ABSTRACT

Title of Dissertation:	THE IMPACT OF SHORT-TERM SLEEP EXTENSION ON COGNITIVE AND MOTOR PERFORMANCE IN COLLEGE TACTICAL ATHLETES
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U.S. service members are commonly referred to as “tactical athletes” because of the physical training they undergo to maintain and improve occupational performance. Because performance in the military can literally determine the outcome in ‘life and death’ situations, it is critical that tactical athletes are prepared to perform optimally, both physically and mentally. Accordingly, it is important for tactical athletes to focus on health behaviors, like sleep, known to impact both aspects of performance. Little is known about the sleep health of college tactical athletes enrolled in The Reserve Officer's Training Corps (ROTC) and there have been no well-controlled studies on the immediate and residual effects of sleep extension on executive and cognitive motor performance. To address this knowledge gap, a randomized control trial (Sleep extension versus Control) was conducted to determine the immediate and residual effects of a four-night sleep extension intervention (10 hours time in bed) in this population. Consented participants wore a wrist actigraph for fifteen nights in order to measure sleep duration and a cognitive motor battery was conducted after seven nights of habitual sleep (Day 8 – pre-test), after the four nights of sleep extension intervention (Day 12 – post-test), and after the resumption of habitual sleep for four nights (Day 16 – follow-up). Between group comparisons of mean pre- to post-test score changes and mean pre-test to follow-up score changes were performed using independent sample t-tests. Results revealed that the sleep extension group significantly increased their mean sleep duration over the intervention period and that the four nights of sleep extension resulted in immediate benefits in alertness, psychomotor vigilance/attention, executive function performance, standing broad jump performance, and motivation levels. Benefits of sleep extension on broad jump performance and motivation level were still evident four days after resumption of habitual sleep schedules. These results suggest that sleep extension enhances both cognitive and motor performance in college tactical athletes, with some performance benefits lasting days after returning to habitual sleep patterns. Considering the performance improvements noted following sleep extension, a four-night intervention should be considered for training programs aiming to enhance overall performance.

THE IMPACT OF SHORT-TERM SLEEP EXTENSION ON COGNITIVE AND MOTOR PERFORMANCE IN COLLEGE TACTICAL ATHLETES

by

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Dedication

I would like to dedicate this dissertation to all “tactical athletes” who chose their profession knowing the sacrifices and everything at stake with that decision. I would also like to dedicate this manuscript to my entire family, especially my wife (Karen), children (Brandon and Mallory), parents (Tim and Val), and siblings (Trevor and Tracy) for their unconditional love and support throughout this journey.

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Chapter 1: A Review of Literature

1.1 Public Health Significance of Sleep Duration

Chronic inadequate sleep is a significant public health concern. A consensus statement by the American Academy of Sleep Medicine (AASM) and Sleep Research Society (SRS) recommended that adults should sleep at least 7 hours per night consistently in order to promote optimal health (Watson et al., 2015). Failure to consistently sleep these amounts are associated with adverse health outcomes like weight gain, obesity, diabetes, hypertension, heart disease and stroke, depression, increased risk of death, as well as, impaired immune function, increased pain, impaired performance, increased errors, and greater risk of accidents (Cappuccio, D'Elia, Strazzullo, & Miller, 2010a, 2010b; Schmid, Hallschmid, & Schultes, 2015; Watson et al., 2015; Wolk, Gami, Garcia-Touchard, & Somers, 2005). Chronic sleep restriction has been associated with impairments in sleepiness, attention, mood, alertness, and memory (Cote, Milner, Osip, Baker, & Cuthbert, 2008; Dinges et al., 1997; Gumenyuk et al., 2011). When a person does not get the recommended amount of sleep or enough sleep for their individualized need, they are said to accumulate “sleep debt” regardless of how that sleep loss occurs (i.e. chronic sleep restriction, night-work shift work, experimental manipulation) (Van Dongen, Rogers, & Dinges, 2003).

1.2 Prevalence of Shorter Sleep Duration

Regardless of the biological need for sleep, chronic short sleep has become much more common due to professional demands, domestic responsibilities, and social/technological availability (Knutson, Van Cauter, Rathouz, DeLeire, & Lauderdale, 2010). Only about two-thirds of the general U.S. adult population report sleeping at least seven hours per night (Krueger & Friedman, 2009) even though the National Sleep Foundation recommends 7 to 9 hours of sleep per night for younger adults (ages 18 to 25) and adults (ages 26-64) (Hirshkowitz et al., 2015). Many college students are sleeping less than the recommended amounts and are characterized as poor sleepers (Lund, Reider, Whiting, & Prichard, 2010; Orzech, Salafsky, & Hamilton, 2011). In addition, collegiate athletes, elite athletes, and U.S. service members are not getting the recommended amounts of sleep (Fietze et al., 2009; Lastella, Roach, Halson, & Sargent, 2015; Leeder, Glaister, Pizzoferro, Dawson, & Pedlar, 2012; Luxton et al., 2011; Mah, Mah, Kezirian, & Dement, 2011; Mysliwiec et al., 2013; Sargent, Halson, & Roach, 2014; Schwartz & Simon, 2015). This is noteworthy because young adults and athletes may depend on longer sleep durations to perform optimally (Mah et al., 2011; Schwartz & Simon, 2015; Watson et al., 2015). In addition, a chronic lack of sleep has been associated with an increased risk of a sport injury in adolescent athletes (Milewski et al., 2014). Considering many young adults, including collegiate athletes and U.S. service members, do not consistently achieve the recommended amounts of sleep, it is imperative to understand the acute consequences of insufficient sleep on human performance (both physically and cognitively) and devise interventions to mitigate these consequences.

1.3 Sleep Restriction/Deprivation and Athletic/Motor Performance

A recent review of sleep and athletic performance outlined the effects of sleep loss (both restriction and deprivation) on exercise performance, as well as physiological and cognitive responses to exercise (Fullagar et al., 2015). The review concluded that total sleep deprivation negatively affects athletic performance on endurance tasks and repeated bouts of exercise. For example, one study found that sleep deprivation for 30 hours resulted in running less distance during a 30-minute endurance test compared to running after habitual sleep amounts, even with comparable perceptions of effort (Oliver, Costa, Laing, Bilzon, & Walsh, 2009). The evidence on the effects of partial sleep loss (sleep restriction) on athletic performance is less consistent. Partial sleep deprivation research does not consistently reveal significant impacts on single bouts of aerobic exercise and maximum strength measures (Fullagar et al., 2015). In contrast, sports-specific skill execution, submaximal strength and muscular and anaerobic power are more consistently found to decline following sleep restriction (Fullagar et al., 2015). One study found that in tennis players, reducing sleep amounts to 5 hours for one night significantly decreased serving accuracy (Reyner & Horne, 2013). Similar results have been found in dart throwing accuracy following a single night of restricted sleep compared to habitual sleep patterns (Edwards & Waterhouse, 2009). One potential reason for the discrepancy in results in partial sleep deprivation research is that many of the studies were underpowered. In addition, a recent study investigating the sleep characteristics of athletes in a national netball tournament found a strong correlation between total sleep duration and final tournament placement, with teams that slept less placing lower/worse (Juliff, Halson, Hebert, Forsyth, & Peiffer, 2018). The exact mechanism behind the effect of sleep on motor and athletic performance remains speculative. However, Fullagar et al. (2015) suggests that the cognitive consequences of sleep loss, including deficits in reaction time, fine motor movement, memory (i.e. consolidation of motor tasks) and decision-making, may be contributing factors of decreased performance in physical/sport-specific performance (Fullagar et al., 2015). Collectively, these may also be reasons why in adolescent athletes, those that habitually slept less than 8 hours are at 1.7 times greater risk of injury than those athletes who sleep 8 hours or more (Milewski et al., 2014). Considering the potential impact cognitive ability has on athletic/motor performance, it is important to understand the impact sleep has on cognitive performance.

1.4 Sleep Restriction/Deprivation and Cognitive Performance

Much of what is known about the relationship between sleep and cognitive performance is based on studies of partial or total sleep deprivation. It has been suggested that total sleep deprivation primarily impairs *attention* and *working memory,* an executive function that will be discussed in more detail later, and partial sleep deprivation (restriction) primarily impairs *attention, especially vigilance* (Alhola & Polo-Kantola, 2007). The Psychomotor Vigilance Test (PVT) (Dinges & Powell, 1985) is currently considered a "gold standard" for assessing the behavioral effects of sleep on cognition (alertness/attention/vigilance) because of its high reliability, sensitivity to circadian rhythm influences, and minimal learning effects (Dinges et al., 1997; Killgore, 2010; Van Dongen, Maislin, Mullington, & Dinges, 2003). Sleep loss consistently impairs alertness/attention/vigilance as noted in slower PVT mean reaction times, as well as the fastest 10% of responses, and increased attentional lapses (reaction times longer than 500 ms) (Lim & Dinges, 2008, 2010). Prolonged PVT reaction times (decline of alertness/attention/vigilance) associated with the build-up of homeostatic sleep pressure have been proposed as a "behavioral biomarker" of sleepiness (Balkin, 2011) and chronic sleep restriction has been shown to result in poorer PVT performance in a dose-response manner (Belenky et al., 2003; Van Dongen, Maislin, et al., 2003). Interestingly, age has been shown to moderate the effects of sleep deprivation or sleep restriction on psychomotor vigilance, with younger participant's performing worse than older participants after sleep deprivation (Duffy, Willson, Wang, & Czeisler, 2009; Stenuit & Kerkhofs, 2005). Overall, both total and partial sleep deprivation have consistently been shown to negatively impact cognitive performance, as noted above. Attention is a necessary and basic component of cognitive performance, including executive functions such as problem solving and creativity (Basner & Dinges, 2011). Consequently, it is important to understand how sleep may impact executive functions.

While executive function as a cognitive construct is not a matter of consensus and can vary depending on the research discipline, all appear to agree to the multifarious nature of executive functions (Yuan & Raz, 2014). Executive function (also called executive control or cognitive control) is a subcategory of cognitive ability and is generally defined as 'higher level cognitive processes' (Alvarez & Emory, 2006). Some core executive functions are *inhibition* [response inhibition (self-control—resisting temptations and resisting acting impulsively) and interference control (selective attention and cognitive inhibition)], *working memory*, and *cognitive flexibility* (including creatively thinking "outside the box," seeing things from a different perspective, and quickly and flexibly adapting to changed circumstances) (Diamond, 2013). *Inhibitory control* includes behavior that may be appropriate under one set of circumstances, but may be better withheld under other circumstances (Killgore, 2010). *Working memory* is the ability to maintain and manipulate information at a given time and is component of most executive functions (Goel, Rao, Durmer, & Dinges, 2009). *Working memory* capacity is the amount of information that can be accessed and attentively maintained at any given time (Vandewalle et al., 2009). Other executive functions include problem solving, planning, initiating, sequencing, selective and sustained attention, utilization of feedback, multi-tasking, monitoring of complex goal-directed behavior, and ability to deal with novelty (Chan, Shum, Toulopoulou, & Chen, 2008; Royall et al., 2002). Executive functions play vital roles in everyday adaptions to the environment (Zhao et al., 2016). Executive functions are higher-level cognitive processes that help enable individuals to regulate their thoughts and actions during goal-directed behavior (Friedman & Miyake, 2017). Poor executive functioning leads to difficulty with planning, attention, using feedback, and mental inflexibility (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001), each of which could undermine judgment, decision making, and motor performance. In one review of sleep and athletes, it has been argued that executive function may be the most important domain for athletic performance because it encompasses the higher level of thinking required to apply strategy, make decisions, and manage attention (Simpson, Gibbs, & Matheson, 2017).

Some tasks of executive function appear to be sensitive to sleep loss (Jones & Harrison, 2001; Nilsson et al., 2005). *Inhibitory control* performance has been shown to decrease following sleep deprivation (Drummond, Paulus, & Tapert, 2006). One meta-analysis revealed that *working memory* performance is adversely impacted by sleep deprivation (Lim & Dinges, 2010). A review on the impact of sleep deprivation and decision making revealed that sleep deprivation negatively impacts lateral, innovative, and *flexible* thinking (Harrison & Horne, 2000). In addition, total sleep time has also been associated with better performance on *task-switching* and *preparation* (executive function tasks) in young and older adults (Wilckens, Woo, Kirk, Erickson, & Wheeler, 2014) and a meta-analysis revealed that longer sleep durations positively influence some cognitive domains in children, specifically executive functions and cognitive performance involving multiple cognitive domains (Astill, Van der Heijden, Van Ijzendoorn, & Van Someren, 2012). As a result, sleep loss may impact some aspects of cognition, including executive functions, more than others.

Some studies that have failed to reveal a decrease in executive function performance during sleep deprivation (Pace-Schott et al., 2009; Tucker, Whitney, Belenky, Hinson, & Van Dongen, 2010). As such, some have hypothesized that different types of executive functions may be more or less affected by sleep restriction or deprivation (Killgore, 2010). A meta-analysis revealed no significant impact of sleep deprivation on certain aspects of executive functions, like reasoning and crystallized intelligence (Lim & Dinges, 2010). One study that did not find executive function changes following a night of sleep restriction proposed that some high-functioning young adults with chronically sleep-restricting lifestyles may confer resistance to the cognitive effects of sleep deprivation (Pace-Schott et al., 2009). However, it should be noted that the participants in this study averaged 7.4 hours of sleep per night, which is above recommended sleep amounts (Watson et al., 2015), which may have contributed to the participants being resilient to the impact of the sleep deprivation. Another study revealed individuals that are able to maintain *inhibitory control* performance after sleep deprivation had higher activation of the right ventral prefrontal cortex (PFC) and right insula relative to those whose inhibitory control performance declined (Chuah, Venkatraman, Dinges, & Chee, 2006). The authors hypothesized that the increased activation in these regions may be a compensatory response to sleep deprivation in those that demonstrated less performance changes following sleep deprivation. The extent to which certain cognitive tasks can utilize associated cortical regions for compensatory assistance likely determines how sleep fluctuations may impact that task. Considering the potential compensatory brain changes that may take place during sleep deprivation, it is important to review the brain regions that have been shown to be involved during cognitive tasks.

1.5 Brain Regions involved during Cognitive Tasks:

A meta-analysis that analyzed neuroimaging studies in healthy adults found that larger PFC volume and greater thickness correlated with better executive function performance and that the lateral PFC especially acts as a major neural substrate of executive performance (Yuan & Raz, 2014). A functional magnetic resonance imaging (fMRI) study revealed that *inhibitory control* capacity was found to be modulated by the right inferior lateral prefrontal cortex (Chuah et al., 2006). *Working memory* capacity relies on the dorsolateral regions of the prefrontal cortex (Vandewalle et al., 2009). While the involvement of the frontal lobes during executive function tasks is likely necessary, it is also likely that other non-frontal, subcortical brain regions are also necessary (Alvarez & Emory, 2006). One meta-analysis concluded that a superordinate cognitive control network in the brain that supports a broad range of executive functions resides in a network of brain regions that include the dorsolateral prefrontal, anterior cingulate, and parietal cortices, that supports a broad range of executive functions (Niendam et al., 2012). A fMRI study revealed that faster response times on the PVT were associated with activation in the prefrontal, parietal and motor regions, as well as the basal ganglia (Drummond et al., 2005). Cognitive processing speed has been proposed to be a key cognitive resource along with attention, working memory, and inhibition (Kail & Salthouse, 1994). An MRI study in young, healthy adults, found a positive relationship between processing speed performance and whole brain white matter volume (WMV) and that processing speed performance did not correlate with regional WMV in any specific brain region, which supports the idea that WMV is associated globally with processing speed performance regardless of the type of processing speed task (Magistro et al., 2015). With attention/alertness (as measured by PVT) and executive function tasks being associated with activation primarily in the prefrontal regions of the brain, understanding how sleep impacts this part of the brain can provide some insight as to how these types of tasks may be impacted by fluctuations in sleep duration.

