Posttraumatic Stress Disorder, Traumatic Brain Injury, Sleep, and Performance in Military Personnel

Brian A. Moore, PhD[a,b,*], Matthew S. Brock, MD[c], Allison Brager, PhD[d], Jacob Collen, MD[e], Matthew LoPresti, PhD[f], Vincent Mysliwiec, MD[a]

KEYWORDS

• Posttraumatic stress disorder (PTSD) • Traumatic brain injury (TBI) • Sleep disorders • Performance • Military personnel • Veterans

KEY POINTS

- Unequivocally posttraumatic stress disorder, traumatic brain injury, and disturbed sleep negatively impact the performance of military personnel; however, the magnitude of the associated performance degradation is not fully known.
- For military leaders it is paramount to address sleep disturbances because many are amenable to therapy and improvement of sleep is critical in maintaining performance.
- The inciting trauma, temporal proximity to the trauma, and comorbid disorders impact the performance in patients with posttraumatic stress disorder.
- Performance decrements associated with traumatic brain injury are typically commensurate with the severity of the injury.
- Because posttraumatic stress disorder, traumatic brain injury, and sleep disturbances are frequently comorbid, studies must evaluate the presence or absence of these disorders to determine how each disorder individually and in combination affects performance.

INTRODUCTION

Long-accepted research has shown that no act of will or ethical passion, no degree of training will preserve the ability to discriminate friend from foe, armed enemy from noncombatant, or a militarily useful target from a distraction after 96 hours of sleep deprivation.[1]

Although the need for sleep as self-care is recognized by the military, it remains at the extremes of sleep loss, as this quote highlights, whereby military leaders acknowledge performance impairments. In fact, obtaining fewer than

Disclaimer: The opinions and assertions in this article are those of the authors and do not represent those of the Department of the Air Force, Department of the Army, Department of Defense, or the U.S. Government.

[a] The University of Texas Health Science Center at San Antonio, 7550 IH 10 West, Suite 1300, San Antonio, TX 78229, USA; [b] The University of Texas at San Antonio, One UTSA Circle, San Antonio, TX 78229, USA; [c] Department of Sleep Medicine, Wilford Hall Ambulatory Surgical Center, 1100 Wilford Hall Loop Building 4554, JBSA-Lackland AFB, San Antonio, TX 78236, USA; [d] Human Performance Operations and Education Recruiting Outreach Company, United States Army Recruiting Command, Fort Knox, KY, 40121, USA; [e] Uniformed Services University of the Health Sciences, 4301 Jones Bridge Road, Bethesda, MD 20814, USA; [f] US Army Medical Research Directorate-West, Walter Reed Army Institute of Research, 9933 W. Johnson St., Joint Base Lewis-McChord, WA 98433, USA

* Corresponding author. The University of Texas at San Antonio, One UTSA Circle, San Antonio, TX 78229.
E-mail address: Mooreb6@uthscsa.edu

Sleep Med Clin 15 (2020) 87–100
https://doi.org/10.1016/j.jsmc.2019.11.004

6 hours of sleep on a regular nightly basis can negatively impact performance.[2] There is growing body of literature indicating that posttraumatic stress disorder (PTSD) and traumatic brain injury (TBI), both of which are relatively common in the active military population, can similarly impact performance. In this article, we review the literature regarding these disorders and the performance of military personnel. The concept of performance is primarily cognitive in nature, but also includes social and physical domains. Whereas the performance of military duties is impaired when these disorders are present, we describe that there is a current lack of understanding of the magnitude of the associated performance decrements. This gap is present because most performance assessments, especially in the setting of PTSD and TBI, are standardized neuropsychological tests, as opposed to the actual performance of military duties or skill relevant tasks.

POSTTRAUMATIC STRESS DISORDER

The roots of pathologic stress response syndromes can be readily identified in writings dating back thousands of years. The Assyrians, Romans, and Greeks all wrote of a disorder with no corporeal cause that would afflict their most stalwart warriors, causing them to break down into hysteria and lose their sight and the ability to speak.[3] These early descriptions provide insight into the acute complete incapacitation of a traumatized individual, whereby they had severe decrements, if not the total inability to perform their duties. In the last century, a disorder like that described in ancient cultures has been called by many names (eg, shell shock, gross stress reaction, battle stress, combat fatigue, and traumatic war neuroses). Most recently, the term posttraumatic stress disorder, or more commonly PTSD, has been used to encompass this constellation of symptoms.[4]

Although combat-related trauma and its effects on individuals have been written about for millennia, it was not until World War I that the effects of trauma exposure (psychological and physical) were systematically characterized. During the Great War, large numbers of soldiers who could no longer perform their military duties presented with symptoms of amnesia, poor concentration, headache, tinnitus, dizziness, and difficulty sleeping. Physicians noted that the symptoms manifested in a similar manner to soldiers presenting with cerebral injury and dubbed this "shell shock."[5] This disorder was poorly understood because exposure to traumatic events, lack of sleep, and physical injury were all potential reasons for a soldier's incapacitation. Shell shock was a contentious diagnosis, especially in the absence of physical injury, and eventually became stigmatized.[6,7] Currently, it is recognized that mental disorders, to include PTSD, "are usually associated with significant distress or disability in social, occupational, or other important activities."[4] Thus, the stigma associated with what is now known as PTSD may have developed in part because afflicted soldiers were viewed as incapable of performing their duties.[8] Although our current understanding of disorders akin to shell shock (eg, PTSD and/or TBI) has substantially advanced since the initial characterizations, there is a limited understanding of the acute and chronic effects of PTSD and TBI on a soldier's ability to perform their military duties.

MILITARY TRAINING, STRESS, AND PERFORMANCE

Combat operations expose military personnel to many stressors that result in combat stress. Some military personnel respond to combat stress with an unprecedented ability for heroism and duty performance[9]; conversely, others become incapacitated and unfit for combat.[10] Although combat stress is not a diagnosis of PTSD, it is for many the precursor to this disorder with 10% to 20% of soldiers developing PTSD.[11,12] Although objective assessments of performance in actual combat operations are not available, there are studies that evaluated active duty military personnel in a number of stressful situations, including simulated prisoner of war camps,[13] survival school,[14] combat diving school, Army Rangers, and Navy Seals.[15] The findings of these studies reported that the stressful training environment, as well as symptoms of dissociation, were negatively associated with the performance of military relevant skills. The authors reported that military personnel received "little sleep,"[13] and in 1 study that the Rangers obtained 3 hours of sleep in 72 hours and 1 hour of sleep in 73 hours for the Navy Seals.[15] Near-complete lack of sleep is frequently present in combat operations. How this major factor, sleep deprivation before military or combat operations, degrades performance and/or contributes in and of itself to combat stress and increased risk of accidents and PTSD/TBI, is truly unknown but of primary importance, specifically because obtaining sleep is a defined target that can be obtained as opposed to avoiding trauma or casualties.

