



Comprehensive Fatigue Management: Maintaining Cognitive Dominance and the Tactical Advantage in Multi-Domain Operations

1) Relevance to Warfighter: Cognitive dominance is an essential element of success for multi-domain operations (MDO). Within the MDO context, the American Soldier will need to process large amounts of information, sort through the noise, and identify and respond to threats during vulnerable periods of the normal wake-rest cycles. The Soldier's ability to maintain vigilance, creativity, and flexibility is compromised during periods of stress and fatigue. Over the past four decades, the Sleep Research Team (SRT) at the Walter Reed Army Institute of Research (WRAIR) is the world's leader in developing solutions to maintain Warfighter cognitive dominance. The American Warfighter owns the night and will continue to do so with cutting edge technology, knowledge products, and pharmacologic interventions developed at WRAIR.

1A) Incidence and Prevalence: It is well known that Soldiers consistently fail to obtain the 7+ hours of nightly sleep that is jointly recommended by the American Academy of Sleep Medicine and the Sleep Research Society (Watson, 2015). In fact, more than 62% of Soldiers average less than 6 hours of sleep per night and almost half of all service members meet the definition for a significant sleep problem (Troxel, 2015). Thus, a majority of Soldiers are chronically sleep restricted – a situation that reduces the military's competitive edge in increasingly complex and multi-faceted environments.

1B) Performance: It is well established that sleep loss reduces readiness in the operational environment. Sleep loss has its greatest effects on high-level mental tasks such as problem solving, decision making, situation awareness, and/or sustained vigilance. But lower level cognitive tasks are affected as well. For example, after a 3-day field exercise, Soldier's ability to identify and shoot the enemy decreased by 220%, errors in decision-making increased by 86%, and reaction time slowed 22% (Lieberman, 2005). Soldiers operating on 3 hours of sleep have been shown to have reduced marksmanship accuracy (McLellan, 2005). Also, in a recent study conducted by researchers from WRAIR it was found that Special Operations Command (SOCOM) Soldiers report lower morale, motivation, and higher levels of fatigue after sleep loss (Mantua, 2019). These Soldiers also had a marked reduction (from 80%-69%) in subjective ratings of both physical and mental readiness. Thus, even the most highly trained and motivated Soldiers are not immune to the decremating effects of sleep loss.

1C) Safety: Sleep loss increases rates of errors and

operational accidents. In a study examining the effects of sleep loss on safety during a deployment, it was found that 51% of reported accidents were attributable to sleep loss, and over 1/3 of Soldiers reported falling asleep on duty (LoPresti, 2016). Drivers who sleep <4 hours in the past 24 hours were 11.5 times more likely to crash their vehicle than those that slept 7+ hours (Tefft, 2016). The accident risk associated with driving after having slept for only 4-5 hours is similar to the crash risk associated with driving with a breath alcohol content (BAC) of 0.08 (the legal limit in all U.S. states); which increases to BAC 0.12-0.15 after sleeping < 4 hours. (Czeisler, 2016; Compton, 2015; Bloomberg, 2005). It should also be noted that sleep loss is costly. It has been estimated that sleep loss-related errors, accidents, inefficiencies, absenteeism and presenteeism in the U.S. workforce accounts for a \$411 billion economic loss every year (Hafner, 2016). Although similar estimates are not currently available for the DoD, it is reasonable to infer that – in addition to the costs borne by military personnel in terms of their health, safety, and well-being – the financial burden of sleep loss on the military is considerable. As one example, it has been reported that the cost of repairing the USS Fitzgerald damage following its fatigue-related mid-sea collision was \$367,000,000. Furthermore, it has been found that Soldiers in an elite training battalion who reported poor quality sleep had higher levels of job burnout than those reporting good sleep quality (Bessey, 2019). Job burnout is itself a predictor of workplace errors and accidents (Weeks, 2010). These findings, and a multitude of others, confirm what decades of science as well as common sense dictates: that sleep loss constitutes a significant threat to force readiness.

