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ANALYSIS OF SHORE-BASED SHIFTWORK SCHEDULE ROTATIONS AND SLEEP

by

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Navy and Marine Corps personnel, engaged in support and training operations, face challenges to obtaining consistent sleep due to shiftwork and rotating schedules. Shiftwork has been shown to decrease sleep quality and quantity, which contributes to fatigue and degraded cognitive functions including decision making, alertness, reaction time, problem solving, and ability to learn. When shift changes are more recurrent, the human body must adapt to artificial time changes more often, thereby increasing the likelihood of circadian misalignment and desynchrony. Circadian desynchrony reduces quality and quantity of sleep, which has a cascading negative effect on personnel performance. To ameliorate the negative effects of shift work, rapidly rotating schedules, and associated sleep deprivation, the timing of external cues may be intentionally modified to support circadian alignment to the required wake/work hours. Aligning more quickly to shifting work hours could result in decreased sleep deprivation, improved sleep quality, decreased fatigue, and reductions in the negative impact on cognitive function. This work assessed the current state of sleep, fatigue, mood, and performance of a shore-based watchfloor, establishing a baseline for further study and comparative analysis when a schedule change or intervention is introduced. This study will inform recommendations to shore-based watchfloors that utilize non-traditional work schedules to cover 24-hour operations.

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ANALYSIS OF SHORE-BASED SHIFTWORK SCHEDULE ROTATIONS AND SLEEP

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ABSTRACT

Navy and Marine Corps personnel, engaged in support and training operations, face challenges to obtaining consistent sleep due to shiftwork and rotating schedules. Shiftwork has been shown to decrease sleep quality and quantity, which contributes to fatigue and degraded cognitive functions including decision making, alertness, reaction time, problem solving, and ability to learn. When shift changes are more recurrent, the human body must adapt to artificial time changes more often, thereby increasing the likelihood of circadian misalignment and desynchrony. Circadian desynchrony reduces quality and quantity of sleep, which has a cascading negative effect on personnel performance. To ameliorate the negative effects of shift work, rapidly rotating schedules, and associated sleep deprivation, the timing of external cues may be intentionally modified to support circadian alignment to the required wake/work hours. Aligning more quickly to shifting work hours could result in decreased sleep deprivation, improved sleep quality, decreased fatigue, and reductions in the negative impact on cognitive function. This work assessed the current state of sleep, fatigue, mood, and performance of a shore-based watchfloor, establishing a baseline for further study and comparative analysis when a schedule change or intervention is introduced. This study will inform recommendations to shore-based watchfloors that utilize non-traditional work schedules to cover 24-hour operations.

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LIST OF ACRONYMS AND ABBREVIATIONS

BAC	Blood alcohol content
CFEMP	Comprehensive Fatigue and Endurance Management Policy
DOD	Department of Defense
DHHS	Department of Health and Human Services
ESS	Epworth Sleepiness Scale
FAST	Fatigue Avoidance Scheduling Tool
HEV	high energy visible
IGT	Iowa Gambling Task
ISI	Insomnia Severity Index
IW	Information Warfare
NAVIFOR	Naval Information Forces
NPS	Naval Postgraduate School
NTI	National Telecommuting Institute
POMS	Profile of Mood States
PSQI	Pittsburgh Sleep Quality Index
SAFTE	Sleep, Activity, Fatigue and Task Effectiveness
SAIC	Science Applications International Corp
SBIR	small business innovation research
SCN	Suprachiasmatic nucleus or nuclei
SSO	Special Security Office
TMD	total mood disorder

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EXECUTIVE SUMMARY

In support of 24/7 hour operations around the globe, Navy and Marine Corps watchfloors provide information, intelligence, and technical support to the warfighter. Personnel working on these watchfloors face challenges to obtaining consistent sleep due to shiftwork and rotating schedules. Shift work has been shown to decrease sleep quality and quantity, which, in turn, contributes to elevated fatigue and degraded cognitive function including decision making, alertness, reaction time, problem-solving, and ability to learn (Abe et al., 2014; Harrison & Horne, 2000; Killgore et al., 2006; Mullette-Gillman et al., 2015). These neurobehavioral functions are essential for watchstanders to perform effectively. Degradation in attention, alertness, working memory, problem-solving, or risk-taking are all undesirable effects for watchstanders.

The overarching aim of this study was to inform recommendations for shore-based watchfloors to improve sleep and schedule rotations. The study objectives were the following: to model the predicted effectiveness of a current watch rotation schedule, collect sleep, fatigue, and mood data from watchstanders working on the current rotation, and develop a data-driven rotation schedule designed to improve sleep, safety, and performance.

The first phase of the study included the evaluation of a real-world shiftwork schedule currently implemented on a shore-based watchfloor. We first described the modeling of sleep-wake schedules for watchstanders working in the shore-based watchfloor. Based on the watch rotation schedule and feedback provided by the command leadership, a nominal sleep/work/commute daily schedule was developed for initial modeling analysis. The second phase included collecting data from the watchstanders when working on their typical watch schedule. During the second phase, to improve the fidelity of the model in the first phase of collection, watchstanders self-reported their work and sleep hours associated with the watch rotation. Study participants also responded to survey questions about their sleep, wellbeing, fatigue, insomnia symptoms, and mood.

The results of the model indicate that the most problematic area for predicted effectiveness was the mid shift. During the mid-shift watches, the predicted effectiveness drops steeply throughout the shift. A majority of this shift occurs at a blood alcohol content (BAC) equivalency level greater than 0.08, i.e., the performance is expected to be comparable to an individual who is legally drunk. The timing of low predicted effectiveness coincides with the time period where personnel are briefing leadership and during their commute home from work. The timing of low predicted effectiveness poses an elevated risk during commuting following mid-shift watches.

Through pre-study questionnaire responses and recorded daily activity logs, the 11 study participants' sleep quality, daytime sleepiness, insomnia symptoms, and mood were analyzed. Nine participants (82%) were classified as poor sleepers. Six participants (55%) were classified as having elevated daytime sleepiness. Ten participants (91%) were classified as having subthreshold insomnia or worse. All 11 participants are young in age and are physically active, yet they reported mood levels that are worse than the adult norm for tension-anxiety, depression, anger-hostility, fatigue, and confusion-bewilderment. More striking, they reported low levels of vigor-activity, with 10 (91%) of the participants having a lower vigor-activity score than the adult norm. They also reported high levels of fatigue, with eight participants (73%) scoring higher than the adult norm for fatigue.

As the next step of this effort, we recommend that a new schedule rotation incorporating slower rotations and longer times on a given shift should be implemented. During implementation of this new schedule rotation, sleep data should be collected with a wearable sleep device and standardized questionnaires should be administered to the watchstanders. Preferably, the data collection period will last through least one a full cycle of the newly implemented rotation schedule. Sleep data, as well as self-reported questionnaire data, will provide data for comparison with the baseline sleep, fatigue, and mood data contained here. The sleep and fatigue data associated with the new schedule rotation can then be analytically assessed for improvements. A recommended schedule is included in this thesis.

There are several benefits to the recommended schedule. The recommended schedule rotation would enable watchstanders to maintain regular sleep schedules that are less disruptive to their circadian rhythms. The schedule increases both the number of days off and weekend days off, with two to three full weekends off per month. Predicted effectiveness is improved throughout the rotation cycle as compared to the current schedule. The BAC equivalency is also lower, with the trough not occurring during the outbrief and commuting times. Implementing a watch schedule that incorporates shiftwork best practices provides the opportunity for better sleep, reduces safety risk, enables improved performance, and supports enhanced mood (Miller, 2008).

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I. INTRODUCTION

A. OVERVIEW

Navy and Marine Corps personnel who are engaged in support and training operations face challenges to obtaining consistent sleep due to shift work and rotating schedules. In support of 24/7 hour operations around the globe, watchfloors provide information, intelligence, and technical support to the warfighter. Oftentimes personnel on these watchfloors work long shifts surpassing full-time civilian workweeks (40 hours/week), including night and weekend shifts. Similarly, trainees frequently work long hours with non-traditional schedules, including both shift and night work, with the expectation of rapidly gaining new knowledge and skills. Watch and training schedules commonly include frequent shift changes, also referred to as rapidly rotating schedules.

Shift work has been shown to decrease sleep quality and quantity, which in turn contributes to elevated fatigue and degraded cognitive function including decision making, alertness, reaction time, problem-solving, and ability to learn (Abe et al., 2014; Harrison & Horne, 2000; Killgore et al., 2006; Mullette-Gillman et al., 2015). These neurobehavioral functions are essential for watchstanders to perform effectively. Degradation in attention, alertness, working memory, problem-solving, or risk-taking are all undesirable effects for watchstanders and trainees.

In the U.S. Navy, service-wide guidance on sleep is minimal, with some of the sleep guidance outdated and difficult to find within broadly scoped manuals and instructions (Troxel et al., 2015). Guidance on best practices for rotating to a different shift time, such as day shift to night shift, is even more rare (Office of the Chief of Naval Operations, 2020; Troxel et al., 2015). Some warfare communities have filled this gap with community-specific guidance, but there is no such directive for shore-based watchfloors. Without specific directives or guidance, individual commands and watchfloors are too often left to develop their own watchbills rotations.

Work and training schedules are developed by watchbill coordinators and senior watch officers who are generally junior to midgrade officers or non-commissioned officers.

These schedule managers rarely have training in sleep and circadian rhythms, resulting in work schedules and rotations uninformed by sleep science. Through a combination of necessity and lack of sleep hygiene education, watch schedules often involve frequent shift changes. When shift changes occur, the human body must adapt more often, thereby increasing the likelihood of circadian desynchrony, whereby the circadian rhythm and sleep-wake schedule are severely misaligned (Härmä et al., 2018). Circadian desynchrony reduces the quality and quantity of sleep which has a cascading negative effect on personnel performance and runs contrary to the need for high human performance to achieve mission success (Kazemi et al., 2016). To ensure optimal performance and reduce the risk of error and accident, it is imperative that strategies be developed to decrease the detrimental consequences of shift work and rapidly rotating schedules on shore-based watchfloors so that they may function at optimal performance levels.

Recognizing the potential for improvements in sleep and watchfloor schedule rotations, the Naval Information Forces (NAVIFOR) force surgeon requested guidance from the Naval Postgraduate School (NPS) Crew Endurance Team for improving watchfloor rotation schedules.

B. BACKGROUND

The United States Navy and Marine Corps conduct missions 24/7/365, requiring round-the-clock support. The challenges encountered by leaders, operators, and support personnel demand complex, dynamic decision making and action. Consequently, high level human performance is essential to mission success. The Department of the Navy prioritizes people first in its published mission, vision, and priorities, stating that "our military and civilian workforce is our greatest resource. We will enhance the performance of our force by improving policies, programs, and training. … Our actions across these priorities will ensure mission success today and in the future" (Secretary of the Navy, 2017, p. 1-2).

Furthermore, the Navy and Marine Corps invest time and funding to train and educate every sailor and marine, providing opportunities to improve critical thinking, memory, problem-solving, risk assessment, and decision-making. To maximize the value of training and education during dynamic operations and decision making, the mind must be sharp, alert, and attentive. Optimizing the potential of the human mind to think and respond with clarity requires adequate sleep (Kazemi et al., 2016).

Some warfare communities provide community-specific sleep guidance, directives, and regulations, which are largely absent from Navy-wide guidance (Commander Naval Air Forces, 2017, Commander Naval Surface Force Atlantic, & Commander Naval Surface Force Pacific, 2017; Troxel et al., 2015). These communities provide an example of how other warfare communities, such as the Information Warfare (IW) community, could develop community-specific guidance to address sleep. Aviation mishaps, in particular, are often linked to human error caused by inadequate sleep and fatigue, and frequently receive public attention due to fatalities and loss of aircraft (Office of the Chief of Naval Operations, 2014). As a result of mishaps associated with fatigue and degraded performance, the aviation community has strict crew rest requirements in place to ensure that aviators have sleep opportunities prior to flying (Commander Naval Air Forces, 2017). By instruction, flight crews are required crew rest with a minimum of an eight-hour sleep opportunity prior to each flight (Commander Naval Air Forces, 2017).

The surface warfare community has followed suit and invested in sleep and shipboard watchstanding research in efforts to improve crew sleep and performance (Commander Naval Surface Force Atlantic, & Commander Naval Surface Force Pacific, 2017). Over 35 surface ships have participated in sleep and performance studies administered by the Naval Postgraduate School (Shattuck et al., 2018; Naval Postgraduate School Crew Endurance, n.d.). In November 2017, the Atlantic and Pacific Naval Surface Force commanders jointly released the Comprehensive Fatigue and Endurance Management Policy (CFEMP). The CFEMP mandated that surface ships implement a circadian-based watchbill and afford each sailor a seven-hour sleep opportunity at the same time each day (Commander Naval Surface Force Atlantic, & Commander Naval Surface Force Pacific, 2017). Despite these advances in sleep requirements in the aviation and surface warfare communities, no such modern, overarching guidance or directive regulates shift work at shore-based commands and training commands beyond entry level (Troxel et al., 2015).

Since military operations require round-the-clock support and training, the necessity to operate the watchfloors 24/7 unavoidably results in shift work. Non-traditional work schedules such as shift work, night operations, and rapidly rotating watch schedules disrupt regular sleep (Kazemi et al., 2016). Poor sleep quality or inadequate sleep duration negatively impact health and performance (Watson et al., 2015). The nature of shift work requires that workers sleep during non-traditional times, often during daylight hours. While the human body is capable of realigning slowly to different sleep hours on a 24-hour clock, rapidly rotating shifts challenges our ability to adapt (Härmä et al., 2018).

One of the most effective mitigation techniques to reduce circadian disruption and prevent fatigue is through the optimization of work schedules by increasing the number of personnel and reducing the daily work hours (Abe et al., 2014). However, this option is often unattainable in a military setting. The ability to increase personnel assigned to a given watchbill and develop circadian-based schedules can be limited by manning and operational requirements. The need to operate the watchfloors 24/7 and quickly train personnel endures despite these limitations, and as a result, necessitates long working hours and rotating shifts. Consequently, an alternative technique is needed to help personnel better cope with rotating shifts.

C. STUDY AIM AND OBJECTIVES

The overarching aim of this study is to inform recommendations for shore-based watchfloors to improve sleep and schedule rotations. The study objectives are the following:

- To model the predicted effectiveness of a current watch rotation schedule and assess its strengths and weaknesses.
- Based on the modeling assessment of the current schedule, to develop alternative watch rotation schedules.
- To assess the sleep, work, and commuting times of watchstanders working on the current rotation schedule.

- To develop a data-driven rotation schedule to propose to the command, designed to improve sleep, mood, safety, and performance.

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II. LITERATURE REVIEW

When attempting to develop an understanding of watchstander sleep habits when rotating shifts, it is important to first review the scientific literature around this broad topic. This chapter discusses the general topic of sleep, the nature of shiftwork, problems associated with shiftworkers' sleep, and some of the mitigation measures that have been used to reduce the detrimental impact of shiftwork on sleep, performance, safety, and morale.

A. SLEEP

As a fundamental aspect of human life, the role of sleep must first be considered. Understanding the role of sleep drivers and external stimuli lays the foundation to later review how shiftwork disrupts sleep.

1. Sleep Basics

Sleep is a vital component for overall human health and performance, impacting biological and physiological processes (Zaki et al., 2020). Human biology depends on sleep to manage cardiovascular, immune, and metabolic health (van Cauter et al., 2007; Zaki et al., 2020). Cognitive processes for learning, memory, and emotion rely on sleep for proper functioning (Krause et al., 2017; Yoo et al., 2007). Without adequate sleep, both health and cognitive function will perform at reduced effectiveness, risking poor health outcomes and suboptimal brain function.

Good sleep hygiene, whereby adequate quality and quantity of sleep is achieved, contributes to overall health and cognitive function. Scientific evidence and expert consensus support the recommendation for healthy adults, from age 18 to 60 years of age, to consistently sleep at least seven hours per night. Sleeping less than seven hours per night is associated with poor health outcomes and cognitive impairment (Watson et al., 2015). Inadequate sleep increases health risks, ranging from obesity, heart conditions, and even death (Watson et al., 2015).

Sleeping at the same time each day contributes to better quality sleep and reduced sleep onset latency (Härmä et al., 2018). By maintaining a consistent sleep schedule, the body's circadian rhythm, homeostatic sleep pressure, and external cues all align to encourage sleep during designated sleep hours and promote wakefulness during waking hours (Czeisler & Gooley, 2007). Each of these contributions to sleep will be discussed in more detail. When a person's sleep opportunity shifts to a different time within the 24-hour day, these biological processes must adjust. This adjustment takes time, which is the reason that when someone travels across time zones, they will often experience difficulty sleeping at night and reduced alertness during waking hours for several days, even when external cues are aligned with the new desired sleep schedule.

2. Circadian Rhythm

Cycles throughout nature reveal a tendency to have a 24-hour wake/sleep period (Vitaterna et al., 2001). The field of chronobiology examines biological cycles, to include this daily wake/sleep cycle, also known as circadian rhythm. The word circadian comes from "circa diem," a Latin phrase translated as "about a day." Nearly all animal and plant species exhibit daily changes and patterns that follow this 24-hour. Human biological clocks demonstrate a daily cycle, with the physiological processes adhering to this schedule and showing adverse responses when the natural cycle is disrupted (Vitaterna et al., 2001).

The circadian rhythm will continue to operate with a nearly 24-hour period and keep precise time even in the absence of external stimuli and cues such as light and social interaction (Borbély, 1982; Czeisler & Gooley, 2007 Duffy et al., 2009). While the circadian rhythm inherently functions consistently, external stimuli have the capacity to influence and alter the circadian rhythm (West & Bechtold, 2015). These external factors and influences that impact the circadian rhythm are known as *zeitgebers*, a German term translated as "time-giver." When strong enough, these external cues and environmental changes can cause a shift or resetting in the circadian phase.

Phase resetting occurs when the circadian rhythm becomes offset from its current 24-hour alignment. The circadian rhythm can change either through a phase delay or a phase advance. In a phase delay, the cycle shifts forward in time, whereas a phase advance moves the cycle earlier (Vitaterna et al., 2001). In a practical example, if a person naturally goes to sleep each night at 10 pm, a one-hour phase delay would shift his/her sleep time later to 11 pm. A one-hour phase advance would shift the sleep time earlier in the evening to 9 pm.