POSTTRAUMATIC STRESS DISORDER AND PERFORMANCE

In general, patients with PTSD report cognitive difficulties, especially attending to and recalling

information.[16,17] Some memory impairments are postulated to be PTSD specific,[18] with 36% of patients with PTSD reporting some level of impaired explicit recall.[17] Conversely, these same patients often report vivid recall of prior traumatic experiences as well as trauma-related nightmares.[19] In assessing the literature regarding PTSD and performance, which includes civilian as well as veteran populations, there are variations in terms of the timing of the assessments, which has ranged from a real-time performance assessments after a stressful training exercise to formal neuropsychological testing conducted days to decades after the inciting traumatic experience; the specific tests used to evaluate performance[20,21]; and the diagnostic criteria for PTSD, which has changed since its initial presentation in the third edition of the *Diagnostic and Statistical Manual of Mental Disorders*,[22] to the current criteria in the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders*.[4] Despite the noted variances, the evidence supports that individuals with PTSD have neurocognitive deficits in overall executive functioning and verbal memory,[23] although the deficits may be subtle and vary among the population studied.[24]

In an early study assessing the cognitive performance of Vietnam Veterans with chronic PTSD, compared with those with anxiety alone and a control group with no underlying behavioral health disorder, comprehensive neuropsychological testing including the Wechsler Adult Intelligence Scale-Revised Block Design subtest, the California Verbal Learning Test, the Rey-Osterrieth Complex Figure Drawing Test, and the Paced Auditory Serial Addition Test found no significant differences in performance.[21] Similarly, LeBlanc and colleagues[25] examined the impact(s) of prior traumatic experiences and ongoing stress-related symptoms on performance in an adaptive simulated stressful training exercise in a cohort of police recruits. They found police recruits with high levels of trauma symptoms did not exhibit impairments in judgment, communication, or situational control compared with those with little to no trauma symptoms.[25]

Conversely, Esterman and colleagues[26] examined 123 veterans and found those with PTSD (most of whom had comorbid sleep disturbances) demonstrated reductions in sustained attention. Similarly, Brandes and colleagues[20] evaluated the acute effects on performance in trauma survivors (n = 48) and found that relative to patients with low levels of PTSD symptoms, those with higher levels had impaired attention and immediate recall for figural information as well as lower IQ scores. When the high PTSD symptom group was compared with the low PTSD symptom group, controlling for depressive symptoms, no significant differences were present. The authors of this study concluded that a lower IQ and impaired attention were associated with both PTSD and depressive symptoms.[20] This assertion is not unique; other investigators have reported PTSD to be correlated with lower intelligence and neuroanatomic changes to include most notably smaller hippocampal volume.[27] Interestingly, in a study that evaluated women who suffered abuse as children, there were no differences in hippocampal volume or memory.[28] These contrasting findings in terms of both neuroanatomic changes and cognitive performance may emanate from the timing of the trauma to the subsequent assessment and/or to the nature of the trauma itself (ie, combat, motor vehicle accident, sexual assault) as well as if there were other factors such as sleep deprivation present preceding the traumatic event that precipitated an individual's PTSD. Another potential reason for decreased cognitive performance in PTSD is locus coeruleus dysfunction.[29] The locus coeruleus is important in maintaining focus and dysregulation of the locus coeruleus could explain some of the cognitive deficits in PTSD.[30]

A meta-analysis evaluated 60 studies that assessed neurocognitive function in PTSD and included 1779 individuals with PTSD, 1446 trauma-exposed controls, and 895 true controls.[23] The findings of this study supported significant neurocognitive deficits in PTSD with the most pronounced in verbal learning, speed of information processing, attention/working memory, and verbal memory.[23] In this article, individuals with PTSD who were treatment seeking had more pronounced deficits. More recently, a rigorous study that controlled for comorbid TBI, depression, and substance abuse evaluated neuropsychological function in veterans with PTSD compared with individuals with combat exposure without PTSD.[31] This study found that veterans with PTSD had significantly worse speed of information processing and executive functioning; however, they had no decrements in attention or working memory, verbal/language functioning, visuoconstruction, or episodic memory. Notably, the decrease in executive functioning in this study correlated with self-reported decreased occupational performance.

Other factors that may contribute to decreased performance is that military personnel and veterans with PTSD are typically male, have had combat-related trauma, and higher levels of comorbid behavioral health issues such as depression.[32] In a relatively large study of 5353 Korean War Veterans, the comorbidity of PTSD and

depression was the most frequent diagnosis, followed by PTSD, and then depression alone.[33] Although this study did not directly evaluate performance, veterans with PTSD and depression had the lowest self-reported quality of life and life satisfaction. Additionally, patients with PTSD are at greater risk for maladaptive social functioning.[34] Maladaptive behaviors include an increased risk of substance abuse, suicide attempts, domestic violence, divorce, and homelessness.[35] These symptoms may in part emanate from the symptoms of PTSD as well as the fact that individuals with PTSD tend to have less social support and decreased family cohesion and life satisfaction.[36] Although the maladaptive behaviors, especially substance abuse, can negatively impact performance, our understanding of the impact of these behaviors on performance in PTSD is limited by a lack of standardized assessments used to assess social functioning and the subsequent impact on an individual's performance.[34]

Regarding work performance, there are some studies that have reported that individuals who suffer from PTSD are less productive, work fewer hours, and use more sick days compared with individuals without PTSD. One study assessed 325 Vietnam Veterans who received treatment for PTSD; in this study, individuals with more severe PTSD symptoms were more likely to work part time or not at all.[37,38] Thus, it would be reasonable to equate this decreased ability to work full time associated with PTSD and PTSD symptoms as a decrease in the overall performance of an individual. To date, the quantifiable impacts of PTSD (eg, cognitive, physical, socioeconomic, or task specific) on an individual's actual duty performance are insufficiently evaluated. The decrement in performance seems to vary in the acute versus chronic state of PTSD. Further, the actual performance impairment is further complicated by the frequent presence of comorbid disorders, which can further negatively impact performance.

TRAUMATIC BRAIN INJURY AND PERFORMANCE

TBIs occur after trauma that induces structural injury or physiologic disruption to normal brain functioning.[39] The standard practice and diagnostic guidelines for the management of TBI classify each by severity, namely, as mild, moderate, or severe.[40] It is worth clarifying that mild TBI, concussion, mild head trauma, and mild head injury are frequently used interchangeably.[41] For this article, we use mild TBI to address these differences in terminology. The most frequently diagnosed severity of TBI is mild TBI, followed by moderate and severe TBIs (82.3%, 9.7%, and 1%, respectively).[42] Individuals who experience a mild TBI frequently report acute symptoms such as dizziness, nausea, difficulties sleeping, reduced attention, amnesia, or headache,[42,43] as well as other cognitive deficits such as memory acquisition, slowed processing speed, issues multitasking, losing train of one's thoughts, and global cognitive functioning.[41] In mild TBI, symptoms typically manifest within 24 hours after the injury[41] and resolve without medical attention in approximately 7 days.[44–51]

Recent studies report TBI to be a persistent concern for active duty military personnel.[42,52,53] This is largely due to the nature of the contemporary operating environment. Specifically, military personnel are at increased risk of exposure to a number of circumstances that may be related to TBI ,including rocket-propelled grenades, artillery, and blast exposure from improvised explosive devices. A RAND survey completed in 2008 reported data from initial waves of military personnel involved in the troop surge to Iraq in 2006 and found that nearly 20% experienced a mild TBI during deployment.[35] A separate study by Swanson and colleagues[39] reported similar rates nearly 10 years later. A more recent report by the Defense and Veterans Brain Injury Center identified 383,947 cases of TBI diagnosed in the Department of Defense since 2000.[42] Although TBI is prevalent among military personnel, approximately 10 million cases are recorded annually among the global populace, primarily owing to car accidents or sporting events.[54] As such, a large portion of the extant literature on TBI and performance is derived from sports medicine[43] with civilian patients. For this reason, the present section addresses the acute and long-term performance decrements in both civilians and military personnel.

TRAUMATIC BRAIN INJURY IMPACTS ON PERFORMANCE IN ATHLETES AND OTHER CIVILIANS

A seminal study of athletes with a history of TBI followed 79 college football players over the course of 90 days.[48] This study found that, relative to non-TBI controls, those with a mild TBI displayed higher levels of cognitive impairment and balance problems immediately after experiencing the mild TBI, but most symptoms resolved within 7 days. Specifically, mild cognitive impairments improved to baseline levels within 5 to 7 days and balance impairments resolved within 3 to 5 days.[48] In their sample, McCrea and colleagues[48] found no significant differences in functional impairments between the controls and participants with a mild

TBI at 90 days. Other studies that assessed concussed athletes at 1, 3, and 5 days after injury have shown similar findings with mild deficits in balance, concentration, working memory, immediate memory recall, and rapid visual processing after injury.[55] A meta-analysis of 21 studies evaluated the neuropsychological impact of sports-related mild TBI on athletes and found within the first 24 hours to 7 days after injury, there were decrements in delayed memory, memory acquisition, and global cognitive functioning.[45] When considering the results of 21 studies, however, Belanger and Vanderploeg[45] determined that within 7 to 10 days after the injury the overall cognitive performance of participants with a TBI did not differ from noninjured control subjects. It is important to note there is no established acute period of symptoms related to a TBI; the literature broadly discusses acute impacts of TBI as occurring within 7 days after the injury.

