Naval Submarine Medical Research Laboratory

NSMRL/F1209/TR--2018-1318 16 January 2018

Circadian Rhythm Phase Locking for Traveling Special Forces Operators: Using Light Exposure to Maintain Time Zone Entrainment

Sarah Chabal, Ph.D.[1]

LT Katherine Couturier, M.D., M.P.H.[1]

Jeff Dyche, Ph.D.[2]

CDR Shawn Soutiere, Ph.D.[1]

Mariana Figueiro, Ph.D.[3]

Barbara Plitnick, R.N.[3]

[1]Naval Submarine Medical Research Laboratory

[2]James Madison University

[3]Lighting Research Center, Rensselaer Polytechnic Institute

Approved and Released by:
F. YEO, CAPT, USN
Commanding Officer
NAVSUBMEDRSCHLAB

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
16-01-2018	Technical Report	2013 - 2017

4. TITLE AND SUBTITLE

Circadian Rhythm Phase Locking for Traveling Special Forces Operators: Using Light Exposure to Maintain Time Zone Entrainment

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Sarah Chabal, Ph.D. (NSMRL)
LT Katherine Couturier, M.D., M.P.H. (NSMRL)
Jeff Dyche, Ph.D. (James Madison University)
CDR Shawn Soutiere, Ph.D. (NSMRL)
Mariana Figueiro, Ph.D. (Lighting Research Center, Rensselaer

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

F1209

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Submarine Medical Research Laboratory
Box 900
Groton, CT 06349-5900

8. PERFORMING ORGANIZATION REPORT NUMBER

NSMRL/F1209/TR--2018-1318

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

United States Special Operations Command
7701 Tampa Point Blvd
Macdill Air Force Base, Florida 33621

10. SPONSOR/MONITOR'S ACRONYM(S)

USSOCOM

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A. Approved for public release. Distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Special Operations Forces (SOF) must be prepared to deploy and perform complex operations during times that are out of sync with their circadian rhythms, which may lead to dangerous or costly errors. The present study investigated whether performance deficits can be reduced by locking operators to a circadian phase through the use of controlled light exposures. Eleven male subjects from active duty SOF commands were flown from Guam (UTC +10:00) to Troy, NY (UTC -05:00; Δ 9 hours) while wearing blue-light goggles and blue-blocking, orange-tinted glasses in a carefully-prescribed schedule designed to maintain entrainment to the desired circadian time (UTC +10:00). Biochemical indices (dim-light melatonin onset) showed that no change in circadian phase was detected after approximately 2.5 days of travel across 9 time zones, indicating that circadian rhythms were successfully locked. Similarly, no change in performance on cognitive assessments was detected pre- and post- travel for any assessed metric. This provides preliminary evidence that judicious control of light exposure can be used to successfully phase lock SOF.

15. SUBJECT TERMS

circadian rhythms; jet lag; dim-light melatonin onset

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			NAVSUBMEDRSCHLAB Commanding Officer
U	U	U	SAR	30	19b. TELEPHONE NUMBER *(Include area code)* 860-694-3263

Reset

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

[THIS PAGE INTENTIONALLY LEFT BLANK]

Circadian Rhythm Phase Locking for Traveling Special Forces Operators: Using Light Exposure to Maintain Time Zone Entrainment

Sarah Chabal, Ph.D.[1]

LT Katherine Couturier, M.D., M.P.H.[1]

Jeff Dyche, Ph.D.[2]

CDR Shawn Soutiere, Ph.D.[1]

Mariana Figueiro, Ph.D.[3]

Barbara Plitnick, R.N.[3]

[1]Naval Submarine Medical Research Laboratory

[2]James Madison University

[3]Lighting Research Center, Rensselaer Polytechnic Institute

Approved and Released by:

F. YEO, CAPT, USN

Commanding Officer

Naval Submarine Medical Research Laboratory

Submarine Base New London Box 900

Groton, CT 06349-5900

Administrative Information:
The views expressed in this report are those of the author and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, nor the U.S. Government. I am a military service member (or employee of the U.S. Government). This work was prepared as part of my official duties. Title 17 U.S.C. §105 provides that 'Copyright protection under this title is not available for any work of the United States Government. This work was supported by and/or funded by work unit number F1209. Naval Submarine Medical Research Laboratory certifies that this research has been conducted in compliance with all applicable federal regulations governing the protection of human subjects in research (NSMRL.2013.0011, RPI Protocol #1222).

[THIS PAGE INTENTIONALLY LEFT BLANK]

Acknowledgments

The authors would like to thank LT Matthew Keller, Mark Rea, Ashley Shemery, Sharon Lesage, Geoffrey Jones, Dennis Hull, Gregory Ward, HM1 John Connors, and Rebecca Welles for assistance with study planning, execution, and report generation; and Theresa Delgado and Gwen Jones for operational support of data shipment and travel. We would like to thank the support staff of USSOCOM and all study participants for their time and efforts.

Abstract

Special Operations Forces (SOF) must be prepared to deploy and perform complex operations during times that are out of sync with their circadian rhythms, which may lead to dangerous or costly errors. The present study investigated whether performance deficits can be reduced by locking operators to a circadian phase through the use of controlled light exposures. Eleven male subjects from active duty SOF commands were flown from Guam (UTC +10:00) to Troy, NY (UTC -05:00; Δ 9 hours) while wearing blue-light goggles and blue-blocking, orange-tinted glasses in a carefully-prescribed schedule designed to maintain entrainment to the desired circadian time (UTC +10:00). Biochemical indices (dim-light melatonin onset; DLMO) showed that circadian phase did not change after approximately two and a half days of travel across nine time zones (pre-travel DLMO: 20:31 UTC +10:00, post-travel DLMO: 20:21 UTC +10:00; $p > 0.4$), indicating that circadian rhythms were successfully locked. Similarly, performance on cognitive assessments did not differ pre- and post- travel for any assessed metric (all p values > 0.2). These results provide preliminary evidence that judicious control of light exposure can be used to successfully phase lock SOF.

Table of Contents

Introduction

Service members, particularly those involved in special operations, must be prepared to deploy and perform efficiently and safely on a moment's notice. Many will be expected to perform complex operations during times that are out of sync with their circadian rhythms. Evidence suggests that operational performance during circadian misalignment may lead to dangerous or costly errors (e.g., Bourgeois-Bougrine, Carbon, Gounelle, Mollard, & Coblentz, 2003; Miller, Matsangas, & Shattuck, 2008). Appropriate scheduling of light and dark exposure can be used to ensure that periods of wakefulness and alertness coincide with occupational or social obligations (e.g., Appleman, Figueiro, & Rea, 2013; Figueiro, Plitnick, & Rea, 2014b). One novel technique would be to maintain (i.e., lock) circadian phase during and after trans-meridian travel so that nighttime operations at destination coincide with an individual's circadian day and, therefore, performance is optimized. The purpose of this study was to investigate whether controlled lighting exposures could be used to lock operators to a circadian phase even after traveling through nine time zones. Specifically, the study sought to validate the use of a personal blue-light treatment device ("goggles;" 470 nm, LED) in combination with orange-tinted glasses (to block short-wavelength blue light) to maintain circadian entrainment and sustain performance.

Circadian Rhythm

Circadian rhythms, which are the physiological processes that maintain the 24-hour sleep/wake cycle, are governed by both endogenous (e.g., biological clock located in the suprachiasmatic nuclei; SCN) and exogenous (e.g., light) inputs that interact to regulate each person's sleep-wake cycles. Human circadian rhythms are diurnal, which leads to being awake during the day and asleep at night. Attempts at work and wakefulness outside of this diurnal rhythm, such as shift work or travel across time zones, may lead to decreased performance (e.g., Whitmire et al., 2009), increased impulsivity (e.g., Karatsoreos, 2012), and can contribute to long-term health concerns (e.g., Davis & Mirick, 2006; Stevens, Blask, Brainard, Hansen, & Lockley, 2007).

Without external stimuli, the human biological clock runs with an average periodicity of 24.2 hours (Dijk & Lockley, 2002). This is due to so-called "clock genes" within individual cells, which use positive and negative feedback loops to produce rhythmic gene transcription, phosphorylation, and post-transcriptional processing with a cycle of just over 24 hours (Prasai, Pernicova, Grant, & Scott, 2011; Relogio et al., 2011; Reppert & Weaver, 2002). These clock genes are coordinated into observable circadian rhythmicity by the SCN, a small collection of hypothalamic cells just above the optic chiasm (Relogio et al., 2011). Under normal circumstances, the SCN entrains the regular circadian oscillation to a 24-hour cycle through the use of external stimuli referred to as *zeitgebers* (German: "time-giver"). Zeitgebers may include stimuli such as eating schedules, activity levels, and social cues; in humans and most animals, exposure to light and dark is the most significant time cue (Dunlap, Loros, & DeCoursey, 2004).

The circadian light response is mediated primarily by intrinsically photosensitive retinal ganglion cells (ipRGCs; Berson, Dunn, & Takao, 2002; Thapan, Arendt, & Skene, 2001), which are cells in the retina that are separate from the traditional photoreceptors involved in conscious vision (i.e., rods and cones). ipRGCs utilize a photopigment called melanopsin that responds most strongly to short-wavelength blue light of 480 nm (Cajochen et al., 2005; Lockley, Brainard, & Czeisler, 2003; Thapan et al., 2001). The ipRGCs also receive indirect input from rods and cones, and pass the combined information from the retina to the SCN via a

neuroanatomical pathway called the retinohypothalamic tract. The retinohypothalamic tract is a direct conduit from the retina to the SCN that allows the SCN to distinguish between day and night using light-dark pattern information.