Light is the principle *zeitgeber* that causes changes in circadian rhythm and can induce phase shifts (Czeisler & Gooley, 2007). While the average human circadian period is 24.2 hours, individuals vary in the period of their circadian rhythm, with some rhythms longer than and some shorter than 24 hours. Since the human body's internal clock varies by individual, daily light exposure serves as a daily entrainment mechanism to phase delay for those individuals with circadian periods less than 24 hours and phase advance when their circadian period exceeds 24 hours (Czeisler & Gooley, 2007).

Modern technology and industrialization have provided the ability for humans to work and sleep at times that conflict with daylight hours and the natural circadian rhythm. Engaging in these non-traditional work schedules disrupts the synchrony between the circadian rhythm and the 24-hour day. Since the circadian rhythm contributes to health, wellness, and sleep on a daily basis, misalignment of the circadian rhythm and wake-sleep cycle can be problematic (Zaki et al., 2020).

3. Homeostatic Sleep Pressure

The second driving force in human sleep is homeostatic sleep pressure. Sleep pressure increases with each hour of wakefulness and is most effectively relieved with sleep (Czeisler & Gooley, 2007). The interaction of the circadian rhythm and homeostatic sleep pressure regulates the daily sleep cycle in humans (Dijk & Czeisler, 1995). When sleep occurs at the same time each 24-hour cycle, and for sufficient duration for each sleep episode, the circadian rhythm and homeostatic sleep pressure work together to induce sleepiness and sleep at the same time each day (Dijk & Czeisler, 1995). Sleeping at the same time each day supports the alignment of an individual's sleep-wake schedule with their circadian rhythm, and manages homeostatic sleep pressure so that sleepiness and wakefulness correspond more closely with sleep and wake times, respectively.

Neurobehavioral functions are impacted by both the circadian rhythm and homeostatic sleep pressure, with each operating independently of the other (Goel et al., 2013). The interaction between circadian rhythm and homeostatic sleep pressure influences the timing of alertness and sleepiness in relation to waking and sleeping hours (Goel et al., 2013). When these two sleep drivers become offset due to irregular sleep, both drivers continue to work independently which can result in sleepiness during wake hours and alertness during sleep hours (Dijk & Czeisler, 1995; Goel et al., 2013). The misalignment of sleep drivers and wake-sleep hours can make it difficult to fall asleep even when tired after extended periods of wakefulness. When misalignment results in poor sleep quality or inadequate sleep quantity, health and cognitive function can be negatively impacted (Zaki et al., 2020).

B. SHIFTWORK

Different types of shiftwork schedules and rotations are reviewed here.

1. Definition of Shiftwork

Modern society involves round-the-clock operations, production, and services, which elicits the requirement for shiftwork (Department of Health and Human Services [DHHS], 1997). The 2017–2018 American Time Use Survey indicates that 16% of full-time wage earners in the United States have jobs involving shiftwork or non-standard working hours (U.S. Bureau of Labor Statistics, 2019). Shift workers range from police officers, nurses, protective services, international flight crews, machine operators, transportation professionals, industrial workers, food preparation, technical support, and the military. Many shift workers work an alternative schedule because it is a requirement of the job, rather than personal preference (U.S. Bureau of Labor Statistics, 2019). Shiftwork involves working hours that do not align with the standard workday, often considered 8 am to 4 pm (U.S. Congress, Office of Technology Assessment, 1991) or a more generous window of 7 am to 6 pm (DHHS, 1997). Long hours occur when the workweek exceeds 40 hours as established by the Fair Labor Standards Act of 1938 (Department of Labor, 2011).

2. Types of Shiftwork

Within the broad definition of shiftwork, many variations occur with length of shift, shift rotations, and shift frequency. Shift durations often fall between eight and 12 hours; however, shorter and longer shifts are implemented in some sectors of the labor market (Office of Technology Assessment, 1991). Shifts may rotate forward or backward. With forward rotation, work hours shift clockwise from mornings to evenings, and then to nights. Backward rotations occur in the counterclockwise direction from mornings to nights, and then to evenings.

Independent of the rotation direction, shifts may rotate quickly with only 1–3 days on each shift, slowly with 3–4 weeks or more on each shift, or somewhere in between (Office of Technology Assessment, 1991). Shifts may occur on a regular basis, such as daily, or may be infrequent, irregular, or ad hoc. Irregular shifts may be based on a variable schedule such as transoceanic flight schedules or may be additional duty on top of a normal work schedule, whereby the worker primarily works daytime hours during the workweek and then occasional has a night or weekend shift. Less research has been done on irregular shifts as compared to the work done on regular shifts (Harma et al., 2018). Infrequent or ad hoc shift work could occur when a person with a specific expertise is needed to help cover for the normal shift worker who becomes sick or experiences an emergency.

3. Variations in Shift Schedules

Endless scheduling solutions could be created to ensure personnel coverage over the 24-hour day. In some settings, schedules do not shift, and night workers are always night workers, at least for an extended period of six months or more. In the military, slowly rotating watch schedules can be implemented when personnel standing the watch are on deployment, whether based on land or onboard a ship. These types of schedules are conducive to the deployed environment due to the separation from daily family and social obligations, which are generally tied to daylight hours. In non-deployed military watchfloors, however, watch shifts rotate to allow for other duties to be performed during the day, to support social and family needs, and to spread the burden of night work across the watch team. To support this type of schedule, rapidly rotating or slowly rotating shifts are implemented.

C. PROBLEMS ASSOCIATED WITH SLEEP AND SHIFTWORK

When watchfloors engage in shiftwork, the watchstanders are subject to the risks and problems associated with shiftwork. Shiftwork may disrupt the alignment of sleep times with the circadian rhythm. Inadequate sleep and degraded sleep quality can contribute to many health and performance problems (Zaki et al., 2020). Inadequate sleep affects not only the individual worker but also negatively impacts the company or military unit. Decreased sleep quantity and quality, due to shiftwork, can contribute to sleep-related accidents and decreased productivity (Akerstedt, 2003). Accidents can result in equipment damage, personnel injury, and even death. In business, suboptimal productivity decreases the bottom line, and in the military, it degrades mission effectiveness.

1. Poor Sleep on Shiftwork

In a study conducted by Akerstedt et al. (2010), shiftwork was examined through the lens of entering and exiting shift work. The researchers found shiftwork to be associated with difficulty falling asleep during sleep opportunities and challenges staying awake during work hours. Participants entering shiftwork reported increased difficulty falling asleep, and a reversal was reported of decreased difficulty falling asleep when leaving shiftwork. Those entering shiftwork and continuing shiftwork experienced an increased probability of falling asleep during working hours, as compared to those exiting or never participating in shiftwork (Akerstedt et al., 2010).

Shifting to the night shift can make it more difficult to fall asleep and stay asleep during daytime sleep opportunities. Especially during the first night after shifting, the circadian rhythm remains aligned to the previous work and sleep schedule. After shifting to night shift, the first sleep period is often observed to be shorter than a typical night of sleep. Involuntary sleep during the work shift can occur (Akerstedt, 2003). The sleep schedule of night shift workers offsets a worker’s sleep pattern so that he/she is trying to sleep during the period of highest alertness (~4-5 pm) and trying to be alert when sleepiness is greatest (~4-5 am) (Akerstedt, 2003).

2. Health

Shift workers are at higher risks than day workers for health problems related to shifting schedules and reduced quality and quantity of sleep. Overall health is compromised, with increased risk of weight gain, diabetes, stroke, depression, and death (Watson et al., 2015). Potential health problems directly affecting sleep, such as sleep apnea, insomnia, and shift work disorder have been associated with shift work (Rajaratnam et al., 2013). Cardiometabolic diseases and mood disorders occur at higher incidence in shift workers (Rajaratnam et al., 2013).

Health problems associated with inadequate sleep impact not just the individual with poor sleep, but also overall military resilience and readiness. When considering the amount of sleep in relation to resilience, a study found that both short sleep (< 6 hours) and long sleep (>8 hours) predicted lower resilience among military service members (Seelig et al., 2016). When considering the active-duty members of the Millennium Cohort Study, 50.8% of the 29,247 participants reported sleeping six hours per night or less. Sleeping less than six hours per night was predictive of lower self-assessed general health, increase in lost workdays, increased separation from active duty, and increased hospitalization (Seelig et al., 2016). Inadequate sleep over time can impact not just the individual's work quality during shift work, but reduce resilience, readiness, long-term health, and personnel retention.

A health concern directly linked to shiftwork is shiftwork disorder. Symptoms of shiftwork disorder include either extreme sleepiness, insomnia, or in some cases both (Wickwire et al., 2017). Shift work negatively impacts work performance, mood, and quality of life. In some cases, personnel show minimal to no adjustment of circadian rhythm to work schedule (Wickwire et al., 2017). Lack of adaption leads to daily fatigue and sleepiness during work hours and difficulty falling asleep during designated sleep periods. Shift work disorder can have a long-term impact on sleep quality and quantity and require intervention to remedy.

3. Fatigue and Safety

Complete sleep deprivation and sustained shortened sleep periods both result in fatigue. More clinical studies have examined the effects of sleep deprivation; however, shortened sleep results in many of the same fatigue, health, and performance degradations. A week of sleep lasting 4.5 hours per night can result in the same sleepiness as a complete lack of sleep (Akerstedt, 2003). Inadequate sleep has been associated with increased error rates and safety risks.

A safety issue associated with shiftwork is the commute at the end of a night shift. Similar to military personnel, police officers must be available 24/7 and ready to quickly respond to emerging and dynamic situations. This need necessitates working in shifts and requires high performance at all hours of the day. A 2012 study with police officers assessed the effect of working five consecutive night shifts compared to the end of three off-duty days (Waggoner et al., 2012). Participants reported higher levels of sleepiness, exhibited reduced vigilance, increased lane deviations, and several of them crashed in the simulator after working five night shifts (Waggoner et al., 2012). These findings showed how commuting at the end of a night shift can increase safety risk due to increased error rate.

Night work and sleep loss have been observed to impair visual threat detection, i.e., the ability to visually distinguish between an item or situation that presents a threat and one that does not represent a threat. When participants completed a luggage screening task, sleep loss and night work were both correlated to reduced vigilance and accuracy in identifying items that posed a threat, such as a weapon (Basner et al., 2008). When executing the simulation, sleep-deprived personnel had an increased error rate whereby the participants failed to detect the threat object or identified a non-threat object as a threat. These results indicate that sleep deprivation impacts threat detection in an unpredictable fashion, sometimes overstimulating threat perception and at other times, failing to recognize a threat.

Rapidly rotating shifts may lead to fatigue, both on and off duty, and difficulty falling asleep during designated sleep times. Härma et al. conducted a study examining impacts on fatigue, sleep duration, and sleep onset latency when work shifts rotated or increased in intensity for hospital employees (Härma et al., 2018). In this study, participants worked for 3–4 consecutive night shifts. During the period where they worked the night shift, participants reported increased fatigue during the work shift, increased fatigue during days off, and increased challenges falling asleep. Furthermore, quick returns from night to day shift, defined as less than 11 hours off between shifts, corresponded to increased fatigue during work hours, off-hours, and increased sleep onset latency.

By tracking sleepiness across the full shift, Kazemi and colleagues (2016) showed that sleepiness increased throughout the shift for individuals working night shifts, whereas workers on the day shift started sleepy but sleepiness declined as the day progressed. The authors attributed these findings to day shift workers waking early in the morning, cutting short their sleep and causing sleepiness early in the day. Based on their findings, Kazami et al. proposed three mitigation measures to decrease the effects of long shifts, i.e., reducing shift hours, improving lighting during working hours, and allowing naps during long night shifts.

4. Degraded Attention

An important component of many tasks is the ability to maintain attention to perform the task. Attention involves the simultaneous process of selecting the pertinent stimulus or information on which to focus while recognizing and subsequently ignoring distracters (Caputo and Guerra, 1997). An individual's ability to pay attention at a given time can be measured through attention tests, which assess the capability to distinguish between relevant and irrelevant information (Santhi et al., 2007). Sleep deprivation has negative consequences on attention and working memory (Krause et al., 2017). The amount of time awake increases sleep pressure, which then degrades performance on attention-related tasks (Krause et al., 2017).

In a study by Santhi et al. (2007), where participants shifted from four day shifts to three night shifts, a decline in attention, vigilance, and alertness were observed, with personnel experiencing the greatest cognitive degradation during the first night shift. The first night shift revealed cognitive slowing, whereby participants demonstrated slower response times and, in some cases, missed stimuli altogether. This reduced cognitive function, most evident on the first night shift, was further evident in decreased accuracy, degraded sensitivity, and increased frequency of attentional lapses (Santhi et al., 2007). Participants spent less time scanning the data presented but then took longer to decide and were less accurate in their decisions. Even with feedback between trials, participants failed to adjust with feedback, suggesting suboptimal cognitive processing and decision-making (Santhi et al., 2007).

Sleep deprivation negatively affects multiple cognitive functions, to include attention, memory, processing speeds, and reasoning (Lim et al., 2010). The cognitive domain most affected by short-term sleep deprivation, whereby the individual has been deprived one night of sleep, is the area of sustained attention, followed by working memory and executive attention (Lim et al., 2010). Attention and working memory are closely linked and sleep deprivation tends to impact each simultaneously (Krause et al., 2017). When sustained attention is impaired, the ability to monitor and maintain situational awareness decreases, which in turn increases the risk of micro-sleeps and missed cues (Lim et al., 2010). Micro-sleeps pose a safety risk, both during work hours and while commuting home after work.

5. Performance

The literature indicates that both low-level and high-level cognitive skills are negatively impacted by sleep deprivation (Harrison & Horne, 1999). Higher-level cognitive functions most impaired are the ability to think with creativity, innovation, and flexibility. The sleep-deprived individual demonstrates more rigid thinking, degraded capability to integrate new information, and inability to revise plans when faced with a dynamic situation (Harrison & Horne, 1999).

Extensive studies have examined the link between sleep deprivation and performance (Alhola & Polo-Kantola, 2007). Through numerous studies and various cognitive tests, it is well documented that sleep deprivation is associated with deficits in attention, degraded working memory and long-term memory, decreased visuomotor performance, less effective decision making and critical reasoning, and degraded verbal functions (Alhola & Polo-Kantola, 2007).

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In a series of eight cognition tests designed to measure memory retrieval, processing speed, and attention, Markuie et al. (2005) found that shift work can lead to deteriorated memory performance and cognition. The most common type of shift work in the study was rotating shift work where the workers' schedule alternated among the three daily shifts of morning, afternoon, and night (Markuie et al., 2005). Rapidly rotating shifts contribute to suboptimal cognitive performance.

A 2016 study by Kazemi et al. compared sleepiness, cognitive performance, and sleep quality associated with both day and night shift work. The study found that long working shifts, defined as 10 hours and 12 hours, resulted in fatigue and reduced cognitive performance regardless of whether the long shift occurred during the day or at night. By the third night on night shifts, those on 12-hour shifts had a 36% increased risk of error or accident, and those on 10-hour shifts had a 17% increase in risk. Workers at the end of 12-hour shifts, both day and night, demonstrated decreased cognitive performance in the areas of reaction time, working memory, and sustained attention. The decline of sustained attention was more pronounced for those working the night shift (Kazemi et al., 2016).

Killgore et al. (2006) studied the effects of 49.5 hours of sleep deprivation on decision making under uncertainty, using the Iowa Gambling Task (IGT). Participants showed significant changes in their decision making after sleep deprivation, shift from a normal state of learning from poor outcomes to making risky decisions even after experiencing negative feedback. This degradation of high-level cognitive processing and executive function follows the same trajectory as that of a brain-injury patient with lesions in the prefrontal cortex, although the effect is not as drastic (Killgore et al., 2006).

Study results by Killgore et al. (2006) indicate that sleep-deprived individuals experience degraded ability to integrate executive functions, especially cognitive and emotional processing, which are needed to make decisions involving risk and uncertainty. The effects of sleep deprivation on decision making were more pronounced in older participants, with older including participants ages 25–39 as compared to younger participants ages 19–24 (Killgore et al., 2006). The demonstrated increase in risky decision making for older participants is especially concerning in the military context where many mid to senior-level decision makers, including watch captains, watch officers, officers of the day, and command duty officers fall within this age range (E-6 to E-8 and O-2 to O-5).

D. LIGHT

The role of light is considered in more detail here because light is an important external stimulus to maintain circadian rhythm and normal sleep patterns, and regular light exposure is disrupted when engaging in shiftwork and rotation shifts. Studies have shown that light can have either a positive effect on the body's ability to sleep by helping it align to the appropriate circadian rhythm or a negative impact by disrupting circadian rhythm (Chellappa et al., 2013). The circadian rhythm operates on a 24-hour cycle, serving as a master clock for the human body and brain (Reppert & Weaver, 2002). The 24-hour pattern of the circadian rhythm regulates neurobehavioral functions like attention and alertness. It is also one of the body's primary biological sleep drivers (Abe et al., 2014).

Naturally occurring melatonin helps regulate the sleep/wake schedule in humans by modulating the circadian rhythm (Cajochen et al., 2003). Additionally, certain external factors such as light, temperature, meals, and social interaction also help regulate the circadian rhythm (Reppert and Weaver, 2002; Bodenstein et al. 2012; Manoogian and Panda, 2017). High energy visible (HEV) light has the potential to provide this external stimulus to influence the body's circadian rhythm to align to a new shift more quickly (Rimmer et al., 2000). This realignment is also called circadian entrainment. HEV light exposure has been shown to delay melatonin secretion, a contributing factor in maintaining a regular circadian rhythm (Cahochen et al., 2005).

The body's master clock that controls the circadian rhythm resides in the suprachiasmatic nuclei (SCN) (Weaver, 1998). The circadian rhythm is naturally synched to daylight hours through the retina's exposure to light (Reppert & Weaver, 2002). Rautkylä et al. (2012) contend that light influences alertness, not just by suppressing melatonin secretion but also through a limbic pathway. Their research indicates that this limbic pathway provides a mechanism for increased alertness through the exposure to light even during the daytime when melatonin secretion is minimal (Rautkylä et al., 2012).

Beyond just reduction in sleepiness, exposure to bright light has been shown to improve performance and reaction times (Phipps-Nelson et al., 2003). Blue-enriched white light exposure can reduce fatigue and daytime sleepiness, and improve alertness, mood, sleep quality, sleep duration, and performance (Viola et al., 2008). Lower mental effort and reduced discomfort, including headache and eyestrain, along with increased energy, concentration, and clear thinking have also been associated with strategic application of light (Viola et al., 2008).