1.6 Brain Changes following Sleep Restriction/Deprivation:

Neuroimaging has been used to determine what areas of the brain are impacted by sleep restriction. A key study used positron emission tomography (PET) during sleep deprivation and found significant global decreases in brain metabolic activity, primarily observed in the prefrontal, thalamus, and posterior parietal cortices, were correlated with declines in alertness and cognitive performance (Thomas et al., 2000). Another electrophysiological study utilizing electroencephalography (EEG) to evaluate the effects of sleep restriction on measures of waking arousal (EEG power of theta and alpha frequencies) found a reduction of power of waking EEG on the frontal sites, indicating a reduced level of arousal, after the first night of sleep restriction (Cote et al., 2008). Certain aspects of sleep, such as slow-wave sleep, appear to have preferential benefits to restore prefrontal cortex function, which may in turn benefit cognitive processes dependent on the prefrontal cortex (Anderson & Horne, 2003; Goel et al., 2009; Maquet et al., 1997; Muzur, Pace-Schott, & Hobson, 2002; Picchioni, Duyn, & Horovitz, 2013; Wilckens, Erickson, & Wheeler, 2012; Wilckens, Hall, Nebes, Monk, & Buysse, 2016). Slow-wave sleep involves neural synchrony predominantly over the prefrontal cortex, which reflects synchronized depolarization of neurons (Steriade, McCormick, & Sejnowski, 1993) which may enhance efficiency of the executive control network to support executive processing (Wilckens, Hall, et al., 2016). Therefore, a hypothesis on why sleep restriction may impair performance on executive function and attentional tasks, is because these tasks appear more reliant on the function of the prefrontal cortex, which is negatively impacted by sleep deprivation. Considering there are areas of the brain that could potentially provide compensatory assistance during executive functions and attentional tasks after sleep deprivation, it has been hypothesized that different types of cognitive functions may be more or less affected by sleep restriction or deprivation (Killgore, 2010).

1.7 Sleep Extension Research

Based on the literature described above, sleep duration appears important for both cognitive and motor performance. While the above literature primarily focused on sleep restriction/deprivation research, recently there have been researchers investigating the impact sleep interventions, such as sleep extension, have on performance. Sleep extension is an intervention that aims to increase the total sleep amount in participants over a set period of time. To date, there has been a relative dearth of sleep extension literature.

1.7.1 Sleep Extension and Athletic/Motor Performance

A recent systematic review on sleep interventions and athletic performances revealed that sleep extension had beneficial effects on subsequent performance measures (Bonnar, Bartel, Kakoschke, & Lang, 2018). One study found that sleep extension over a 5-7 week period, with the goal of being in bed for 10 hours each night, in male basketball players significantly improved sprint time, shooting percentage (free throw and 3-point percentage), PVT reaction time, and mood (Mah et al., 2011). In this study, subjective sleepiness, as measured by the Epworth Sleepiness Scale (ESS) significantly decreased and Profile of Mood States (POMS) scores improved in the vigor (increased) and fatigue (decreased) subscales. Compared to the habitual baseline week, the basketball players slept about 1.8 hours more per night/day during the sleep extension period. During the baseline period, the basketball players averaged about 6.7 hours per night/day compared to the extension period where they were averaged about 8.5 hours/night. These findings provide evidence that athlete performance may be enhanced, both cognitively and physically, following sleep extension. A critical limitation of this study was its lack of a control group and small sample size (n=11). A control group would have helped elucidate the impact of the sleep extension versus the impact of the basketball training considering the study took part while the basketball players were in-season. While these changes occurred over a longer period of time (5-7 weeks), other researchers have found sport performance benefits of sleep extension over a shorter duration.

A shorter-term sleep extension (one week, with the goal of sleeping for 9 hours a night) intervention in college tennis players resulted in significant improvements in serving accuracy and improvements in subjective sleepiness, as measured by the ESS and the Stanford Sleepiness Scale (SSS) (Schwartz & Simon, 2015). Compared to the habitual baseline week, the tennis players slept about 1.7 hours more per night/day during the sleep extension period. Considering the subjective baseline habitual sleep levels were around 7.1 hours of sleep at night, the findings corroborate the view that athletes may need more sleep to optimally perform. Once again, a lack of a control group and small sample size (n=12) limited the significance of the findings. However, the serving accuracy improvement is consistent with another study showing that sleep deprivation negatively impacts tennis serving accuracy (Reyner & Horne, 2013).

Another sleep extension study on athletes found that one week of sleep extension (up to 60 minutes per day) in twenty-one female collegiate track and field athletes improved mood, but did not significantly impact psychomotor vigilance or peak power on anaerobic exercise performance (Famodu et al., 2017). While the baseline habitual sleep amounts were around 7.1 hours of sleep at night, one potential reason there were no significant differences in the attention/vigilance or peak power on the anaerobic exercise is because the athletes only increased their sleep time by about 0.4 hours per night, which may have been insufficient to realize a significant difference from baseline. However, the peak power did show a trend towards significance (*p* =.07), which may be meaningful in higher competitive circumstances.

Thus, sleep extension in college athletes has been shown to improve performance in sprint speed and shooting/serving accuracy, and reaction time (attention/alertness), as well as improving mood and subjective levels of alertness. These findings suggest that, in general, college athletes may habitually obtain less sleep than they need to perform optimally. In the studies where baseline values were around 7 hours and extended by at least 1.7 hours per day/night over a period of 1 to 7 weeks, athletes improved in sport-specific activities as well as cognition and/or mood. In another study, in which sleep was only extended by about 0.4 hours over a period of 1 week, athletes improved in mood, but not cognitive or motor performance. Collectively, this suggests that the amount of sleep extension determines the extent to which performance benefits accrue. As previously noted, these prior studies each had critical limitations including small sample sizes and a lack of control groups.

1.7.2 Sleep Extension and Cognitive Performance:

Sleep extension over a 6 day period in healthy, normal sleeping young men with no complaints of sleepiness improved sleepiness and alertness differentially between "sleepy" and "alert" participants (Roehrs, Timms, Zwyghuizen-Doorenbos, & Roth, 1989). In this study, multiple sleep latency tests (MSLT) revealed that half of the participants (12) had basal average daily sleep latencies of ≤ 6 minutes (categorized as “sleepy”) and the other half (12) had basal average daily sleep latencies of ≥ 16 minutes (categorized as “alert”). The sleep extension improved sleepiness differentially between the groups, with the “sleepy” participants showing both earlier and greater improvements in sleepiness/alertness (improved daytime sleepiness and reaction time). This study demonstrates that the effect of a 6-day sleep extension intervention may depend on baseline levels of sleepiness. Consistent with this idea, the same research team investigated the impacts of a longer (2-week) sleep extension intervention in “sleepy” (MSLT latency of ≤ 6 minutes) men and women (Roehrs, Shore, Papineau, Rosenthal, & Roth, 1996). After the 2-week intervention, average daily sleep latencies increased (improved) by roughly 10 minutes. The authors speculated that the increased sleep latencies noted after the extension period suggested that the sleep participants were not habitually getting enough sleep relative to their biological sleep need and in a state of “sleep debt”. Once again, not all participants improved, as noted by 36% of the participants that did not increase their sleep latency in response to sleep extension. The authors speculated that there are important individual differences in the ability to adapt to new sleep schedules, as suggested by the finding that some participants that did not increase their sleep latency and slept less efficiently during the extension period. While the majority of the participants improved their sleepiness following the intervention, it is noteworthy that there are participants that may not be able to take advantage of longer sleep schedules and, therefore, may not benefit from a sleep extension intervention.

Extending sleep over a variable period of time in healthy, normal sleeping college students has led to significant improvements in daytime alertness (MSLT latency), attention/vigilance (reaction time), and mood (vigor and fatigue) (Kamdar, Kaplan, Kezirian, & Dement, 2004). Healthy college students reporting minimal daytime sleepiness were encouraged to sleep as much as possible during the sleep extension period. The study concluded when participants self-reported reaching maximum subjective alertness levels and feeling that they were unable to obtain more sleep. MSLT scores, PVT reaction times, and POMS ratings were measured at baseline, mid-extension (7 days after sleep extension), and end-extension (6 to 48 days after mid-extension testing). MSLT scores, the majority of the PVT measures, including mean reaction time, significantly improved at mid- and end-extension. POMS vigor (increased) and fatigue (decreased) scores significantly improved at mid- and end-extension. The objective baseline habitual sleep amounts for the participants was just over 7 hours per night/day. Similar to sleep extension studies on athletes, this study provides evidence that younger adults benefit from more than 7 hours of sleep. This study demonstrated that in healthy, normal sleeping college students, extended sleep benefits in alertness, attention/vigilance, and mood could be observed within 7 days. While the study had a smaller sample size (n=15), the main limitation of the study was a lack of a control group.

In adolescents with chronic sleep restriction symptoms (loss of energy, shortness of sleep, sleepiness, and irritation), 2 weeks of sleep extension resulted in significant improvements in cognitive performance (visuospatial processing and divided attention) (Dewald-Kaufmann, Oort, & Meijer, 2013). The tasks tested working memory, which some have identified as a core executive function (Diamond, 2013). The participants were primarily female and were randomly assigned to a control group (received no instruction) or a sleep extension group (gradual increase of sleep time each day over a 2-week period). Cognitive testing was performed before and after the intervention period. The extension group showed a significant improvement in cognitive function compared to the control group. Specifically, the extension group performed better on working memory tasks that measured visuospatial processing and divided attention. Stronger differences were noted on the visuospatial processing. This is the only study that has reported improvements in executive function tasks following a gradual increase in sleep time over a 2-week period in adolescents with symptoms of chronic sleep restriction. Future research is needed to determine if other executive functions may benefit from a sleep extension intervention.

The above studies demonstrated that sleep extension can improve sleepiness (MSLT latency), reaction time (alertness/attention), mood (fatigue/vigor), and visuospatial processing and divided attention (using working memory/executive function task). One study highlighted that some participants were unable to tolerate sleeping longer and therefore did not respond to the sleep extension intervention (Roehrs et al., 1996). In addition, sleepier individuals (as measured by MSLT latency) appeared to respond better to sleep extension intervention (Roehrs et al., 1989). Aside from the above-mentioned research, to date, no other studies have examined the impact sleep extension has on executive functions.

1.7.3 Sleep Extension prior to Sleep Restriction/Deprivation:

Researchers have investigated the impact that “sleep banking” (which is extending sleep durations prior to periods of wakefulness/restricted sleep) has on performance and alertness and found that sleep duration history appears to influence cognitive and motor performance during subsequent periods of wakefulness (Arnal et al., 2016; Arnal et al., 2015; Rupp, Wesensten, Bliese, & Balkin, 2009). One study found that extending nightly time in bed for 7 days provided cognitive performance benefits during subsequent sleep restriction and facilitated recovery from that sleep restriction (Rupp et al., 2009). After participants were monitored for 2 weeks of their habitual sleep pattern at home with wrist actigraphy, they were randomly assigned to either a habitual sleep group or a sleep extension group (10 hours time in bed) for 7 days followed by 7 days of sleep restriction (nightly time in bed from 0400 to 0700 hours) and then 5 days of sleep recovery (time in bed from 2300 to 0700 hours). Participants in the sleep extension group had less frequent lapses on the PVT across the sleep restriction phase compared to participants in the habitual sleep group. During the recovery sleep period, the PVT speed rebounded faster (and PVT lapsing recovered significantly after the first night of recovery sleep) in the extension group. This study revealed that the extent to which sleep restriction impairs objectively measured alertness and performance, and the rate at which these impairments are subsequently reversed by recovery sleep, varies as a function of the amount of nightly sleep obtained prior to the sleep restriction period.

In healthy, normal sleeping participants, 6 nights of sleep extension (around 10 hours time in bed) resulted in improved attention (both faster PVT reaction time and fewer PVT lapses) and reduced sleep pressure (longer MSLT scores) at baseline (following the 6 nights of sleep extension), limited the increase of PVT lapses and microsleeps during total sleep deprivation without changing PVT speed and MSLT, and had persistent effects after one night of recovery sleep (Arnal et al., 2015). This study used a randomized crossover design to investigate the effects of 6 nights of sleep extension on sustained attention and sleep pressure before and during *total* sleep deprivation and after a subsequent recovery sleep. In each condition, participants performed two consecutive phases: 6 nights of either habitual sleep or 6 nights of extended sleep followed by laboratory testing, which consisted of baseline testing, total sleep deprivation, and 10 hours of recovery sleep. There was a 6-week washout period between the conditions. Overall, the 6 nights of extended sleep resulted in immediate improvements in attention and sleep pressure, and a protective role against PVT lapses and microsleep degradation during total sleep deprivation. In addition, these beneficial effects persisted after one night of recovery sleep. These findings are consistent with those of Rupp et al. (2009) who found beneficial effects of sleep banking during subsequent sleep restriction.

Six nights of sleep extension has resulted in significantly longer time to exhaustion while performing a submaximal isometric knee extensor exercise compared to a habitual sleep condition both before and after a sleep deprivation period (Arnal et al., 2016). Considering the aforementioned cognitive benefits to “sleep banking”, this study aimed to investigate the effects of six nights of sleep extension on motor performance and associated neuromuscular function before and after one night of total sleep deprivation. In this randomized crossover study, participants performed either six nights of sleep extension or habitual sleep prior to baseline testing. After sleep deprivation, the rate of perceived exertion (RPE) during the exercise was significantly lower following the period of sleep extension versus the habitual sleep period, however prior to the sleep deprivation, there were no group differences in RPE during the exercise. Overall, this study shows that compared to habitual sleep, six nights of sleep extension improves sustained contraction time to exhaustion. The authors speculated that the beneficial effect on motor performance following sleep extension was likely do to the reduced RPE following total sleep deprivation.

Overall, the above studies provide supporting evidence on the potential benefit of “sleep banking”. Extending habitual amounts of sleep for 6-7 days provided cognitive and motor benefits and during subsequent sleep restriction and facilitated recovery from that sleep restriction. To date, no one has investigated the residual benefits of sleep extension after participants return to their habitual sleep amounts.

1.7.4 Brain Changes following Sleep Extension

Sleep extension for one week has been found to normalize the EEG P50 evoked response potential (ERP) of waking auditory sensory gating in healthy habitual short sleeping individuals (Gumenyuk, Korzyukov, Roth, Bowyer, & Drake, 2013). This study found that habitual short sleepers have impaired auditory sensory gating, as measured by EEG P50 ERP. The authors speculated that the lower amplitude in ERP in short sleepers may be related to an increased homeostatic sleep pressure and may be objective evidence of a neuronal deficit associated with short total sleep time. After these habitually short sleepers extended their sleep for one week this impaired auditory sensory gating effect was reversed to a more normal amplitude. The enhancement of the gating amplitude after sleep extension was observed over the frontal and central electrodes, suggesting a positive effect of sleep extension on fronto-central cortical brain regions. This finding is consistent with previous research showing the gating response to be primarily mediated by the prefrontal cortex and auditory cortex (Korzyukov et al., 2007; Mayer et al., 2009). Sensory gating has been described as a fundamental brain function that prevents the sensory neuronal system from becoming overloaded by irrelevant information, thus enabling the brain to perform higher order cognitive processes (Gumenyuk et al., 2013; McGhie & Chapman, 1961). These findings corroborate the added benefit extending sleep may have on the prefrontal cortex and its associated functions.

An MRI study found that after nine days of sleep extension mood improved (negative affect measured by the PANAS improved) and amygdala regional cerebral blood flow (rCBF) significantly decreased compared to baseline testing (Motomura et al., 2017). This study found that the amygdala had a significantly greater functional connectivity with the medial prefrontal cortex after the extension period compared to baseline. The authors suggested that sleep extension suppresses amygdala activity and improves mood by enhancing prefrontal inhibition of the amygdala. The authors hypothesized that sleep extension optimizes mood regulation by altering the functional connectivity between the amygdala and the prefrontal cortex. This is consistent with the loss of functional connectivity between the amygdala and the medial PFC following sleep deprivation (Yoo, Gujar, Hu, Jolesz, & Walker, 2007). After the nine days of sleep extension, the participants experienced one night of total sleep deprivation. After the night of sleep deprivation, the amygdala rCBF returned to baseline (reverted), along with negative affect (mood). This study provides evidence on why a sleep extension intervention may enhance brain dynamics, mainly the functional connectivity between the prefrontal area and the amygdala, which may result in improved mood. The brain and mood changes reverted back to baseline levels following one night of sleep deprivation.

Overall, sleep extension appears to have an impact on the brain, especially the frontal regions. Consequently, extending sleep beyond habitual amounts may be able to affect waking functions that are more reliant on the prefrontal areas of the brain, like executive functions and attention. Cognitive processes less supported by the prefrontal cortex may be less affected by fluctuations in sleep duration (Wilckens et al., 2012).

