Military health and performance optimization: a circadian strategy in response to governmental policies [version 1; peer review: awaiting peer review]

Allison Brager1, Ashlee McKeon2, Dale W. Russell3,4, Rachel R. Markwald5

1G35, Plans, Analysis, and Futures, U.S. Army John F. Kennedy Special Warfare Center and School, Fort Bragg, NC, 28310, USA
2Directorate of Psychological Application, US Army Special Operations Command, Fort Bragg, NC, 28310, USA
3US Naval Surface Force, Pacific Fleet, U.S. Navy, Coronado, CA, USA
4Department of Psychiatry, Uniformed Services University of the Health Sciences, Bethesda, MD, USA
5Warfighter Performance Department, Naval Health Research Center, San Diego, CA, USA

Abstract
In 2017, USS Fitzgerald and USS John S. McCain, both guided-missile destroyers, experienced underway collisions that resulted in the deaths of 17 Sailors and degradation of national defense as two warships were removed from the frontline. This incident garnered Congress' attention leading to numerous fatigue management policies and working groups instituted at various levels across the Department of Defense. One policy of the Department of the Navy (3120.2A; Dec 11, 2020) specifically addressed risk mitigation factors for maritime operations occurring in the overnight and early morning hours around the circadian nadir or trough in alertness and vigilance. Despite these circadian challenges that come with mission demands of military service, there are many opportunities as outlined in the Department of Navy policy to reduce and/or eliminate the performance-related risks associated with circadian misalignment. In regard to actionable systems and processes aligned with these policies, the first step is to perform a risk assessment to identify circadian-related problems that could arise in response to conducting the military training exercise or operation. The second step is to integrate a means to monitor 24-hour physiology, mitigate performance risk through fatigue countermeasures, and/or re-align the circadian timing system of military personnel to enhance sleep, manage fatigue, and optimize performance. Most importantly, the approach is not a one size fits all. Each military operation will require unique adaption (re-alignment) to the environment and each military operation may require a unique countermeasure(s).

Keywords
caffeine, light, national security, sleep, sleep deprivation, shift work
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Scope of the problem
In the US, the Department of Defense (DoD) employees millions of personnel to support national security efforts, which often entail physically and cognitively demanding works that leads to acute and chronic physiological strain and emotional distress. Throughout the War on Terrorism (2005–2019), the incidence rates of obstructive sleep apnea (OSA) and insomnia increased from 11 to 333 and 6 to 272 (per 10,000) in active-duty service members (ADSM), respectively (Moore et al., 2021). This increased incidence rate has led to the development of a military-specific sleep questionnaire aimed to assess factors precipitating sleep disturbances in military personnel for use in medical treatment facilities (Mysliwiec et al., 2021). Ultimately, increased incidence rates of sleep disturbances and sleep disorders threaten our national security interests and mission accomplishment. Insufficient and non-restorative sleep directly compromise military performance, impacting most if not all aspects of physical training, cognitive performance (including decision-making and risk assessment), and interpersonal communication (reviewed in Good et al., 2020).

As a result of these safety-related incidents, numerous fatigue management policies and working groups have been instituted at various levels throughout the Department of Defense has developed to include the recent CNSF policy (Department of the Navy, 2020) which the authors of this paper have supported. U.S. Congressionally appropriated research and development initiatives now center on fatigue management and target military operations occurring during the circadian nadir (Mantua et al., 2020; Brown et al., 2020; Hernández et al., 2018; Harrison et al., 2022; Chabal et al., 2022). In some cases, commanders of military units have implemented circadian-centered fatigue management policies. For example, the U.S. Army’s fleet of commercial truck drivers have restricted “twilight” driving (between sunset and sunrise) after the National Highway Traffic Safety Administration determined that accidents involving commercial trucks are highest around the circadian nadir (Brager, 2022).