1. Spectral-Enriched Light

Multiple studies have looked at the impact of spectrally enriched lights to gain insight into the impact of light color on melatonin suppression and circadian phase shifts. The color of light, also known as the color temperature, is measured in degrees Kelvin (K) and ranges from warm light (below 3,000 K) that appears more red, neutral or natural light (between 3,000 to 5,000 K) that appears white, and cool light (above 5,000 K) that appears more blue. As a reference, a typical household light bulb measures between 2,000 and 3,000 K, and a garage, workspace, or security light typically resides in the 3,000 to 6,000 K range. Various hypotheses propose that blue-enriched light has a greater impact on melatonin suppression and phase shifting.

Absent natural sunlight in the most extreme light conditions during Antarctic winter, absent natural sunlight, participants used white lights (5,000 K) and blue-enriched lights (17,000 K) for several weeks, to compare circadian phase and sleep attributes associated with each type of light exposure (Mottram et al., 2010). Compared to white light, exposure to blue light was associated with an additional decrease in sleep onset of 19 minutes whereas the circadian phase shifted to the left by 45 minutes. Total sleep time, sleep quality, and wake time were not significantly different between white and blue-enriched light (Mottram et al., 2010). These results indicate that blue-enriched light might have increased benefit to phase-shifting compared to white light.

2. Bright versus Dim Light

Studies have considered the differences between bright light and dim light exposure. Light brightness is measured in lumens, or luminous flux. When brightness of light is considered in relation to the space the light illuminates, the measurement is reported as lux. In a study by Phipps-Nelson et al. (2003), daytime bright light (1,000 lux) exposure reduces afternoon sleepiness compared to dim light (<5 lux) exposure during the same period. Beyond just reduction in sleepiness, participants exposed to bright light improved performance, measured by reaction times. These improvements became significant after one hour of bright light exposure compared to dim light exposure during that same period (Phipps-Nelson et al., 2003).

Zeitzer et al. (2000) found that late evening bright light exposure impacted melatonin and circadian entrainment. When bright light was administered between 11 pm and 5:30 am, the study found that melatonin was almost completely suppressed, with observed suppression rates over 90% when light brightness exceeded 200 lux. The greatest impact on melatonin suppression occurred when light brightness exceeded 200 lux and the observed phase shift was longest when light brightness exceeded 550 lux. Phase resetting was observed as dose-dependent, with higher brightness associated with greater phase shift. According to the model developed in the study, normal indoor room light of 80–160 lux produces a phase shift of half what is obtainable through 6.5 hours of bright light, with a phase shift around one and a half hours compared to a potential phase shift of three hours with bright light exposure (Zeitzer et al., 2000).

3. Intermittent Light

Intermittent bright light exposure, in contrast to continuous light, may have a similar capacity to entrain the circadian rhythm. A study by Rimmer et al. (2000) showed a non-linear relationship between the amount of bright light exposure and the number of phase advances observed in the participants. The study considered bright light exposure at different intervals and found that the benefit of light exposure exceeds the proportional amount of time: when exposed to bright light for 31% of the time, compared to full exposure, the resetting response was 70% and when exposed to bright light for 63% of the time, the resetting response was 90%. These results suggest that there is a disproportional increase in phase resetting of the circadian rhythm during the initial minutes of exposure to bright light (Rimmer et al., 2000).

4. Filtering Light

Night shift work disrupts sleep not only while on night shift but also after returning to day shift. Filtering light during working hours has been shown to provide some improvement in sleep quantity and quality. By filtering visual short wavelengths less than 480nm for nurses working on the night shift, Rahman et al. (2013) observed an improvement in sleep length and efficiency. Furthermore, they found that not only was daytime sleep disrupted when working on the night shift, but even after returning to day shift or non-workdays, nighttime sleep remained disrupted. Of note, mean total sleep time increased by 40 minutes with the introduction of the short wavelength filtering, compared to no light filtering. Participants also experienced reduced sleep onset latency and fewer awakenings during sleep (Rahman et al., 2013).

E. CIRCADIAN PHASE-SHIFTING

The timing of light exposure impacts the direction of circadian phase-shifting. When a light stimulus occurs in the evening or early night hours, a delayed phase shift occurs where circadian rhythm is shifted later; and conversely, when light is applied in the early morning hours, the circadian phase shift advances meaning it shifts earlier (Duffy et al., 2009). When intentionally exposing shift workers to light when rotating between shifts, it is important to understand how the time of light exposure impacts circadian phase-shifting. Light exposure alone, without considering timing, is not guaranteed to be beneficial. In fact, if light exposure occurs at the wrong time, it could have the opposite effect intended and contribute to phase-shifting in the opposite direction.

When work hours and sleep opportunities do not align with daylight and nighttime respectively, as experienced by shift workers, deliberate exposure to bright light has the potential to reset the circadian rhythm (Rimmer et al., 2000). To ameliorate the negative effects of shift work, rapidly rotating schedules, and associated sleep deprivation, the timing of external cues may be intentionally modified to support circadian alignment to the required wake/work hours. Aligning more quickly to shifting work hours could result in decreased sleep deprivation, improved sleep quality, decreased fatigue, and reductions in the negative impact on cognitive function.

Light exposure has the potential to assist with not just minor phase shifts such as the daily circadian entrainment for a person's natural cycle that exceeds or falls short of the 24-hour day, but to assist with larger phase shifts as desired when traveling across time zones or shifting to a different work shift. In an early study of phase shifting through deliberate application of light conducted in 1986, an individual with a misaligned circadian clock was realigned by six hours in just two days of deliberate evening light exposure (Duffy & Czeisler, 2009). Another study indicated a phase shift of 0.41 hours for each hour of deliberate light, up to four hours of exposure (Chang et al., 2012).

F. SHIFTWORK MITIGATIONS

Shiftwork mitigations provide potential measures for watchfloors and watchstanders, to reduce the impact of shiftwork on sleep and the associated problems with poor sleep previously discussed.

1. Scheduling

When 24/7 shiftwork is required, there are best practices that have been identified for designing and implementing the supporting watch schedule. James Miller developed a manual for the Air Force Inspector General and Air Staff, highlighting nine components and nine principles of shift work scheduling (Miller, 2008). These components and principles are designed to consider the elements of shift work schedule development and incorporate biological human needs to sleep and perform, as well as social needs. He recommends incorporating these factors and best practices into watch schedules that include shift rotations.

Table 1. Nine components of shiftwork scheduling. Adapted from Miller (2008).

	Component	Description
People Components	Number of crews	The number of crews determines the number of hours worked per year, and the average number of hours worked per week by each shift worker. Four sections provide the optimal balance between demands on the worker and cost to the employer.
	Employment ratio	Staff strength must be greater than the day-to-day demand to accommodate leave, sickness, training, administrative time, or other unforeseen circumstance that disrupts the normal ratio. Maintain a ratio from 1:1.15 to 1:1.35 depending on the frequency of alternative schedule demands.
Time Components	Shift type	Shifts may be fixed or rotating. Shifts may rotate forward (clockwise) or backward (counterclockwise).
	Shift length	Shift lengths tend to occur in even factors of the 24-hour day (2, 4, 6, 8, 12, or 24 hours). Shift overlap for turnover should be considered.
Structural Components	Shift system	The ratio of nominal workdays to nominal free days determines the shift system.
	Shift plan	The shift plan is composed of the sequence of workdays, specified by shift, and days off.
Interaction Components	Shift differentials	Shift differentials refer to the pay rate differences between day and night shift work. This may be balanced out by rotating through different shift times.
	Alignment of workdays and days off with weekends	The way that the shift plan aligns with the weekend determines the number of weekend days off.
	Shift change times	The morning shift turnover time impacts the number of shift workers allowed to sleep during night hours.

Table 2. Nine principles of shiftwork scheduling. Adapted from Miller (2008).

Principle	Description	Recommendations
Circadian stability	Working at the same time each day creates conditions for the greatest stability in circadian rhythm. Working between midnight and dawn disrupts the circadian rhythm.	Work exclusively night shift and try to shift circadian rhythm. Otherwise, limit night work to a maximum of three consecutive nights, followed by good-quality sleep for at least three nights.
Short shift length	Shift lengths of eight hours are preferred over 12-hour shifts. Risk increases exponentially and vigilance declines between hour eight and hour 12 of a shift.	Twelve-hour shifts should be limited to jobs with low physical requirements, minimal emotional work stress, and limited need for vigilance.
Minimum consecutive night shifts	Minimize consecutive night shifts. A single night shift in the shift plan is preferred.	Safety risk increases by a factor of 2.5 on successive night shifts compared to successive day shifts. By the fourth night, risk has increased an additional 36%.
24 hours of off time after each night shift	The day following a night watch is spent sleeping or being sleepy. Personnel is at higher risk of automobile accidents during this time.	The day that a shift worker finishes a night watch should not be considered a free day or quality day off. This period is for recovery and repaying the sleep debt gained from night work.
Maximum number of free days on weekends	Personnel often value the number of free weekend days.	Workers may pressure to shift to 12-hour weekend shifts to increase weekend days off, but this should be balanced with the increased risk of on-the-job errors and safety commuting at the end of a shift.
At least 104 days off per year	Shift workers should have at least 104 days off per year, which is the equivalent of a weekday worker having 52	Shift workers should have more days off per year to ensure quality days off and to balance additional strains and stressors placed on shift workers. Days that a worker

Principle	Description	Recommendations
	weekends off (for a total of 104 days).	gets off the night shift should not be considered as a quality day off.
Equity	Schedules should distribute the burden of long hours, night work, and weekend work among shift workers.	Planned schedules, with minimal last-minute changes, and consideration of weekends will provide the most equity.
Predictability	Simple schedules with a clear cycle allow workers to predict their workdays and days off well into the future.	The ability to understand and predict the work schedule and days off well into the future contributes to worker morale. The administrative burden is also reduced with a simple, clear schedule rotation.
Good quality of time off	Quality time off is a priority for most shift workers. The number of weekend days and number of consecutive days off contribute to the quality of time off.	Quality time off must be balanced with risk and safety concerns that can arise with longer shifts designed to consolidate workdays.

The morning shift change time impacts the hours of night sleep available to the day shift. In a study of morning shift change times, evidence indicated that early wake-up times, around 4–5 am, lead to decreased sleep duration the night before and increased sleepiness on shift (Akerstedt, 2003). Shift change would better support sleep with a morning turnover of 0700 instead of the traditional 0600. For the first night on the night shift, a nap during the shift could significantly decrease the drop in alertness in the early morning. Such a nap should last 0.5-2 hours with a 5–15min wake-up period to combat sleep inertia to regain alertness (Akerstedt, 2003).

Aligning shift schedules so that the worker can sleep at the same time each day can improve sleep quality and quantity. In a study of six different watch rotations onboard Canadian Naval ships, the authors observed the best cognitive performance when standing eight hours of continuous watch at the same time each day (Paul & Love, 2021). When 12-hours of watch coverage was required, the watch schedule with the second-best resulting performance included an 8–4-4-8 schedule in which watchstanders worked for eight hours, had four hours off, stood watch for another four hours, and then had eight hours off (Paul & Love, 2021). Both watch rotations provide a sleep opportunity of at least seven hours at the same time each day, assuming that the eight-hour period off watch is protected sleep time.

Forward rotating shifts can be employed to avoid quickly returning to day shift from night shift (Harma et al., 2018). Forward rotations, especially if combined with days off, allow for more time to transition between work shifts. This time to transition allows the circadian rhythm to stabilize.

2. Related Studies

Civilian shiftwork studies often focus on careers like commercial aviation and medical fields. The Crew Endurance Team at the Naval Postgraduate School has conducted many military sleep studies and studies comparing watch schedules with various rotations. A majority of these studies are in the operational environment, including sailors on naval ships, aircrew, ground troops, and security details (Shattuck et al., 2018). Several of the studies have involved military education and training, but few have specifically addressed military shore-based watchfloors.

Military shore-based watchfloors differ from these other studies in several ways. They are unlike ships and aircraft in that the environments are significantly different. They often differ from deployed situations because watchstanders have competing demands and social obligations that differ from deployment. Furthermore, military shore-based watch floors often involve long periods of sitting, monitoring computer screens, and constantly assessing the situation. Shore-based watchstanders must employ both low-level cognition through alertness and vigilance, and also higher-level cognition by making decisions, and employing critical reasoning, innovation, and creativity at a moment's notice.

A study of the White House Military Office President's Emergency Operations Center contains some similarities and applicability (Shattuck et al., 2015). In their original schedule rotation, watchstanders stood 12-hour shifts for 2–3 days and then had 2–3 days off, with a shift from days to nights or nights to days every two weeks. With the new schedule studied, watchstanders stood watch for 24-hours with three days off in between. During that 24-hour period, watchstanders would sleep for five hours, either 1700–2400 or 0000–0500. By sleeping during the work period, participants were able to better maintain their circadian rhythm and cause fewer sleep disruptions. Study participants reported feeling better rested, more productive, improved sleep quality, and improved quality of life (Shattuck et al., 2015).

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III. METHODS

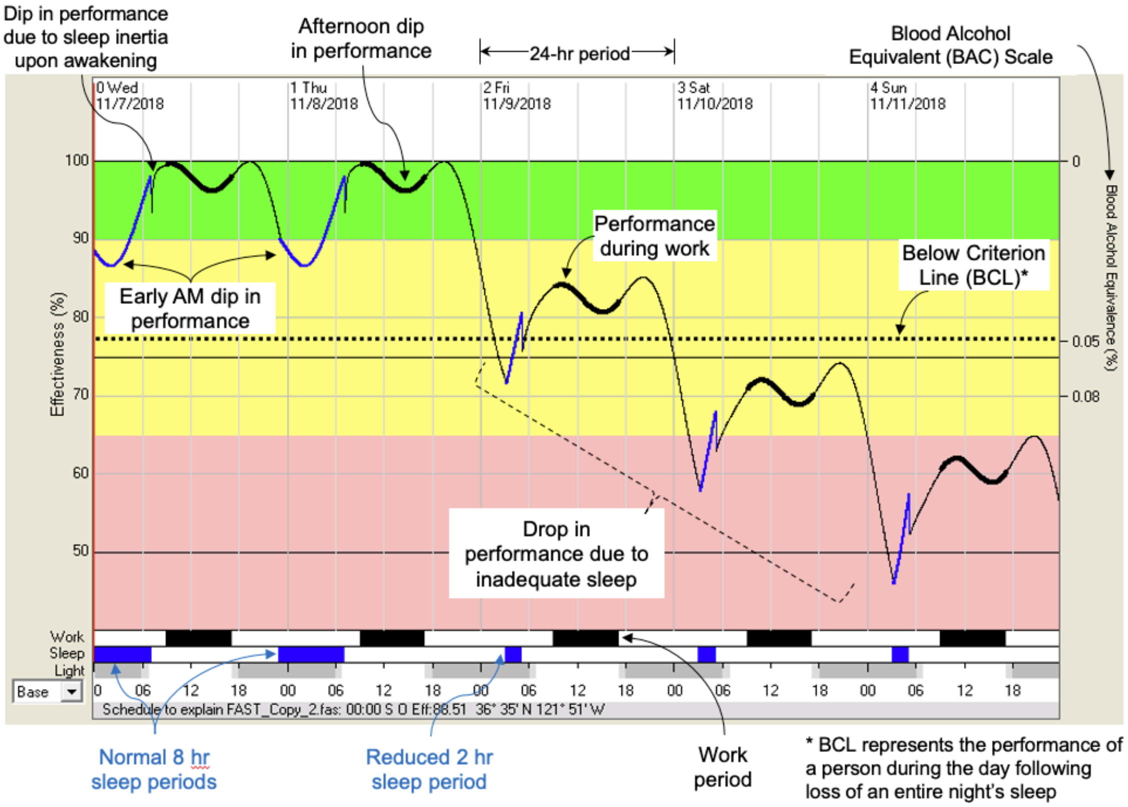
A. OVERVIEW

Focusing on watchstanders working in a shore-based watchfloor, this study was initially designed to have three phases. The first phase would include the evaluation of the watch schedule the watchstanders were working on using a validated model and developing an improved watch schedule. The second phase would include collecting data from the watchstanders when working on their typical watch schedule. The third phase would include collecting data when watchstanders worked on and the improved watch schedule combined with a light exposure intervention. Due to delays with obtaining security approval for a wearable sleep tracking device, the third phase of the study, whereby the improved schedule and/or intervention would be implemented, was delayed until approvals were obtained. Therefore, the study described herein is focused on the first and second phases of the initially envisioned plan. First, we describe the modeling of sleep-wake schedules for watchstanders working in the shore-based watchfloor. Based on the watch rotation schedule and feedback provided by the command leadership, a nominal sleep/work/commute daily schedule was developed for initial modeling analysis. To improve the fidelity of the model, the first phase of collection involved watchstanders self-reporting their work and sleep hours associated with the watch rotation.

B. SCHEDULE MODELING

1. The Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) Model

The Fatigue Avoidance Scheduling Tool (FAST) version 3.3.01T, employing the Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model, is used to gain insight into how a sleep schedule impacts personnel predicted effectiveness. FAST is a Microsoft-based software, developed by Science Applications International Corp (SAIC) and National Telecommuting Institute (NTI) through small business innovation research (SBIR) (Hursh et al., 2004a). FAST allows a user to input sleep and waking hours over a period of days, weeks, or even months. FAST displays the time, sleep hours, work hours, predicted effectiveness, and blood alcohol equivalent (BAC) scale over the chosen time period, as shown in Figure 1.



Source: N. Shattuck and P. Matsangas, PowerPoint slides, March 4, 2021.

Figure 1. FAST output display description.

The FAST software uses the SAFTE model, invented by Dr. Steven Hursh and colleagues, and validated through scientific review and research studies (Hursh et al., 2004a, 2004b). The Department of Defense (DOD) has accepted the SAFTE model as the most complete and accurate model for studying sleep schedules and predicted effectiveness (Hursh et al., 2004a). Figure 2 depicts the contributing components to the algorithm employed in the SAFTE model.

