



**NAVAL
POSTGRADUATE
SCHOOL**

MONTEREY, CALIFORNIA

THESIS

**ASSESSING THE EFFECT OF A LIGHT
INTERVENTION ON SLEEP QUALITY AND
PERFORMANCE OF PENTAGON WATCHSTANDERS**

by

John L. Ramage

March 2023

Thesis Advisor:

Nita L. Shattuck

Second Reader:

Panagiotis Matsangas (contractor)

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REPORT DOCUMENTATION PAGE			<i>Form Approved OMB No. 0704-0188</i>
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1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE March 2023	3. REPORT TYPE AND DATES COVERED Master's thesis	
4. TITLE AND SUBTITLE ASSESSING THE EFFECT OF A LIGHT INTERVENTION ON SLEEP QUALITY AND PERFORMANCE OF PENTAGON WATCHSTANDERS			5. FUNDING NUMBERS RNNQD
6. AUTHOR(S) John L. Ramage			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Medical Research Center – Advanced Medical Development Program Silver Spring, MD 20910			10. SPONSORING / MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			12b. DISTRIBUTION CODE A
13. ABSTRACT (maximum 200 words) Around the world, watchfloors provide information, intelligence, and technical support to operational commands 24 hours a day. Watchstanders often work long shifts surpassing full time 40-hour work weeks, which include night and weekend shifts. Shiftwork has been associated with a decreased amount of sleep in both quantity and quality, which leads to exhaustion and compromised cognitive function. Exposure to high energy visible (HEV) light at appropriate times has the potential to shift the body's circadian rhythm to align faster to a new shift schedule. Adjusting to shifting work hours quicker could lead to less sleep loss, enhanced sleep quality, and less severe levels of fatigue. This study aims to assess the impact and potential benefits of intentionally introducing HEV light when watchstanders on a shore-based watchfloor are transitioning to a different work shift. The study will consider how the strategic application of HEV light affects circadian entrainment, thereby impacting sleep, performance, mood, and sleepiness. This work will inform recommendations to other shore-based watchfloors at the Pentagon that require non-traditional work schedules to support watchstanding operations.			
14. SUBJECT TERMS sleep, shiftwork, light, circadian entrainment, rotating schedule, watchfloor, performance, fatigue, cognitive function			15. NUMBER OF PAGES 85
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

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**ASSESSING THE EFFECT OF A LIGHT INTERVENTION ON SLEEP
QUALITY AND PERFORMANCE OF PENTAGON WATCHSTANDERS**

John L. Ramage
Lieutenant Commander, United States Navy
BA, University of Saint Thomas, 2011

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

**NAVAL POSTGRADUATE SCHOOL
March 2023**

Approved by: Nita L. Shattuck
Advisor

Panagiotis Matsangas
Second Reader

W. Matthew Carlyle
Chair, Department of Operations Research

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ABSTRACT

Around the world, watchfloors provide information, intelligence, and technical support to operational commands 24 hours a day. Watchstanders often work long shifts surpassing full time 40-hour work weeks, which include night and weekend shifts. Shiftwork has been associated with a decreased amount of sleep in both quantity and quality, which leads to exhaustion and compromised cognitive function. Exposure to high energy visible (HEV) light at appropriate times has the potential to shift the body's circadian rhythm to align faster to a new shift schedule. Adjusting to shifting work hours quicker could lead to less sleep loss, enhanced sleep quality, and less severe levels of fatigue. This study aims to assess the impact and potential benefits of intentionally introducing HEV light when watchstanders on a shore-based watchfloor are transitioning to a different work shift. The study will consider how the strategic application of HEV light affects circadian entrainment, thereby impacting sleep, performance, mood, and sleepiness. This work will inform recommendations to other shore-based watchfloors at the Pentagon that require non-traditional work schedules to support watchstanding operations.

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LIST OF ACRONYMS AND ABBREVIATIONS

BAC	blood alcohol content
BCL	below the criterion line
CDC	Centers for Disease Control
CFEMP	Comprehensive Fatigue and Endurance Management Policy
CNO-IP	Chief of Naval Operations Intelligence Plot
DOD	Department of Defense
EEG	electroencephalogram
ESS	Epworth Sleepiness Scale
FAST	Fatigue Avoidance Scheduling Tool
HEV	high energy visible
ISI	Insomnia Severity Index
NPS	Naval Postgraduate School
NREM	non-rapid eye movement
NTI	National Telecommuting Institute
POMS	Profile of Mood States
PSG	polysomnography
PSQI	Pittsburgh Sleep Quality Index
REM	rapid eye movement
SAFTE	Sleep, Activity, Fatigue and Task Effectiveness
SAIC	Science Applications International Corp
SBIR	small business innovation research
SCN	suprachiasmatic nucleus
TMD	total mood disorder
WASO	wake after sleep onset

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EXECUTIVE SUMMARY

United States Navy shore-based watchfloors are manned 24/7 to provide information, intelligence, and technical support to the warfighter, and to support various maritime operations around the globe. Typically, service members in watchfloors are working in shifts. Shift working includes standing watch at various times of the day, sometimes at night and on weekends, with working hours oftentimes exceeding the normal 40 hours per week (Troxel et al., 2015). Consequently, shiftwork has been associated with restricted sleep duration, deteriorated quality of sleep, and elevated levels of fatigue (Shattuck & Matsangas, 2015). Without the proper amount of healthy sleep humans will experience degraded cognitive function and deteriorated health .

This study focused on a watchfloor at the Pentagon and aimed to improve watchstander sleep attributes, well-being, and performance. Specifically, the objectives of this study were the following: assess watchstander sleep patterns, sleep attributes, and well-being while they are on their current watch schedule; use a validated model of sleep and predicted effectiveness to assess the current watch schedule; identify strengths and weaknesses of the current watch schedule; develop a new watch schedule for the watchfloor that can be implemented and assessed; and assess whether strategically timed high-energy visible (HEV) light exposure when participants are transitioning to a different shift will improve overall sleep quality and performance at work.

Twenty-one watch standers volunteered to participate in this study. Participants completed questionnaires at the beginning, midpoint, and end of the study that included questions about sleep quality, symptoms of insomnia, daytime sleepiness, and mood states. Sleep patterns were assessed with wearable devices. The study was divided into the baseline and the treatment periods. During the treatment period, participants were issued light therapy glasses and light canvases were installed on the watchfloor. Median night sleep durations for each participant during each study period were calculated. A sleep/work schedule was modeled based on the current watch rotation and sleep data collected during the baseline period of the study. Additionally, using the same sleep data

we developed and modeled two additional watch rotation schedules for the watchfloor to consider implementing.

Analysis of the current schedule model output indicated that the mid shift was the most problematic in terms of predicted effectiveness. The predicted effectiveness drops significantly throughout the mid shift watch. A majority of this shift occurs at a BAC equivalency level greater than 0.08%. This means that reaction time is expected to be comparable to an individual who is legally drunk. The timing of low predicted effectiveness coincides with the time where personnel are briefing leadership and during their commute home from work. The two alternate rotation schedules that were developed and modeled seem to provide an improvement over the current schedule. The advantage of the alternate schedule is the decrease in number of mid shifts, providing watch standers the ability to recover quicker and perform at a higher level during the day and evening shifts. This change is in line with Miller's scheduling principles of shorter shifts and minimizing consecutive night shifts (Miller, 2008). The disadvantage is these alternative schedule rotations only allow two to four weekend days off per month, which contradicts Miller's principle of shiftwork scheduling to maximize weekend days off (Miller, 2008).

Of the 21 participants, 14 (66%) received less than seven hours of sleep on average throughout the duration of the study, which is less than the recommended amount of sleep needed to promote optimal health in an adult (Watson et al., 2015). Additionally, we did not identify a statistically significant improvement in night sleep duration between the baseline (MD=6.79, IQR=0.94) and light treatment period (MD=6.73, IQR=0.94) despite using the prescribed light treatments of HEV glasses and light canvases. Based on the effects light can have on a person's circadian rhythm this is not the result we expected. This finding, however, reveals how difficult it can be to replicate the proven effects of a light intervention in a laboratory study when in a real world environment. In addition to the lack of sleep quantity for many of the watch standers, results from the questionnaires reveal a lack of sleep quality as well. Daytime sleepiness was elevated for six (75%) of the participants at the beginning of the study, five (62.5%) at the midpoint, and six (75%) at the end of the study. Symptoms of insomnia were prevalent with five

(62.5%) participants displaying a minimum of sub-threshold insomnia throughout the three points of the study.

For a follow-on study, we recommend implementing one of the two alternate schedules that were developed. Prior to implementing this new schedule rotation, standardized questionnaires should be administered to the watch standers and sleep data should be collected to establish a new baseline period for the study. Preferably the collection period needs to last for a full cycle of the current watch schedule. After the baseline period is established sleep data can then be collected for another full cycle of the alternate schedule that is implemented. Then comparisons can be made between the sleep and questionnaire data collected from the alternate schedule and from the current schedule and the alternate schedule can be analytically assessed for improvements. Additionally, a new model can be developed using the sleep data collected while on the alternate schedule. The predicted effectiveness in this model can be compared to the model that was originally developed using current schedule sleep data and assessed for improvements. This study could also be taken one step further if watch standers are satisfied with the alternate schedule and there is a statistically significant improvement in sleep quantity and quality. Sleep data could be collected and analyzed for another cycle on the alternate schedule with light interventions implemented to determine if strategically timed light can further improve sleep and performance.

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ACKNOWLEDGMENTS

To my advisory team, Dr. Nita Shattuck and Dr. Panagiotis Matsangas, I would like to say thank you for all your guidance and mentorship throughout this process. Without your motivation and unwavering support, this research would not have been possible. It was an honor and a pleasure to be a part of the Crew Endurance Team.

I would like to thank LT Ben Hernandez for taking a leap of faith and reaching out to the Crew Endurance Team. You were my biggest advocate at the Pentagon and this study would not have happened without your dedication and support. I would also like to thank all the watchstanders who participated and made this study possible.

To my fellow graduate students and specifically my study group DBSG, thank you for always being there to support me and always having my back. I am forever grateful for the lifelong friendships we have formed.

To my parents, thank you for teaching me that a strong work ethic and positive attitude will always lead to success in the long run. Thank you for your constant love and support. To my wife Courtney and my two boys, this is dedicated to you. Thank you for believing in me always and keeping me motivated and focused to the very end. I love you more than I could ever put into words.

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I. INTRODUCTION

A. BACKGROUND

United States Navy shore-based watchfloors are manned 24/7 to provide information, intelligence, and technical support to the warfighter, and to support various maritime operations around the globe. Typically, service members in watchfloors are working in shifts. Shift working includes standing watch at various times of the day, sometimes at night and on weekends, with working hours oftentimes exceeding the normal 40 hours per week (Troxel et al., 2015). Consequently, shiftwork has been associated with restricted sleep duration, deteriorated quality of sleep, and elevated levels of fatigue (Shattuck & Matsangas, 2015). Also, working the night shift has consistently been linked to deteriorated vigilance and performance (Kazemi et al., 2016).

According to Troxel et al. (2015) sufficient sleep, both in quality and duration, is “vital for optimal mental and physical health, cognitive functioning, and performance” (Troxel et al., 2015). Scientific evidence and expert consensus stipulate that adults need seven hours of sleep or more per twenty-four hours. When humans do not receive the sleep they require in terms of sleep duration, sleep quality, and/or sleep at the appropriate times, they are considered sleep deprived (Shattuck et al., 2019). A study by Killgore et al. (2006) showed that sleep deprivation affects “the brain region responsible for higher-order cognitive processes, including judgment and decision-making” (Killgore et al., 2006).

Innovative methods have been developed to enhance the quality and quantity of sleep resulting in improved workplace performance (Sunde et al., 2020). One of these methods is high energy visible (HEV) light. According to research completed by Cajochen et al. (2005) and Duffy & Czeisler (2009), exposure to HEV light at appropriate times “has the potential to counter the immediate effects of night shiftwork by improving alertness and sleep quality, and decreasing fatigue levels” (Cajochen et al., 2005; Duffy & Czeisler, 2009).

In November 2017, the Atlantic and Pacific Naval Surface Force commanders jointly released the Comprehensive Fatigue and Endurance Management Policy (CFEMP), which mandated that surface ships implement circadian-based watch bills that afford each Sailor at least a seven-hour sleep opportunity at the same time each day (Commander Naval Surface Force Atlantic, & Commander Naval Surface Force Pacific, 2017). This policy was a significant shift from traditional Navy watchstanding schedules, where it was common for service members to sleep and work at a different time each day. Studies have shown implementing circadian-based watch bills leads to significant improvements in work performance, mood, and quality of sleep (Shattuck & Matsangas, 2015). Despite the advances made in addressing fatigue in the surface warfare community, this guidance does not regulate shiftwork at shore-based commands (Troxel et al., 2015). Absent specific directives or guidance, individual commands and watchfloors are left to develop their own watch rotations. Work and training schedules are developed by watch bill coordinators and senior watch officers who are generally junior to midgrade officers or non-commissioned officers. These schedule managers rarely possess sleep training, resulting in work schedules and rotations uninformed by sleep science. Through a combination of necessity and lack of sleep education, watch schedules often require frequent shift changes. A study that results in improved sleep quality and work performance could provide recommendations to other shore-based watchfloors that require non-traditional work schedules to support watchstanding operations.

