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AVIATION SHIFTWORK: SAFELY TRANSITIONING FROM DAY TO NIGHT FLIGHTS

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THESIS

AVIATION SHIFTWORK: SAFELY TRANSITIONING FROM DAY TO NIGHT FLIGHTS

by

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September 2021

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13. ABSTRACT (maximum 200 words)

The study was requested by the Marine Corps Aviation community with a focus on risk mitigation strategies for aviators transitioning from day to night flights. Avoiding the use of stimulants and sedatives to aid in fatigue mitigation, the study instead used a four-hour period of continuous bright light exposure to shift the circadian rhythm. The main goals of this study were to determine if the light intervention protocol successfully shifted the circadian rhythm of our participants, how large of a phase delay shift was possible, and whether the light intervention affected the participants' perceived levels of fatigue. To reach these goals, we examined melatonin secretion levels to determine dim light melatonin onset (DLMO) over the course of three nights. Phase delay shift calculations were computed using differences in DLMO from night to night. Additionally, self-reported scores on the Karolinska Sleepiness Scale (KSS) provided insight into individual perceived levels of fatigue. Results of the study show successful implementation of the light intervention method by an average phase delay shift of 1 hour 20 minutes ± 22 minutes. However, analyzing the KSS scores did not provide statistically significant results. This study can provide a baseline for future fatigue risk mitigation strategies for military aviation.

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AVIATION SHIFTWORK: SAFELY TRANSITIONING FROM DAY TO NIGHT FLIGHTS

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Submitted in partial fulfillment of the
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LIST OF ACRONYMS AND ABBREVIATIONS

AUC	area under the curve
BWS	Bedford Workload Scale
CNAF	Command Naval Air Forces
DON	Department of the Navy
DLMO	dim light melatonin onset
DLMOff	dim light melatonin offset
ESS	Epworth Sleepiness Scale
HEV	high-energy visible
HSIL	Human Systems Integration Laboratory
IRB	Institutional Review Board
KSS	Karolinska Sleepiness Scale
M-E	morningness-eveningness
NPS	Naval Postgraduate School
OPNAV	Office of Chief of Naval Operations
PSQI	Pittsburgh Sleep Quality Index
PVT	Psychomotor Vigilance Test
SCN	suprachiasmatic nuclei

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EXECUTIVE SUMMARY

The aviation community currently adheres to strategies for mitigating risks associated with fatigue. Strategies currently include allowing aviators eight hours of uninterrupted sleep before flight, the use of stimulants and sedatives upon flight surgeon recommendation, and the use of combat naps. Unfortunately, these methods are not always reliable and can have negative side effects. This study provides an additional risk mitigation method specifically for use when transitioning from day to night flights. The study used bright light exposure to entrain the circadian rhythms of participants by shifting melatonin onset to a later time. The study looked to see how large a phase shift was possible using only light intervention and whether the light treatment had any effect on participants' flight scores, psychomotor vigilance performance, and fatigue levels. The study was conducted as a joint thesis with LCDR James Reily, a U.S. Coast Guard aviator in the NPS Human Systems Integration curriculum. This thesis addressed two of the study outcome measurements: salivary melatonin onset and self-reported fatigue levels.

Nine volunteers from the NPS community participated in the study each over roughly 10 days. All participants had a background in aviation and are qualified pilots. Participants were given activity, sleep, and light tracking devices to be worn for the entirety of the study. Throughout the study, participants answered questionnaires relating to their sleep habits and reported scores of perceived fatigue levels. The final three days of the study protocol consisted of a baseline dim light setting night, a bright light exposure night, and a final dim light setting night. On nights 1 and 3, participants were kept in dim light settings under 10 lux while on night 2 participants were in light levels around 1000 lux. Saliva samples were collected 12 times per night to be used for the analysis of melatonin levels. The levels of melatonin determined the time of dim light melatonin onset (DLMO) which is a phase marker for the start of the circadian rhythm.

The results of this study indicate successful implementation of the bright light exposure method for shifting the circadian rhythm as indicated by melatonin onset determined by dim light melatonin onset (DLMO) analysis. All participants successfully saw a phase delay, shifting their circadian rhythm to the right as indicated by DLMO

analysis. There was an average phase shift of 1 hour 20 minutes ± 22 minutes (minimum = 53 minutes, maximum = 1 hour 56 minutes). Participants' self-reported levels of fatigue according to scores on the Karolinska Sleepiness Scale (KSS) showed significant differences across the three nights of the study. Using Tukey's HSD test for multiple comparisons, the KSS change from Night 1 to Night 2 was statistically significant ($df = 94$, $p < 0.001$, C.I. = [0.369, 1.520]). Night 2 to Night 3 was also statistically significant ($df = 94$, $p = 0.019$, C.I. = [-1.242, -0.091]). However, the KSS change from Night 1 to Night 3 was not statistically significant (Tukey's HSD test, $df = 94$, $p = 0.486$, C.I. = [-0.298, 0.853]) indicating that changes in KSS scores did not carry over from Night 2 to Night 3 as an effect of the light intervention.

An expansion on this study's light intervention protocol could greatly benefit the military aviation community. The methods proposed in this study could potentially aid in reducing the risk caused by circadian misalignment and could also potentially reduce fatigue-related incidents and mishaps. Though the study was successful in entraining the participants' circadian rhythm, we did not see carryover effects for perceived levels of fatigue on the single item Karolinska Sleepiness Scale. Further studies should be conducted where the duration of the study is lengthened to include more nights of bright light exposure and more nights to examine the lasting effects on the participants. Additionally, future studies should include a larger sample size to gain a greater understanding of the benefits of this circadian entrainment protocol.

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I would like to thank my advisor, Dr. Nita Shattuck, and my second reader, Dr. Panagiotis Matsangas, for their patience, support, and guidance throughout the entirety of my thesis process. I would also like to thank LCDR James Reily for his encouraging words as we both worked to make this study a success. Additionally, I would like to thank the rest of the NPS Crew Endurance team for their assistance in the data collection process, especially those who sacrificed their weekends to spend late nights in the lab.

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I. INTRODUCTION

A. BACKGROUND

Awareness, focus, and preparation play a major role in the success of any job, task, or mission. In the aviation community, this assertion is especially true due in part to the nature of their work and the risks involved in daily operations. Aviators' schedules vary based on training and operational conditions which can result in switching back and forth from day to night operations. These schedule changes can disrupt one's circadian rhythm if not given the proper time and consideration for adjustment. The circadian rhythm refers to the roughly 24-hour cycles that govern many internal processes, to include sleep-wake cycles (Brzezinski, 1997). Sleep schedules out of sync with this biological clock adversely impact the quality and quantity of sleep thus negatively affecting the ability to perform cognitive functions (Blatter & Cajochen, 2007). For aviators, a reduction in performance can lead to aviation mishaps that may result in loss of life and/or property. Night operations specifically are inherently more stressful and demanding than their day counterparts (Commander Naval Air Forces [CNAF], 2016). Some guidance on fatigue and stress mitigation specific to military aviators exists in current military manuals used by military flight surgeons (Department of the Navy [DON], 2016). However, current strategies often include the use of stimulants, sedatives, or combat naps to adjust sleep schedules and alertness which often have negative side effects or restrictions (DON, 2016). Naval aviation leadership wants to provide well-defined guidance to supplement current regulations in adjusting from day to night operations that will be practical in operational settings.

B. MOTIVATION

Due to advanced technologies such as night-vision goggles and flight instruments, the aviation community is not constrained to day operations. However, night operations come with a cost. The cognitive stresses and physical demands with night operations increase as visibility is reduced, dependence on flight instruments increases, and crew rest varies. Crew rest for the aviation community is defined as the non-duty time before a flight

duty period begins and includes meals, personal time, transportation time, and rest (CNAF, 2016). Though the Naval aviation community already requires eight hours of uninterrupted sleep before flight, it does not guarantee the rest period is adequately utilized, especially when shifting between day and night operations (CNAF, 2016). Due to the increased stress and the need for higher levels of alertness, proper crew rest is important for the aviation community to minimize potential human error. Without proper rest, sleep deprivation can set in, contributing to slower reaction times and increased error rates (Lim & Dinges, 2008). For aviators, any decrease in performance can lead to mistakes in the air and potential mishaps. The category of human factors represents over 80 percent of causal factors in aviation mishaps and are harder to detect (Office of the Chief of Naval Operations [OPNAV], 2014).

C. SCOPE

Exposure to light is a well-known external cue that is instrumental in determining human circadian rhythmicity (Duffy & Czeisler, 2009). Previous studies have demonstrated that high-energy visible (HEV) light is a *zeitgeber* or "time giver" and is effective in aiding in circadian entrainment (Zeitzer et al., 2000; Burgess et al., 2002). The specific goal of this thesis is to assess the effect of HEV light on the rate of human circadian entrainment, as measured by dim light melatonin onset (DLMO). A second closely related thesis, explored by LCDR James Reily, will cover the performance metrics of the data collected in this study. The results of these combined theses will be used to provide fatigue recommendations to Naval aviation leadership to mitigate risk to aircrew, specifically when transitioning from day to night operations.

D. RESEARCH QUESTIONS

This thesis will focus on three research questions:

- Can light intervention methods aid in shifting melatonin secretion and phase delay the circadian rhythm of military aviators?
- If the light intervention method is successful, on average how large of a phase delay is possible following this procedure?

- Does the phase shift impact the military aviators' perception of their fatigue levels due in part to light intervention methods?

E. THESIS OUTLINE

Chapter I provided an introduction, motivation, and purpose for the study at hand. Chapter II details a review of background information on existing aviation practices and current literature related to this study. Chapter III outlines the study's methodology and procedure followed by an analysis of the results in Chapter IV. Chapter V concludes with a discussion on the outcome of the study and provides recommendations to the fleet along with suggestions for future and continuing work.

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II. LITERATURE REVIEW

A. CIRCADIAN RHYTHM

Sleep regulation is controlled by two processes known as the homeostatic and circadian rhythms (Saper et al., 2005). The homeostatic process is driven by the need for sleep, or sleep propensity, after extended periods of wakefulness (Borbely, 1982). The circadian process, however, is intrinsically controlled by an internal oscillator at intervals based on activity (Borbely, 1982). Figure 1 illustrates the internal circadian process compared with the self-regulated homeostatic process (Borbely, 1982). The top portion of the figure shows the onset of activity based on the internal oscillator while the bottom portion overlays the oscillator with the increase in activity until upper thresholds are met of the homeostatic process (Borbely, 1982).

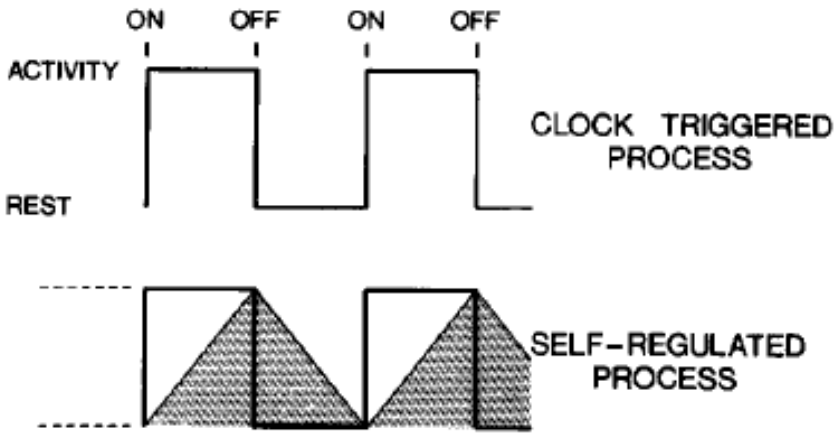

Figure 1. Clock triggered vs. self-regulated process. Source: Borbely (1982).

The sleep-wake cycle for humans is primarily dependent on an internal biological clock and provides the basis for one's circadian rhythm. The internal biological clock is found in the suprachiasmatic nuclei (SCN) in the hypothalamus at the base of the brain (Vitaterna et al., 2001). The SCN receives information through light inputs to the retina

during the day and aids in melatonin secretion at night (Saper et al., 2005). The light inputs, or lack thereof, allow the SCN to reset and work as a timing device aligning the circadian rhythm with the typical day-night cycle resulting in normal sleep patterns (Saper et al., 2005). Beyond influencing sleep-wake cycles, the circadian rhythm also impacts other physiological functions such as core body temperature and various hormone production such as cortisol and melatonin which can impact human performance and alertness (Shattuck et al., 2019).

Circadian, which comes from the Latin words circa and dies, meaning about and day respectively, indicate that a circadian rhythm operates on a roughly 24-hour cycle (McCallum et al., 2003). Initial studies in humans conducted by Aschoff and Wever placed individuals in artificial isolation units to investigate the endogenous processes of the circadian rhythm (Wever, 1979). The first study maintained a constant environment and removed all natural time cues. The study lasted 9 days and resulted in a 25.1-hour circadian period indicated by measurements of activity, rectal temperature, and six urine constituents (Wever, 1979). In follow on studies of longer length, similar results were recorded with circadian periods closer to 25 hours rather than 24 (Wever, 1979). The subject was able to resynchronize the rhythm in roughly 4 days following reentering the environment (Wever, 1979). The results of these studies prove the endogenous nature of the circadian rhythm (Wever, 1979).

Age influences the sleep patterns associated with circadian rhythms and varies over one's lifespan (Miller et al., 2008). Infants begin with needing many short periods of sleep until they build up to sleeping through the night. From roughly 1 year to 4 years old, children still require naps throughout the day but increase the duration of sleep at night. As children become adolescents, naps tend to disappear completely from their sleep pattern. They then have an increased need for more sleep at night reaching a peak when they become young adults. Young adults tend to need extended periods of sleep relating to an increase in hormone levels and development resulting in approximately 0.5 to 1.25 hours of additional sleep per night compared to mature adults (Miller et al., 2008). After this peak, on average, mature adults need roughly 8 hours of sleep each night (Miller et al.,

2008). Figure 2 depicts the shift in sleep patterns throughout a lifespan starting as infants to full-grown adults (Miller et al., 2008).

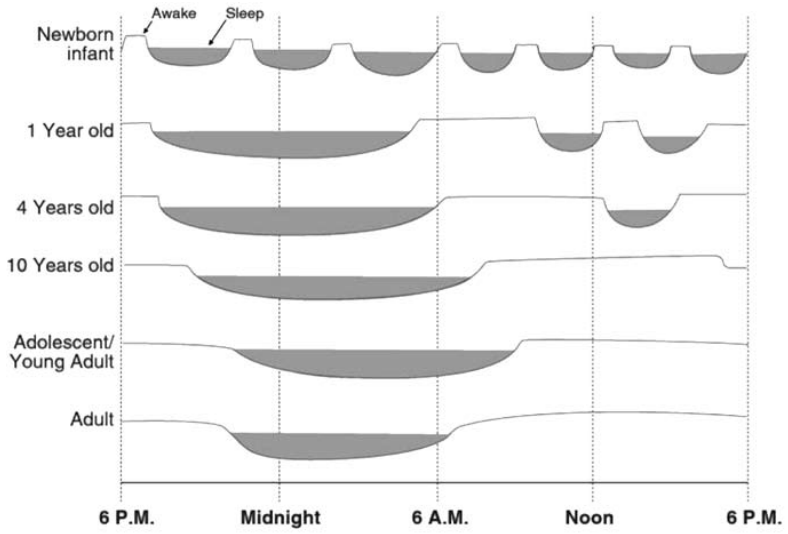

Figure 2. Varying sleep patterns over life cycle. Source: Miller et al. (2008).

In adults, the circadian rhythm has two peaks and two troughs that occur throughout the day. The troughs occur during early morning hours (0200-0700) and in midafternoon (1400-1500) thus resulting in lower levels of alertness and performance (Mitler et al., 1988). During these dips in circadian rhythm, performance errors increase (Mitler et al., 1988). One study that portrays the increase in performance errors was conducted by Bjerner, Holm, and Swensson (Mitler et al., 1988). The study covered a 20-year period where 75,000 meter-reading errors were assessed over a 24-hour distribution resulting in error peaks during the 0200–0400 and 1400–1600 hours (Mitler et al., 1988).

As previously stated, circadian rhythms exist without environmental factors, demonstrating they are endogenous and are derived internally (Aschoff, 1960). However, exogenous factors can impact the periodicity of the circadian rhythm (Aschoff, 1960). Known as zeitgebers (“time givers”), external cues such as light, food, and social engagement can shift (“entrain”) the circadian rhythm (Heyde & Oster, 2019). Of these zeitgebers, light is the most effective in entraining the circadian rhythm to a 24-hour cycle (Duffy & Czeisler, 2009). Entrainment of the circadian rhythm depends on three aspects:

the intrinsic period, the light-dark cycle, and the strength of the zeitgeber (Gronfier et al., 2007). In a study conducted by Gronfier et al., entrainment of the circadian rhythm was assessed using light of three different strengths (25 lux, 100 lux, and a modulated light exposure protocol) as zeitgebers with the goal of entrainment to a 25-h cycle (Gronfier et al., 2007). Entrainment in the study was evaluated by core body temperature and melatonin levels (Gronfier et al., 2007). Participants who were subjected to the 25 lux level protocol did not entrain to the new cycle, but all participants exposed to the 100 lux protocol and modulated light exposure protocol did successfully entrain their circadian rhythms (Gronfier et al., 2007). In the study, the difference between the intrinsic period and light-dark period was kept constant at 1 hour and the phase angle change followed the same convention as previous studies conducted in other mammals; stronger zeitgeber results in narrower phase angle and vice versa (Gronfier et al., 2007). Findings from the study suggest that appropriately timed and properly generated light exposure protocols aid in the entrainment of the circadian rhythm (Gronfier et al., 2007). The combined endogenous and exogenous factors, allow humans to regulate the circadian rhythm to a 24-hour cycle (Aschoff, 1960). In humans, disturbing the normal circadian rhythm, where activity is associated with light periods, can result in mental and physical disorders as well as negatively impact performance and productivity levels (Vitaterrna, Takahashi, & Turek, 2001).

B. MELATONIN

Melatonin, which is produced by the pineal gland based on light-dark cycles, aids in the determination of the circadian rhythm (Rzepka-Migut & Paprocka, 2020). Melatonin secreted by the pineal gland occurs during the dark cycle assists in resting the SCN (Saper et al., 2005). Melatonin secretion begins roughly two to three hours before nocturnal sleep, continues and peaks throughout the night, and dwindles down to nothing during daytime hours (Molina & Burgess, 2011). Melatonin levels are measured in various ways including plasma, saliva, and urine samples, each having its own collection methods and levels of invasiveness. Though plasma has the highest levels of melatonin, its invasiveness measures make plasma collection methods less desirable compared to saliva collection methods even though saliva has a lower concentration of melatonin (Rzepka-Migut & Paprocka, 2020).

A study conducted by Zeitzer et al. assessed the impact of a single episode of light exposure with intensities varying from 3 to 9100 lux on melatonin profiles and the circadian pacemaker (Zeitzer et al., 2000). After an initial baseline period determined the phase of circadian rhythm and time of minimum core body temperature for each participant, participants were exposed to 6.5 hours of light exposure (Zeitzer et al., 2000). The exposure was scheduled to start 6.75 hours prior to minimum core body temperature to encapsulate known regions that induce phase delays in the circadian rhythm (Zeitzer et al., 2000). Throughout the study, blood samples were taken every half hour to later determine concentration levels of plasma melatonin in the participants (Zeitzer et al., 2000). Results of the study showed that subjects exposed to low lux levels were unable to suppress their melatonin levels and had minimal phase shifts of the melatonin circadian rhythm (Zeitzer et al., 2000). However, those who were exposed to light intensity levels of roughly 200 lux or greater successfully suppressed melatonin secretion and light intensity exposure of greater than about 550 lux caused an ample phase shift of their rhythm (Zeitzer et al., 2000). Figure 3 illustrates the melatonin phase shift and melatonin suppression results of the study based on illuminance levels.

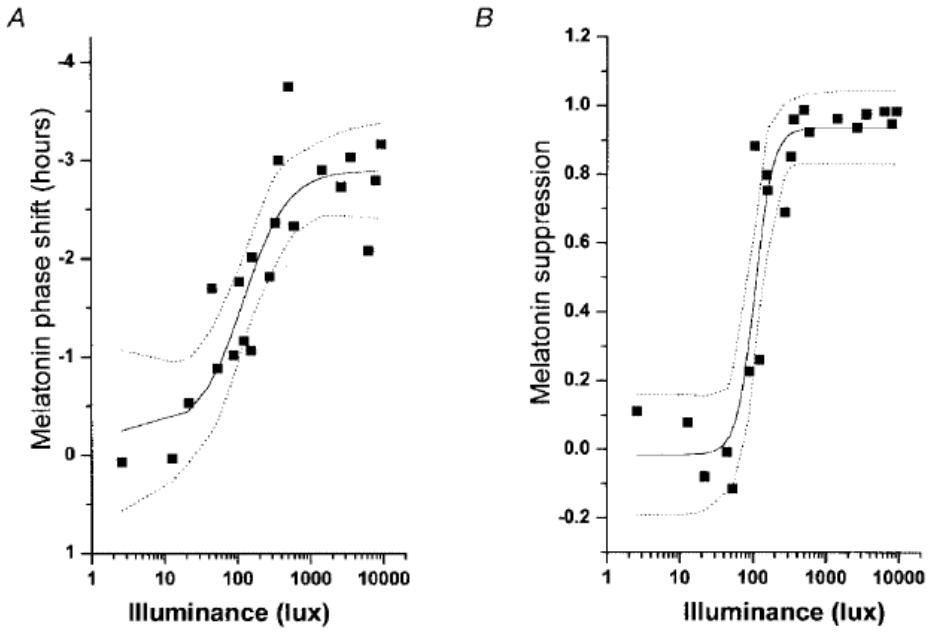

Figure 3. Melatonin phase shift and melatonin suppression vs. illuminance. Source: Zeitzer et al. (2000).

Previous studies have denoted melatonin secretion onset occurs roughly 7 hours before minimum core body temperature while offset occurs roughly 40 minutes after minimum core body temperature (Shanahan et al., 1997). The procedure for examining melatonin onset is called Dim Light Melatonin Onset (DLMO) which can be examined over the entire period of a day or as short as four to seven hours (Rzepka-Migut & Paprocka, 2020). DLMO serves to provide information on the circadian phase through a melatonin profile of an individual and reflect the onset timing of the circadian pacemaker (Klerman et al., 2002). DLMO-based methods are preferred since melatonin onset occurs before sleep (Lewy et al., 1999). A full melatonin profile includes points DLMO and dim-light melatonin offset (DLMOff) using a specified threshold, typically 10 pg/ml for (Lewy et al., 1999). A sample 24-hour melatonin secretion profile is shown in Figure 4 (Burgess et al., 2002). Due to radioimmunoassays with higher sensitivity and specificity, lower concentration levels (4 pg/ml) may now be used for determining DLMO and DLMOff (Lewy et al., 1999). Using saliva collection methods and DLMO, one can analyze when

melatonin production begins to determine the timing of the circadian rhythm (Molina & Burgess, 2011).