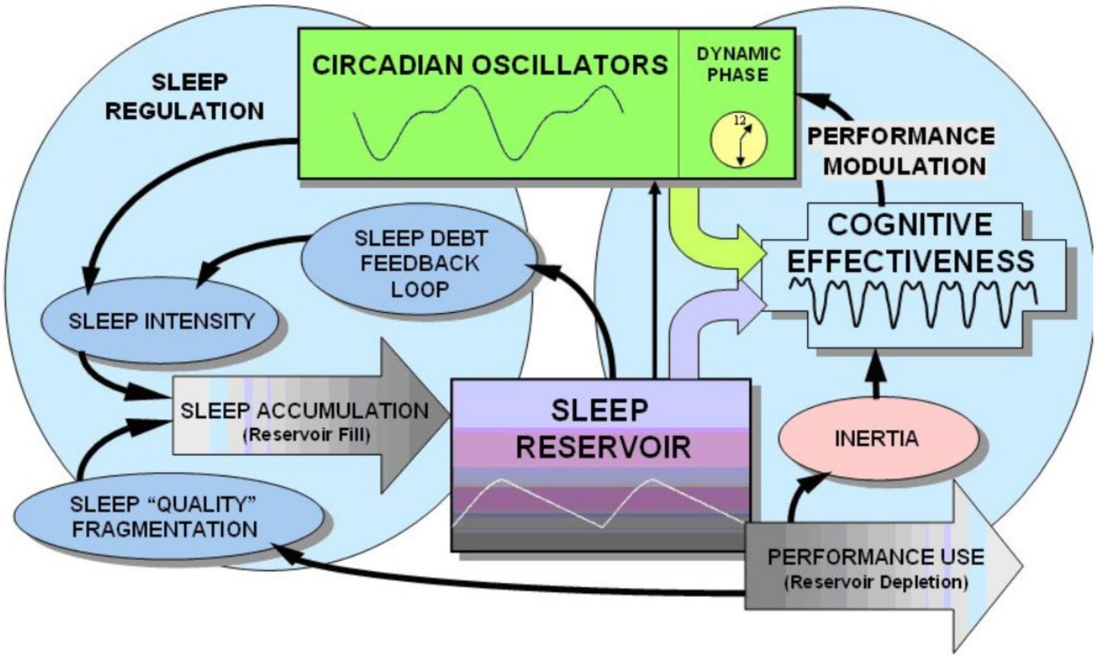


Figure 2. Sleep, activity, fatigue and task effectiveness (SAFTE) model conceptual diagram. Source: Fatigue Science (2009).

The performance effectiveness predicted by the SAFTE model has been validated against laboratory studies to accurately represent degradation in cognitive performance (Hursh et al., 2004a). When predicted effectiveness fluctuates, the components of cognitive performance are also projected to be impacted, i.e., discernment, speed of reaction, mental processing capacity, cognitive reasoning, and language skills (Hursh et al., 2004a).

The SAFTE model can serve as a proxy for laboratory data to predict how shiftwork and changing sleep hours impact performance. To more accurately represent how sleep and performance are impacted by shiftwork, the SAFTE model considers the circadian process, adjustments to the circadian phase, duration of sleep, sleep propensity, sleep intensity, accumulated sleep debt, equilibrium states, and sleep timing (Hursh et al., 2004a, 2004b). Sleep propensity and sleep intensity are determined by the alignment, or misalignment, of sleep hours with the circadian rhythm (Hursh et al., 2004a). While the model does allow the circadian rhythm to shift when sleep hours shift, the model implements the phase shift over time. For each day of degraded sleep, the model increases the accumulated sleep debt until an equilibrium is reached, which in turn has a negative effect on predicted effectiveness (Hursh et al., 2004a). The inclusion of equilibrium states in the model incorporates the concept that sleep deficits cause sleep debt to accumulate. By the seventh day of consistent sleep deficit, sleep debt reaches an equilibrium in the model (Hursh et al., 2004a). Though this equilibrium is well below baseline, it will persist until another sleep characteristic changes.

The SAFTE model accounts for circadian rhythm and homeostatic sleep pressure. Adjustments to new sleep hours, such as changing to a new shift, are included in the model's calculations of cognitive effectiveness (Hursh et al., 2004a). The sleep reservoir accounts for the duration of sleep, sleep quality, sleep intensity, and accumulated sleep dept enables the model output to reflect the impact of accumulated sleep characteristics over time (Hursh et al., 2004a, 2004b).

Three attributes are used to compare predicted performance between different schedule rotations, including predicted effectiveness, lowest predicted effectiveness, and shift time spent below the criterion line (BCL). The criterion line is set to 77.5% effectiveness, which is the effectiveness percentage that represents the performance of a person during the day following loss of an entire night's sleep (Fatigue Science, 2009). Therefore, the percentage of time an individual spends below the criterion line indicates the percentage of a given shift where an individual's performance is predicted to be equivalent to, or worse than, an individual who has lost a night of sleep.

Predicted effectiveness is the average effectiveness for all work hours during a specified shift. For example, a predicted effectiveness of 80% for day shift means that the average predicted effectiveness for all day shift work hours, during the time period represented, is 80%. The lowest predicted effectiveness is the lowest value that the effectiveness dips to on a specified shift during the period of interest. Using the day shift example, a value of 60% for lowest predicted effectiveness means that the lowest dip in effectiveness during day shifts is 60%. The shift time spent below the criterion line conveys what percentage of a work shift is below the criterion line. A value of 5% indicates that of all the time on day shift during the time period examined, 5% is spent below the criterion line and 95% is spent above the criterion line. These values are calculated for each shift to help identify which shifts may be more problematic for effectiveness. These values also help with predicted effectiveness comparison among different shift rotation schedules. While these values are useful for comparison, they do not provide enough information to understand all the attributes of a schedule rotation. The full graph, which displays the predicted effectiveness for the entire period of interest, is considered and analyzed for a more thorough understanding of the watchbill decisions.

2. Procedures

To understand the current state of the watch schedule, the Nimitz Operational Intelligence Center provided the watch schedule for their 24/7 Global Maritime Watch. Twenty-five watchstanders are broken up into five watch sections that ensure coverage of the Global Maritime Watch 24/7/365. These watchstanders work on the watchfloor within the same watch section for one year before moving on to another role within the command.

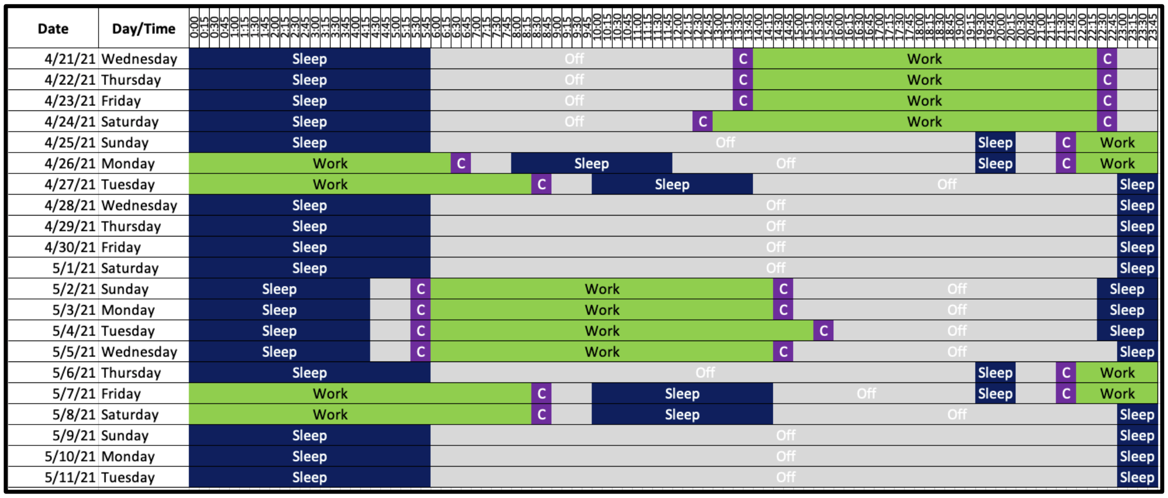
While deployed and underway on a Navy ship, it is common for watchstanders to work a fixed shift. For example, personnel who work the night shift could work that shift for the full duration of the deployment. On a shore-based watchfloor, this option is much less desirable due to the other demands on the watchstanders. Both work and social demands make fixed watches untenable. Personnel needs to be able to attend to medical, pay, and other administrative issues that contribute to not only personal wellbeing but also command and naval readiness. Furthermore, many have family and other social obligations that make permanent night shift work infeasible. Competing demands and constraints have contributed to the selection of a rotating schedule rather than a fixed schedule.

3. Current Schedule Model

The Global Maritime Watch currently operates with a 20-day cycle that rotates watchstanders through the day, swing, and mid shifts. During this cycle, watchstanders have four day shifts, four swing shifts, four mid shifts, six days off, and two days where the mid shift ends. Day shift hours are 0630 to 1430, swing hours are 1430 to 2230, and mid shift hours are 2230 to 0630. Shift turnover is conducted 30 minutes preceding the beginning of a shift, so that watchstanders begin working at 0600, 1400, and 2200 for the day, swing, and mid shifts respectively. In addition to normal shift hours, a weekday brief is held at 0730 on weekdays. The off-going mid shift watchstanders present this brief to command leadership on Mondays, Wednesdays, and Fridays and internally to the watch team on Tuesdays and Thursdays. This brief and the subsequent debrief take approximately one hour, extending the working hours of the mid shift to 0830 on weekdays.

The only additional work obligation for watchstanders is two added administrative hours during the 20-day cycle. Administrative time is added to the work schedule in one-hour increments, once at the conclusion of a day shift extending work hours to 1530, and once at the beginning a swing shift commencing work hours at 1300 that day. The administrative hours are built in to accomplish training or other administrative requirements. Additional duties and work are minimized for watchstanders. Extenuating circumstances that take watchstanders off the watch, such as an emergency, sickness, or leave, are covered by personnel from another division. Watch section cohesion is maintained and personnel from alternate sections are not recruited to cover watches for an absent watchstander.

For initial performance analysis, the work-sleep schedule was input into the SAFTE model using FAST software. The schedule was verified with the watchstanders on the unit. The work-sleep schedule includes a commute of 30 minutes, which was the average reported commute from the watchstanders. The schedule ensures at least one hour between waking time and commute time. The schedule includes six hours of good sleep per 24-hour period on workdays and seven hours of good sleep on days off. For the days surrounding the mid shift, the sleep time modeled is reduced to five hours and split into two nap periods. Watchstanders reported less sleep on these days, with naps of 2–4 hours, and attempted immediate return to normal night sleep hours once off the mid shift. Apart from days surrounding mid shifts, napping is minimized in the modeled sleep-wake schedule. Figure 3 depicts the nominal sleep and work schedule associated with the current rotation schedule.



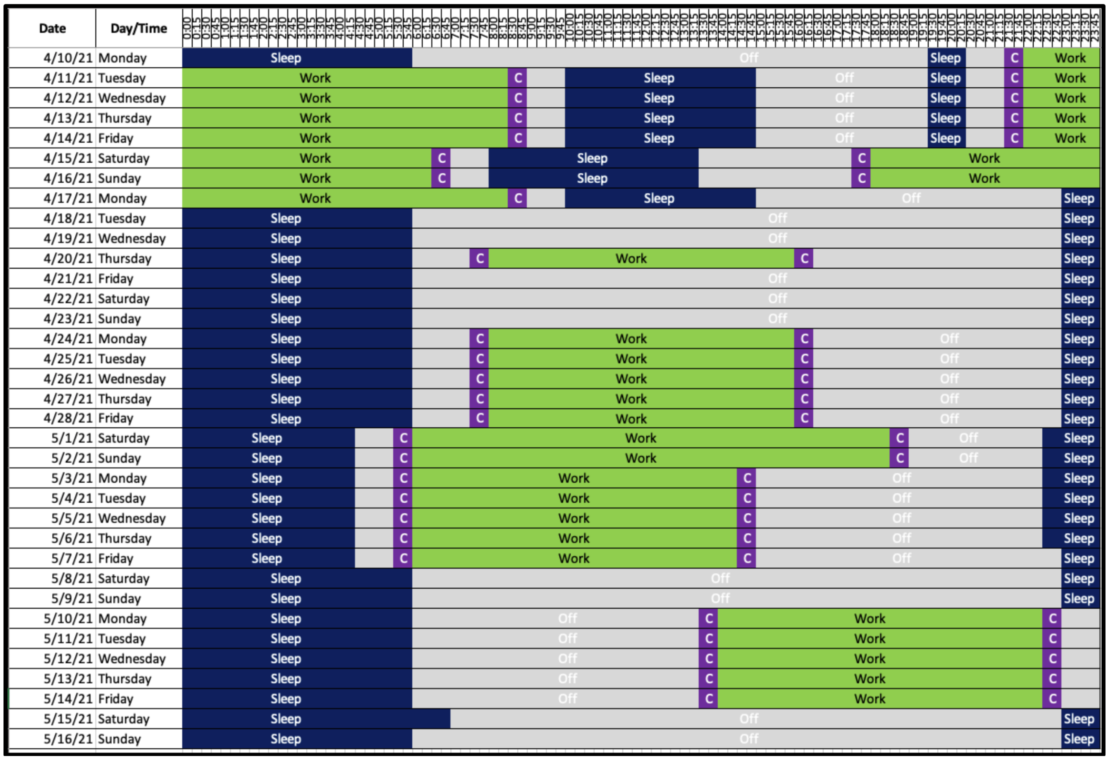
Date	Day/Time							
4/21/21	Wednesday	Sleep	Off	C	Work	C		
4/22/21	Thursday	Sleep	Off	C	Work	C		
4/23/21	Friday	Sleep	Off	C	Work	C		
4/24/21	Saturday	Sleep	Off	C	Work	C		
4/25/21	Sunday	Sleep	Off	Sleep	C	Work		
4/26/21	Monday	Work	C	Sleep	Off	Sleep	C	Work
4/27/21	Tuesday	Work	C	Sleep	Off	Sleep		
4/28/21	Wednesday	Sleep	Off	Sleep				
4/29/21	Thursday	Sleep	Off	Sleep				
4/30/21	Friday	Sleep	Off	Sleep				
5/1/21	Saturday	Sleep	Off	Sleep				
5/2/21	Sunday	Sleep	C	Work	C	Off	Sleep	
5/3/21	Monday	Sleep	C	Work	C	Off	Sleep	
5/4/21	Tuesday	Sleep	C	Work	C	Off	Sleep	
5/5/21	Wednesday	Sleep	C	Work	C	Off	Sleep	
5/6/21	Thursday	Sleep	Off	Sleep	C	Work		
5/7/21	Friday	Work	C	Sleep	Off	Sleep	C	Work
5/8/21	Saturday	Work	C	Sleep	Off	Sleep		
5/9/21	Sunday	Sleep	Off	Sleep				
5/10/21	Monday	Sleep	Off	Sleep				
5/11/21	Tuesday	Sleep	Off	Sleep				

Figure 3. Nominal sleep/work schedule for the current rotation

4. Proposed Schedule Models

The Global Maritime Watch provided two additional watch rotation schedules that they are considering. In addition to the current rotation schedule, these two schedules are also modeled using the SAFTE model. For clarity, they are referred to as proposed schedule one and proposed schedule two. The proposed schedules both maintain five self-contained watch sections that rotate through the same cycle. Both of the proposed rotations have a 35-day cycle, nearly twice as long as the current 20-day cycle. Shift hours, turnover time, and weekday briefs all remain the same as the current schedule. The proposed schedules remove the two administrative hours per month and instead include administrative days. These administrative days are intended to allow more flexibility for watchstanders to take leave and attend training for career progression. The administrative days are modeled with more standard work hours of 0800 to 1600. Sleep is modeled as seven hours of good sleep on days off and administrative days, six hours of good sleep on the day and swing shifts workdays, and five hours of sleep split into two nap periods on the mid shift workdays.

Both proposed schedules extend shift length on the weekends to 12 hours. By incorporating 12-hour shifts on the weekends, weekend work hours are consolidated and watchstanders are required to work fewer weekend days, enabling more free weekend days off. The modified 12-hour shifts are 0630–1830 for the day shift and 1830–0630 for the night shift. Because the night shift presents the Monday morning brief, the Sunday night shift hours are 1830 to 0830 the following morning. The nominal sleep and work hours for proposed schedules one and two are depicted in Figure 4 and Figure 5.