1D) Physical Health: In general, limited sleep is well documented to increase risk for musculoskeletal injury (MSKI), obesity, hypertension, diabetes, stroke, and heart attack. MSKI causes more morbidity among Army Soldiers than any other health condition (Canham-Chervak, 2018). Prevalence of injury is high, such as a 2017 finding that 56% of Soldiers were diagnosed with a new injury (U.S. Army Public Health Center, 2018). On average, there are 37 limited duty days per injury (Canham-Chervak, 2018). In 2017, MSK injuries and related conditions resulted in 2 million medical encounters and roughly 10 million limited duty days (U.S. Army Public Health Center, 2018). The risk for MSK injury increases as sleep duration decreases (Grier, 2019). In 2017, only 1 in 3 Active Duty Soldiers got the recommended 7-9 hours of sleep per night during the week (U.S. Army Public Health Center, 2018).



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If not addressed, poor sleep can result in long-term effects such as sleep disorders, chronic disease, decreased readiness, and poor Soldier retention (Shattuck, 2019). Poor sleep leads to demonstrable decreased physical performance, such as decreased likelihood of passing the Army Physical Fitness Test (APFT) in the top quartile, decreased chance of meeting aerobic and resistance training recommendations, and increased injury risk (Vanderburgh, 2008; Lentino, 2013).

1E) Behavioral Health: A study conducted with Soldiers deployed during Operation Iraqi Freedom (OIF) found that those who slept <6 hours had 11.4 times greater risk for depression, versus those sleep 6+ hours were only associated with 3.5 times greater risk for depression (Luxton, 2011). Short sleep duration is the strongest predictor of Post-Traumatic Stress Disorder (PTSD), indicating that the odds are 4.7 times higher if a Soldier had less than 6 hours of sleep. Overall, poor sleep in military populations result in decreased memory, reaction time, decision making abilities, motivation and morale (Vanderburgh, 2008; Lentino, 2013).

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2) What is WRAIR Doing About It?

2A) Lines of Effort: Maximize Human Potential and Soldier Lethality

- Military Operational Medicine Research Program (MOMRP) - Physiological Health and Performance, Q5a: Restorative Sleep for Performance and Health, BPE: Medical Aspects of Performance Optimization and Enhancement
- The Joint Program Committee-5 (JPC-5) - Fatigue Mechanisms and Countermeasures

2B) Historical Success: Substantial contributions to the body of research regarding sleep deprivation and sleep restriction began as early as 1959 with the Lapse Hypothesis of sleep deprivation, which established four features of lapses during sleep deprivation: that similar to lapses in fatigue and hypoxic conditions, as sleep loss progresses, lapse frequency and duration increases, there are strong effects from stimulus monotony, and the effect of performance varies with the properties of the task (Williams, 1959). Since the discovery of the sleepiness-induced speed/performance tradeoff (1967) and the first description of sleep inertia (1976), the grogginess you feel upon awakening, significant progress has been made to be used as a layered stand-off against fatigue-related performance impairments.

WRAIR developed the first actigraph that is now worn on the wrists of many Americans. We developed the SAFE-T model now utilized by the commercial airline industry to regulate the sleep / wake schedule for pilots and crews. WRAIR continues to be at the cutting edge now developing personalized, machine learning optimized strategies to individualize recommendations for sleep and caffeine intake. Recommendations for improving sleep in the general population are often inappropriate for military personnel in high OPTEMPO operational environments. WRAIR's SRT continues to develop and transition solutions for the unique and increasingly complex military operational environment. Recent successes since the 1980's include mathematical performance prediction modeling, field studies of sleep and performance in Soldiers, and unique head-to-head comparisons of pharmaceutical agents to determine behavioral effects / suitability for use in military operations. For example, the WRAIR SRT helped

develop and validate caffeine gum administration recommendations to provide alertness enhancement (Kamimori, 2002) and a performance prediction algorithm (2B-Alert) to be used either online (sleep.bhsai.org) or to provide individualized predictions via a smartphone application (Reifman, 2019). The WRAIR SRT is currently focused on making limited sleep opportunities more restorative (via a fieldable slow-wave sleep enhancement headband); developing pharmaceutical methods for rapidly inducing and reversing both sleep and alertness; and strategically enhancing alertness (via individualized caffeine dosing/timing recommendations and application of novel transcranial electrical stimulation signals). Solutions and products developed through our research can be employed across all domains, culminating in a comprehensive fatigue management system. The comprehensive fatigue management will be a multi-domain solution to maximize human performance and increase soldier lethality.