Sheehan (2021) studied a shore-based watchfloor at the Pentagon requiring 24-hour watchstanding operations. She evaluated their current watch schedule using a validated fatigue model (Hursh et al., 2004), developed an improved watch schedule, and collected data from the watch standers while they were working on their original schedule by having the study participants complete a daily activity log electronically through the TimeUse application (Sheehan, 2021). Due to delays in obtaining security approval for wearing a sleep-tracking device, limited conclusions could be made from the data that was obtained (Sheehan, 2021). Additionally, because of COVID restrictions on

travel the study was completed remotely, which led to lower watchstander compliance throughout the study and limited the size of the dataset.

B. STUDY AIM AND OBJECTIVES

Personnel at the Chief of Naval Operations Intelligence Plot (CNO-IP) watchfloor at the Pentagon currently follow a schedule that requires frequent shift changes, which necessitates them to work different hours. As a result, many of these watch standers are reporting poor sleep quality and significant fatigue levels, which may affect their work performance and overall health. This study will focus on the above watchfloor and aims to improve watchstander sleep attributes, well-being, and performance. Specifically, the objectives of this study are the following:

- Assess watchstander sleep patterns, sleep attributes, and well-being while they are on their current watch schedule.
- Use a validated model of sleep and predicted effectiveness to assess the current watch schedule.
- Identify strengths and weaknesses of the current watch schedule.
- Develop a new watch schedule for the watchfloor that can be implemented and assessed.
- Assess whether strategically-timed HEV light exposure when participants are transitioning to a different shift will improve overall sleep quality and performance at work.

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II. LITERATURE REVIEW

A. SLEEP

1. Sleep Basics

According to Zaki et al. (2020) sleep is “an essential physiological process, which profoundly affects a wide range of biological activities” including cardiovascular, immunological, and metabolic activity (Zaki et al., 2020). Sleep also supports essential functions in the central nervous system including learning, memory, cognition, and emotional regulation (Zaki et al., 2020). Human health and cognitive functions will operate at a reduced effectiveness without the proper amount of healthy sleep resulting in poor health and degraded brain functionality.

The American Academy of Sleep Medicine and Sleep Research Society determined the recommended amount of sleep needed to promote optimal health in an adult is at least seven or more hours per night on a consistent basis (Watson et al., 2015). According to Watson et al. (2015) healthy sleep “requires adequate duration, good quality, appropriate timing, and a consistent schedule” (Watson et al., 2015). Adults who consistently sleep less than seven hours per night are at an increased risk for obesity, diabetes, hypertension, heart disease and depression. Additionally, consistently sleeping less than seven hours leads to impaired immune function and performance, increased number of mistakes, and greater risk of accidents (Watson et al., 2015).

Falling asleep and waking up at the same time each day results in enhanced sleep quality and reduced sleep onset latency (Vitaterna et al., 2001). A human’s circadian rhythm, homeostatic sleep pressure and external cues align to support sleep during designated sleep hours and support wakefulness during waking hours when a consistent sleep schedule is maintained (Czeisler & Gooley, 2007). Circadian rhythm and homeostatic sleep pressure are the two driving forces in human sleep and will be discussed in further detail. When it is necessary for a person to shift their sleep to a different time period, these two driving forces must adjust. This adjustment takes time; when a person travels across time zones, he or she will often experience daytime fatigue

and insomnia for several days and in some cases, for multiple weeks (Drake & Wright, 2011).

2. Human Circadian Rhythms

Sleep need is affected by the human circadian rhythm. It is the daily sleep/wake cycle followed by nearly all plant and animal species. The word circadian comes from a Latin phrase called “circa diem,” which translates to “about a day.” 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).

In the absence of external stimuli and cues such as light and social interaction, the circadian rhythm will continue to operate with a nearly 24-hour period and keep precise time (Czeisler & Gooley, 2007). External stimuli have the capacity to influence and alter the circadian rhythm, despite its inherent ability to function consistently (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 (Zaki et al., 2020).

When the circadian rhythm becomes offset from its current 24-hour alignment, the body clock becomes desynchronized. The body begins to realign itself in a process known as phase resetting. The circadian rhythm can change either through a phase delay (lengthening the day) or a phase advance (shortening the day). In a phase delay, the cycle shifts forward in time, whereas a phase advance moves the cycle earlier (Vitaterna et al., 2001). To give a practical example, if a person naturally goes to sleep each night at 10 pm, a one-hour phase delay would shift his or 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 dominant zeitgeber that causes changes in circadian rhythm and can induce phase shifts (Zaki et al., 2020). 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 (Czeisler & Gooley, 2007). Since the human body’s

internal clock varies by individual, 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).

There are endless opportunities for humans to work and sleep at times that conflict with daylight hours and the natural circadian rhythm due to modern technology and industrialization. The alignment between the circadian rhythm and the 24-hour day is disrupted by these non-traditional work schedules. When the circadian system is misaligned, it is always a cause for concern because the circadian rhythm contributes to health, wellness, and daily sleep (Zaki et al., 2020).

3. Homeostatic Sleep Pressure

Homeostatic sleep pressure is the second driving force in human sleep. A chemical called adenosine found in all human cells builds up in the body and brain, increasing in concentration every minute an individual is awake (Czeisler & Gooley, 2007). According to Dijk & Czeisler (1995), “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). The alignment of an individual’s sleep-wake schedule with their circadian rhythm benefits from sleeping at the same time every day and manages homeostatic sleep pressure so that sleepiness and wakefulness correspond more closely with sleep and wake times, respectively.

The circadian rhythm and homeostatic sleep pressure operate independently but both have a significant impact on neurobehavioral functions (Goel et al., 2013). The timing of alertness and sleepiness in relation to waking and sleeping hours is influenced by the interaction between the circadian rhythm and homeostatic sleep pressure (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). Even if an individual is tired after extended periods of wakefulness, the misalignment of endogenous sleep drivers and wake-sleep hours can make it difficult to fall asleep. Health and cognitive function can be negatively impacted by poor sleep quality or inadequate sleep quantity caused by this misalignment (Zaki et al., 2020).

4. Ways of Measuring Sleep

There are various methods for measuring the aspects of sleep and its different stages. Rapid eye movement (REM) and non-rapid eye movement (NREM) are the two primary sleep stages. Additionally, total sleep time (TST) and total time spent in bed (TIB) are two interest items for sleep studies (Miller et al., 2015). Since factors for quality sleep include adequate duration and appropriate timing, TST and TIB become significant measurements. Polysomnography (PSG), also known as a sleep study, is the most precise method for measuring sleep events. Electroencephalogram (EEG) electrodes are attached to the participant's scalp to measure brain activity and determine sleep and wake states (Miller et al., 2015). This technique requires highly controlled laboratory conditions and a substantial amount of effort by the researcher and participant. The researcher must be precise when attaching the electrodes to the participant's scalp and it is less than comfortable for the participant to sleep with electrodes attached to his or her scalp.

In recent years, wearable technology has been developed that is less invasive and capable of estimating sleep. Wrist-worn actigraphy devices can determine an individual's sleep-wake patterns by recording motion information continuously for long periods of time (Dimsdale et al., 2003). In the last few years, a multi-sensor sleep tracking device called the ŌURA ring has been developed. The ring provides numerous advantages, including a dedicated smart phone application to view user data in real-time. A study conducted in 2019 compared PSG sleep data to sleep data recorded using the ŌURA ring (de Zambotti et al., 2019). The study involved 41 adolescents and young adults and the duration was for one night. The results showed that within a satisfactory level, the ŌURA

ring was comparable to PSG in detecting TST and wake after sleep onset (WASO) (de Zambotti et al., 2019).

B. LIGHT AND THE CIRCADIAN SYSTEM

Studies have shown that light can either disrupt the circadian rhythm and have a negative impact or help the body align to the appropriate circadian rhythm and have a positive effect (Chellappa et al., 2013). The circadian rhythm is controlled by naturally occurring melatonin that helps regulate the sleep/wake schedule in humans (Cajochen et al., 2003). The circadian rhythm is also regulated by certain external factors such as meals, social interaction, temperature, and light (Reppert and Weaver, 2002). Circadian entrainment is influencing the body's circadian rhythm to align to a new shift more quickly, which can possibly be accomplished with an external stimulus such as HEV light (Rimmer et al., 2000). A contributing factor in maintaining a regular circadian rhythm is melatonin secretion, which can potentially be delayed by HEV light exposure (Cajochen et al., 2005).

The suprachiasmatic nucleus (SCN) is the region of the brain that is “the body’s master clock that controls the circadian rhythm” (Weaver, 1998). The circadian rhythm is “naturally synched to daylight hours through the retina’s exposure to light” (Reppert & Weaver, 2002). Research completed by Rautkylä et al. (2012) concludes that light influences alertness, “not just by suppressing melatonin secretion but also through a limbic pathway.” Their research also 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).

1. Spectral-Enriched Light

Multiple studies have examined the effects of spectrally enriched lights to gain an understanding of how light color impacts 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 studies have tested whether blue-enriched light has a greater impact on melatonin suppression and phase shifting. One study, conducted in 2003 absent natural sunlight in the most extreme conditions during Antarctic winter, had participants using white light (5,000 K) and blue-enriched light (17,000 K) for three months, to compare circadian phase and sleep attributes associated with both light exposures (Francis et al., 2008). Compared to white light, exposure to blue light was associated with slightly higher sleep efficiency. Total sleep time, sleep quality, and wake time were not significantly different between white and blue-enriched light (Francis et al., 2008). Their results suggested that blue-enriched light might have increased benefit to phase-shifting compared to white light.

2. Bright and Dim Light

Many studies have analyzed the differences between exposure to bright light and dim light. The amount of visible light emitted by a light source or light brightness is measured in lumens. The measurement is reported as lux when brightness of light is considered in relation to the space the light illuminates. An in-lab study at Monash University in Australia found that a daytime bright light exposure of 1,000 lux reduced afternoon sleepiness in participants compared to dim light exposure of less than 5 lux during the same period (Phipps-Nelson et al., 2003). An additional measure of participants' performance was reaction times. Participants exposed to bright light improved their reaction times; reaction times were slower for those who were exposed to dim light. Improvements in reaction times appeared almost immediately while improvements in afternoon sleepiness became significant after one hour of exposure to bright light (Phipps-Nelson et al., 2003).

3. Intermittent Light

Studies have shown that a similar ability exists to entrain the circadian rhythm when exposed to intermittent bright light instead of continuous bright light. One such study completed by Rimmer et al. (2000) provided evidence that repeated five-minute exposures to intermittent bright light exposure can reset the circadian rhythm with nearly

the same effectiveness as having continuous bright light exposure for five hours. The study considered bright light exposure at 25 or 90-minute intervals and found that when exposed to bright light for 31% of the time, compared to full bright light exposure, 70% of the response was preserved. When exposed to bright light for 63% of the time, 90% of the response was preserved (Rimmer et al., 2000). These results are important because despite eliminating light exposure for 37% of the time period only 10% of the circadian resetting response was lost (Rimmer et al., 2000).

4. Filtering Light

Sleep is not only disrupted during night shiftwork but also after returning to a day shiftwork schedule and sleeping at night. Studies have shown improvement in sleep quantity and quality has occurred when filtering light during working hours. One study observed an improvement in sleep length and efficiency in nurses working the night shift when they wore glasses that filtered out light with wavelengths less than 480 nanometers resulting in mean total sleep time increasing by 40 minutes compared to those not exposed to filtered light (Rahman et al., 2013). Additionally, participants experienced fewer awakenings during sleep as well as reduced sleep onset latency. This study also revealed that after returning to the day shift or having the day off, nighttime sleep was disrupted in addition to having disrupted daytime sleep when working the night shift (Rahman et al., 2013).

5. Circadian Phase-Shifting

The timing of light exposure impacts the direction of circadian phase-shifting. When shift workers are deliberately exposed to light when rotating between shifts it is imperative to understand the effect light exposure has on circadian phase-shifting. When timing is not considered, there is no guarantee light exposure will benefit shift workers. Light exposure occurring at the wrong time could lead to the opposite effect and contribute to phase-shifting in the opposite direction.

Intentional exposure to bright light has the potential to reset the circadian rhythm when sleep opportunities and work hours do not line up with daylight and nighttime hours (Shattuck & Matsangas, 2017). A study by Rimmer et al. (2000) discovered that

various negative effects of shiftwork and sleep deprivation can be improved by deliberately modifying the timing of external cues, thereby shifting the circadian alignment to the required working hours (Rimmer et al., 2000). The ability to adapt quicker to shifting work hours could improve sleep quality, decrease fatigue and sleep deprivation, and reduce negative impacts on cognitive function.

It is possible light exposure can be a tool used not only for 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 also for assisting with larger phase shifts that are required when traveling across multiple time zones or shifting to a different work shift with a drastic change in sleep/wake hours. During one study of phase shifting through intentional light exposure, an individual with a misaligned circadian clock was successfully realigned by six hours with two days of light exposure for several hours each evening (Duffy & Czeisler, 2009). The results of another study demonstrated a substantial and more efficient phase shift of the human circadian pacemaker can occur with only a short exposure to light (Chang et al., 2012). In 12 minutes of light exposure, the circadian pacemaker reset at a rate of 5.4 minutes per minute of light; compared to four hours of light exposure, the circadian pacemaker reset at a rate of less than one minute per minute of light exposure (Chang et al., 2012).