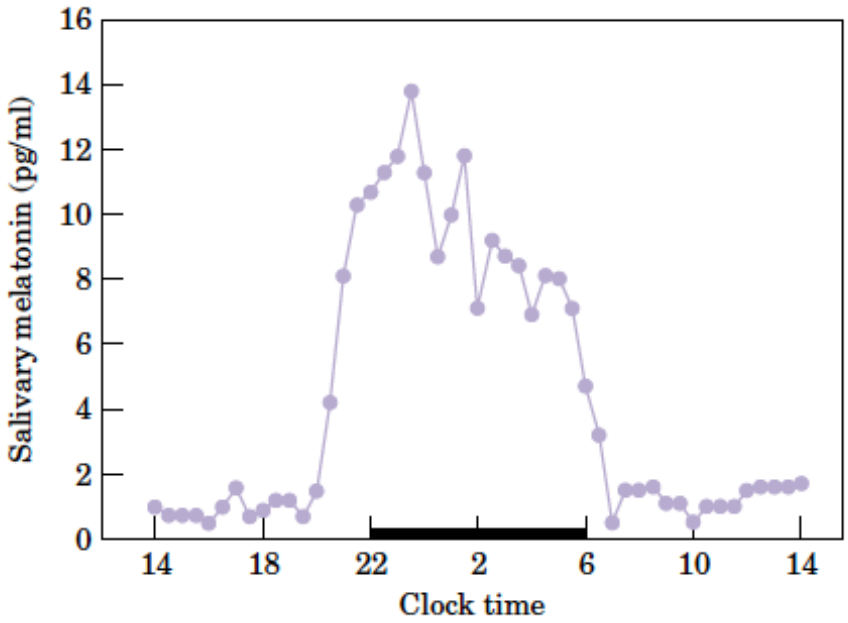

Figure 4. Typical 24-hour melatonin secretion profile. Source: Burgess et al. (2002).

A study conducted by Revell et al. used a portable blue light stimulus device to demonstrate the ability to phase advance and phase delay the onset of salivary melatonin confirmed by analysis of DLMO (Revell et al., 2012). Subjects participated in two laboratory sessions, one to use as a control and the other to apply the blue light stimulus, where salivary samples were collected every 30 minutes (Revell et al., 2012). The light exposure of about 185 lux occurred at six different clock times over the course of 2 hours in three 30-minute pulses with 15 minutes between each pulse during three consecutive days (Revell et al., 2012). DLMO threshold in the study was determined to occur at 25% of the maximum normalized melatonin level (Revell et al., 2012). Phase shifts for individuals were calculated by subtracting control DLMO shifts from light exposure DLMO shifts (Revell et al., 2012). Figure 5 depicts both the raw control and blue light

administered melatonin profiles for one individual indicating a roughly 1-hour phase delay from the blue light exposure pulses (Revell, Molina, & Eastman, 2012).

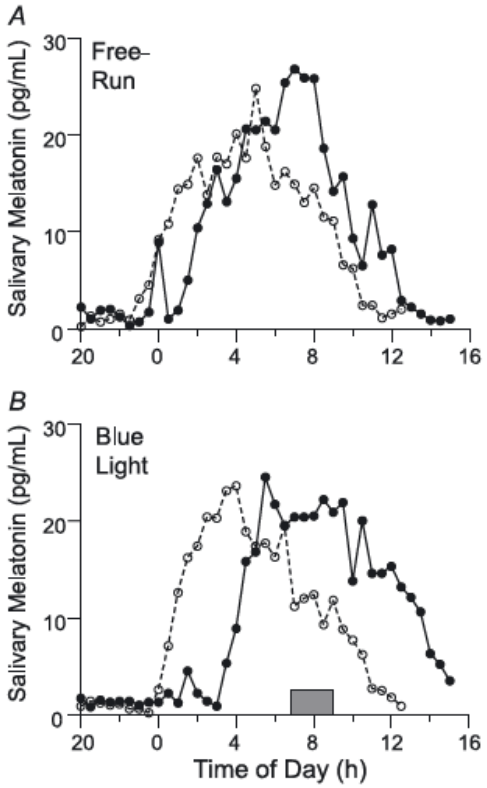

Figure 5. Melatonin profile: control vs. blue light exposure. Source: Revell et al. (2012).

Overall, the study had several main conclusions. A small blue light device is just as capable of inducing phase delay and phase advances of melatonin profiles as larger white-light alternatives. Results of the study indicate that phase delays occur when light is administered at night while phase advances occur when light is applied throughout the day as shown by the phase response curve in Figure 6 relative to control DLMO (Revell et al., 2012). Salivary melatonin samples provide sufficient levels of melatonin concentration for DLMO analysis and provide accurate depictions of phase shifts due to light intervention methods (Revell et al., 2012).

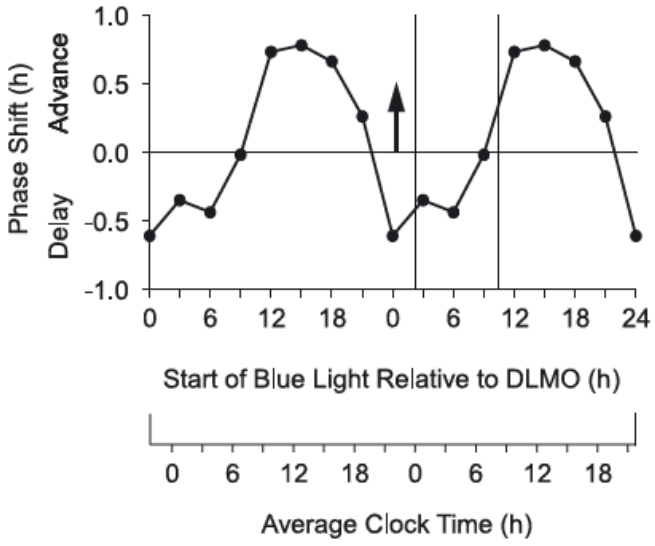

Figure 6. Phase shift average from varying light exposure clock times. Source: Revell et al. (2012).

C. LIGHT INTERVENTION

Many studies have been conducted to analyze the use of light to minimize the amount of time it takes to adjust for shiftwork. Specifically, the use of high-energy visible light (HEV) is used to advance or delay the circadian rhythm by suppressing melatonin levels (Zeitzer et al., 2000). Duration, timing, intensity, and wavelength impact the effect light has on one's circadian rhythm (Duffy & Czeisler, 2009). A study conducted by Lewy et al. indicates high-intensity light (above 1000 lux) is necessary to suppress melatonin levels in humans (Lewy et al., 1980). The suppression of melatonin occurs rapidly after the introduction of bright light (Lewy et al., 1980; Brown, 1994). The direction of the phase shift through light exposure aligns with the timing of the minimum core body temperature; light before minimum temperature time results in phase delay and light after minimum temperature time results in phase advance (Burgess et al., 2002). To delay melatonin onset, light intervention should be conducted in the evening while light intervention should be conducted in the morning to advance melatonin onset (Lewy et al., 1985). The closer the exposure is to the minimum core body temperature time, the larger the expected phase shift will occur (Burgess et al., 2002).

The influence of high-intensity outdoor light following a night shift can mask the phase delay shift in circadian rhythm following light exposure before minimum core body temperature (Burgess et al., 2002). However, there have been successful studies that show the use of high-intensity bright light during the evening hours plus the use of dark light-blocking goggles on commutes home and blackout curtains during day sleep periods support circadian entrainment claims (Boivin & James, 2002). In Boivin and James' study, two groups of permanent night shift workers observed under different conditions (6 hours of bright light and usage of dark goggles vs. no change to current work conditions) illustrate positive results from the light intervention method as those exposed successfully delayed their circadian rhythm (Boivin & James, 2002). A study conducted by Eastman, Liu, and Fogg indicates that long periods of bright light exposure are not necessary to achieve a phase delay shift (Eastman et al., 1995). Bright light duration exposure of 6 hours and 3 hours both effectively shifted 69% and 65% of participants respectively (Eastman et al., 1995). For some workers, long exposure to bright light is not practical due to the nature of their work. In these cases, pulse or intermittent light exposure can be just as successful as continuous light exposure (Burgess et al., 2002). Baehr and colleagues demonstrated over the course of three days that bright light exposure of roughly 5000 lux in one 40-minute session resulted in positive phase delay for all participants involved (Baehr et al., 1999). To conclude, the use of high-intensity bright light intervention methods, continuous or intermittent, aids in entraining one's circadian rhythm to a new sleep-wake schedule.

D. SHIFTWORK

The term shiftwork refers to work that is outside of the typical daytime working hours and usually involves rotating schedules to accommodate 24-hour coverage (Åkerstedt & Wright, 2009). Normally, shiftwork is broken down into day, afternoon, and night shifts where workers either cycle through the different shifts or are assigned on a permanent basis (Åkerstedt, 1990). Shiftwork may also refer to work that is unstructured in nature causing irregular and sometimes unpredictable work hours (Åkerstedt, 1990). Many industry, medical, first responder, and military jobs rely on shiftwork to maintain productivity, effective practices, and continuous protection. However, shiftwork is uncharacteristic of normal human physiology and often results in lower performance levels

(Shattuck et al., 2019). Since humans have an inherently diurnal circadian rhythm (awake during the day and asleep at night), transitioning to shiftwork and night hours requires time to adjust (Monk, 1986). On average it takes roughly one day to adjust for a one-hour shift due to shiftwork or crossing time zones (Revell & Eastman, 2012). In the military aviation community, shiftwork, particularly night work, is often unpredictable due to delayed scheduling notices. Consequently, aviators may not have sufficient time to adjust their sleep schedule to maintain optimal performance in flight, though all possible efforts are made by commands to allow for appropriate crew rest (CNAF, 2016).

Studies have shown that shiftwork, specifically night shifts, result in poorer sleep habits and higher rates of performance degradation (Åkerstedt & Wright, 2009). Recorded comparisons show performance levels during night hours equivalent to blood alcohol levels of 0.05% or greater (Åkerstedt, 1990). As a result, working night shifts can increase the risk of accidents on the job by 30–50% (Åkerstedt & Wright, 2009). In aviation, an increase of accident risk of that caliber could be detrimental to the mission and life of the aircrew in both training and operational settings.

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III. METHODS

A. EXPERIMENTAL DESIGN

This was a longitudinal experimental study conducted in controlled conditions (the Human Systems Integration Lab [HSIL]).

B. PARTICIPANTS

Ten participants volunteered for the study from the NPS student, staff, and faculty population. Each participant had a background in either the United States Army, Air Force, Marine Corps, or Navy. All participants were qualified aviators from their respective communities with varying flying experience and diverse platform backgrounds. The participants' age ranged from 30–44 and consisted of one female and nine males.

The NPS Institutional Review Board (IRB) approved the study protocol (NPS.2021.00012-AM01-EP3-4-7-A) and all participants gave written informed consent before participating in the study. The IRB-approved consent form is included in Appendix A.

C. EQUIPMENT AND INSTRUMENTS

1. Laboratory Set-up

Two laboratory rooms, Sim Room A and Sim Room B, were used throughout the study. The two rooms were subdivided into a simulator space and a light exposure space. Participants were assigned to one of the two rooms for the entirety of the study based on availability on their weekend. Once the participant was assigned a room, they were allowed to adjust the simulator chair and controls to their liking. The simulator space for the participant consisted of a TV monitor used to display X-planes, a simulator chair, and a side table for storing questionnaires and approach plates. Six feet behind the participant, a desk with a computer monitor was used for the researcher to oversee and set up the different flight scenarios. In the light exposure space, the participant had the option of sitting in a comfortable chair or at a desk in a rolling chair for the hours before the simulator. Various light boxes were set up in this area to be used each night of the study.

2. Questionnaires

Various questionnaires and scales were used throughout the study to gain insight on participant sleep habits, sleep tendencies, perceived fatigue levels, and workload ratings of completed tasks.

a. Enrollment Questionnaire

An Enrollment Questionnaire was administered to each participant at the time of consent. The questionnaire consisted of demographic and background information. A morningness-eveningness (M-E) questionnaire was also included as part of the enrollment questionnaire. The M-E questionnaire was developed by James A. Horne and Olov Östberg (1976) to distinguish between individual differences in circadian rhythm. From the 19 questions in the questionnaire, individuals fall into one of five categories: definitely morning type, moderately morning type, intermediate type, moderately evening type, and definitely evening type. A modified version of the M-E questionnaire that included more definitive time range scales was used for this study (Terman M. & Terman J. S., 2005). A copy of the Enrollment Questionnaire, including the M-E questionnaire, can be found in Appendix B.

b. Pre-flight Questionnaire

As shown in Appendix C, a pre-flight questionnaire which included the Epworth Sleepiness Scale (ESS), Karolinska Sleepiness Scales (KSS), and Pittsburgh Sleep Quality Index (PSQI) questionnaires was administered prior to the morning baseline flight scenarios. The ESS uses responses from eight different situations to determine an individual's sleep propensities (Johns, 1991). The individual rates each situation from 0–3 to indicate their likelihood of dozing off which are then summed to a total between 0–24 where higher scores are representative of higher daytime sleepiness (Johns, 1991). The KSS assesses current subjective ratings of individual sleepiness from a nine-point scale ranging from 1-extremely alert to 9-very sleepy, great effort to keep awake, fighting sleep (Akerstedt & Gillberg, 1990). Additional KSS were overseen between all flight scenarios and at 30-minute intervals during the three night sessions. The KSS responses were used to track individual sleepiness perception over time. The PSQI provides insight on recent

sleep quality for each individual through responses to sleep latency, sleep duration, and sleep disturbance-based questions (Buysse et al., 1988). The PSQI contains 14 questions reflecting sleep habits over the past week with ratings from 0–3 and four questions requiring written responses. Scores are combined to create seven component scores and a global score for each participant (Buysse et al., 1988).

c. Bedford Workload Scale (BWS)

The BWS was developed by Roscoe and Ellis (1990) to provide a scale that enables pilots to rate the workload needed to complete a specific task in flight. Roscoe and Ellis conducted a preliminary questionnaire to determine how pilots interpret workload and concluded that the majority of pilots think of workload in terms of effort and spare capacity (Roscoe & Ellis, 1990). Today, the scale consists of ten different ratings that are reached by way of a decision tree. Through three yes or no questions, pilots rate workload for a specific task based on descriptors and associated ratings such as "1 - workload insignificant" to "10 - task abandoned, pilot unable to apply sufficient effort" (Roscoe & Ellis, 1990). The ratings are broken down into four separate sections based on the questions then pilots choose the best descriptor available from that section. The BWS form is provided in Appendix D. For our study, participants were directed to complete the BWS after completion of each flight scenario for a total of 12 completed BWS questionnaires.

3. Devices

Participants were given several devices as a way to collect baseline sleep schedules, exposure to different light, and activity levels throughout the duration of the study protocol.

a. Respironics Spectrum Plus Actiwatch

Philips Respironics Spectrum Plus Actiwatches were configured before each participant's arrival using Respironics Actiware 6 software. Participants were each given an actiwatch to wear for approximately ten days to measure their activity and sleep patterns. Participants were instructed to wear the watch during the day and night unless participating in water sports or showering on whichever wrist felt most comfortable. Upon completion of the study, participants returned the actiwatch and researchers downloaded the

appropriate data using the Respironics Actiware 6 software. Data from the actiwatch was used to verify the participants' habitual bedtimes for scheduling their night sessions.

b. Oura ring

Participants were given an Oura ring and charger set to use with the Oura app as a secondary method for gathering activity and sleep data. The rings were worn for approximately ten days and worn on whatever finger was most comfortable. Participants were instructed to always wear the ring, specifically at night while sleeping. Participants consented to share their Oura ring app data with our research team via an Oura Teams account. The Oura ring data provided an additional tool to verify the participants' habitual bedtime and to ensure they were maintaining a consistent bedtime and awakening schedule.

c. HOBO Pendant data logger

A HOBO Pendant data logger that collects light and temperature data was given to each participant to be worn on their upper arm for approximately ten days. The pendant was to be worn so the sensor was facing in the direction of the participant's gaze. Participants were instructed to wear the HOBO device during all waking hours.

d. Activity log

Participants filled out a daily activity log throughout the study. Participants listed their daily activities in 15-minute intervals including meals, working out, caffeinated beverages, exposure to different kinds of light, sleeping, and times of actiwatch removal. A sample activity log page can be found in Appendix E.

e. AMI Motionlogger PVT

For participants 5–10, participants completed PVTs throughout the study. The test was administered using an AMI Motionlogger PVT and lasted three minutes. Participants were instructed when to start the PVT and pressed one of the side buttons any time they saw the word "Push" on the screen.

D. PROCEDURES

The study included simulated flight performance and melatonin secretion levels of volunteers who underwent a rapid shift from day to night operations. Additionally, self-reported sleepiness and workload scores, melatonin levels from saliva samples collected at 30-minute intervals over the course of three consecutive nights, and approximately 10 days of estimated sleep from wearable devices provided additional sources of insight for the study. Performance metrics were collected from three flight scenarios and 16 psychomotor vigilance tests (PVTs) over the course of the three nights.

a. Recruiting

A one-time mass email was sent to the NPS student, faculty, and staff population containing information regarding the study along with a study flyer. Additionally, a call for volunteers including the study flyer was included on the NPS student muster page for two months. A copy of the study flyer is included in Appendix F.

b. Consent Day

During the consent process, researchers briefed participants on expectations throughout the study, and questions or concerns from the participants were addressed at this time. Once the participant felt they fully understood the study and wanted to participate, they signed a copy of the consent form and were given a copy for their records. Additionally, participants signed the California Bill of Rights and completed the Enrollment Questionnaire at this time. Participants were briefed on each device and set up their Oura account with the aid of the researchers. Finally, the participants were given a tour of the lab and a final brief of the remainder of the study schedule.

c. Familiarization Flight

To reduce any learning curve associated with the flight scenarios and simulator, participants completed a familiarization day flight roughly two days prior to the data collection. Researchers sent approach plates, weather overview, and a brief ILS refresher description for the flight scenarios the night before the participant's familiarization flight via email. Copies of the approach plates given in the familiarization email are included in

Appendix G. The familiarization flight consisted of 4 different flight scenarios. The first scenario was an ILS refresher flight provided by the X-planes simulator landing at Seattle Airport. The following three scenarios were day variations of the flights used for the remainder of the study. The three scenarios were final approaches via ILS at San Francisco, Las Vegas, and Martha's Vineyard Airports with increasing weather difficulty. Participants asked any flight-specific questions they had and adjusted the chair and controls to their liking. At the conclusion of the flights, the remainder of the study schedule was finalized based on the sleep data collected from the Oura ring and actiwatch. Participants scheduled their morning baseline flight based on what worked best with their schedule and the night scenarios arrival times were set up three hours prior to their habitual bedtime.

d. Baseline Day Flight

Upon arrival to the baseline day flight scenarios, participants completed the pre-flight questionnaire. Participants then completed the three flight scenarios in the daytime setting - SFO, LAS, and MVY. After each scenario, participants completed a copy of the KSS and BWS scales. For participants 5–10, a three-minute PVT was conducted before starting the simulator and after each scenario. Once all scenarios and questionnaires were finished, the researcher reminded the participants of their arrival time for night scenarios and emphasized the importance of eating before they arrive and refraining from any caffeinated beverages four hours prior. Researchers saved each flight scenario in an individual folder for each participant.

e. Night Data Collection

Prior to participant arrival, researchers readied the necessary scenario spaces. Eight KSS forms were placed in the light exposure space for the first four hours of the study. Four additional KSS and three BWS forms were placed on the small table beside the simulator chair for use during the flight scenarios. Researchers verified that a fully-charged AMI Motionlogger PVT was also on the table for participants 5–10. Researchers prepared 12 salivettes for participant saliva samples ensuring proper labeling included ID number (XX), sample number (night.sample), date, and time in thirty-minute increments. Researchers started the X-planes system to confirm the program was working correctly and

an individual folder was still active for each participant. Finally, researchers set the light boxes and software (Circadian Positioning Systems, Newport, RI) to the correct configuration for each night and verified using CL-500A Illuminance Spectrophotometer Konica Minolta. For nights 1 and 3, the space was kept at dim light settings for the entirety of the night. Dim light settings for this study were set at less than 10 lux. For night 2, lights were set at a high blue-boosted white light setting of approximately 1000 lux for the first four hours. After those four hours, participants were given a 30-minute transition period to dim light (less than 10 lux) to simulate dark adaptation for a night flight.

Upon participant arrival, researchers verified that the participant was in good health and had maintained their assigned sleep schedule. Participants were then placed in the light management area for the first four hours of the study where they were able to work on homework, read, watch movies, etc. A researcher verified that the lux levels of their devices' output were less than 10 lux. If participants needed to go to the restroom during dim light periods of the study, they were given welding goggles to prevent hallway/ restroom light exposure. Every thirty minutes, researchers would ask the participant to fill out one KSS form and give a saliva sample. Researchers would also verify the lux levels at this time. Five minutes before taking saliva samples, participants were asked to swish water in their mouth and swallow to remove any excess residue that may have existed from food particles. Saliva samples were taken at the top of the hour and the half-hour mark. To conduct the saliva sampling, researchers handed the participant the correctly labeled salivette and asked the participant to tip the dental cotton into their mouth. Participants rolled the cotton in their mouth for one minute and then spit the cotton back in the salivette. Researchers verified that the sample was at least 9.0 g. If the sample was between 8.5 and 8.9 g, participants were asked to top off the sample by spitting directly on top of the cotton. If the sample was below 8.5 g, participants were given a second salivette with dental cotton for an additional minute. Once the sample was verified, participants were allowed to continue working on homework, reading, watching movies, etc., between samples.

Researchers took the salivette to be spun down using a centrifuge and following the procedure set by Circadian Positioning Systems (Crowley et al., 2014). The sample was balanced in the centrifuge using a blank salivette tube for three minutes at 340 revolutions

per minute. Once the sample was spun down, the top portion of the salivette containing the dental cotton was removed and thrown out. The cap was replaced on the salivette tube and placed in the refrigerator until the end of the night. At the conclusion of the night, all 12 salivettes were rubber-banded together and placed in a Ziploc bag labeled with participant ID, date, and night number. The Ziploc bag was then placed in the -80ºC freezer until it was time to ship the samples. Saliva samples were sent via overnight FEDEX to the SolidPhase laboratory in Portland, Maine for analysis.