Chronic cognitive deficits associated with TBI are known to interfere in nearly every aspect of daily living, including work, relationships, and leisure activities.[56] These cognitive deficits contribute to impaired performance, primarily in areas such as disorganized memory encoding[57,58] and deficits in executive functioning,[57] attentional focus,[59,60] planning, and decision making.[61,62] Numerous studies have reported when post-TBI symptoms persist beyond 3 to 6 months, individuals are also more likely to develop vocational disabilities. For instance, Sinopoli and colleagues[63] recently examined a cohort of 13 individuals with a history of mild TBI at 3 and 6 months after injury. Compared with a noninjured control group, the participants with a history of mild TBI performed slower on tasks that required working memory and dual tasking. In line with this, a sample of 111 individuals with TBI showed significant deficits 1-year after injury related to executive functioning, rather than speed of processing or memory.[64] Recently, Nelson and colleagues[65] examined 1154 individuals who sustained a mild TBI and were treated at 11 separate US level I trauma centers. In all, they found that functional impairments were most severe at 2 weeks after injury, but that 53% of the study participants reported persistent functional impairments at 12 months after injury with 17% reporting work-related and social functioning difficulties.

In regard to the dynamic relationship between TBI and performance, specific considerations must be given to the severity and manifest symptoms, the environment,[66] or mode[67] by which a TBI is sustained (eg, blast related vs blunt force), and the effected neuroanatomic regions. The exact physiologic mechanisms by which TBI impacts performance are not fully elucidated; yet, it is known that TBIs frequently impact the frontal lobes and circuitry[68] and a major factor influencing the impact of TBI on performance is the severity of the injury. Moderate and severe TBIs frequently result in more severe and chronic cognitive deficits (eg, decrements in awareness, reasoning, language, visuospatial processing, and general intelligence) than mild TBI.[45]

There are a number of factors related to a mild TBI that can determine if an individual develops long-term performance decrements to include single versus multiple mild TBI, age, and acute symptomatology. In the majority of individuals, an isolated mild TBI is unlikely to cause persistent cognitive deficits.[69,70] Repeated injuries, however, pose an increased risk of long-term cognitive deficits.[71–73] In some of these studies, repeated injuries were found to have a dose–response relationship whereby more injuries resulted in greater cognitive performance deficits. Further supporting the long-term consequences of multiple mild TBIs is a meta-analysis of 21 studies that found athletes with multiple mild TBIs were nearly 8 times more likely to exhibit decreased performance in memory tasks relative to athletes who had never sustained a mild TBI.[45]

Age at time of injury has also been shown to influence the chronicity of TBI symptoms, whereby younger individuals seem to be more susceptible to long-term cognitive deficits. Lah and colleagues[74] examined 14 children who had sustained a severe TBI during childhood and found that severe TBI impacts both explicit and implicit memory, specifically in children who sustained a TBI early in life (<6 years of age). A meta-analysis of 6 studies examining time to recovery between high school and collegiate athletes with mild TBI found recovery times for cognitive impairments were roughly equal between the 2 groups (7 days vs 5 days, respectively), but that high school athletes took 2.5 times longer (15 days vs 6 days) to report feeling asymptomatic.[75] Numerous other studies have examined the impacts of mild TBI symptoms on recovery. One study of 107 high school football players with a history of mild TBI found that individuals who reported immediate feelings of dizziness were 6.3 times more likely to have a prolonged period of recovery (eg, $\geq$3 weeks).[76] In another study, McCrea and colleagues[47] examined 570 athletes with mild TBI, reporting that acute onset symptoms to include loss of consciousness and amnesia were related to a prolonged mild TBI symptomatology. Similarly, a study of 139 prisoners with a history of TBI found the severity of a sustained TBI negatively correlated with intellectual performance

such that intellectual functioning was poorer among the sample with a TBI and observed performance was commensurate with the severity of the injury.[77] In all, the preponderance of evidence in athletes and civilians shows mild TBI results in acute impaired cognitive performance[45] as well as neurologic symptoms, which could impair performance in the majority of individuals.

TRAUMATIC BRAIN INJURY IMPACTS ON PERFORMANCE IN THE MILITARY

The impact of TBI on the performance of military duties is not as well understood as the acute neurocognitive deficits in civilians. A recently completed systematic review of 31 military-related TBI studies reported inconsistent findings surrounding long-term impacts of TBI, frequent methodologic shortcomings, and substantial variation in measurement approaches among the reviewed studies.[78] Numerous studies have indicated a key limitation to interpreting the impacts of TBI in military personnel is the confounding factor of behavioral health concerns.[78–83] For instance, between 33% and 65% of veterans with TBI also report PTSD symptoms.[84–87] A separate systematic review of 13 articles identified only 3 that were deemed to be at low risk of bias[88] and acceptable for analysis. This study found that military personnel with mild TBI frequently have PTSD symptoms. It also concluded that although there was a slight decrease in neurocognitive performance in patients with mild TBI, it was within the realm of normal cognition. Conversely, Boyle and colleagues[88] identified only limited evidence supporting the supposition that behavioral health issues impact recovery and prognosis after mild TBI.

A seminal study conducted by Luethcke and colleagues[89] examined 82 forward-deployed military personnel who met criteria for a mild TBI (n = 42 non–blast-related injury and n = 40 blast-related injury) within 72 hours. Using computerized neurocognitive testing, clinical interviews, and a battery of subjective measures, they found the groups did not significantly differ in terms of alterations in consciousness, somatic symptoms, concentration impairment, or sleep disturbances.[89] However, immediately after the injury, postural stability was impacted more in the nonblast cohort, whereas hearing deficiencies were more frequent in the blast group.[89] Although they did not find significant differences between the groups in cognitive performance on the Automated Neuropsychological Assessment Metrics subtests, test performance inversely correlated with duration of loss of consciousness. Interestingly, Luethcke and colleagues[89] also did not note any differences in PTSD or insomnia symptoms, or psychological symptoms between the 2 groups. This finding may have been related to the temporal proximity of the comprehensive evaluation as opposed to nearly all other studies, which performed the evaluation months to years after the initial injury.

The literature has shown that, regardless of etiology, acute symptoms of psychological distress related to combat may cause higher rates of perceived cognitive dysfunction than is solely due to a mild TBI.[78,90] Specifically, Brickell and colleagues[90] examined 101 military personnel with a history of TBI and found long-term neurocognitive performance to be unrelated to postinjury levels of executive function. Rather, they asserted that subjective symptoms of executive dysfunction were more strongly related to psychological distress than objective observations.[90] A larger study by Mortera and colleagues[91] found 236 veterans with a history of TBI had high pain levels, irritability, sleep disturbances, forgetfulness, and headaches. Additionally, nearly 40% of this sample reported poor performance in the domain of productivity. The authors attributed this finding to high rates of comorbid depression.[91] Another study compared groups of military personnel who were within 6 months of having a TBI (mild TBI, n = 41; moderate TBI, n = 42) and found no significant differences between groups on measures of neurocognitive functioning.[92] Lange and colleagues[92] reported that military personnel with an uncomplicated mild TBI had significantly higher levels of anxiety and aggression than military personnel who experienced a complicated mild TBI. Similarly, a series of studies examined 249 veterans with a history of TBI. In this study the veterans who rated their TBI sequelae as very severe were more likely to put forth suboptimal efforts on objective testing.[93] In total, these findings further substantiate the impact of both diagnosed and undiagnosed behavioral health disorders on the combined performance decrements in military personnel and veterans.