Circadian influence can be seen on a variety of systems within the human body including sleep-wake patterns (e.g., Duffy, Rimmer, & Czeisler, 2001), core body temperature (e.g., Refinetti & Maenaker, 1992), and melatonin and cortisol secretion (e.g., Bailey & Heitkemper, 2001; Wehr, 1991). These rhythmic fluctuations can be used to create a profile of each individual's circadian phase at any given point in time. Generally, the pattern shows: 1) an onset of melatonin secretion followed 1-2 hours later by sleep and the nadir of cortisol secretion; 2) the core body temperature minimum (CBTmin) 6-8 hours later accompanied by rising cortisol levels; and 3) a trough in serum melatonin and awakening around 2 hours after the trough in CBTmin (Dunlap et al., 2004). When a person has regular sleep-wake patterns, the timing of the initial release of melatonin, called dim light melatonin onset (DLMO), is generally considered the gold standard for marking a person's circadian phase (Lewy, Cutler, & Sack, 1999; Molina & Burgess, 2011; Pandi-Perumal et al., 2007).

A phase response curve (PRC) demonstrates the relationship between the administration of a *zeitgeber*, such as light, and its effect on circadian phase (measured by CBTmin or DLMO). The PRC for light is characterized by a sinusoidal pattern (see Figure 1), where morning light exposure advances the circadian phase while evening exposure causes a phase delay. Physiologically, this sinusoidal curve centers on the CBTmin, with phase delays occurring before, phase advances after, and periods of minimal effect at and 12 hours after the CBTmin. A similar PRC can be seen for both white and narrow-band (470 nm, blue) light, although some research (Revell, Molina, & Eastman, 2012) suggests a slightly longer phase advancing region for blue light.

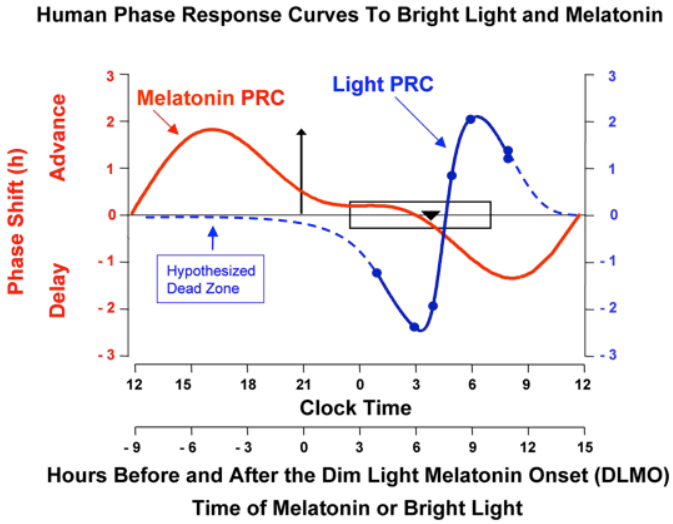

Figure 1. Human phase response curves to melatonin and light. Phase response curves (PRC) as a function of bright light (3500 lux) and melatonin (3 mg). Black upward arrow is average baseline DLMO; black triangle is estimated time of body temperature minimum, usually considered peak sleepiness (DLMO+7 h); rectangle is normal sleep period. Note that light from 1200 to 2000 is a relative "dead zone," where exposure to light has little to no effect on entrainment (Eastman & Burgess, 2009).

Circadian Misalignment

Circadian cycles have been shown to impact performance. For strength-based tasks, peak athletic performance is generally seen in the late afternoon and early evening (Manfredini, Mandredini, Fersini, & Conconi, 1998); conversely, accuracy and fine motor control tend to peak in the morning (Drust, Waterhouse, Atkinson, Edwards, & Reilly, 2005). Military needs often require personnel to perform complex operations at times misaligned with circadian rhythms of optimum performance. This is problematic, as performance, health, and safety concerns arise as a result of circadian misalignment.

While circadian misalignment can stem from a number of sleep disorders (Sateia, 2014), it can also result from time zone changes (jet lag). The American Academy of Sleep Medicine (AASM) defines jet lag syndrome as "varying degrees of difficulties in initiating or maintaining sleep, excessive sleepiness, decrements in subjective daytime alertness and performance, and somatic symptoms (largely related to gastrointestinal function) following rapid travel across multiple time zones" (Sateia, 2014). The severity of jet lag is affected not only by the hours of shift required but also by the direction of travel. Humans can more easily phase delay (postpone sleep) than phase advance (go to sleep early), resulting in longer recovery from eastward than westward shifts (Sateia, 2014). On average, people can adjust by approximately 90 minutes per day after a phase delay (westward travel), but only 60 minutes per day after a phase advance (eastward travel). To put it another way, when traveling east, the body takes approximately one day to acclimate for each time zone crossed; after westward travel, the body recovers slightly faster.

In addition to the difference in the human body's ability to delay vs. advance sleep, the worsened circadian misalignment attributed to eastward travel may also be due to the timing of light exposure. When traveling east through up to nine time zones, the body clock must be advanced in order to synchronize with clock time. This can be done by exposure to light after the CBTmin and avoidance of light before the CBTmin (see Figure 1). However, these periods of optimal light exposure are often not compatible with the natural light in the new (traveled to) time zone. As Waterhouse (1999) notes, for example, a traveler flying from the United Kingdom to Hong Kong (eight time zones east) requires light from 1300-1900 local time (0500-1100 body time) and should avoid light from 0500-1100 local time (2100-0300 body time). The avoidance of light from 0500-1100 local time is often difficult, prolonging the body's adjustment period (see Waterhouse, 1999 for a full discussion).

Research demonstrates that even brief circadian misalignment can cause adverse physiological changes to metabolic and cardiovascular function (Scheer, Hilton, Mantzoros, & Shea, 2009). Accordingly, reported symptoms of jet lag include increases in fatigue, headaches, irritability, and indigestion (Waterhouse, Reilly, Atkinson, & Edwards, 2007). Jet lag is also associated with cognitive deficits, difficulty falling asleep (especially when traveling east), waking too early (especially when traveling west), and overall disturbed sleep (Waterhouse et al., 2007). These disturbances in sleep can, in turn, manifest in detriments associated with fatigue and sleep deprivation. For example, fatigue results in measurable impairment to simple reaction time and vigilance (e.g., Dinges et al., 1997), complex decision-making abilities (e.g., Harrison & Horne, 1999, 2000), visuo-spatial attention (e.g., Bocca & Denise, 2006), working memory (e.g., Smith, McEvoy, & Gevins, 2002), and logical reasoning (e.g., Blagrove, Alexander, & Horne, 1995).

Manipulating Circadian Rhythm

One way to potentially mitigate some of the circadian effects of travel is through the strategic management of light exposure, as light is the most significant zeitgeber (Dunlap et al., 2004) and may be even more important than sleep scheduling for determining circadian phase (Appleman et al., 2013; Figueiro et al., 2014b). Research has shown that even low levels of light can be sufficient to entrain or hinder entrainment to a new sleep-wake schedule, depending on the timing of exposure (Boivin & James, 2002). Therefore, manipulation of light exposure and avoidance has been investigated extensively in both field and laboratory settings for its use in mitigating the effects of jet lag and shift work (e.g., Czeisler et al., 1990; Deacon & Arendt, 1996; Lahti, Terttunen, Lappamaki, Lonnqvist, & Partonen, 2007; Samel & Wegmann, 1997; Thompson et al., 2013).

Most studies have used light boxes or light banks to exert an effect on the circadian system (e.g., Herljevic, Middleton, Thapan, & Skene, 2005; Jewett et al., 1997). However, these devices may not be practical under the operational conditions or travel required by many military personnel. More recent investigations have shown that a battery-operated, personal light treatment device (goggles) using blue LED light (peak wavelength 470 nm) can effectively suppress nocturnal melatonin in both field and laboratory scenarios (Appleman et al., 2013; Figueiro, Bierman, Bullough, & Rea, 2009; Figueiro et al., 2014b). Conversely, when light exposure should be avoided to permit the onset of physiological night time, orange-tinted glasses can be used to block blue light (Sasseville, Paquet, Sevigny, & Hebert, 2006). Thus, the method of light delivery likely matters less than the judicious scheduling of light and dark exposure. Goggles and glasses may be a viable option for affecting the circadian rhythms of Special Operations Forces (SOF).

Present Study

We tested whether carefully-scheduled lighting exposure can be used to manipulate the circadian rhythms of traveling SOF in order to prevent some of the negative performance-based consequences associated with circadian misalignment. For this study, we focused on phase locking subjects to their "home" time, thus aligning their circadian day with local night after travel. SOF volunteers stationed in Guam (UTC +10:00) were flown east across nine time zones to Troy, NY (UTC -05:00). During travel, blue-light goggles and orange-tinted sunglasses (to block blue light) were used to control light exposure and lock subjects' circadian rhythms. We hypothesized that judiciously-scheduled light exposure using goggles and glasses could be used to suppress nocturnal melatonin, locking circadian phase to the desired time, and eliminating the performance decrements associated with circadian misalignment. This was predicted to result in similar biochemical indices of circadian phase and cognitive performance pre- and post-travel.

Methods

Participants

Eleven male subjects were recruited from active duty SOF commands in Guam (Chamorro Time Zone, UTC +10:00). Subjects ranged in age from 24 to 45 years, with a mean age of 32 (*SD* = 6.67). Exclusionary criteria were: 1) any previous diagnosis of a chronic sleep or psychiatric disorder; 2) travel across multiple time zones in the previous month; 3) diagnosis of any chronic medical condition or use of any medication that could mask or exacerbate any sleep disorder; and 4) chronotypic extremes, as assessed by the Morningness-Eveningness Questionnaire (MEQ; Horne & Ostberg, 1976). Subjects reported low-to-moderate use of

caffeine in their daily lives. During a week of recorded activity, subjects self-reported that they consumed an average of 1.32 caffeinated beverages per day (*SD* = 1.17; range = 0 – 4.25). A sudden abstinence from caffeine doses as low as 100 mg per day can result in withdrawal symptoms lasting up to nine days (Juliano & Griffiths, 2004); therefore, subjects were permitted to continue normal caffeine consumption throughout the duration of the study.

