human circadian pacemaker. Science. 1999; 284(5423): 2177-2181.

31. Wyatt JK, Ritz-De Cecco A, Czeisler CA, Dijk D. Circadian temperature and melatonin rhythms, sleep, and neurobehavioral function in humans living on a 20-h day. Am J Physiol Cell Physiol. 1999;277:R1152-R1163.

32. Wright HR, Hughes RJ, Kronauer RE, Dijk D, Czeisler CA. Intrinsic near-24-hour pacemaker period determines limits of circadian entrainment to a weak synchronizer in humans. Proc Natl Acad Sci. 2001;98:14027-14032.

33. Aschoff J, Wever R. The circadian system of man. In: Aschoff J, editor. Biological Rhythms. New York, NY: Springer; 1981. 311-331.

34. Dijk D, Duffy JF, Czeisler CA. Circadian and sleep/wake dependent aspects of subjective alertness and cognitive performance. J Sleep Res. 1992;1(112-117).

35. Borbely AA. A two process model of sleep regulation. Hum Neurobiol. 1982;1(3):195-204.

36. Harrington J, Lee-Chiong T. Basic biology of sleep. Dent Clin North Am. 2012;56(2):319-330.

37. Saper CB, Scammell TE, Lu J. Hypothalamic regulation of sleep and circadian rhythms. Nature. 2005;437(7063):1257-1263.

38. Porkka-Heiskanen T, Strecker RE, McCarley RW. Brain site specificity of extracellular adesnosine concentration changes during sleep deprivation and spontaneous sleep: An in vivo microdialysis study. Neuroscience. 2000;99:507-517.

39. Niatoh P, Beare AN, Biersner RJ, Englund CE. Altered circadian periodicities in oral temperature and mood in men on an 18-hour work/rest cycle during a nuclear submarine patrol. Int J Chronobiol. 1983;8(3):149-173.

40. Krueger GP. Sustained military performance in continuous operations: Combatant fatigue, rest and sleep needs. In: Gal R, Manglesdorff AD, editors. Handbook of Military Psychology. Chichester, England: John Wiley & Sons, Ltd; 1991. p. 244-277.

41. Pilcher JJ, Nadler E, Busch C. Effects of hot and cold temperature exposure on performance: A meta-analytic review. Ergonomics. 2002;45(10):682-698.

42. Dijk DJ, Neri DF, Wyatt JK, Ronda JM, Riel E, Ritz-De Cecco A, et al. Sleep, performance, circadian rhythms, and light-dark cycles during two space shuttle flights. Am J Physiol Cell Physiol. 2001;281(5):1647-1664.

43. Keller MW, Steele CT, Figueiro M, Marvin K, Rea M. At-sea trial of 24-hour based submarine watchstanding schedules: Implications for circadian rhythm optimization [NSMRL Technical Report 2011-001]. Groton, CT: Naval Submarine Medical Research Laboratory, 2011.

44. OPNAV Instruction 1000.16K U.S. Navy Total Force Manpower Policies and Procedures, 2007.

45. Advanced Change Notice 1-3 to Submarine Standard Organization and Regulations Manual Pearl Harbor, HI: COMSUBPAC Pearl Harbor HI, 2014.

46. Duplessis CA, Miller JC, Crepeau LJ, Osborn CM, Dyche J. Sumarine watch schedules: Underway evaluation of rotating (contemporary) and compressed (alternative) schedules. Undersea Hyperb Med. 2003;34(1):21-33.

47. Miller JC, Dyche J, Cardenas R, Walter W. Effects of three watchstanding schedules on submariner physiology, performance and mood [NSMRL Technical Report #TR1226]. Groton, CT: Naval Submarine Medical Research Laboratory, 2003.

48. Hunt PD, Kelly TL. Light levels aboard a submarine: Results of a survey with a discussion of the implications for circadian rhythms [Naval Health Research Center Technical Document 95-1A]. San Diego, CA: Naval Health Research Center, 1995.

49. Lewy AJ, Wehr TA, Goodwin FK, Newsome DA, Markey SP. Light suppresses melatonin secretion in humans. Science. 1980; 210(4475):1267-1269.

50. Duffy JF, Wright HR. Entrainment of the human circadian system by light. J Biol Rhythms. 2005;20(4):326-338.

51. Young CR, Jones GE, Figueiro MG, Soutiere SE, Keller MW, Richardson AM, et al. At-sea trial of 24-h-based submarine watchstanding schedules with high and low correlated color temperature light sources. J Biol Rhythms. 2015;30(2):144-154.