After the first four hours of the study, participants moved from the light exposure space to the simulator space. Researchers prepared the first flight scenario - ILS into SFO airport - while participants completed a KSS form and a PVT for participants 5–10. Once the participant was ready, the same procedure was followed as during the baseline day flights apart from the scenarios having a night setting to them. Researchers saved each scenario after completion of each flight and ensured the participant completed a KSS, BWS, and PVT when appropriate. Saliva samples continued to be collected at thirty intervals which aligned with the time between flight scenarios. At the conclusion of the night, participants were reminded to not nap during the day or have caffeine four hours prior to their arrival the next night. Researchers gathered all KSS and BWS forms and placed them in the participant's binder under the appropriate night's tab. PVT data was downloaded when necessary and flight data was backed up on an external hard drive. Once the participant had safely left for the night and all samples were placed in the freezer, researchers cleaned the laboratory space in preparation for the next night. After the third night of the study, participants returned all devices and logs to the researchers for analysis.

E. ANALYTICAL APPROACH

Analyses were conducted on the collected salivary melatonin data and reported KSS scores from the duration of the study.

1. Salivary Melatonin

Salivary Melatonin was analyzed in three phases. The initial phase sent salivary melatonin samples to SolidPhase Laboratory with assistance from Circadian Positioning Systems to determine DLMO and phase shifts. The second phase analyzed individual and

group trends of melatonin levels. The final phase addressed suppression calculations from the light intervention procedure.

a. DLMO

The study analyzed the DLMO phase during spring months for ten participants over the course of three nights. Serial saliva samples were collected in thirty-minute intervals over the course of 6 hours each night surrounding the habitual bedtime of the individual. Samples were centrifuged, then chilled upon initial collection, and frozen within 7 hours in a -80ºC freezer. Samples were collected under lighting conditions discussed in the previous section. Melatonin concentration in saliva was determined using radioimmunoassay (RIA; Novolytix) with a sensitivity of 0.9 pg/mL, intra-assay coefficient of variation (CV) 7.9%, and inter-assay CV of 9.8%. A 4 pg/mL threshold was used when determining the DLMO phase through linear interpolation (Crowley et al., 2016).

b. Trends

Initial assessment of salivary melatonin trends indicated one participant had abnormally high melatonin levels thus was removed from the analysis portion of the study. Salivary melatonin trends and statistical analysis were conducted on an individual and group basis. Analysis was conducted in JMP Pro 15 (SAS Institute; Cary, NC) by comparing melatonin levels with time relative to habitual bedtime. Individual trends were analyzed by comparing changes in melatonin levels between Night 1 and Night 3. Group trends were analyzed by comparing individual and average melatonin levels across all three data collection nights.

c. Suppression

Suppression calculations were conducted using the area under the curve (AUC) to calculate the suppression percentages from Night 1 to Night 2. Average suppression percentages were used for analyzing group trends. Individual suppression trends were analyzed in the same manner.

2. KSS

KSS analysis was conducted in two parts. First, KSS data were scrubbed for erroneous entries and missing values. Next, statistical analysis was carried out to determine individual and group trends.

a. Cleaning

KSS scores were cleaned in an Excel Spreadsheet to account for any missing values. Missing values were marked and replaced with the most recent reported KSS score. For the entire dataset, there were 7 missing values out of 360 for the nine participants included in the analysis portion of the study.

b. Trends

KSS trends were analyzed in JMP Pro 15 and Excel for individual and group statistics. Group trends were determined using mean and standard deviation calculations to show increasing reported scores over time for each night of the study. Further group analysis was conducted on the final four reported scores for each night using a mixed model with fixed effects of light condition and order of reported score plus random effects from participant ID. Statistical significance in KSS scores between each of the nights was determined using Tukey HSD Pairwise comparisons. Individual trends for KSS scores were assessed in Excel by examining reported scores for each time step by night.

IV. RESULTS

A. BASIC INFORMATION

1. Demographics

Initially, ten members (one female and nine male) from the NPS student, staff, and faculty population volunteered to participate in the study. After preliminary examination, one male participant (Participant 04) was excluded from analysis due to abnormally high salivary melatonin levels. The remaining nine participants ranged in age from 30 to 44 years old with an average age of 34 years old. Participants represented the U.S. Air Force, Army, Marine Corps, and Navy communities with ranks ranging from O-3 to O-5. On average, participants had an average of 1,282 total flight hours with an average of 987 hours in their primary aircraft. Demographic data are summarized in Table 1 shown below.

Table 1. Demographic data

Demographic Data		
Age in years, M ± SD		34.0± 4.47
Gender, #		
	Female	1
	Male	8
Branch of Service, #		
	US Air Force	1
	US Army	2
	US Marine Corps	2
	US Navy	4
Rank, #		
	O-3	5
	O-4	2
	O-5	2
Total flight hours, M ± SD		1282± 689
Primary aircraft flight hours, M ± SD		987± 542

Participants who reported themselves as users of caffeine (8 participants) or nicotine products (2 participants) refrained from these products for at least four hours before arriving for night data collection periods.

2. Baseline Characteristics

Participants completed several questionnaires to determine baseline sleep characteristics such as M-E preference type, ESS type, and PSQI type. Responses to the M-E questionnaire indicate our participants fall into the Morning Type and Intermediate Type categories with an average score of 56.6 ± 6.36. Based on their ESS scores with an average score of 4.40 ± 1.78, all participants had normal average daytime sleepiness (ESS score≤10). Based on their PSQI scores, two of the nine participants were classified as "poor" sleepers (PSQI>5). Questionnaire summary responses are provided in Table 2 below.

Table 2. Questionnaire response summary

Questionnaire Responses	
M-E preference score, M ± SD	56.6 ± 6.36
M-E preference type, #	
Definitely Morning Type	1
Moderately Morning Type	2
Intermediate Type	6
ESS score, M ± SD	4.40 ± 1.78
Normal daytime sleepiness	9
Elevated daytime sleepiness	0
PSQI score, M ± SD	4.60 ± 1.35
Good sleeper	7
Poor sleeper	2

Habitual bedtimes were determined and verified from Actiwatch and Oura ring data. Habitual bedtimes ranged from 21:30 to 00:00 and are summarized in Table 3. Participants arrived for night data collections three hours before their recorded habitual bedtime with the first salivary melatonin sample scheduled 2 hours and 30 minutes before habitual bedtime and the last sample three hours after habitual bedtime. A full summary

table of habitual bedtime and associated questionnaire scores for each participant is available in Appendix H.

Table 3. Habitual bedtime and sample time range

Participant ID	Habitual bedtime	Start	End
CEAS01	21:30	19:00	0:30
CEAS02	23:00	20:30	2:00
CEAS03	23:00	20:30	2:00
CEAS05	0:00	21:30	3:00
CEAS06	0:00	21:30	3:00
CEAS07	22:30	20:00	1:30
CEAS08	22:30	20:00	1:30
CEAS09	0:00	21:30	3:00
CEAS10	23:00	20:30	2:00

Start indicates first salivary melatonin sample collection time.

End indicates final sample collection time.

B. DAILY TRENDS

1. Salivary Melatonin Trends

For all participants, salivary melatonin levels increased as time went on throughout each night. Participants had varying initial levels of melatonin and maximum melatonin levels were dependent on the individual. In dim light settings (< 10 lux) on Night 1, melatonin levels displayed the largest amount of variation from participant to participant and had an average DLMO 1 hour 22 minutes ± 1.5 minutes before habitual bedtime. Participants were in the bright light setting (~1000 lux) until 1.5 hours after habitual bedtime on Night 2 resulting in little to no melatonin secretion during that time. Once participants transitioned to the dim light setting, their melatonin secretion increased causing an average DLMO 1 hour 28 minutes ± 1 minute after habitual bedtime. Salivary melatonin levels for two participants never reached the 4 pg/mL threshold for DLMO on Night 2. Night 3, once again in dim light settings for the entirety of the night, resulted in an average DLMO 46 minutes ± 2 minutes after habitual bedtime indicating a phase delay shift from the light intervention method. Figure 7 below compares the salivary melatonin

levels from night to night for all participants. Night 2 clearly shows melatonin suppression occurred while participants were in the bright light settings.

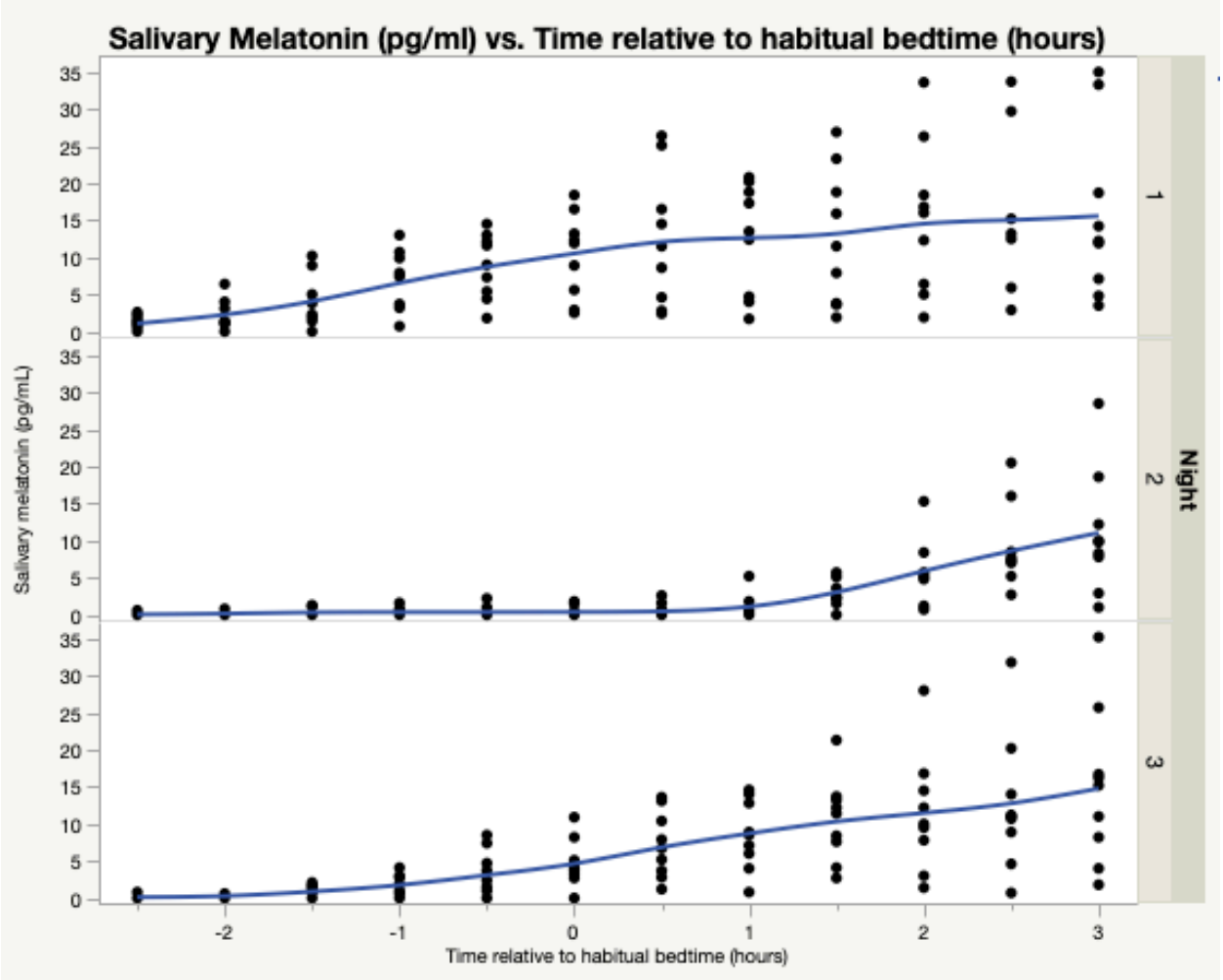

Figure 7. Salivary melatonin trends by night

2. KSS trends

KSS scores, based on a single-item 1 to 9 rating scale ranging from extremely alert to very sleepy, were used as a subjective measure to gauge how sleepy an individual feels in that moment. KSS scores were reported for each participant in half-hour intervals throughout the course of the data collection periods. KSS reporting is somewhat limited as individuals may interpret levels of sleepiness differently and may have a different

understanding of their personal levels of sleepiness. Overall, KSS scores increased throughout each night regardless of light exposure settings. Higher KSS scores indicate higher levels of self-reported fatigue. Figure 8 below depicts the individual KSS scores across each night collection period for all participants. Appendix I provides individual participant changes in KSS scores amongst themselves. Three participants reported highest KSS scores on Night 1, 3 participants reported highest KSS scores on Night 3, and 3 participants had little to no difference in reported KSS scores on Night 1 to Night 3. One participant showed no change in reported KSS scores for the entirety of the study regardless of light condition. On average, KSS scores on Night 1 were 3.33 ± 1.32 at the beginning of the night and an average of 6.67 ± 2.23. Night 2 had an average of 3.11 ± 1.61 at the beginning of the night and an average of 5.44 ± 1.88 at the end of the six-hour period. KSS scores on Night 3 averaged 3.11 ± 1.36 at the beginning of the night and 6.33 ± 2.06 at the end of the night. A full table of average KSS score comparisons by night is provided in Appendix J.

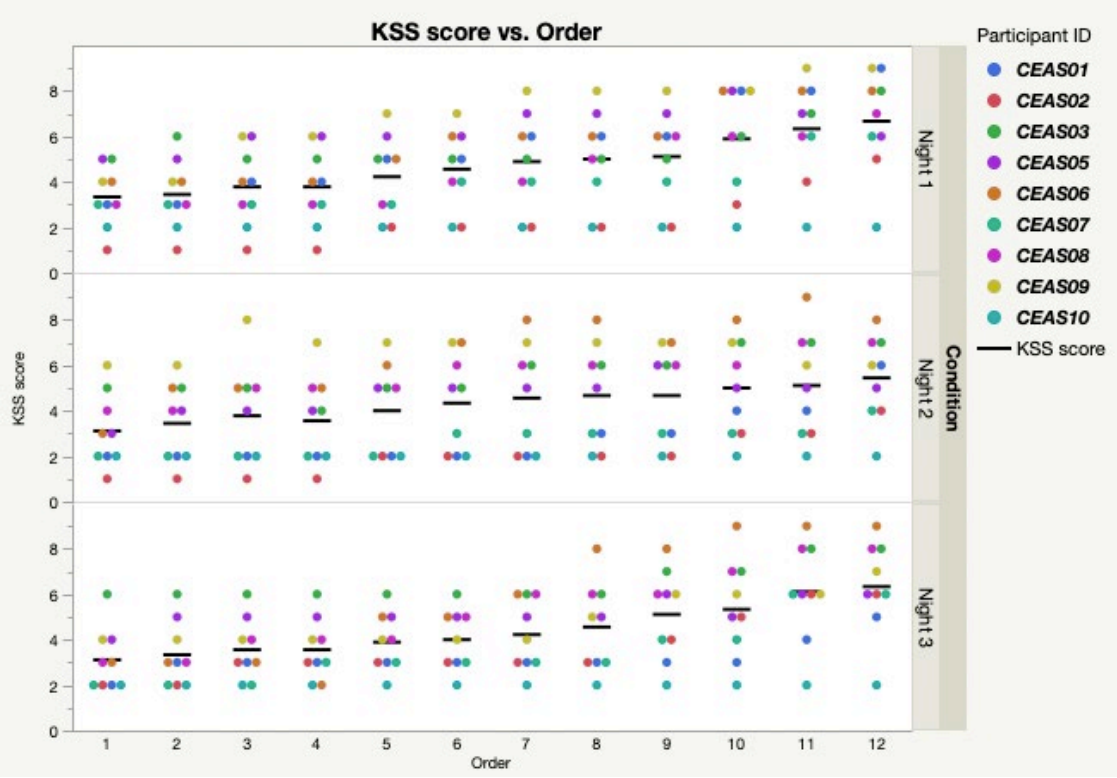

Figure 8. KSS scores trends by night

C. OVERALL RESULTS

1. Salivary Melatonin

a. Suppression

Participants were in the bright light setting (~1000 lux) for the first eight salivary melatonin samples on Night 2. The final four samples were collected in dim light settings (<10 lux). Suppression percentages represent the AUC for bright light settings on Night 2 compared to dim light settings on Night 1 for the salivary melatonin levels. Salivary melatonin levels of less than 0.5 pg/mL were changed to 0.0 pg/mL to complete calculations. Figure 9 shows during the bright light setting (shown by yellow shaded area), melatonin samples reach an average of 91.03% suppression for the first eight samples. For samples 9-12 (shown in gray shaded area), there is a gradual decrease in suppression percentages as the circadian rhythm begins to adjust to the dim light settings with an average of 41.10% suppression.

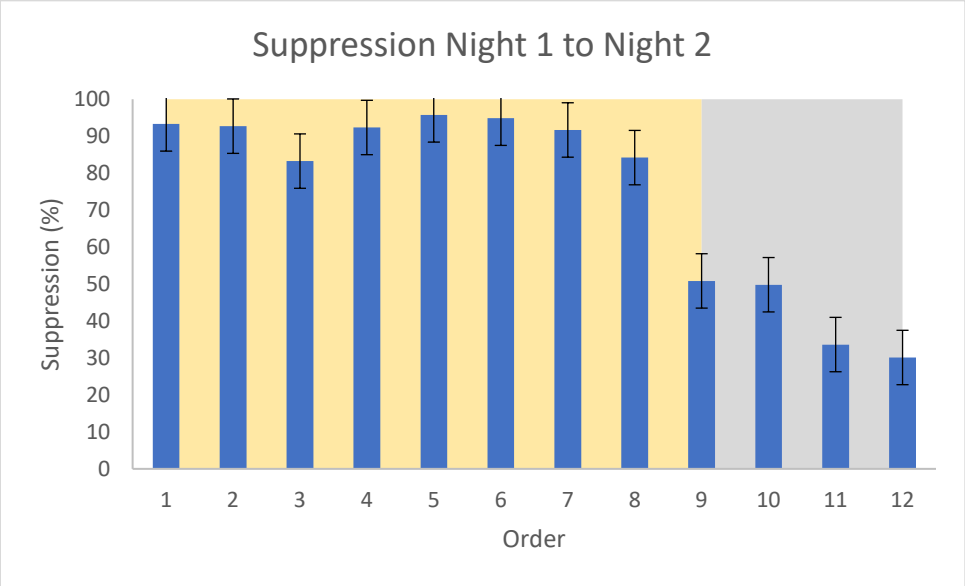

Figure 9. Average suppression percentages with standard error bars

Our results show that utilizing the bright light intervention method on Night 2 resulted in suppression of melatonin levels for all participants. Individual suppression percentage trends are provided in Appendix K.

b. Night 1 to Night 3 comparison

Phase delay shift calculations were computed by finding the difference between DLMO on Night 1 and Night 3. All participants had a successful phase delay, shifting their circadian rhythm to the right regardless of their habitual bedtime. On average, there was a phase delay shift of 1 hour 20 minutes ± 22 minutes (t-test, $t=-10.58$, $df = 8$, $p<0.001$) with a maximum phase delay of 1 hour 56 minutes and minimum phase delay of 53 minutes. Table 4 depicts individual phase delay calculations. Our results demonstrate that exposure to bright light was successful in delaying the circadian phase. Individual salivary melatonin profiles are provided in Appendix L.

Table 4. Participant phase delay calculations

Participant ID	Habitual Bedtime	DLMO Night 1	DLMO Night 3	Phase Delay (hours:mins)
CEAS01	21:30	20:36	21:29	0:53
CEAS02	23:00	21:31	23:01	1:30
CEAS03	23:00	21:42	23:38	1:56
CEAS05	0:00	23:12	0:56	1:44
CEAS06	0:00	21:41	23:06	1:24
CEAS07	22:30	21:33	22:41	1:08
CEAS08	22:30	20:43	21:36	0:53
CEAS09	0:00	0:49	2:18	1:28
CEAS10	23:00	20:59	21:59	0:59

2. KSS

As previously stated, KSS scores for most individuals increased as the night when on regardless of the light condition. Focusing on recorded scores 9-12 (time during dim light settings) across all nights, mean KSS scores decreased from Night 1 to Night 2 and increased from Night 2 to Night 3 as seen in Figure 10 below. These changes are expected as the participants were in bright light settings for the previous 8 recorded scores on Night 2.

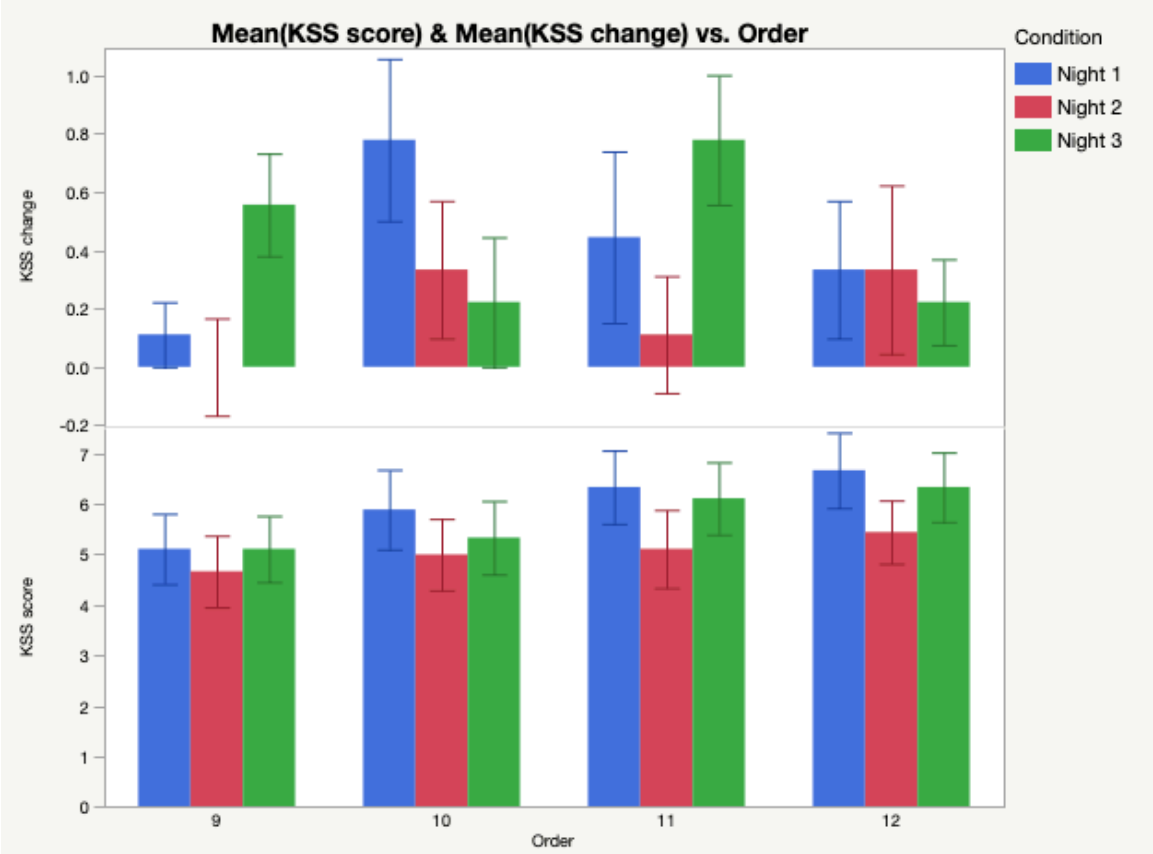

Figure 10. Mean KSS scores and mean KSS change with standard error bars over time

Using Tukey's HSD test for multiple comparisons, the average change in KSS scores from Night 1 to Night 2 was statistically significant (df = 94, $p < 0.001$, 95% C.I. = [0.369, 1.520]). Night 2 to Night 3 was also statistically significant (df = 94, p = 0.019, 95% C.I. = [-1.242, -0.091]). However, the average change in KSS scores from Night 1 to

Night 3 was not statistically significant (Tukey's HSD test, df = 94, p = 0.486, 95% C.I. = [-0.298, 0.853]) indicating there was not a substantial difference in self-reported KSS scores resulting from carryover effects from the light intervention method. Figure 10 also shows the relative change from the previous KSS score to the current KSS score. On Night 1 and Night 3, when participants were kept in dim light for the entirety of the evening, there was a larger change in average successive KSS scores compared to Night 2. When participants were in bright light settings for the majority of the night, there was either no change or a small increase in average sequential KSS scores. Overall, the changes in average KSS scores indicate an increasing trend for all participants on all three nights.