Date	Day/Time							
4/10/21	Monday	Sleep	Off	Sleep	C	Work		
4/11/21	Tuesday	Work	C	Sleep	Off	Sleep	C	Work
4/12/21	Wednesday	Work	C	Sleep	Off	Sleep	C	Work
4/13/21	Thursday	Work	C	Sleep	Off	Sleep	C	Work
4/14/21	Friday	Work	C	Sleep	Off	Sleep	C	Work
4/15/21	Saturday	Work	C	Sleep	C	Work		
4/16/21	Sunday	Work	C	Sleep	C	Work		
4/17/21	Monday	Work	C	Sleep	Off	Sleep		
4/18/21	Tuesday	Sleep	Off	Sleep				
4/19/21	Wednesday	Sleep	Off	Sleep				
4/20/21	Thursday	Sleep	C	Work	C	Sleep		
4/21/21	Friday	Sleep	Off	Sleep				
4/22/21	Saturday	Sleep	Off	Sleep				
4/23/21	Sunday	Sleep	Off	Sleep				
4/24/21	Monday	Sleep	C	Work	C	Off	Sleep	
4/25/21	Tuesday	Sleep	C	Work	C	Off	Sleep	
4/26/21	Wednesday	Sleep	C	Work	C	Off	Sleep	
4/27/21	Thursday	Sleep	C	Work	C	Off	Sleep	
4/28/21	Friday	Sleep	C	Work	C	Off	Sleep	
5/1/21	Saturday	Sleep	C	Work	C	Off	Sleep	
5/2/21	Sunday	Sleep	C	Work	C	Off	Sleep	
5/3/21	Monday	Sleep	C	Work	C	Off	Sleep	
5/4/21	Tuesday	Sleep	C	Work	C	Off	Sleep	
5/5/21	Wednesday	Sleep	C	Work	C	Off	Sleep	
5/6/21	Thursday	Sleep	C	Work	C	Off	Sleep	
5/7/21	Friday	Sleep	C	Work	C	Off	Sleep	
5/8/21	Saturday	Sleep	Off	Sleep				
5/9/21	Sunday	Sleep	Off	Sleep				
5/10/21	Monday	Sleep	Off	C	Work	C		
5/11/21	Tuesday	Sleep	Off	C	Work	C		
5/12/21	Wednesday	Sleep	Off	C	Work	C		
5/13/21	Thursday	Sleep	Off	C	Work	C		
5/14/21	Friday	Sleep	Off	C	Work	C		
5/15/21	Saturday	Sleep	Off	Sleep				
5/16/21	Sunday	Sleep	Off	Sleep				

Figure 4. Nominal sleep and work schedule for proposed schedule one

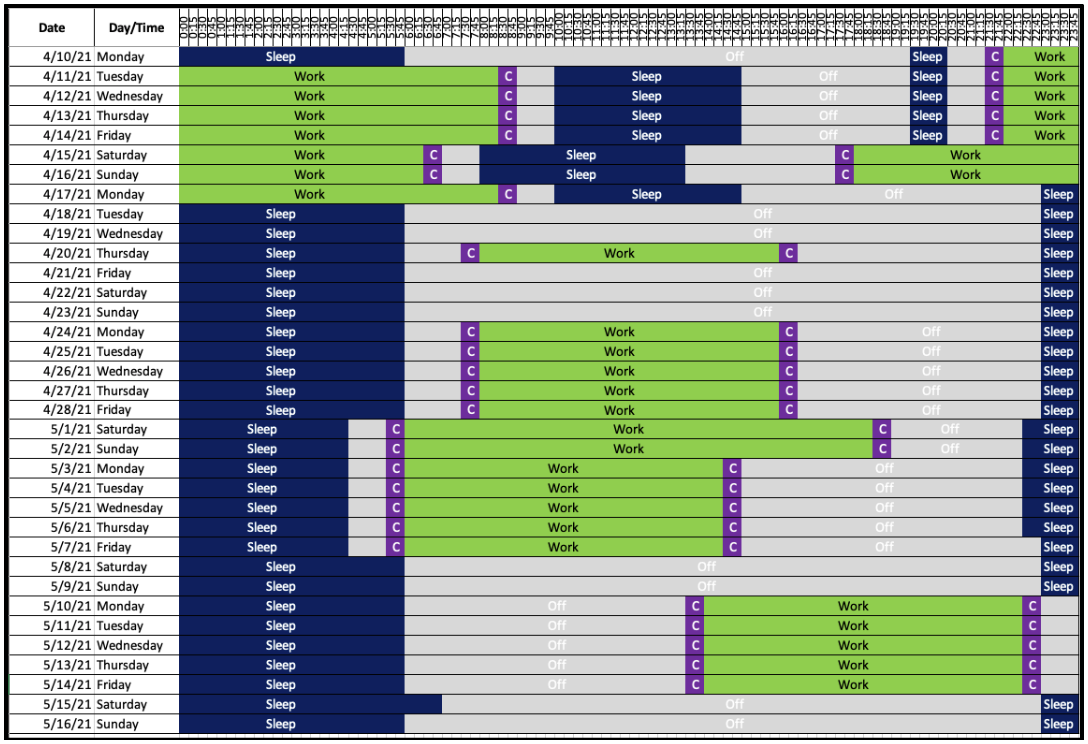


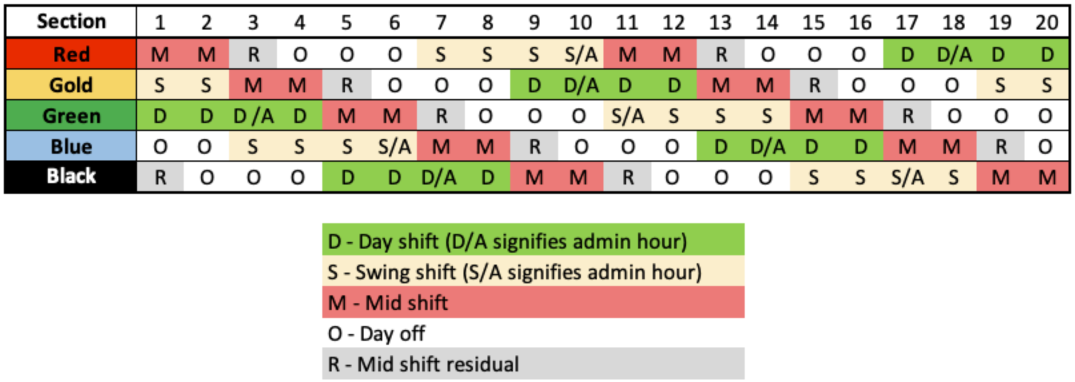
Figure 5. Nominal sleep and work schedule for proposed schedule two

C. DATA COLLECTION

1. Participants

Watchstanders from the Office of Naval Intelligence Global Maritime Watch participated in this research study. Requirements to participate include current assignment to the Global Maritime Watch schedule and active-duty military status. A recruitment brief solicited participation from all 25 current Global Maritime Watch watchstanders. Of the 25 watchstanders, 14 volunteered to participate in the study. Eleven (44%) completed the consent form, pre-study questionnaire, and documented daily activity during the study period.

Personnel participated from the five duty sections of the Global Maritime Watch. Although they work on the watchfloor at different hours each day, the 20-day watch cycle is the same for all five watch sections. Each watch section is at a different point in the cycle on any given day. By collecting for three weeks, each watch section rotates through a complete rotation cycle during the collection period. An example of the watch sections and where they are in a cycle is depicted in Figure 6.



Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Red	M	M	R	O	O	O	S	S	S	S/A	M	M	R	O	O	O	D	D/A	D	D
Gold	S	S	M	M	R	O	O	O	D	D/A	D	D	M	M	R	O	O	O	S	S
Green	D	D	D /A	D	M	M	R	O	O	O	S/A	S	S	S	M	M	R	O	O	O
Blue	O	O	S	S	S	S/A	M	M	R	O	O	O	D	D/A	D	D	M	M	R	O
Black	R	O	O	O	D	D	D/A	D	M	M	R	O	O	O	S	S	S/A	S	M	M

D - Day shift (D/A signifies admin hour)
S - Swing shift (S/A signifies admin hour)
M - Mid shift
O - Day off
R - Mid shift residual

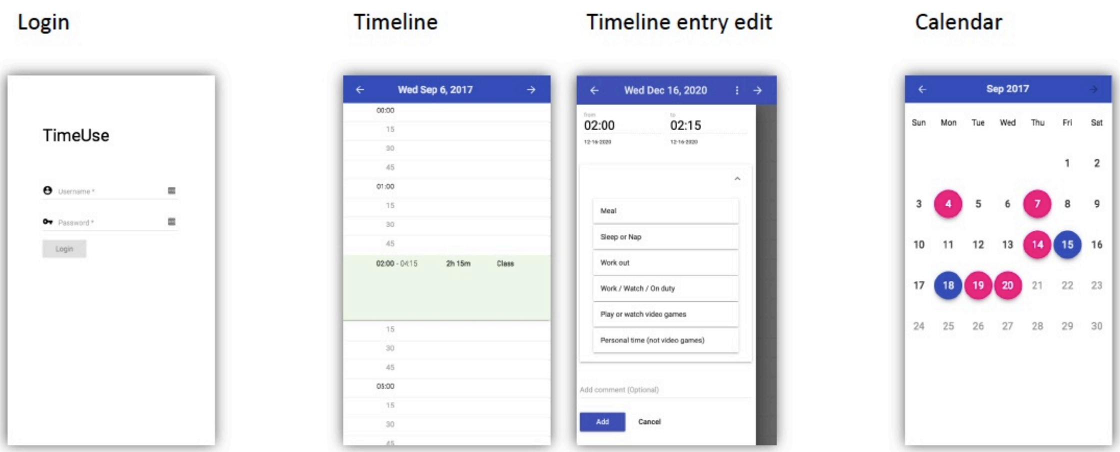
Figure 6. Current Global Maritime Watch schedule rotation for the five-section watch schedule

2. Tools

a. Sleep and Activity Logs

Participants were asked to self-report their work schedule and sleep obtained during the collection period. These logs include hours of sleep, work, and commuting. Participants completed the daily activity log electronically through the TimeUse application, on either a desktop or mobile device. Each day of the study, participants logged into the TimeUse application and documented their daily activities in 15-minute increments. Participants were provided unique user login accounts to the TimeUse application, which facilitated user documentation of their activities.

The categories of activity documented include "Sleep or Nap," "Work / Watch / On duty," and commuting hours. As shown in the Appendix, the TimeUse application instructions, participants could select their activities associated with each 15-minute increment of the day. Due to limitations in the TimeUse application at the time of collection, the options did not include commuting, so participants were asked to select "Play or watch video games" to document time commuting to and from work. Participants were not required to keep track of any of the other options provided in the application, such as meals, workouts, or personal time. Figure 7 depicts the TimeUse application screens displayed to the user.



Login

Timeline

Timeline entry edit

Calendar

Source: TimeUse application subject interface guide, March 17, 2021.

Figure 7. TimeUse application user screens for tracking daily activity.

b. *Questionnaires*

Participants completed questionnaires at the beginning of the study and at the end of the collection period. In addition to a demographics questionnaire at the study onset, participants completed the Pittsburgh Sleep Quality Index (PSQI), the Epworth Sleepiness Scale (ESS), the Insomnia Severity Index (ISI), and the Profile of Mood States (POMS). Initial consent and pre-study questionnaires were administered electronically through Qualtrics. Each participant was provided a unique participant identification number to distinguish among participants in the study without the use of personally identifiable information.

(1) Pittsburgh Sleep Quality Index (PSQI) – sleep quality

The Pittsburgh Sleep Quality Index (PSQI) contains questions inquiring about a participant's amount of sleep and self-assessed reasons for poor sleep. The PSQI measures seven different areas related to sleep quality and disruptions, and combines all of the areas into one composite score (Buysse et al., 1989). The questions inquire about the participants' sleep latency and about specific reasons they believe are interfering with their ability to sleep. Additionally, the PSQI asks about the participants' assessment of their overall sleep quality, ability to stay awake during wake hours, and general enthusiasm level.

(2) Epworth Sleepiness Scale (ESS) – daytime sleepiness

The Epworth Sleepiness Scale uses self-assessed questions about activities where the respondent feels tired, to determine a participant's level of daytime sleepiness (Johns, 1991). The ESS is a validated tool for measuring daytime sleepiness (Johns, 1991). The questionnaire asks the participants to indicate their chance of dozing when participating in activities such as watching the television, sitting in traffic while driving, or reading.

(3) Insomnia Severity Index (ISI) – insomnia symptoms

The Insomnia Severity Index is a screening tool to identify symptoms of insomnia (Bastien, 2001). The ISI has been validated as a reliable tool to obtain self-reported answers from a respondent and indicates a person's perception of their insomnia symptoms (Bastien, 2001). ISI questions include an individual's difficulty falling asleep, staying asleep, or awakening before a pre-determined sleep period has concluded. Furthermore, it asks about satisfaction with one's own sleep, perception of potential sleep problems, and impact of any perceived sleep problems on daily function.

(4) Profile of Mood States (POMS) – mood

The Profile of Mood States includes 65 words and short phrases, and then asks the respondent to identify the best response to describe their feelings (McNair et al., 1971). The list of feelings includes words like unhappy, energetic, restless, fatigued, unable to concentrate, lively, and cheerful. The person taking the assessment can then choose whether they have had these feelings "Not at all," "A little," "Moderately," "Quite a bit," or "Extremely." Based on the responses, the POMS evaluates seven aspects of an individual's mood: fatigue-inertia, anger-hostility, vigor-activity, confusion-bewilderment, depression-dejection, tension-anxiety, and friendliness (McNair et al., 1971).

D. ANALYTICAL APPROACH

1. Data Cleaning

All questionnaires were scored using standardized scoring conversions. There were four missing values (6%) in one individual's POMS questionnaire. Two responses were missing from the Tension-Anxiety subcategory and two responses were missing from the Depression subcategory. Values were imputed using the average of that individual's responses within the affected subcategory.

For the participants' PSQI responses about bedtime, time in bed, and waketime, the data were interpolated to determine time in bed. Since the participants work all three shifts in a 20-day period, their sleep times vary every few nights. In response to what time they go to bed, and what time they wake up, some participants listed multiple bedtimes and wake times. For these participants, the times most closely aligned with night sleep were used to calculate time spent in bed. Other participants responded that they could not answer the question due to inconsistent sleep/wake times, or simply stated that their sleep/wake times varied. In these cases of non-specific free text responses, the time spent in bed was deduced to the nearest half-hour by combining the individual's response for time spent sleeping and his/her response for how long it takes to fall asleep.

Participants who completed less than half of the daily log collection (less than 11 days) were excluded from the daily sleep/wake schedule analysis. For the daily activity log, several participants had missing details such as no sleep listed for a 24-hour period or commute to and from work reported, but no work reported. If a full day is missing sleep, the sleep hours are imputed with the best match of the sleep/wake pattern of the surrounding days (six imputed sleep entries, 7%) . If a commute was reported to and from work, it was assumed that the full period between those commute times was work (14 imputed work entries, 25%). If a commute time is missing, the same commute time reported on other days is used (10 imputed commute entries, 14%). If work and commute hours are missing, but sleep hours are reported, the sleep hours combined with the known schedule rotation are used to impute the assumed work and commute hours (10 imputed work and commute entries, 18%) .

2. Analysis Roadmap

The analysis of the SAFTE models and the collected data from the study participants were examined to better understand the current state of watchstander sleep, mood, and wellbeing. We examined the schedule model output to identify areas of low predicted effectiveness and high BAC equivalency levels. This analysis provides a better understanding of how sleep/wake schedule, sleep debt, and rotation schedules are predicted to impact the effectiveness of a watchstander. The daily activity logs and questionnaire responses provide additional fidelity on how individual watchstanders sleep on the current rotation and how they self-assess their own sleep quality, mood, and wellbeing. Descriptive statistical analysis provides insight into the sleep and wellbeing of the watchstanders as a group. With such a small population (25 watchstanders) and an even smaller participant group (11 watchstanders, 44%), comparative and inferential statistics have limited usefulness in this study. Due to the small sample size, ranges and median are reported rather than mean and standard deviation, unless otherwise noted.

IV. RESULTS

A. SCHEDULE ANALYSIS

The FAST output depicts the predicted effectiveness for the three rotation schedules modeled. The attributes are calculated for working hours only and are broken down by shift type (i.e., day, swing, and mid).

1. Current Rotation Schedule

The current rotation schedule provides the baseline predicted effectiveness for the watchbill schedule as-is. The FAST output for the current schedule is shown in Figure 8 and predicted effectiveness attributes show in Table 3. The most problematic area for predicted effectiveness is the mid shifts. During the mid-shift watches, the predicted effectiveness drops steeply throughout the shift, into the red zone. A majority of this shift occurs at a BAC equivalency level greater than 0.08. This means that the performance is expected to be comparable to an individual who is legally drunk. The timing of low predicted effectiveness coincides with the time period where personnel are briefing leadership and during their commute home from work. Note the elevated risk during commuting following mid-shift watches. The day shift watches begin low due to carryover from mid-shift and early awakenings. While on this schedule rotation cycle, the predicted effectiveness continues to cycle below 90% predicted effectiveness, never reaching the green zone of high predicted effectiveness.

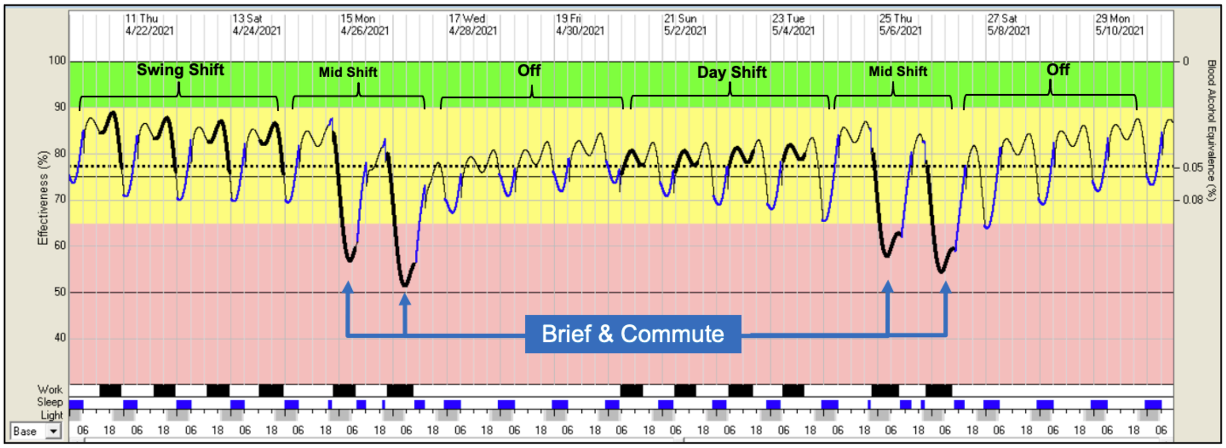


Figure 8. SAFTE modeled predicted effectiveness on current schedule rotation

Table 3. Current schedule attributes

	During Work Hours		
Attributes	Day	Swing	Mid
Predicted Effectiveness (PE)	79%	84%	62%
Lowest PE	75%	75%	52%
Shift time spent Below the Criterion Line (BCL)	8%	3%	93%

2. Alternate rotation schedule one

In the first alternate rotation, schedule modifications include the consolidation of the mid-shift watches into a seven-day period, an increase in cycle length to 35 days, and 12-hour shifts, instead of 8-hour shifts, on the weekends. The resulting predicted effectiveness is depicted in Figure 9 and attributes are shown in Table 4. The mid-shift results in the largest decline in predicted effectiveness, with predicted effectiveness dropping steeply throughout the shift. The predicted effectiveness drops into the red zone, with most of the shift occurring when the BAC equivalency level is above 0.08. The 12-hour duration of weekend mid shifts contributes to steeper drops in predictive effectiveness that continues to worsen each day of the mid-shift, dropping below 50% on the last two days of the shift. Like in the current schedule, the lowest points of predictive effectiveness correspond with the time that the watchstanders are briefing leadership and commuting home from work. The day shift begins low because of carryover from mid-shift and early awakenings. The commute into work on the first three days of the day shift occurs when predicted effectiveness is below the BCL and above a BAC equivalency of 0.05. The swing shift poses risk during the commute home in the late evening when the BAC equivalency is above 0.05.