Studies of military personnel have also reported findings similar to those found in the civilian literature. For instance, numerous cases of military personnel with repeated head injuries have shown advanced instances of chronic traumatic encephalopathy.[94–96] Clinically, chronic traumatic encephalopathy is recognized as a progressive neurodegenerative disease[97] that presents with behavioral changes, executive dysfunction, memory loss, and cognitive impairments.[98] There is a series of case studies involving 5 military personnel who experienced multiple concussions.

This study found evidence of early-onset chronic traumatic encephalopathy as well as PTSD in the service members.[98] Because some TBIs can result in long-term neurologic concerns, it is unsurprising that the systematic review by O'Neil and colleagues[78] found approximately 20% of veterans with a history of TBI reported issues integrating into the civilian workforce. Other studies have reported long-term impairments in the social domain to include developing friendships as well as decreased satisfaction with and quality of life.[99,100] However, not all research supports long-term sequelae related to TBI. A study of 907 soldiers with a TBI by Terrio and colleagues[101] found that symptoms related to TBI, primarily headaches and dizziness, subsided over time with no long-term decrements in performance.

One of the challenges in assessing the impact of TBI on performance is a lack of validity in standardized approaches[102] or consensus on how the assessment of TBI should be performed. A common method is focusing on symptom-based outcomes such as the resolution of postconcussion syndrome.[103] This approach is limited because TBI symptoms are primarily subjective and many are nonspecific and can occur with medical and behavioral medicine disorders.[104] Other TBI research has looked at the structural impact of acute and chronic TBI using sophisticated neuroimaging techniques.[105] Although useful, functional neuroimaging gives little information about performance, remains largely exploratory, and therefore is not practical for all patients with TBI. Questionnaires and neuropsychological testing are commonly used to assess individuals after TBI, but even these do not necessarily translate into a performance assessment that can determine the patient's ability to perform at work, on the field, or on the battlefield. A standardized assessment of performance after injury at set time points is needed to aid in prognostication after TBI as well as the development of outcomes-based prevention and treatment strategies.

SLEEP AND PERFORMANCE

It is widely accepted that initial military training, even at elite military academies,[106,107] is characterized by highly demanding physical and academic training loads in the setting of insufficient sleep. Beyond initial entry training, 2 large-scale studies found that 72% and 69% of military personnel report sleeping fewer than 6 hours per night,[108,109] with the number of combat exposures and combat-related injuries being strong predictors of even shorter sleep duration, that is, less than 5 hours per night. In the most recent population-based survey of sleep collected during Operation Enduring Freedom, 57% of 6118 military personnel reported highly disrupted sleep with the severity dependent on mission type (eg, day vs night operations) and number of deployments.[110] Thus, insufficient and disrupted sleep is normative and pervasive across a service member's career.

Military personnel have nonstandard shift work schedules, routinely participate in sustained operations that are more than 24 hours in duration, distributed operations greater than 12 hours in duration across several days or weeks, and work in austere environments. These occupational requirements manifest in total sleep deprivation (TSD), chronic sleep restriction (CSR), misaligned internal sleep/wake rhythms with environmental rhythms (ie, circadian misalignment), and sleep fragmentation.[111] Further, the consolidated and restorative sleep that is required to perform optimally in physically and mentally demanding military operations is rarely achieved. Thus, despite austere environmental conditions and suboptimal sleeping conditions, the high physiologic drive to sleep owing to acute and chronic insufficient sleep is one of many reasons military personnel are stereotyped for being able to sleep at any given opportunity.

There is a rich body of evidence showing direct change, largely decline, in psychophysiologic performance with sleep loss. The rate of decline in performance with sleep loss and return of performance to baseline levels varies with TSD (sustained operations) and CSR (distributed operations) for both simple (ie, reaction time) and complex (ie, creativity) cognitive domains.[112] For example, although tasks requiring vigilance and mathematical addition and subtraction show a dose–response curve in decline with consecutive hours of sleep lost under TSD, performance can recover to baseline levels within a single night of adequate recovery sleep.[113,114] Regarding cognitive performance under CSR, although there are dose–response deficits in performance for every night of insufficient sleep (<5 hours sleep per night), it is rare that performance recovers to baseline levels within a single night of adequate recovery sleep. In some cases, and depending on the nature of sleep loss, recovery in performance can extend for more than 7 days.[113,115] Further, recent brain imaging studies have shown via beta-amyloid deposition in the brain that neurophysiologic health minimally recovers after sleep loss, both for TSD and CSR.[116] The studies of TSD and CSR conducted in military science laboratories have additionally discovered that the rate

of cognitive decline under TSD and CSR is trait dependent, with select individuals showing more stable performance (relative to baseline levels) under sleep loss (ie, termed resilient) compared with select individuals showing immediate and continual decline under sleep loss (ie, termed sensitive).[117,118]

Sleep fragmentation and subsequent sleep inertia (delayed transition from a state of sleep to high levels of alertness owing to environmental disruption) are also cause for concern for military performance. A recent study determined that higher-order performance decreases quickly and recovers slowly during episodically brief interruptions of deep (restorative) sleep, similar to episodically short total sleep durations.[119] Further, sleep inertia experienced in the middle of a nighttime sleep episode results in cognitive decline comparable to 24-hour TSD, reaching a zenith when the biological drive to sleep in the early morning hours is greatest.[120,121] Because sleep inertia is an operationally significant issue, military researchers evaluated the impact of caffeine gum to ameliorate this condition.[122] Interestingly, 100 mg of caffeine gum was found to decrease sleep inertia's effects at both 0100 and 0600 in otherwise healthy individuals.

The extrapolation of testing and evaluating psychophysiologic domains of military performance in military sciences laboratories to actual, operational performance is complex. First, psychophysiologic decline during combat operations is largely confounded by environmental stressors of heat, dehydration, and malnourishment.[123] However, not even a high-energy diet can protect against psychophysiologic decline after more than 3 days of CSR,[124] indicating that a loss of combat effectiveness is inevitable with sleep loss. In fact, 2 separate studies of combat effectiveness measured against objectively reported sleep time in a previous (Gulf War) and current (Afghanistan) military conflict found that performance degraded by 15% to 25% for every nighttime sleep duration of less than 7 hours per night. Nighttime sleep durations of less than 4 hours resulted in total combat effectiveness of 15%.[125,126] Increases in mistakes and decreased mental acuity in high-risk military environments (eg, crewmen in a nuclear reactor department) have also been reported.[127] Another important aspect of military operations is moral reasoning. In a simulated training environment where officer candidates obtained 2.5 hours of sleep per 24 hours over days, they had substantially impaired ability to conduct mature and principally oriented moral reasoning.[128] Thus, the ramifications of sleep loss on the performance of military personnel are substantial and inversely correlated with total sleep time.

To dissect how psychophysiologic attributes at the individual level contribute to a loss of combat effectiveness at the group level under sleep loss (both TSD and CSR), most of the data, particularly for CSR studies, derive from military-relevant rather than military populations: athletes, healthcare professionals, and law enforcement. However, several parallels can be drawn from the tactical responsibilities of military personnel and sport-specific and occupational-specific schedules and psychophysiologic demands of these military-relevant populations. Each profession requires high degrees of vigilance, decision making, and emotional valence for cognitive domains and endurance, power, hand–eye coordination, and agility for physical domains. Similar to military personnel, the number of self-reported sleep complaints reaching a clinical threshold and requiring follow-up sleep consultation is indeed pervasive in collegiate athletes; reaching as high as 66% (Burke TM, Maguire K, Skeiky L, et al. Characterizing Sleep and Chronobiology in College Football Athletes. J Strength Cond Res. [Under review]).[129] Although TSD is less common for athletes, CSR in athletes is associated with more than sports-related injuries,[130] leading to reductions in cardiorespiratory capacities,[131] anaerobic power,[132] poor choice reaction time,[133] and increased confusion.[134]

There are a few studies of TSD in military populations that show the salient impact on broad domains of psychophysiologic performance. In general, the impact of TSD on the cognitive versus physical performance attributes of sustained operations, such as cardiovascular strain and tasks of divided attention, are not mutually exclusive.[135] The impact of sleep loss can be lessened to an extent through pre-exercise napping[136] of varying durations.[137] Further, the amount of cardiovascular strain during sustained endurance operations (ie, >96-hour ultra-endurance race) can modulate the degree of cognitive processing.[138] Even if cognitive performance is decreased under sleep loss, cognitive performance can still be optimized in these extreme environments by means of maintaining less than 50% maximal cardiovascular output. In a study evaluating marksmanship (a core military skill) increasing cognitive load while having restricted sleep periods further worsened performance.[139] From these studies, it is apparent that not only decreased sleep periods but also the physical and cognitive loads can synergistically decrease performance.