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V. DISCUSSION AND RECOMMENDATIONS

A. DISCUSSION

The study was requested by the Marine Corps Aviation community with a focus on risk mitigation strategies for aviators transitioning from day to night flights. Avoiding the use of stimulants and sedatives to aid in fatigue mitigation, the study instead used four hours of continuous bright light exposure to shift the circadian rhythm. The main goals of this study were to determine if the light intervention protocol successfully shifted the circadian rhythm of our participants, how large of a phase delay shift was possible, and whether the light intervention affected the participants' performance and perceived levels of fatigue.

Based on our nine participants, all successfully had a phase delay of their circadian rhythm. By analyzing the DLMO times on Night 1 and Night 3, we were able to calculate the phase delay shifts for each participant. The minimum phase delay observed was 53 minutes and the maximum phase delay observed was 1 hour 56 minutes. There was an average phase delay shift of 1 hour 20 minutes ± 22 minutes ranging from 53 minutes 1 hour 56 minutes, demonstrating that exposure to continuous bright light can successfully shift the circadian rhythm. The results of the phase delay provide a positive start for future application of bright light exposure methods in military aviation communities. The method used in this study could be employed in aviation ready rooms as pilots and aircrew prepare for night operations with little interference with the tasks they need to complete.

Participants' levels of perceived fatigue were analyzed using KSS scores reported every 30 minutes throughout the data collection periods. Each participant had increasing KSS scores regardless of night and light conditions. Night 1 to Night 2 saw a decrease in reported KSS scores and had a statistically significant change, signifying an impact from the bright light exposure. Night 2 to Night 3 saw an increase in reported KSS scores and also had a statistically significant change. However, Night 1 to Night 3 only had a slight decrease in reported scores and was not statistically significant. The changes from Night 2 to Night 3 and the overall change from Night 1 to Night 3 indicate the light intervention

method had immediate impacts on self-reported perceived levels of fatigue; however, these effects were not lasting.

B. LIMITATIONS

The study could be improved by lengthening the duration of the study protocol. Using only one night of bright light exposure followed by a single night to assess change limited the information that could be gained on the lasting effects of the light intervention method. Increasing the number of days of bright light exposure and/or increasing the number of follow-on assessment days could provide better indicators of the long-term effects of utilizing this bright light intervention method. Additionally, allowing participants to return home between data collection periods with little restriction on what type of light was authorized could have impacted the total amount of phase delay shift that was possible.

The study protocol could be improved by broadening the criteria for eligible participants. Recruiting only experienced aviators from the NPS community limited an already small population and resulted in only ten volunteers. Expanding or changing the protocol to include novice aviators could result in a larger sample size enabling more concrete conclusions on KSS trends, salivary melatonin level trends, and phase delay shifts.

The sample population also limited the study because participants were in an academic environment rather than a training or deployed environment. The personal schedules of our participants, including their sleep schedules, may vary from a population of individuals who are in training or deployed. The NPS academic environment allows individuals to have a more consistent sleep schedule compared to individuals who must schedule sleep around military training and operations. Using participants who had consistent schedules allowed us to accurately calculate habitual bedtimes ensuring DLMO was captured. However, if the light intervention method was applied to training or deployed squadrons where sleep schedules are not as consistent, resulting phase delay shifts and perceived fatigue levels may not reach the same level of circadian rhythm entrainment.

C. RECOMMENDATIONS

Continuing to expand on this study's light intervention protocol could greatly benefit the military aviation community. The methods proposed in this study could aid in reducing the risk caused by circadian misalignment and could potentially reduce fatigue-related incidents and mishaps. A larger sample size is necessary to gain a better understanding of the benefits of this circadian entrainment protocol. One way to increase the sample size is to remove the requirement for qualified aviators to participate in the study and include individuals who are inexperienced in aviation. Alternatively, the protocol could be implemented over a series of weeks at an aviation training command that has ongoing day and night flight schedules. Additionally, the protocol duration should be extended to include more days of bright light exposure and more days analyzing the phase delay shifts over time. Extending the length of the study would help examine the lasting effects of the light intervention method.

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APPENDIX A. CONSENT FORM

NPS IRB Approved
5 MAR 2021

Naval Postgraduate School
Consent to Participate in Research

Introduction. You are invited to participate in a research study entitled AVIATION SHIFTWORK AND TRANSITIONING FROM DAY FLIGHTS TO NIGHT FLIGHTS**.** The purpose of the research is to evaluate the effectiveness of using strategic light exposure to help aviators transition from day to night operations.

Participation is voluntary. If you decline to participate, there will be no penalty or loss of benefits to which you would otherwise be entitled, and you may discontinue participation at any time without penalty or loss of benefits to which you otherwise would be entitled. The alternative to participating in this study is to not participate in this study. We anticipate approximately 10-20 volunteers to participate in this study.

Procedures. This study will take place in the Human Systems Integration Laboratory, Rm 221, Glasgow Hall, at the Naval Postgraduate School. At the beginning of the study, you will be asked to complete a Pre-Study Questionnaire (~20 minutes), given a wearable light sensor (HOBO), a wearable sleep monitor (actiwatch), a sleep log, and an Oura Ring, which measures heart rate, heart rate variability, respiration, movement, and temperature. You will be asked to wear the light sensor, actiwatch and Oura Ring, fill in the log (~5 minutes per day), and maintain a consistent sleep/wake schedule for approximately one week prior to the testing. You will also be asked to get a COVID-19 test, which will be performed at a local testing facility and will be provided at no cost to you. You will be asked to come to the lab sometime during that week for a familiarization session in the flight simulator. At the end of the week, you will come in for three consecutive testing days/evenings. On the first testing day, you will fly a simulated day flight in the morning and a night flight later in the evening on that same day. On the second testing day, you will come to the lab in the early evening, receive light exposure (the "treatment") and have a simulated night flight later that same evening. On the third testing day, you will perform a night flight without light exposure. The "treatment", an experimental light exposure with moderate to bright light, will be administered only once on the second test day. During the first study session you will be asked to complete a Pre-Flight Questionnaire (~3-5 minutes) and before each night session you will be asked to verify the Pre-Flight Checklist. While in the flight simulator you will be asked to rate your workload every 30 minutes (~10 seconds each time). During each study sessions you will be asked to rate your sleepiness (~10 seconds each time) and provide a brief voice recording (~30 seconds each time) every 30 minutes. During all night flight sessions, you will also be asked to provide a saliva sample every 30 minutes (~1 minute each time). You will be asked to provide a total of up to 36 saliva samples. Each of the simulated flights will be less than 2 hours duration. For the 3 night flight sessions, you will be asked to come to the lab 2-3 hours before your habitual bedtime and stay until 2-3 hours after your habitual bedtime. The total duration of each study session will be up to 6 hours. The total number of days of participation in this study will be approximately 11 days including the pre-study period. You may be video recorded while you are in the flight simulator to document your performance and responses during these testing sessions.

The risks associated with participating in this study are minimal; however, please be aware of the following:

Privacy risks. There is a minor risk of breach of privacy and confidentiality. All personal identifiable information (PII) will be concealed once the data has been collected, and data will be identified using a study ID number. Data will be presented based on group analysis. Individual data will not be disclosed to anyone outside the research team.

Version #2.0
Date: 17 FEB 2021

Oura Ring risks. The study requires the participant to wear an Oura ring for the duration of the study. As with any ring, risks include discomfort to the finger, including but not limited to swelling, skin irritation, and de-gloving. The manufacturer does not recommend wearing the ring while participating in any activities where the ring may become lodged, such as weightlifting. Please protect yourself and the equipment and remove the ring for the duration of any such activity. If skin irritation or swelling does occur, remove the device and inform research personnel immediately. Additionally, biometric data regarding heart rate, movement, and temperature will be collected by the ring and analyzed using proprietary algorithms via the Oura App. This information will be uploaded to a cloud-based server that is secured per California Law and GDPR standards. There is, however, with any cloud-based platform, the risk that the data could be compromised. The data will not include any personally identifiable information if the instructions are followed, and no modifications are made to the participant's profile during the study. The Oura ring and App are designed to provide the wearer with personalized feedback broken into three categories: Sleep, Readiness, and Activity. The participant will have access to the feedback for the duration of the study and may analyze the data further using Oura on the Web. The Oura Ring is not intended to diagnose, treat, cure, or prevent any disease or medical condition. Before making changes to your sleep or activity, you should speak with your medical care professional.

Drowsiness risks. There is a risk that you may experience drowsiness as a result of staying up past your habitual bedtime. If you feel drowsy, you are asked to not drive yourself home. Upon completion of the evening study sessions, please ask a friend or family member to come pick you up.

COVID-19 precautions. These safety guidelines will be followed to reduce the risk of spread of COVID-19:

- There will only be one person in each rooms at a time. If two people have to be in the same room at one time, they will maintain 6 feet of distance, and wear masks at all times.
- The saliva collection is going to be self-administered. Research personnel will wear appropriate PPE while handling any saliva samples.
- The contact log will be filled out before anyone enters the lab and will be retained for two weeks.

Cost. There is no cost to participate in this research study.

Compensation for Participation. No tangible compensation will be given. You will not receive any direct benefit from participating in this research, however, the results of this study may inform practices and procedures that could improve the safety and performance of aviators engaged in round-the-clock operations.

Confidentiality & Privacy Act. Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential but total confidentiality cannot be guaranteed. Hard copies of your data will be kept in cipher-locked rooms and digital copies are kept on secure NPS servers. Upon completion of this study, personal identifiers will be removed from your data, and the de-identified data may be used in future research without additional informed consent. All biospecimens will be destroyed upon completion of the analysis.

Data collected via the Oura ring will be stored within the Oura App on your mobile device and on the secure Oura on the Web cloud server. You will have access to your own data. The NPS research team can also access your data via the Oura Teams platform. At the conclusion of the study, data will be securely stored on the NPS Sakai website and maintained in accordance with the DoN instructions by the

NPS IRB Approved
5 MAR 2021

NPS Research Team and will be deleted from the Oura cloud server. Account and data deletion from the Oura server and Oura App deletion will also remove the data from your mobile device. Your de-identified data will be stored at NPS and may be used in future related studies.

The use of a study email is the primary method of minimizing risk of breach of your confidentiality. This prevents your identity from being shared with members outside of NPS such as the Oura Cloud Server. The Oura Cloud Server also adheres to the stringent privacy guidelines of the GDPR and California Law. Once data are downloaded to NPS servers from the Oura Cloud Server, the data will be deleted from the Oura server.

Points of Contact. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact the Principal Investigator, Dr. Nita Shattuck, 831-656-2281, nlshattu@nps.edu. Questions about your rights as a research subject or any other concerns may be addressed to the Navy Postgraduate School IRB Vice Chair, Mr. Bryan Hudgens, 831-656-2039, bryan.hudgens@nps.edu.

Statement of Consent. I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I have been provided a copy of this form for my records and I agree to participate in this study. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

☐ I consent to participate in the research study.

☐ I do not consent to participate in the research study.

Signature of Participant _____ Date _____

Version #2.0
Date: 17 FEB 2021

California Experimental Subject's Bill of Rights

Any person who is requested to consent to participate in a research study involving a medical experiment, or who is requested to consent on behalf of another, has the right to:

1. Learn the nature and purpose of the study.

2. Receive an explanation of the procedures to be followed in the medical study, and a description of any drug or device to be used.

3. Be informed of any related discomforts and risks that can reasonably to be expected from participating in the study.

4. Learn about any benefits you might expect from the study, if applicable.

5. Be told about any other procedures, drugs or services that might be helpful to you and the relative risks and benefits of these alternatives.

6. Be informed of the medical treatment, if any, available to you if you are injured because of the study.

7. Ask any questions about the study.

8. Stop the study at any time without any effect on your healthcare benefits or medical care, even if you stop the study.

9. Receive a copy of the signed and dated consent form when one is required.

10. Decide to consent or not to consent to a medical study without feeling forced to participate

_____
Printed Name of the Participant

_____
Signature of the Participant

Date:_____

APPENDIX B. ENROLLMENT QUESTIONNAIRE

Naval Postgraduate School

Date: _____ Participant ID: _____

Enrollment Questionnaire

Instructions: *Please answer ALL questions as accurately as possible. ALL information is confidential and will be used only for research purposes.*

1. What is your age: _____ years
2. **What is your sex (Check one ☑)** ☐ **Male** ☐ **Female**
3. What is your branch of service? _____
4. **What is your rank:** _____
5. Are you a pilot? (Check one ☑) ☐ Yes ☐ No
6. **What aircraft have you flown in the last 12 months?** _____
7. Approximately how many total flight hours do you have? _____
8. **Do you habitually use nicotine products? (Check one ☑)** ☐ **Yes** ☐ **No**

   If YES, please indicate which products you use, and how often you use them:
   - ☐ **Cigarettes** _____ **Times per week**
   - ☐ **Chewing tobacco/snuff** _____ **Times per week**
   - ☐ **Nicorette gum or patches** _____ **Times per week**
   - ☐ **Electronic smoke** _____ **Times per week**
   - ☐ **Other (specify):** _____ _____ **Times per week**
9. How many of the following caffeinated beverages do you drink **on average** each day? (Check ALL that apply ☑) and indicate daily amount)
   - ☐ Tea Servings/Cups per day: _____
   - ☐ Coffee Servings/Cups per day: _____
   - ☐ Soda/pop/soft drinks Servings/Cups per day: _____
   - ☐ Energy drinks (Monster/RedBull, etc.) Servings/Cups per day: _____
   - ☐ Other (specify): _____ How often: _____ (Example: 4 times per day)
10. **Do you take any prescribed or over-the-counter medications? (Check one ☑)** ☐ **Yes** ☐ **No**

    If YES, please list all medications you take:

    _____

    _____
11. Have you ever been diagnosed by a physician with a sleep-related disorder? ☐ Yes ☐ No

    If YES, please describe: _____

M-E Instructions: *For each question, please select the answer that best describes you by circling the point value that best indicates how you have felt in recent weeks.*

1. Approximately what time would you get up if you were entirely free to plan your day?

[5] 5:00 AM–6:30 AM (05:00–06:30 h)	[4] 6:30 AM–7:45 AM (06:30–07:45 h)	[3] 7:45 AM–9:45 AM (07:45–09:45 h)	[2] 9:45 AM–11:00 AM (09:45–11:00 h)	[1] 11:00 AM–12 noon (11:00–12:00 h)
☐	☐	☐	☐	☐

2. **Approximately what time would you go to bed if you were entirely free to plan your evening?**

[5] 8:00 PM–9:00 PM (20:00–21:00 h)	[4] 9:00 PM–10:15 PM (21:00–22:15 h)	[3] 10:15 PM–12:30 AM (22:15–00:30 h)	[2] 12:30 AM–1:45 AM (00:30–01:45 h)	[1] 1:45 AM–3:00 AM (01:45–03:00 h)
☐	☐	☐	☐	☐

3. If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?

[4] Not at all	[3] Slightly	[2] Somewhat	[1] Very much
☐	☐	☐	☐

4. **How easy do you find it to get up in the morning (when you are not awakened unexpectedly)?**

[1] Very difficult	[2] Somewhat difficult	[3] Fairly easy	[4] Very easy
☐	☐	☐	☐

5. How alert do you feel during the first half hour after you wake up in the morning?

[1] Not at all	[2] Slightly alert	[3] Fairly alert	[4] Very alert
☐	☐	☐	☐

6. **How hungry do you feel during the first half hour after you wake up?**

[1] Not at all hungry	[2] Slightly hungry	[3] Fairly hungry	[4] Very hungry
☐	☐	☐	☐

7. During the first half hour after you wake up in the morning, how do you feel?

[1] Very tired	[2] Fairly tired	[3] Fairly refreshed	[4] Very refreshed
☐	☐	☐	☐

8. **If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?**

[4] Seldom or never later	[3] Less that 1 hour later	[2] 1-2 hours later	[1] More than 2 hours later
☐	☐	☐	☐

9. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week, and the best time for him is between 7-8 AM (07-08 h). Bearing in mind nothing but your own internal "clock," how do you think you would perform?

[4] Would be in good form	[3] Would be in reasonable form	[2] Would find it difficult	[1] Would find it very difficult
☐	☐	☐	☐

10. **At approximately what time in the evening do you feel tired, and, as a result, in need of sleep?**

[5] 8:00 PM–9:00 PM (20:00–21:00 h)	[4] 9:00 PM–10:15 PM (21:00–22:15 h)	[3] 10:15 PM–12:45 AM (22:15–00:45 h)	[2] 12:45 AM–2:00 AM (00:45–02:00 h)	[1] 2:00 AM–3:00 AM (02:00–03:00 h)
☐	☐	☐	☐	☐

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirely free to plan your day. Considering only your "internal clock," which one of the four testing times would you choose?

[6] 8 AM–10 AM (08–10 h)	[4] 11 AM–1 PM (11–13 h)	[2] 3 PM–5 PM (15–17 h)	[0] 7 PM–9 PM (19–21 h)
☐	☐	☐	☐

12. If you got into bed at 11 PM (23 h), how tired would you be?

[0] Not at all tired	[2] A little tired	[3] Fairly tired	[5] Very tired
☐	☐	☐	☐

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?

[4] Will wake up at usual time, but will not fall back asleep	[3] Will wake up at usual time and will doze thereafter	[2] Will wake up at usual time, but will fall asleep again	[1] Will not wake up until later than usual
☐	☐	☐	☐

14. One night you have to remain awake between 4-6 AM (04-06 h) in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?

[1] Would not go to bed until the watch is over	[2] Would take a nap before and sleep after	[3] Would take a good sleep before and nap after	[4] Would sleep only before the watch
☐	☐	☐	☐

15. You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal "clock," which of the following times would you choose?

[4] 8 AM–10 AM (08–10 h)	[3] 11 AM–1 PM (11–13 h)	[2] 3 PM–5 PM (15–17 h)	[1] 7 PM–9 PM (19–21 h)
☐	☐	☐	☐

16. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10-11 PM (22-23 h). Bearing in mind only your internal "clock," how well do you think you would perform?

[1] Would be in good form	[2] Would be in reasonable form	[3] Would find it difficult	[4] Would find it very difficult
☐	☐	☐	☐

17. Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting, and you are paid based on your performance. At approximately what time would you choose to begin?

[5] 5 hours starting between 4–8 AM (05–08 h)	[4] 5 hours starting between 8–9 AM (08–09 h)	[3] 5 hours starting between 9 AM–2 PM (09–14 h)	[2] 5 hours starting between 2–5 PM (14–17 h)	[1] 5 hours starting between 5 PM–4 AM (17–04 h)
☐	☐	☐	☐	☐

18. At approximately what time of day do you usually feel your best?

[5] 5–8 AM (05–08 h)	[4] 8–10 AM (08–10 h)	[3] 10 AM–5 PM (10–17 h)	[2] 5–10 PM (17–22 h)	[1] 10 PM–5 AM (22–05 h)
☐	☐	☐	☐	☐

19. One hears about "morning types" and "evening types." Which one of these types do you consider yourself to be?

[6] Definitely a morning type	[4] Rather more a morning type than an evening type	[2] Rather more an evening type than a morning type	[1] Definitely an evening type
☐	☐	☐	☐

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APPENDIX C. PRE-FLIGHT QUESTIONNAIRE

Naval Postgraduate School

Date: _____ Participant ID: _____

Pre-flight Questionnaire

ESS instructions: *How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? This refers to your usual way of life in the **last week**. Even if you have not done some of these things recently try to work out how they would have affected you. Check ☑ the most appropriate number for each situation.*

	CHANCE OF DOZING			
	None (0)	Slight (1)	Moderate (2)	High (3)
Sitting and reading	O	O	O	O
Watching TV	O	O	O	O
Sitting inactive in a public place (e.g. a theater or a meeting)	O	O	O	O
As a passenger in a car for an hour without a break	O	O	O	O
Lying down to rest in the afternoon when circumstances permit	O	O	O	O
Sitting and talking to someone	O	O	O	O
Sitting quietly after a lunch without alcohol	O	O	O	O
In a car, while stopped for a few minutes in traffic	O	O	O	O

KSS Instructions: *Here are some descriptors about how alert or sleepy you might be feeling right now. Please read them carefully and CIRCLE the number that best corresponds to the statement describing how you feel at the moment.*

1. Extremely alert
2. Very alert
3. Alert
4. Rather alert
5. Neither alert nor sleepy
6. Some signs of sleepiness
7. Sleepy, no effort to stay awake
8. Sleepy, some effort to stay awake
9. Very sleepy, great effort to keep awake, fighting sleep

PSQI instructions: *The following questions relate to your usual sleep habits during the* ***last week only****. Your answers should indicate the most accurate reply for the majority of days/nights in the* ***last week****. Please answer all questions.*

1. In the last week, what time have you usually gone to bed at night?	Bed Time: _____
1. During the last week, how long (in minutes) has it usually taken you to fall asleep each night	Number of Minutes:_____
2. In the last week, what time have you usually gotten up in the morning?	Getting up time:_____
3. During the last week, how many hours of actual sleep did you get at night? (this may be different than the number of hours you spent in bed.)	Hours of Sleep per Night:__

Instructions: *For each of the questions, check the one best response.*

4. During the last week, how often have you had trouble sleeping because you…	Not during the past month	Less than once a week	Once or twice a week	3 or more times a week
a) Cannot get to sleep within 30 mins	O	O	O	O
b) Wake up in the middle of the night or early morning	O	O	O	O
c) Have to get up to use the bathroom	O	O	O	O
d) Cannot breathe comfortably	O	O	O	O
e) Cough or snore loudly	O	O	O	O
f) Feel too cold	O	O	O	O
g) Feel too hot	O	O	O	O
h) Had bad dreams	O	O	O	O
i) Have pain	O	O	O	O
j) Other reason(s), please describe: _____ How often during the last week have you had trouble sleeping because of this other reason?	O	O	O	O
5. During the last week, how would you rate your sleep quality overall?	Very Good O	Fairly Good O	Fairly Bad O	Very Bad O
6. During the last week, how often have you taken medicine to help you sleep (prescribed or "over the counter")?	Not during the past week O	Less than once a week O	Once or twice a week O	Three or more times a week O
7. During the last week, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?	O	O	O	O
8. During the last week, how much of a problem has it been for you to keep up enough enthusiasm to get things done?	Not a problem at all	Only a very slight problem	Somewhat of a problem	A very big problem