Understanding the problem
The common U.S. military modus operandi is winning our nation’s wars at night, which means that high-risk night operations against enemy forces are a priority over daytime operations; for instance, the capture of Osama bin Laden by Navy SEALS in Abbottabad, Pakistan in 2011 during the circadian nadir highlights the value of this modus operandi from the vantage point of senior military leaders. Elite, special operations units such as the U.S. Army Rangers are assessed, selected, and trained to fight at night. As a result, Army Rangers are a target population for circadian studies focused on military operations (Mantua et al., 2020; Ritland et al., 2021). As part of winning our nation’s wars through night operations, readiness continues to be the “#1 priority” endorsed by the Joint Chiefs of Staff. What this means for the military components is that a soldier, sailor, marine, airman, and guardian (Space Force) must be able to switch from daytime to nighttime operations performed at an extremely high operational tempo regarding physical and cognitive load at a moment’s notice. A secondary feature of readiness is that there is limited time allotted for sufficient recovery from military operations. Thus, how do military personnel perform and recover optimally given operational constraints?

Military operations to include night operations (2200 – 0800) and continuous/sustained operations (> 24 h to weeks/months) present unique cases of acute and chronic circadian misalignment and/or disruption. For example, the U.S. Navy
maintains a forward deployed global presence that requires staffing of round the clock operations for months at a time. Sailors operate on shift work schedules that require sleeping and working at all times of the day and night in order to maintain the ship as combat ready. This chronic circadian disruption that results from nightwork and shift rotations likely contributes to the sleep deficiency widely reported by Sailors (Russell et al., 2021). While a US Navy ship or submarine is an example of an austere environment, there are many additional examples of austere environments across the US military where personnel must endure sudden changes in altitude, time zones, and climate that as a result, have multitudinous impacts on sleep quantity and quality (Mantua et al., 2019). In some studies such as at the Belgrano II Argentine Antarctic station, longitudinal assessments of circadian biomarkers of core body temperature, sleep architecture, and neurocognitive performance have been assessed (Folgueira et al., 2019). These ecological studies are important for our field because the Antarctic station revealed that the human circadian timing system can in fact adapt to extreme changes in latitude (constant darkness/constant light) and climate largely by adopting multi-phasic sleep schedules that do not impact measures of cognition. As such, there are three major themes of circadian disruption in military personnel:

i. Night operations

ii. Continuous/sustained operations

iii. Extreme environments (constant darkness/constant light)

A circadian-centered military strategy for addressing governmental policies

The U.S. defense strategy is broadly defined by “ends, ways, and means” (Miller et al., 2017). Ends are objectives (goals), ways are tactics for accomplishing ends, and means are resources provided for the ways. From the perspective of monitoring and mitigating circadian misalignment and/or fatigue experienced while operating near or at the circadian nadir, a circadian-centered military strategy can be defined as:

i. Ends (Objective) - Adjust and recover quickly from circadian challenges.

ii. Ways (Tactic) – Identify a tactic that meets all or most of the following parameters for monitoring and/or mitigating circadian disruption:

   a. The tactic has primary application for mass (unit-level) with secondary potential for inter-individual optimization.

   b. The tactic is robust and has shown proof of concept in controlled laboratory and field-based studies.

   c. The tactic can be seamlessly and effortlessly measured using emerging sensor technologies or single time point collections (e.g., blood, saliva, and sweat).

   d. The tactic has a known impact on end-point military performance in that the mission can continue with appropriate application of a countermeasure such as blue-enriched light pulsing, tactical napping, sleep banking, or psychostimulant administration.

iii. Means (Resources) – An evidence-based resource that is holistic/non-pharmacological (napping), technological (blue-enriched light protocol), and pharmacologic (caffeine/hypnotic) in nature.