C. SHIFTWORK

1. Definition of Shiftwork

The Office of Technology Assessment defines shiftwork as “any nonstandard work schedule to include evening or night work, a rotating shift when hours change regularly or a split shift when a period of work is followed by time off and then a return to work” (U.S. Congress, Office of Technology Assessment, 1991). Modern society operates 24 hours a day and as a result essential services such as public safety, military defense, health care and public utilities must be provided at all times (Department of Health and Human Services [DHHS], 1997). In 2011, 18% to 26% of the workforce in the United States were shift workers on a regular basis (Drake, 2011).

2. Types of Shiftwork

Shift schedules vary in terms of shift length, rotation between different shifts, and frequency. A typical shift duration ranges from eight to 12 hours but shifts can be shorter or longer depending on the nature of the work involved (Office of Technology Assessment, 1991). When a shift rotates forward, the work hours shift clockwise from mornings to evenings followed by nights. The opposite is true for shifts that rotate backwards, rotating counterclockwise from mornings to nights followed by evenings.

The amount of time a worker spends on one shift before switching to another shift could be three days, four weeks or somewhere in between (Office of Technology Assessment, 1991). Shifts may occur on a daily, infrequent, or irregular basis. Transoceanic flight schedules or duty in addition to a normal work schedule are examples of irregular shiftwork when workers must work daytime hours during the workweek and occasional night or weekend shifts (Office of Technology Assessment, 1991). Infrequent shiftwork occurs when a worker with specific job responsibilities is needed to step in and cover for the normal shift worker who becomes sick or experiences a family emergency.

3. Variations in Shift Schedules

Numerous scheduling solutions have been developed to guarantee constant personnel coverage over the 24-hour day. In certain industries, schedules do not shift, and night workers remain on the same shift for an extensive period of at least six months if not longer. In the military, when land-based or shipboard personnel are standing watch during a deployment, slowly rotating watch schedules are often executed. Separation from family and social commitments allow for this type of schedule to be implemented in a deployed environment. When personnel are standing watch at non-deployed military watchfloors, rapidly rotating schedules are implemented to allow for training and other workplace tasks to be performed during the day, and to support social and family events that take place during daytime hours.

4. Shiftwork in the Military

Shiftwork in the military is often characterized by long workdays divided into two distinct activities: watchstanding and multiple off watch tasks including maintenance, drills, and training evolutions. All of these duties often result in 12-to-15-hour workdays with little recovery time (Shattuck & Matsangas, 2017). Specifically in a naval environment at sea, watches are manned 24 hours a day and are either fixed (when watch standers work the same watch every day) or rapidly rotating (when watch standers work a shift at different times each day). The decision to use a fixed or rapidly rotating schedule depends on command culture, prior experiences of command leaders, and the number of crew members available and qualified to stand watch (Shattuck & Matsangas, 2017). The number of qualified crew members is a critical factor for those commands with a limited crew size. Given these factors, multiple rotating and fixed watch schedules can be implemented including 4-hours on watch followed by 8-hours off watch, 6-hours on watch followed by 6-hours off watch, 12-hours on watch followed by 12-hours off watch, 6-hours on watch followed by 18-hours off watch, or a fixed 3-hours on watch followed by 9-hours off watch (Shattuck & Matsangas, 2017).

D. PROBLEMS ASSOCIATED WITH SLEEP AND SHIFTWORK

1. Consequences of Poor Sleep on Overall Health, Fatigue, and Safety

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 shiftwork disorder have been associated with shiftwork (Rajaratnam et al., 2013). Cardiometabolic diseases and mood disorders occur at higher incidence in shift workers (Rajaratnam et al., 2013).

2. Performance Decrements and Degraded Attention with Sleep Loss

The ability to maintain attention is a critical component needed to perform a task. Attention involves the simultaneous process of choosing the relevant information on

which to focus while recognizing and subsequently ignoring distracters or irrelevant information (Caputo & Guerra, 1997). Attention tests assess the capability to distinguish between relevant and irrelevant information and can measure an individual's ability to pay attention at a certain time (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).

3. Performance

Research indicates that sleep deprivation has a negative impact on both low-level and high-level cognitive skills (Harrison & Horne, 1999). The ability to think with creativity, innovation, and flexibility are the functions most impaired by sleep deprivation. 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).

E. SHIFTWORK MITIGATIONS

1. Light Interventions

Many studies have been conducted to determine what effect light interventions have on shift worker performance. According to Zaki et al. (2020), light interventions during the first half of a night shift have the potential to improve nocturnal functioning and daytime sleep (Zaki et al., 2020). A recent study completed by Sunde et al. (2020) provided insight on whether exposure to light impacted performance and alertness during a simulated night shift and compared the effects of short wavelength light and long wavelength light (Sunde et al., 2020). The results of the study revealed a significant difference between short wavelength light and long wavelength light. The participants experienced improved performance and less fatigue when exposed to short wavelength light while the improvements were less significant when the participants were exposed to long wavelength light (Sunde et al., 2020).

Portable devices have been developed in recent years that allow individuals to perform self-administered light interventions. A study by Comtet et al. (2019) attempted to answer the question of whether a light intervention can assist with counteracting the effects of sleep deprivation. The study compared traditional light therapy boxes and LED glasses (Comtet et al., 2019). Eighteen individuals received 30 minutes of light treatment after experiencing one night of complete sleep deprivation. The results of the study showed that light intervention with the light therapy boxes and LED glasses “can significantly enhance vigilance, cognition and also tends to improve mood” (Comtet et al., 2019).

2. Scheduling

With 24/7 shiftwork so often a necessary requirement, best practices have been created for designing and executing watch schedules that support 24/7 operations. In 2008, Dr. Jay Miller developed a manual for the Air Force Inspector General and Air Staff that consists of nine components and nine principles to consider when creating a shiftwork schedule (Miller, 2008; see Tables 1 and 2). These components and principles incorporate social needs as well as human biological needs to sleep and perform while operating in a shiftwork environment. Miller recommends incorporating these components and principles into watch schedules that include rotating shifts.

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

	Component	Description
People Components	Number of crews	The number of crews determines “the work demand in a regular schedule, and the average number of hours worked by each individual worker.” Four sections provide the optimal balance between different demands on the worker and personnel cost to the employer.
	Employment ratio	Staff strength “must be greater than the day-to-day demand to accommodate holidays, annual leave, sick leave, training time, administrative time, or other unforeseen circumstances that disrupt the ability to meet 24/7 work demand.” Must “maintain a ratio from 1:1.15 to 1:1.35 depending on the industry type”.
Time Components	Shift type	Shifts may be “fixed or rotating.” Shifts may rotate “forward (clockwise) or backward (counterclockwise)”.
	Shift length	Useful 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 needs to be considered.
Structural Components	Shift system	Determined by “the ratio of workdays to free days”.
	Shift plan	The “sequence of workdays, and days off within a shift system.”
Interaction Components	Shift differentials	Hourly pay rate differences “between day and night shifts.” Can also “be provided by adjusting number of hours worked on each shift while keeping pay constant”.
	Alignment of workdays and days off with weekends	The way that “the shift plan aligns with the calendar week determines the number of weekend days off”.
	Shift change times	The morning shift start time impacts the number of shift workers able to maximize their sleep quality and quantity during nighttime 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 almost always disrupts the circadian rhythm”.	Work “exclusively night shift and try to shift circadian rhythm as much as possible.” 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 no more than eight hours” are encouraged. Risk increases exponentially between hour eight and hour 12 of a shift.	Twelve-hour shifts should be limited to “jobs with low physical and emotional work stress, and low demands for vigilance”.
Minimum consecutive night shifts	“Minimize number of consecutive night shifts.” A single night shift in the shift plan is preferred.	“Productivity goes down and safety risk increases by a factor of 2.5 on successive night shifts compared with successive day shifts.” Studies show by the fourth night, risk of accident and injury increases by 36%.
24 hours of off time after each night shift	The day following a night watch is spent recovering from the night work. During this time workers “may be a safety hazard to themselves and coworkers.”	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	Resolving the issue of perceived inequality when attempting to ensure all workers receive equality number of weekend days off.	If 12-hour weekend shifts are implemented to increase weekend days off, this should be balanced with the increased risk of on-the-job errors and safely commuting home at the end of a night shift.
At least 104 days off per year	Shift workers should have at least 104 quality days off per year, which is the equivalent of a weekday worker having	Shift workers should have more than 104 days off per year to ensure quality days off and to balance additional strains and stressors

Principle	Description	Recommendations
	52 weekends off which also equals 104 days.	placed on shift workers. Days that a worker gets off following a night shift should not be considered as a quality day off.
Equity	Shift workers “should be exposed to an equal amount of long hours, night work, weekend work, and have equal access to quality time off.”	Planned schedules, with minimal last-minute changes, and consideration of weekends will provide the most equity.
Predictability	Simple and easy to understand schedules with a clear cycle allow workers “to predict their workdays and off days well into the future”.	Schedule predictability is the third highest concern in shift workers. The ability to understand and predict the work schedule and days off well into the future contributes to worker morale.
Good quality of time off	Quality time off is the primary concern 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 and consecutive night shifts designed to consolidate workdays.

The hours of night sleep available to day shift workers are affected by the timing of the morning shift change. A study assessing the impact of morning shift change times found that early wake-up times between 4 and 5 am result in decreased sleep duration the previous night and increased daytime sleepiness during the shift (Akerstedt, 2003). A morning shift change time at 0700 instead of 0600 could lead to increased sleep duration and decreased daytime sleepiness. If it is feasible in the operating environment, a nap during the night shift could boost shift worker alertness in the early morning hours of the shift. Research shows a nap should last 30 minutes to two hours with a five to fifteen wake-up period to combat sleep inertia and regain alertness prior to resuming shiftwork responsibilities (Akerstedt, 2003).

Aligning to a fixed schedule instead of a rapidly rotating schedule so shift workers can sleep at the same time each day can improve sleep quality, performance and overall mood (Shattuck & Matsangas, 2015; Shattuck et al., 2015). In a two-phased study of watch standers onboard USS NIMITZ, the authors assessed Sailors while they were working two different watch schedules, a rapidly rotating schedule with five hours on watch/10 hours off watch and a fixed schedule with three hours on watch/nine hours off watch (Shattuck & Matsangas, 2015; Shattuck et al., 2015). Despite having the same average sleep duration on both schedules, Sailors observed on the fixed watch schedule experienced less daytime sleepiness, improved mood, 30% faster reaction times and 40% fewer mistakes compared to these same Sailors observed on the rapidly rotating 5/10 schedule (Shattuck & Matsangas, 2015; Shattuck et al., 2015). This study provides evidence that moving to a fixed schedule gives watch standers the ability to have a consistent sleeping period during the natural circadian rhythm and leads to improved performance and overall quality of life.

3. Related Studies

Several studies conducted by the Crew Endurance Team at the Naval Postgraduate School (NPS) have assessed the strengths and weaknesses of watch schedules used in the military. Many of these studies were conducted during military operations, including Sailors on naval ships, trainees, aircrew, ground troops, and security details (Shattuck et al., 2018). Some of these studies were conducted in military education and training commands, but very few have specifically assessed military shore-based watchfloors (Sheehan, 2021).

The operational environment in a military shore-based watchfloor differs from a ship, submarine, or aircraft squadron. In watchfloors there are often competing work responsibilities as well as social and family obligations that are not factors in a deployed environment. Like certain watch stations on a ship or submarine, working in a watchfloor often involves extended periods of sitting and monitoring computer screens while constantly assessing the situation. Watch standers are required to use a unique combination of low-level cognition through vigilance and alertness as well as high-level

cognition at a moment's notice when employing critical thinking and problem-solving skills to make decisions.

A study conducted in the White House Military Office President's Emergency Operations Center provide insight regarding the challenges experienced in watchfloors (Shattuck et al., 2015). In their original "Panama" schedule, watch standers stood 12-hour shifts for 2–3 days and then had 2–3 days off. Every two weeks the watch standers would shift from days to nights or nights to days. A new schedule was developed that had the watch standers standing a 24-hour shift followed by three days off before the next 24-hour shift. Watch standers would sleep for five hours, either 1700–2400 or 0000–0500 during their 24-hour watchstanding period (Shattuck et al., 2015). Watch standers were able to better maintain their circadian rhythm with fewer sleep disruptions when sleeping during their work period. Watch standers were overwhelmingly in favor of the new schedule; they reported feeling more rested and better suited to meet their family and social obligations (Shattuck et al., 2015).

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III. METHODS

A. STUDY OVERVIEW

1. Participants

Twenty-one watch standers from the CNO-IP watchfloor volunteered to be participants in this research study. Personnel participated from all five duty sections of the CNO-IP watchfloor. Although they work on the watchfloor at different hours each day, the 35-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. We were able to collect data for two complete rotation cycles during the baseline and treatment period of the study. An example of the watch sections and where they are in a cycle is shown in Figure 1.