Performance Assessments

All performance assessments were administered on Dell Latitude E6520 laptops with a 15" display and a screen resolution of 1920x1080. Laptops were equipped with hard-wired mice and joysticks.

Go-no-go. The go-no-go task was used as an assessment of attention and inhibition (Georgiou & Essau, 2011). Participants were presented with a black screen on which a green or red circle appeared at a randomized time interval (every 2-8 seconds) (see Figure 2). Participants were instructed to click the left mouse button as quickly as possible when they saw a green circle; they were instructed not to respond when a red circle was presented. The task lasted a total of 15 minutes, and was similar to the go-no-go task used in past work by researchers at the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute (Figueiro, Sahin, Wood, & Plitnick, 2016).

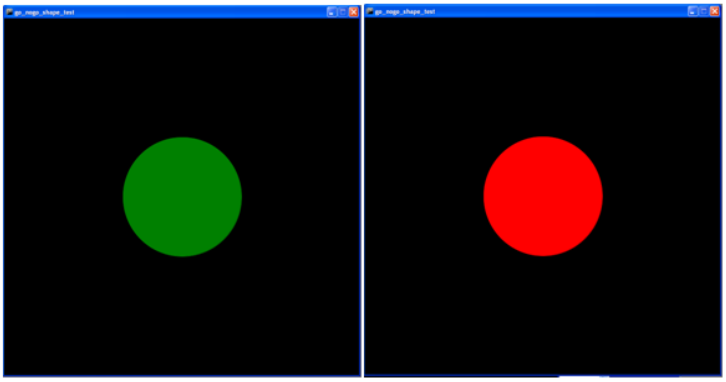

Figure 2. Go-no-go task display. Subjects were instructed to click the mouse button when a green dot appeared and were instructed not to respond when a red dot appeared.

Button-press responses were automatically recorded by the computer. Responses faster than 100 ms were considered anticipations and were not considered valid. Dependent variables derived from the go-no-go task were:

1. Percent error: the number of missed green dots, clicked red dots, and response anticipations ÷ the total number of trials presented
2. Reaction time: the mean of all valid response times (correct clicks on green dots)

Simon memory. The Simon memory task was used to assess memory and concentration. The task was designed by researchers at the LRC and was adapted from Humes and Floyd (2005). Four colored squares flashed in a randomized sequence, and participants were instructed to repeat the sequence by clicking on the colored squares in the presented order. After each correct response, the sequence grew by one (e.g., red-blue; red-blue-green; red-blue-green-green;

red-blue-green-green-yellow, etc.); after an incorrect response, the screen flashed and a new sequence began. The task lasted 15 minutes.

Mouse clicks were automatically recorded by the computer. The dependent variable derived from the Simon memory task was sequence length, conceptualized as the mean of the top three lengths achieved over the 15 minute test.

MATB II. The Multi-Attribute Test Battery II (MATB II; Santiago-Espada, Myer, Latorella, & Comstock, 2011) was used to assess multi-task performance. MATB II is a computer-based task designed to evaluate performance by requiring the simultaneous monitoring and execution of four different tasks: system monitoring, tracking, resource management, and communications (see Figure 3). The *system monitoring* sub-task assessed attention and impulsivity. Participants were instructed to visually track two warning lights and three continuously-moving scales; response was required when a warning light turned from green to red or when any of four scales reached a critical zone (deviation of more than one unit around the central point). The *tracking* sub-task assessed manual dexterity and visual-motor performance. Participants used a joystick to keep a moving target in the center of the screen for seven-minute intervals; after seven minutes the computer maintained "autopilot" status for two minutes. The *resource management* sub-task assessed planning and problem-solving abilities. Participants were instructed to visually monitor fuel levels in simulated fuel tanks and click to refill or empty the tanks when levels dropped below or rose above a critical threshold (2500 ± 100 units). The *communications* sub-task required participants to listen for their designated call sign and change a "radio frequency" when requested to do so. The task lasted 27 minutes.

All mouse clicks, button responses, and joystick movements were automatically recorded by the computer. For the present study, the dependent variables derived from MATB II were: 1) system monitoring response time, conceptualized as the reaction time mean (in milliseconds) of correct responses on the system monitoring subtask; 2) resource management deviation, conceptualized as the mean of the absolute deviation of tanks A and B measured at 30-second intervals in the resource management subtask; 3) mean tracking deviation, conceptualized as the deviation from the center target in pixel units measured at one-minute intervals in the tracking subtask.

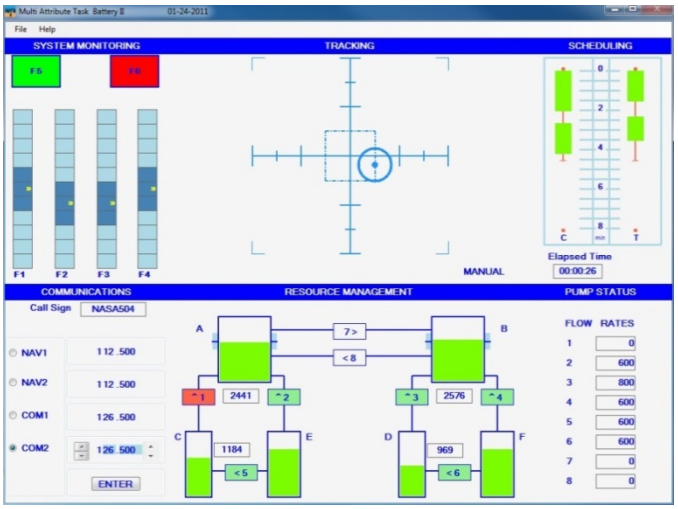

Figure 3. MATB II display. Subjects were instructed to simultaneously monitor and execute four different tasks: system monitoring, tracking, resource management, and communications.

Biochemical Assessment

Circadian phase assessments were based on melatonin concentrations from saliva samples obtained using the Salivette system (SciMart, Saint Louis, MO). Salivary sampling has been validated as a means for determining the circadian phase marker, and melatonin secretion onset times derived from saliva and plasma are highly correlated (Voultsios, Kennaway, & Dawson, 1997). Saliva samples were centrifuged and frozen at −20 °C until assayed for melatonin levels by radioimmunoassay using a commercially-available kit from Labor Diagnostika Nord (Nordhorn, Germany). The limit of detection was 1.4 pg/mL and the intra-assay and inter-assay coefficients of variability were determined to be 11.4% and 14.6%, respectively. All saliva samples from each subject were assayed in the same batch. As in Figueiro and colleagues (2014b), DLMO saliva collection began 2 hours prior to the estimated time of DLMO and continued every 20 minutes until 2 hours after the predicted time of DLMO. To prevent contamination, participants were not allowed to eat or drink between DLMO saliva sample times.

Light Treatment Devices

Each subject was given a pair of blue-light goggles and blue-blocking, orange-tinted sunglasses. Blue-light goggles were the same as those used by Figueiro, Plitnick, and Rea (2014b), and consisted of four blue LED lights (λ_{max} = 476 ± 1 nm, full-width half-maximum ~20 nm) mounted on clear safety glasses (two LED lights per lens). See Figueiro et al. (2014b) for detailed specifications and calibration information. Orange-tinted glasses were commercially-available, aviator-style sunglasses that blocked short wavelength light in the blue range covering 470 nm.

Procedure

Pre-travel. Performance and biomarker measures were collected from all participants while in Guam, prior to any travel. Subjects came into the lab for a 27-hour period beginning at 0700 local time (UTC +10:00). Performance testing was administered five times: at 0800, 1200, 1600, 2000, and 0800 the following day. Salivary melatonin was sampled at 0800, 1200, 1600, every 20 minutes from 1900 to 2300, and at 0600, 0700, and 0800 the following day. See Figure 4 for the pre-travel testing schedule.

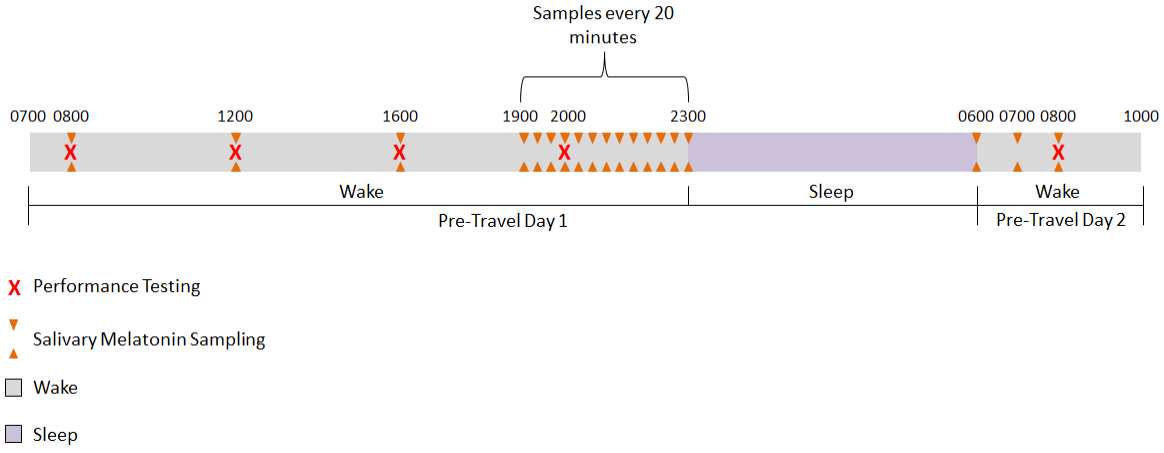

Figure 4. Pre-travel schedule. Schedule of pre-travel performance and biomarker testing. All times listed are UTC +10:00.