Table 1 outlines examples of ends, ways, and means with examples (below) based on supporting studies. First, recent advancements in wearable technologies provide cardiorespiratory biomarkers of circadian phase. These biomarkers include temporal distributions in heart rate, respiratory rate, and skin temperature. In fact, biometrics from one commercial off-the-shelf (COTS) wearable (Oura Ring) was interfaced with dim-light melatonin onset (DLMO) data in in Navy personnel to determine overall impact of transitioning from daytime to nighttime aviation operations on circadian phase (McDonough, 2022). Second, recent evidence shows that inter-individual variability in circadian phase is predictive of PVT (psychomotor vigilance test) performance in response to sleep deprivation (Sletten et al., 2015; Bermudez et al., 2016). The PVT is the most ecological valid measure of neurocognition and has successfully been used to measure longitudinal changes in circadian phase in one of the most austere places in the world: Belgrano II Argentine research station (Folgueira et al., 2019). Third, recent technological development of non-invasive sensors to measure small metabolites predictive of circadian phase are emerging (Bhide et al., 2021). Although several small metabolites have been screened and identified to be predictive of circadian phase and metabolic status (reviewed in Chen et al., 2014),
the highest yield candidates for military use and application include cortisol and lactate as both are strongly predictive of anabolic versus catabolic processes (Cadegiani et al., 2019) and are circadian-driven (Guan and Lazar, 2021).

Conclusions and actionable way ahead: developing and integrating a risk assessment matrix during military operations
Despite an increasing understanding that circadian misalignment has acute and chronic negative consequences to health and performance, security and defense strategies will not likely change. The following assumptions must be considered when developing and deploying circadian-centered ends, ways, and means into real-time military operations:

### Table 1. Integrating gold-standard circadian-focused measures and countermeasures during military operations. The type of measure and subsequent countermeasure adopted will vary with type of military operation.

| Misalignment Problem | Measure | Countermeasure |
|----------------------|---------|---------------|
| Night Operations (Sunset - Sunrise) | Dim-Light Melatonin Onset (DLMO) | Use DLMO which is moderately feasible to collect during nighttime training operations, develop a photic phase-response curve via blue-enriched light exposure |
| | Cardiorespiratory Output via Wearables | Monitor 24 h peaks and troughs in heart rate, respiratory rate, and skin temperature prior to mission execution in order to best time time-point stimulant supplementation (i.e., caffeine dosing) |
| 24-48 h Operations | Attention/Vigilance via Psychomotor Vigilance Test | Monitor 24 h peaks and troughs in neurophysiological measures during training operations to best time continuous stimulant supplementation (i.e., caffeine dosing) |
| | Cardiorespiratory Output via Wearables | |
| >48 h Operations/Austere Environments | Cardiorespiratory, activity and sleep output via Wearable devices | Monitor 24 h peaks and troughs in physiological measures during sustained operations to develop photic (and non-photic (via 5-HT supplementation) phase response curves aligned with "peak" performance zones. |
| | Small metabolites in sweat | Monitor and manage indicators of circadian disruption such as sleep patterns in order to develop mitigation strategies such as adjustments to the watchbill organization, and use of napping strategies. |

Figure 1. Adapted from military doctrine (Department of the Army) to describe how risk is measured and assessed during military operations. Circadian-centered strategies outlined in Table 1 can be integrated to reduce, control, and avoid severe and catastrophic risk in military health and performance. This figure has been adapted from Department of the Army ATP 5-19 with permission from the Department of the Army.
The bottom line is that fatigue is inevitable. It is a matter of balancing and calculating risks of operational performance/safety versus providing opportunities for rest/recovery outside circadian nadirs. The military routinely uses risk assessment matrices to inform decision-making. The matrices (adapted from ATP 5-19; Figure 1) measure risk through (i) frequency of occurrence; and (ii) consequences of failure. Circadian-centered strategies from Table 1 can be integrated along this matrix to mitigate risk. Ideally, the intent is to reduce risk to acceptable levels (green: performance optimization, control for performance compromises (amber) through countermeasures, and avoid catastrophe (red or blue) at all costs. Thus, it is through a circadian-centered strategy that the entire military system of health and performance can be optimized and enhanced.

Data availability
No data are associated with this article.

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