IPWA Watchbill																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
	S	M	T	W	R	F	S	S	M	T	W	R	F	S	S	M	T	W	R	F	S	S	M	T	W	R	F	S	S	M	T	W	R	F	S	
Section 1	O	8	8	8	8	8	O	O	8	8	8	8	8	12	12	O	O	O	O	O	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	O
Section 2	12	8	8	8	8	8	O	O	8	8	8	8	8	O	O	8	8	8	8	8	12	12	O	O	O	O	O	D	D	D	D	D	D	D	D	12
Section 3	D	D	D	D	D	D	12	12	8	8	8	8	O	O	8	8	8	8	8	O	O	8	8	8	8	8	12	12	O	O	O	O	O	O	O	D
Section 4	O	8	8	8	8	8	12	12	O	O	O	O	O	D	D	D	D	D	D	D	12	12	8	8	8	8	O	O	8	8	8	8	8	O	O	
Section 5	12	O	O	O	O	O	D	D	D	D	D	D	D	12	12	8	8	8	8	O	O	8	8	8	8	8	O	O	8	8	8	8	8	12		

D	DUTY	12	(0600-1800)
O	OFF	12	(1800-0600)
		8	(0600-1400)
		8	(1400-2200)
		8	(2200-0600)

Figure 1. Current CNO-IP schedule rotation for the five-section watch schedule

Approval for the study was obtained from the Naval Postgraduate School Institutional Review Board. Participation was voluntary and all participants provided informed consent. Each participant was provided a unique identification number that was used to distinguish among participants in the study without the use of personally identifiable information.

2. Tools

a. Sleep Assessment

Total night sleep time and rest durations were assessed by ÖURA ring wearable devices (ÖURA Health Ltd, Oulu, Finland). An ÖURA ring is a non-invasive device that can be worn day and night and fits on an individual's finger of their choosing. Studies show the rings can accurately record total sleep time and sleep duration (de Zambotti et al., 2019). We determined the total night sleep durations of the 21 participants using the data for hours of sleep per night collected from the ÖURA rings.

b. Light Interventions

Before the treatment period of the study, participants were issued Luminette 3 light therapy glasses. Luminette glasses emit blue-enriched white light that peaks at 468 nm. Special HEV light canvases that emit approximately 2000 lux installed on the watchfloor.

c. Questionnaires

Participants completed pen-and-paper questionnaires at the beginning of the study, the midpoint, and at the end of the collection period. The pre-study questionnaire included items on demographic characteristics (age, sex), occupational characteristics (military occupational specialty, rank), caffeine use, exercise routine, and four standardized tools, i.e., the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989), the Insomnia Severity Index (ISI) (Bastien, Vallieres, & Morin, 2001), the Epworth Sleepiness Scale (ESS) (Johns, 1991), and the Profile of Mood States (POMS) (McNair et al., 1971).

The mid-study and the end-of-study questionnaires included the same four standardized tools. Also, the end-of-study questionnaire included questions relating to personal experiences when using the light-emitting devices, and questions regarding their satisfaction with the current watchstanding schedule.

(1) Pittsburgh Sleep Quality Index (PSQI)

The Pittsburgh Sleep Quality Index (PSQI) was used to assess sleep quality (Buysse et al., 1989). PSQI includes questions inquiring about a participant's amount of sleep and self-assessed reasons for poor sleep. 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 general enthusiasm level, ability to stay awake during wake hours, and overall sleep quality. The PSQI combines all the areas into one composite score (range 0–21) based on seven different areas related to sleep quality and disruptions (Buysse et al., 1989). Participants with scores less than or equal to five were classified as “good sleepers” and those with scores greater than five were classified as “poor sleepers.”

(2) Insomnia Severity Index (ISI)

The Insomnia Severity Index was used to assess the severity of insomnia symptoms (Bastien, Vallieres, & Morin, 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, Vallieres, & Morin, 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. Participants with scores ranging from 0 to 7 are considered having no indication of insomnia, 8 to 14 as subthreshold insomnia, 15 to 21 as moderately severe insomnia, and 22 to 28 as severe insomnia (Bastien, Vallieres, & Morin, 2001).

(3) Epworth Sleepiness Scale (ESS)

The Epworth Sleepiness Scale was used to assess average daytime sleepiness (Johns, 1991). ESS uses self-assessed questions about activities where the respondent feels tired, to determine a participant's level of daytime sleepiness (Johns, 1991). The

questionnaire uses eight items asking the participants to indicate their chance of dozing when participating in activities such as watching the television, sitting in traffic while driving, or reading (Johns, 1991). Scores range from 0 to 24 with scores less than or equal to 10 considered normal and scores greater than 10 indicate excessive or “elevated” daytime sleepiness (Johns, 1991).

(4) Profile of Mood States (POMS)

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 tense, considerate, active, weary, alert, lively, and good natured. 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 and scores seven qualities of an individual’s mood: fatigue, anger-hostility, vigor-activity, confusion-bewilderment, depression, tension-anxiety, and total mood disturbance (McNair et al., 1971). An individual is said to display that quality if an individual’s score is greater than the 50th percentile of adults in the general population (McNair et al., 1971).

3. Procedures

The study was meant to be as non-invasive as possible to maximize compliance and not interfere with watchstander tasks and responsibilities. Figure 2 shows the general outline of the study. At the beginning of the study, May 31-June 1, 2022, participants were issued an ŌURA ring and asked to download the phone-based app to track their daily sleep activity during the study period.

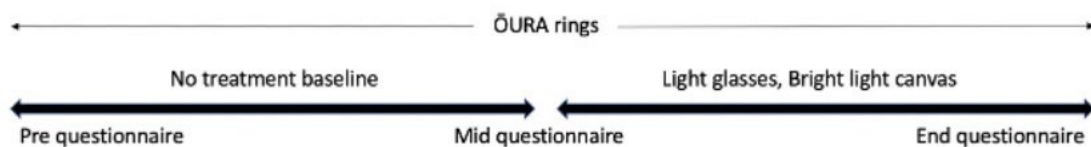


Figure 2. General study outline.

After signing the consent form, participants were asked to complete the Pre-study questionnaire. All questionnaires throughout the study were administered in a conference room outside of the watchfloor in the Pentagon. Participant sleep data from the ÖURA rings were recorded over two complete watch rotation cycles during the baseline period. ÖURA ring data was collected via the app and automatically synced by the user every few days throughout the study. Emails reminding participants to wear their ÖURA rings were sent as necessary to ensure sleep duration data was collected.

After the baseline period of the study (August 17–18, 2022), participants were asked to complete the mid-study questionnaire. After completion of the mid-study questionnaire, participants were issued Luminette 3 light therapy glasses, instructed on their use, and trained on the treatment regime of wearing the glasses for the first 30 to 60 minutes after commencing watch on the mid shift. Light canvases were also installed on the watchfloor during this time. Additionally, command leadership was briefed on two alternate schedule recommendations that had been developed by the research team.

Participant sleep data from ÖURA rings were recorded over two complete watch rotation cycles during the treatment period. At the conclusion of the study on December 15–16, 2022, participants completed the end-of-study questionnaire. All ÖURA rings and light devices were collected at this time.

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, was used to gain insight into how a person’s predicted effectiveness is impacted by their sleep schedule. 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., 2004). FAST allows a user to input the hours they are asleep and awake over a period of days, weeks, or even months. FAST displays the time, sleep hours, work hours, predicted effectiveness, and equivalent blood alcohol equivalent (BAC) scale over the chosen period of time, as shown in Figure 3.

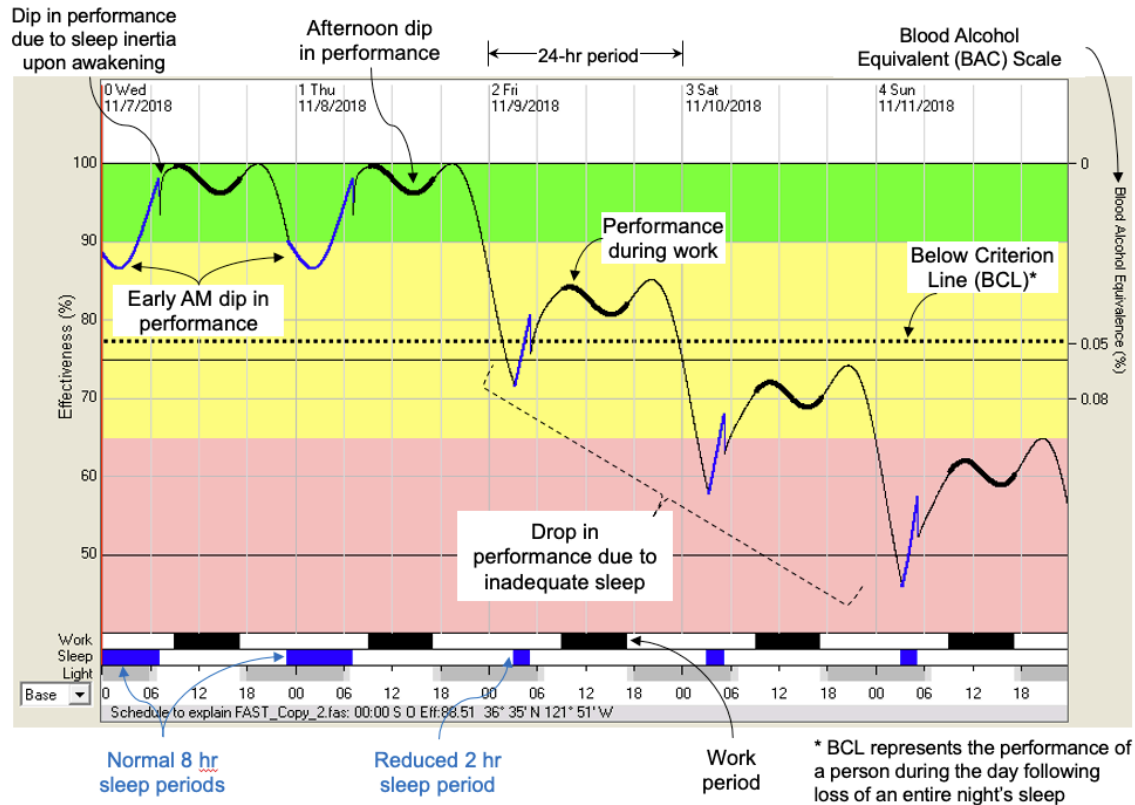


Figure 3. FAST output display description. Source: N. Shattuck and P. Matsangas, PowerPoint slides (2021).

The FAST software uses the SAFTE model, developed by Dr. Steven Hursh and colleagues, and validated through scientific review and research studies (Hursh et al., 2004). 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., 2004). Figure 4 depicts the contributing components to the algorithm employed in the SAFTE model.

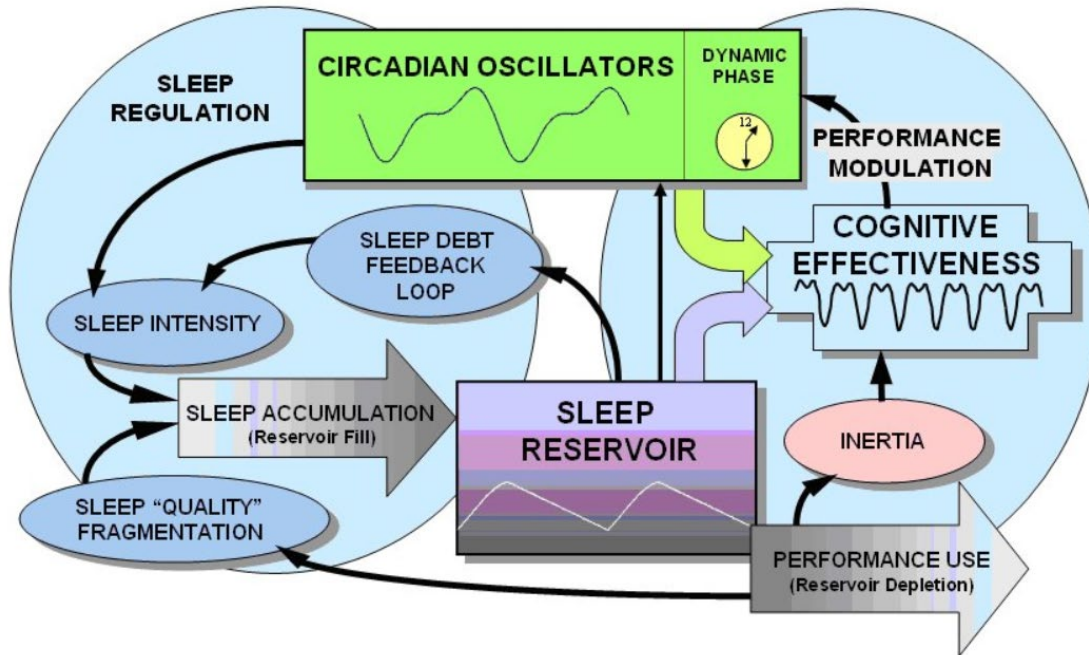


Figure 4. Sleep, activity, fatigue and task effectiveness (SAFTE) model conceptual diagram. Source: Fatigue Science (2004).

The performance effectiveness predicted by the SAFTE model has been validated against laboratory studies to accurately represent degradation in cognitive performance due to sleep deprivation (Hursh et al., 2004). 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., 2004]).

The SAFTE model can serve as an alternative for laboratory data to predict how shiftwork and constantly changing sleep hours impact performance. 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 to more accurately represent how sleep and performance are impacted by shiftwork (Hursh et al., 2004). Sleep propensity and sleep intensity are determined by the alignment, or misalignment, of sleep hours with the circadian rhythm (Hursh et al., 2004). 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., 2004). 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., 2004). Though this equilibrium is well below baseline, it will persist until another sleep characteristic changes.

The SAFTE model attempts to account 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., 2004). The sleep reservoir accounts for the duration of sleep, sleep quality, sleep intensity, and accumulated sleep debt enables the model output to reflect the impact of accumulated sleep characteristics over time (Hursh et al., 2004).