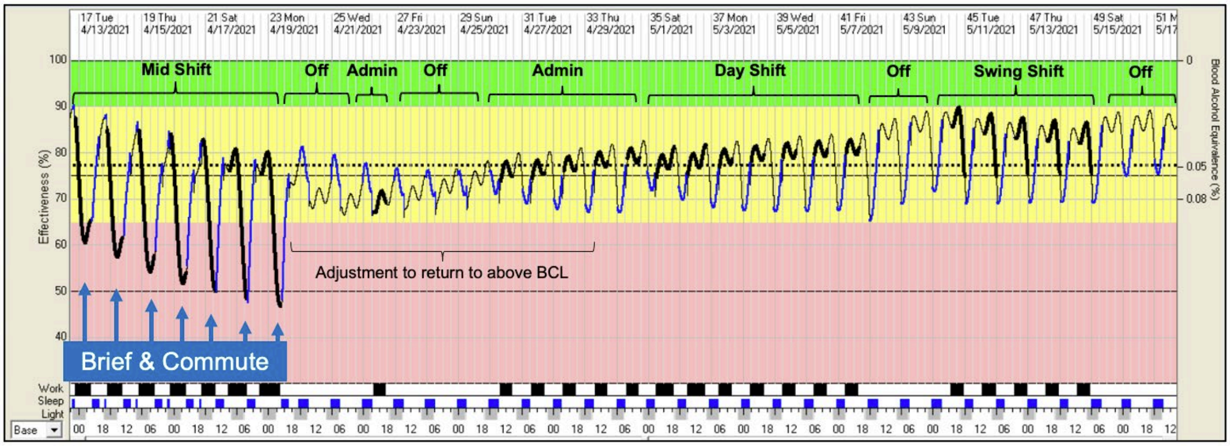


Figure 9. SAFTE modeled predicted effectiveness on alternate schedule rotation one

Table 4. Alternate schedule one attributes

Attributes	During Work Hours Day	Swing	Mid	Admin
Predicted Effectiveness (PE)	80%	85%	65%	84%
Lowest PE	77%	75%	47%	67%
Shift time spent Below the Criterion Line (BCL)	10%	5%	79%	17%

3. Alternate Rotation Schedule Two

The second alternate rotation schedule has similar attributes to the first alternate rotation schedule and the resulting model output is comparable, as shown in Figure 10 and Table 5. Predicted effectiveness attributes are listed in Table 5. The predicted effectiveness drops steeply during mid-shift watches, with the 12-hour shifts on the last two days of mid-shift contributing to steep drops in predicted effectiveness that worsen with each day on mid-shift. During the mid-shift days, the predicted effectiveness drops into the red zone and most of the shift occurs with the BAC equivalency above 0.08. The swing shift induces risk during the commute home in the late evening. The day shift begins low because of the carryover from the mid shift, combined with early awakenings. The extended off period of nine days provides an opportunity to prioritize sleep and recover from mid shift sleep debt.

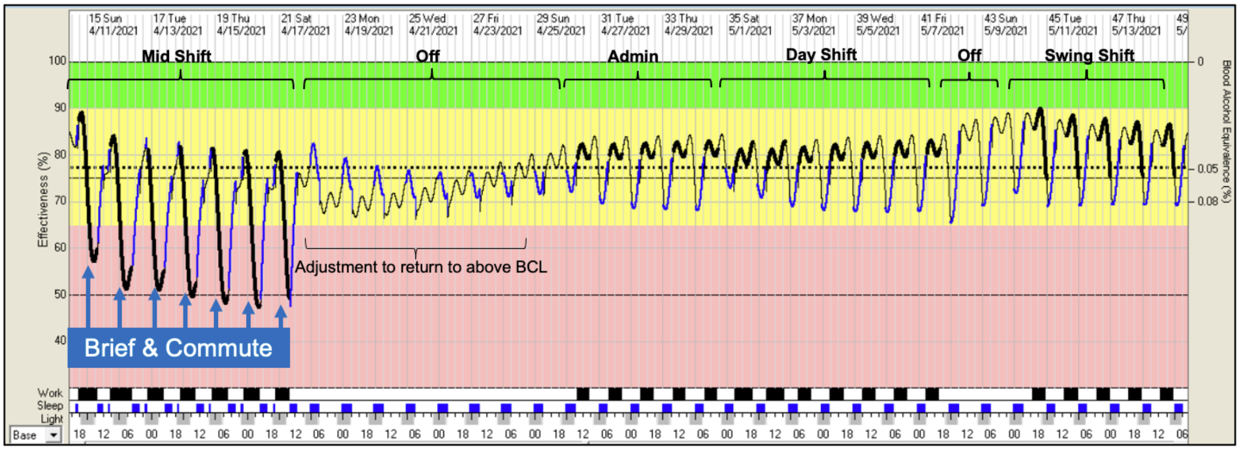
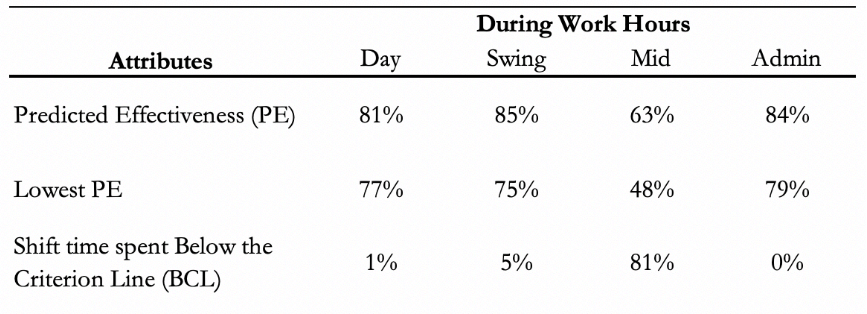


Figure 10. SAFTE modeled predicted effectiveness on alternate schedule rotation two

Table 5. Alternate schedule two attributes



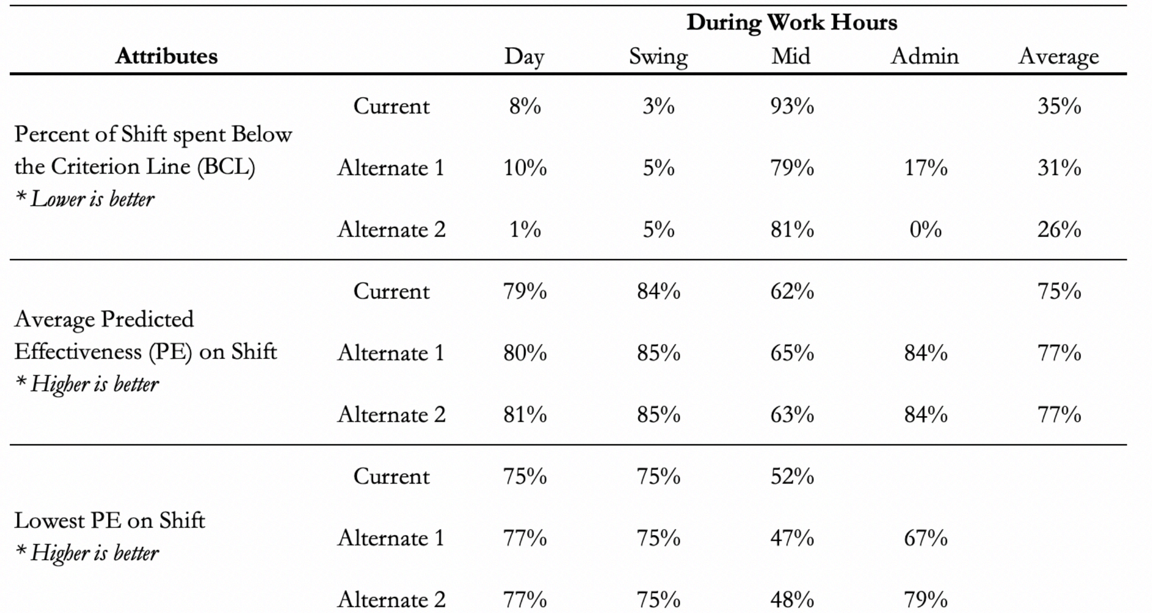
	During Work Hours			
Attributes	Day	Swing	Mid	Admin
Predicted Effectiveness (PE)	81%	85%	63%	84%
Lowest PE	77%	75%	48%	79%
Shift time spent Below the Criterion Line (BCL)	1%	5%	81%	0%

4. Schedule Rotation Model Comparison

The attributes of each schedule's model output are depicted in Table 6. The mid shift is the riskiest shift for all three schedule rotations. All mid shift briefs and commutes occur when predicted effectiveness is below the BCL and above a BAC equivalency of 0.08. That is, watchstanders participate in briefings and commute with a predicted performance level of someone who is legally drunk. The current shiftwork schedule rotates so rapidly that performance never fully recovers from the mid shifts. Residual mid shift impacts, combined with early awakenings on the day shift, result in continued degraded predicted performance the first few days of the day shift. The two alternate rotation schedules provide a slight benefit with slower shifting. The slower shifting enables recovery to a higher predicted effectiveness level following the mid shifts. However, the addition of the 12-hour weekend shifts results in an even lower PE by the last few mid shifts.

The proposed alternative schedule rotations do not provide an improvement over the current schedule. The advantage of the alternate schedule is the increase in weekends off, providing each watchstander two to three full weekends off per month. Compared to two to four weekend days off per month on the current schedule, this change provides an improvement in Miller's principle of shiftwork scheduling to maximize weekend days off (Miller, 2008). In contrast, the inclusion of seven consecutive mid shifts with the last two shifts extending to 12-hours runs contrary to Miller's scheduling principles of shorter shifts and minimizing consecutive night shifts (Miller, 2008).

Table 6. Schedule attribute comparison

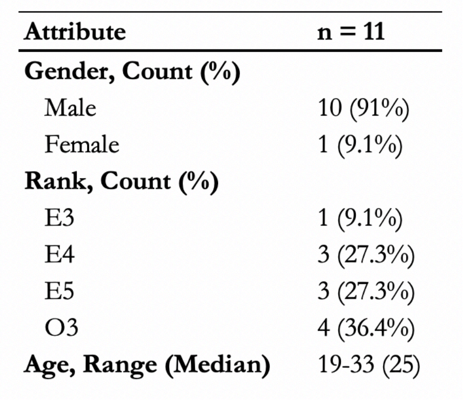


		During Work Hours				
Attributes		Day	Swing	Mid	Admin	Average
Percent of Shift spent Below the Criterion Line (BCL) _* Lower is better_	Current	8%	3%	93%		35%
	Alternate 1	10%	5%	79%	17%	31%
	Alternate 2	1%	5%	81%	0%	26%
Average Predicted Effectiveness (PE) on Shift _* Higher is better_	Current	79%	84%	62%		75%
	Alternate 1	80%	85%	65%	84%	77%
	Alternate 2	81%	85%	63%	84%	77%
Lowest PE on Shift _* Higher is better_	Current	75%	75%	52%		
	Alternate 1	77%	75%	47%	67%	
	Alternate 2	77%	75%	48%	79%	

B. PARTICIPANT DEMOGRAPHICS

Out of the 25 personnel who work on the watchfloor, 11 (44%) volunteered to participate in the data collection portion of the study. There were 10 male participants and one female participant. Participants ranged in age from 19 to 33, with a median of 25 years old. Four watch officers participated and seven enlisted members of the watch teams participated. The rank breakdown is displayed in Table 7.

Table 7. Demographics of study participants.



Attribute	**n = 11**
Gender, Count (%)	
Male	10 (91%)
Female	1 (9.1%)
Rank, Count (%)	
E3	1 (9.1%)
E4	3 (27.3%)
E5	3 (27.3%)
O3	4 (36.4%)
Age, Range (Median)	19-33 (25)

C. SLEEP AND WELLNESS

In the pre-study questionnaire, participants were asked to provide information about personal attributes and daily habits related to overall wellness. These questions included height, weight, caffeine usage, tobacco and/or nicotine usage, and exercise. Reported height and weight information was used to calculate body mass index (BMI), with participants ranging from 20.4 to 37.6 (median 27.3) for BMI. Seven participants reported drinking at least one caffeinated beverage (coffee, tea, soda, or energy drink) per day. Two additional participants reported drinking approximately one caffeinated beverage per week. One participant reported daily tobacco use and one reported daily nicotine salt use. All eleven participants engage in weekly exercise, ranging from three to eight exercise sessions per week, with a duration of 50 to 120 minutes per session. Reported exercise included cardio, weightlifting, cycling, swimming, and cross-training. Participants slept at varied hours due to their shiftwork schedule.

D. PITTSBURGH SLEEP QUALITY INDEX (PSQI)

Responses to the PSQI questionnaire were used to assess an individual's sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, and daytime dysfunction. These attributes were combined for an overall global score. A global score of six or more classifies the individual as a poor sleeper. Nine participants (82%) were classified as poor sleepers by the PSQI survey. The distribution of participants' PSQI global scores is shown in Figure 11.

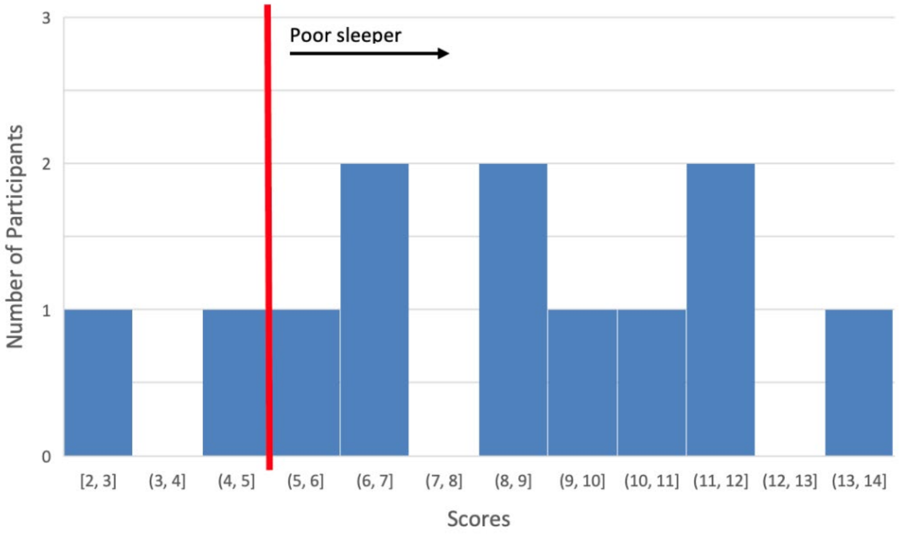


Figure 11. PSQI scores for sleep attributes

Within the PSQI survey, participants reported time spent sleeping each day. The time spent sleeping each day ranges from five to 8.5 hours, with a median of six hours. Seven participants (64%) reported a sleep duration of fewer than seven hours per day. The time spent in bed, which includes time where the participants reported they were unable to sleep, ranges from six to 10 hours, with a median of 7.5 hours. Figure 12 includes boxplots of the distribution of the amount of time participants spent in bed compared to the amount of time participants spent sleeping.

Figure 12. Boxplots comparing participants' sleep duration and time spent in bed

E. EPWORTH SLEEPINESS SCALE (ESS)

In the ESS measure of daytime sleepiness, participants ranged in score from two to 22. A score over 10 is classified as elevated average daytime sleepiness and a score of 10 or below is classified as normal. Six participants (55%) scored over 10 and are classified as having elevated daytime sleepiness. Of those classified as having elevated daytime sleepiness, four scored between 13 and 15 which is classified as moderate excessive daytime sleepiness and two scored 16 or above which is classified as severe excessive daytime sleepiness. ESS score distribution is depicted in Figure 13.

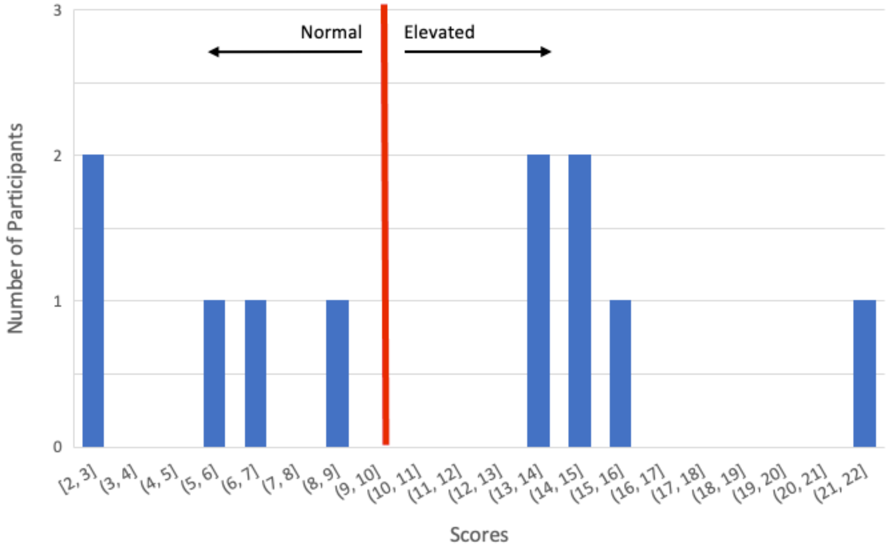


Figure 13. Participants' ESS scores for average daytime sleepiness

F. INSOMNIA SEVERITY INDEX (ISI)

In participants' responses to questions about insomnia symptoms, scores ranged between six and 23. One participant who had a score of less than seven was identified as having no clinically significant insomnia. Six participants scored between eight and 14 and were classified as subthreshold insomnia. Three participants had a score between 15 and 21 and were classified as having moderately severe clinical insomnia. One participant who scored between 22 and 28 was classified as severe clinical insomnia. ISI scores are depicted in Figure 14 and ISI categories are shown in Figure 15.