1.8 Summary of Sleep and Human Performance

Based on the aforementioned review of literature, human performance, in both cognitive and motor capacity, varies as a function of sleep duration, with less-than-normal sleep durations resulting in performance deficits and greater-than-normal sleep durations resulting in enhanced performance, both immediately and following a period of sleep restriction. Neuroimaging has provided evidence that the prefrontal cortex is impacted in both sleep restriction (negatively) and sleep extension (positively), which provides a hypothetical framework for the types of tasks that may be impacted by sleep fluctuation. Sleep extension research is scarce and many of the studies had critical limitations (i.e. small samples sizes, no control group) or lacked executive function and motor tasks. Consequently, more research is needed to better understand what types of tasks benefit from extending sleep.

1.9 Study Population of Dissertation – College Tactical Athletes

United States (U.S.) service members, as well as personnel in physically demanding professions like law enforcement, fire fighters, and other first responders, are sometimes referred to as “tactical athletes” because of the physical training that they undergo to maintain and improve occupational performance (Scofield & Kardouni, 2015). The Reserve Officer's Training Corps (ROTC) acts as the largest commissioning source of officers among all military branches (Oliver et al., 2017). Students enrolled in ROTC can be classified as college tactical athletes considering they are training physically and mentally to become future leaders and decision makers in the U.S. military. It is important for these students to focus on health behaviors, like sleep, that are known to impact performance in all aspects. Little is known about the sleep health of college tactical athletes enrolled in the ROTC, how habitual sleep duration impacts their performance on a cognitive motor battery and motivation to perform the battery, and how a sleep extension intervention may impact the performance in this population.

1.10 Knowledge Gap and Research Aims

To date, sleep extension research remains scarce and there have been no well-controlled studies on the immediate and residual effects of sleep extension on executive and cognitive motor performance. This dissertation addressed this gap. The overall aim of this dissertation was to investigate how sleep extension impacts cognitive motor performance in college tactical athletes enrolled in ROTC. A secondary aim of this dissertation was to determine the extent to which effects of sleep extension persist following resumption of habitual sleep schedules for four nights. The study design allowed for the investigation on the impact habitual sleep amounts had on the cognitive motor test battery, the immediate impacts of a sleep extension intervention, and the residual impacts of a sleep extension program after participants returned to habitual sleep amounts.

1.11 Dissertation Hypotheses

Prior to the sleep extension, it was hypothesized that college tactical athletes enrolled in ROTC would habitually sleep less than the recommended amounts and that their habitual sleep amounts would be associated with performance on a cognitive motor test battery, especially tests of executive function and attention. Immediately following the sleep extension, it was hypothesized that there would be improvements in attention/vigilance, executive function measures, standing broad jump performance, and motivation levels following the sleep extension intervention. Lastly, it was hypothesized that participants would resume their habitual sleep schedules following the sleep extension intervention period, and that all behavioral effects of sleep extension would dissipate after four nights of non-extended, ad-lib sleep.

Chapter 2: Habitual Sleep Health of College Tactical Athletes Enrolled in ROTC and the Impact Sleep Duration has on Cognitive and Motor Performance and Motivation

2.1 Abstract

Objective: To examine habitual sleep duration, quality, and subjective sleepiness and to determine whether, and the extent to which, habitual sleep duration impacts cognitive motor performance in college tactical athletes enrolled in the Reserve Officers' Training Corps (ROTC) at a large, state university.

Design: Observational, using objective and subjective measures of sleep, and measures of cognitive and motor performance.

Setting: University setting.

Participants: 54 young tactical athletes enrolled in all 3 services of ROTC.

Measurements: Participants wore wrist actigraph devices and completed sleep diaries for 7 days prior to completing a cognitive motor test battery.

Results: The mean objective total sleep time of the participants was 6.17 ± 0.69 hours, with only 7.41% of participants averaging at least 7 hours of sleep per day. The mean Karolinska Sleepiness Scale (KSS) and Epworth Sleepiness Scale (ESS) ratings were within normal limits at 4.70 ± 1.56 and 8.80 ± 3.24, respectively. Average objective total sleep duration was significantly associated with performance times on the Trail Making Test – A (TMT-A) ($p = .038$) and TMT-B ($p = .049$), and with performance on the Symbol Digit Modalities Test (SDMT) ($p = .023$) and motivation to perform the cognitive tasks ($p = .009$). Average objective habitual sleep duration was not significantly associated with performance on the following: Psychomotor Vigilance Test (PVT), Flanker task, Standing Broad Jump (SBJ), or motivation to perform the SBJ.

Conclusions: College tactical athletes enrolled in ROTC habitually slept less than 7 hours per day, experienced normal levels of subjective daytime sleepiness, and their habitual sleep durations were associated with both motivation level and various measures of performance, with longer durations of sleep being associated with better performance and greater motivation.

2.2 Introduction

Sleep restriction has consistently been found to impair various aspects of physical performance including sport-specific skill execution, submaximal strength and muscular power (Fullagar et al., 2015). One study revealed that submaximal lifting tasks are especially impacted by sleep loss, although some maximal lifting tasks, like the leg press, are also negatively impacted (Reilly & Piercy, 1994). In addition to (and possibly because of) these physical impacts, a chronic lack of sleep in younger athletes has also been found to be associated with an increased risk of injuries (Milewski et al., 2014). It has been hypothesized that the cognitive consequences of sleep loss, including deficits in reaction time, fine motor movement, memory (i.e. consolidation of motor tasks) and decision-making may be contributing factors to impaired physical performance (Fullagar et al., 2015).

Chronic sleep restriction has been shown to be associated with cognitive impairments in sleepiness, attention, mood, alertness, and memory (Cote et al., 2008; Dinges et al., 1997; Gumenyuk et al., 2011). Age has been shown to moderate the effects of sleep deprivation or sleep restriction on psychomotor vigilance, with younger participants performing worse than older participants during sleep deprivation (Duffy et al., 2009; Stenuit & Kerkhofs, 2005). While there is a broad consensus that insufficient sleep leads to a general slowing of response speed and increased variability in performance for simple cognitive measures (alertness, attention and vigilance), there is less agreement about the effects of sleep loss on many higher level cognitive capacities, including executive functions (Killgore, 2010). Executive functions are a subcategory of cognitive ability that is generally considered to reflect the 'higher level cognitive processes' (Alvarez & Emory, 2006), which are especially important for regulation of thoughts and actions during goal-directed behavior (Friedman & Miyake, 2017). It has been suggested that executive functions may be especially important for athletic performance because they encompass the rapid formulation and application of strategy, decision making, and management of attention (Simpson et al., 2017). Better executive function performance has been correlated with the prefrontal cortex (PFC) area of the brain (Yuan & Raz, 2014), an area of the brain that has also been correlated with better psychomotor vigilance (attention) (Drummond et al., 2005) and involved in motivating thoughts or actions in relation to internal goals (Kouneiher, Charron, & Koechlin, 2009). The PFC is also one of the regions of the brain, along with the thalamus, and inferior parietal/superior temporal cortex where the greatest reductions in brain activity occur as a result of sleep loss (Thomas et al., 2000). Consequently, restricted sleep may impact performances that are more reliant on these brain regions.

In order to promote optimal health and performance, it has been recommended that adults consistently sleep at least 7 hours per night (Watson et al., 2015). Only about two-thirds of the general U.S. adult population report sleeping at least seven hours per night (Krueger & Friedman, 2009) and many college students, collegiate athletes, elite athletes, and U.S. service members have all been found to habitually sleep less than the recommended 7 hours per night (Fietze et al., 2009; Lastella et al., 2015; Leeder et al., 2012; Lund et al., 2010; Luxton et al., 2011; Mah, Kezirian, Marcello, & Dement, 2018; Mah et al., 2011; Mysliwiec et al., 2013; Sargent et al., 2014; Schwartz & Simon, 2015). This is especially important considering younger adults and athletes may require more than the recommended 7 hours of sleep per night (Mah et al., 2011; Schwartz & Simon, 2015; Watson et al., 2015).

United States (U.S.) service members, as well as personnel in physically demanding professions like law enforcement, fire fighters, and other first responders, are sometimes referred to as "tactical athletes" because of the physical training that they undergo to maintain and improve occupational performance (Scofield & Kardouni, 2015). Because performance in these occupations can literally determine the outcome in 'life and death' situations, it is critical that tactical athletes are prepared to perform optimally, both physically and mentally. Accordingly, it is important for tactical athletes to focus on health behaviors, like sleep, that are known to impact performance in all aspects. The Reserve Officers' Training Corps (ROTC) acts as the largest commissioning source of officers among all military branches (Oliver et al., 2017). Little is known about the sleep health of college tactical athletes enrolled in the ROTC and how habitual sleep duration impacts their performance on a cognitive motor battery and motivation to perform the battery. Because performance of tactical athletes depends on both optimal physical and cognitive functioning, it is important to determine and document the relationship between habitual sleep and performance in this population. It was hypothesized that college tactical athletes enrolled in ROTC would sleep less than the recommended amounts, experience daytime sleepiness, and that their habitual sleep amounts would impact performance on a cognitive motor test battery, especially tests of executive function and attention. Considering ROTC students are training to become future leaders and decision makers in the U.S. military, knowledge regarding the extent to which their habitual sleep behaviors potentially impact operationally relevant physical and mental performance is an important first step toward implementation of interventions that will optimize health and readiness in this population.

2.3 Methods

2.3.1 Participants

College students (age 18-30 years), enrolled in a ROTC program at the University of Maryland, College Park were invited to participate in the study. Participants were excluded if they had a self-reported history of psychiatric disorder, took medications with sleep-related side effects, used illicit drugs, or self-reported that they averaged more than 8.5 hours of sleep per 24-hours, or if they report extending their sleep by more than 90 minutes per night on weekend nights compared to weekday nights, or if they did not feel like they could comply with the study procedures after the details were explained to them. The study was approved by the

University of Maryland Institutional Review Board and written informed consent was obtained from all participants.

2.3.2 Sleep-wake Monitoring

With the goal of measuring sleep-wake patterns in the participants' natural sleep environment, participants wore wrist actigraphs and completed the Consensus Sleep Diary (Carney et al., 2012) for 7 days prior to performing a cognitive motor test battery. All monitoring started on a Monday to ensure that all participants were on the same weekday/weekend cycle prior to testing. Participants were instructed to wear the Actiwatch 2 wrist actigraph 24 hours per day for the duration of the study. In addition, participants used a sleep diary to record their sleep-wake activity and daily sleep quality (Scored as: 1 = Very Poor, 2 = Poor, 3 = Fair, 4 = Good, 5 = Very Good), and were asked to annotate the diary anytime they removed their wrist actigraph. Participants received daily reminders via text messaging to keep their actigraph watches on and keep up-to-date on their sleep diaries. The raw actigraphy data (1-min epoch length) was sleep-scored using the a commercially available, validated, proprietary software (Actiware software, Philips Respironics, Andover, MA*)*. The consensus sleep diary was scored independently.

Wrist actigraphy is a widely-accepted method of objectively measuring and quantifying daily sleep-wake timing and duration (Littner et al., 2003). Actigraphy is known to be a reliable and valid measure to study sleep in natural (e.g., home) environments (Kushida et al., 2001; Morgenthaler et al., 2007). Wrist actigraphy has been validated against polysomnography, which is the "gold standard" for objective measurement of sleep parameters, including: sleep duration, efficiency, and fragmentation (Ancoli-Israel et al., 2015).

2.3.3 Performance Testing

Every participant conducted testing on a Monday, after the 7 nights of sleep monitoring. Testing was conducted in the same laboratory room with consistent temperature/lighting/noise/etc. To control for the effects of caffeine on performance, participants were instructed to refrain from caffeine ingestion for 6 hours prior to testing.

Testing order and procedures were identical for all participants. Upon arrival for testing, participants confirmed they had not consumed caffeine during the previous 6 hours and completed questionnaires on subjective sleepiness (Epworth Sleepiness Scale (ESS) and Karolinska Sleepiness Scale (KSS)), and anxiety (State-Trait Anxiety Inventory (STAI)). Upon completion of the questionnaires, the participants performed the *Cognitive Motor Test Battery* with subtests administered in the following order: Psychomotor Vigilance Test – 5-minute version, Flanker Task, the Trail Making Task (A and B), Symbol Digit Modalities Task (SDMT) (written and oral versions), and a maximum standing broad jump (3 times). Following the cognitive motor test battery, participants were asked to annotate their motivation levels to perform the cognitive tasks (as a whole) and the standing broad jumps using a 100-mm Visual Analogue Scale (VAS) (anchors = No motivation, Highest possible motivation).

Daytime sleepiness was recorded using the Epworth Sleepiness Scale (ESS; (Johns, 1991) and the Karolinska Sleepiness Scale (KSS) (Akerstedt & Gillberg, 1990). The ESS measures subjective sleep propensity in 8 standardized situations on a 0-3 scale, with higher scores reflecting greater sleepiness. It is a simple and reliable method for measuring sleepiness in adults (Johns, 1992). The KSS assesses subjective sleepiness on a 9-point scale ranging from 1 (Extremely alert) to 9 (Extremely sleepy, great effort to keep awake, fighting sleep) and has been shown to be a valid measure of extant sleepiness (Kaida et al., 2006). The State-Trait Anxiety Inventory (STAI) was used to measure trait and state anxiety (Spielberger, 1983) prior to performing the cognitive motor battery.

A 5-minute modified version of the Psychomotor Vigilance Task (PVT) (Thorne, Genser, Sing, & Hegge, 1985) was administered on the computer using the PEBL software program (Mueller & Piper, 2014). Each 5-minute trial consisted of stimuli (red circle on computer monitor) occurring at intervals ranging from 2 to 5 seconds after each response from the participant. Participants responded to the stimuli by pressing the spacebar on the keyboard as quickly as possible. The primary outcomes of interest were mean reaction time and number of lapses (reaction times > 500 milliseconds).

A modified version of the Flanker Task (Eriksen & Eriksen, 1974) was administered on the computer using the PEBL software program (Mueller & Piper, 2014). Each trial consisted of either congruent (<<<<<, >>>>>) or incongruent (<<><<, >><>>) arrow stimuli presented on the computer screen, with the middle arrow being the target stimulus. Throughout the task, congruent and incongruent trials appeared in random order and pointed in the right and left direction. The participant pressed the left-shift button with the left index finger if the target stimulus pointed to the left and a right-shift button with the right index finger if the target stimulus pointed to the right. Participants were instructed to respond as quickly and accurately as possible. The inter-trial interval (ITI) was 1000 ms and if the participant responded after 1500 ms, the trial was counted as an error of omission. Participants performed a brief practice trial with three practice stimuli prior to beginning the experimental task. One block of 200 trials was presented, with 100 congruent trials and 100 incongruent trials. Only correct responses were used in the analysis. Mean reaction time on the congruent trials and incongruent trials was calculated. Also, an interference score using the following equation:

$$\frac{incongruent\ mean\ RT - congruent\ mean\ RT}{congruent\ mean\ RT}\ x\ 100$$

was calculated as a metric of inhibitory control unbiased by differences in base reaction time (Colcombe et al., 2004; Liu-Ambrose, Nagamatsu, Voss, Khan, & Handy, 2012; Wilckens, Erickson, & Wheeler, 2016).

The Trail Making Test A (TMT-A) and B (TMT-B)(Lezak, 1995) were administered with pen and paper. Part A (TMT-A) required participants to draw lines between consecutive encircled numbers in ascending order, from 1 to 25. Part B (TMT-B) required participants to draw lines connecting 25 encircled numbers and letters in an alternating progressive sequence (i.e., 1 to A to 2 to B) from 1 to 13. Time to completion was measured, and the difference between TMT-B and TMT-A was calculated.

The Symbol Digit Modalities Test (SDMT) (Smith, 1982) was administered with pen and paper. At the top of the page was a key that paired 9 numbers with 9 corresponding geometric figures. Below the key were rows of symbols. Participants were instructed to write, in order, as many numbers associated with symbols as possible within 90 seconds. After the participants completed a written version of the test, they performed an oral version of the same 90-second test, where they verbally instructed the researcher to write in the number with the corresponding symbol. The combination of the written and oral version was calculated as the total score.

The last test administered was a gross motor task: a ‘maximum effort’ standing broad jump. Participants stood with their toes behind a start line and were instructed to “jump as far as possible” while landing with both feet. Performance was the measurement from the starting line to the posterior heel that was closest to the start line. Participants performed three jumps and were allowed up to two minutes of between-trial recovery between jumps. Performance was measured as the average of the three jumps.