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). According to the FAST Start Guide written by Archinoetics LLC (2006), 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” (Archinoetics, 2006). Therefore, the percentage of time an individual spends below the criterion line indicates the percentage of a given shift wherein 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 85% for an evening shift means that the average predicted effectiveness for all evening shiftwork hours, during the time period represented, is 85%. The lowest predicted effectiveness is the lowest value that the effectiveness dips to on a specified shift during the period of interest. Using the evening shift example, a value of 70% for lowest predicted effectiveness means that the lowest dip in effectiveness during evening shifts is 70%. The shift time spent below the criterion line conveys what percentage of a work shift is below the criterion line. A value of 10% indicates that of all the time on the evening shift during the time period examined, 10% is

spent below the criterion line and 90% 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.

2. Current Schedule Model

The CNO-IP watchfloor currently operates with a 35-day cycle that rotates watch standers through the day, evening, and mid shifts. During this cycle, watch standers have seven day shifts, five evening shifts, and seven mid shifts. Two days are taken off between day shift and evening shift and between evening shift and mid shift. After the mid shift there are 12 days off before starting the day shift again. The last seven of the off days are spent in a duty status where a watchstander can be called in to fill one of the watch sections if a watchstander is sick, has a family emergency or another extenuating circumstance preventing him or her from standing watch that day. Day shift hours are 0600 to 1400, evening shift hours are 1400 to 2200, and mid shift hours are 2200 to 0600. On weekends, shifts are consolidated into two 12-hour sections with a day section from 0600 to 1800 and mid section from 1800 to 0600. Shift turnover is conducted 30 minutes preceding the beginning of a shift, so that watch standers begin working at 0530, 1330, and 2130 for the day, evening, and mid shifts respectively during weekdays. On the weekends watch standers begin working at 1730 or 0530. Additionally, mid shift watch standers present a daily operations and intelligence briefing to the OPNAV staff at 0600 on weekdays extending the working hours of the mid shift to 0630.

The work-sleep schedule was input into the SAFTE model using FAST software to conduct initial performance analysis. The schedule was verified with the watchfloor leadership. The work-sleep schedule includes a commute of 30 minutes, which was the average reported commute from the watch standers. The schedule ensures the watch standers have at least one hour between waking time and starting their commute. Sleep duration for each shift was modeled using ÖURA data collected during the baseline period of the study. The schedule includes six hours of good sleep per 24-hour period before a day shift, seven hours of good sleep before an evening

shift, and six and a half hours of good sleep before a mid shift. Watch standers attempted to immediately return to normal night sleep hours once off the mid shift. Figure 5 depicts the nominal sleep and work schedule associated with the current rotation schedule.

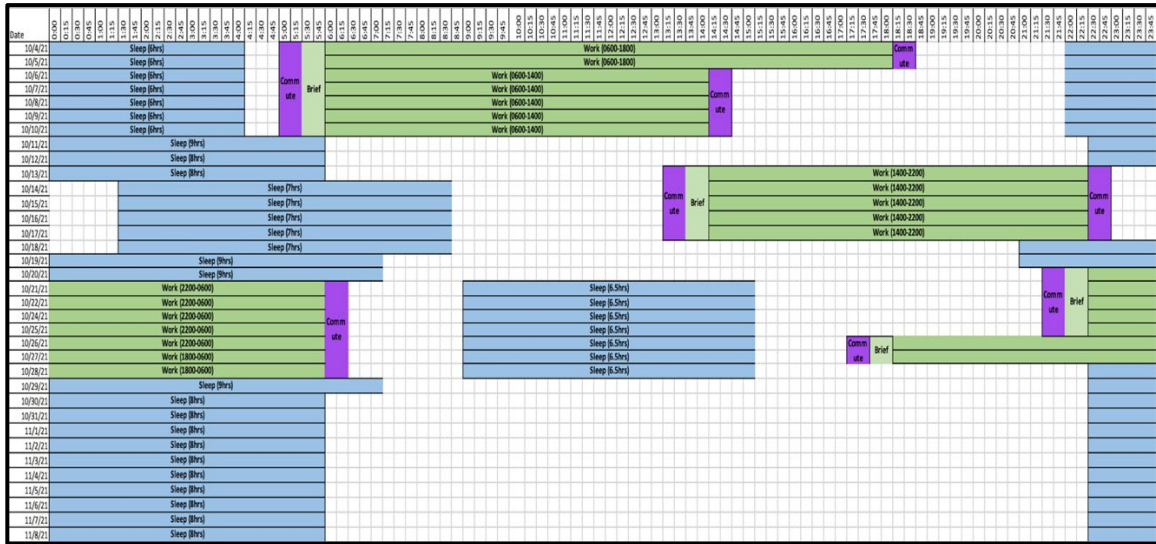


Figure 5. Nominal sleep/work schedule for the current rotation

3. Alternate Schedule Models

We developed two additional watch rotation schedules for the CNO-IP watchfloor to consider implementing. In addition to the current rotation schedule, these two schedules are also modeled using the SAFTE model.

C. STATISTICAL ANALYSIS

Statistical analysis was conducted with a statistical software package (JMP Pro 16; Statistical Discovery LLC; Cary, North Carolina). Data are presented as mean (M) ± standard deviation (SD) or median (MD), as appropriate. Significance level was set at $p < 0.1$. All variables underwent descriptive statistical analysis to determine demographic characteristics of the study population. The data were assessed for normality using the Shapiro–Wilk test. Due to the lack of normality in questionnaire responses and sleep data, nonparametric methods were used to analyze the data. One-sided tests were chosen

to determine if light treatment had any improvement in the variables measured. Our hypothesis was that light treatment would improve sleep and performance, so an improvement throughout the study was determined by comparing data from the different study periods.

Sleep data from the ÖURA rings were collected from 01 June 2022 to 13 December 2022. Data were downloaded every two weeks from the ÖURA website and aggregated using Microsoft Excel. Data were aggregated into baseline and treatment groups by participant for comparison. Median night sleep durations for each participant during each study period were calculated. Differences between participant sleep duration during baseline and light treatment periods were compared using Wilcoxon Signed Rank test.

Questionnaire scores (PSQI, ISI, ESS, POMS) were calculated using standard scoring templates for each test. When ranges were given by participants (e.g., 0430–0530 or 60–90 minutes), when the questionnaire asked for the “average time” the average was used for analysis. Any missing responses for the participant’s POMS responses were handled in accordance with the POMS manual (McNair et al., 1971). The changes in questionnaire scores between the pre, mid, and end point of the study were assessed using pairwise Wilcoxon Signed Rank test. POMS categorizations for greater than or less than the 50th percentile of adults in the general population were also analyzed using McNemar’s test.

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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, evening, and mid).

1. Current Rotation Schedule

The current rotation schedule provides the baseline predicted effectiveness for the Pentagon watch bill schedule. The FAST output for the current schedule is shown in Figure 6 and predicted effectiveness attributes shown 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 where personnel are briefing leadership and during their commute home from work. The day shift watches begin low due to fatigue carryover from mid-shift and early awakenings for the day shift. While on this schedule rotation cycle, the predicted effectiveness continues to cycle below 90% predicted effectiveness during the day and mid shift, never reaching the green zone of high predicted effectiveness.

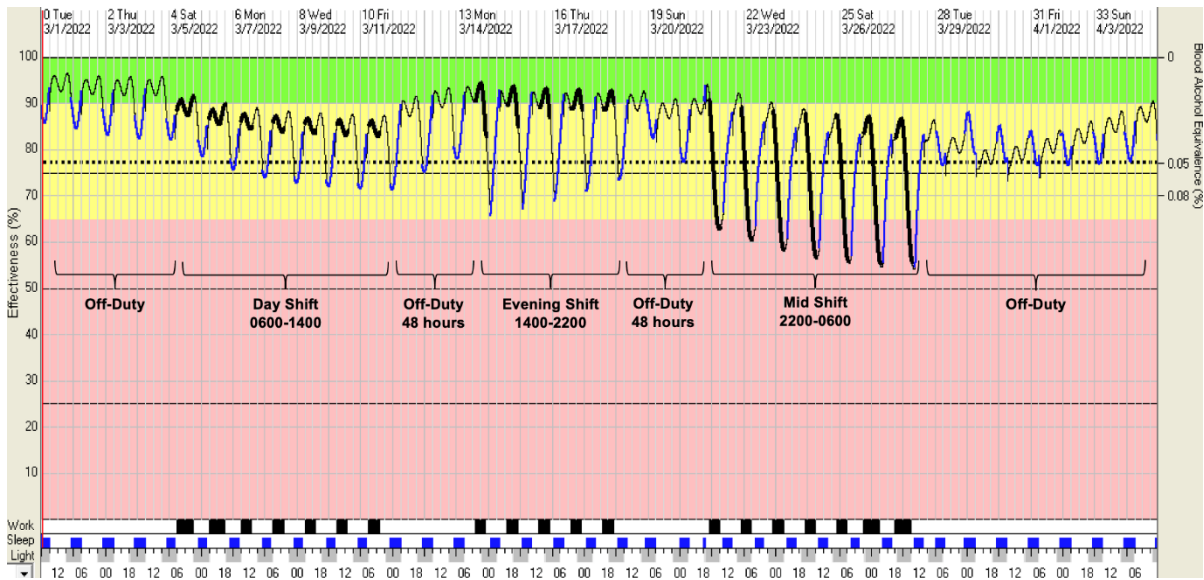


Figure 6. SAFTE-modeled predicted effectiveness on current schedule rotation

Table 3. Current schedule attributes

Attributes	During Work Hours		
	Day	Evening	Mid
Predicted Effectiveness (PE)	86%	91%	73%
Lowest PE	83%	80%	54%
Shift time spent Below the Criterion Line (BCL)	0%	0%	56%

2. Alternate Rotation Schedules

We developed two additional watch rotation schedules for the CNO-IP watchfloor to consider implementing. For clarity, they are referred to as alternate schedule one and alternate schedule two. The alternate schedules both maintain five self-contained watch sections that rotate through the same cycle. Alternate schedule one has a 20-day cycle and alternate schedule two has a 15-day cycle, which are both reduced from the current 35-day cycle. Shift hours, turnover time, and weekday briefs all remain the same as the current schedule. However, the alternate schedules do not have the consolidated 12-hour

sections on the weekends and the number of consecutive days on the mid shift is reduced to four days for alternate schedule one and three days for alternate schedule two. Sleep is modeled using the same ÖURA data collected during the baseline period of the study. The nominal sleep and work hours for alternate schedules one and two are depicted in Figure 7 and Figure 8.

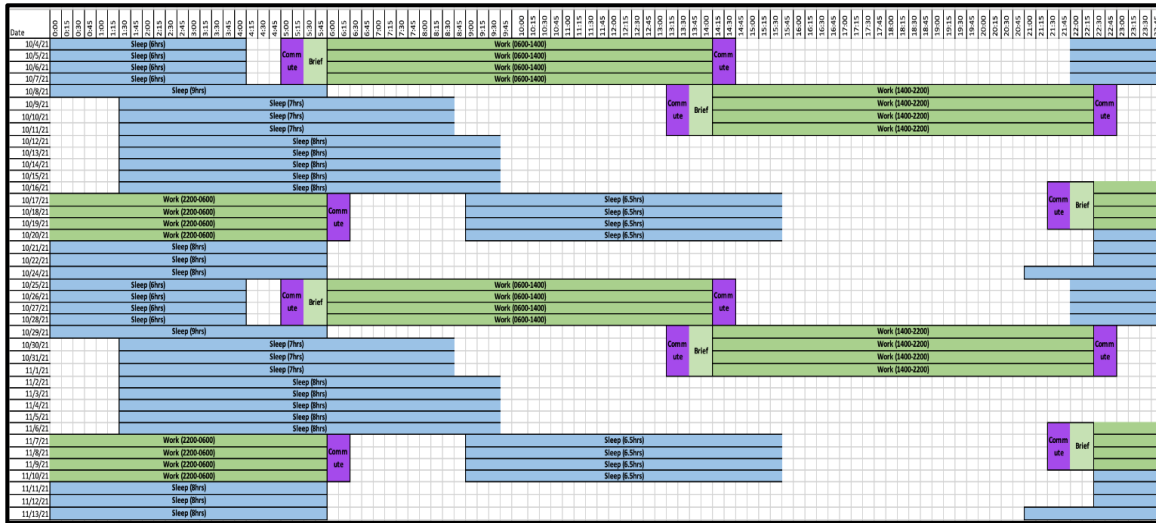


Figure 7. Nominal sleep and work schedule for alternate schedule one

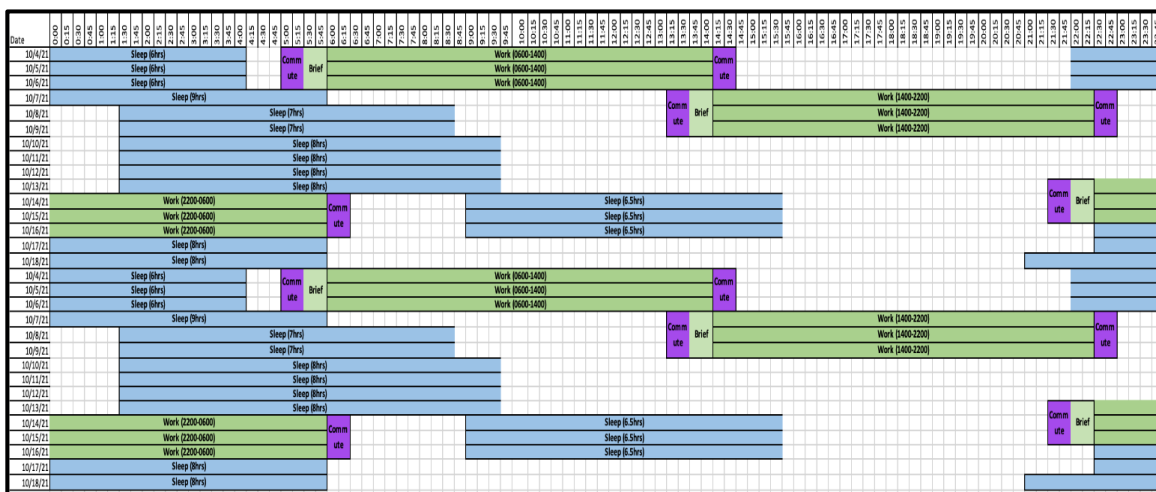


Figure 8. Nominal sleep and work schedule for alternate schedule two

a. *Alternate Rotation Schedule One*

In the first alternate rotation, schedule modifications include the consolidation of the mid-shift watches from seven days down to a four-day period, a decrease in cycle length to 20 days, and eliminating 12-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. However, the predicted effectiveness only drops into the red zone at the very end of the shift on the third and fourth day, with most of the shift occurring when the BAC equivalency level is less than 0.08%. Like in the current schedule, the lowest points of predicted effectiveness correspond with the time that the watch standers are briefing leadership and commuting home from work. The day shifts have an overall higher predicted effectiveness because proper recovery occurs during off days with the number of consecutive mid shift days being reduced to four.