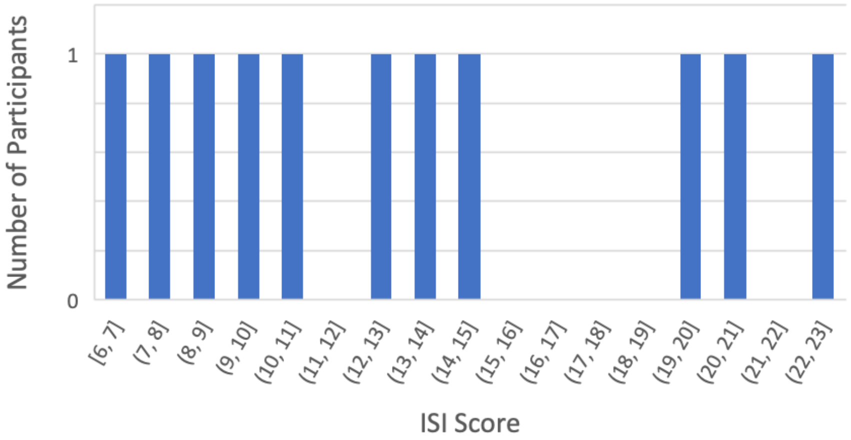


Figure 14. Participants' ISI scores measuring symptoms of clinical insomnia

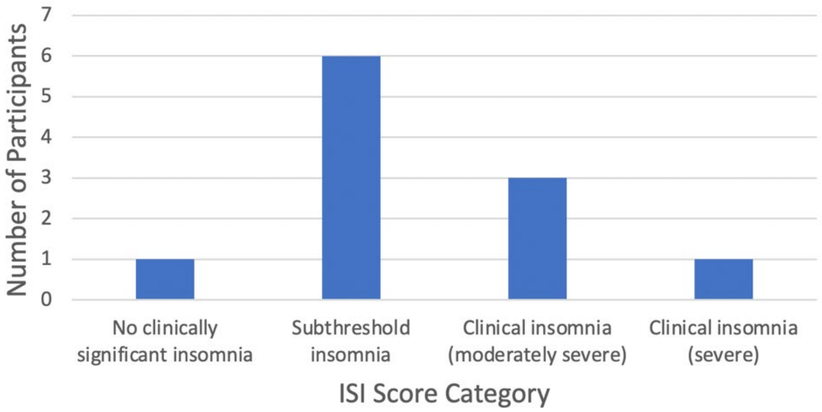


Figure 15. Participants' ISI score categories

G. PROFILE OF MOOD STATES (POMS)

For each of the POMS subcategory scales, the majority of participants reported worse mood (<50th percentile for Vigor-Activity and >=50th percentile for all other subcategories) than the adult norm for each of the six subcategories (Tension-Anxiety, Depression, Anger-Hostility, Vigor-Activity, Fatigue, and Confusion-Bewilderment). Seven participants had a total mood disorder score greater than the 50th percentile. Figure 16 depicts the score distributions for each of the POMS subscales, and Figure 17 shows the percentage of participants that scored below and above the 50th percentile of the adult norms.

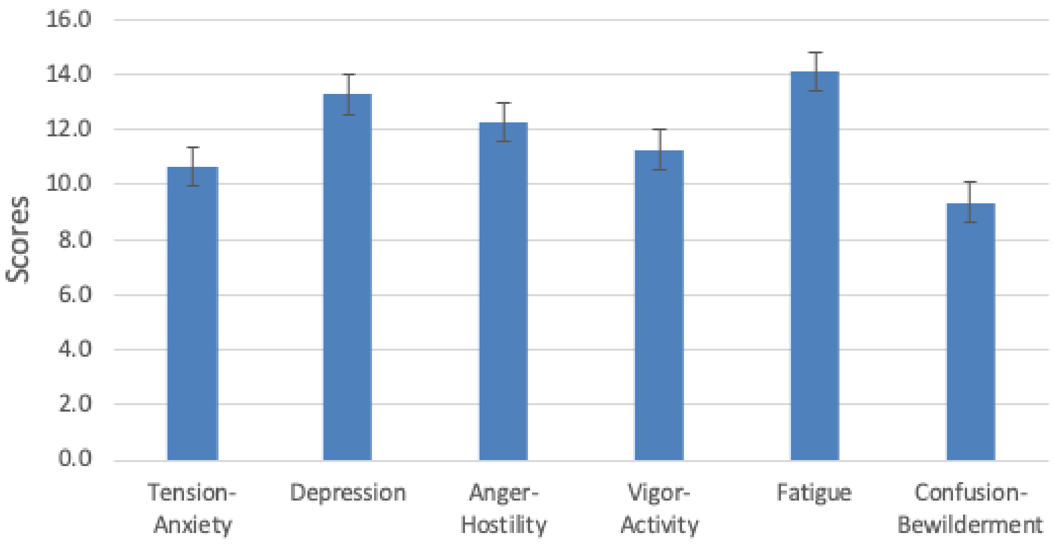
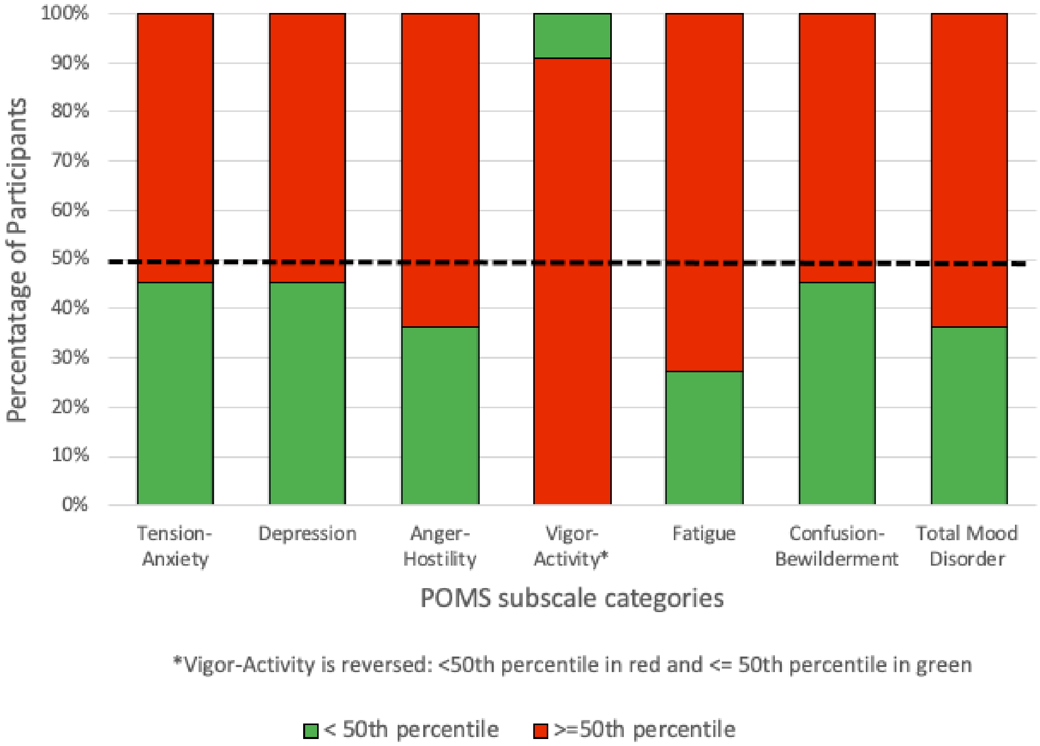


Figure 16. POMS subscale scores. Scores presented as mean +/- standard error



*Vigor-Activity is reversed: <50th percentile in red and <= 50th percentile in green

Figure 17. Participants’ POMS scores measuring mood

Ten of the eleven participants (91%) had Vigor-Activity scores worse (<50th percentile) than the adult norm. The scores for the Vigor-Activity subscale are displayed in Figure 18.

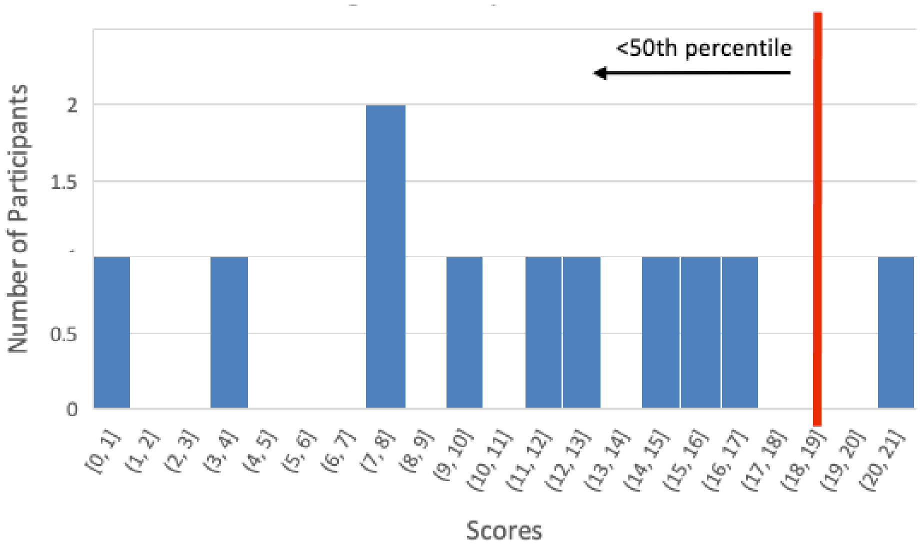


Figure 18. Vigor-Activity subscale scores (<50th percentile is worse than adult norm)

Eight participants had fatigue scores greater than the 50th percentile of the adult norms. Figure 19 shows the fatigue subscale scores.

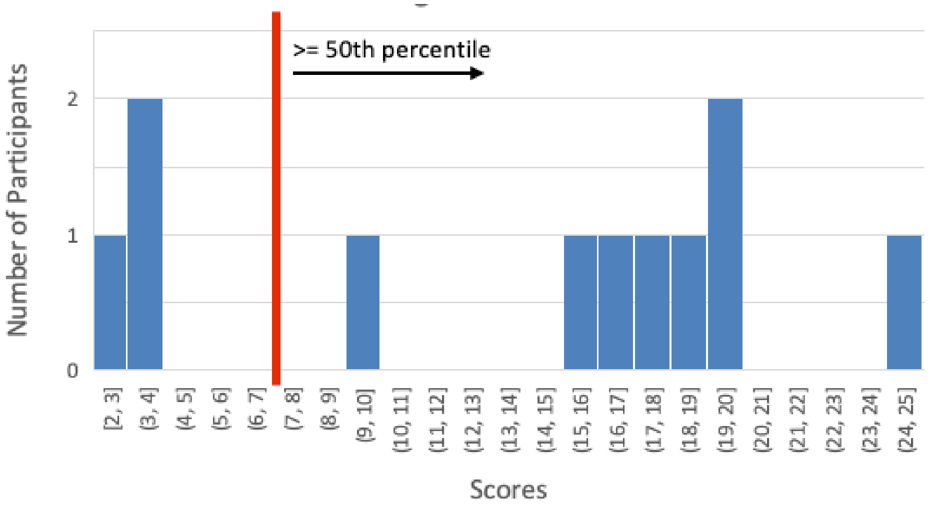


Figure 19. Fatigue subscale scores (>=50th percentile is worse than adult norm)

Seven participants (64%) had total mood disorder (TMD) scores higher than the 50th percentile adult norm, which means they scored worse than the 50th percentile. TMD scores are depicted in Figure 20.

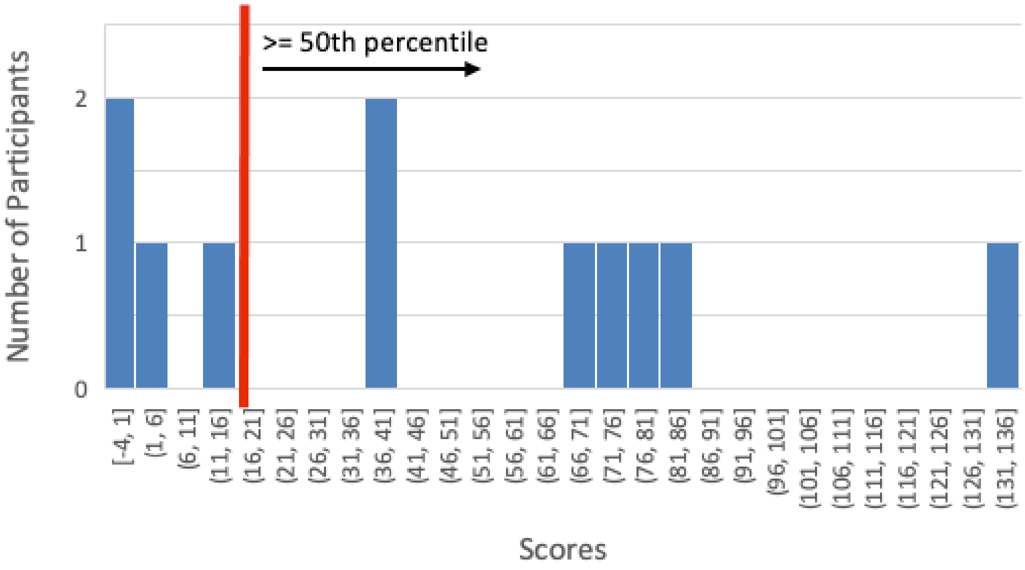


Figure 20. POMS total mood disorder scores (>=50th percentile is worse than adult norm)

H. DAILY ACTIVITY

With only five participants completing the majority of the daily activity logging, the results are limited to observations about the data. There is minimal consistency among the participants in the hours of wakefulness and sleep surrounding the rotation schedule.

Two of the participants had a sleep/wake schedule very similar to the modeled sleep timing, but their sleep habits contained more variability in sleep duration. Some nights had as many as eight hours of sleep, whereas others had as few as five hours of sleep. The days with shorter sleep duration were clustered around shift changes. Daytime sleep associated with mid shifts was further reduced to between three and four hours on some days. Both individuals appeared to anchor their sleep to normal night hours on days where they work the day shift or swing shift. Compared to these two participants, the SAFTE-modeled nightly sleep was somewhat conservative for day shifts, a good representation for swing shifts, and optimistic for mid shifts.

Another participant had a fairly consistent sleep duration of six to seven hours, but the timing of sleep was more varied. This participant slept at approximately the same time each day when on a given shift, and then completely altered the timing of sleep when on a different shift. The sleep was not anchored to night hours. This individual reported excessive sleepiness when commuting, and described falling asleep while driving on four days when commuting home and one day when commuting to work. When compared to this individual's sleep schedule, the SAFTE modeled schedule was conservative in duration and optimistic in timing.

A fourth participant had inconsistent sleep timing and duration. This individual had multiple nap periods varying in length from 45 minutes to four hours. These naps tended to be clustered around the mid-shift days. Sleep duration and timing appeared to stabilize after several days on the day or swing shift. Both sleep duration and timing, however, seem to be disrupted again when on the mid shift. This participant reported difficulty falling asleep and multiple migraines during the collection period. The SAFTE modeled schedule was optimistic in both timing and duration when compared to this individual's sleep-wake schedule.

The fifth participant mostly slept from early morning hours through late morning or early afternoon, except when on day shift where early awakening was required. Sleep duration was reported as six to eight hours for day and swing shifts. Sleep surrounding mid shifts was shorter, with as short as 2.5 to three hours of sleep on some days. The SAFTE modeled sleep schedule was inconsistent with this individual's sleep habits.

V. DISCUSSION

A. CONCLUSIONS

As a group, the watchstanders were dissatisfied with their sleep on the current watch rotation. Nine (82%) of the participants are poor sleepers, and six of the participants (55%) have elevated daytime sleepiness. Participants were sleeping less than the recommended seven to nine hours per night for healthy adults (Watson et al., 2015). Ten participants (91%) are categorized as having subthreshold or higher levels of insomnia. Due to their rotation schedule, they were unable to sleep at the same time each day. Based on the five documented activity logs, some participants anchored their sleep to normal night sleep hours as much as possible, while others had haphazard sleep patterns. The collected activity log data shows that each participant had insufficient sleep duration, lack of consistent sleep at the same time each day, or in some cases both deficiencies.

The self-reported data from the participants echo the SAFTE-modeled predicted effectiveness for the current schedule rotation. Overall, the modeled sleep schedule is a good aggregate sleep/wake schedule to represent the sleep of the watchstanders. While it does not accurately represent any single watchstander, it is optimistic for some watchstanders and conservative for others. Based on the collected sleep and wake data, the modeled schedule is an acceptable representation. That is, some watchstanders are getting longer duration sleep and likely performing better than the model's predicted effectiveness. Other individuals have shorter sleep durations and less consistent timing than the modeled schedule, and they may be performing worse than the model's predicted effectiveness.

The highest risk to cognitive performance and safety occurs at the end of the mid shift. During this time, watchstanders are briefing leadership and commuting home from work. With poor sleep and high levels of fatigue, these watchstanders have a predicted effectiveness worse than someone who has lost a full night of sleep and a BAC equivalency level above the legal limit of 0.08. The model, and supporting data, indicate that the watchstanders are briefing and commuting with the cognitive performance of someone who is legally drunk.

All eleven participants are young in age and are physically active, yet they report mood levels that are worse than the adult norm for tension-anxiety, depression, anger-hostility, fatigue, and confusion-bewilderment. More striking, they report low levels of vigor-activity, with 10 (91%) of the participants having a lower vigor-activity score than the adult norms. They also report high levels of fatigue, with eight participants (73%) scoring higher than the adult norm for fatigue.

B. LIMITATIONS

This study has several limitations. The small size of the watch team limited the number of potential participants to 25. With 11 personnel (44%) volunteering to participate in the study, the data set is small. Of the 11 people that responded to the pre-study questionnaire, only five of them completed the daily activity log for the majority of the three-week collection period. Low compliance with the daily activity logging limits the conclusions that can be made from that portion of the study data.

Another limitation was the inability to use a wearable sleep tracker during the study. Security approvals were required for a wearable sleep device to enter the secure building where the watch team works. The approval process was initiated, but not approved prior to the collection period. Without a wearable device, information about participants' sleep habits was only obtained through the self-reported TimeUse application. Combined with the low compliance of personnel filling out the daily logs, the daily sleep/wake data are limited.

The timing of the study coincided with a holiday weekend and was a rare opportunity for watchstanders to take leave. This timing may have limited the number of personnel who volunteered to participate in the study, and it disrupted the normal work schedule for at least one of the five participants who tracked their daily activity.

The FAST schedule modeling is based on a nominal wake/sleep schedule. The hours, timing, and quality of sleep were based on feedback from the watch team, but the modeled sleep/wake schedule is a generalization and does not represent the actual sleep/wake schedule of every individual on the watch team.

Of the 11 participants who completed the pre-study questionnaire, only four (36%) completed the post-study questionnaire. Limited participation in the second questionnaire reduced the comparative analysis that could be completed between the pre-study and post-study responses.