Travel. After baseline testing was complete, subjects were given a pair of blue-light goggles, a set of orange-tinted glasses, and a detailed schedule for sleep and personal light treatment device use during travel (see Figure 5). Subjects were flown from Guam to the LRC at Rensselaer Polytechnic Institute in Troy, NY (UTC -05:00). For the duration of the study, subjects were kept on the sleep/wake schedule corresponding to Guam night/day. On both travel days, subjects were instructed to remain awake from 0600 to 2300 while wearing blue googles from 0600-1500 and orange-tinted glasses from 1500 to 2300. Subjects were instructed to sleep from 2300-0600; if travel schedules prevented sleep, subjects wore orange-tinted glasses while awake (see top half of Figure 5, all times listed are in UTC +10:00).

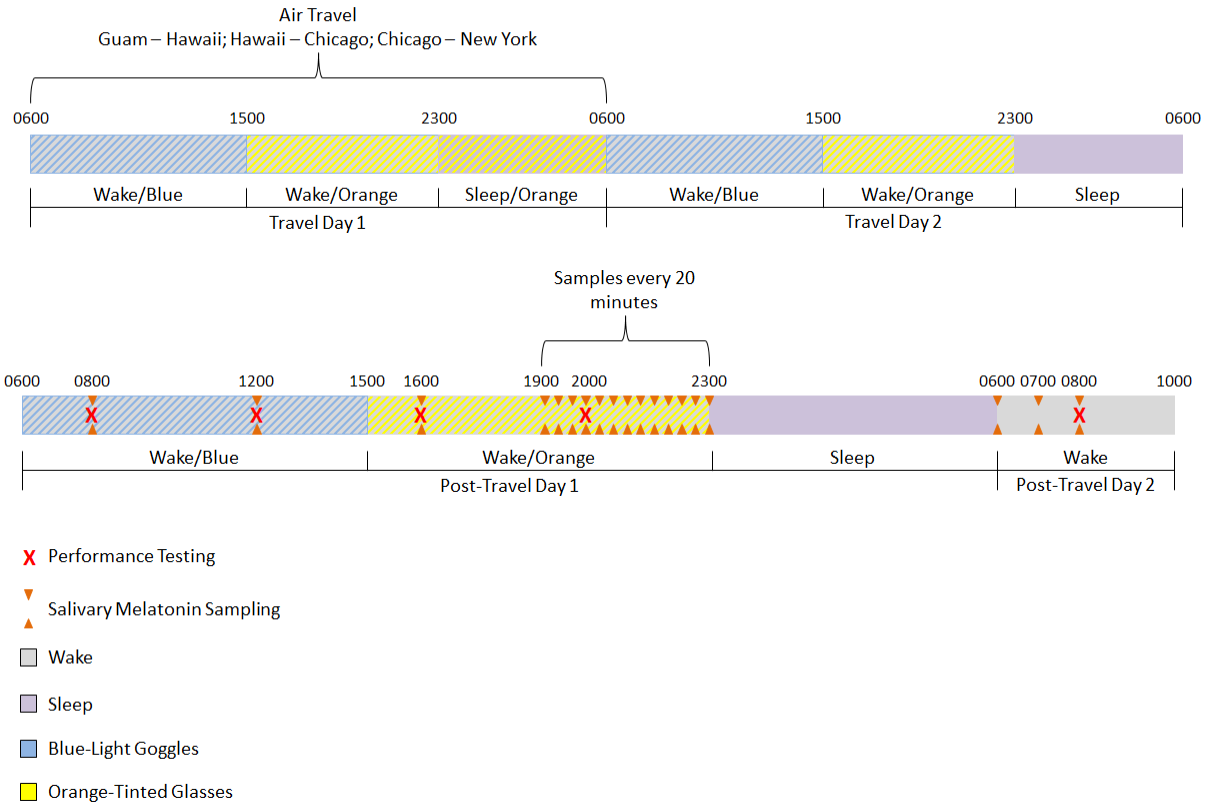

Figure 5. Travel and testing schedule. Schedule of travel, personal light treatment device use, and post-travel performance and biomarker testing. “Blue” represents when subjects were instructed to wear the blue-light goggles; “orange” represents when subjects were instructed to wear the orange-tinted glasses. Travel day 2 and post-travel day 1 fell on consecutive days. All times listed are UTC +10:00.

Post-travel. Post-travel performance and biochemical measures were collected at the LRC in the two days immediately following travel. The timing of task administration matched that of the pre-travel measures (see bottom half of Figure 5): performance testing was administered at 0800, 1200, 1600, 2000, and 0800 the following day. Salivary melatonin was sampled at 0800, 1200, 1600, every 20 minutes from 1900 to 2300, and at 0600, 0700, and 0800 the following day (all times in UTC +10:00).

Design and Data Analysis

The present study was conceptualized as a within-subject comparison of operators' performance and circadian rhythms before and after travel.

Visual inspection of all performance data revealed the presence of likely practice effects resulting from multiple assessment sessions (e.g., see Figure 6). Performance reached an asymptote by session 4 (2000 on pre-travel day 1). In order to control for these practice effects, analyses were conducted on tests from the final pre-travel session (session 5; in Guam) and the first post-travel session (session 6; on the East Coast). As both sessions occurred at 0800 UTC + 10:00 (Guam time), this also controlled for potential time-of-day effects on performance. Paired-sample *t*-tests were used to compare performance pre- and post- travel.

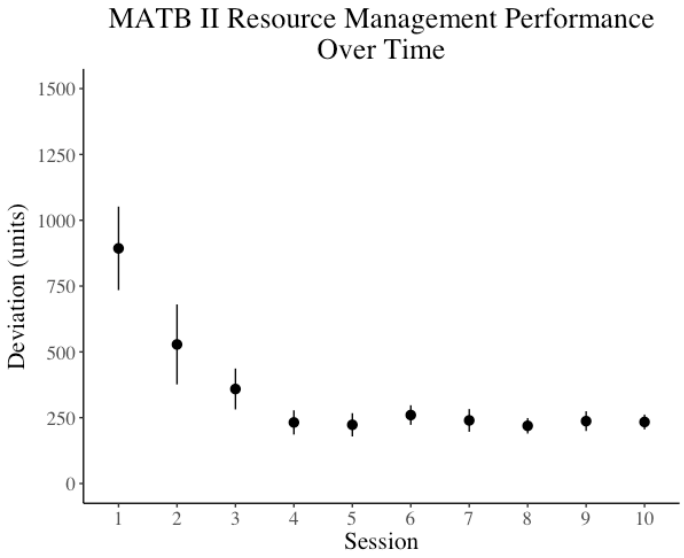

Figure 6. Performance on MATB II resource management across all ten testing sessions. Y-axis represents mean normalized deviation from 2500 units measured at 30-second intervals; dots represent mean group performance, and vertical lines represent standard error.

DLMO thresholds were calculated using one of two techniques: either by taking the average of the three lowest points plus twice the standard deviation of these points (3L; Voultsios et al., 1997) or by taking the average of the five continuous lowest points plus 15% of the five continuous highest points (5H/5L; Smith, Revell, & Eastman, 2009). The DLMO analysis technique was determined on a participant-by-participant basis through visual inspection of the data; the 3L method was used for subjects with steep melatonin profiles while the 5H/5L method was used for subjects with shallow melatonin profiles (Figueiro, Plitnick, & Rea, 2014a). The time of the DLMO phase was determined by linear interpolation between the time points before and after melatonin concentration increased and remained above the thresholds. Paired-sample *t*-tests were used to compare DLMO times pre- and post- travel.

Results

Performance Assessments

As shown in Table 1, performance was not significantly different pre- and post-travel on any assessed metric (all p values > 0.20); effect size (d_z) ranged from 0.06 to 0.39. This indicates that operators were able to maintain cognitive performance in spite of a 9-hour time zone change.

Table 1
Performance on Assessments Pre- and Post-Travel

Performance Test	Pre-Travel *Mean* (*SD*)	Post-Travel *Mean* (*SD*)	*df*	*t*	*p*	d_z
Go-No-Go						
Error Rate	0.03 (0.02)	0.02 (0.02)	10	0.41	0.69	0.12
Reaction Time (ms)	475.64 (51.49)	478.45 (47.52)	10	-0.20	0.85	0.06
Simon Memory						
Sequence Length	11.15 (1.89)	11.79 (2.79)	10	-0.67	0.52	0.20
MATB II						
System Monitoring (ms)	3550 (975.87)	3699 (948.99)	9	-0.77	0.46	0.24
Resource Management (units)	223.09 (146.87)	260.09 (118.18)	9	-0.92	0.38	0.29
Tracking Deviation (pixels)	31.30 (4.77)	33.70 (8.00)	9	-1.24	0.25	0.39

Note. Post-travel MATB II data were missing from one subject.

As shown in Figures 7-11, there were no discernible trends of individuals performing better or worse post-travel. Numerically, on the go-no-go task, six individuals improved on performance post-travel as measured by reaction time, five worsened; on the Simon memory task, seven individuals improved on performance post-travel, four worsened; on MATB II system monitoring and tracking, four individuals improved on performance post-travel, six worsened; on MATB II resource management, two individuals improved on performance post-travel, six worsened, and two maintained performance within one unit.