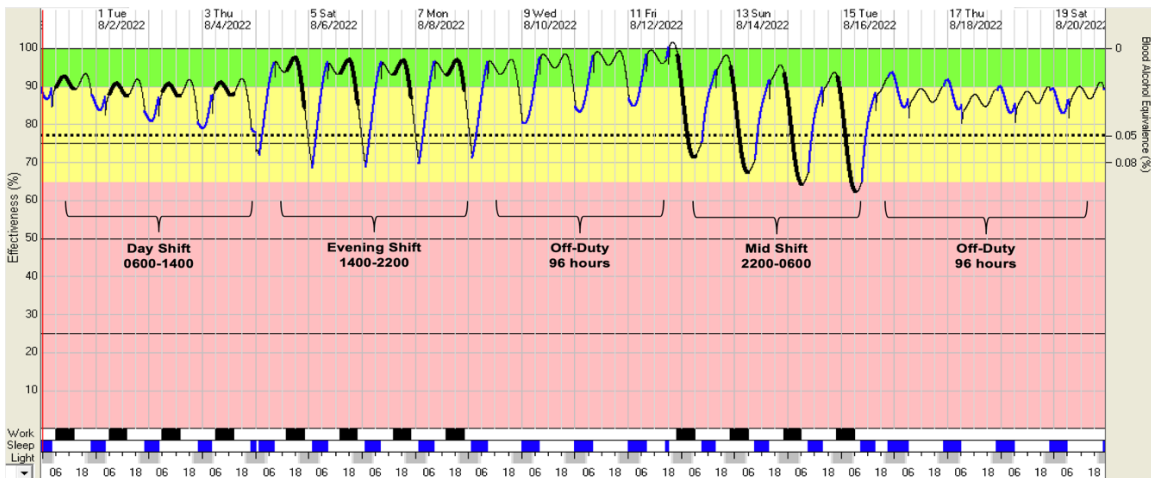


Figure 9. SAFTE modeled predicted effectiveness on alternate rotation schedule one

Table 4. Alternate schedule one attributes

Attributes	During Work Hours		
	Day	Evening	Mid
Predicted Effectiveness (PE)	90%	95%	78%
Lowest PE	88%	84%	63%
Shift time spent Below the Criterion Line (BCL)	0%	0%	55%

b. Alternate Rotation Schedule Two

The second alternate rotation schedule has attributes similar to the first alternate rotation schedule, but the number of mid-shift watches is further reduced to three and cycle length is reduced to 15 days. The resulting model output is similar, 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, but the predicted effectiveness only drops into the red zone at the very end of the shift on the third day, with most of the shift occurring when the BAC equivalency level is less than 0.08%. As was the case with alternate schedule one, the day shifts have an overall higher predicted effectiveness because proper recovery occurs during off days with the number of consecutive mid shift days being reduced to three. Having off only three days in a row limits the ability to maximize weekend days off.

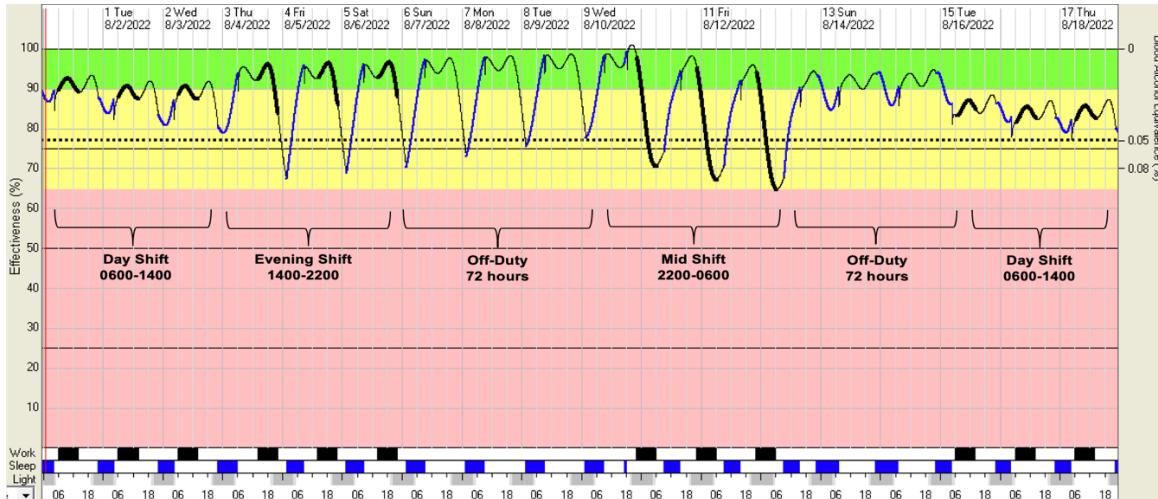


Figure 10. SAFTE-modeled predicted effectiveness on alternate rotation schedule two

Table 5. Alternate schedule two attributes

Attributes	During Work Hours		
	Day	Evening	Mid
Predicted Effectiveness (PE)	90%	94%	79%
Lowest PE	88%	85%	65%
Shift time spent Below the Criterion Line (BCL)	0%	0%	53%

3. Schedule Rotation Model Comparison

The attributes of each schedule’s modeled output are depicted in Table 6. The mid shift is the most problematic shift for all three schedule rotations. All mid shift briefings and commutes occur when predicted effectiveness is below the BCL and above a BAC equivalency of 0.08%. That is, watch standers participate in briefings and commute with a predicted performance level of someone who is legally drunk. The current shiftwork schedule rotates with seven consecutive mid shifts never allows performance to fully recover 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 benefit with less consecutive

mid shifts. The reduced number of mid shifts enables recovery to a higher predicted effectiveness level following the mid shifts.

Table 6. Schedule attribute comparison

Attributes		During Work Hours		
		Day	Evening	Mid
Percent of Shift spent	Current	0%	0%	56%
Below the Criterion Line (BCL) <i>*Lower is better</i>	Alternate 1	0%	0%	55%
	Alternate 2	0%	0%	53%
Average Predicted Effectiveness (PE) on Shift <i>*Higher is better</i>	Current	86%	91%	73%
	Alternate 1	90%	95%	78%
	Alternate 2	90%	94%	79%
Lowest PE on Shift <i>*Higher is better</i>	Current	83%	80%	54%
	Alternate 1	88%	84%	63%
	Alternate 2	88%	85%	65%

B. PARTICIPANT DEMOGRAPHICS

Twenty-one participants were recruited for the study. The study sample included 12 (57%) males and nine (43%) females. The participants consisted of 12 (57%) officer watch standers, with the other 9 (45%) consisting of enlisted watch standers. The median age of participants was 30 (IQR=9) years.

Due to various issues, 13 participants were unable to complete the mid or end-of-study questionnaire. Therefore, their partial questionnaire data was excluded from the final analysis. In addition, four participants did not wear their ŌURA rings during the treatment period of the study and their data were also excluded. Consequently, 17 participants were used for ŌURA sleep data analysis and eight participants were used for questionnaire data analysis.

C. SLEEP AND WELLNESS

All 21 participants reported drinking at least one caffeinated beverage (coffee, tea, soda, or energy drink) per day. Two participants reported daily tobacco use. Also, 19 out of 21 participants reported having an exercise routine, ranging from three to six exercise sessions per week, with a duration of 30 to 90 minutes per session. Reported exercise included cardio, weightlifting, and cross-training.

Throughout the overall study, participants received a median of 6.65 (IQR=2.03) hours of night sleep out of 7.66 (IQR=2.32) hours rest period. Of the 21 participants, 14 (66%) received less than seven hours of sleep on average throughout the duration of the study. Figure 11 shows the distribution plot of participants by night sleep duration.

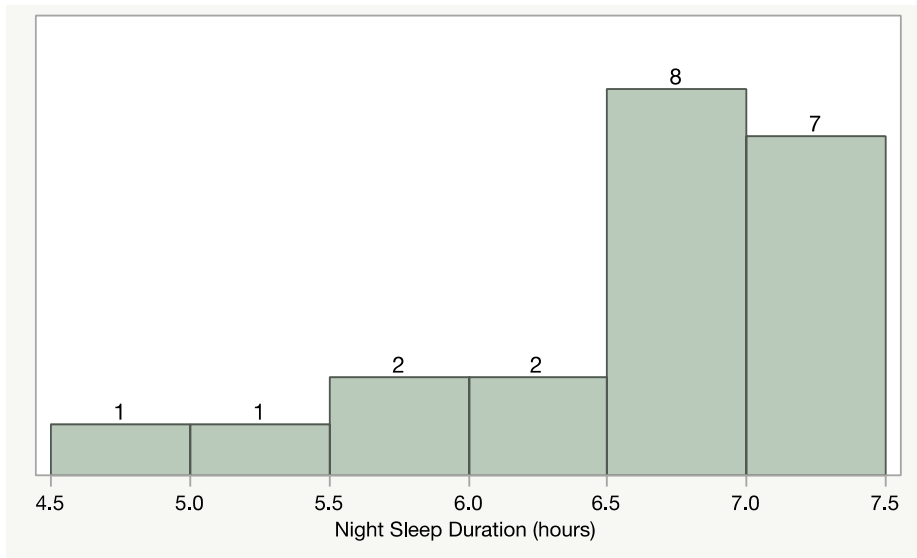


Figure 11. Night sleep duration in hours per night for the entire study. Numbers above bars denote the number of participants.

During the baseline period without the HEV light treatment, participants received a median of 6.79 (IQR=0.94) hours of night sleep out of 7.78 (IQR=1.27) hours night rest. During the light treatment period, participants received 6.73 (IQR=0.94) hours of night sleep out of 7.7 (IQR=1.4) hours night rest. Figure 12 shows the median night sleep duration by day for all participants across the entirety of the study. Blue bars denote the

baseline period and red bars denote the light treatment period. Black dots represent individual data for each participant and day.

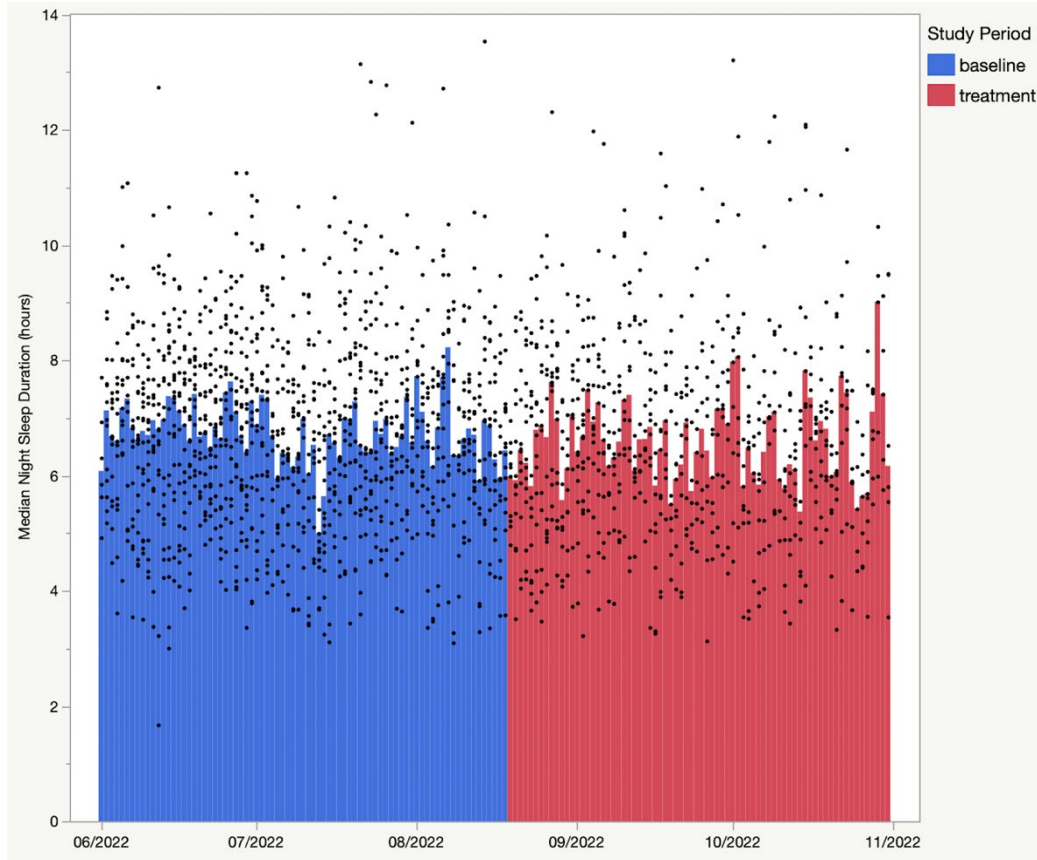


Figure 12. Median total sleep time over duration of study grouped in baseline and treatment.