52. Revell VL, Arendt J, Terman M, Skene DJ. Short-wavelength sensitivity of the human circadian system to phase-advancing light. J Biol Rhythms. 2005;20(3):270-273.

53. Wright HR, Lack LC, Kennaway DJ. Differential effects of light wavelength in phase advancing the melatonin rhythm. J Pineal Res. 2004;36:140-144.

54. Money KE. Motion sickness [AD0704683]. Toronto, Ontario: Defence Research Establishment Toronto Downsview, 1969.

55. Graybiel A, Knepton J. Sopite syndrome: A sometimes sole manifestation of motion sickness. Clin Med. 1976;47(8):873-882.

56. Lawson BD, Mead AM. The sopite syndrome revisited: Drowsiness and mood changes during real or apparent motion. Acta Astronaut. 1998;43(3-6):181-192.

57. Graybiel C, Kennedy RS, Knoblock EC, Guedry FE, Mertz W, McLeod ME, et al. Effects of exposure to a rotating environment (10 RPM) on four aviators for a period of twelve days. Aviat Space Environ Med. 1965:733-754.

58. Kiniorski ET, Weider SK, Finley JR, Fitzgerald EM, Howard JC, Di Nardo PA, et al. Sopite symptoms in the optokinetic drum. Aviat Space Environ Med. 2004;75(10):872-875.

59. Dowd PJ. Sleep deprivation effects on the vestibular habituation process. J Appl Psychol. 1974;59(6):748-752.

60. Irwin M, McClintick J, Costlow C, Fortner M, White J, Gillin JC. Partial night sleep deprivation reduces natural killer and cellular immune responses in humans. FASEB J. 1996;10(5):643-653.

61. Nagai M, Morikawa Y, Kitaoka K, Nakamura K, Sakurai M, Nishijo M, et al. Effects of fatigue on immune function in nurses performing shift work. J Occup Health. 2011;53:312-319.

62. Antunes LC, Levandovski R, Dantas G, Caumo W, Hidalgo MP. Obesity and shift work: Chronobiological aspects. Nutr Res Rev. 2010;23:155-168.

63. Scheer FAJL, Hilton MF, Mantzoros CS, Shea SA. Adverse metabolic and cardiovascular consequences of circadian misalignment. Proc Natl Acad Sci. 2009;16(11):4453-4458.

64. Killgore WDS, Balkin TJ, Wesensten NJ. Impaired decision-making following 49 h of sleep deprivation. J Sleep Res. 2006; 15:7-13.

65. Harrison Y, Horne JA. One night of sleep loss impairs innovative thinking and flexible decision making. Organ Behav Hum Decis Process. 1999;78(2):128-145.

166. Bocca M, Denise P. Total sleep deprivation effect on disengagement of spatial attention as assessed by saccadic eye movements. Clin Neurophysiol. 2006;117:894-899.

67. Smith ME, McEvoy LK, Gevins D. The impact of moderate sleep loss on neurophysiological signals during working-memory task performance. Sleep. 2002;25(7):784-794.

68. Blagrove M, Alexander C, Horne JA. The effects of chronic sleep reduction on the performance of cognitive tasks sensitive to sleep deprivation. Appl Cogn Psychol. 1995;9:21-40.

69. Alhola P, Polo-Kantola P. Sleep deprivation: Impact on cognitive performance. Neuropsychiatr Dis Treat. 2007;3(5):553-67.

70. Philip P. Sleepiness of occupational drivers. Ind Health. 2005; 43:30-33.

71. Tharion WJ, Shukitt-Hale B, Lieberman HR. Caffeine effects on marksmanship during high-stress military training with 72 hour sleep deprivation. Aviat Space Environ Med. 2003;74(4):309-314.

72. Perelli LP. Fatigue stressors in simulated long-duration flight: Effects on performance, information processing, subjective fatigue, and physiological cost [SAM-TR-80-49]. Texas: Brooks Air Force Base, 1980.

73. Porkka-Heiskanen T, Kalinchuk A, Alanko L, Urrila A, Stenberg D. Adenosine, energy metabolism, and sleep. Sci World J. 2003;3:790-798.

74. Watson NF, Badr MS, Belenky G, Bliwise DL, Buston OM, Buysse DJ, et al. Recommended amount of sleep for a healthy adult: A joint consensus statement of the American Academy of Sleep Medicine and Sleep Research Society. J Clin Sleep Med. 2015;11(6):591-592.