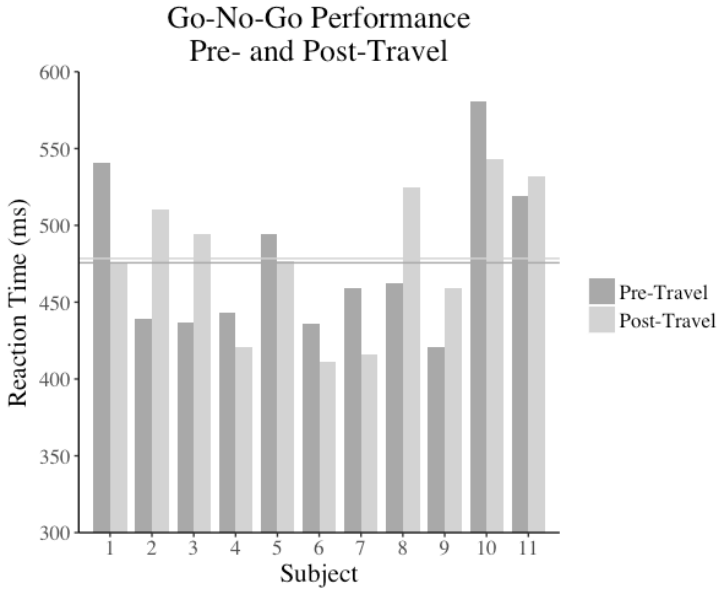

Figure 7. Change in go-no-go performance by subject. Y-axis represents reaction time in milliseconds (ms); horizontal lines represent mean group performance.

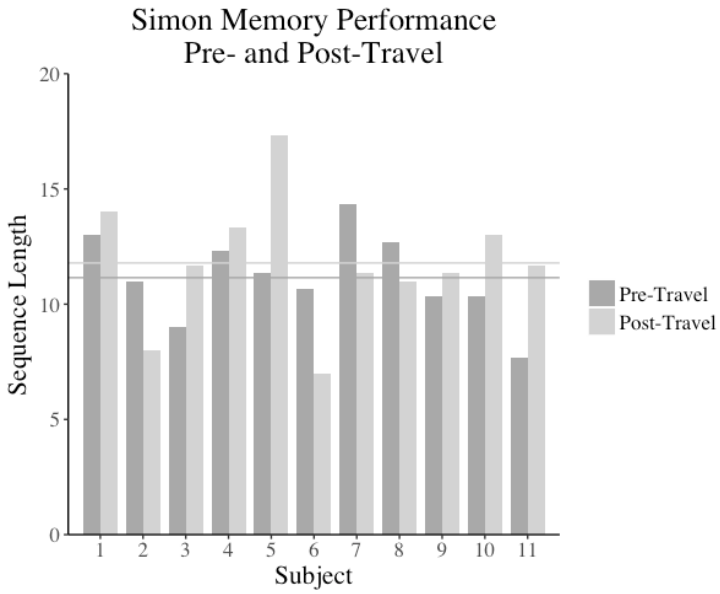

Figure 8. Change in Simon memory performance by subject. Y-axis represents the mean of the top three lengths achieved over the 15 minute test; horizontal lines represent mean group performance.

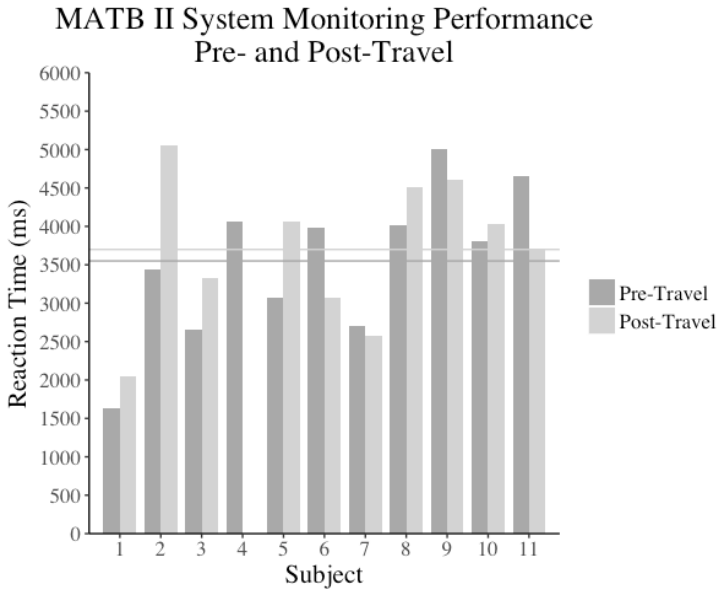

Figure 9. Change in MATB II system monitoring performance by subject. Post-travel data from one subject (4) are missing. Y-axis represents the mean reaction time in milliseconds (ms); horizontal lines represent mean group performance.

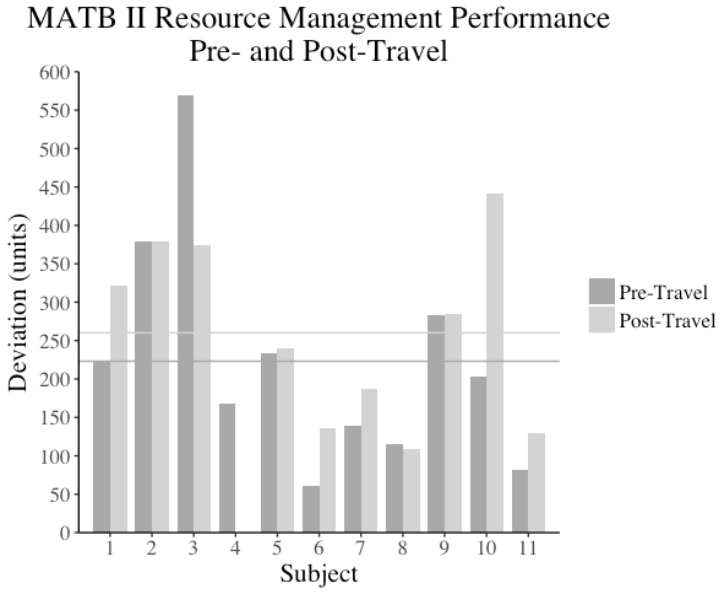

Figure 10. Change in MATB II resource management performance by subject. Post-travel data from one subject (4) are missing. Y-axis represents the mean normalized deviation from 2500 units measured at 30-second intervals; horizontal lines represent mean group performance.

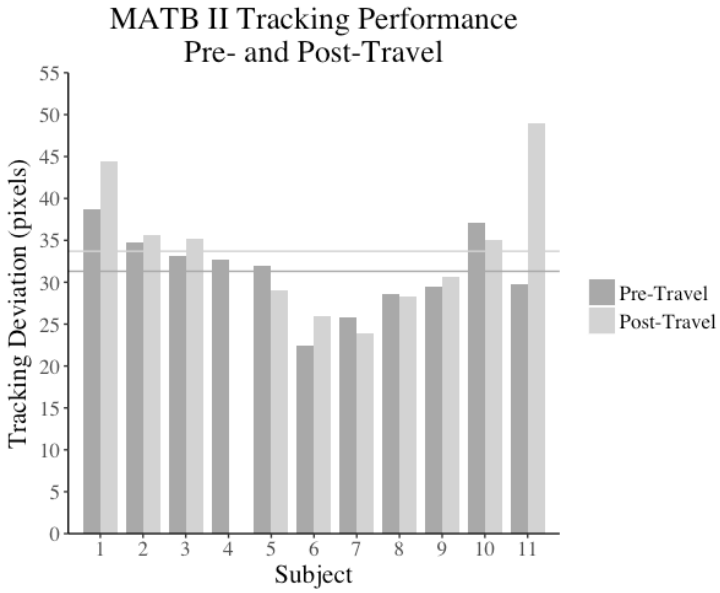

Figure 11. Change in MATB II tracking performance by subject. Post-travel data from one subject (4) are missing. Y-axis represents the deviation from the center target in pixel units measured at one-minute intervals; horizontal lines represent mean group performance.

Biochemical Assessment

Data from one subject were unavailable, as melatonin values were variable throughout the DLMO collection period and a threshold could not be obtained. For the remaining 10 subjects, mean DLMO was unchanged (pre-travel: 20:21 ± 44.89 min UTC +10:00; post-travel: 20:31 ± 50.48 min UTC +10:00; $t(9) = -0.79$, $p > 0.40$, $d_z = 0.25$). Figure 12 shows the DLMO

shift by participant: five of ten participants shifted 10 minutes or less; nine of ten participants shifted by less than an hour.

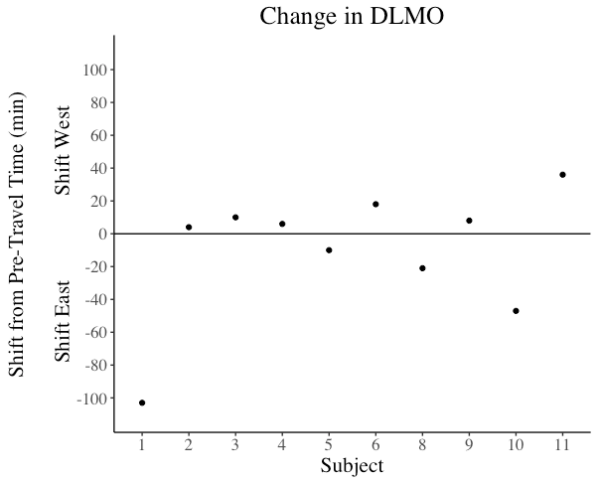

Figure 12. Change in DLMO by subject. Data from one subject (7) are missing. Y-axis represents the shift (in minutes) from pre-travel DLMO to post-travel DLMO; horizontal line represents no shift. A positive value means that the post-travel time is earlier than the pre-travel time (westward shift); a negative value means that the post-travel time is later than the pre-travel time (eastward shift).