APPENDIX D. BEDFORD WORKLOAD SCALE

During Flight Assessment:
Bedford Workload Scale

Time:_____

BWS Instructions: *Below is a decision tree and descriptors about your workload. Please read them carefully and CIRCLE the number that best corresponds to the statement describing your workload.*

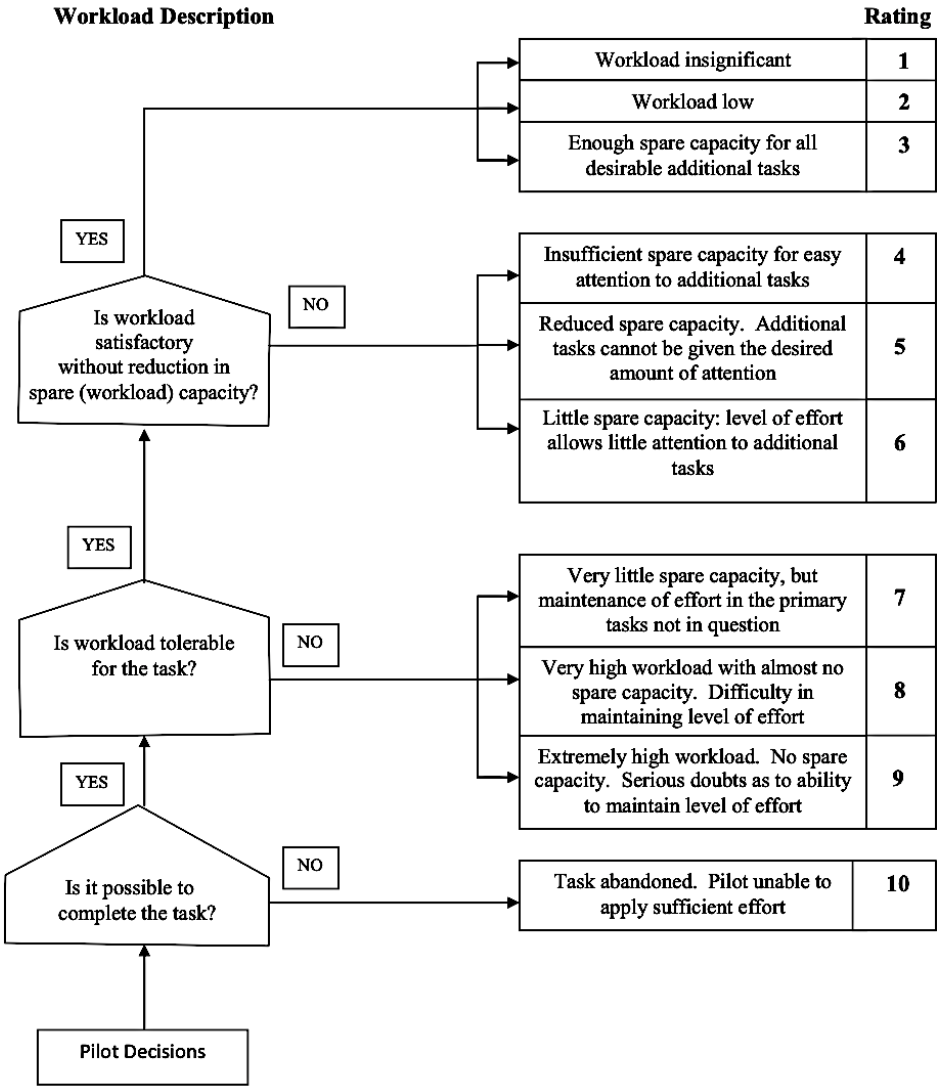

Figure 1. Bedford Workload Rating Scale.

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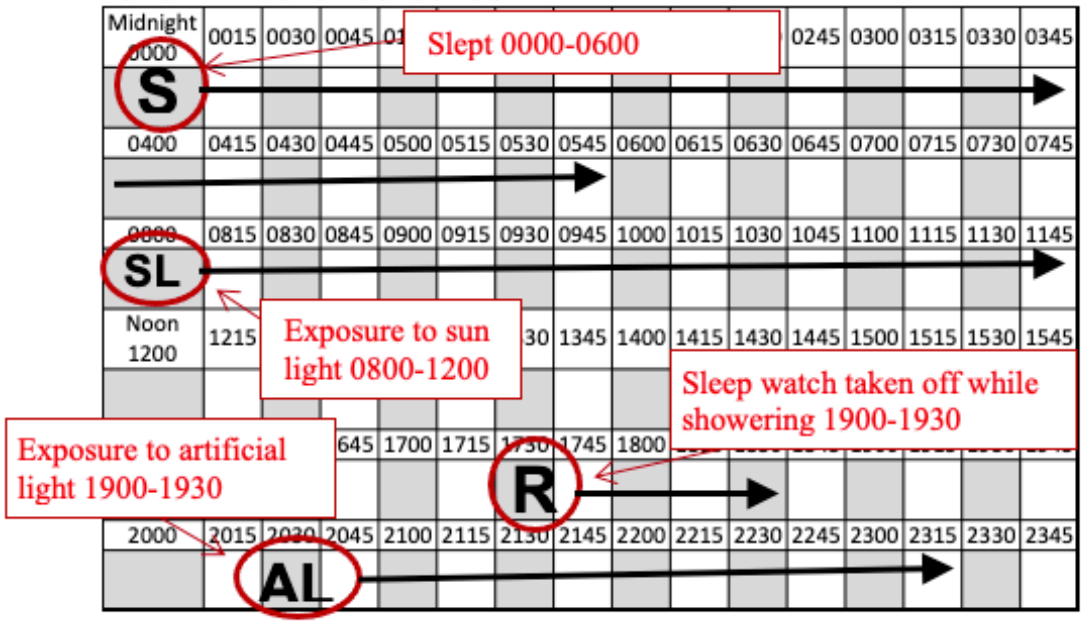
APPENDIX E. ACTIVITY LOG PAGE EXAMPLE

Example Log: The descriptions of daily activities are shown in the red boxes.



Activities

C Drinking a caffeinated beverage/energy drink (please indicate type in notes)
E Eating a meal or snack
R Removing sleep watch
S Sleeping/napping
SL Exposure to sun light
AL Exposure to artificial ambient light / used light emitting devices, etc.
W Working out

Additional Notes:

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APPENDIX F. RECRUITMENT FLYER

ARE YOU A MILITARY AVIATOR?

Ever had difficulties *adjusting* from day flights to night flights?

Our study assesses whether light exposure can be used to speed up the day-to-night operations transition period.

Participation is voluntary

Requirements:

- Two familiarization flights in the HSI Lab Flight Simulator
- Three ~6 hour evening/night sessions in the HSI Lab
- Wear a light sensor, sleep monitor, Oura ring, and provide saliva samples

Participants will receive COVID-19 testing at no charge.

Please sign up for this important study!

QUESTIONS?

LTJG Meghan McDonough
E-mail: meghan.mcdonough@nps.edu

LCDR James Reily
E-mail: james.reily@nps.edu

Principal Investigator: Dr. Nita Shattuck
E-mail: nlshattu@nps.edu
Phone: (831)656-2281

IRB Vice Chair: Mr. Bryan Hudgens
E-mail: bryan.hudgens@nps.edu
Phone: (831)656-2039

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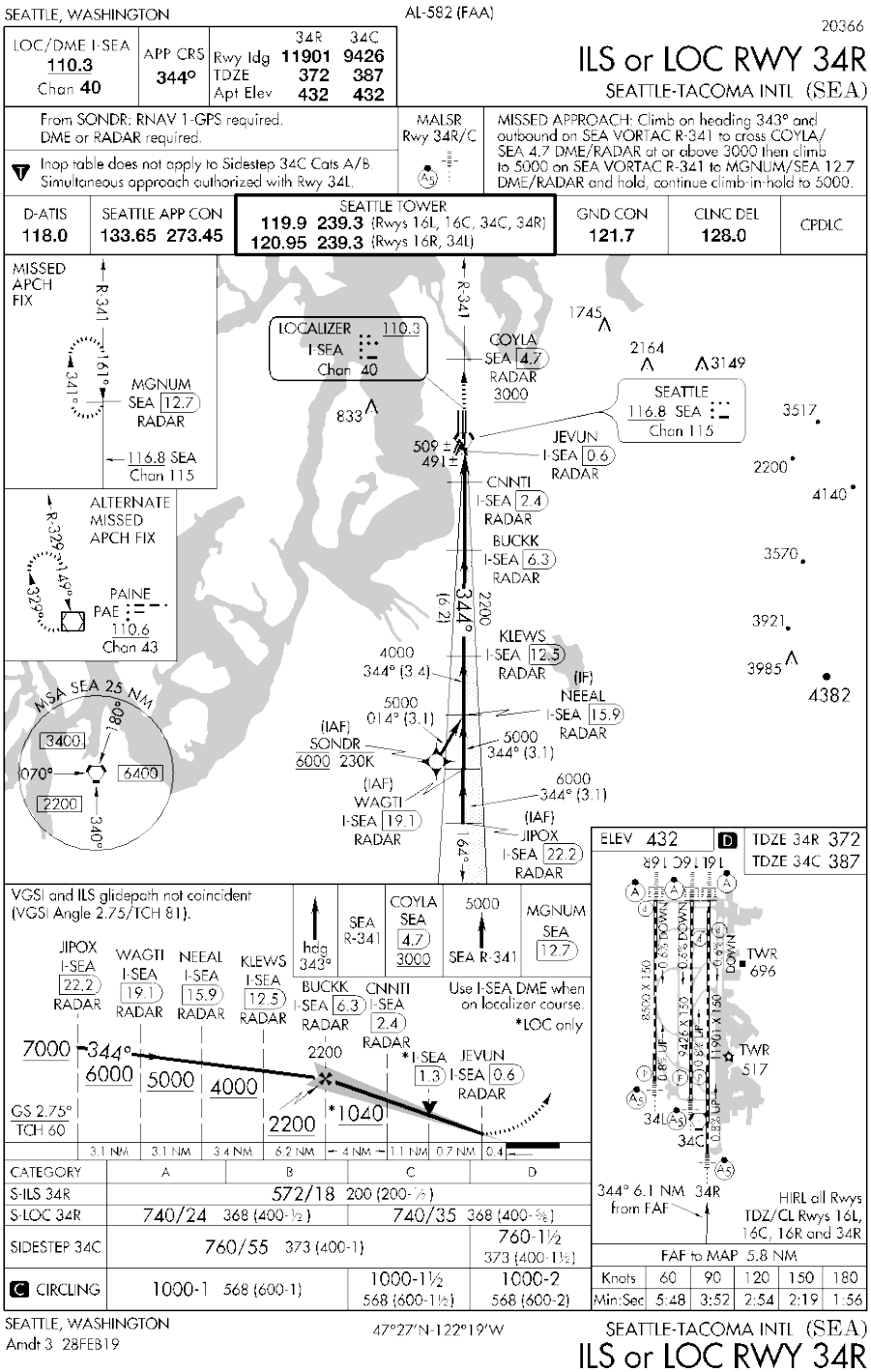
APPENDIX G. APPROACH PLATES



NW-1, 25 MAR 2021 to 22 APR 2021

NW-1, 25 MAR 2021 to 22 APR 2021

ILS or LOC RWY 28R

SAN FRANCISCO INTL (SFO)

LOC/DME I-GWQ	APP CRS		28R	28L
111.7	284°	Rwy Idg	11236	10275
Chan 54		TDZE	13	13
		Apt Elev	13	13

RNAV 1-GPS or RADAR required for procedure entry.

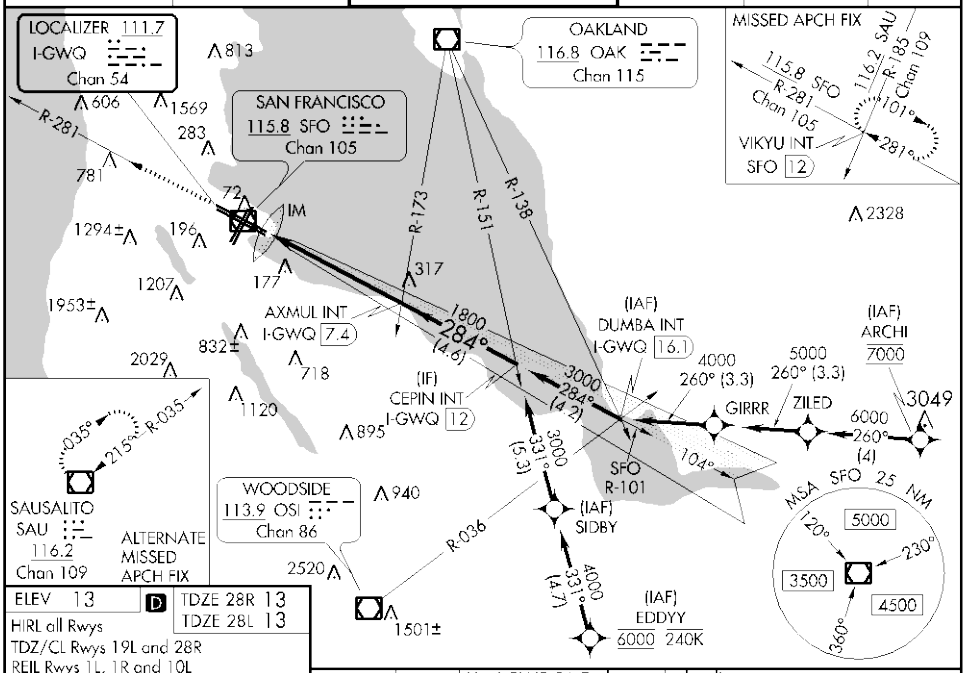
Circling NA to Rwys 10L, 10R, 19L, and 19R. Circling Rwy 1L, 1R NA at night. For inop ALS increase S-LOC 28R# Cat C/D visibility to 1⅞ SM. LOC procedure NA during simultaneous operations. Simultaneous approach authorized. Simultaneous operations require use of vertical guidance; maintain last assigned altitude until established on glideslope.

ALSF-2 Rwy 28R

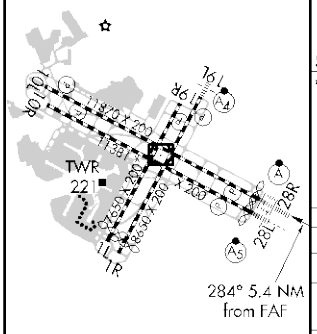
MALSR Rwy 28L

MISSED APPROACH: Climb to 3000 on SFO VOR/DME R-281 to VIKYU INT/SFO 12 DME and hold.
Missed approach requires minimum climb of 350 feet per NM to 1900; if unable to meet climb gradient, see ILS or LOC RWY 28L.

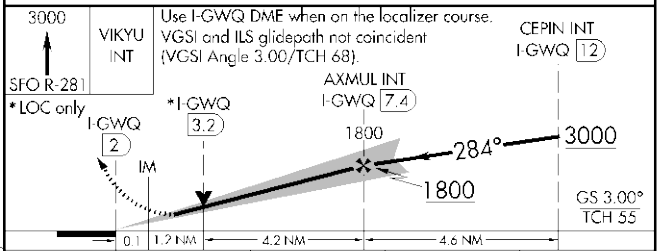
D-ATIS	NORCAL APP CON	SAN FRANCISCO TOWER	GND CON	CLNC DEL	CPDLC
113.7 115.8 118.85	134.5 338.2	120.5 269.1	121.8	118.2	



ELEV 13 D	TDZE 28R 13
HIRL all Rwys	TDZE 28L 13
TDZ/CL Rwys 19L and 28R	
REIL Rwys 1L, 1R and 10L	



FAF to MAP 5.4 NM					
Knots	60	90	120	150	180
Min:Sec	5:24	3:36	2:42	2:10	1:48



CATEGORY	A	B	C	D
S-ILS 28R#	213/18 200 (200-½)			
S-LOC 28R#	480/24 467 (500-½)		480/50 467 (500-1)	
SIDESTEP # 28L	480/55 467 (500-1)			480-1½ 467 (500-1½)
C CIRCLING	740-1 727 (800-1)	960-1¼ 947 (1000-1¼)	1560-3 1547 (1600-3)	NA

SAN FRANCISCO, CALIFORNIA
Amdt 15A 03JAN19

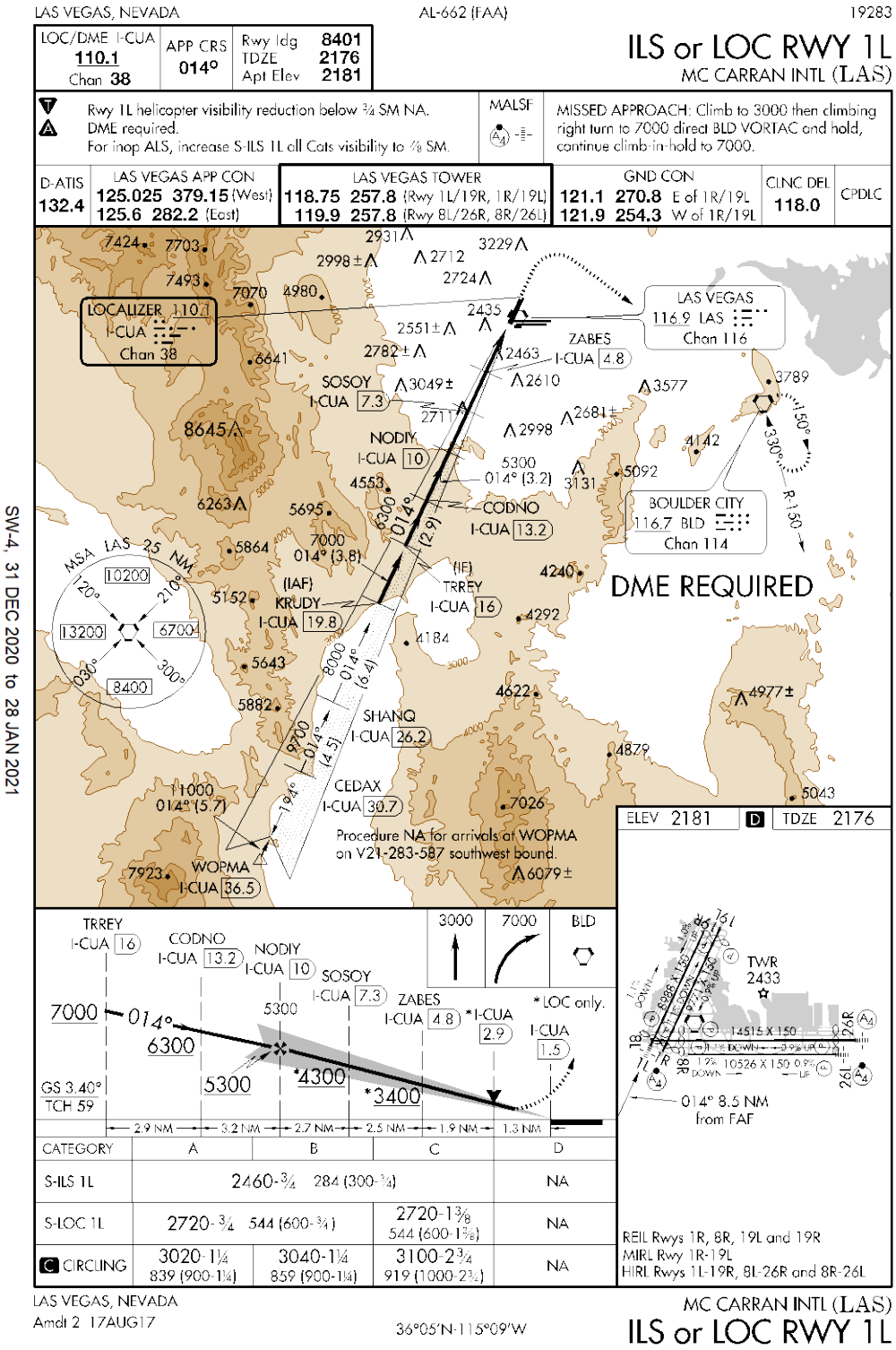
37°37'N-122°23'W

SAN FRANCISCO INTL (SFO)

ILS or LOC RWY 28R

SW-2, 31 DEC 2020 to 28 JAN 2021

SW-2, 31 DEC 2020 to 28 JAN 2021



SW-4, 31 DEC 2020 to 28 JAN 2021

SW-4, 31 DEC 2020 to 28 JAN 2021

ILS or LOC RWY 24

MARTHA'S VINEYARD (MVY)

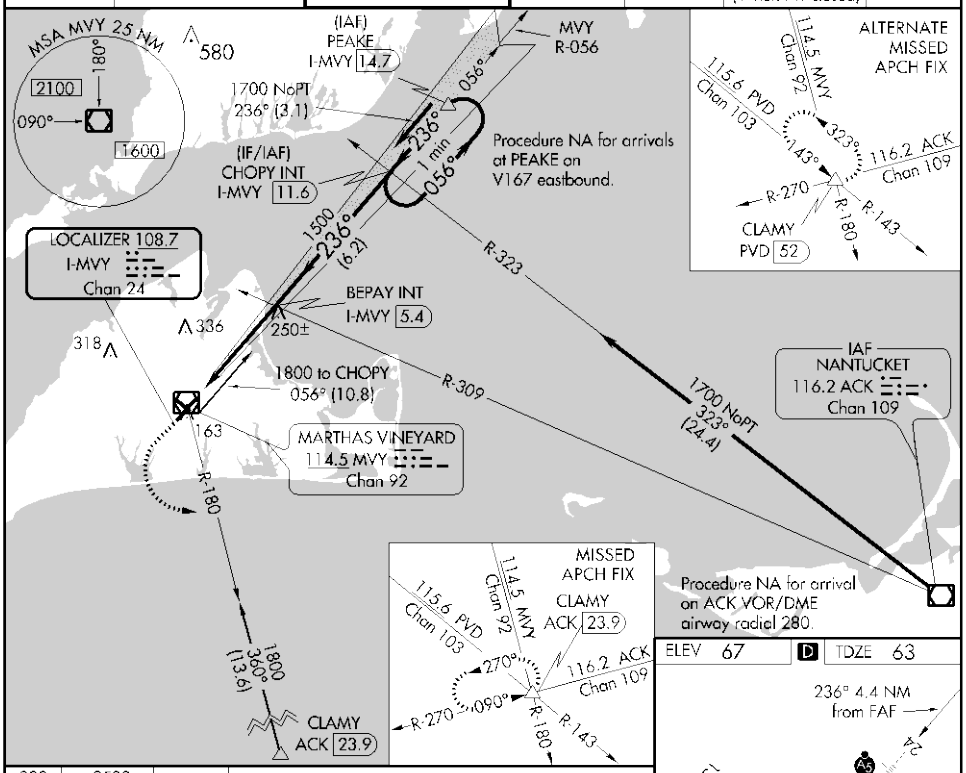
LOC/DME I-MVY	APP CRS	Rwy Idg	5504
108.7 Chan 24	236°	TDZE	63
		Apt Elev	67

VDP NA with Hyannis altimeter setting. When local altimeter setting not received, use Hyannis altimeter setting and increase all DA to 317 feet and all MDA 60 feet, increase S-LOC Cats C and D visibility to RVR 5000, Circling Cat C and D visibility ¼ SM. For inoperative MALSR when using Hyannis altimeter setting, increase S-LOC Cats C and D visibility to 1⅜ mile. Circling Rwy 15 NA at night. ** RVR 1800 authorized with use of FD or AP or HUD to DA (NA when using Hyannis altimeter setting).