2C) Lab Success/Transitions: Major lab successes include: sleep banking, caffeine studies, and mathematical performance prediction modeling. Sleep banking is a phenomenon discovered by WRAIR scientists and published in 2009. It is the knowledge that extending sleep prior to a period of sleep loss reduces the rate at which alertness and performance decline during that sleep loss. It had previously been thought that extended sleep provided little to no benefit - and that the recuperative value of sleep was reduced as sleep was extended. We showed that sleep extension does have benefits, but these benefits are only apparent under the "challenge" of subsequent sleep loss which was transitioned to the FM 7-22 manual (Holistic Health and Fitness). Sleep-related guidance now indicates that sleep duration should be maximized to the greatest extent possible given extant operational constraints. Prior guidance placed a cap on the amount of sleep that should be obtained (e.g., 7-9 h).

In 2018, dose-response effects of caffeine were explored using aggregated data from several of the WRAIR studies that assessed the effects of caffeine during sleep loss. This exploration resulted in the development of guidance for the use of caffeine during military operations. This information was also transitioned to



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FM 7-22, which includes detailed suggestions for timing and dosing of caffeine during military operations. WRAIR has conducted several studies in which the relative effects and efficacy of various stimulants (e.g., modafinil, d-amphetamine, and caffeine) were compared and contrasted. Findings show that with judicious timing and dosing, caffeine is just as effective as the controlled substances. Thus, caffeine is the recommended stimulant for sustaining alertness/performance during sleep loss during military operations.

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2B-Alert application is a smartphone app that facilitates fatigue management in operational environments. It provides individualized performance predictions based on the level of sleep debt, the circadian rhythm of alertness (time of day/night) and caffeine consumption. Findings from the caffeine studies have been transitioned to provide information for the 2B-Alert algorithm. The updated algorithm now includes predictions and guidance (based on WRAIR data) on dosing and timing of caffeine administration to proactively avoid significant performance/alertness deficits during military operations involving sleep loss and/or circadian rhythm disruption. Due to further studies in which caffeine’s effects were compared to other stimulants, the decision was made to model the effects of caffeine and utilize this model to the 2B-Alert application.

Forward-looking success includes exploring the Trans-

Cranial Electrical Stimulation (TES) method for enhancing the recuperative value of sleep. This is an ongoing effort with promising preliminary results. Preliminary results suggest that it is possible to enhance the minute-by-minute recuperative value of sleep by “driving” slow wave EEG activity during sleep (e.g., it may be possible to condense 8 hours of sleep recovery into 5 hours of actual sleep). Future interventions developed will mitigate the consequences of sleep loss as well as enhance the restorative value of the sleep that is able to be obtained.

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3) Way Forward

3A) Description: Since the inception of our republic when George Washington crossed the Delaware at night, the American Warfighter has been capitalizing on the element of surprise when adversaries are asleep (both physically and cognitively). The continued development and implementation of these cutting-edge solutions for enhancing sleep and optimizing alertness will support sustained operational readiness and cognitive dominance while providing the tactical advantage on the Multi



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Domain Battlefield. As the technical capabilities of near-peer adversaries approach parity with those of the US military, victory in multi domain warfare will increasingly depend upon the superior mental acuity, resilience, and resourcefulness of the US warfighter – capabilities that are achieved, sustained, and enhanced by sleep - and capabilities that WRAIR scientists are maximizing via application of cutting-edge brain science.