Discussion

Behavioral and biochemical data demonstrate that blue-light goggles and orange-tinted glasses can be used to systematically phase lock Special Forces operators to a desired schedule during extensive travel. SOF traveled east through nine time zones from Guam to Troy, NY while using personal light treatment devices (blue-light goggles and blue-blocking, orange-tinted glasses) to judiciously manage light exposure. In spite of the nine-hour difference, and in spite of approximately two and a half days between testing sessions, operators' circadian cycle (as measured by DLMO) did not shift, suggesting that circadian phase was locked. This was also reflected in a lack of detectable performance difference pre- and post- travel on a battery of cognitive tasks. Despite the fact that performance tests in Troy, NY were conducted during the local nighttime, subjects remained phase-locked to Guam time and were therefore performing the tests during their circadian day.

This study represents the first phase of research using light to manage traveling operators' circadian rhythms and optimize performance. Our results provide preliminary evidence that personal light treatment devices (blue-light goggles and blue-blocking, orange-tinted glasses) can successfully be used to prevent the errors associated with circadian misalignment. Interpretations from this study are limited due to the lack of a control group but provide a foundation for the utilization of non-chemical circadian controls. Future research should compare the performance and circadian cycles of operators traveling with and without personal light treatment devices.

One benefit of lighting-based strategies for the mitigation of circadian misalignment is they could reduce the need for drug-based countermeasures. There is a current precedent in SOF communities for the use of pharmacologic strategies to manage fatigue and circadian phase (e.g.,

Caldwell & Caldwell, 2005). For example, the U.S. Air Force has extensive experience with the pharmacologic management of fatigue (go/no-go pills), including the common usage of zolpidem (Ambien), temazepam (Restoril), zaleplon (Sonata), and dexamphetamine (Schultz & Miller, 2004); similar regimens are employed by the Army (Caldwell & Caldwell, 2005). Over-the-counter medications such as caffeine and melatonin are also employed (Caldwell & Caldwell, 2005; McLellan et al., 2005). Although these chemical strategies are considered safe, it has been noted that behavioral and scheduling countermeasures should be considered as the first line of defense against operator fatigue in order to protect against potential pharmacological side effects (Caldwell & Caldwell, 2005). Moreover, command policy may prohibit the use of no-go pills during certain operational periods (Schultz & Miller, 2004), thereby limiting the utility of drug-based interventions. It is possible that the use of light exposure may alleviate the need for, or supplement the use of, pharmaceutical stimulants.

Although light exposure would likely help to mitigate SOF's circadian misalignment regardless of the method of administration (goggles, light banks, etc.), the use of goggles provides additional benefits. Unlike light banks, goggles are mobile and can be used anywhere, and transparent lenses allow the wearers to continue with their daily routines while receiving light treatment. Moreover, because the goggles and glasses can be worn and removed according to the lighting schedule required to maintain a desired circadian cycle, multiple operators can receive different lighting treatments at the same time, allowing for collaborations between individuals who are on different light cycles. This could potentially facilitate operational planning and increase mission efficiency.

In addition to providing preliminary empirical evidence for the utility of personal light treatment devices for manipulating the circadian rhythms of traveling SOF, our results also underscore an important consideration for the maintenance of healthy circadian cycles. In the present study, very minimal amounts of blue light were required to affect circadian phase- the light emitted from the blue-light goggles was sufficient, and full-room lighting was not required. Because even low levels of short-wavelength lighting can have meaningful impacts, operators must be careful to restrict the usage of light-emitting electronic devices (e.g., laptops, cell phones, tablets) outside of the prescribed light schedule. In fact, even in the absence of controlled blue light, the light from computer monitors may be sufficient to impact DLMO timing (Figueiro, Wood, Plitnick, & Rea, 2011). As "the capacity to consciously perceive light is a distinct phenomenon from the capacity of the light to entrain the circadian pacemaker" (Boivin & James, 2002, p. 36), operators may be unaware of the daily light exposures that are working to entrain their systems.

Limitations

There are a few constraints that limit the generalizability and strength of conclusions of the current research. The first is the lack of a control group. In the present study, subjects' circadian phase (as measured by DLMO) did not meaningfully shift following travel across nine time zones. Although circadian research has conventionally cited shifts of approximately an hour per day for eastward travel (e.g., Eastman & Burgess, 2009; Houpt, Boulos, & Moore-Ede, 1996; Klein & Wegmann, 1980; Revell & Eastman, 2005), and although the second DLMO measurement occurred about two and a half days after the onset of travel, the subjects' lack of shift cannot be definitively linked to their use of the light treatment devices. It is possible that the time between the pre- and post- travel measurements was not sufficient to shift travelers' circadian cycles, thereby leading to the lack of significant results.

In the absence of a control group, the expected shift in circadian cycle (without scheduled light exposure) can be estimated using values from past experimental work. During eastbound travel with no lighting manipulations, circadian entrainment to the new time zone can shift as slowly as 56 minutes per day, on average, with different circadian functions resynchronizing with divergent speeds – mental performance shifts by 57 minutes per day, heart rate shifts by 60 minutes per day, and body temperature shifts by 39 minutes per day (Klein & Wegmann, 1980). Therefore, two and a half days after beginning travel, it would be expected that subjects should shift by 140 minutes (56 min/day x 2.5 days). As rates of re-entrainment are not linear, with time shifts occurring most rapidly immediately after travel and more slowly later on (Houpt et al., 1996; Klein & Wegmann, 1980), an expected shift of 140 minutes east is likely a conservative estimate. When exposed to the scheduled lighting manipulation, subjects in the present study only shifted an average of 9.9 minutes east. This number is largely driven by Subject 1, who shifted 103 minutes. If that subject is excluded from analyses, the mean shift drops to 0.44 minutes in the westward direction. Therefore, it is likely that the lack of circadian shift observed in the present experiment can be attributed to the lighting manipulation, and not to an insufficient time for circadian rhythms to shift naturally following travel.

The absence of a control group also makes it difficult to ensure that the lack of observed shift is not attributed to insensitive measures of circadian phase. It is possible that DLMO measurements are not sensitive enough to measure circadian phase, resulting in a circadian shift that was not observed. This is unlikely, as analyses of melatonin have lower variance and are considered to be more reliable for measurement of circadian phase than assessments using cortisol or body temperature (Klerman, Gershengorn, Duffy, & Kronauer, 2002). In fact, DLMO derived from either saliva or plasma is considered “the single most accurate marker for assessing the circadian pacemaker” (Pandi-Perumal et al., 2007, p. 1). In the absence of any circadian manipulation, the coefficient of variation for repeated sampling of salivary DLMO has been reported to be as low as 1.3% (Voultsios et al., 1997).

A second limitation of the present experiment is the small sample size, which may have contributed to an under-powered study. Post hoc achieved power was calculated using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) for two-tailed matched pairs *t*-tests, using the effect size and alpha values reported in Table 1 and on page 20. Power for performance data ranged from 0.52 (MATB II tracking) to 0.85 (go-no-go reaction time); power for the DLMO analysis was 0.53. Statistical convention generally specifies a desired power of 0.8 (Cohen, 1988); therefore, six of the seven conducted analyses are at least slightly underpowered. By definition, power represents the probability that a study will detect an effect when one exists. As power increases, the probability of making a Type II error (concluding that there is no effect when there is one; i.e., false negative) is reduced. Therefore, a study with low power may incorrectly assume no effects (in this case, we may incorrectly assume that performance was the same pre- and post-travel). One way to increase statistical power is to increase the sample size. However, if we were to increase the sample size of the present experiment to a level large enough to measure differences pre- and post- travel at the effect sizes presently observed, we would require an unrealistically large number of subjects (e.g., 199 subjects to detect differences on the Simon memory task; 2183 subjects to detect differences in go-no-go reaction time). This difference, though perhaps statistically significant, would likely not represent an operationally-meaningful change. Critics of post hoc power analysis (e.g., Goodman & Berlin, 1994; Hoenig & Heisey, 2001; Streiner, 2003) note that, “because of sampling error, there will always be a difference between groups, no matter how similar they may be. Further, if we simply increase the sample

size sufficiently, we will always be able to show that this difference is statistically significant" (Streiner, 2003, p. 757). Instead, it may be more meaningful to examine effect sizes, which quantify differences between two groups or measures: "The larger this value, the greater the degree to which the phenomenon under study is manifested" (Cohen, 1988, p. 10). Convention specifies that a value of 0.2 represents a small effect, 0.5 represents a medium effect, and 0.8 represents a large effect. Effect sizes in the current study ranged from 0.06 (go-no-go reaction time) to 0.39 (MATB II tracking); six of seven analyses yielded effect sizes less than 0.3. This suggests that any effect of travel on subjects' circadian systems was not meaningful. Given the lack of observed statistical changes across all performance and biochemical metrics, and the small effect sizes for all measures, we believe it is unlikely that our interpretations represent a Type II error. Nevertheless, the relatively small sample size of the current study means that results should be interpreted with caution.