75. Thomas M, Sing H, Belenky G, Holcomb H, Mayberg H, Dannals R, et al. Neural basis of alertness and cognitive performance impairments during sleepiness. I. Effects of 24 h of sleep deprivation on waking human regional brain activity. J Sleep Res. 2000;9(4):335-352.

76. Thomas ML, Sing HC, Belenky G, Holcomb HH, Mayberg HS, Dannals RF, et al. Neural basis of alertness and cognitive performance impairments during sleepiness II. Effects of 48 and 72 h of sleep deprivation on waking human regional brain activity. Thalamus Relat Sys. 2003;2(3):199-229.

77. Dinges DF, Pack F, Williams K, Gillen KA, Powell JW, Ott GE, et al. Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decremented during a week of sleep restricted to 4-5 hours per night. Sleep. 1997;20(4):267-277.

78. Henelius A, Sallinen M, Huotilainen M, Muller K, Virkkala J, Puolamaki K. Heart rate variability for evaluating vigilant attention in partial chronic sleep restriction. Sleep. 2014;37(7):1257-1267.

79. Banks S, Dinges DF. Behavioral and physiological consequences of sleep restriction. J Clin Sleep Med. 2007;3(5):519-528.

80. Miller NL, Matsangas P, Kenney A. The role of sleep in the military: Implications for training and operational effectiveness. In: Laurence JH, editor. The Oxford Handbook of Military Psychology. New York, NY: Oxford University Press; 2012.

81. Shay J. Ethical standing for commander self-care: The need for sleep. Parameters. 1998;28(2):93-105.

82. Pilcher JJ, Walters AS. How sleep deprivation affects psychological variables related to college students' cognitive performance. J Am Coll Health. 1997;46(3):121-126.

83. Engle-Friedman M, Riela S, Golan R, Ventuneac AM, Davis CM, Jefferson AD, et al. The effect of sleep loss on next day effort. J Sleep Res. 2003;12:113-124.

84. Dinges DF, Kribbs NB, Steinberg KN, Powell JW. Do we lose the willingness to perform during sleep deprivation? J Sleep Res. 1992;21.

85. Sallinen M, Onninen J, Tirkkonen K, Haavisto M, Harma M, Kubo T, et al. Effects of cumulative sleep restriction on self-perceptions while multitasking. J Sleep Res. 2013;22:273-281.

86. Mental Health Advisory Team 9 (MHAT 9) Operation Enduring Freedom (OEF) 2013 Afghanistan Fort Sam Houston, TX: Office of the Surgeon General, 2013.

87. Ainsworth LL, Bishop HP. The effects of a 48-hour period of sustained field activity on tank crew performance [HumRRO-TR-71-16]. Alexandria, VA: Human Resources Research Organization, 1971.

88. Whitmire AM, Leveton LB, Barger L, Brainard G, Dinges DF, Klerman E, et al. Risk of performance errors due to sleep loss, circadian desynchronization, fatigue, and work overload [NASA SP-2009-3405]. Washington, DC: National Aeronautics and Space Administration, 2009.

89. Karatsoreos IN. Effects of circadian disruption on mental and physical health. Curr Neurol Neurosci Rep. 2012;12:218-225.

90. Taub JM, Berger RJ. Acute shifts in the sleep-wakefulness cycle: Effects on performance and mood. Psychosom Med. 1974; 36:164-173.

91. Taub JM, Berger RJ. Performance and mood following variations in the length and timing of sleep. Psychophysiol. 1973; 10(6):559-570.

92. Gunzelmann G, Moore LR, Gluck KA, Van Dongen HP, Dinges DF. Fatigue in sustained attention: Generalizing mechanisms for time awake to time on task. In: Ackerman PL, editor. Cognitive Fatigue: Multidisciplinary Perspectives on Current Research and Future Applications. Washington, DC: American Psychological Association; 2010.

93. Lim J, Wu W, Wang J, Detre JA, Dinges DF, Rao H. Imaging brain fatigue from sustained mental workload: An ASL perfusion study of the time-on-task effect. Neuroimage. 2010;49(4):3426-3435.

94. Mockel T, Beste C, Wascher E. The effects of time on task in response selection - An ERP study of mental fatigue. Natur Sci Rep. 2015;5(10113).

95. van der Hulst M, Meijman T, Rothengatter T. Maintaining task set under fatigue: A study of time-on-task effects in simulated driving. Transp Res Part F Traffic Psychol Behav. 2001;4(2):103-118.