MALSR

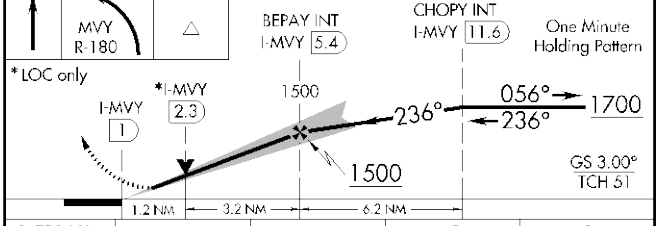
MISSED APPROACH: Climb to 800 then climbing left turn to 2500 on MVY VOR/DME R-180 to CLAMY INT/ACK 23.9 DME and hold.

ATIS	BOSTON APP CON *	VINEYARD TOWER *	GND CON	CLNC DEL	CLNC DEL	UNICOM
126.25	119.7	121.4 (CTAF)	124.35	124.35	119.7 (When twr closed)	122.95



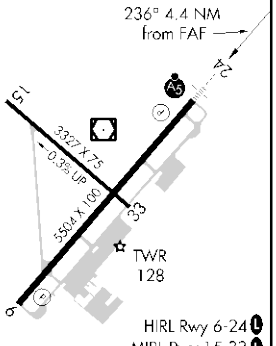
800	2500	CLAMY
↑	MVY R-180	△

Use I-MVY DME when on the localizer course.



CATEGORY	A	B	C	D
S-ILS 24**	263/24 200 (200-½)			
S-LOC 24	500/24 437 (500-½)		500/40	437 (500-¾)
C CIRCLING	500-1 433 (500-1)	540-1 473 (500-1)	700-1¾ 633 (700-1¾)	780-2¼ 713 (800-2¼)

ELEV 67 D TDZE 63



FAF to MAP 4.4 NM					
Knots	60	90	120	150	180
Min:Sec	4:24	2:56	2:12	1:46	1:28

VINEYARD HAVEN, MASSACHUSETTS
Amdt 3C 23APR20

41°24'N-70°37'W

MARTHA'S VINEYARD (MVY)
ILS or LOC RWY 24

NE-1, 31 DEC 2020 to 28 JAN 2021

NE-1, 31 DEC 2020 to 28 JAN 2021

APPENDIX H. HABITUAL BEDTIMES AND QUESTIONNAIRE RESPONSES

Habitual bedtimes were determined from Actiwatch and Oura ring data for 5-8 days prior to participation in data collection days and were rounded to the nearest hour or half hour. The morning-eveningness scores can range from 16-86 where lower scores indicate evening types while higher scores indicate morning types. ESS scores range between 0 and 24 where higher scores indicate higher levels of daytime sleepiness. Scores greater than 5 on the PSQI indicate "poor" sleep while scores below 5 are normal. M-E, ESS, PSQI scores were recorded once during the study.

Participant ID	Habitual bedtime	ME score	ME Type	ESS score	PSQI Global Score
CEAS01	21:30	50	Intermediate Type	5	7
CEAS02	23:00	57	Intermediate Type	3	3
CESAS03	23:00	53	Intermediate Type	5	4
CEAS05	0:00	51	Intermediate Type	5	6
CEAS06	0:00	63	Moderately Morning Type	8	5
CEAS07	22:30	59	Moderately Morning Type	1	5
CEAS08	22:30	71	Definitely Morning Type	5	5
CEAS09	0:00	54	Intermediate Type	4	5
CEAS10	23:00	55	Intermediate Type	4	3

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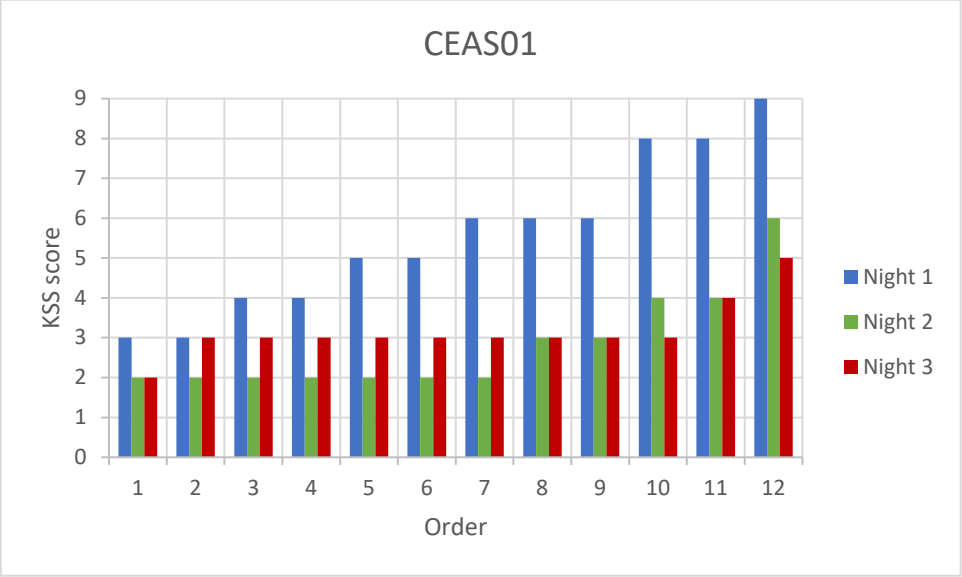
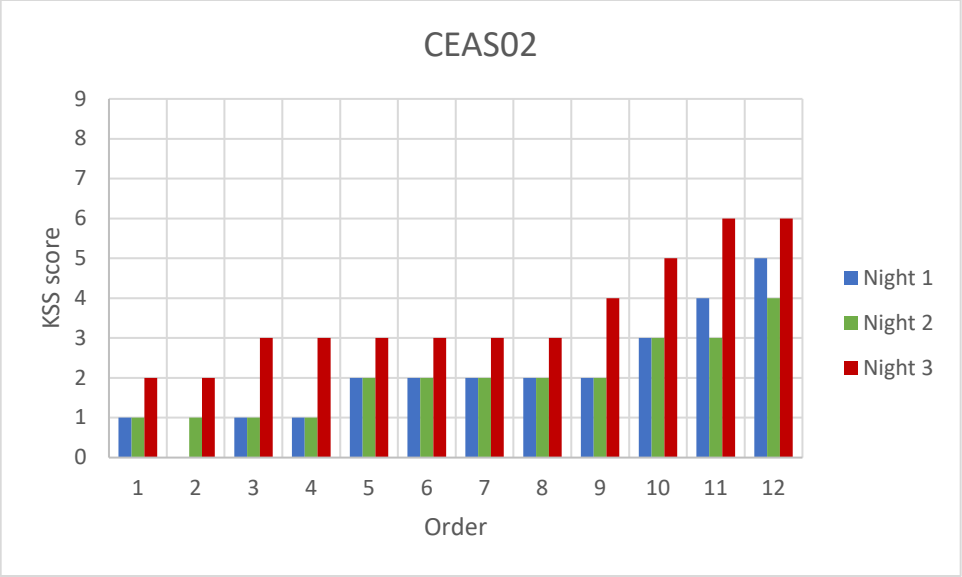
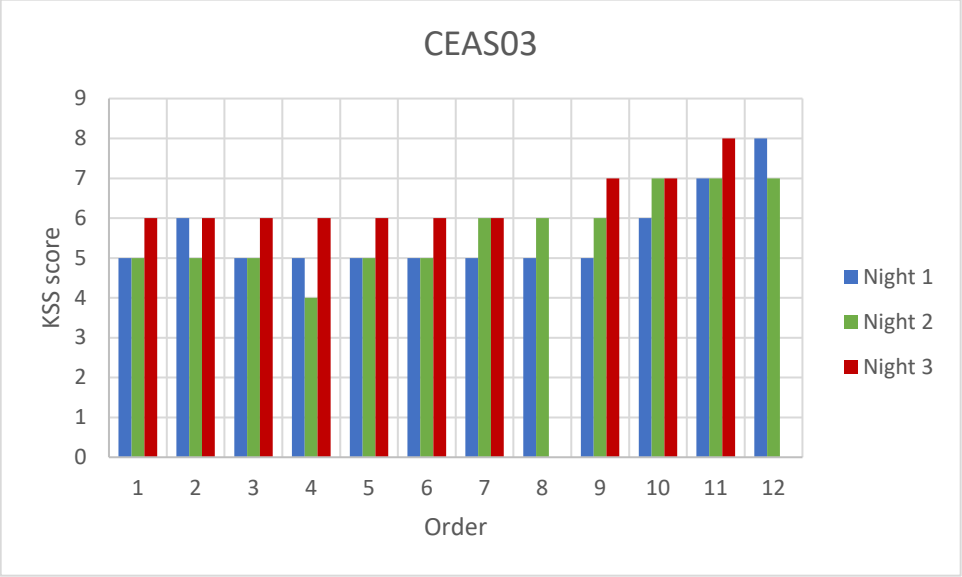
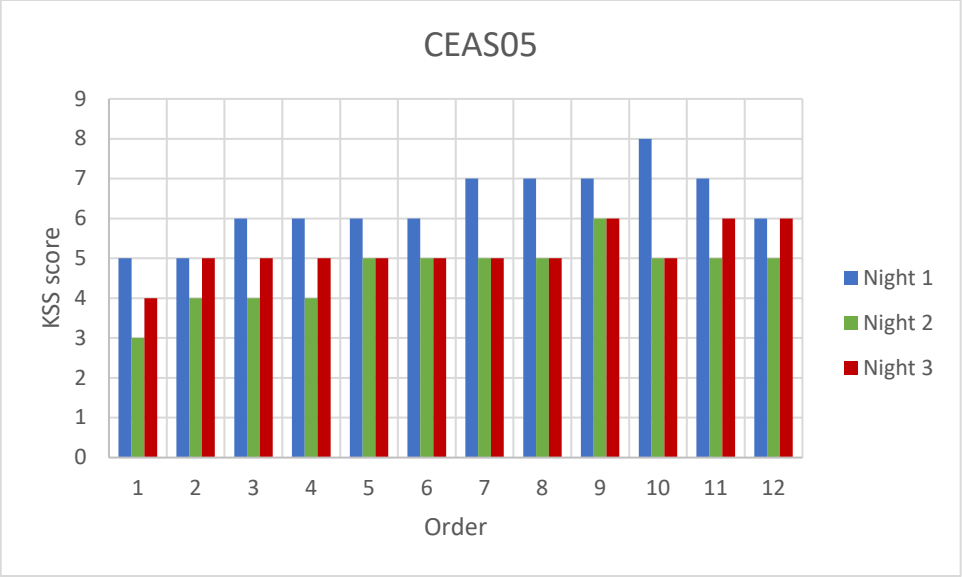
APPENDIX I. INDIVIDUAL KSS BY NIGHT

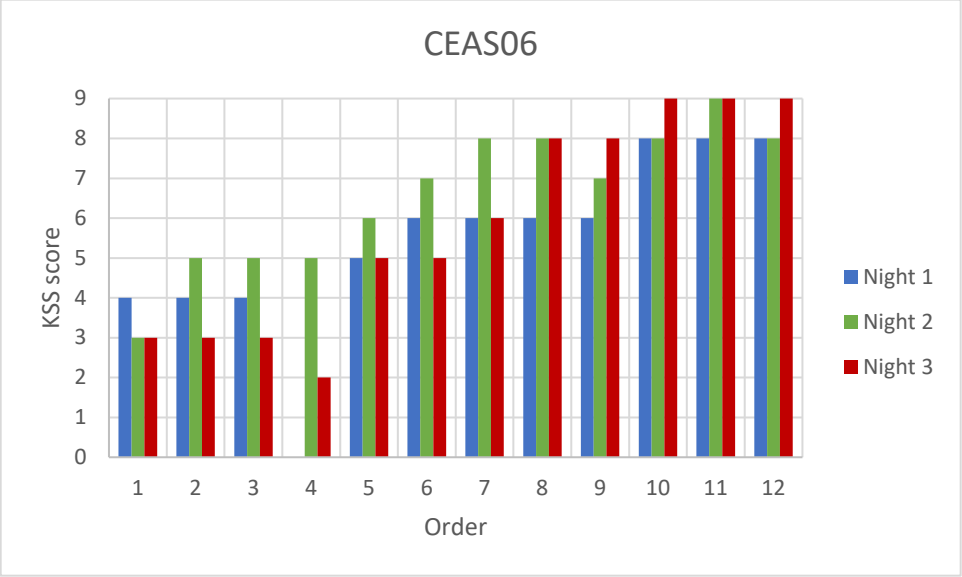
KSS scores range from 1-very alert to 9-very sleep, great effort to stay awake, fighting sleep. Individuals responded every half hour throughout the night based on what they were feeling at that moment. Any scores that were missing for participants were reported as the same as the most recent KSS score.

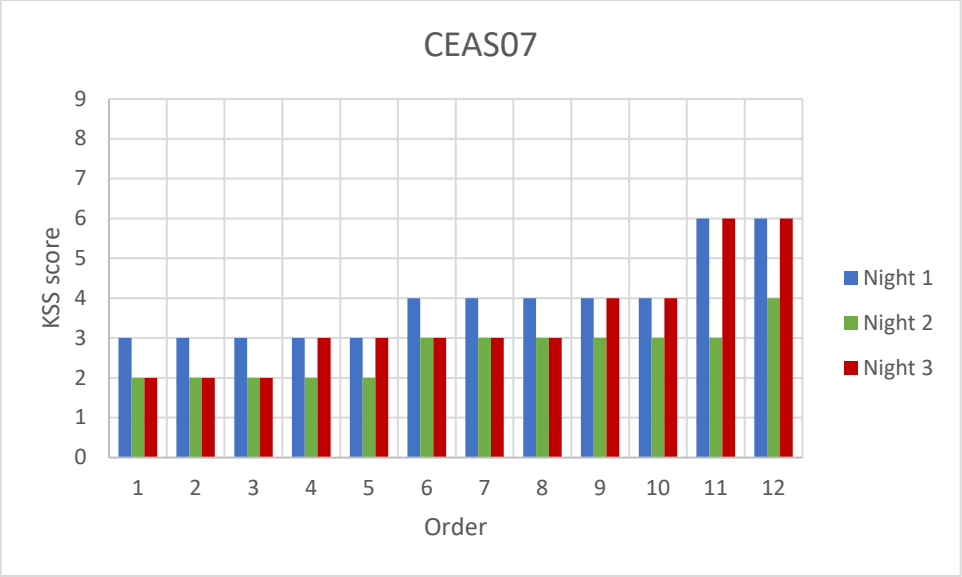


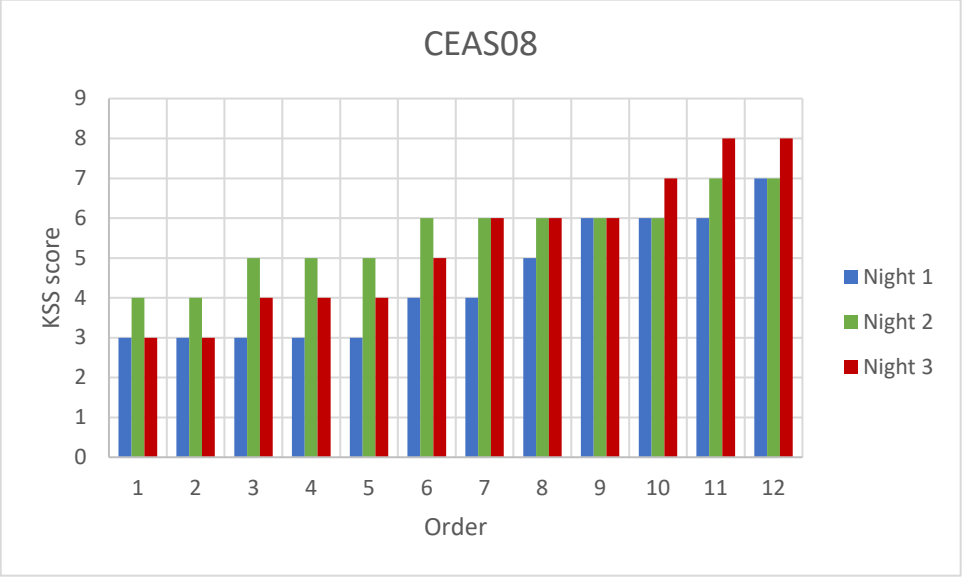

CEAS02
KSS score
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Order
Night 1
Night 2
Night 3

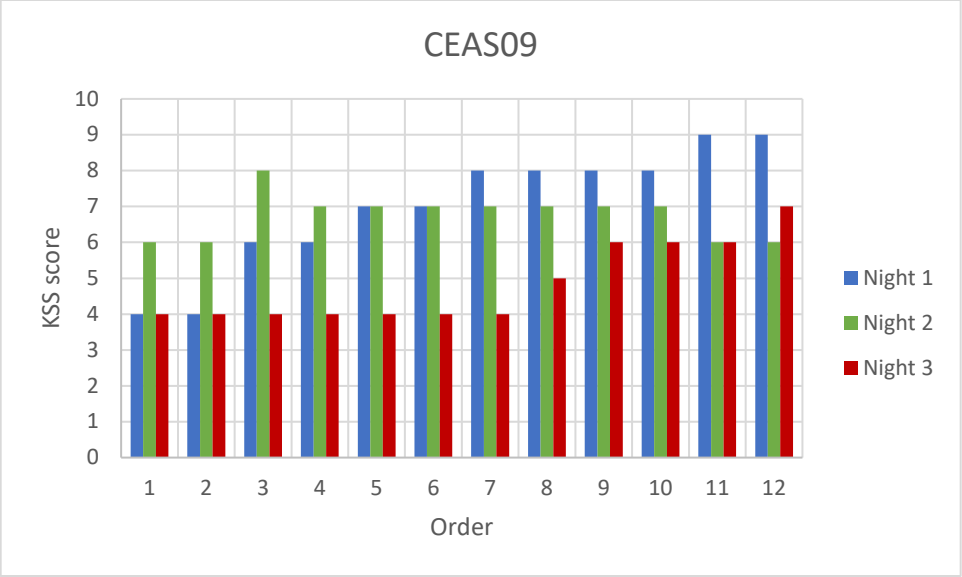

CEAS03
KSS score
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Order
Night 1
Night 2
Night 3

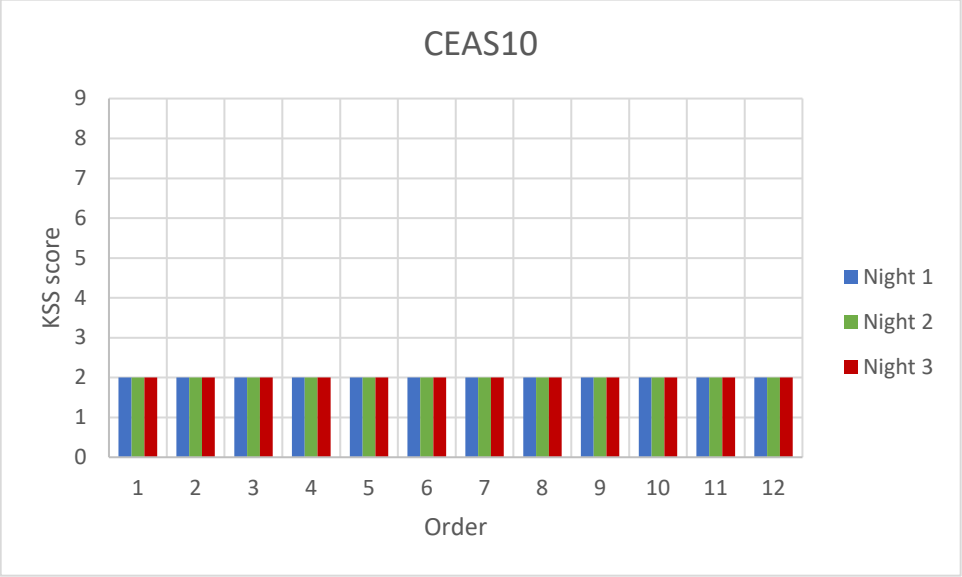

CEAS05
KSS score
0
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
10
11
12
Order
Night 1
Night 2
Night 3


CEAS06
KSS score
0
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
10
11
12
Order
Night 1
Night 2
Night 3


CEAS07
KSS score
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Order
Night 1
Night 2
Night 3


CEAS08
KSS score
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Order
Night 1
Night 2
Night 3


CEAS09
KSS score
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Order
Night 1
Night 2
Night 3


CEAS10
KSS score
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Order
Night 1
Night 2
Night 3

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APPENDIX J. AVERAGE KSS BY NIGHT COMPARISON

The table provides average KSS scores for all participants by night and order of recorded KSS scores.