Four participants had missing sleep data in the treatment period. Therefore, only 17 matched pairs were able to be compared. Statistical comparison of median night sleep duration between baseline and light treatment periods revealed no statistically significant improvement (One-sided Wilcoxon Signed Rank test, $S = 16.0$, $p = 0.466$).

D. SLEEP QUALITY

Sleep quality was measured with the Pittsburg Sleep Quality Index (PSQI) questionnaire at three stages during the study (Pre, Mid, and End). PSQI global scores

amongst the eight participants ranged from 4 to 14 throughout the study with a median score of 8 (IQR=4). As shown in in Figure 13, the median PSQI score at the beginning of the study was of 8 (IQR=4.25), 9 (IQR=4.5) at the mid-point, and 6.5 (IQR=3.75) at the end. The vertical lines in the graph denote the IQR. No significant statistical improvement was indicated between the Pre and the End point (One-sided Wilcoxon Signed Rank, test stat, $S = -7.0$, $p = 0.406$) or between the Mid and the End point (One-sided Wilcoxon Signed Rank test, $S = -3.5$, $p = 0.703$).

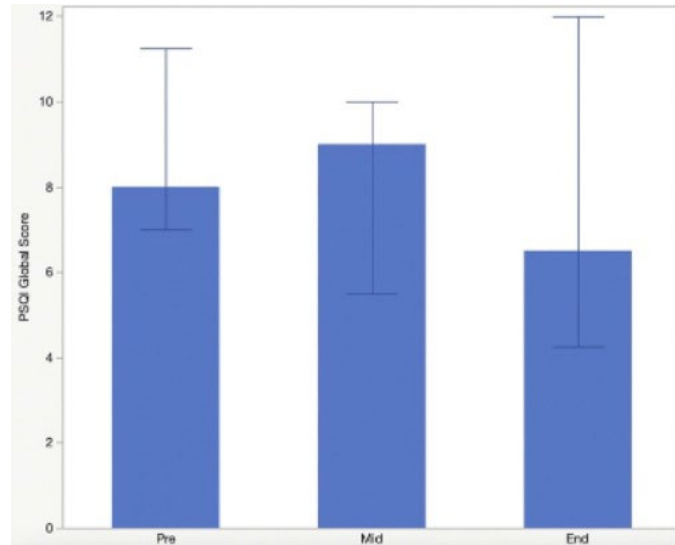


Figure 13. Median PSQI scores.

As shown in Figure 14, eight (100%) of the participants were classified as “poor sleepers” based on their PSQI scores in the beginning of the study. At the midpoint, two (25%) participants were classified as “good sleepers” and six (75%) as “poor sleepers.” At the end of the study, three (37.5%) were classified as “good sleepers” and five (62.5%) as “poor sleepers.” A visual inspection of the figure shows improvement in the number of poor sleepers from the beginning of the study to the end of the study.

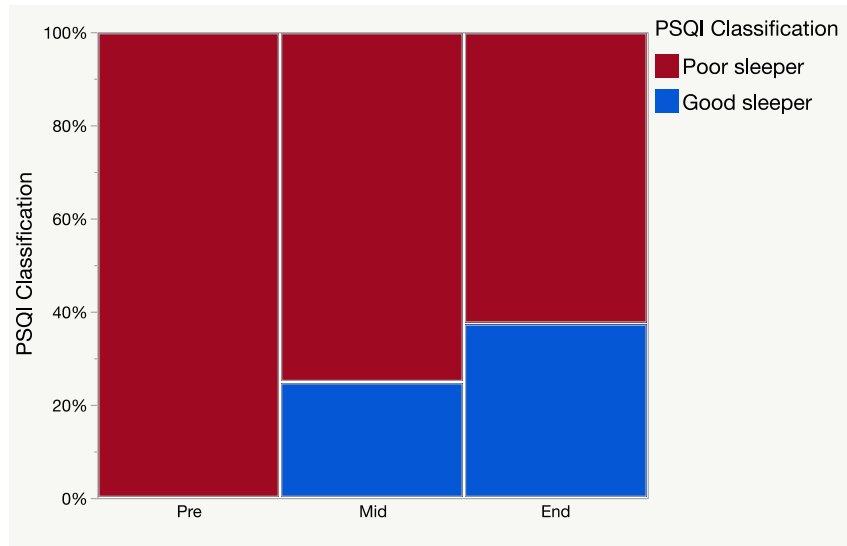


Figure 14. PSQI classification breakdown.

E. AVERAGE DAYTIME SLEEPINESS

Throughout the study, ESS scores ranged from 4 to 21 with a median 13 (IQR=6.75). As seen in Figure 15, six (75%) participants at the pre-study questionnaire reported ESS scores denoting elevated daytime sleepiness. Mid-study five (62.5%) participants reported ESS scores denoting elevated daytime sleepiness, whereas at the end of the study six (75%) participants reported ESS scores denoting elevated daytime sleepiness. No statistically significant improvement was found when comparing Pre to End scores of participants (One-sided Wilcoxon Signed Rank test, $S = 2.5$, $p = 0.750$) and Mid-End scores (One-sided Wilcoxon Signed Rank test, $S = 3.5$, $p = 0.664$).

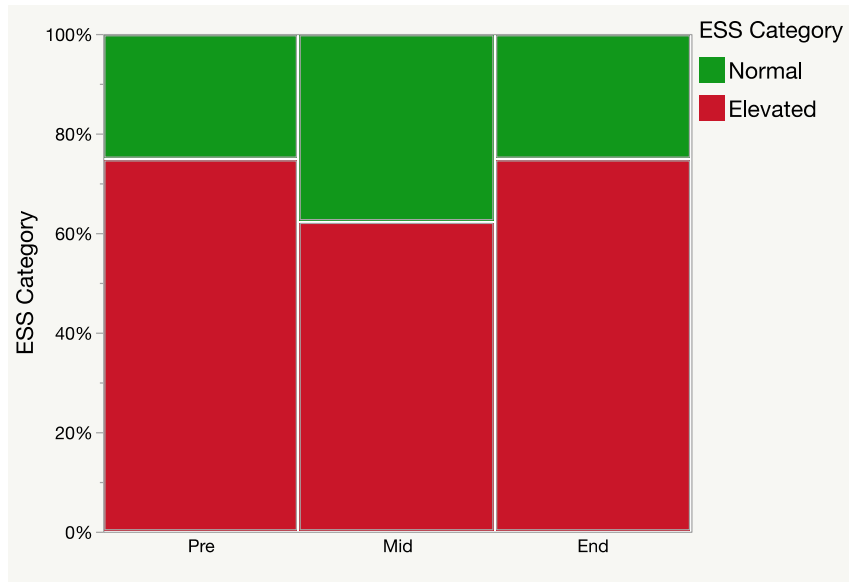


Figure 15. Daytime sleepiness classification based on ESS scores.

F. INSOMNIA SYMPTOMS

ISI scores throughout the study ranged from 3 to 21 with a median score of 11 (IQR=8.75). As displayed in Figure 16, at the beginning of the study three (37.50%) participants did not show any significant symptoms of insomnia, whereas three (37.50%) showed subthreshold insomnia symptoms and two (25%) showed moderately severe symptoms. At the midpoint, three (37.50%) participants did not show any significant symptoms of insomnia, whereas two (25%) showed subthreshold insomnia symptoms and three (37.50%) showed insomnia symptoms of moderate severity. At the end of the study, three (37.50%) participants did not show any significant symptoms of insomnia, whereas two (25%) showed symptoms of subthreshold insomnia and three (37.50%) showed symptoms of moderate severity insomnia.

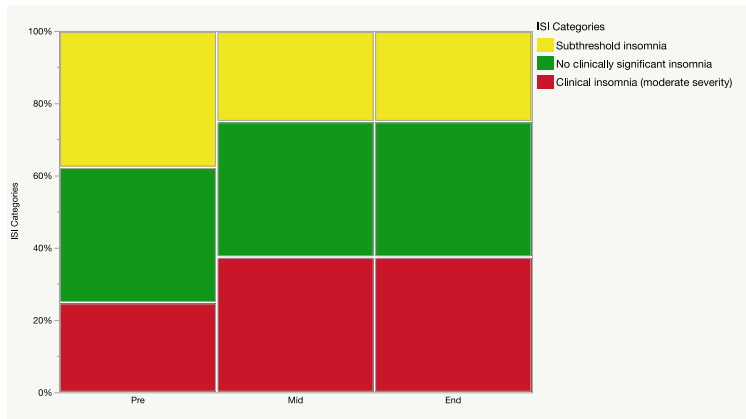


Figure 16. Insomnia groups based on ISI scores

ISI scores did not show any statistically significant improvement (i.e., decrease in scores) between the Pre and the End point (One-sided Wilcoxon Signed Rank test, $S = -1.0$, $p = 0.500$) or between the Mid and the End point (One-sided Wilcoxon Signed Rank test, $S = -6.0$, $p = 0.742$).

G. MOOD STATES

POMS scores did not change at a statistically significant level during the study. In particular, no statistically significant improvement was found when comparing Pre to End scores for Tension (One-sided Wilcoxon Signed Rank test, $S = 6.5$, $p = 0.469$), Depression ($S = 11.0$, $p = 0.148$), Anger ($S = 4.5$, $p = 0.578$), Vigor ($S = -1.0$, $p = 0.945$), Fatigue ($S = 6.0$, $p = 0.445$), Confusion ($S = 2.5$, $p = 0.719$), and Total Mood Disturbance ($S = 9.0$, $p = 0.250$).

Also, no statistically significant improvement was found when comparing Mid to End scores for Tension (One-sided Wilcoxon Signed Rank test, $S = -3.0$, $p = 0.711$), Depression ($S = -5.0$, $p = 0.547$), Anger ($S = -8.5$, $p = 0.273$), Vigor ($S = 1.5$, $p = 0.836$), Fatigue ($S = -10.5$, $p = 0.219$), Confusion ($S = -7.0$, $p = 0.359$), and Total Mood Disturbance ($S = -10.0$, $p = 0.180$).

Displayed in Figure 17 is the percentage of participants with POMS scores greater than the 50th percentile scores for the general adult population compared to the percentage of participants with scores less than the 50th percentile. No statistically

significant differences were found when comparing Pre to End POMS scores for Depression (McNemar’s test, $X^2(1)= 0.3, p = 0.564$), Anger (McNemar’s test, $X^2(1)= 0, p = 1.0$), Vigor (McNemar’s test, $X^2(1)= 0.3, p = 0.564$), Fatigue (McNemar’s test, $X^2(1)= 0.3, p = 0.564$), Confusion (McNemar’s test, $X^2(1)= 2, p = 0.157$), and Total Mood Disturbance (McNemar’s test, $X^2(1)= 0, p = 1.0$).

There was a statistically significant increase in the percentage of participants with scores greater than the 50th percentile when comparing Pre to End POMS Tension (McNemar’s test, $X^2(1) = 3, p = 0.083$).

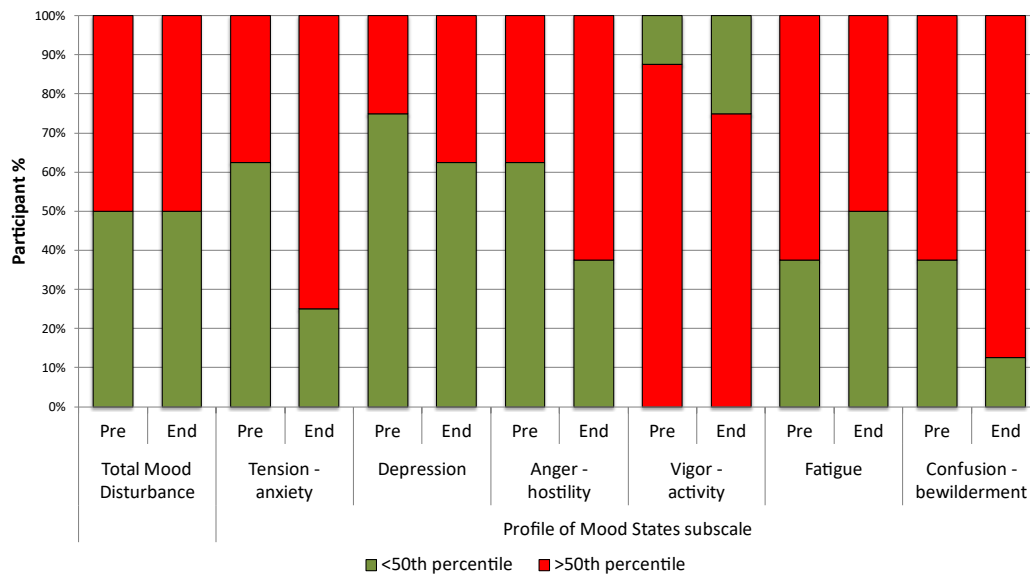


Figure 17. Percentage of participants above and below the 50th percentile of the POMS norms for the adult population at the beginning (“Pre”) and end of the study (“End”).