A final limitation is the lack of controlled travel and sleep schedules. For all subjects, travel began in Guam at 0600 on travel day 1 (Figure 5), but precise itineraries for individual subjects are unknown. Travel from Guam to Troy, NY lasted approximately 24 hours, and included at least two layovers (e.g., Guam-Hawaii-Chicago-Albany) and a drive of approximately 20 minutes. As a result, sleep received by subjects during travel day 1 was not in a bedroom environment; subjects likely slept on the aircraft or in the airport terminal between flights. Subjects did not receive natural light or access to environmental lighting cues at destination until the morning of travel day 2, at the earliest. Relatedly, subjects did not utilize blackout masks to prevent artificial light exposures (e.g., in the airport) that could have prevented subjects from falling or staying asleep. As a result of these travel schedules and lack of ideal sleeping environments, the actual quality and duration of sleep obtained by subjects during travel is unknown; acute sleep deprivation during travel cannot be ruled out. However, if subjects were sleep deprived prior to the laboratory testing in Troy, NY, they would be expected to perform worse during post-travel testing than pre-travel testing due to the negative effects of fatigue on cognitive performance (e.g., Harrison & Horne, 2000); this effect was not observed. Nevertheless, controlled travel schedules with carefully-documented incidents of sleep, preferably through the use of actigraphy watches, is required for future research.

The careful control of subjects' schedules will also allow for the well-documented control of subjects' caffeine and over-the-counter stimulant use. Though all subjects reported low levels of caffeine use and were instructed to maintain their typical levels of caffeine intake throughout the duration of the study, any potential changes in stimulant usage were not captured in this experiment. Caffeine usage has been shown to impact performance on behavioral measures such as the go-no-go task (Barry et al., 2007), and may have influenced the present results.

Future Directions

This research represents the first step in the development of personal light treatment devices for traveling Special Operations forces. Now that we have demonstrated the feasibility of utilizing goggles to control circadian rhythms during travel, there are numerous avenues for future research.

The first step in future research is to confirm the utility of personal light treatment for phase locking in a more controlled experiment. Three groups of operators should travel the same route under the same schedule; one group should wear goggles and follow a prescribed sleep/wake schedule, a second group should not wear goggles but follow a prescribed sleep/wake schedule, and the third group should not wear goggles and should sleep and awaken as desired

without the use of a prescribed schedule. Stimulant use should be carefully controlled to ensure equivalent use between groups and during all phases of travel and testing. Circadian phase, as measured through biochemical assessments (DLMO, CBTmin) should be assessed for multiple days prior to departure and after arrival. Performance on cognitive batteries should be assessed (as in the current study), as should performance on operationally-relevant tasks such as marksmanship. The inclusion of multiple control groups and different types of tasks will ensure that goggle use is operationally effective and meaningful. An expanded timeframe of study post-travel will determine the length of time (i.e., number of days) through which lighting manipulation can be used to sustain DLMO and performance levels equivalent to those observed pre-travel.

Future research should also determine whether both blue-light goggles *and* blue-blocking glasses are required to ensure circadian phase locking. As mentioned in the Introduction, although ipRGCs respond most strongly to short-wavelength blue light (Cajochen et al., 2005; Lockley et al., 2003; Thapan et al., 2001), they also receive input from traditional photoreceptors (rods and cones) that respond to long-wavelength light. Therefore, even long-wavelength red light could serve as a potential zeitgeber. It is possible, then, that blocking light (through the use of blue-blocking goggles) might be sufficient to lock in circadian rhythms; blue-light goggles might be extraneous when light exposure is plentiful (e.g., in an airport).

Once the utility of blue-light goggles for circadian phase locking is confirmed, the next step in future research is to empirically test the goggles' ability to help operators shift to a new time zone. Rather than waiting for operators to adjust to a new sleep-wake cycle after arrival (with the body shifting approximately one time zone per day; Sateia, 2014), operators could be shifted prior to travel and then locked to that cycle using the methods employed in the current paper. Future research on phase shifting can be accomplished without the need for travel, by shifting sleep/wake and lighting exposure schedules to correspond to a later or earlier circadian cycle.

If phase shifting can be accomplished using the controlled light exposure, the final phase of future research would be to combine phase shifting with phase locking. The most operationally-useful scenario for SOF conducting short-run missions would be to shift circadian phase to an optimal zone (e.g., ensuring that any night operations would occur during circadian day) and then phase lock to that schedule while traveling to the mission destination. This would ensure that, upon arrival, operators are performing at their peak. Future research should test the feasibility of this scenario by using controlled lighting exposures to phase-shift operators, having them travel through multiple time zones while using lighting exposures to lock their circadian phase, and assessing performance pre- and post-travel.

Conclusions

Although additional research with appropriate control conditions is needed to confirm the findings of the present experiment, we provide preliminary evidence that the performance of SOF can be maintained, even after extensive travel, by the use of judiciously-scheduled lighting exposures. After traveling through nine time zones, circadian phase (as measured biochemically through DLMO) and cognitive performance remained stable at pre-travel levels for approximately two and a half days following the initiation of travel. Personal light treatment devices may therefore be a viable alternative and/or supplement to the pharmacological countermeasures currently employed by SOF to minimize the negative effects of circadian misalignment.

References

Appleman, K., Figueiro, M., & Rea, M. S. (2013). Controlling light-dark exposure patterns, rather than sleep schedules, determines circadian phase. *Sleep Medicine, 14*(5), 456-461.

Bailey, S. L., & Heitkemper, M. M. (2001). Circadian rhymicity of cortisol and body temperature: Morningness-eveningness effects. *Chronobiology International, 18*(2), 249-261.

Barry, R. J., Johnstone, S. J., Clarke, A. R., Rushby, J. A., Brown, C. R., & McKenzie, D. N. (2007). Caffeine effects on ERPs and performance in an auditory Go/NoGo task. *Clinical Neurophysiology, 118*, 2692-2699.

Berson, D. M., Dunn, F. A., & Takao, M. (2002). Phototransduction by retinal ganglion cells that set the circadian clock. *Science, 295*, 1070-1073.

Blagrove, M., Alexander, C., & Horne, J. A. (1995). The effects of chronic sleep reduction on the performance of cognitive tasks sensitive to sleep deprivation. *Applied Cognitive Psychology, 9*, 21-40.

Bocca, M., & Denise, P. (2006). Total sleep deprivation effect on disengagement of spatial attention as assessed by saccadic eye movements. *Clinical Neurophysiology, 117*, 894-899.

Boivin, D. B., & James, F. O. (2002). Circadian adaptation to night-shift work by judicious light and darkness exposure. *Journal of Biological Rhythms, 17*(6), 556-567.

Bourgeois-Bougrine, S., Carbon, P., Gounelle, C., Mollard, R., & Coblentz, A. (2003). Perceived fatigue for short- and long-haul flights: A survey of 739 airline pilots. *Aviation, Space, and Environmental Medicine, 74*(10), 1072-1077.

Cajochen, C., Munch, M., Kobialka, S., Krauchik, K., Steiner, R., Oelhafen, P., . . . Wirz-Justice, A. (2005). High sensitivity of human melatonin, alertness, thermoregulation, and heart rate to short wavelength light. *The Journal of Clinical Endocrinology & Metabolism, 90*(3), 1311-1316.

Caldwell, J. A., & Caldwell, J. L. (2005). Fatigue in military aviation: An overview of U.S. military-approved pharmacological countermeasures. *Aviation, Space, and Environmental Medicine, 76*(7), C39-C51.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Czeisler, C. A., Johnson, M. P., Duffy, J. F., Brown, E. N., Ronda, J. M., & Kronauer, R. E. (1990). Exposure to bright light and darkness to treat physiologic maladaptation to night work. *The New England Journal of Medicine, 322*(18), 1253-1259.

Davis, S., & Mirick, D. K. (2006). Circadian disruption, shift work, and the risk of cancer: A summary of the evidence and studies in Seattle. *Cancer Sauces Control, 17*, 539-545.

Deacon, S., & Arendt, J. (1996). Adapting to phase shifts, I. An experimental model for jet lag and shift work. *Physiology & Behavior, 59*(4-5), 665-673.

Dijk, D., & Lockley, S. W. (2002). Integration of human sleep-wake regulation and circadian rhythmicity. *Journal of Applied Physiology, 92*, 852-862.

Dinges, D. F., Pack, F., Williams, K., Gillen, K. A., Powell, J. W., Ott, G. E., . . . Pack, A. I. (1997). Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decremented during a week of sleep restricted to 4-5 hours per night. *Sleep, 20*(4), 267-277.

Drust, B., Waterhouse, J., Atkinson, G., Edwards, B., & Reilly, T. (2005). Circadian rhythms in sports performance- An update. *Chronobiology International, 22*(1), 21-44.

Duffy, J. F., Rimmer, D. W., & Czeisler, C. A. (2001). Association of intrinsic circadian period with morningness-eveningness, usual wake time, and circadian phase. *Behavioral Neuroscience, 115*(4), 895-899.

Dunlap, J. C., Loros, J. J., & DeCoursey, P. J. (2004). *Chronobiology: Biological timekeeping*: Sinauer Associates.

Eastman, C. I., & Burgess, H. J. (2009). How to travel the world without jet lag. *Sleep Medicine Clinics, 4*(2), 241-255.

Faul, F., Erdfelder, E., Lang, A., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175-191.

Figueiro, M., Bierman, A., Bullough, J. D., & Rea, M. S. (2009). A personal light-treatment device for improving sleep quality in the elderly: Dynamics of nocturnal melatonin suppression at two exposure levels. *Chronobiology International, 26*(4), 726-739.

Figueiro, M., Plitnick, B., & Rea, M. (2014a). Pulsing blue light through closed eyelids: Effects on acute melatonin suppression and phase shifting of dim light melatonin onset *Nature and Science of Sleep, 6*, 149-156.

Figueiro, M., Plitnick, B., & Rea, M. S. (2014b). The effects of chronotype, sleep schedule and light/dark pattern exposures on circadian phase. *Sleep Medicine, 15*, 1554-1564.