96. Akerstedt T, Ingre M, Kecklund G, Anund A, Sandberg D, Wahde M, et al. Reaction of sleepiness indicators to partial sleep deprivation, time of day and time on task in a driving simulator - The DROWSI project. J Sleep Res. 2010;19:298-309.

97. Stern JA, Boyer D, Schroeder DJ, Touchstone RM, Stoliarov N. Blinks, saccades, and fixation pauses during vigilance task performance: II. Gender and time of day [DOT/FAA/AM-96/9]. Washington, DC: Office of Aviation Medicine, 1996.

98. Stern JA, Boyer D, Schroeder DJ, Touchstone RM, Stoliarov N. Blinks, saccades, and fixation pauses during vigilance task performance: I. Time on task [DOT/FAA/AM-94/26]. Washington, DC: Office of Aviation Medicine, 1994.

99. Basner M, Rubinstein J, Fomberstein KM, Coble MC, Ecker A, Avinash D, et al. Effects of night work, sleep loss and time on task on simulated threat detection performance. Sleep. 2008; 31(9): 1251-1259.

100. Boksem MAS, Meijman TF, Lorist MM. Effects of mental fatigue on attention: An ERP study. Brain Res Cogn Brain Res. 2005; 25: 107-116.

101. Lorist MM, Klein M, Nieuwenhuis S, De Jong R, Mulder G, Meijman T. Mental fatigue and task control: Planning and preparation. Psychophysiol. 2000;37:614-625.

102. Mascord DJ, Heath RA. Behavioral and physiological indices of fatigue in a visual tracking task. J Safety Res. 1992;23:19-25.

103. Krueger GP. Sustained work, fatigue, sleep loss and performance: A review of the issues [USAARL Report No. 89-22]. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory, 1989.

104. Angus RG, Pigeau RA, Heslegrave RJ. Sustained-operations studies: From the field to the laboratory. In: Stampi C, editor. Why We Nap. Boston, MA: Birkhauser; 1992.

105. Gawron V. Summary of the performance effects of sustained operations. Hum Perf Extrem Environ. 2015;12(1).

106. Caldwell JA, Caldwell JL. Fatigue in military aviation: An overview of U.S. military-approved pharmacological countermeasures. Aviat Space Environ Med. 2005;76(7):C39-C51.

107. Van Dongen HP, Baynard MD, Maislin G, Dinges DF. Systematic interindividual differences in neurobehavioral impairment from sleep loss: Evidence of trait-like differential vulnerability. Sleep. 2004;27(3):423-433.

108. Leproult R, Colecchia EF, Berardi AM, Stickgold R, Kosslyn SM, Van Cauter E. Individual differences in subjective and objective alertness during sleep deprivation are stable and unrelated. Am J Physiol Regul Integr Comp Physiol. 2003;284:R280-R90.

109. Wilkinson RT. Interaction of lack of sleep with knowledge of results, repeated testing, and individual differences. J Exp Psychol. 1961;62(3):263-271.

110. Van Dongen HP, Vitellaro KM, Dinges DF. Individual differences in adult human sleep and wakefulness: Leitmotif for a research agenda. Sleep. 2005;28(4):479-496.

111. Saksvik IB, Bjorvatn B, Hetland H, Sandal GM, Pallesen S. Individual differences in tolerance to shift work - A systematic review. Sleep Med Rev. 2011;15(4):221-235.

112. Chabal S, Armbruster RR, Bowers C, Steed R, Lamb J. Measuring and improving submarine tactical team performance. Submarine Technology Symposium 2016; Laurel, MD2016.

113. Gladstein DL. Groups in context: A model of group task effectiveness. Adm Sci Q. 1994;29(4):499-517.

114. Hackman JR. The design of work teams. In: Lorsch JW, editor. Handbook of Organizational Behavior. Englewood Cliffs, NJ: Prentice Hall; 1987.

115. Salas E, Sims DE, Burke CS. Is there a "big five" in teamwork? Small Group Res. 2005;36(5):555-559.

116. Presidential Commission on the Space Shuttle Challenger Accident. Report of the Presidential Commission on the Space Shuttle Challenger Accident Washington, DC: 1986.

117. Harrison Y, Horne JA. Sleep deprivation affects speech. Sleep. 1997;20(10):871-877.

118. Bard EG, Sotillo C, Anderson AH, Thompson HS, Taylor MM. The DCIEM map task corpus: Spontaneous dialogue under sleep deprivation and drug treatment. Speech Commun. 1996;20:71-84.

119. Tilley A, Warren P. Retrieval from semantic memory during a night without sleep. Q J Exp Psychol. 1982;36(2):281-289.