	Condition					
	Night 1		Night 2		Night 3	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Order	KSS score	KSS score	KSS score	KSS score	KSS score	KSS score
1	3.33	1.32	3.11	1.62	3.11	1.36
2	3.44	1.51	3.44	1.74	3.33	1.41
3	3.78	1.72	3.78	2.22	3.56	1.33
4	3.78	1.72	3.56	1.94	3.56	1.33
5	4.22	1.79	4.00	2.00	3.89	1.27
6	4.56	1.74	4.33	2.12	4.00	1.32
7	4.89	2.09	4.56	2.35	4.22	1.56
8	5.00	2.06	4.67	2.24	4.56	1.94
9	5.11	2.09	4.67	2.12	5.11	1.96
10	5.89	2.37	5.00	2.12	5.33	2.18
11	6.33	2.18	5.11	2.32	6.11	2.15
12	6.67	2.24	5.44	1.88	6.33	2.06

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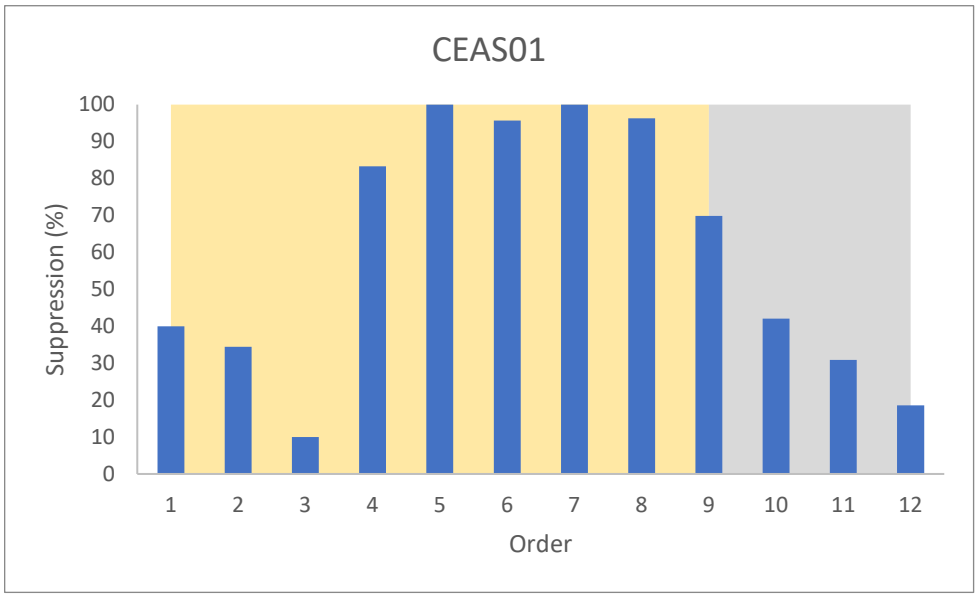
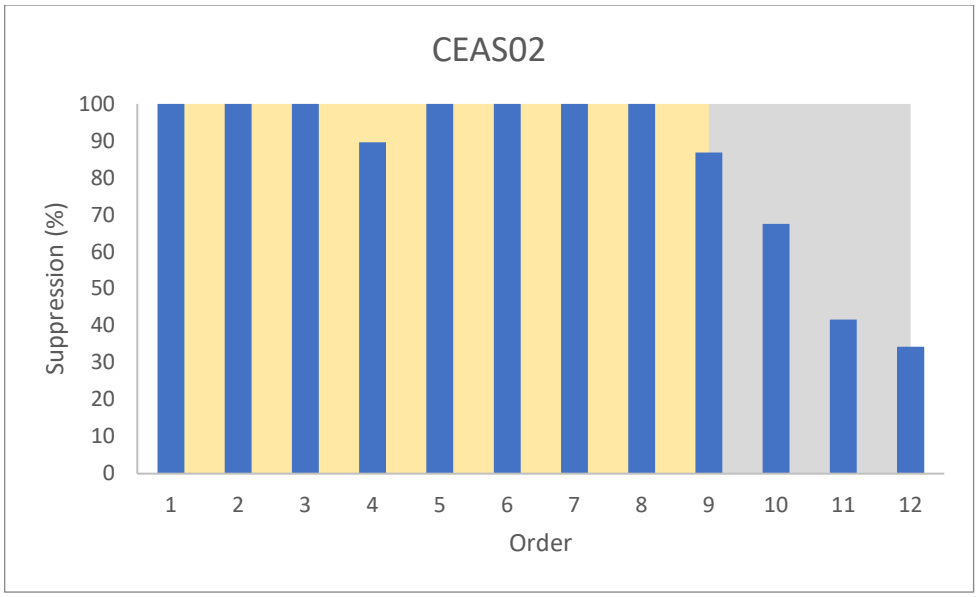
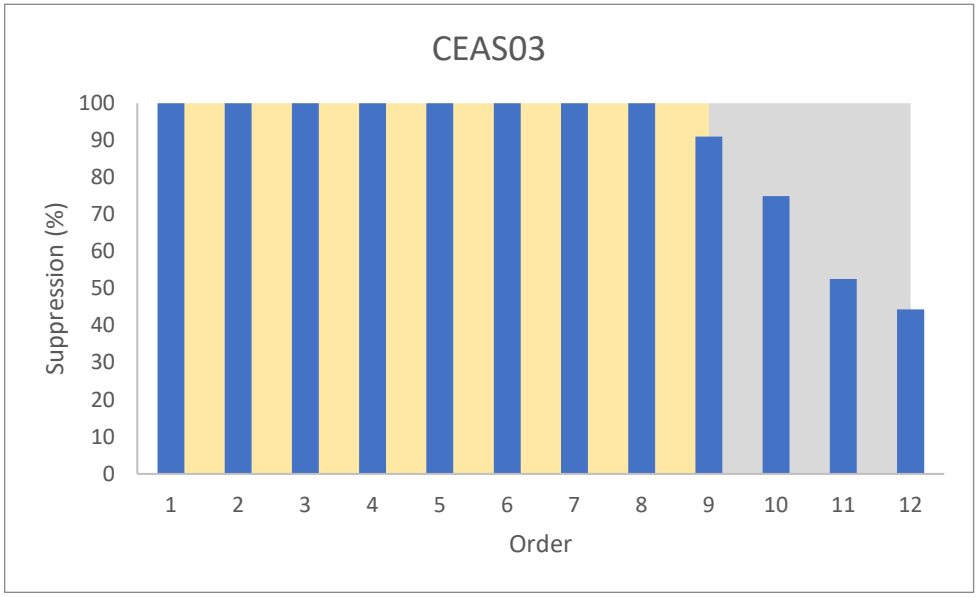
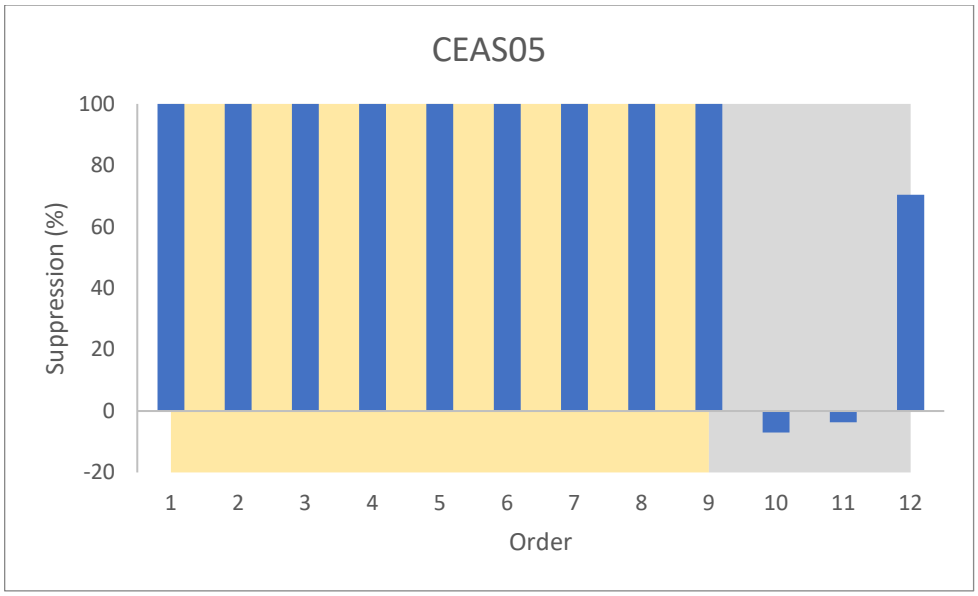
APPENDIX K. INDIVIDUAL SUPPRESSION TRENDS

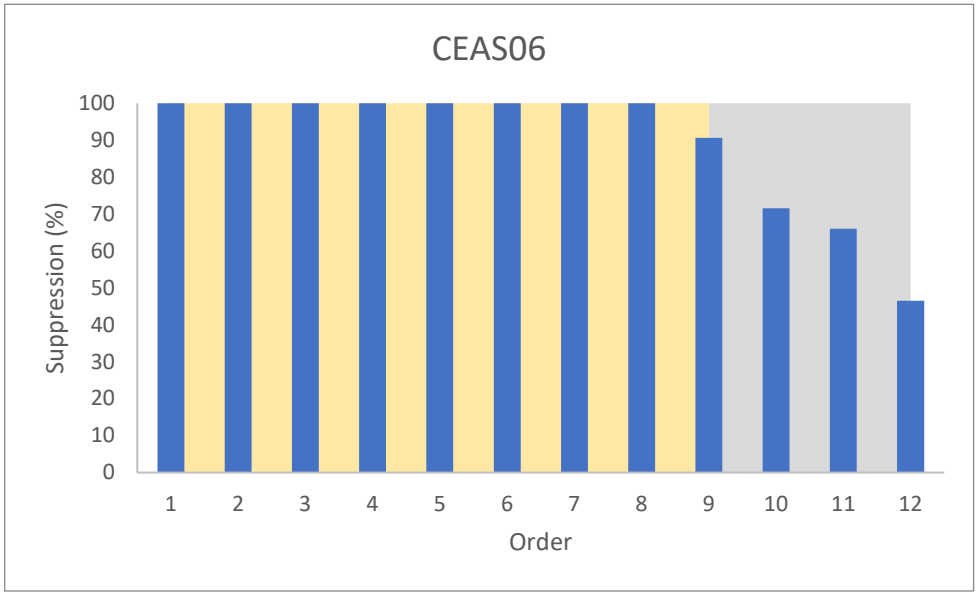
Suppression percentages represent the AUC for bright light settings on Night 2 compared to dim light settings on Night 1 for the salivary melatonin levels. The area shaded in yellow indicates samples collected during bright light (~1000 lux) periods while the gray shaded area represents dim light (<10 lux) periods on Night 2.

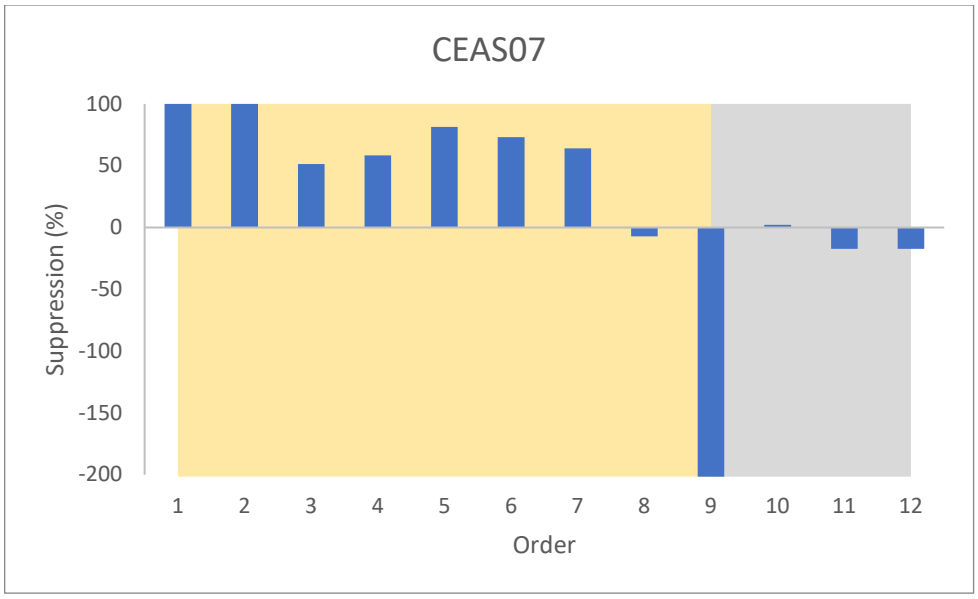


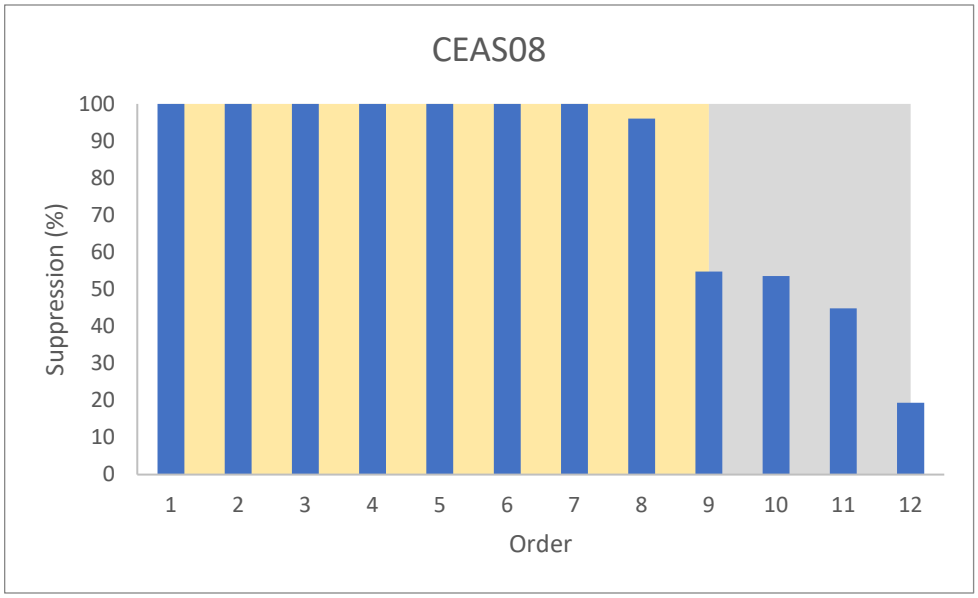

CEAS02
Suppression (%)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Order

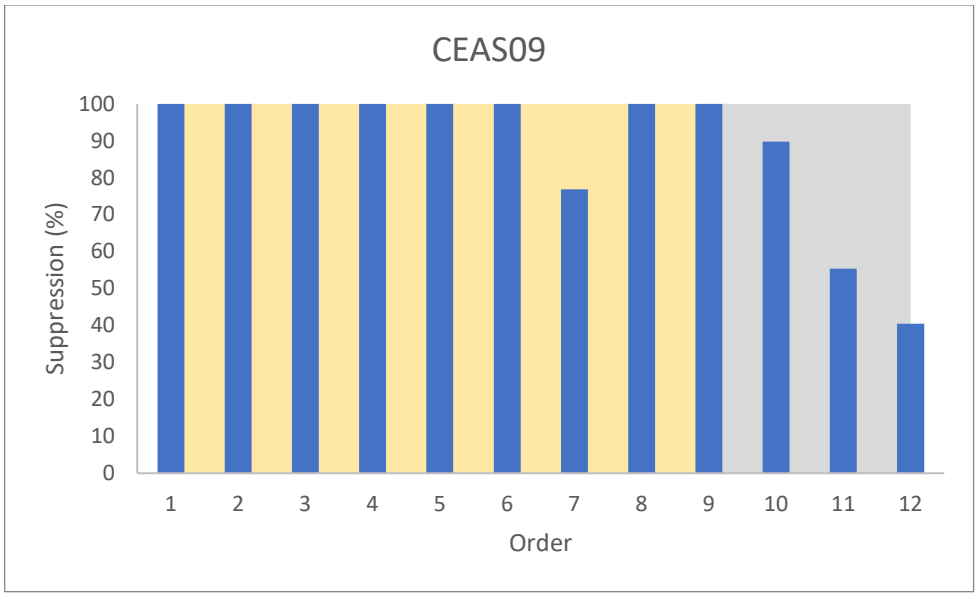

CEAS03
Suppression (%)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Order

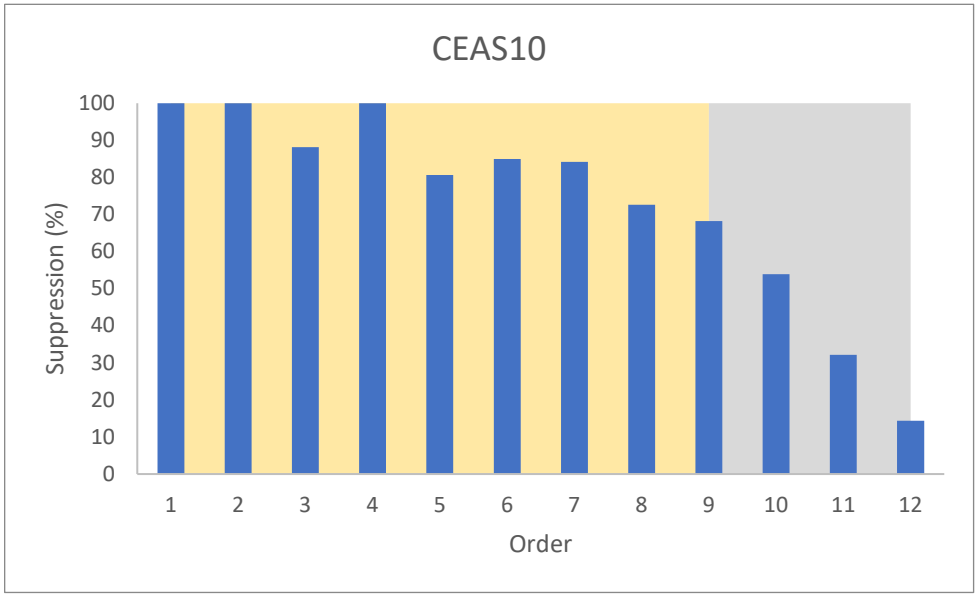

CEAS05
100
80
60
40
20
0
-20
Suppression (%)
1
2
3
4
5
6
7
8
9
10
11
12
Order


CEAS06
100
90
80
70
60
50
40
30
20
10
0
Suppression (%)
1
2
3
4
5
6
7
8
9
10
11
12
Order


CEAS07
100
50
0
-50
-100
-150
-200
Suppression (%)
1
2
3
4
5
6
7
8
9
10
11
12
Order


CEAS08
100
90
80
70
60
50
40
30
20
10
0
Suppression (%)
1
2
3
4
5
6
7
8
9
10
11
12
Order