When delineating the impact of TSD on physical performance attributes of sustained operations,

the impact is readily apparent. Studies in military personnel have reported significant declines in submaximal performance,[140] increased latency to neuromuscular fatigue, and loss of power as well as anthropometric changes with greater than 24 hours of continuous sleep loss.[141] Interestingly, the rate of decline in the speed of individual cognitive processing during sustained military operations has been reported to be more robust, showing minimal to modest declines with 36 to 72 hours of (survival) training, respectively.[142,143] However, one remarkable observation is that in both of these studies, the modest (rather than rapid decline) in cognitive processing did not return to optimal/baseline levels after military training,[142,143] pointing once again to the operational significance of adequate sleep.

SUMMARY

Sleep disturbances, PTSD, and TBI are all highly prevalent in military personnel and veterans. These conditions often overlap, are interrelated, and result in impaired performance. Insufficient sleep leads to nearly immediate and pervasive increases in physiologic and psychological stress, brain inflammation, and cortisol over-reactivity. Collectively, these physiologic and psychological states can contribute to comorbidities with PTSD and TBI owing to decreased resiliency and neuroprotection. From a performance standpoint, appropriate levels of sleep may serve to mitigate risk and maintain performance in military personnel. For years, the prevailing culture in the military favored sleep deprivation as a means of demonstrating mental and physical toughness.[107] Currently, the military is in a position to change cultural attitudes about sleep. As with their civilian counterparts, military leaders are becoming increasingly aware of the impact of sleep loss and sleep disorders on the health, safety, and performance of service members. In recent years, military branches have published doctrine on sleep and well-being, such as *The Leader's Guide to Soldier Health and Fitness* developed by the Office of the Army Surgeon General (ATP 6–22.5) that must be adopted by senior leadership while engaging in training and mission planning. Additional measures facilitating this culture shift include the development of a comprehensive, individualized sleep and alertness management system to optimize performance after sleep loss as well as the inclusion of sleep with exercise and nutrition in the US Army's Performance Triad public health campaign.[111,144]

Ensuring adequate, quality sleep in military personnel is paramount for the health and safety of service members and the success of routine and sustained operations both stateside and abroad. An understanding of how military-specific stressors contribute to the development of disturbed sleep and sleep disorders is required to develop novel individualized, effective strategies to combat poor sleep in this critical population. Further research on the relationship between disturbed sleep, PTSD, and TBI and their impact on the performance of military personnel, especially their ability to adequately perform their duties, is required.

DISCLOSURE

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

1. Shay J. Ethical standing for commander self-care: the need for sleep. Parameters 1998;28(2):93–105.
2. Alhola P, Polo-Kantola P. Sleep deprivation: impact on cognitive performance. Neuropsychiatr Dis Treat 2007;3(5):553–67.
3. Abdul-hamid WK, Hughes JH. Nothing new under the sun: post-traumatic stress disorders in the ancient world. Early Sci Med 2014;19(6):549–57.
4. Diagnostic and statistical manual of mental disorders: DSM-5. Arlington (VA): American Psychiatric Association; 2013.
5. Turner WA. Cases of nervous and mental shock observed in the base hospitals in France. J R Army Med Corps 1915;24:343–52.
6. Jones E, Fear NT, Wessely S. Shell shock and mild traumatic brain injury: a historical review. Am J Psychiatry 2007;164(11):1641–5.
7. Crocq MA, Crocq L. From shell shock and war neurosis to posttraumatic stress disorder: a history of psychotraumatology. Dialogues Clin Neurosci 2000;2(1):47–55.
8. Riggs DS, Mallonee S. Barriers to care for the complex presentation of Post-traumatic Stress Disorder and other post-combat psychological injuries. Handbook of Military Psychology. Springer International Publishing; 2017.
9. Bonanno GA. Loss, trauma, and human resilience: have we underestimated the human capacity to thrive after extremely aversive events? Am Psychol 2004;59(1):20–8.
10. Moore BA, Mason ST, Crow BE. Assessment and management of acute combat stress on the battlefield. In: Kennedy CH, Zillmer E, editors. Military psychology: clinical and operational applications. Guilford Press; 2012. p. 73–92.
11. Hoge CW, Riviere LA, Wilk JE, et al. The prevalence of post-traumatic stress disorder (PTSD) in US

combat soldiers: a head-to-head comparison of DSM-5 versus DSM-IV-TR symptom criteria with the PTSD checklist. Lancet Psychiatry 2014;1(4): 269–77.
12. Kok BC, Herrell RK, Thomas JL, et al. Posttraumatic stress disorder associated with combat service in Iraq or Afghanistan: reconciling prevalence differences between studies. J Nerv Ment Dis 2012;200(5):444–50.
13. Eid J, Morgan CA. Dissociation, hardiness, and performance in military cadets participating in survival training. Mil Med 2006;171(5):436–42.
14. Morgan CA, Doran A, Steffian G, et al. Stress-induced deficits in working memory and visuoconstructive abilities in Special Operations soldiers. Biol Psychiatry 2006;60(7):722–9.
15. Lieberman HR, Bathalon GP, Falco CM, et al. The fog of war: decrements in cognitive performance and mood associated with combat-like stress. Aviat Space Environ Med 2005;76(7 Suppl):C7–14.
16. McNally RJ, Frueh BC. Why are Iraq and Afghanistan War Veterans seeking PTSD disability compensation at unprecedented rates? J Anxiety Disord 2013;27(5):520–6.
17. Hart J, Kimbrell T, Fauver P, et al. Cognitive dysfunctions associated with PTSD: evidence from World War II prisoners of war. J Neuropsychiatry Clin Neurosci 2008;20(3):309–16.
18. Danckwerts A, Leathem J. Questioning the link between PTSD and cognitive dysfunction. Neuropsychol Rev 2003;13(4):221–35.
19. Wolfe J, Schlesinger LK. Performance of PTSD patients on standard tests of memory. Implications for trauma. Ann N Y Acad Sci 1997;821:208–18.
20. Brandes D, Ben-schachar G, Gilboa A, et al. PTSD symptoms and cognitive performance in recent trauma survivors. Psychiatry Res 2002;110(3): 231–8.
21. Zalewski C, Thompson W, Gottesman I. Comparison of neuropsychological test performance in PTSD, generalized anxiety disorder, and control Vietnam veterans. Assessment 1994;1(2): 133–42.
22. The diagnostic and statistical manual of mental disorders. 3rd edition. Washington, DC: American Psychiatric Association; 1980.
23. Scott JC, Matt GE, Wrocklage KM, et al. A quantitative meta-analysis of neurocognitive functioning in posttraumatic stress disorder. Psychol Bull 2015;141(1):105–40.
24. Newman J, Marmar C. Executive function in posttraumatic stress disorder. In: Executive functions in health and disease, 20. Academic Press; 2017. p. 487–524.
25. Leblanc VR, Regehr C, Jelley RB, et al. Does posttraumatic stress disorder (PTSD) affect performance? J Nerv Ment Dis 2007;195(8):701–4.
26. Esterman M, Fortenbaugh FC, Pierce ME, et al. Trauma-related psychiatric and behavioral conditions are uniquely associated with sustained attention dysfunction. Neuropsychology 2019;33(5): 711–24.
27. O'Doherty DC, Chitty KM, Saddiqui S, et al. A systematic review and meta-analysis of magnetic resonance imaging measurement of structural volumes in posttraumatic stress disorder. Psychiatry Res 2015;232(1):1–33.
28. Pederson CL, Maurer SH, Kaminski PL, et al. Hippocampal volume and memory performance in a community-based sample of women with posttraumatic stress disorder secondary to child abuse. J Trauma Stress 2004;17(1):37–40.
29. Pietrzak RH, Gallezot JD, Ding YS, et al. Association of posttraumatic stress disorder with reduced in vivo norepinephrine transporter availability in the locus coeruleus. JAMA Psychiatry 2013; 70(11):1199–205.
30. Aston-Jones G, Rajkowski J, Cohen J. Role of locus coeruleus in attention and behavioral flexibility. Biol Psychiatry 1999;46(9):1309–20.
31. Wrocklage KM, Schweinsburg BC, Krystal JH, et al. Neuropsychological functioning in veterans with posttraumatic stress disorder: associations with performance validity, comorbidities, and functional outcomes. J Int Neuropsychol Soc 2016; 22(4):399–411.
32. Polak AR, Witteveen AB, Reitsma JB, et al. The role of executive function in posttraumatic stress disorder: a systematic review. J Affect Disord 2012; 141(1):11–21.
33. Ikin JF, Creamer MC, Sim MR, et al. Comorbidity of PTSD and depression in Korean War Veterans: prevalence, predictors, and impairment. J Affect Disord 2010;125(1–3):279–86.
34. Frueh BC, Turner SM, Beidel DC, et al. Assessment of social functioning in combat Veterans with PTSD. Aggress Violent Behav 2001;6(1):79–90.
35. Tanielian T, Jaycox LH. Invisible wounds of war psychological and cognitive injuries, their consequences, and services to assist recovery: summary. Santa Monica, (CA): RAND Corporation; 2008.
36. Tsai J, Harpaz-rotem I, Pietrzak RH, et al. The role of coping, resilience, and social support in mediating the relation between PTSD and social functioning in Veterans returning from Iraq and Afghanistan. Psychiatry 2012;75(2):135–49.
37. Smith MW, Schnurr PP, Rosenheck RA. Employment outcomes and PTSD symptom severity. Ment Health Serv Res 2005;7(2):89–101.
38. Stergiopoulos E, Cimo A, Cheng C, et al. Interventions to improve work outcomes in work-related PTSD: a systematic review. BMC Public Health 2011;11:838.