120. Whitmore J, Fisher S. Speech during sustained operations. Speech Commun. 1996;20:55-70.

121. CTQS Exam Grading Form BS45.01 Watch Team Dynamics Submarine Force Continuing Training and Qualification Software.

122. Pilcher JJ, Huffcutt AI. Effects of sleep deprivation on performance: A meta-analysis. Sleep. 1996;19(4):318-326.

123. Kahn-Greene ET, Lipizzi EL, Conrad AK, Kamimori GH, Killgore WDS. Sleep deprivation adversely affects interpersonal responses to frustration. Personal Individ Differ. 2006;41:1433-1443.

124. De Dreu CKW, Weingart LR. Task versus relationship conflict, team performance, and team member satisfaction: A meta-analysis. J Appl Psychol. 2003;88(4):741-749.

125. Killgore WDS, Kahn-Greene ET, Lipizzi EL, Newman RA, Kamimori GH, Balkin TJ. Sleep deprivation reduces perceived emotional intelligence and constructive thinking skills. Sleep Med. 2008;9:517-526.

126. Etkin A, Engner T, Kalisch R. Emotional processing in anterior cingulate and medial prefrontal cortex. Trends Cogn Sci. 2011; 15(2):85-93.

127. Beauregard M, Levesque J, PBourgouin P. Neural correlates of conscious self-regulation of emotion. J Neuroscie. 2001;21.

128. Davidson RJ, Irwin W. The functional neuroanatomy of emotion and affective style. Trends Cogn Sci. 1999;3(1):11-21.

129. Kamphuis J, Meerlo P, Koolhaas JM, Lancel M. Poor sleep as a potential causal factor in aggression and violence. Sleep Med. 2012;13:327-334.

130. Yoo S, Gujar N, Hu P, Jolesz FA, Walker MP. The human emotional brain without sleep - a prefrontal amygdala disconnect. Curr Biol. 2007;17(20):R877-R878.

131. Sandal GM, Leon GR, Palinkas LA. Human challenges in polar and space environments. Rev Environ Sci Bio Technol. 1970; 5(2):399-414.

132. Griffit W, Veitch R. Hot and crowded: Influence of population density and temperature on interpersonal affective behavior. J Pers Soc Psychol. 1971;17(1):92-98.

133. Schoenewolf G. Emotional contagion: Behavioral induction in individuals and groups. Mod Psychoan. 1990;15(1):49-61.

134. Barsade SG. The ripple effect: Emotional contagion and its influence on group behavior. Adm Sci Q. 2002;47(4):644-675.

135. Dasborough MT, Ashkanasy NM, Tee EYJ, Tse HHM. What goes around comes around: How meso-level negative emotional contagion can ultimately determine organizational attitudes toward leaders. Leadersh Q. 2009;20:571-585.

136. Latane B, Williams K, Harkins S. Many hands make light the work: The causes and consequences of social loafing. J Pers Soc Psychol. 1979;37(6):822-832.

137. Harkins SG, Petty RE. Effects of task difficulty and task uniqueness on social loafing. J Pers Soc Psychol. 1982;43(6):1214-1229.

138. Harkins SG, Szymanski K. Social loafing and group evaluation. J Pers Soc Psychol. 1989;56(6):934-941.

139. Williams K, Harkins S, Latane B. Identifiability as a deterrent to social loafing: Two cheering experiments. J Pers Soc Psychol. 1981;40(2):303-311.

140. Karau SJ, Hart JW. Group cohesiveness and social loafing: Effects of a social interaction manipulation on individual motivation within groups. Group Dyn. 1998;2(3):185-191.

141. Baron RS. Distraction-conflict theory: Progress and problems. Adv Exp Soc Psychol. 1986;19:1-36.

142. LePine JA, Van Dyne L. Peer responses to low performers: An attributional model of helping in the context of groups. Acad Manag Rev. 2001;26(1):67-84.

143. Jackson CL, LePine JA. Peer responses to a team's weakest link: A test and extension of LePine and Van Dyne's model. J Appl Psychol. 2003;88(3):459-475.

144. Dorrian J, Lamond N, Holmes AL, Burgess HJ, Roach GD, Fletcher A, et al. The ability to self-monitor performance during a week of simulated night shifts. Sleep. 2003;26(7):871-877.

145. COMSUBFOR. Commander's intent for the United States Submarine Force and supporting organizations Norfolk, VA: Commander, Submarine Force, 2014.

146. FON Special crew rest edition. CSL-CSP Force Operational Notes Newsletter.

✦