2.3.4 Statistical Analysis

All Statistical analyses were performed using SPSS 24.0 (SPSS Inc., Chicago, IL, USA). Mean total sleep duration and mean sleep quality were calculated over the 7 days of habitual sleep monitoring. A Pearson correlation was employed to assess the association between objective and subjective sleep data. Mean scores on each questionnaire and test of the cognitive motor battery were calculated. Linear regression analysis was performed to examine the association between objective total sleep duration (independent variable) and performance on each test and subjective questionnaire (dependent variables). *P* values <.05 were considered statistically significant.

2.4 Results

2.4.1 Participants

57 participants provided written consent and started the study, three participants did not complete the study and were excluded from the analyses (two did not wear the wrist actigraph during the study and one actigraph malfunctioned). A total of 54 (20.07 ± 1.75 years, 29 male, 25 female) college tactical athletes, who were members of each ROTC branch (Air Force, Army, Navy) at the University of Maryland, College Park, completed the study. Table 2.1 provides demographic information and characteristics of the study population.

2.4.2 Sleep Duration

Mean objective total sleep time (as determined with wrist actigraphy) was 6.17 ± 0.69 hours. Only 7.41% of the participants averaged at least 7 hours of sleep per day, while 53.70% of participants slept between 6.0 and 6.9 hours per day. Figure 2.1 shows the percentage of participants and average total sleep time over the 7 days. The sleep diary mean total sleep amount was 6.46 ± 0.83 hours, which moderately correlated with the actigraph data ($r = .553$, $p < .001$).

2.4.3 Subjective Sleep Quality

Mean subjective sleep quality as measured on the Consensus Sleep Diary was 3.40 ± 0.57, which is between the “Fair” (3) to “Good” (4) range. 59.26 % of participants had a mean rating between “Fair” (3) and “Good” (4). 22.22 % of participants had a mean rating between “Poor” (2) and “Fair” (3). 81.48% of the participants reported an average sleep quality rating less than “Good” (4). Figure 2.2

shows the relationship between the percentage of participants and average sleep quality over the 7 days.

2.4.4 Subjective Daytime Sleepiness

The mean Epworth Sleepiness Scale (ESS) rating was 8.80 ± 3.24 (i.e., within normal limits), with 35.19% of participants reporting scores ≥ 10, indicating significant levels of sleepiness. Likewise, the mean Karolinska Sleepiness Scale (KSS) rating was 4.70 ± 1.56 (which is within normal limits), with 38.89 % reporting some signs of sleepiness (KSS ≥ 6). KSS ratings were significantly correlated with ESS ratings (r = .335, p =.013). Figures 2.3 and 2.4 show the participants mean KSS and ESS ratings, respectively.

2.4.5 Cognitive Motor Battery and Motivation

From the linear regression analysis, objective total sleep duration was significantly associated with performance times on the TMT-A (p = .038) and TMT-B (p = .049), and associated with SDMT performance (p = .023). On average, TMT-A speed decreased/improved 3.25 (SE = 1.53) seconds, TMT-B speed decreased/improved 4.52 (SE = 2.24) seconds, and SDMT total performance increased/improved by 8.27 (SE = 3.53) items for each additional hour of sleep duration. Total sleep time was also positively associated with motivation to perform the cognitive tasks (p = .009), with motivation increasing by 6.43 (SE = 2.36) mm on the VAS for each additional hour of sleep duration. No significant associations between habitual TST and any other measures (PVT, Flanker Task, Standing Broad Jump (SBJ), or motivation to perform the SBJ) were found. Table 2.2 outlines the estimated regression coefficients for the associations between objective total sleep duration (independent variable) and performance on each test and subjective questionnaire (dependent variables).

2.5 Discussion

In the present study, sleep health and the relationships between habitual sleep duration and daytime performance and motivation were assessed in college tactical athletes enrolled in ROTC at a large, state university. The mean objective sleep time was 6.17 ± 0.69 hours in this sample, which appears shorter in duration than both the 7.02 ± 1.15 hours reported in a large undergraduate population (Lund et al., 2010) and 6.98 ± 1.15 hours reported in a large group of student-athletes (Mah et al., 2018). The majority of the participants (53.70%) in the present study averaged between 6 and 7 hours of sleep per day. The results revealed that over 92% of the participants averaged objective sleep amounts less than 7 hours per day, which is the recommended amount for optimal health (Watson et al., 2015). These percentages appear much higher than the self-reported 39.1% from a large student-athlete population (Mah et al., 2018). While not a primary aim of the current study, the subjective sleep duration, measured via the Consensus Sleep diary, was found to moderately correlate (Pearson's $r = .553$, $p < .001$) with objective sleep data. This was similar to the moderate correlation (Pearson's $r = .53$) previously found between self-reported sleep hours and actigraphy in adolescents (Wolfson et al., 2003). Collectively, the present findings suggest that college tactical athletes enrolled in ROTC appear to obtain less daily sleep amounts compared to other undergraduate students, including other student-athletes. Future research is needed to determine if there are significant differences between the groups of college students.

More than 80% of the study sample had an average subjective sleep quality rating below “good” (scored 4 on the Consensus Sleep Diary). Around 60% of participants reported an average sleep quality between “fair” (scored 3 on the Consensus Sleep Diary) and “good” (4). Around 22% of participants reported an average sleep quality between “poor” (scored 2 on the Consensus Sleep Diary) and “fair” (3). In a large population of college students, it has been found that over 60% were categorized as poor-quality sleepers by the Pittsburgh Sleep Quality Index (PSQI) and that poor sleep quality was associated with negative moods and physical illness (Lund et al., 2010). While the current study obtained sleep quality utilizing a different measure, it appears that there is a lower percentage of college tactical athletes that categorize their sleep as poor compared to a large population of college students. However, nearly a quarter of the participants may be dealing with a level of sleep quality that could negatively impact their mental and physical health.

The mean subjective sleepiness ratings for the Epworth Sleepiness Scale (ESS) and the Karolinska Sleepiness Scale (KSS) were both within normal limits. However, over 35% had ESS scores ≥ 10, suggesting significant levels of daytime sleepiness. These percentages are between the 51% found in other college athletes (Mah et al., 2018) and the 25% found in a large undergraduate population (Lund et al., 2010). Considering the college tactical athletes in the current study appeared to report lower levels of sleepiness even though they appeared to average less sleep compared to other college athletes (Mah et al., 2018), future research should compare these groups of athletes to determine if there are characteristics of athletes that make them more resilient to lower levels of sleep durations.

Habitual sleep amount was associated with performance on two (of the four) cognitive tests, including one that measures executive functioning, but not with the gross motor task. The significant associations were found with the TMT (both TMT-A and TMT-B) and the SDMT. The TMT is a widely used instrument in neuropsychological assessment as an indicator of speed of cognitive processing and executive functioning (Sanchez-Cubillo et al., 2009), and performance on the SDMT is an indicator of information processing speed and efficiency (Benedict et al., 2017; Wilckens et al., 2014). In undergraduate students, TMT-A is thought to reflect "sustained attention" and "set maintenance" (Langenecker, Zubieta, Young, Akil, & Nielson, 2007) and it has been used to assess processing speed (Wilckens et al., 2014), whereas the TMT-B (which involves alternation between letters and numbers) is more reflective of executive functions of task-set inhibition ability, cognitive flexibility, and set-shifting (Arbuthnott & Frank, 2000; Langenecker et al., 2007). Executive functions are thought to be vital for athletic performance (Simpson et al., 2017). In addition, athletes have been shown to outperform non-athletes (Jacobson & Matthaeus, 2014), and higher-level athletes have been shown to outperform lower lever athletes, on measures of executive functioning and performance on these tasks has significantly correlated with sport-specific performance (number of goals/assists in soccer players) as long as two seasons later (Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012). It is reasonable to hypothesize that executive functions are similarly important for the performance of tactical athletes. Poor executive functioning leads to difficulty with planning, attention, using feedback, and mental inflexibility (Anderson et al., 2001), each of which could undermine judgment, decision making, and motor performance. The findings in this study provide evidence that longer habitual sleep durations are associated with better performance on a task reflective of executive functions of task-set inhibition ability, cognitive flexibility, and set-shifting, as well as on two tasks commonly used to access cognitive processing speed.

It was hypothesized that executive function tasks and attention tasks would be impacted by habitual sleep durations because performance on these tasks have been correlated with the PFC (Drummond et al., 2005; Yuan & Raz, 2014) and the PFC is one of the regions of the brain, along with the thalamus, and inferior parietal/superior temporal cortex where the greatest reductions in brain activity occur as a result of sleep loss (Thomas et al., 2000). The present findings partially support this hypothesis. Habitual sleep duration were not significantly associated with performance on the Flanker task or TMT B-A, both of which are widely used measures of specific executive functions (Diamond, 2013; Sanchez-Cubillo et al., 2009), and – most surprisingly - it failed to predict performance on the PVT, which is considered the “gold standard” behavioral measure of sleepiness because of its high reliability, sensitivity to circadian rhythm influences, and absence of learning effects (Dinges et al., 1997; Killgore, 2010; Van Dongen, Maislin, et al., 2003). While participation of the frontal lobes during executive function tasks is likely necessary, it is also likely that other non-frontal brain regions are necessary (Alvarez & Emory, 2006). A meta-analysis concluded that a superordinate cognitive control network in the brain that supports a broad range of executive functions resides in a network of brain regions that include the dorsolateral prefrontal, anterior cingulate, and parietal cortices (Niendam et al., 2012). Similarly, aside from the prefrontal region of the brain, psychomotor vigilance (attention) performance has also been associated with activation in the parietal and motor regions, as well as the basal ganglia (Drummond et al., 2005). Because executive function tasks and attention tasks also involve non-frontal regions of the brain, this may explain why there were no associations between habitual sleep amounts and PVT performance or other executive function measures.

Another finding in this study was that the average total sleep amount was positively associated with the motivation to perform the cognitive tests measures. The PFC has been found to be involved in motivating thoughts or actions in relation to internal goals (Kouneiher et al., 2009), which may be one of the reasons longer sleep durations are associated with higher motivation levels for the cognitive task. There is a possibility that longer sleep durations improve task motivation levels, which may result in an increased "attentional effort" during a cognitive task (Sarter, Gehring, & Kozak, 2006) that results in improved cognitive performance. While habitual sleep amounts were associated with motivation to perform the cognitive tasks, it was not associated with motivation to perform the gross motor task, which may have been a contributing factor on why there was no significant association with the gross motor task. Because motivation levels were obtained after the participant performed the task, there is a chance that their own perception of how they performed the tasks may have confounded how they reported their motivation levels. Future research should consider measuring motivation levels prior to performance.

Study limitations included the following: first, this study was a part of a larger study that examined the effects of a sleep manipulation that excluded participants if they self-reported habitually sleeping more than 8.5 hours a night. While no one was excluded during the screening process for this reason, it is unknown how many did not voice an interest in participating in the study knowing the exclusion criteria. Therefore, the inclusion of more longer sleepers may have impacted the results of this study. Second, the habitual sleep amount for this study was only measured over 1 week for each participant. Although data collection occurred over the course of the academic semester for all participants, there is a chance that when a participant was monitored, they were getting more or sleep less than their usual.

Future studies should investigate how sleep enhancement techniques, like sleep extension, may impact performance in this population to help elucidate potential ways to optimize performance and motivation levels. In addition, future studies should include neuroimaging during the performance testing to further understand how differences in habitual sleep duration may be associated with differences in neural dynamics during performance.

2.6 Conclusions

Habitual sleep health and various aspects of cognitive motor performance and motivation were assessed in tactical athletes enrolled in all ROTC branches at a large, state university. Participants habitually slept less than 7 hours per day and experienced normal levels of subjective daytime sleepiness. Longer sleep durations were found to be associated with better performance on various measures of cognitive performance, including processing speed and executive function, and higher motivation levels. The present findings provide awareness of sleep health in young adults training to become future leaders of the U.S military and how performance and motivation is positively impacted by longer habitual sleep durations.

Table 2. 1 Demographic Information of Participants

Total Study Participants	
# of participants, n	54
Gender	
Male	29 (53.7%)
Female	25 (46.3%)
Age, years	20.07 ± 1.75
Height (m)	1.71 ± 0.09
Weight (kg)	69.19 ± 10.85
BMI (kg/m^2)	23.61 ± 2.59
Trait Anxiety (STAI Y2)	33.44 ± 9.35
State Anxiety (STAI Y1)	31.35 ± 8.85
Ethnicity	
African American	5 (9.3%)
Asian/Pacific Islander	9 (16.7%)
Caucasian/White	39 (72.2%)
Multiracial	1 (1.9%)
ROTC Branch	
Air Force	11 (20.4%)
Army	32 (59.3%)
Navy	11 (20.4%)
School Year	
Freshman	8 (14.8%)
Sophomore	14 (25.9%)
Junior	17 (31.5%)
Senior	12 (22.2%)
Graduate	3 (5.6%)

Data are presented as mean ± standard deviation unless otherwise indicated. BMI = body mass index. STAI = state-trait anxiety inventory.

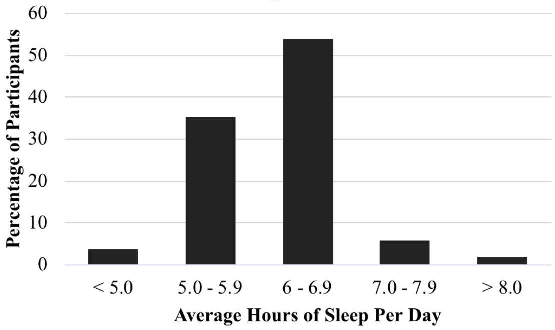

Figure 2. 1. Percentage of participants by average sleep duration (measured by actigraphy) per day over 7 days

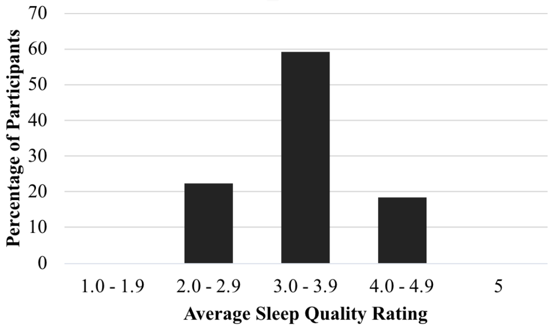

Figure 2. 2. Percentage of participants by average sleep quality from consensus sleep diary over 7 days.
1 = Very Poor, 2 = Poor, 3 = Fair, 4 = Good, 5 = Very Good.

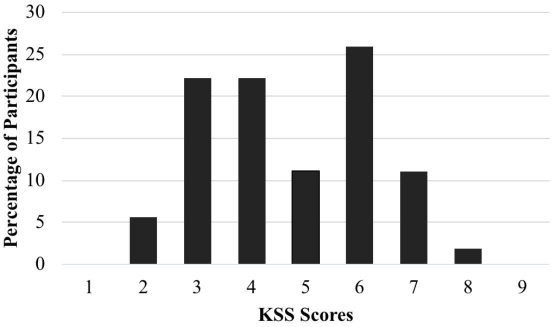

Figure 2. 3. Percentage of participants by average Karolinska Sleepiness Scale (KSS) rating.
1 = Extreme alert, 2 = Very alert, 3 = Alert, 4 = Rather alert, 5 = Neither alert nor sleepy, 6 = Some signs of sleepiness, 7 = Sleepy, but no difficulty remaining awake, 8 = Sleepy, some effort to keep alert, 9 = Extremely sleepy, great effort to keep awake, fighting sleep.

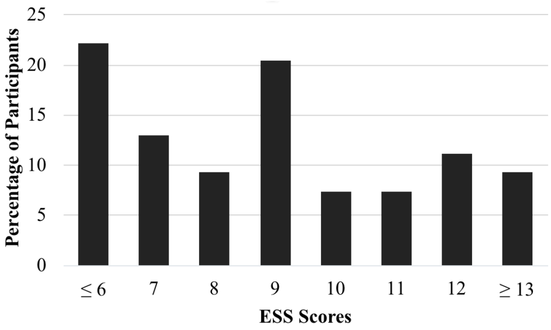

Figure 2. 4. Percentage of participants by average Epworth Sleepiness Scale (ESS) rating.
Ratings below 10 are considered to be normal ranges of sleepiness.