39. Swanson TM, Isaacson BM, Cyborski CM, et al. Traumatic brain injury incidence, clinical overview, and policies in the US Military Health System since 2000. Public Health Rep 2017;132(2):251–9.
40. Management of Concussion/mTBI Working Group. VA/DoD clinical practice guideline for management of concussion/mild traumatic brain injury. J Rehabil Res Dev 2009;46(6):CP1-68.
41. Prince C, Bruhns ME. Evaluation and treatment of mild traumatic brain injury: the role of neuropsychology. Brain Sci 2017;7(8).
42. Defense and Veterans Brain Injury Center (DVBIC). DoD worldwide numbers for TBI. Website. Available at: https://dvbic.dcoe.mil/system/files/tbi-numbers/worldwide-totals-2000-2018Q1-total_jun-21-2018_v1.0_2018-07-26_0.pdf. Accessed August 5, 2019.
43. Ling H, Hardy J, Zetterberg H. Neurological consequences of traumatic brain injuries in sports. Mol Cell Neurosci 2015;66(Part B):114–22.
44. Carroll LJ, Cassidy JD, Peloso PM, et al. Prognosis for mild traumatic brain injury: results of the who collaborating centre task force on mild traumatic brain injury. J Rehabil Med 2004;36(Supplement 43):84–105.
45. Belanger H, Vanderploeg R. The neuropsychological impact of sports-related concussion: a meta-analysis. J Int Neuropsychol Soc 2005;11(4): 345–57.
46. Hoge CW, McGurk D, Thomas JL, et al. Mild traumatic brain injury in US soldiers returning from Iraq. N Engl J Med 2008;358(5):453–63.
47. McCrea M, Guskiewicz K, Randolph C, et al. Incidence, clinical course, and predictors of prolonged recovery time following sport-related concussion in high school and college athletes. J Int Neuropsychol Soc 2013;19(1):22–33.
48. McCrea M, Guskiewicz KM, Marshall SW, et al. Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study. JAMA 2003;290(19):2556–63.
49. Lee YM, Odom MJ, Zuckerman SL, et al. Does age affect symptom recovery after sports-related concussion? A study of high school and college athletes. J Neurosurg Pediatr 2013; 12(6):537–44.
50. Erlanger D, Kaushik T, Cantu R, et al. Symptom-based assessment of the severity of a concussion. J Neurosurg 2003;98(3):477–84.
51. Zuckerman SL, Kuhn A, Dewan MC, et al. Structural brain injury in sports-related concussion. Neurosurg Focus 2012;33(6):E6, 1–12.
52. Institute of Medicine. Gulf war and health: volume 9: long-term effects of blast exposures. Washington, DC: The National Academies Press; 2014.
53. Okie S. Traumatic brain injury in the war zone. N Engl J Med 2005;352(20):2043–7.
54. World Health Organization. Neurological disorders: public health challenges. Geneva, Switzerland: WHO press. Available at: https://www.who.int/mental_health/neurology/neurological_disorders_report_web.pdf. Accessed July 5, 2019.
55. Guskiewicz KM, Ross SE, Marshall SW. Postural stability and neuropsychological deficits after concussion in collegiate athletes. J Athl Train 2001;36(3):263–73.
56. Rabinowitz AR, Levin HS. Cognitive sequelae of traumatic brain injury. Psychiatr Clin North Am 2014;37(1):1–11.
57. Dikmen SS, Corrigan JD, Levin HS, et al. Cognitive outcome following traumatic brain injury. J Head Trauma Rehabil 2009;24(6):430–8.
58. Levin HS, Mattis S, Ruff RM, et al. Neurobehavioral outcome following minor head injury: a three-center study. J Neurosurg 1987;66:234–43.
59. Dockree PM, Kelly SP, Roche RA, et al. Behavioural and physiological impairments of sustained attention after traumatic brain injury. Brain Res Cogn Brain Res 2004;20(3):403–14.
60. Stuss DT, Alexander MP. Executive functions and the frontal lobes: a conceptual view. Psychol Res 2000;63(3–4):289–98.
61. Malkki H. Traumatic brain injury: impaired medical decision-making capacity in TBI. Nat Rev Neurol 2016;12(10):555.
62. Sood N, Godfrey C, Anderson V, et al. Rehabilitation of executive function in pediatric traumatic brain injury (REPeaT): protocol for a randomized controlled trial for treating working memory and decision-making. BMC Pediatr 2018;18(1):362.
63. Sinopoli KJ, Chen JK, Wells G, et al. Imaging "brain strain" in youth athletes with mild traumatic brain injury during dual-task performance. J Neurotrauma 2014;31(22):1843–59.
64. Spitz G, Ponsford JL, Rudzki D, et al. Association between cognitive performance and functional outcome following traumatic brain injury: a longitudinal multilevel examination. Neuropsychology 2012;26(5):604–12.
65. Nelson LD, Temkin NR, Dikmen S, et al. Recovery after mild traumatic brain injury in patients presenting to US level I trauma centers: a transforming research and clinical knowledge in traumatic brain injury (TRACK-TBI) study. JAMA Neurol 2019; 76(9):1049–59.
66. Baldassarre M, Smith B, Harp J, et al. Exploring the relationship between mild traumatic brain injury exposure and the presence and severity of postconcussive symptoms among Veterans deployed to Iraq and Afghanistan. PM R 2015;7(8): 845–58.
67. Mendez MF, Owens EM, Reza-berenji G, et al. Mild traumatic brain injury from primary blast vs. blunt forces: post-concussion consequences and