CEAS09
Suppression (%)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Order


CEAS10
Suppression (%)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Order

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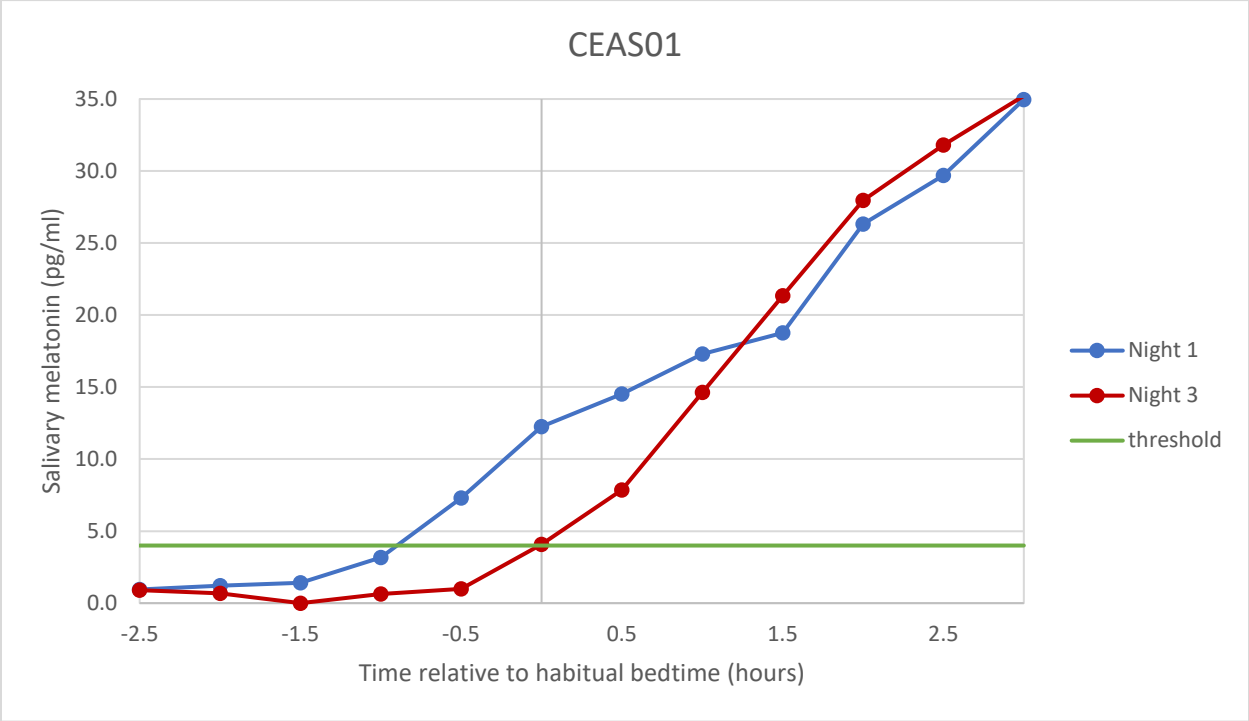
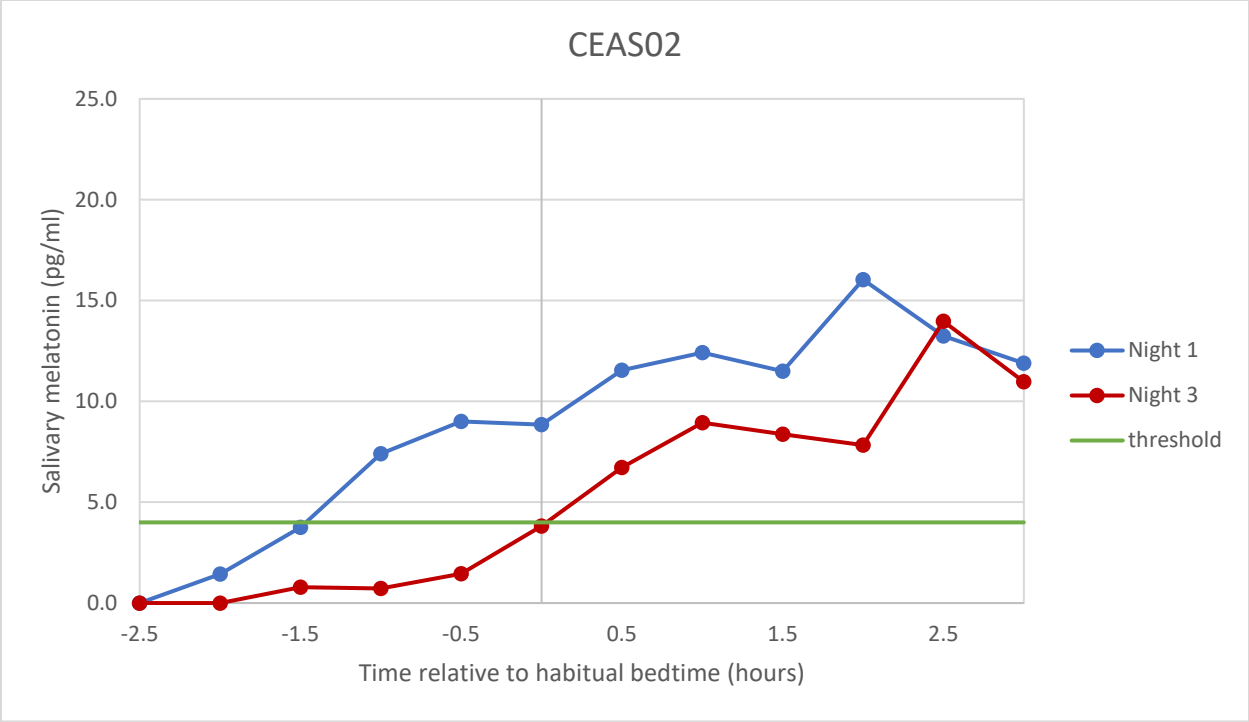
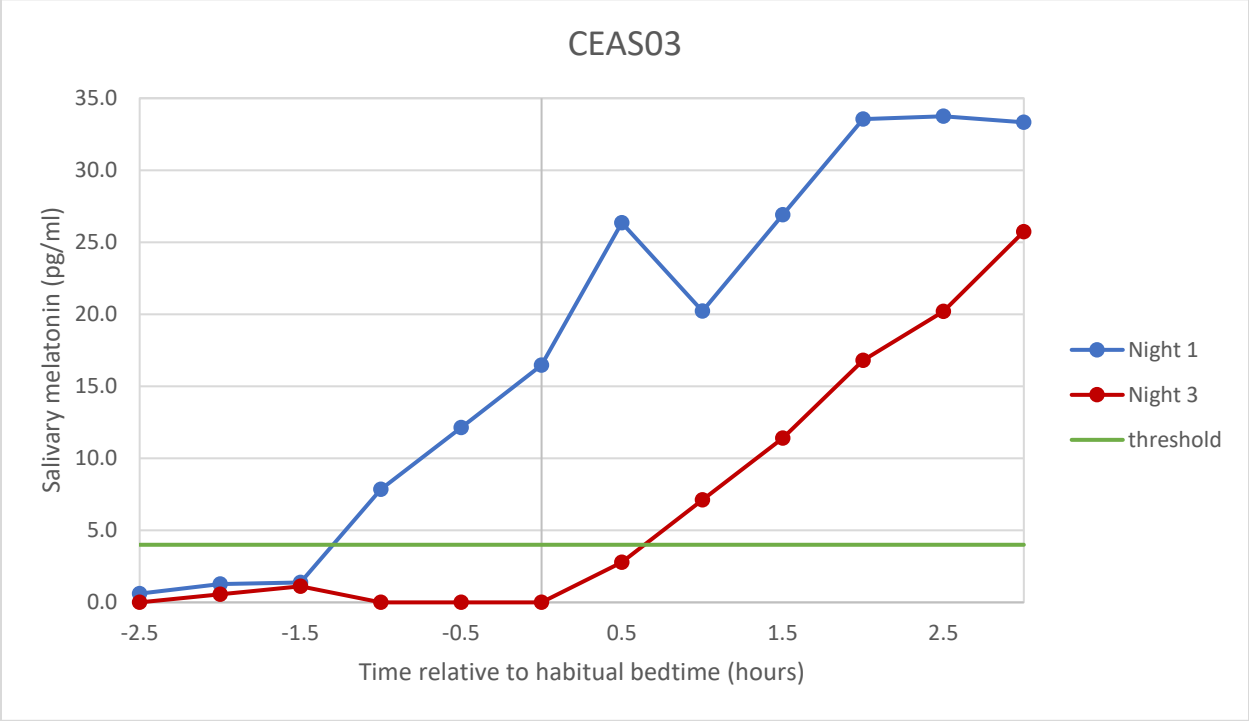
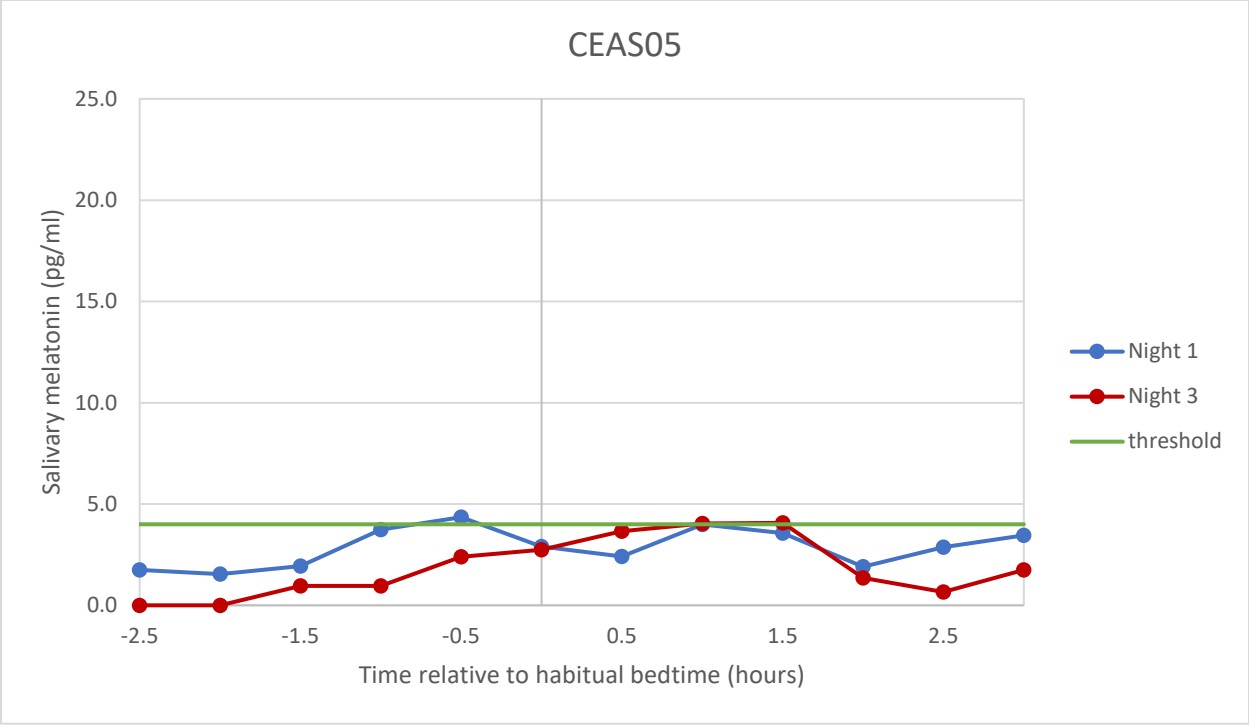
APPENDIX L. INDIVIDUAL MELATONIN PROFILES

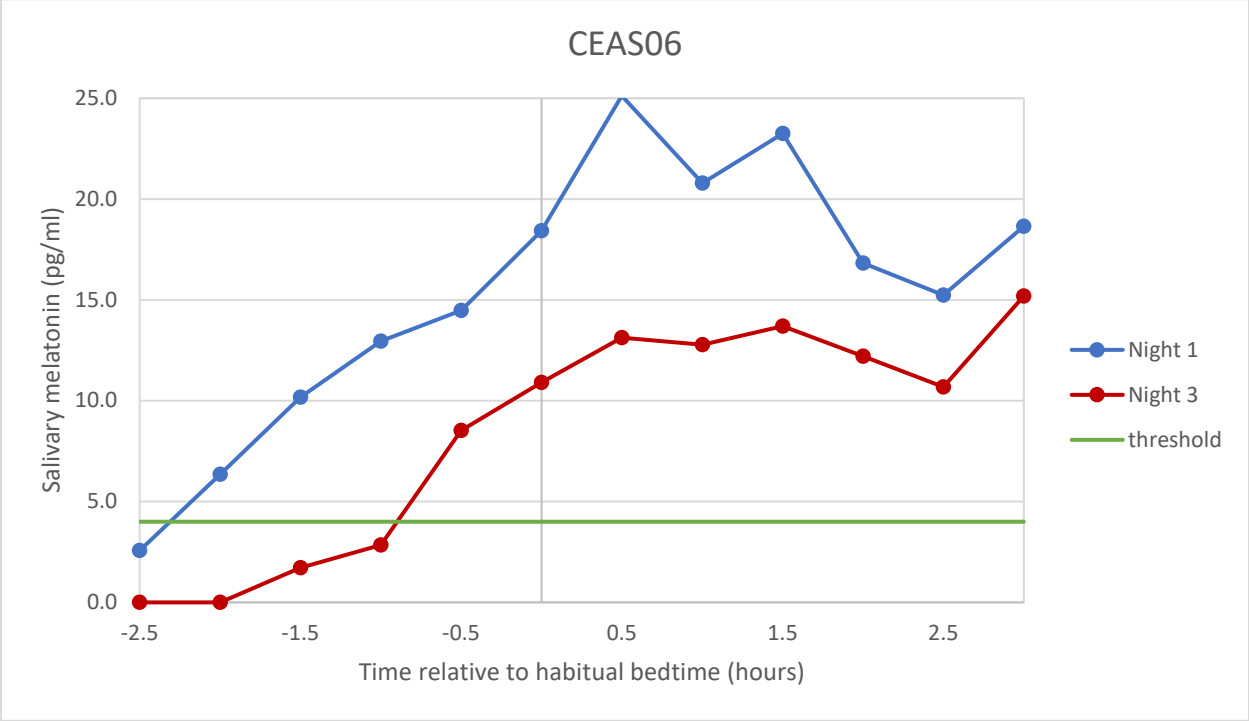
Participants with a maximum salivary melatonin level greater than 25 pg/ml have a default maximum y-axis value of 35.0 pg/ml. All other participants have a default maximum y-axis value of 25.0 pg/ml. Time is reported as hours relative to individual habitual bedtime. Salivary melatonin values of < 0.5 pg/ml are reported as 0.0 pg/ml for clarity. DMLO threshold is kept constant at 4.0 pg/ml throughout the entirety of the study. Participant 04 is excluded from analysis due to abnormally high salivary melatonin values.

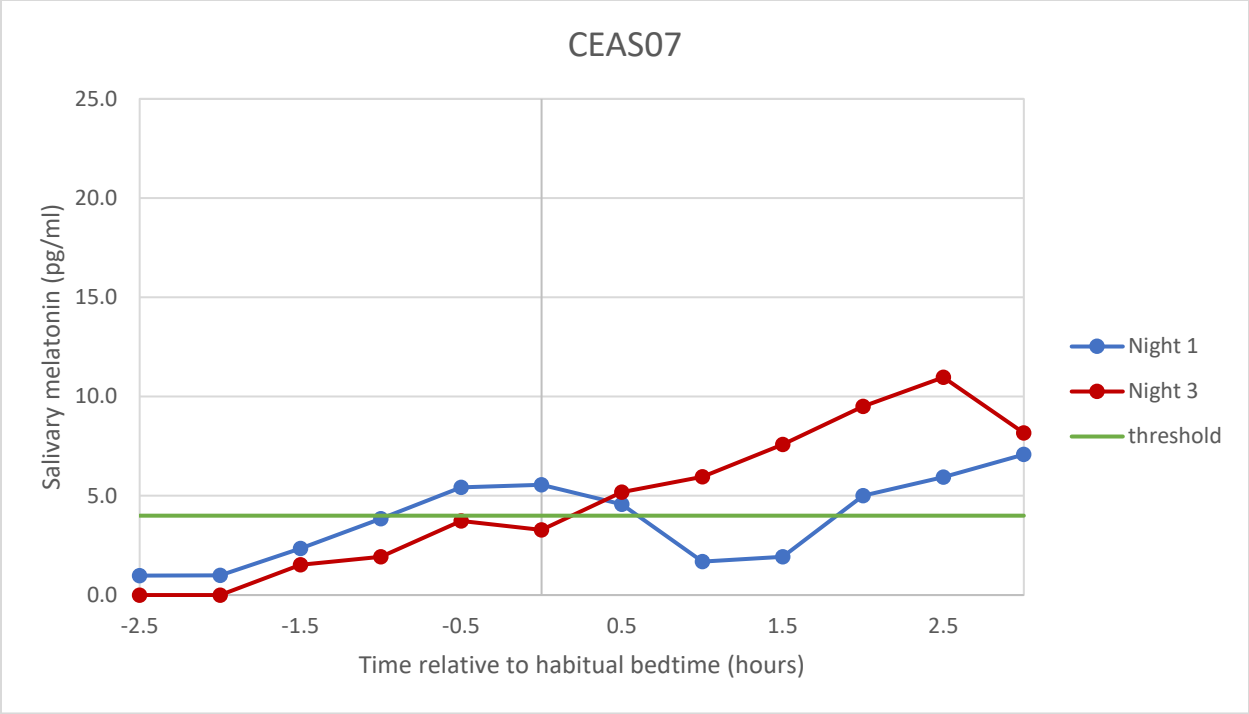


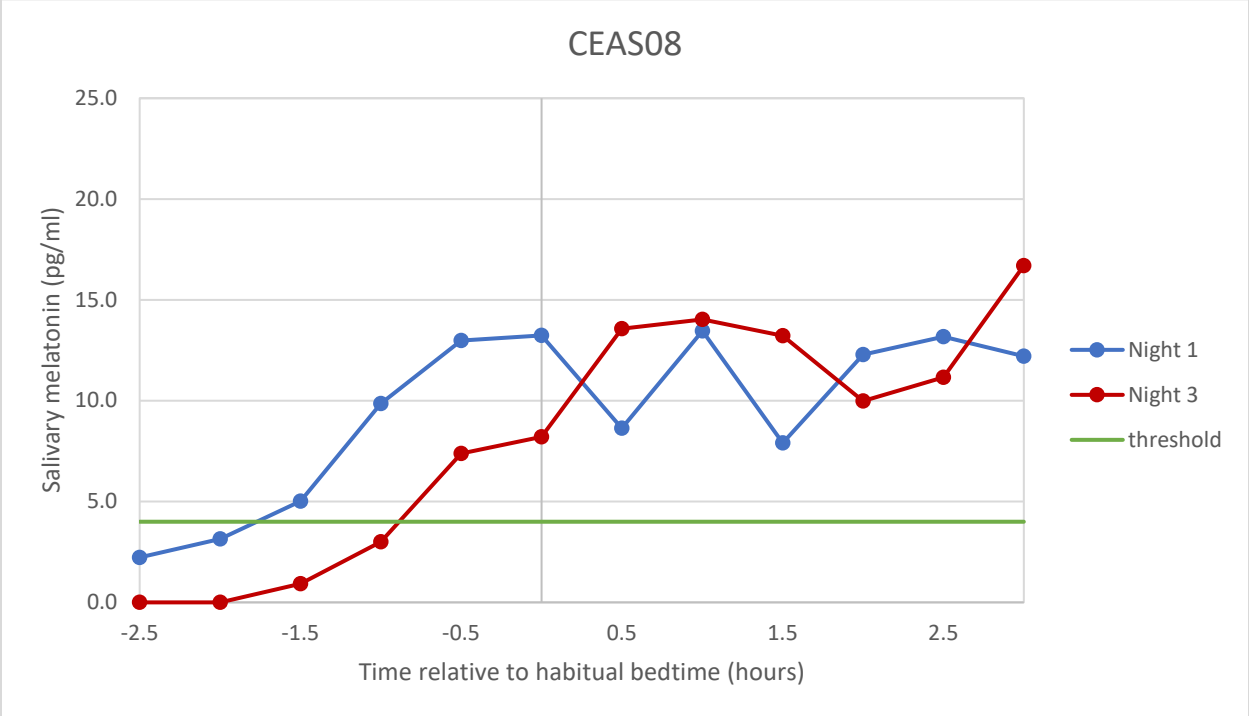

CEAS02
25.0
20.0
15.0
10.0
5.0
0.0
Salivary melatonin (pg/ml)
-2.5
-1.5
-0.5
0.5
1.5
2.5
Time relative to habitual bedtime (hours)
Night 1
Night 3
threshold

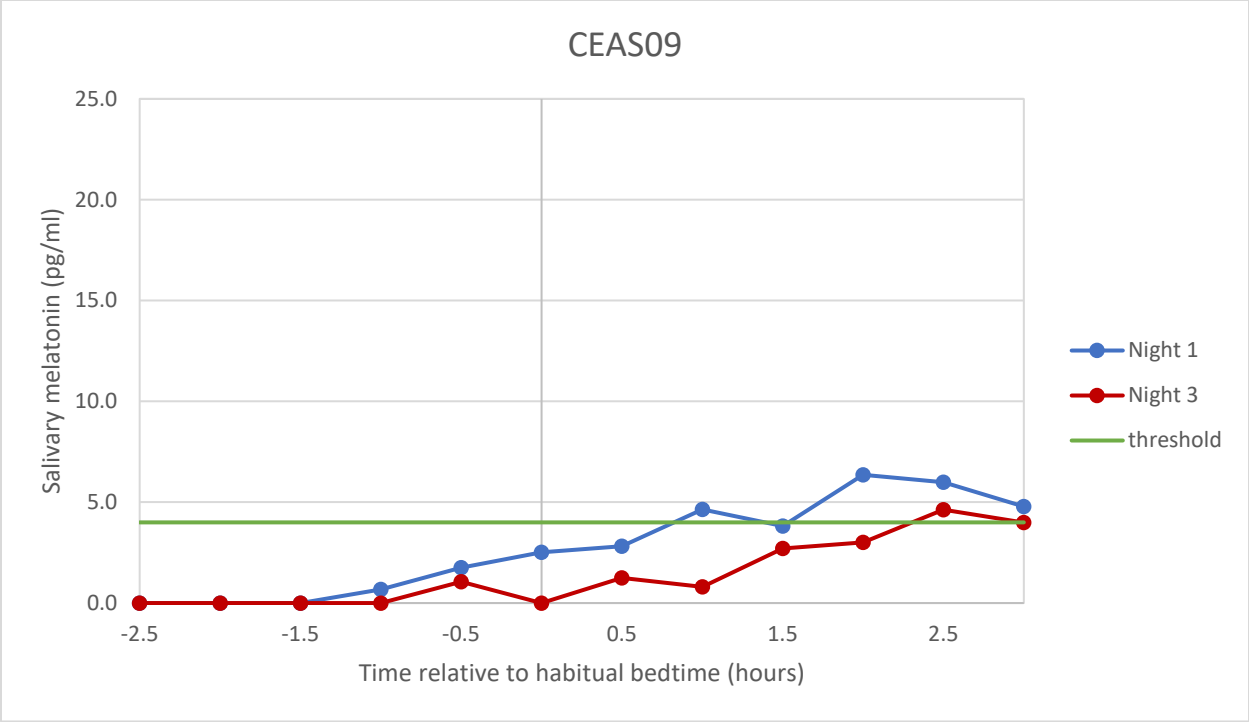

CEAS03
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Salivary melatonin (pg/ml)
-2.5
-1.5
-0.5
0.5
1.5
2.5
Time relative to habitual bedtime (hours)
Night 1
Night 3
threshold

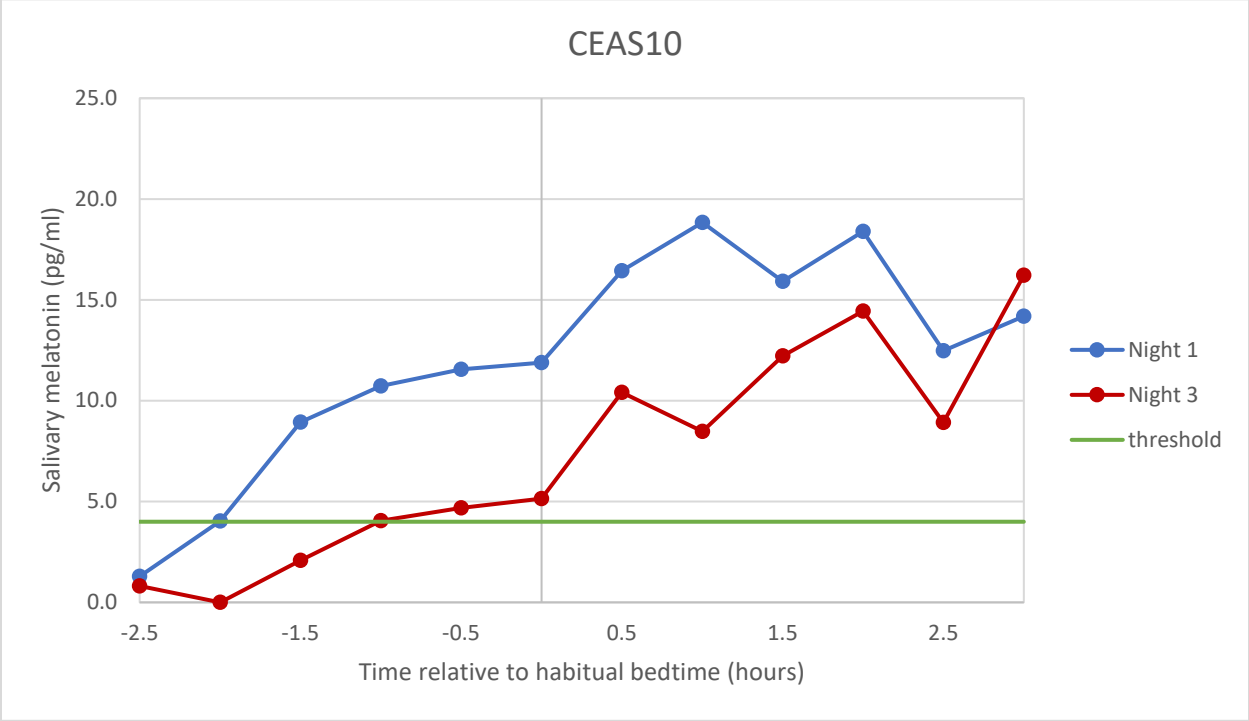

CEAS05
25.0
20.0
15.0
10.0
5.0
0.0
Salivary melatonin (pg/ml)
-2.5
-1.5
-0.5
0.5
1.5
2.5
Time relative to habitual bedtime (hours)
Night 1
Night 3
threshold


CEAS06
25.0
20.0
15.0
10.0
5.0
0.0
Salivary melatonin (pg/ml)
-2.5
-1.5
-0.5
0.5
1.5
2.5
Time relative to habitual bedtime (hours)
Night 1
Night 3
threshold


CEAS07
25.0
20.0
15.0
10.0
5.0
0.0
Salivary melatonin (pg/ml)
-2.5
-1.5
-0.5
0.5
1.5
2.5
Time relative to habitual bedtime (hours)
Night 1
Night 3
threshold


CEAS08
25.0
20.0
15.0
10.0
5.0
0.0
Salivary melatonin (pg/ml)
-2.5
-1.5
-0.5
0.5
1.5
2.5
Time relative to habitual bedtime (hours)
Night 1
Night 3
threshold


CEAS09
25.0
20.0
15.0
10.0
5.0
0.0
Salivary melatonin (pg/ml)
-2.5
-1.5
-0.5
0.5
1.5
2.5
Time relative to habitual bedtime (hours)
Night 1
Night 3
threshold


CEAS10
25.0
20.0
15.0
10.0
5.0
0.0
Salivary melatonin (pg/ml)
-2.5
-1.5
-0.5
0.5
1.5
2.5
Time relative to habitual bedtime (hours)
Night 1
Night 3
threshold

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