Table 2. 2 Linear Regression Analysis of Each Test and Motivation on Objective Average Total Sleep Duration

	Regression Coefficients		
	B	***SE***	**Sig. Value**
PVT			
Lapses	-0.83	0.90	.359
Mean RT	-10.55	9.42	.268
Flanker Task			
Congruent RT	-0.57	14.86	.970
Incongruent RT	-7.36	16.15	.651
Interference Score	-1.29	1.15	.266
TMT			
TMT A	-3.25	1.53	.038*
TMT B	-4.52	2.24	.049*
TMT B-A	-1.27	1.97	.524
SDMT (Written and Oral)	8.27	3.53	.023*
Standing Broad Jump (Avg)	-1.70	6.96	.808
Motivation to perform:			
Cognitive Tests	6.43	2.36	.009**
Standing Broad Jump	1.63	2.10	.422

Notes: * <.05, ** <.01; *B* = unstandardized coefficient; *SE* = standard error; RT = reaction time

Chapter 3: Effects of Four Nights of Sleep Extension on Cognitive and Motor Performance and Motivation in College Tactical Athletes

3.1 Abstract

Objective: The aim of this study was to assess the effects of four nights of sleep extension (10h time in bed per night) on cognitive and motor performance in college tactical athletes enrolled in the Reserve Officers' Training Corps (ROTC). A second aim was to determine the extent to which effects of sleep extension persist following resumption of habitual sleep schedules.

Design: Randomized control trial utilizing two groups (Sleep extension = EXT vs Control = CON) and three testing times (Pre-test, Post-test, Follow-up). The pre-test was conducted after seven nights of habitual sleep, the post-test was conducted after the four nights of sleep extension intervention, and the follow-up was conducted after the resumption of habitual sleep for four nights.

Setting: University setting.

Participants: 50 (EXT: 25, 12 female, 20.12 ± 2.01 yrs vs CON: 25, 13 female, 19.76 ± 1.09 yrs) college tactical athletes enrolled in all services of ROTC.

Measurements: Participants wore a wrist actigraph for fifteen consecutive nights and completed a cognitive motor battery on days 8 (pre-test), 12 (post-test), and 16 (follow-up) as outlined above.

Results: During the four-night intervention period, the EXT group significantly increased mean sleep time (1.36 ± 0.71 hours, $p < .001$), the CON group did not (-0.25 ± 0.78 hours, $p = .121$). After sleep extension, there were significant between-group differences on the mean score change since baseline in Psychomotor Vigilance Test (PVT) reaction time (EXT = -16.09 ± 26.07 ms vs CON = -1.75 ± 17.16 ms; $p = .026$), Trail Making Test – B (TMT-B) time (EXT = -11.77 ± 6.67 s vs CON = -7.07 ± 7.77 s; $p = .027$), standing broad jump (SBJ) distance (EXT = 9.07 ± 8.21 cm vs CON = -2.31 ± 9.18 cm, $p < .001$), and motivation to perform the cognitive tasks (EXT = 4.44 ± 11.85 mm vs CON = -7.04 ± 13.63 mm, $p = .003$) and the SBJ (EXT = 4.36 ± 6.78 mm vs CON = -1.60 ± 8.69 mm, $p = .009$). After resuming habitual sleep schedules for four nights, significant between-group differences on the mean score change since baseline persisted on SBJ distance (EXT = 9.47 ± 12.86 cm vs CON = -1.59 ± 9.48 cm, $p = .001$) and motivation to perform the SBJ (EXT = 1.92 ± 6.11 mm vs CON = -3.28 ± 10.32 mm, $p = .035$).

Conclusions: Four nights of sleep extension resulted in immediate benefits in reaction time, an executive function task, standing broad jump distance, and motivation levels. Benefits of sleep extension on broad jump performance and motivation level were still evident four days after resumption of habitual sleep schedules.

3.2 Introduction

For those professions (e.g. military, law enforcement, fire response, etc.) in which deficits in neurocognitive and/or motor performance can mean the difference between success and failure (and sometimes life and death), sleep extension provides a potential strategy for helping to sustain operational effectiveness. Personnel in such professions have been termed “tactical athletes”, reflecting the nature of the training that is administered so as to specifically prepare/condition individuals for the physical challenges that they are likely to encounter in the operational environment (Scofield & Kardouni, 2015). The Reserve Officers' Training Corps (ROTC) acts as the largest commissioning source of officers among all military branches (Oliver et al., 2017) and prepares college tactical athletes for their future role in the military.

A recent systematic review of sleep interventions and athletic performance revealed that sleep extension enhances subsequent performance (Bonnar et al., 2018). Significant improvements in sprint time, basketball shooting percentage (free-throw and three-point percentage), Psychomotor Vigilance Test (PVT) reaction time, subjective sleepiness and mood have been found in male basketball players following a sleep extension intervention (10 hours TIB per night) that lasted five to seven weeks (Mah et al., 2011). A shorter-term sleep extension intervention (9 hours of sleep per day) of one week resulted in significant improvements in serving accuracy and improvements in subjective sleepiness in college tennis players (Schwartz & Simon, 2015). However, in a study that utilized a one week sleep extension (up to 60 more minutes per day than baseline) intervention in female collegiate track and field athletes, no significant improvements in psychomotor vigilance or peak power on anaerobic exercise performance were found, although mood was improved following the intervention (Famodu et al., 2017). Findings in athletes have generally been consistent with those of non-athletes, with sleep extension resulting in significant improvements in daytime alertness, attention/vigilance, and mood (Kamdar et al., 2004). Despite limitations in all of the aforementioned studies, including smaller sample sizes and a lack of control groups, the results provide evidence that sleep extension interventions have positive effects on performance and mood in college athletes and non-athletes.

A magnetic resonance imaging (MRI) study revealed that after nine days of sleep extension, negative mood and amygdala regional cerebral blood flow were significantly reduced (Motomura et al., 2017). It was hypothesized that the sleep extension may have optimized mood regulation by enhancing the functional connectivity between the amygdala and the prefrontal cortex (PFC), which sends inhibitory input to the amygdala. This is consistent with the loss of functional connectivity between the amygdala and the medial PFC following sleep deprivation (Yoo et al., 2007). In addition, a brain event-related potential (ERP) study revealed the positive effects on fronto-central brain regions and their associated functions after one week of sleep extension in habitual short sleepers (Gumenyuk et al., 2013). Consequently, extending sleep beyond habitual amounts may benefit waking functions more reliant on the PFC including attention (Drummond et al., 2005), executive functions (Yuan & Raz, 2014), and motivation (Kouneiher et al., 2009). Cognitive processes less dependent upon prefrontal cortex functioning may be less affected by variations in sleep duration (Wilckens et al., 2012).

Researchers have investigated the impact of “sleep banking”, which is extending sleep durations prior to periods of sleep loss, and have revealed that sleep extension is an effective strategy for prophylactically mitigating the deleterious effects of subsequent sleep loss. Benefits of sleep banking have been demonstrated for both cognitive (attention/vigilance) and motor (aerobic/endurance exercise) performance for both sleep restriction and sleep deprivation (Arnal et al., 2016; Arnal et al., 2015; Rupp et al., 2009). In these studies, sleep was extended (10 hours time in bed per night) for six to seven consecutive nights and the salutary effects on cognitive and motor performance were immediately evident, as were benefits with respect to recovery from sleep loss – i.e., by reducing the amount of recovery sleep needed to return to baseline levels of alertness and performance.

To date, relatively little research has been conducted to determine the extent to which sleep extension strategies might prove useful in operational environments, and there have been no well-controlled studies on the immediate and residual effects of sleep extension on executive and cognitive motor performance in college tactical athletes. The primary aim of this study was to investigate the immediate effects of sleep extension on the performance of college tactical athletes enrolled in ROTC. A second aim was to determine whether any effects of sleep extension remained detectable four days after the participants had resumed their habitual sleep schedules. It was hypothesized that there would be immediate improvements in attention/vigilance, executive function measures, standing broad jump performance, and motivation following the sleep extension intervention. Lastly, it hypothesized that participants would resume their habitual sleep schedules following the sleep extension intervention period, and that all behavioral effects of sleep extension would dissipate after four nights of non-extended, ad-lib sleep.

3.3 Methods

3.3.1 Participants

Young college students (age 18-30 years), at the University of Maryland, College Park enrolled in any ROTC program, were invited to participate in the study.

Participants were recruited by word of mouth and with advertisement flyers posted in ROTC training areas. Participants were excluded if they had a self-reported history of psychiatric disorder, took medications with sleep-related side effects, used illicit drugs, or self-reported that they averaged more than 8.5 hours of sleep per 24-hours, or if they extended their sleep by more than 90 minutes per night on weekend nights compared to weekday nights, or if they did not feel like they could comply with the study procedures after the details were explained to them. The study was approved by the University of Maryland Institutional Review Board and written informed consent was obtained from all participants.

3.3.2 Study Design/Experimental Timeline

This study utilized a two (Group) x three (Time) design to investigate the immediate and residual effects of a short-term sleep extension intervention on a cognitive motor test battery. This was accomplished by conducting a randomized controlled trial, assigning participants into a "sleep extension group" or a "control group", over fifteen nights. Every participant's "Day 1" was a Monday to control for weekday/weekend sleep patterns. During the first seven days/nights, all participants were instructed to sleep as they habitually do to in order to establish habitual sleep patterns. The sleep manipulation/intervention period lasted the next four days/nights (nights 8-11). During this period, the sleep extension group participants were instructed to sleep more than they habitually do with the goal of spending 10 hours in bed each night. If participants were unable to spend 10 hours in bed during the nighttime/morning hours, they were asked in spend any additional time in bed during the day to reach the 10 hours. The control group participants were instructed to remain on their habitual sleep schedule. After the intervention phase, all participants were instructed to resume their habitual sleep patterns for the last four days/nights (nights 12-15). Performance testing took place after the first seven nights of habitual sleep (Pre-Test), after the four-night intervention period (Post-Test), and after the four nights following the intervention period (Follow-up). Participants were notified of their assigned group after they performed their first performance testing. Participants were paid $50 at the end of the study if they successfully completed the entire study.

3.3.3 Sleep-wake Monitoring

With the goal of measuring sleep-wake patterns in the participants' natural sleep environment, participants wore actigraph watches and completed consensus sleep diaries (Carney et al., 2012) in their own home environment for the entire duration of the study. We used the Actiwatch 2 Watch (and Actiware Software actigraphy system) and participants were instructed to wear the watch 24 hours a day for the duration of the study on their non-dominant arm. In addition to using the sleep diary to record their sleep-wake activity, they were asked to annotate anytime they removed their watch. Participants received daily reminders via text messaging to keep their actigraph watches on and keep up-to-date on their sleep diaries. The raw actigraphy data (1-min epoch length) were analyzed after the participant completed the study. Actigraphic sleep data were analyzed using a validated proprietary algorithm within the commercial software (Actiware software, Philips Respironics, Andover, MA*)*. The consensus sleep diary was used primarily to help validate scoring the actrigraphic data.

Actigraphy is a widely accepted method of using accelerometers to measure participant movement to quantify sleep-wake activity (Littner et al., 2003). Actigraphy is known to be a reliable and valid measure to study sleep in a natural environment (Kushida et al., 2001; Morgenthaler et al., 2007). Wrist actigraphy has been validated against polysomnography, which is considered the gold standard for measuring all sleep parameters, including: sleep duration, efficiency, and fragmentation (Ancoli-Israel et al., 2015).

3.3.4 Performance Testing

Every participant was tested on a day 8 (Monday), day 12 (Friday), and day 16 (Tuesday). Testing was conducted in the same laboratory room with consistent temperature/lighting/noise/etc. To control for the effects of caffeine on performance, participants were instructed to refrain from any caffeine intake within 6 hours of their testing time. Testing times were equally distributed between groups in order to control for impacts of circadian rhythms. Likewise, participants had to test within an hour of their original test time.

Testing order and procedures remained the same on each day for all participants. Upon arrival for testing, participants confirmed they had not consumed caffeine over the previous 6 hours and completed questionnaires on their sleepiness and state anxiety. After the questionnaires, the participants performed the *Cognitive Motor Test Battery* (in order or performance): Psychomotor Vigilance Test – 5-minute version, Flanker Task, the Trail Making Task (A and B), Symbol Digit Modalities Task (SDMT) (written and oral versions), and a maximum standing broad jump (3 times). Following the cognitive motor test battery, participants were asked to annotate their motivation levels to perform the cognitive tasks (as a whole) and the standing broad jumps using a 100-mm Visual Analogue Scale (VAS) (anchors: No motivation, Highest possible motivation).

Daytime sleepiness was recorded using the Epworth Sleepiness Scale (ESS) (Johns, 1991) and the Karolinska Sleepiness Scale (KSS) (Akerstedt & Gillberg, 1990). The ESS measures sleep propensity in 8 standardized situations on a 0-3 scale, with higher scores reflecting greater sleepiness and is a simple and reliable method for measuring sleepiness in adults (Johns, 1992). The KSS assesses subjective sleepiness on a 9-point scale ranging from 1 (Extremely alert) to 9 (Extremely sleepy, great effort to keep awake, fighting sleep) and has been shown to be valid in measuring sleepiness (Kaida et al., 2006). The State-Trait Anxiety Inventory (STAI) was used to measure anxiety (Spielberger, 1983) prior to performing the cognitive motor battery.

A 5-minute modified version of the Psychomotor Vigilance Task (PVT) (Thorne et al., 1985) was administered on the computer using the PEBL software program (Mueller & Piper, 2014). Each 5-minute trial consisted of stimuli (red circle on computer monitor) occurring at intervals ranging from 2 to 5 seconds after each response from the participant. Participants responded to the stimuli by pressing the spacebar on the keyboard as quickly as possible. The primary outcomes of interest were mean reaction time and number of lapses (reaction times > 500 milliseconds).

A modified version of the Flanker Task (Eriksen & Eriksen, 1974) was administered on the computer using the PEBL software program (Mueller & Piper, 2014). Each trial consisted of either congruent (<<<<<, >>>>>) or incongruent

(<<><<, >><>>) arrow stimuli presented on the computer screen, with the middle arrow being the target stimulus. Throughout the task, congruent and incongruent trials appeared in random order and pointed in the right and left direction. The participant pressed the left-shift button if the target stimulus pointed to the left and a right-shift button if the target stimulus pointed to the right. Participants were instructed to respond as quickly and accurately as possible. The inter-trial interval (ITI) was 1,000 ms and if the participant responded after 1,500 ms, the trial was counted as an error of omission. Participants performed a brief practice trial prior to beginning the experimental task. One block of 200 trials was presented, with 100 congruent trials and 100 incongruent trials. Only correct responses were used in the analysis. We measured mean reaction time on the congruent trials and incongruent trials. Also, and interference score using the following equation,

$$\frac{incongruent\ mean\ RT - congruent\ mean\ RT}{congruent\ mean\ RT}\ x\ 100$$

was calculated as a metric of inhibitory control unbiased by differences in base reaction time (Colcombe et al., 2004; Liu-Ambrose et al., 2012; Wilckens, Erickson, et al., 2016).

The Trail Making Test A (TMT-A) and B (TMT-B)(Lezak, 1995) were administered with pen and paper. Part A (TMT-A) involved the participants drawing a line between consecutive encircled numbers in ascending order, from 1 to 25. Part B (TMT-B) involved the participant connecting 25 encircled numbers and letters in an alternating progressive sequence (i.e., 1 to A to 2 to B) from 1 to 13. TMT-A and TMT-B were timed to completion events. In addition, the difference between TMT-B and TMT-A was calculated.

The Symbol Digit Modalities Test (SDMT) (Smith, 1982) was administered on pen and paper. At the top of the page, there was a key that paired 9 numbers with 9 corresponding geometric figures. Below the key, there were rows of only symbols and the participant was given 90 seconds to write as many numbers associated with symbols as possible. The total number of correctly completed numbers in 90 seconds was the score derived from this test. The participants completed a written and oral version of the test. The combination of the written and oral version was calculated as the total score.

The last test was a gross motor task, where the participant performed three single maximum effort standing broad jumps. Participants stood with their toes behind a start line and were instructed to "jump as far as possible" while landing with both feet. Performance was the measurement from the line to the posterior heel that was closest to the start line. Participants were allowed up to two minutes of between-trial recovery between jumps. Performance was measured as the average of the three jumps.