functional neuroimaging. NeuroRehabilitation 2013;32(2):397–407.
68. Ponsford JL, Parcell DL, Sinclair KL, et al. Changes in sleep patterns following traumatic brain injury: a controlled study. Neurorehabil Neural Repair 2013; 27(7):613–21.
69. Savica R, Parisi JE, Wold LE, et al. High school football and risk of neurodegeneration: a community-based study. Mayo Clin Proc 2012;87: 335–40.
70. Janssen PH, Mandrekar J, Mielke MM, et al. High school football and late-life risk of neurodegenerative syndromes, 1956-1970. Mayo Clin Proc 2017; 92:66–71.
71. Guskiewicz KM, Marshall SW, Bailes J, et al. Association between recurrent concussion and late-life cognitive impairment in retired professional football players. Neurosurgery 2005;57:719–26.
72. Randolph C, Karantzoulis S, Guskiewicz K. Prevalence and characterization of mild cognitive impairment in retired national football league players. J Int Neuropsychol Soc 2013;19(8):873–80.
73. Manley G, Gardner AJ, Schneider KJ, et al. A systematic review of potential long-term effects of sport-related concussion. Br J Sports Med 2017;51(12):969–77.
74. Lah S, Epps A, Levick W, et al. Implicit and explicit memory outcome in children who have sustained severe traumatic brain injury: impact of age at injury (preliminary findings). Brain Inj 2011;25(1): 44–52.
75. Williams RM, Puetz TW, Giza CC, et al. Concussion recovery time among high school and collegiate athletes: a systematic review and meta-analysis. Sports Med 2015;45(6):893–903.
76. Lau BC, Kontos AP, Collins MW, et al. Which on-field signs/symptoms predict protracted recovery from sport-related concussion among high school football players? Am J Sports Med 2011;39(11): 2311–8.
77. Pitman I, Haddlesey C, Ramos SD, et al. The association between neuropsychological performance and self-reported traumatic brain injury in a sample of adult male prisoners in the UK. Neuropsychol Rehabil 2015;25(5):763–79.
78. O'Neil ME, Carlson K, Storzbach D, et al. Complications of mild traumatic brain injury in veterans and military personnel: a systematic review. Washington, DC: Department of Veterans Affairs (US); 2013.
79. Nelson NW, Hoelzle JB, Mcguire KA, et al. Neuropsychological evaluation of blast-related concussion: illustrating the challenges and complexities through OEF/OIF case studies. Brain Inj 2011; 25(5):511–25.
80. Polusny MA, Kehle SM, Nelson NW, et al. Longitudinal effects of mild TBI and PTSD comorbidity on post-deployment outcomes in National Guard soldiers deployed to Iraq. Arch Gen Psychiatry 2011;68:79–89.
81. Vanderploeg RD, Belanger HG, Horner RD, et al. Health outcomes associated with military deployment: mild traumatic brain injury, blast, trauma, and combat associations in the Florida National Guard. Arch Phys Med Rehabil 2012;93(11): 1887–95.
82. Kennedy JE, Cullen MA, Amador RR, et al. Symptoms in military service members after blast mTBI with and without associated injuries. NeuroRehabilitation 2010;26(3):191–7.
83. Uomoto JM, Williams RM, Randa LA. Neurobehavioral consequences of combat-related blast injury and polytrauma. In: Ashley Mark J, editor. Traumatic Brain Injury: Rehabilitation, Treatment, and Case Management, Third Edition. [Online]. CRC Press; 2010. p. 63–95.
84. Carlson KF, Kehle SM, Meis LA, et al. Prevalence, assessment, and treatment of mild traumatic brain injury and posttraumatic stress disorder: a systematic review of the evidence. J Head Trauma Rehabil 2011;26(2):103–15.
85. Pietrzak RH, Johnson DC, Goldstein MB, et al. Posttraumatic stress disorder mediates the relationship between mild traumatic brain injury and health and psychosocial functioning in Veterans of Operations Enduring Freedom and Iraqi Freedom. J Nerv Ment Dis 2009;197(10):748–53.
86. Cohen B, Gima K, Bertenthal D, et al. Mental health diagnoses and utilization of VA non-mental health medical services among returning Iraq and Afghanistan veterans. J Gen Intern Med 2010; 25(1):18–24.
87. Lew HL, Otis JD, Tun C, et al. Prevalence of chronic pain, posttraumatic stress disorder, and persistent postconcussive symptoms in OIF/OEF Veterans: polytrauma clinical triad. J Rehabil Res Dev 2009; 46(6):697–702.
88. Boyle E, Cancelliere C, Hartvigsen J, et al. Systematic review of prognosis after mild traumatic brain injury in the military: results of the International Collaboration on mild traumatic brain injury prognosis. Arch Phys Med Rehabil 2014;95(3 Suppl): S230–7.
89. Luethcke CA, Bryan CJ, Morrow CE, et al. Comparison of concussive symptoms, cognitive performance, and psychological symptoms between acute blast-versus nonblast-induced mild traumatic brain injury. J Int Neuropsychol Soc 2011; 17(1):36–45.
90. Brickell T, Lange R, Bhagwat A, et al. Self-reported symptoms of executive dysfunction and objective neurocognitive performance following military-related Traumatic Brain Injury. Arch Clin Neuropsychol 2013;28(6):606–7.