Figueiro, M., Sahin, L., Wood, B., & Plitnick, B. (2016). Light at night and measures of alertness and performance. *Biological Research for Nursing, 18*(1), 90-100.

Figueiro, M., Wood, B., Plitnick, B., & Rea, M. (2011). The impact of light from computer monitors on melatonin levels in college students. *Biogenic Amines, 25*(2), 106-116.

Georgiou, G., & Essau, C. A. (2011). Go/no-go task. In S. Goldenstein & J. A. Naglieri (Eds.), *Encyclopedia of Child Behavior and Development* Springer US.

Goodman, S. N., & Berlin, J. A. (1994). The use of predicted confidence intervals when planning experiments and the misuse of power when interpreting results. *Annals of Internal Medicine, 121*, 200-206.

Harrison, Y., & Horne, J. A. (1999). One night of sleep loss impairs innovative thinking and flexible decision making. *Organizational Behavior and Human Decision Processes, 78*(2), 128-145.

Harrison, Y., & Horne, J. A. (2000). The impact of sleep deprivation on decision making: A review. *Journal of Experimental Psychology: Applied, 6*(3), 236-249.

Herljevic, M., Middleton, B., Thapan, K., & Skene, D. J. (2005). Light-induced melatonin suppression: Age-related reduction in response to short wavelength light. *Experimental Gerontology, 40*(3), 237-242.

Hoenig, J. M., & Heisey, D. M. (2001). The abuse of power: The pervasive fallacy of power calculations for data analysis. *The American Statistician, 55*(1), 1-6.

Horne, J. A., & Ostberg, C. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology, 4*, 97-110.

Houpt, T. A., Boulos, Z., & Moore-Ede, M. C. (1996). Midnight sun: Software for determining light exposure and phase-shifting schedules during global travel. *Physiology & Behavior, 59*(3), 561-158.

Humes, L. E., & Floyd, S. S. (2005). Measures of working memory, sequence learning, and speech recognition in the elderly. *Journal of Speech, Language, and Hearing Research, 48*(1), 224-235.

Jewett, M. E., Rimmer, D. W., Duffy, J. F., Klerman, E. B., Kronauer, R. E., & Czeisler, C. A. (1997). Human circadian pacemacer is sensitive to light throughout subjective day without evidence of transients. *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology, 273*(5), R1800-R1809.

Juliano, L. M., & Griffiths, R. R. (2004). A critical review of caffeine withdrawal: Empirical validation of symptoms and signs, incidence, severity, and associated features. *Psychopharmacology, 176*, 1-29.

Karatsoreos, I. N. (2012). Effects of circadian disruption on mental and physical health. *Current Neurology and Neuroscience Reports, 12*, 218-225.

Klein, K. E., & Wegmann, H. M. (1980). *Significance of circadian rhythms in aerospace operations*. (AGARD-AG-247).

Klerman, E. B., Gershengorn, H. B., Duffy, J. F., & Kronauer, R. E. (2002). Comparisons of the variability of three markers of the human circadian pacemaker. *Journal of Biological Rhythms, 17*(2), 181-193.

Lahti, T., Terttunen, J., Lappamaki, S., Lonnqvist, J., & Partonen, T. (2007). Filed trial of timed bright light exposure for jet lag among airline cabin crew. *International Journal of Circumpolar Health, 66*(4), 365-369.

Lewy, A. J., Cutler, N. L., & Sack, R. L. (1999). The endogenous melatonin profile as a marker for circadian phase position. *Journal of Biological Rhythms, 14*(3), 227-236.

Lockley, S. W., Brainard, G. C., & Czeisler, C. A. (2003). High sensitivity of the human circadian melatonin rhythm to resetting by short wavelength light. *The Journal of Clinical Endocrinology & Metabolism, 88*(9), 4502-4505.

Manfredini, R., Mandredini, F., Fersini, C., & Conconi, F. (1998). Circadian rhythms, athletic performance, and jet lag. *British Journal of Sports Medicine, 32*, 101-106.

McLellan, T. M., Kamimori, G. H., Voss, D. M., Bell, D. G., Cole, K. G., & Johnson, D. (2005). Caffeine maintains vigilance and improves run times during night operations for special forces. *76, 7*, 647-654.

Miller, N. L., Matsangas, P., & Shattuck, L. G. (2008). Fatigue and its effect on performance in military environments. In P. A. Hancock & J. L. Szalma (Eds.), *Performance Under Stress*. Burlington, VT: Ashgate Publishing.

Molina, T. A., & Burgess, H. J. (2011). Calculating the dim light melatonin onset: The impact of threshold and sampling rate. *Chronobiology International, 28*(8), 714-718.

Pandi-Perumal, S., Smits, M., Spence, W., Srinivasan, V., Cardinali, D. P., Lowe, A. D., & Kayumov, L. (2007). Dim light melatonin onset (DLMO): A tool for the analysis of circadian phase in human sleep and chronobiological disorders. *Progress in Neuro-Pharmacology & Biological Psychiatry, 31*, 1-11.

Prasai, M. J., Pernicova, I., Grant, P. J., & Scott, E. M. (2011). An endocrinologist's guide to the clock. *The Journal of Clinical Endocrinology & Metabolism, 96*(4), 913-922.

Refinetti, R., & Maenaker, M. (1992). The circadian rhythm of body temperature. *Physiology & Behavior, 51*(3), 613-637.

Relogio, A., Westermark, P. O., Wallach, T., Schellenberg, K., Kramer, A., & Herzel, H. (2011). Tuning the mammalian circadian clock: Robust synergy of two loops. *PLoS Computational Biology, 7*(12).

Reppert, S. M., & Weaver, D. R. (2002). Coordination of circadian timing in mammals. *Nature, 418*, 935-941.

Revell, V. L., & Eastman, C. I. (2005). How to trick mother nature into letting you fly around or stay up all night. *Journal of Biological Rhythms, 20*(4).

Revell, V. L., Molina, T. A., & Eastman, C. I. (2012). Human phase response curve to intermittent blue light using a commercially available device. *Journal of Physiology, 590*(19), 4859-4868.

Samel, A., & Wegmann, H. (1997). Bright light: A countermeasure for jet lag? *The Journal of Biological and Medical Rhythm Research, 14*(2), 173-183.

Santiago-Espada, Y., Myer, R. R., Latorella, K. A., & Comstock, J. (2011). *The Multi-Attribute Test Battery II (MATB-II) software for human performance and workload research: A user's guide*. (NASA/TM-2011-217164). Hampton, VA: National Aeronautics and Space Administration.

Sasseville, A., Paquet, N., Sevigny, J., & Hebert, M. (2006). Blue blocker glasses impede the capacity of bright light to suppress melatonin production. *Journal of Pineal Research, 41*, 73-78.

Sateia, M. J. (2014). International classification of sleep disorders- Third edition. *Contemporary Reviews in Sleep Medicine, 146*(5), 1387-1394.

Scheer, F. A. J. L., Hilton, M. F., Mantzoros, C. S., & Shea, S. A. (2009). Adverse metabolic and cardiovascular consequences of circadian misalignment. *Procedings of the National Academy of Science, 16*(11), 4453-4458.

Schultz, D., & Miller, J. C. (2004). Fatigue and use of go/no-go pills in extraordinarily long combat sorties. *Aviation, Space, and Environmental Medicine, 75*, 370-371.

Smith, M. E., McEvoy, L. K., & Gevins, D. (2002). The impact of moderate sleep loss on neurophysiological signals during working-memory task performance. *Sleep, 25*(7), 784-794.

Smith, M. R., Revell, V. L., & Eastman, C. I. (2009). Phase advancing the human circadian clock with blue-enriched polychromatic light. *Sleep Medicine, 10*(3), 287-294.

Stevens, R. G., Blask, D. E., Brainard, G. C., Hansen, J., & Lockley, S. W. (2007). Meeting report: The role of environmental lighting and circadian disruption in cancer and other diseases: Department of Neurology Faculty Papers.

Streiner, D. L. (2003). Unicorns do exist: A tutorial on "proving" the null hypothesis. *Research Methods in Psychiatry, 48*(11), 756-761.

Thapan, K., Arendt, J., & Skene, D. J. (2001). An action spectrum for melatnonin suppression: Evidence for a novel non-rod, non-cone photoreceptor system in humans. *Journal of Physiology, 535*(1), 261-267.

Thompson, A., Batterham, A. M., Jones, H., Gregson, W., Scott, D., & Atkinson, G. (2013). The practicality and effectiveness of supplementary bright light for reducing jet-lag in elite female athletes. *International Journal of Sports Medicine, 34*(7), 582-589.

Voultsios, A., Kennaway, D. J., & Dawson, D. (1997). Salivary melatonin as a circadian phase marker: Validation and comparison to plasma melatonin. *Journal of Biological Rhythms, 12*(5), 457-466.

Waterhouse, J. (1999). Jet-lag and shift work: (1) Circadian rhythms. *Journal of the Royal Society of Medicine, 92*, 398-401.

Waterhouse, J., Reilly, T., Atkinson, G., & Edwards, B. (2007). Jet lag: Trends and coping strategies. *Lancet, 369*, 1117-1129.

Wehr, T. A. (1991). The durations of human melatonin secretion and sleep respond to changes in daylength (photoperiod). *The Journal of Clinical Endocrinology & Metabolism, 73*(6), 1276-1280.

Whitmire, A. M., Leveton, L. B., Barger, L., Brainard, G., Dinges, D. F., Klerman, E., & Shea, C. (2009). *Risk of performance errors due to sleep loss, circadian desynchronization, fatigue, and work overload*. (NASA SP-2009-3405). Washington, DC: National Aeronautics and Space Administration.