3.3.5 Statistical Analysis

All statistical analyses were performed using SPSS 24.0 (SPSS Inc., Chicago, IL, USA). Mean total sleep durations were calculated during the first 7 nights, nights 8-11, and nights 12-15 to account for the test periods described above. Mean scores on each questionnaire and test of the cognitive motor battery were calculated during each testing period (pre-, post-test, and follow-up). Independent sample t-tests were conducted to compare the two groups on the initial habitual sleep amounts and the baseline testing (pre-test). Paired t-tests were conducted to evaluate the within-group mean score changes between the pre-test and post-test, as well as between pre-test and follow-up. In addition, between group comparisons of mean pre- to post-test score changes and mean pre-test to follow-up score changes were performed using independent sample t-tests. *P* values <.05 were considered statistically significant. Standard deviations were recorded with mean values unless otherwise stated.

3.4 Results

3.4.1 Participants

57 participants provided written consent and started the study, seven of these participants were excluded from the analysis (including two who did not wear the actigraph during the study, two whose actigraphs did not activate properly or capture the entire study duration, and three who did not re-test within an hour of their original test time). A total of 50 (25 in each group) tactical athletes, who were members of each ROTC branch (Air Force, Army, Navy) at the University of Maryland, College Park, completed the study. There were no significant differences between the extension group and control group in age (20.12 ± 2.01 years versus 19.76 ± 1.09 years, $p = .449$), height (1.71 ± 0.09 m versus 1.70 ± 0.09 m, $p = .559$), weight (70.55 ± 9.70 kg versus 66.37 ± 11.31 kg, $p = .167$), BMI (24.00 ± 2.47 kg/m^2 versus 22.95 ± 2.73 kg/m^2, $p = .159$), or trait anxiety (33.92 ± 9.38 versus 33.84 ± 9.78, $p = .977$). Table 3.1 provides demographic information and characteristics for each group of the study population.

3.4.2 Sleep Duration

Using actigraphy data, the mean habitual sleep durations during the first seven nights did not differ between the sleep extension group (6.19 ± 0.67 hours) and the control group (6.20 ± 0.73 hours) ($p = .962$). During the four-night intervention period, the sleep extension group significantly increased their average sleep time (1.36 ± 0.71 hours, $p < .001$), but the control group did not (-0.25 ± 0.78 hours, $p = .121$) compared to the baseline habitual sleep durations. There was a significant between-group difference of these mean changes ($p < .001$). Compared to the baseline habitual sleep durations of the first seven nights, the last four-night habitual sleep durations did not significantly differ for either the sleep extension group (0.08 ± 0.60 hours, $p = .531$) or the control group (0.21 ± 0.74 hours, $p = .173$). There were no significant between-group differences between these mean changes ($p = .490$). In addition, when comparing habitual sleep durations of the last four-nights to the same four nights of the week (Friday, Saturday, Sunday, Monday) from the baseline habitual period, there were no significant differences within the extension group (-0.16 ± 0.65 hours, $p = .233$) or the control group (0.09 ± 0.98 hours, $p = .638$) and there were no significant between-group differences between these mean changes ($p = .490$). Average sleep durations for each group during each respective time period are listed in Appendix A.

3.4.3 Immediate Impact of Sleep Extension

3.4.3.1 Daytime Sleepiness and Anxiety

At baseline, there was no significant difference in mean KSS ratings between the sleep extension group (5.00 ± 1.44) and the control group (4.48 ± 1.71) (*p* = .251). Compared to baseline, the mean immediate post-test KSS rating for the sleep extension group significantly decreased (-1.92 ± 1.47, *p* < .001), but the control group did not (-0.20 ± 1.96, *p* = .614). There was a significant between-group difference of these mean changes (*p* = .001) (Table 3.2 and Figure 3.1).

At baseline, there was no significant difference in mean ESS ratings between the sleep extension group (8.40 ± 2.69) and the control group (9.12 ± 3.88) (*p* = .499). Compared to baseline, the mean immediate post-test ESS rating for the sleep extension group significantly decreased (-2.28 ± 2.73, *p* < .001), but the control group did not (0.76 ± 2.42, *p* = .129). There was a significant between-group difference of these mean changes (*p* < .001) (Table 3.2).

At baseline, there was no significant difference in mean state anxiety ratings between the sleep extension group (32.32 ± 8.57) and the control group (31.04 ± 9.65) (*p* = .622). Compared to baseline, the mean immediate post-test state anxiety score for the sleep extension group significantly decreased (-3.36 ± 6.78, *p* = .021), but the control group did not (*M* = -0.04 ± 6.33, *p* = .975). However, there was no significant between-group difference of these mean changes (*p* = .080) (Table 3.2).

Mean daytime sleepiness and anxiety scores for each group and test period are listed in Appendix B.

3.4.3.2 Cognitive Motor Battery and Motivation

Mean scores for each group at each test period are listed in Appendix C. Mean motivation levels for each group and test period are listed in Appendix B.

Psychomotor Vigilance Task:

Total lapses and mean reaction time were evaluated. At baseline, there was no significant difference in mean PVT lapses between the sleep extension group (0.92 ± 1.75) and the control group (1.32 ± 3.01) ($p = .569$). Compared to baseline, the mean immediate post-test lapses did not significantly change for either the sleep extension group (-0.40 ± 2.14, $p = .360$) or the control group (-0.20 ± 0.96, $p = .307$) and there was no significant between-group difference of these mean changes ($p = .672$) (Table 3.3).

At baseline, there was no significant differences in mean PVT reaction time between the sleep extension group (306.10 ± 34.78 ms) and the control group (299.90 ± 39.40 ms) ($p = .558$). Compared to baseline, the mean immediate post-test PVT reaction time for the sleep extension group significantly decreased (-16.09 ± 26.07 ms, $p = .005$), but the control group did not (-1.75 ± 17.16 ms, $p = .615$). There was a significant between-group difference of these mean changes ($p = .026$) (Table 3.3 and Figure 3.2).

Flanker Task:

Congruent reaction time, incongruent reaction time, and an interference score were evaluated. At baseline, there was no significant difference in mean congruent reaction times between the sleep extension group (424.64 ± 43.33 ms) and the control group (421.38 ± 56.26 ms) ($p = .819$). Compared to baseline, the immediate post-test mean congruent reaction times significantly decreased for both the sleep extension group (-33.02 ± 26.31 ms, *p* < .001) and the control group (-21.38 ± 35.51 ms, *p* = .006) and there was no significant between-group difference of these mean changes (*p* = .194) (Table 3.3).

At baseline, there was no significant difference in mean incongruent reaction times between the sleep extension group (*M* = 497.96 ± 54.42 ms) and the control group (*M* = 492.29 ± 72.82 ms) (*p* = .756). Compared to baseline, the mean immediate post-test mean incongruent reaction times significantly decreased for both the sleep extension group (*M* = -38.72 ± 28.50 ms, *p* < .001) and the control group (*M* = -24.55 ± 53.99 ms, *p* = .032) and there was no significant between-group difference of these mean changes (*p* = .251) (Table 3.3).

At baseline, there were no significant differences in mean interference score between the sleep extension group (17.36 ± 6.39) and the control group (16.74 ± 4.97) (*p* = .701). Compared to baseline, the mean immediate post-test interference score did not significantly differ for the sleep extension group (-0.01 ± 4.76, *p* = .994) or the control group (0.47 ± 5.26, *p* = .661) and there were no significant between-group differences of these mean changes (*p* = .740) (Table 3.3).

Trail Making Test:

At baseline, there were no significant differences in mean TMT-A times between the sleep extension group (25.86 ± 5.03 s) and the control group (24.83 ± 4.75 s) (*p* = .462). Compared to baseline, the mean immediate post-test TMT-A times significantly decreased for both the sleep extension group (-5.90 ± 5.04 s, *p* < .001) and the control group (-4.70 ± 4.38 s, *p* < .001) and there was no significant between-group difference of these mean changes (*p* = .373) (Table 3.3).

At baseline, there was no significant difference in mean TMT-B times between the sleep extension group (52.05 ± 9.14 s) and the control group (50.34 ± 11.10 s) (*p* = .553). Compared to baseline, the mean immediate post-test TMT-B times significantly decreased for both the sleep extension group (-11.77 ± 6.67 s, *p* < .001) and the control group (-7.07 ± 7.77 s, *p* < .001). There was a significant between-group difference of these mean changes (*p* = .027) (Table 3.3 and Figure 3.3).

At baseline, there were no significant differences in mean TMT B-A times between the sleep extension group (26.19 ± 9.68 s) and the control group (25.50 ± 10.72 s) (*p* = .812). Compared to baseline, the mean immediate post-test TMT B-A times for the sleep extension group significantly decreased (-5.86 ± 8.74 s, *p* = .003), but the control group did not (-2.37 ± 9.14 s, *p* = .208). However, there was no significant between-group difference of these mean changes (*p* = .173) (Table 3.3).

Symbol Digit Modalities Test:

At baseline, there was no significant differences in mean SDMT total between the sleep extension group (125.96 ± 22.30) and the control group (130.48 ± 12.96) (*p* = .385). Compared to baseline, the mean immediate post-test SDMT total significantly increased for both the sleep extension group (10.92 ± 10.12, *p* < .001) and the control group (10.76 ± 10.49, *p* < .001) and there was no significant between-group difference of these mean changes (*p* = .956) (Table 3.3).

Standing Broad Jump:

At baseline, there was no significant difference in mean average jump distance between the sleep extension group (170.10 ± 32.43 cm) and the control group (178.56 ± 37.28 cm) (*p* = .369). Compared to baseline, the mean immediate post-test average jump distance for the sleep extension group significantly increased (9.07 ± 8.21 cm, *p* < .001) and the control group did not (-2.31 ± 9.18 cm, *p* = .221). There was a significant between-group difference of these mean changes (*p* < .001) (Table 3.3 and Figure 3.4).

Motivation to Perform Cognitive Tests:

At baseline, there was no significant differences in mean motivation to perform the cognitive tests between the sleep extension group (85.72 ± 13.04 mm) and the control group (83.92 ± 12.12 mm) (*p* = .616). Compared to baseline, the mean immediate post-test motivation for the sleep extension group did not significantly change (4.44 ± 11.85 mm, *p* = .073), but the control group's significantly decreased (-7.04 ± 13.63 mm, *p* = .016). There was a significant between-group difference of these mean changes (*p* = .003) (Table 3.2 and Figure 3.5).

Motivation to Perform Gross Motor Task:

At baseline, there was no significant difference in mean motivation to perform the gross motor task between the sleep extension group (87.32 ± 11.66 mm) and the control group (87.64 ± 9.61 mm) (*p* = .916). Compared to baseline, the mean immediate post-test motivation for the sleep extension group significantly increased (4.36 ± 6.78 mm, *p* = .004), but the control group did not (-1.60 ± 8.69 mm, *p* = .367).

There was a significant between-group difference of these mean changes (*p* = .009) (Table 3.2 and Figure 3.6).

3.4.4 Residual Impact of Sleep Extension after Returning to Habitual Sleep

3.4.4.1 Daytime Sleepiness and Anxiety

At follow-up, compared to baseline, the mean KSS rating for the sleep extension group significantly decreased (-1.28 ± 1.77, *p* = .001), but the control group did not (-0.60 ± 1.68, *p* = .087). There was no significant between-group difference of these mean changes (*p* = .170) (Table 3.4).

At follow-up, compared to baseline, the mean ESS rating did not significantly differ for the sleep extension group (-0.80 ± 2.55, *p* = .130) or the control group (0.08 ± 1.91, *p* = .836) and there was no significant between-group difference of these mean changes (*p* = .174) (Table 3.4).

At follow-up, compared to baseline, the mean state anxiety score did not significantly change for either the sleep extension group (-0.60 ± 5.04, *p* = .557) or the control group (2.60 ± 8.67, *p* = .147) and there was no significant between-group difference of these mean changes (*p* = .117) (Table 3.4).

3.4.4.2 Cognitive Motor Battery and Motivation

Psychomotor Vigilance Task:

At follow-up, compared to baseline, the mean PVT lapses did not significantly change for either the sleep extension group (0.08 ± 2.25, *p* = .861) or the control group (0.32 ± 1.75, *p* = .369) and there was no significant between-group difference of these mean changes (*p* = .676) (Table 3.5).

At follow-up, compared to baseline, the mean PVT reaction time did not significantly change for either the extension group (-9.48 ± 28.49 ms, *p* = .109) or the control group (-0.88 ± 26.84 ms, *p* = .871) and there was no significant between-group differences of these mean changes (*p* = .227) (Table 3.5).

Flanker Task:

At follow-up, compared to baseline, the mean congruent reaction times significantly decreased for both the sleep extension group (-33.91 ± 31.75 ms, *p* < .001) and the control group (-26.65 ± 41.38 ms, *p* = .004) and there was no significant between-group difference of these mean changes (*p* = .489) (Table 3.5).

At follow-up, compared to baseline, the mean incongruent reaction times significantly decreased for both the sleep extension group (-37.14 ± 32.03 ms, *p* < .001) and the control group (-39.17 ± 54.46 ms, *p* = .001) and there was no significant between-group difference of these mean changes (*p* = .873) (Table 3.5).

At follow-up, compared to baseline, the mean interference score was not significantly different for the sleep extension group (0.53 ± 4.37, *p* = .550), however, the control group's mean interference score significantly decreased (-1.79 ± 4.03, *p* = .036). There was no significant between-group difference of these mean changes (*p* = .056) (Table 3.5).

Trail Making Test:

At follow-up, compared to baseline, the mean TMT-A times significantly decreased for both the sleep extension group (-7.17 ± 5.01 s, *p* < .001) and the control group (-5.69 ± 4.60 s, *p* < .001) and there was no significant between-group difference of these mean changes (*p* = .282) (Table 3.5).

At follow-up, compared to baseline, the mean TMT-B times significantly decreased for both the sleep extension group (-15.68 ± 6.98 s, *p* < .001) and the control group (-12.27 ± 8.24 s, *p* < .001) and there was no significant between-group difference of these mean changes (*p* = .120) (Table 3.5).

At follow-up, compared to baseline, the mean TMT B-A times significantly decreased for both the sleep extension group (-8.51 ± 8.67 s, *p* < .001) and the control group (-6.57 ± 9.85 s, *p* = .003) and there was no significant between-group difference of these mean changes (*p* = .464) (Table 3.5).

Symbol Digit Modalities Test:

At follow-up, compared to baseline, the mean SDMT total significantly increased for both the sleep extension group (21.08 ± 11.53, *p* < .001) and the control group (19.04 ± 12.81, *p* < .001) and there was no significant between-group difference of these mean changes (*p* = .557) (Table 3.5).

Standing Broad Jump:

At follow-up, compared to baseline, the mean average jump distance for the sleep extension group significantly increased (9.47 ± 12.86 cm, *p* = .001) and the control group did not (-1.59 ± 9.48 cm, *p* = .411). Once again, there was a significant between-group difference of these mean changes (*p* = .001) (Table 3.5 and Figure 3.7).

Motivation to Perform Cognitive Tests:

At follow-up, compared to baseline, the mean motivation did not significantly differ for both the sleep extension group (2.60 ± 10.82, *p* = .241) or the control group

(-3.48 ± 12.41, *p* = .174) and there was no significant between-group difference of these mean changes (*p* = .071) (Table 3.4).

Motivation to Perform Gross Motor Task:

At follow-up, compared to baseline, the mean motivation did not significantly differ for both the sleep extension group (1.92 ± 6.11 mm, *p* = .129) or the control group (-3.28 ± 10.32 mm, *p* = .125). However, there was a significant between-group difference of these mean changes (*p* = .035) (Table 3.4 and Figure 3.8).

3.5 Discussion

The primary aim was to investigate the immediate impact of a short-term sleep extension intervention on performance in collegiate tactical athletes enrolled in ROTC. First, the sleep manipulation was successful in increasing the average sleep duration of about 6.2 hour by an average of about 1.4 hours over the four-night intervention, which was significantly more than the control group during that period. The intervention increased average sleep amounts to a level above the recommended seven hours (Watson et al., 2015). Compared to other sleep extension research, the 1.4 hour per night/day increase was more than the 0.4 hour per night/day increase observed in female track athletes (Famodu et al., 2017) and less than the 1.7-1.8 hour per night/day increase reported in basketball and tennis players (Mah et al., 2011; Schwartz & Simon, 2015). In these other studies, the duration of the sleep extension ranged from 1 to 7 weeks. In this study, the sleep intervention lasted for four nights, which may be more feasible for individuals with demanding schedules that may not be able to accommodate interventions of longer durations.