H. RESULTS SUMMARY

A summary of the study’s results can be seen in Table 7. For this study we were mainly concerned with the differences between the Pre and End scores as well as Mid and End as this denotes changes in baseline and light treatment stages. No light treatment was provided between the Pre and the Midpoint, (i.e., the baseline period of the study).

Table 7. Summary results and statistical significance of all differences.

Measure	Statistical Significance of differences	<i>p value</i>	
		Pre to End	Mid to End
Night Sleep Duration	No	^a 0.466	
Percentage of poor sleepers	-	improved	improved
PSQI scores	No	0.406	0.703
ESS scores	No	0.750	0.664
ISI scores	No	0.500	0.742
POMS-Tension scores	No	0.468	0.711
POMS-Depression scores	No	0.148	0.547
POMS-Anger scores	No	0.578	0.273
POMS-Vigor scores	No	0.945	0.836
POMS-Fatigue scores	No	0.445	0.219
POMS-Confusion scores	No	0.719	0.359
POMS-Total Mood scores	No	0.250	0.180

^a Sleep duration compared median night sleep of baseline and treatment periods

I. SCHEDULE AND LIGHTING ACCEPTANCE

Results from the questions asked in the end of study questionnaire regarding opinions of the current watchstanding schedule provide an overview of watchstanders opinions on how their current schedule affects different aspects of their life. Figure 18 has the individual questions in descending order of negative responses. More than 50% of the participants noted that they do not like their current schedule in terms of the adequacy of their personal time, adequacy of sleep time, quality of sleep, and whether they have enough time to work out.

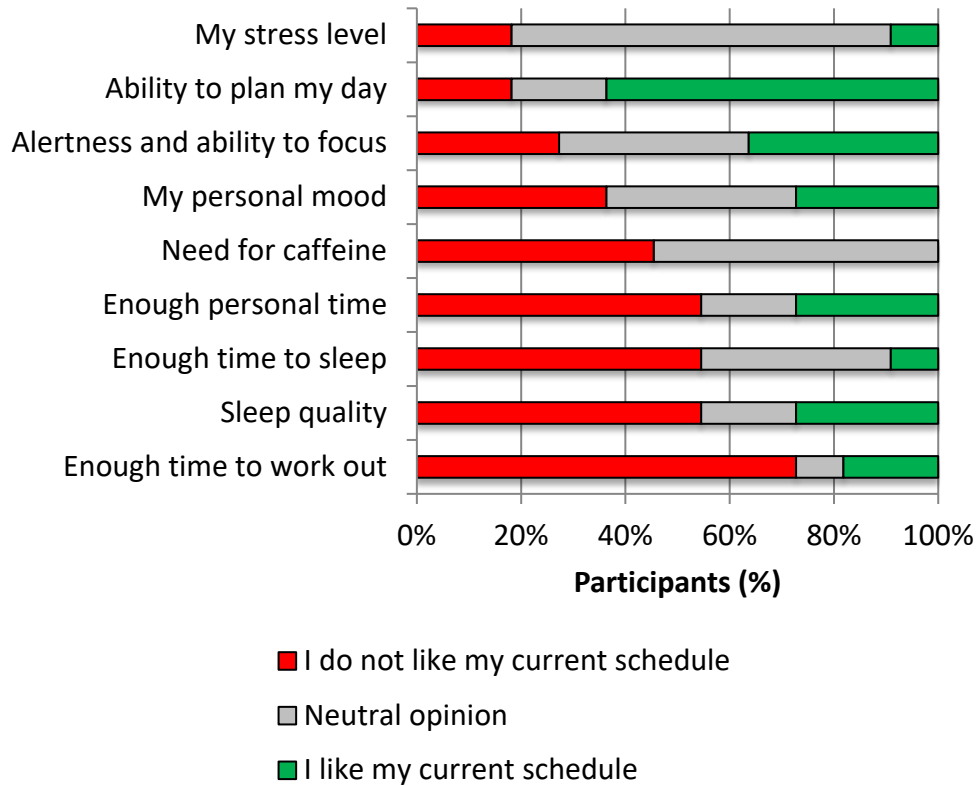


Figure 18. Responses to questions regarding opinion of current schedule in end of study questionnaire. Items are listed in descending order of negative responses.

Also, at the end of the study, participants were asked to rate their satisfaction with the light interventions. Figure 19 shows that all study participants were either indifferent or satisfied with how the different light interventions were implemented, and whether they affected their sleep and mood.

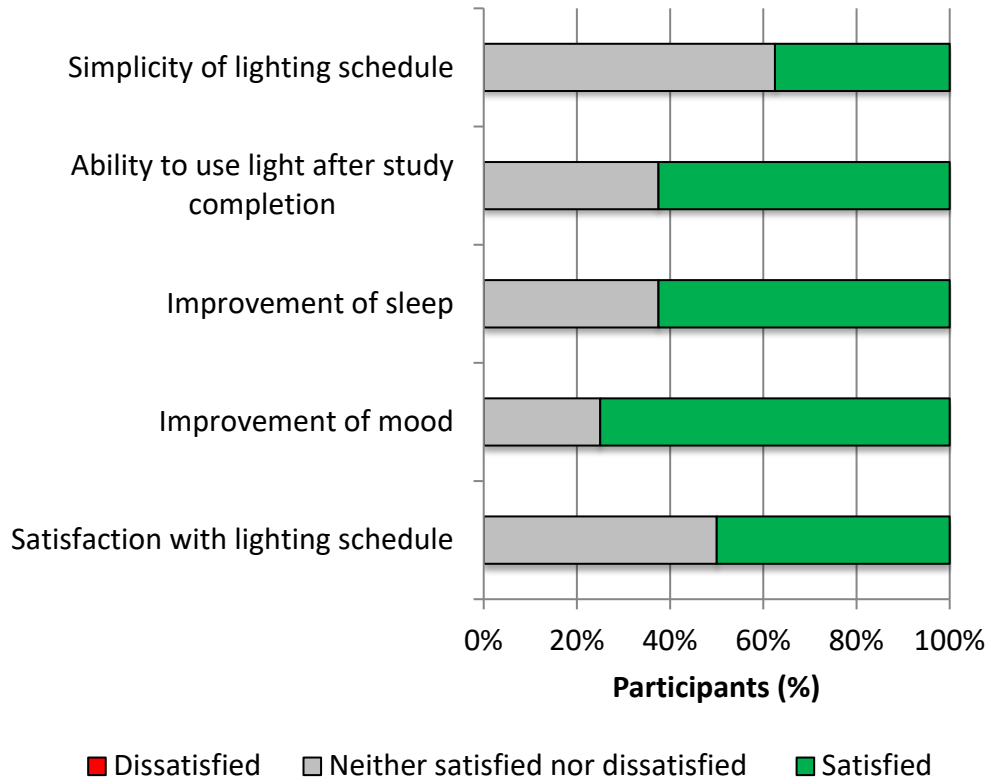


Figure 19. Responses to questions regarding opinion of light interventions.

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V. DISCUSSION

A. CONCLUSIONS

Watch standers at the Pentagon face the challenge to balance a rapidly rotating schedule with competing work demands as well as family and social obligations. Many studies have been conducted onboard surface ships and submarines to assess the utility of watch schedules, but few studies are focused on shore-based watchfloors. With this background in mind, our research assessed whether a schedule that requires frequent shift changes affects work performance and overall health of watchstanders working at the CNO-IP watchfloor. Also, this study explored whether bright light exposure can be effectively used to improve performance and sleep in both quality and quantity. We worked to complete five objectives, which helped gather information that was used to craft answers to the research questions. First, watchstander sleep patterns, sleep attributes, and well-being were assessed while they operated on their current watch schedule. Second, a validated model of sleep and predicted effectiveness was used to assess the current watch schedule. Third, strengths and weaknesses of the current watch schedule were identified. Fourth, two new watch schedules were developed that can be implemented and assessed. Lastly, we assessed whether strategically timed HEV light exposure will improve overall sleep quality and workplace performance.

We found that the median night sleep duration throughout the study was 6.65 (IQR=2.03). Of the 21 participants, 14 (66%) received less than seven hours of sleep on average throughout the duration of the study, which is less than the recommended amount of sleep needed to promote optimal health in an adult (Watson et al., 2015). Additionally, there was not a statistically significant improvement in night sleep duration between the baseline (MD=6.79, IQR=0.94) and light treatment period (MD=6.73, IQR=0.94) despite using the prescribed light treatments of HEV glasses and light canvases. Based on the known effects that light can have on a person's circadian rhythm, these results were somewhat surprising. This result, however, reveals how difficult it can be to replicate the proven effects of a light intervention in a laboratory study when in a real-world environment.

In addition to the lack of sleep quantity for many of the watchstanders, results from the questionnaires reveal a lack of sleep quality as well. Daytime sleepiness measured by the ESS was elevated for six (75%) of the participants at the beginning of the study, five (62.5%) at the midpoint, and six (75%) at the end of the study. Symptoms of insomnia were prevalent with five (62.5%) participants displaying a minimum of sub-threshold insomnia throughout the three points of the study. There were no significant differences in POMS scores throughout the study with one exception, the Tension subscale. There was a significant increase in participants who scored greater than the general population 50th percentile for the general population found when comparing Pre to End POMS categorization for Tension ($p = 0.083$), i.e., more study participants felt tense at the end of the study than at the beginning of the study. However, after a visual inspection of the PSQI scores, the results also reveal fewer participants were classified as “poor sleepers” from the beginning (100%) to the end (62.5%) of the study.

Also, the sleep schedule that was modeled in FAST provided some interesting insights. The results of the model reveal that the end of the mid shift is where the highest risk to safety and cognitive performance occur. Watch standers are briefing their leadership and commuting home from their shift during this period. The model results show these watch standers have a predicted effectiveness and fatigue level worse than someone who has lost a full night of sleep and has a BAC equivalency level above the legal limit of 0.08%. Therefore, the model indicates that the watch standers are briefing and commuting home with an equivalent cognitive performance of someone who is legally drunk. Of note, the model was based on the average sleep duration while on each shift, so it is likely that some watch standers are getting more sleep and performing better than the model’s predicted effectiveness, and some are getting less sleep and performing worse than the model’s predicted effectiveness.

The proposed alternative schedule rotations seem to provide an improvement over the current schedule. The advantage of the alternate schedule is the decrease in number of mid shifts, providing watch standers the ability to recover quicker and perform at a higher level during the day and evening shifts. This change is in line with Miller’s scheduling principles of shorter shifts and minimizing consecutive night shifts (Miller, 2008). The

disadvantage is these alternative schedule rotations only allow two to four weekend days off per month, which contradicts Miller's principle of shiftwork scheduling to maximize weekend days off (Miller, 2008).

B. LIMITATIONS

This study has several limitations. The small size of the watch team limited the number of participants to 21. Due to various issues, 13 participants were unable to complete the mid or end-of-study questionnaire. Therefore, only eight participants were used for comparative analysis that was performed between the pre, mid, and post-questionnaire responses. In addition, four participants did not wear their ŌURA rings during the treatment period of the study and their data were also excluded when performing comparative analysis between baseline and treatment periods.

Another limitation was not having security approval for the study participants to wear the ŌURA rings on the watchfloor. This meant the watch standers had to remove their ŌURA ring prior to entering the watchfloor and then put their ring back on after exiting the watchfloor. While we were able to successfully complete the study, this was not an ideal situation for the watch standers who were responsible for remembering to put their ring back on after the completion of every shift.

A third limitation was not getting approval for the research team to have access to the watchfloor. The research team had to rely on a watchfloor schematic to determine the appropriate number of light devices required and we were unable to assist with the installation of the light canvases on the watchfloor. Additionally, having access to the watchfloor is beneficial when recruiting watch standers to participate in the study and conducting follow up visits to administer mid and end of study questionnaires. For this study the research team was set up in a conference room that was not on the same floor of the Pentagon as the watchfloor. We were reliant on the watch standers to visit the conference room to volunteer for the study and fill out the mid and end of study questionnaire.

C. RECOMMENDATIONS

For a follow-on study, we recommend implementing one of the two alternate schedules that were developed. Prior to implementing this new schedule rotation, standardized questionnaires should be administered to the watch standers and sleep data should be collected with an ŌURA ring to establish a new baseline period for the study. Preferably the collection period needs to last for a full cycle of the current watch schedule. After the baseline period is established sleep data can then be collected for another full cycle of the alternate schedule that is implemented. Then comparisons can be made between the sleep and questionnaire data collected from the alternate schedule and from the current schedule, allowing the alternate schedule to be assessed. Additionally, a new FAST model can be developed using the sleep data collected while on the alternate schedule. The predicted effectiveness in this model can be compared to the model that was originally developed using current schedule sleep data and assessed for improvements. This study could also be taken one step further if watch standers are satisfied with the alternate schedule and there is a statistically significant improvement in sleep quantity and quality. Sleep data could be collected and analyzed for another cycle on the alternate schedule with light interventions implemented to determine if strategically timed light can further improve sleep and performance.

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