3B) Product Map (Next Page):

3C) Product Map Description:

- **Soldier/Squad Fatigue Management:** Currently, the WRAIR SRT uses wearable sleep tracking to provide individualized performance prediction through an algorithm, 2B-Alert, developed with collaborators at BHSAI. In the future, the development of real-time individualized biofeedback on sleep behavior and discovery of novel physical biomarkers will allow for targeted individualized interventions for fatigue management.
- **Sleep Leadership:** Leadership plays a critical role in unit performance. Tools to help educate leaders on Warfighter fatigue management have been developed and implemented via Army training manuals and the Performance Triad. As methods to monitor and predict fatigue, such as passive digital phenotyping, continue to be developed, these informational tools will be integrated for use during training and multi-domain operations. to implement decision-making strategies and countermeasures to maximize human potential.
- **Nutritional Supplements:** Currently, caffeinated gum developed by WRAIR and partners are available in the MORE and First Strike Rations, as well as the knowledge products that teach leaders and Soldiers how to optimize caffeine intake for sustained performance. In the future, a Soldier's unique microbiome and use of trusted and novel supplements can be individualized to maximize efficiency and/or effectiveness to enhance Soldier lethality and performance.
- **Performance Enhancement:** Currently, broad untargeted sleep inducers are widely prescribed to the Warfighter for sleep dysfunction. WRAIR researchers have created a knowledge product to help guide physicians on the various pharmacological options

for sleep aid. Our lab is working on testing targeted sleep inducers that are more easily reversible and less cognitively detrimental as well as targeted wake promoters to increase alertness and maximize human potential.

- **“SMART” Cap:** Current research in our lab using non-invasive brain stimulation demonstrates promise for enhancing the recuperative value of a brief period of sleep and increasing alertness and performance during wakefulness. In the future, we will be developing and testing a ruggedized wearable “smart” cap device capable of stimulation to enhance cognition and performance during multi-domain operations.

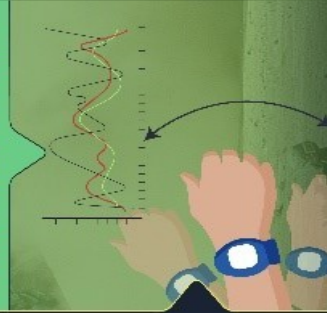
**SOLDIER / SQUAD
 FATIGUE MANAGEMENT**



SLEEP LEADERSHIP



**SLEEP TRACKING &
 PERFORMANCE PREDICTION**



**POLICY & GUIDANCE
 SLEEP BANKING**



**REAL-TIME INDIVIDUALIZED
 BIOFEEDBACK**



**MOBILE EEG &
 DIGITAL BIOMARKERS**



NOVEL PHYSICAL BIOMARKERS

**READINESS DASHBOARD
 FOR LEADERSHIP**

**NUTRITIONAL
 SUPPLEMENTS**



**PERFORMANCE
 ENHANCEMENT**



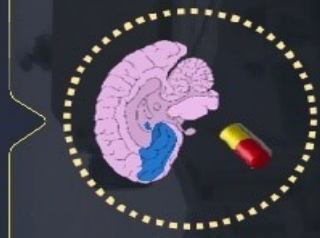
"SMART" CAP



CAFFEINE GUM



**BROAD UNTARGETED
 SLEEP INDUCERS**



**LABORATORY BRAIN
 STIMULATION**



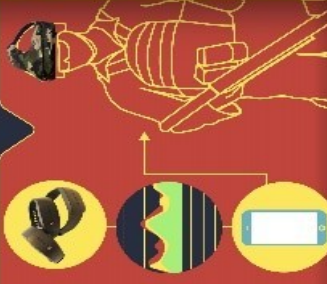
**NOVEL CAFFEINE
 DELIVERABLES**



TARGETED SLEEP INDUCERS



**RUGGEDIZED
 "SMART" CAP**



SUPPLEMENT OPTIMIZATION

TARGETED WAKE PROMOTERS

**COMPREHENSIVE FATIGUE
 MANAGEMENT SYSTEM**