Second, compared to the control group, the sleep extension mean score changes were significantly better on mean PVT reaction time, TMT-B performance, and the average standing broad jump. The PVT is viewed as a “gold standard” for assessing the effects of sleep on cognition because of its high reliability, sensitivity to circadian rhythm influences, and minimal learning effects (Dinges et al., 1997; Killgore, 2010; Van Dongen, Maislin, et al., 2003) and is used extensively in sleep related research to assess attention/vigilance. Previous sleep extension research in athletes has shown that an average increase of 0.4 hours per night over 1 week did not improve PVT reaction times (Famodu et al., 2017), but an increase of 1.8 hours per night over 5-7 weeks did (Mah et al., 2011). The findings from this study add to the knowledge on how much additional sleep may be needed to improve vigilant attention (reaction times) in college tactical athletes. The between-group differences in mean score change on TMT-B performance provides evidence on executive functions that may benefit from sleep extension. Performance on the TMT-B requires executive functions of task-set inhibition ability, cognitive flexibility, and set-shifting (Arbuthnott & Frank, 2000; Langenecker et al., 2007). The sleep extension group also significantly improved their TMT-B-A time, a measure used to assess executive function (Arbuthnott & Frank, 2000; Salthouse, Atkinson, & Berish, 2003; Wilckens, Erickson, et al., 2016), however, there were no significant between-group mean change differences noted. To date, only one other study has reported improvements in executive function performance, using working memory tasks that tested visuospatial processing and divided attention, following two weeks of sleep extension (Dewald-Kaufmann et al., 2013). Executive functions have been hypothesized to be the vital for other athletic performance (Simpson et al., 2017) and it is plausible that executive functions in tactical athletes are equally important. The results of this study reveal aspects of motor performance that may benefit from sleep extension considering the standing broad jump is considered a general index of muscular fitness (Castro-Pinero et al., 2010) and in collegiate athletes, it has been highly related/correlated to muscular strength, peak power output, vertical jumping ability, agility, sprint acceleration, and sprint velocity (Peterson, Alvar, & Rhea, 2006). Supportive of this, one study has found sprint improvements in athletes following sleep extension (Mah et al., 2011). Another study has found that sleep extension resulted in significantly longer time to exhaustion while performing a submaximal isometric knee extensor exercise (Arnal et al., 2016). Overall, the sleep extension intervention provided an immediate enhancement of both cognitive and motor performance.

Third, immediately following the intervention, compared to the control group, the sleep extension mean score changes were significantly different on subjective sleepiness and motivation to perform the cognitive tasks and the gross motor tasks. The findings on subjective sleepiness improvements are consistent to what has been found in sleep extension in other college athletes (Mah et al., 2011; Schwartz & Simon, 2015). The sleep extension group had significant reduction on both the KSS and the ESS, which indicates that following the intervention participants self-reported feeling less sleepy, or more alert. This is the first study to report improvements in motivation levels following sleep extension. While the changes in motivation levels were modest, the improved motivation to perform a task may be a potential pathway by which sleep extension benefits human performance. It is possible that increased motivation levels leads to increased “attentional effort” during a task (Sarter et al., 2006), resulting in improved performance. However, because motivation levels were asked after the participant performed the task, it is also possible that how participants perceived their own performance on a task may have confounded how they reported their motivation. Collectively, the decrease in subjectively sleepiness and improvement in motivation levels likely contributed to the performance benefits following sleep extension.

The results immediately following the sleep extension intervention partially supported the hypotheses. Because of neuroimaging studies have shown sleep extension positively impacts prefrontal and other fronto-central brain regions (Gumenyuk et al., 2013; Motomura et al., 2017), it was hypothesized that extending sleep beyond habitual amounts would have positive impacts on waking functions more reliant on the prefrontal areas like attention, executive functions, and motivation. Likewise, cognitive processes, like cognitive processing speed, that are less supported by the prefrontal region may be less impacted by sleep (Wilckens et al., 2012). The TMT-A and SDMT have both been used to access processing speed (Wilckens et al., 2014) and, as predicted, even though both groups significantly improved their performance on these tasks, likely as a result of a learning effect, there were no significant between-group mean score change differences. There were also no significant between-group mean score change differences on the flanker interference score, which has previously been reported to reflect the execution function of inhibitory control (Colcombe et al., 2004; Liu-Ambrose et al., 2012; Wilckens, Erickson, et al., 2016). One possibility of this finding is that different executive functions may be more or less affected by sleep manipulations, which has been hypothesized in sleep deprivation research (Killgore, 2010). The hypothesis that the sleep extension group would improve more than the control group on the standing broad jump, which was made because of previous research showing sprint improvements following sleep extension (Mah et al., 2011) and the standing broad jump being highly related to sprint acceleration and velocity (Peterson et al., 2006), was supported.

A secondary aim was to determine the extent to which effects of sleep extension persist following resumption of habitual sleep schedules for four nights. Following the sleep extension intervention, the sleep extension group returned to their habitual normal sleep durations levels. After returning to habitual sleep amounts for four nights, the standing broad jump was the only test from the cognitive motor battery that had a significant between-group difference in mean score change from pre-test to follow-up. The extension group essentially maintained the nine-centimeter improvement that was observed immediately following the sleep extension intervention. Similarly, the only other significant between-group difference in mean score change from pre-test to follow-up was the motivation to perform the standing broad jump. As previously hypothesized, the difference in motivation levels between groups may elucidate the reason for the difference in performance during the standing broad jump. There appears to be residual benefits for four days after a short-term sleep extension intervention still present on a gross motor task and motivation to perform the gross motor task, but not on the cognitive tasks when participants return to their habitual sleep amounts.

The main limitation of this study was that both the researcher and the participants were not blinded to the group assignments. Because participants were aware of their group assignment, this may have impacted effort and motivation levels to perform the tasks. However, participants were not aware of their group assignment until after the pre-test and there was a positive association between baseline habitual sleep amounts and pre-test motivation levels. It should also be noted that the age range in the study was 18-26 years that were tactical athletes enrolled in ROTC. It is unknown whether older adults or if other tactical athletes (ie. law enforcement, fire response, etc) would demonstrate similar results. Future studies should utilize older adults as well as other tactical athlete professions to help clarify changes in response to a sleep extension intervention across the lifespan and within other professions.

Some of the strengths of the study include a larger sample size and the utilization of a control group, both of which are lacking in most sleep extension research, especially in an athlete population. Caffeine intake was controlled for by limiting caffeine intake for 6 hours prior to testing. Testing times were matched between groups to control for the circadian impact on performance. Weekday/weekend sleep patterns were controlled for by having all participants started on the same day of the week. The four-night intervention utilized may be more feasible than longer duration interventions for individuals with busier schedules. In addition, a diverse battery of tests and questionnaires were utilized to help test the hypotheses and to determine which types of tests are impacted by extending sleep amount. The utilization of a sample of college tactical athletes that are training to become future leaders in all three services of the U.S. military helps provide some insight on their habitual sleep patterns and how to potentially enhance their performance in the future.

Future research should include neuroimaging during the testing to further understand how a short-term sleep extension intervention may impact the neural dynamics during performance, with a focus on the frontal regions of the brain. Future research may want to expand on the cognitive motor battery, such as other executive function tasks, like decision making, or other motor/physical tasks, like endurance tasks or agility tasks, in order to determine what types of tasks may be positively impacted by increased sleep amounts. Increasing test frequency may also provide a way to determine a dose-response to the intervention and for how long they last. Lastly, investigating other tactical athlete populations and using job specific outcome measures may help determine if sleep extension is a tool that could potentially be used by other professions where cognitive and motor performance is vital.

3.6 Conclusions

This study was the first to investigate the immediate and residual impacts of a short-term (four-night) sleep extension intervention in college tactical athletes. Four nights of sleep extension resulted in immediate benefits in alertness, psychomotor vigilance/attention, executive function performance, standing broad jump performance, and motivation levels. Collectively, the immediate cognitive and motor benefits from sleep extension will likely optimize or enhance occupational performance in professions that rely on both. Benefits of sleep extension were still evident four days after resumption of habitual sleep schedules on the broad jump performance and motivation level to perform the jump. While the majority of the benefits of sleep extension dissipate after four nights, there appears to be ongoing motor benefits that persist, which may continue to contribute to enhanced occupational performance in tactical athletes. Considering the cognitive and motor performance improvements noted following sleep extension, a four-night intervention could be useful tool for tactical athletes looking to enhance their overall performance.

Table 3. 1. Demographic Information of Participants

	Sleep Extension Group	Control Group	p-value
# of participants, n	25	25	
Gender			
Male	12 (48.0%)	13 (52.0%)	
Female	13 (52.0%)	12 (48.0%)	
Age, years	20.12 ± 2.01	19.76 ± 1.09	.449
Height (m)	1.71 ± 0.09	1.70 ± 0.09	.559
Weight (kg)	70.55 ± 9.70	66.37 ± 11.31	.167
BMI (kg/m^2)	24.00 ± 2.47	22.95 ± 2.73	.159
Trait Anxiety (STAI Y2)	33.92 ± 9.38	33.84 ± 9.78	.977
Ethnicity			
African American	0 (0%)	4 (16.0%)	
Asian/Pacific Islander	3 (12.0%)	6 (24.0%)	
Caucasian/White	21 (84.0%)	15 (60.0%)	
Hispanic	1 (4.0%)	0 (0%)	
ROTC Branch			
Air Force	6 (24.0%)	5 (20.0%)	
Army	13 (52.0%)	16 (64.0%)	
Navy	6 (24.0%)	4 (16.0%)	
School Year			
Freshman	5 (20.0%)	3 (12.0%)	
Sophomore	6 (24.0%)	8 (32.0%)	
Junior	9 (36.0%)	6 (24.0%)	
Senior	3 (12.0%)	8 (32.0%)	
Graduate	2 (8.0%)	0 (0%)	

Data are presented as mean ± standard deviation unless otherwise indicated. BMI = body mass index. STAI = State-Trait Anxiety Inventory.

Table 3. 2. Immediate Impact of Sleep Extension on Sleepiness, Motivation, and Anxiety

Between group comparison of mean pre-test to post-test score change on subjective sleepiness, motivation, and anxiety

	Extension	Control	p-value
KSS	-1.92 ± 1.47	-0.20 ± 1.96	.001**
ESS	-2.28 ± 2.73	0.76 ± 2.42	<.001***
Motivation			
Cognitive Tests	4.44 ± 11.85	-7.04 ± 13.63	.003**
Standing Broad Jump	4.36 ± 6.78	-1.60 ± 8.69	.009**
State Anxiety (STAI Y1)	-3.36 ± 6.78	-0.04 ± 6.33	.080

Data are presented as mean ± standard deviation; KSS = Karolinska Sleepiness Scale; ESS = Epworth Sleepiness Scale; STAI = State-Trait Anxiety Inventory; *: p < .05; **: p < .01; ***: p < .001.

Table 3. 3. Immediate Impact of Sleep Extension on Cognitive Motor Battery

Between group comparison of mean pre-test to post-test score change on cognitive motor battery

	Extension Grp	Control Grp	p-value
PVT			
Mean RT (ms)	-16.09 ± 26.07	-1.75 ± 17.16	.026*
Lapses (>500 ms)	-0.40 ± 2.14	-0.20 ± 0.96	.672
Flanker Task			
Congruent RT (ms)	-33.02 ± 26.31	-21.38 ± 35.51	.194
Incongruent RT (ms)	-38.72 ± 28.50	-24.55 ± 53.99	.251
Interference Score	-0.01 ± 4.76	0.47 ± 5.26	.740
TMT			
TMT A (sec)	-5.90 ± 5.04	-4.70 ± 4.38	.373
TMT B (sec)	-11.77 ± 6.67	-7.07 ± 7.77	.027*
TMT B-A (sec)	-5.86 ± 8.74	-2.37 ± 9.14	.173
SDMT			
Total (Written and Oral)	10.92 ± 10.12	10.76 ± 10.49	.956
Standing Broad Jump			
Average Jump (cm)	9.07 ± 1.64	-2.31 ± 1.84	<.001***

Data are presented as mean ± standard deviation; PVT = Psychomotor Vigilance Task; TMT = Trail Making Test; SDMT = Symbol Digit Modalities Test; * < .05, *** < .001.

Table 3. 4. Residual Impact of Sleep Extension on Sleepiness, Motivation, and Anxiety

Between group comparison of mean pre-test to follow-up score change on subjective sleepiness, motivation, and anxiety

	Extension	Control	p-value
KSS	-1.28 ± 1.77	-0.60 ± 1.68	.170
ESS	-0.80 ± 2.55	0.08 ± 1.91	.174
Motivation			
Cognitive Tests	2.60 ± 10.82	-3.48 ± 12.41	.071
Standing Broad Jump	1.92 ± 6.11	-3.28 ± 10.32	.035*
State Anxiety (STAI Y1)	-0.60 ± 5.04	2.60 ± 8.67	.117

Data are presented as mean ± standard deviation; KSS = Karolinska Sleepiness Scale; ESS = Epworth Sleepiness Scale; STAI = State-Trait Anxiety Inventory; *: $p < .05$

Table 3. 5. Residual Impact of Sleep Extension on Cognitive Motor Battery

Between group comparison of mean pre-test to follow-up score change on cognitive motor battery

	Extension	Control	p-value
PVT			
Mean RT (ms)	-9.48 ± 28.49	-0.88 ± 26.84	.227
Lapses (>500 ms)	0.08 ± 2.25	0.32 ± 1.75	.676
Flanker Task			
Congruent RT (ms)	-33.91 ± 31.75	-26.65 ± 41.38	.489
Incongruent RT (ms)	-37.14 ± 32.03	-39.17 ± 54.46	.873
Interference Score	0.53 ± 4.37	-1.79 ± 4.03	.056
TMT			
TMT A (sec)	-7.17 ± 5.01	-5.69 ± 4.60	.282
TMT B (sec)	-15.68 ± 6.98	-12.27± 8.24	.120
TMT B-A (sec)	-8.51 ± 8.67	-6.57 ± 9.85	.464
SDMT			
Total (Written and Oral)	21.08 ± 11.53	19.04 ± 12.81	.557
Standing Broad Jump			
Average Jump (cm)	9.47 ± 12.86	-1.59 ± 9.48	.001**

Data are presented as mean ± standard deviation; PVT = Psychomotor Vigilance Task; TMT = Trail Making Test; SDMT = Symbol Digit Modalities Test; **: $p < .010$.

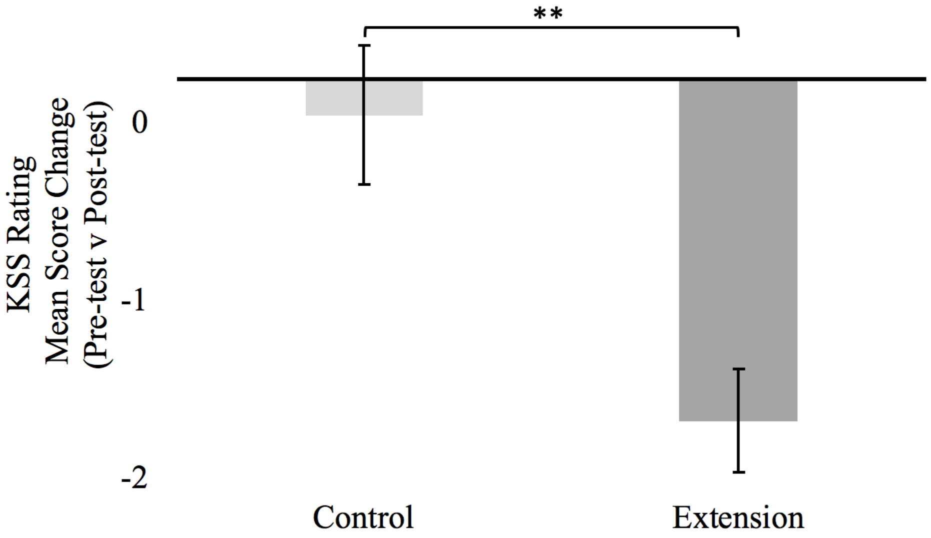

Figure 3. 1. Immediate impact of sleep extension on Karolinska Sleepiness Scale (KSS) rating at post-test.
Mean ± standard error. **: p < .01.