C. RECOMMENDATIONS

1. Implement and Test New Shift Rotation

As the next step, a new schedule rotation incorporating slower rotations and longer times on a given shift should be implemented. During the implementation of this new schedule rotation, sleep data should be collected with a wearable sleep device and standardized questionnaires should be administered to the watchstanders. Preferably the collection period will last through a full cycle of the newly implemented rotation schedule. Sleep data, as well as self-reported questionnaire data, will provide data for comparison with the baseline sleep, fatigue, and mood data contained here. The sleep and fatigue data associated with the new schedule rotation can then be analytically assessed for improvements. A potential recommended schedule is included below.

The schedule is the same as the schedule rotation implemented by the White House Military Office President's Emergency Operations Center. As described in chapter three, the schedule involves 24 hours on shift, followed by 72 hours off shift. When implemented by the White House Military Office President's Emergency Operations Center, the schedule improved watchstanders' sleep quality, increased mood, and decreased fatigue (Shattuck et al., 2015).

The schedule could be modified to account for some of the specific attributes of the Global Maritime Watch, to include five watch sections and incorporate turnover at 0830 to align with weekday morning briefs. With five duty sections, each section would have eight duty days in a 40-day rotation cycle, working every fourth day and having one longer stretch of 8-9 days off per 20-day cycle. Strategic napping would occur between 1900-2400 and 0001-0500 during the 24-hour shift.

There are several benefits to this schedule. It would enable watchstanders to maintain regular sleep schedules that are less disruptive to the circadian rhythm. The strategic napping opportunity is included to mitigate the risk of a 24—hour shift. This schedule increases the number of days off and weekend days off, with two to three full weekends off per month. Figure 21 and Figure 22 depict how predicted effectiveness is improved throughout the rotation cycle as compared to the current and alternate schedules previously examined. The BAC equivalency is also lower, with the trough not occurring during brief and commuting times.

There are several potential challenges associated with this schedule. To incorporate strategic naps, there would be a need to maintain appropriate napping spaces for watchstanders. A potential cognitive risk is that attention and vigilance can decrease over long work hours. The safety risk still remains with the morning commute home occurring after long work hours and only a five-hour nap. For model demonstration, all non-duty days are simulated with seven hours of good quality sleep. Figure 21 depicts the predicted effectiveness of an individual on this schedule rotation who sleeps between 0001 and 0500 when on duty, and Figure 22 shows the predicted effectiveness of an individual sleeping between 1900 and 2400 on duty days. The late sleep (0001-0500) has better predicted performance, but a schedule rotation with either sleep opportunity still performs better than the previously examined schedules. Predicted performance does not dip into the red zone and the brief and commute times correspond to higher predicted performance than the current schedule.

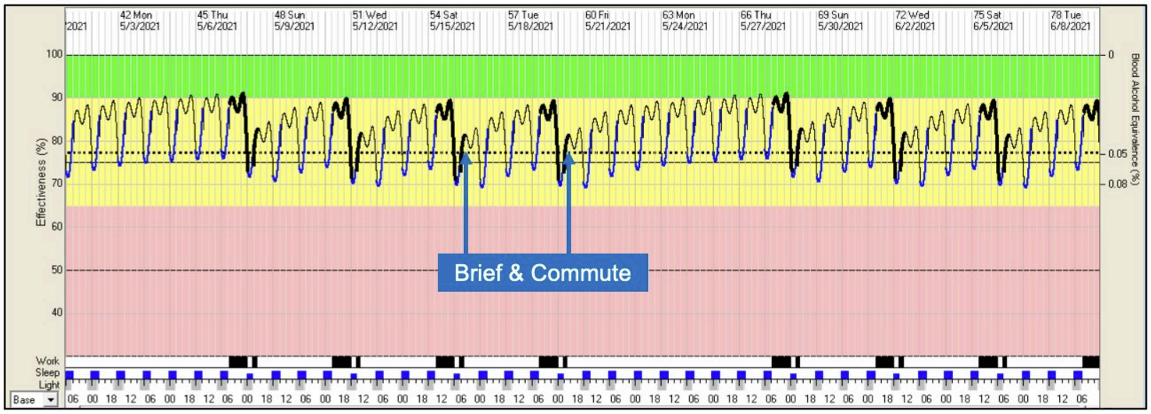


Figure 21. 24/72 alternative schedule model with strategic nap during later night hours (0001-0500)

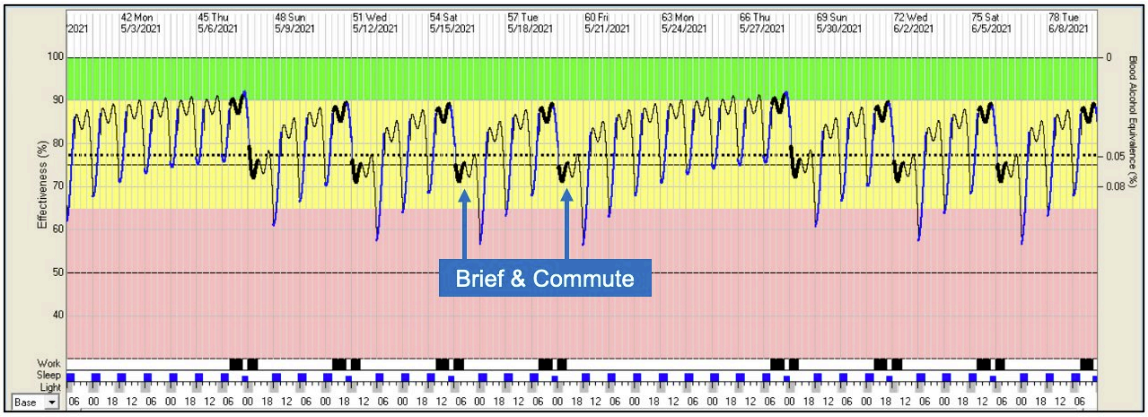


Figure 22. 24/72 alternative schedule model with strategic nap during early night hours (1900-2400)

2. Future Studies

With the ubiquity of shore-based watchfloors in the Navy, and the growing recognition that shore-based watchstanders suffer from poor sleep, performance, and safety, it is imperative to capitalize on the momentum of shore-based shiftwork research and conduct more shore-based watchfloor sleep studies. Conducting research studies on multiple watchfloors will provide a better understanding of how different shore-based shiftwork rotations and conditions impact watchstander sleep, performance, and mood. No two shore-based watchfloors are the same, but they do have similarities. Lessons learned through data-driven analysis will benefit other shore-based watchfloors.

Some recommended measures to improve future studies, avoid the limitations of this study, and acquire better data are discussed.

a. Wearable sleep tracker

Many of the shore-based watchfloors in the Navy are located within secure spaces and have restrictions on the electronic devices that can be brought into the facility. To improve collection on sleep, incorporating a wearable sleep tracker into the study will provide value over the self-reported activity logs. The inclusion of a wearable device ensures that sleep periods are collected for the duration of the study, as long as the participant wears the device. When preparing to conduct a sleep study in a secure shore-based facility, best practice would be to request wearable device access as early in the process as feasible. The approval process can take months and delay the study. If multiple wearable sleep trackers would meet the requirements of the study collection, requesting access for each of the possible wearables could improve the likelihood of gaining approval for one of them.

A longer term solution would be to attempt to gain approval for commonly used wearables (Actiwatch, Oura ring, etc.) through the Navy Special Security Office (SSO). Instead of relying on individual device access requests each time a study is conducted, a blanket approval by the Navy SSO could streamline future approvals in other facilities governed by the same security requirements.

b. Timing

If possible, schedule the study at a time of year that does not coincide with major American holidays such as Christmas, New Year, Thanksgiving, and Independence Day. There is a higher potential for personnel to take leave around these holidays, which disrupts attempts to collect sleep data for the whole collection period. Even if the individual continues to collect sleep data during their leave period, it is not an accurate reflection of their normal schedule rotation. Consult with the command about their operational tempo, and attempt to avoid any additional periods that contain leave or other disruptions.

c. Recruitment

For best results, try to recruit personnel to participate in the research study in person. In person recruitment enables face-to-face interaction to explain the value of the study, obtain better participant buy in, demonstrate the wearable (if used) and other electronic tools (Qualtrics surveys, TimeUse app). Without face-to-face interaction with the participants, the reason for the lack of study compliance is unclear. In person recruitment would make it easier for participants to ask questions and gain a better understanding of the study.

d. Communication

Increased communication with participants throughout the collection period could facilitate improved participant compliance. Direct email communication with study participants, soliciting for questions, and providing study milestone reminders throughout the study could improve communication.

e. Activity log

The TimeUse application is a practical tool for documenting daily activity. Providing a live demonstration to the participants could improve compliance. At least one participant logged in and completed one entry in the application, and then did not record any additional activity for the duration of the study.

The TimeUse application would be more usable if it were adapted so that other activities could be created and included in the activity list options. This update would allow for alternative activity collection and avoid any potential confusion with participants. For example, having the participants log their commuting time as “Play or watch video games” could be avoided. Alternatively, if adapting the TimeUse application is not possible, designing a new, more flexible application would improve usability and decrease confusion. Maintaining the ability to use the application on either a phone or desktop is desirable to enable easy accessibility for participants.

f. Qualtrics

Administering the pre-study questionnaires via Qualtrics was successful. Providing an in-person demonstration and sending more reminders through Qualtrics could potentially improve the number of participants who complete the post-study questionnaires.

g. Data collection

(1) Survey questions

It could be beneficial to incorporate additional questions in the questionnaire related to participants' perceptions of their current watch rotation, using Miller's (2009) shiftwork scheduling principles as a guide. Potential questions could include:

- How satisfied are you with your current watch schedule rotation?
- Rate your fatigue level when on shift for each of the different shifts (day, swing, mid).
- How satisfied are you with the number of days off work per month?
- How satisfied are you with the number of weekend days off per month?
- Do you feel like your schedule rotation is predictable?
- Do you feel like you have good quality time off?
- Do you feel like the workhours are distributed equally among watchstanders?
- Do you attempt to sleep at the same time each day, except when infeasible due to shift hours?

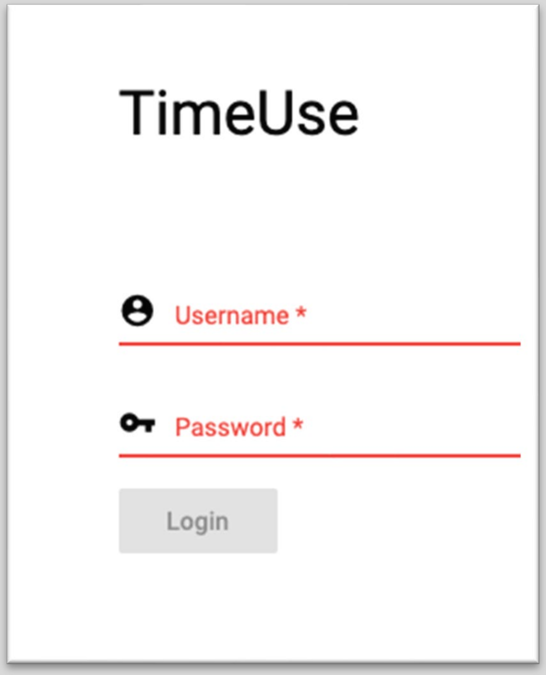
(2) Performance

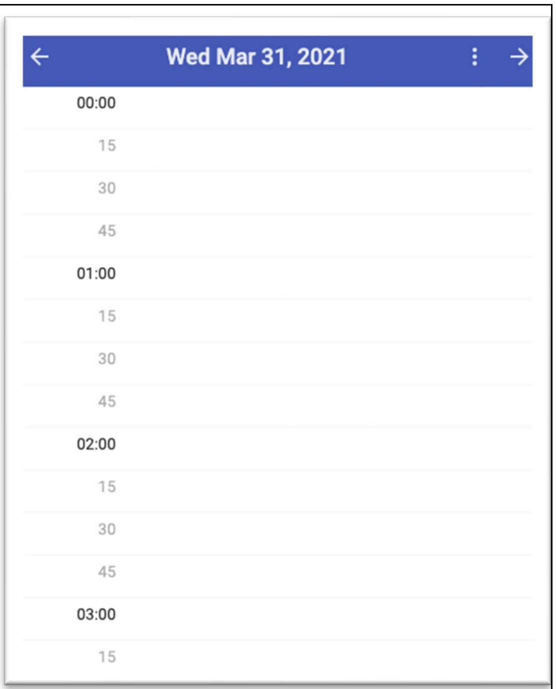
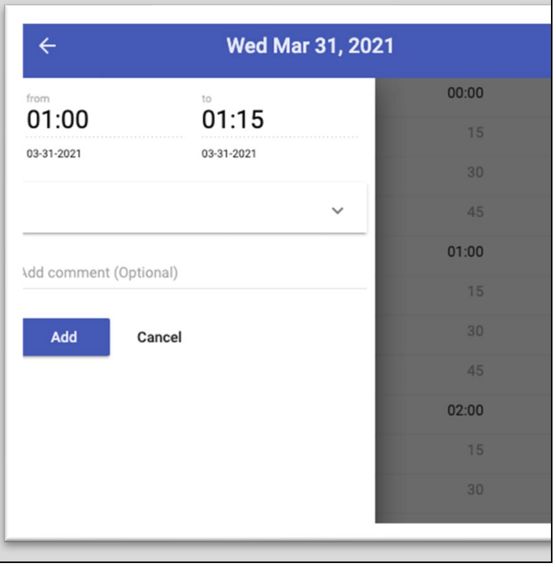
To directly collect performance data, incorporating a short performance task at the beginning and end of each shift, or at least at the beginning and end of mid shifts, would provide better fidelity on individual performance as the participants cycle through the schedule.

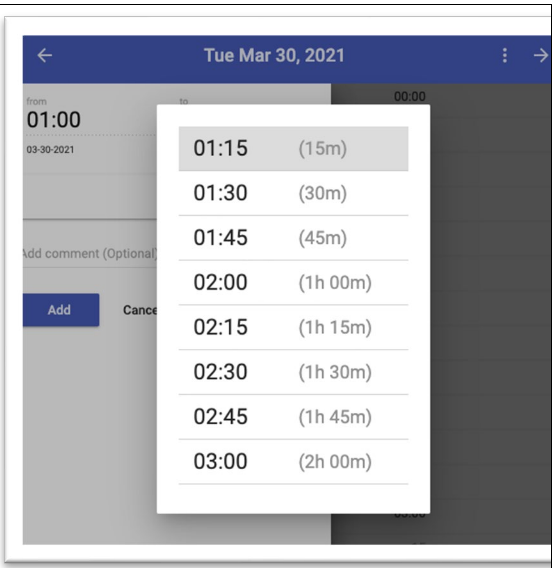
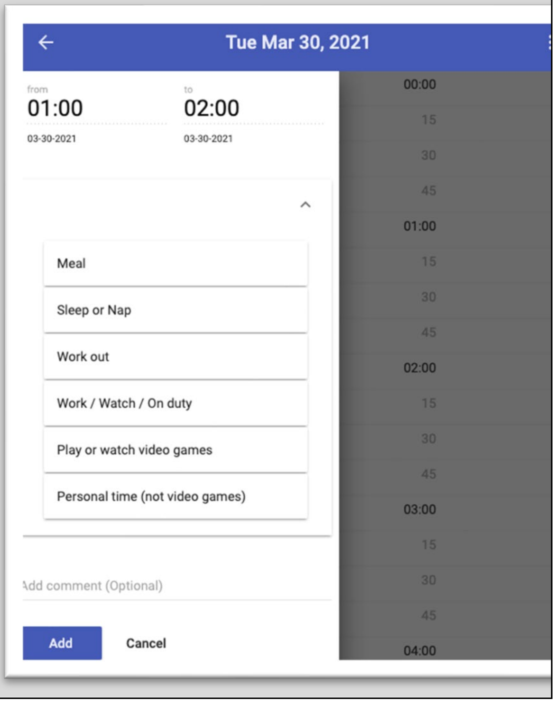
APPENDIX. TIMEUSE APPLICATION INSTRUCTIONS

You can access the app to document your daily activities on your phone or computer at https://timeuse.nps.edu

Try to be as accurate as possible. Remember to enter your activities at the end of each day.

Enter your credentials to log in in the default landing page: Username: your Participant ID Password: XXXX You cannot change the provided password or username.	

After logging in you will see the timeline page. At the top middle there is the day. With the left/right arrows at the top you can navigate forward and back one day at a time. You can logout by tapping the 3 vertical dots. Along the left side, the 24-hour day is split in 15-minute intervals.	
You can add an activity by tapping at the desired staring time. • This will lead to the screen to enter your activity. • If the time that pops-up is not what you want, click outside of the white menu to close it. • You must start an entry on a blank timeslot. • If you use the arrow buttons at the top, it will change the DAY you are looking at, but not the time!	Wed Mar 31, 2021 from 01:00 03-31-2021 to 01:15 03-31-2021

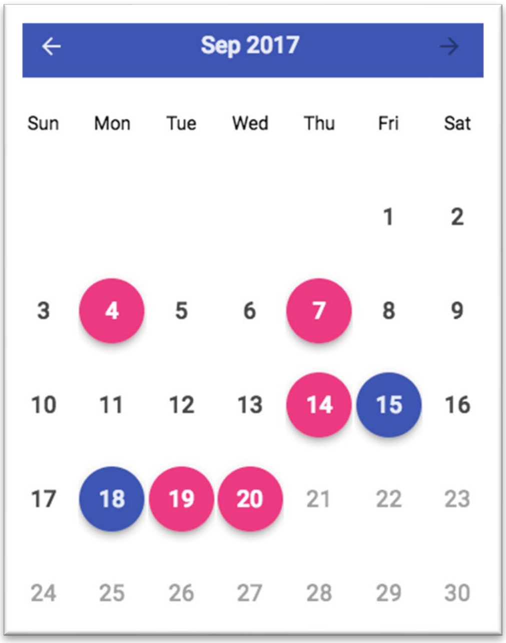
By tapping the end time, you can adjust the end time of the activity as needed.	
Choose the activity by tapping the drop down arrow. Add a comment if needed (optional) Tap "Add" when finished.	

In this example the participant entered that he/she slept between 0100 and 0200 on Tuesday, March 30.

If you want to edit an existing activity entry, just tap on that entry.

If you tap the date at the top middle of the screen you will see the month view.
It provides an overview of the data entered.
In this example:

- Days 4, 7, 14, 19, 20 are partially completed
- Days 15 and 18 are fully completed.
- Days 1, 2, etc., do not have any data entered.
- Days in grey cannot be selected because they occur in the future.



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