91. Mortera M, Kinirons S, Simantov J, et al. Patient profile: operation enduring freedom/operation Iraqi Freedom (OEF/OIF) Veterans suspected of traumatic brain injury. Brain Inj 2016;30:5–6. Taylor & Francis Inc.
92. Lange RT, Brickell TA, French LM, et al. Neuropsychological outcome from uncomplicated mild, complicated mild, and moderate traumatic brain injury in US military personnel. Arch Clin Neuropsychol 2012;27(5):480–94.
93. Spencer RJ, Waldron-Perrine B, Drag LL, et al. Neuropsychological test validity in Veterans presenting with subjective complaints of 'very severe' cognitive symptoms following mild traumatic brain injury. Brain Inj 2017;31(1):32–8.
94. Mckee AC, Stern RA, Nowinski CJ, et al. The spectrum of disease in chronic traumatic encephalopathy. Brain 2013;136(Pt 1):43–64.
95. Omalu B, Hammers JL, Bailes J, et al. Chronic traumatic encephalopathy in an Iraqi war veteran with posttraumatic stress disorder who committed suicide. Neurosurg Focus 2011; 31(5):E3.
96. Goldstein LE, Fisher AM, Tagge CA, et al. Chronic traumatic encephalopathy in blast-exposed military Veterans and a blast neurotrauma mouse model. Sci Transl Med 2012;26(4):134ra60.
97. Mckee AC, Cairns NJ, Dickson DW, et al. The first NINDS/NIBIB consensus meeting to define neuropathological criteria for the diagnosis of chronic traumatic encephalopathy. Acta Neuropathol 2016;131(1):75–86.
98. Mckee AC, Robinson ME. Military-related traumatic brain injury and neurodegeneration. Alzheimers Dement 2014;10(3 Suppl):S242–53.
99. High WMJ, Sander AM, Struchen MA, et al. Rehabilitation for traumatic brain injury. New York: Oxford University Press; 2005.
100. Crooks CY, Zumsteg JM, Bell KR. Traumatic brain injury: a review of practice management and recent advances. Phys Med Rehabil Clin N Am 2007; 18(4):681–710, vi.
101. Terrio H, Brenner LA, Ivins BJ, et al. Traumatic brain injury screening: preliminary findings in a US Army Brigade Combat Team. J Head Trauma Rehabil 2009;24(1):14–23.
102. Armistead-Jehle PC, Wesley R, Stegman RL. Performance and symptom validity testing as a function of medical board evaluation in U.S. military service members with a history of mild traumatic brain injury. Arch Clin Neuropsychol 2018;33(1): 120–4.
103. Makdissi M, Cantu RC, Johnston KM, et al. The difficult concussion patient: what is the best approach to investigation and management of persistent (>10 days) postconcussive symptoms? Br J Sports Med 2013;47(5):308–13.
104. Rao V, Syeda A, Roy D, et al. Neuropsychiatric aspects of concussion: acute and chronic sequelae. Concussion 2017;2(1):CNC29.
105. Irimia A, Chambers MC, Alger JR, et al. Comparison of acute and chronic traumatic brain injury using semi-automatic multimodal segmentation of MR volumes. J Neurotrauma 2011;28(11):2287–306.
106. Miller NL, Shattuck LG. Sleep patterns of young men and women enrolled at the United States Military Academy: results from year 1 of a 4-year longitudinal study. Sleep 2005;28(7):837–41.
107. Miller NL, Shattuck LG, Matsangas P. Longitudinal study of sleep patterns of United States Military Academy cadets. Sleep 2010;33(12):1623–31.
108. Mysliwiec V, McGraw L, Pierce R, et al. Sleep disorders and associated medical comorbidities in active duty military personnel. Sleep 2013;36(2): 167–74.
109. Luxton DD, Greenburg D, Ryan J, et al. Prevalence and impact of short sleep duration in redeployed OIF soldiers. Sleep 2011;34(9):1189–95.
110. Harrison E, Glickman G, Rose E, et al. Self-reported sleep during US navy operations and the impact of deployment-related factors. Mil Med 2017;182(3–4):189–94.
111. Capaldi VF, Balkin TJ, Mysliwiec V. Optimizing sleep in the military: challenges and opportunities. Chest 2019;155(1):215–26.
112. Balkin T, Rupp T, Picchioni D, et al. Sleep loss and sleepiness. Chest 2008;134(3):653–63.
113. Belenky G, Wesensten NJ, Thorne DR, et al. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. J Sleep Res 2003; 12(1):1–12.
114. Van dongen HP, Maislin G, Mullington JM, et al. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep 2003;26(2):117–26.
115. Dinges DF, Pack F, Williams K, et al. Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. Sleep 1997;20(4):267–77.
116. Shokri-kojori E, Wang GJ, Wiers CE, et al. β-Amyloid accumulation in the human brain after one night of sleep deprivation. Proc Natl Acad Sci U S A 2018;115(17):4483–8.
117. Van dongen HP, Baynard MD, Maislin G, et al. Systematic interindividual differences in neurobehavioral impairment from sleep loss: evidence of trait-like differential vulnerability. Sleep 2004;27(3): 423–33.
118. Rupp TL, Wesensten NJ, Balkin TJ. Trait-like vulnerability to total and partial sleep loss. Sleep 2012; 35(8):1163–72.

119. Markwald R, Bessman S, Drummond S, et al. Performance during unplanned night time awakenings and following disrupted sleep. J Sci Med Sport 2017;20:S18.
120. Balkin TJ, Badia P. Relationship between sleep inertia and sleepiness: cumulative effects of four nights of sleep disruption/restriction on performance following abrupt nocturnal awakenings. Biol Psychol 1988;27(3):245–58.
121. Scheer FA, Shea TJ, Hilton MF, et al. An endogenous circadian rhythm in sleep inertia results in greatest cognitive impairment upon awakening during the biological night. J Biol Rhythms 2008; 23(4):353–61.
122. Newman RA, Kamimori GH, Wesensten NJ, et al. Caffeine gum minimizes sleep inertia. Percept Mot Skills 2013;116(1):280–93.
123. Lieberman HR, Bathalon GP, Falco CM, et al. Severe decrements in cognition function and mood induced by sleep loss, heat, dehydration, and undernutrition during simulated combat. Biol Psychiatry 2005;57(4):422–9.
124. Rognum TO, Vartdal F, Rodahl K, et al. Physical and mental performance of soldiers on high- and low-energy diets during prolonged heavy exercise combined with sleep deprivation. Ergonomics 1986;29(7):859–67.
125. Belenky G, Penetar DM, Thorne D, et al. The effects of sleep deprivation on performance during continuous combat operations. In: Marriott BM, editor. Food Components to Enhance Performance: An Evaluation of Potential Performance-Enhancing Food Components for Operational Rations. Washington, DC: Institute of Medicine (US) Committee on Military Nutrition Research; 1994. p. 127–36.
126. LoPresti M, Anderson JA, Saboe KN, et al. The impact of insufficient sleep on combat misison performance. Mil Beh Health 2016;4:356–63.
127. Shattuck NL, Matsangas P. Operational assessment of the 5-h on/10-h off watchstanding schedule on a US Navy ship: sleep patterns, mood and psychomotor vigilance performance of crewmembers in the nuclear reactor department. Ergonomics 2016;59(5):657–64.
128. Olsen OK, Pallesen S, Eid J. The impact of partial sleep deprivation on moral reasoning in military officers. Sleep 2010;33(8):1086–90.
129. Hansen AA, Athey AB, Ross MJ, et al. Sleep and health among collegiate student-athletes. Chest 2019;156(6):1234–45.
130. Milewski MD, Skaggs DL, Bishop GA, et al. Chronic lack of sleep is associated with increased sports injuries in adolescent athletes. J Pediatr Orthop 2014;34(2):129–33.
131. Azboy O, Kaygisiz Z. Effects of sleep deprivation on cardiorespiratory functions of the runners and volleyball players during rest and exercise. Acta Physiol Hung 2009;96(1):29–36.
132. Blumert PA, Crum AJ, Ernsting M, et al. The acute effects of twenty-four hours of sleep loss on the performance of national-caliber male collegiate weightlifters. J Strength Cond Res 2007;21(4): 1146–54.
133. Taheri M, Arabameri E. The effect of sleep deprivation on choice reaction time and anaerobic power of college student athletes. Asian J Sports Med 2012;3(1):15–20.
134. Biggins M, Cahalan R, Comyns T, et al. Poor sleep is related to lower general health, increased stress and increased confusion in elite Gaelic athletes. Phys Sportsmed 2018;46(1):14–20.
135. Keramidas ME, Gadefors M, Nilsson LO, et al. Physiological and psychological determinants of whole-body endurance exercise following short-term sustained operations with partial sleep deprivation. Eur J Appl Physiol 2018;118(7):1373–84.
136. Keramidas ME, Siebenmann C, Norrbrand L, et al. A brief pre-exercise nap may alleviate physical performance impairments induced by short-term sustained operations with partial sleep deprivation - a field-based study. Chronobiol Int 2018;35(10): 1464–70.
137. Hsouna H, Boukhris O, Abdessalem R, et al. Effect of different nap opportunity durations on short-term maximal performance, attention, feelings, muscle soreness, fatigue, stress and sleep. Physiol Behav 2019;211:112673.
138. Lucas SJ, Anson JG, Palmer CD, et al. The impact of 100 hours of exercise and sleep deprivation on cognitive function and physical capacities. J Sports Sci 2009;27(7):719–28.
139. Smith CD, Cooper AD, Merullo DJ, et al. Sleep restriction and cognitive load affect performance on a simulated marksmanship task. J Sleep Res 2019;28(3):e12637.
140. Vaara JP, Oksanen H, Kyrolainen H, et al. 60 h sleep deprivation affects submaximal but not maximal physical performance. Front Physiol 2018;9:1437.
141. Nindl B, Leone C, Tharion W, et al. Physical performance responses during 72 h of military operational stress. Med Sci Sports Exerc 2002;34(11):1814–22.
142. Tomczak A, Dabrowski J, Mikulski T. Psychomotor performance of Polish air force cadets after 36 hours survival trainings. Ann Agric Environ Med 2017;24(3):387–91.
143. Tomczak A. Coordination of motor skill of military pilots subjected to survival training. J Strength Cond Res 2015;29(9):2460–4.
144. Lentino CV, Purvis DL, Murphy KJ, et al. Sleep as a component of the performance triad: the importance of sleep in a military population. US Army Med Dep J 2013;98–108.