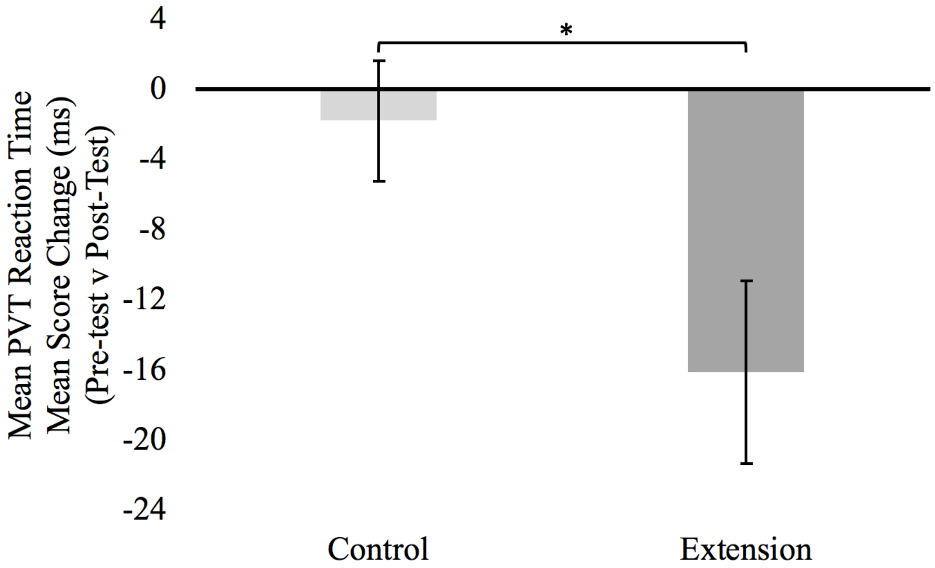

Figure 3. 2. Immediate impact of sleep extension on mean Psychomotor Vigilance Test (PVT) reaction time at post-test.
Mean ± standard error. *: p < .05.

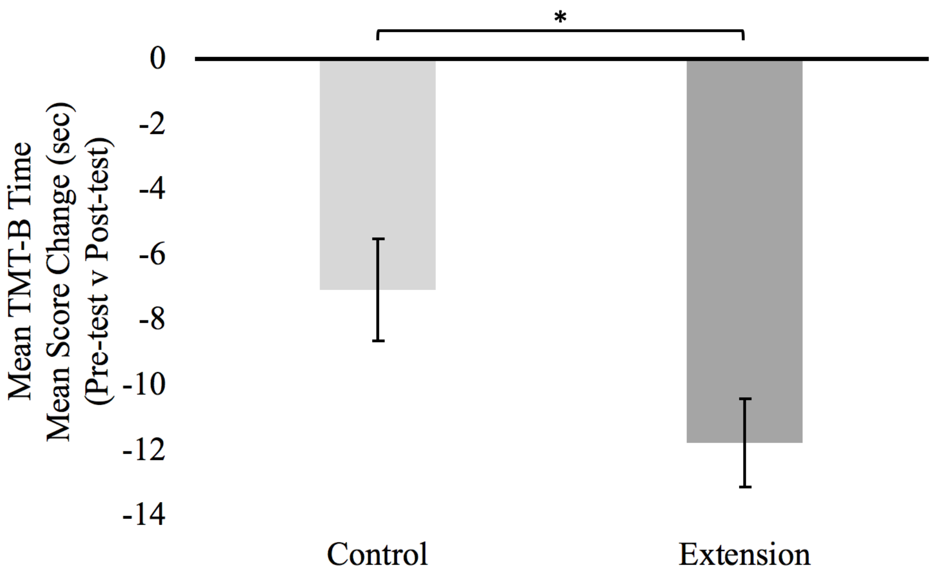

Figure 3. 3. Immediate impact of sleep extension on Trail Making Test-B (TMT-B) time at post-test.
Mean ± standard error. *: p < .05.

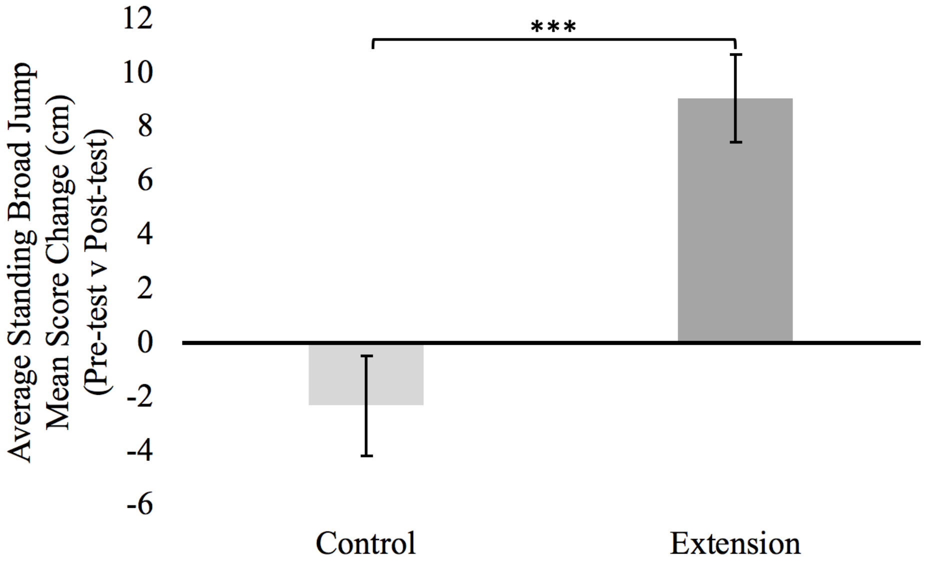

Figure 3. 4. Immediate impact of sleep extension on average standing broad jump at post-test.
Mean ± standard error. ***: p < .001.

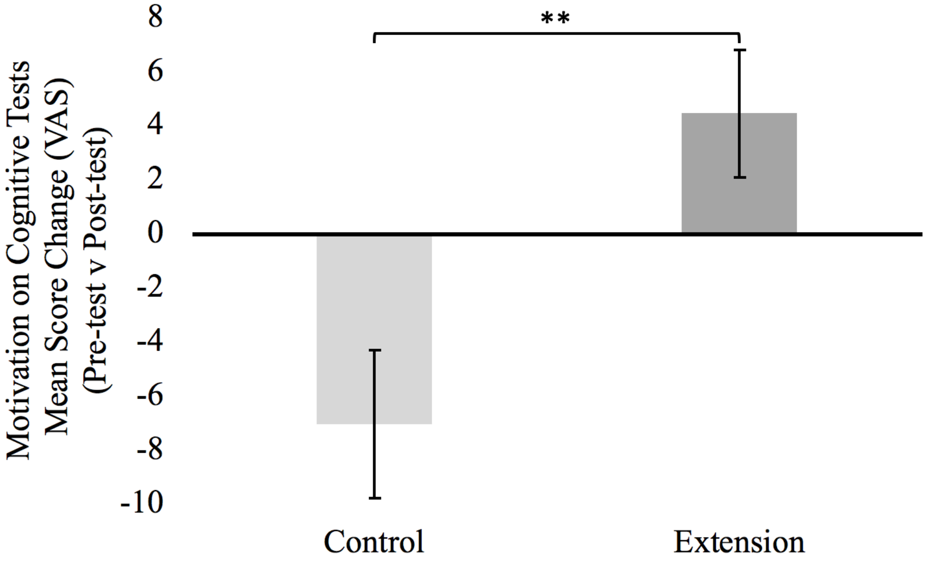

Figure 3. 5. Immediate impact of sleep extension on motivation to perform cognitive tests at post-test.
Mean ± standard error. **: p < .01.

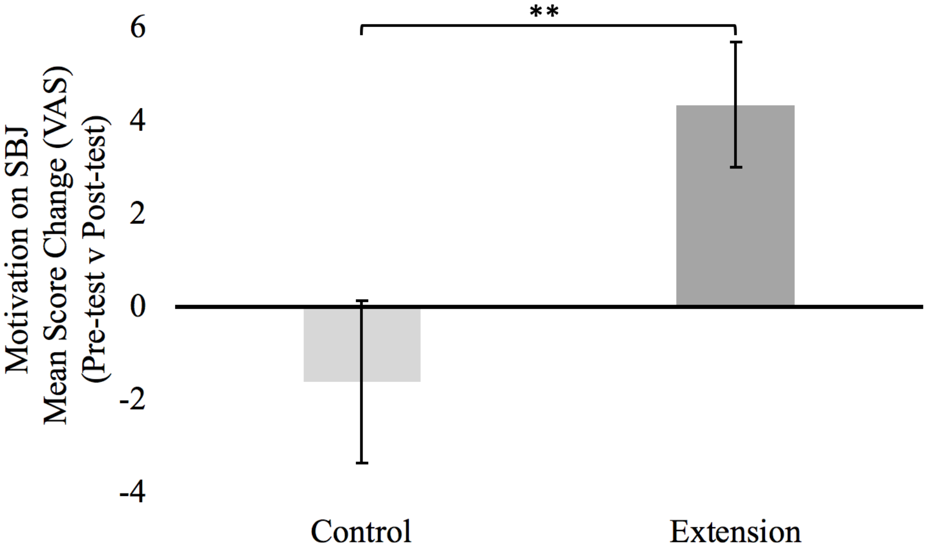

Figure 3. 6. Immediate impact of sleep extension on motivation to standing broad jump (SBJ) at post-test.
Mean ± standard error. **: p < .01.

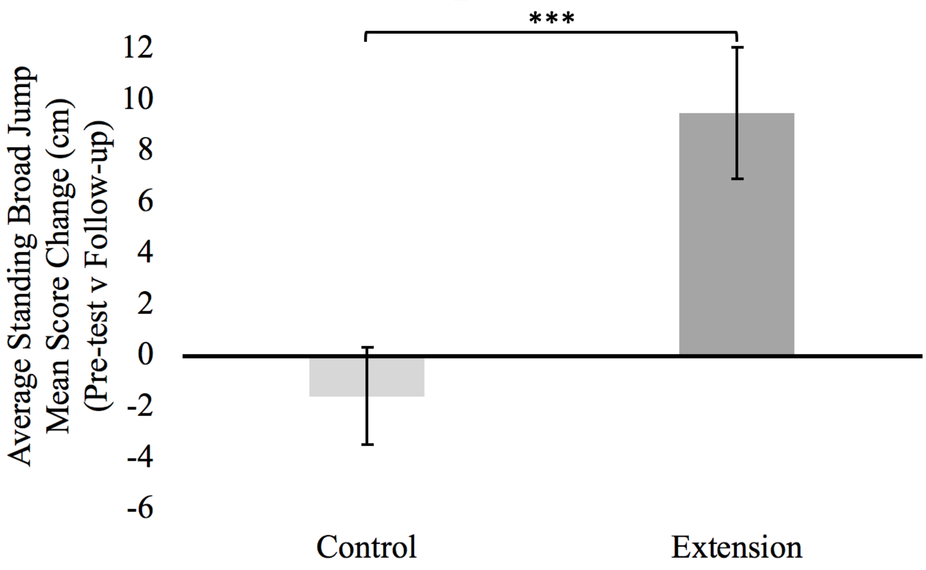

Figure 3. 7. Residual impact of sleep extension on average standing broad jump at follow-up.
Mean ± standard error. ***: p < .001.

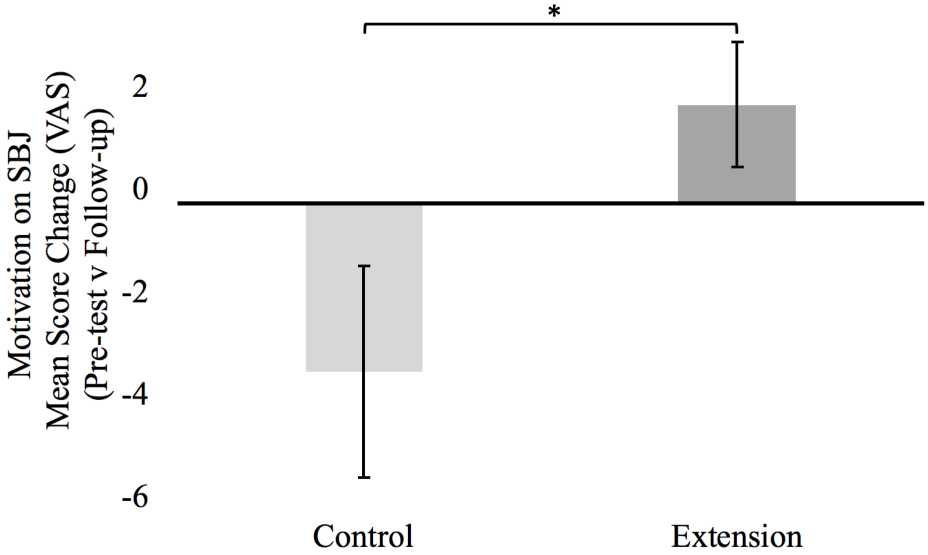

Figure 3. 8. Residual impact of sleep extension on motivation to perform standing broad jump (SBJ) at follow-up.
Mean ± standard error. *: p < .05.

Chapter 4: Dissertation Summary

The overall aim of this dissertation was to investigate how sleep extension impacts cognitive and motor performance in college tactical athletes enrolled in the Reserve Officers' Training Corps (ROTC). The term "tactical athlete" has been used by some to describe personnel in professions, like the military, where regular training is instrumental in preparing individuals for the physical and mental challenges associated with the profession (Scofield & Kardouni, 2015). Optimal performance, both mentally and physically, in such professions has the potential to save lives. As such, determining lifestyle behaviors that may enhance or optimize cognitive and motor performance is critical. Sleep appears to be one such lifestyle behavior. Much of what is known regarding sleep's impact on performance is based off sleep restriction research. Recently, more researchers are investigating how adding sleep to one's habitual amount for a period of time, an intervention called sleep extension, may affect performance. In athletes, compared to napping, sleep hygiene, and other post-exercise recovery strategies, sleep extension is the intervention that has been shown to have the most beneficial effects on subsequent performance (Bonnar et al., 2018). As such, there is potential that sleep extension may be able to enhance performance in tactical athletes.

Prior to this dissertation, there were no well-controlled studies on the immediate and residual effects of sleep extension on executive and cognitive motor performance. This dissertation addressed this knowledge gap by conducting a randomized control trial utilizing two groups, a sleep extension group and a control group, in students enrolled in ROTC from all military branches at a large, state university. The control group slept habitual sleep amounts for the entire duration of the study of fifteen nights. The sleep extension group performed habitual sleep amounts for the first seven nights followed by four nights (nights 8-11) of sleep extension where they were asked to spend 10 hours in bed with the goal of increasing their sleep durations. After the intervention period, the sleep extension group was instructed to return to their habitual sleep amounts for the last four nights (nights 12-15). Each group conducted a cognitive motor battery on day 8 (pre-test), day 12 (post-test), and day 16 (follow-up). This design allowed for the assessment of habitual sleep durations and the impact it has on baseline performance, the immediate effects of four-night sleep extension intervention on performance, and the extent to which the effects of sleep extension persist following resumption of habitual sleep schedules.

Sleep duration was determined utilizing actigraphy, which is known to be a reliable and valid measure to study sleep in a natural environment (Kushida et al., 2001; Morgenthaler et al., 2007) and sleep diaries (Carney et al., 2012). The college tactical athletes in this study habitually slept about 6.2 hours per 24-hour period over the first seven nights, which is less than 7 hours per night recommended amount for optimal health (Watson et al., 2015). Only about 8% of the participants slept over 7 hours per night. These durations appear to be less than what has been reported in other college student athletes (Mah et al., 2018) and other undergraduate students (Lund et al., 2010).

In all participants, longer habitual sleep amounts over the first seven nights (prior to sleep intervention) were associated with better baseline performance on the Trail Making Test A (TMT-A), TMT-B, the Symbol Digit Modalities Test (SDMT), and with more motivation to perform the cognitive tests measures. The TMT is a widely used instrument in neuropsychological assessment as an indicator of speed of cognitive processing and executive functioning (Sanchez-Cubillo et al., 2009). In undergraduate students, the TMT-A is thought to reflect "sustained attention" and "set maintenance" (Langenecker et al., 2007) and has been used to assess processing speed (Wilckens et al., 2014), whereas the TMT-B is more reflective of executive functions of task-set inhibition ability, cognitive flexibility, and set-shifting (Arbuthnott & Frank, 2000; Langenecker et al., 2007). Performance on the SDMT is an indicator of information processing speed and efficiency (Benedict et al., 2017; Wilckens et al., 2014). Consequently, longer habitual sleep durations in the college tactical athlete sample were associated with better performance on two processing speed tasks and an executive function task that is reflective of task-set inhibition ability, cognitive flexibility, and set-shifting. One potential contributing factor to the better performance on these tasks may have been higher motivation levels associated with longer sleep durations. There is a possibility that longer sleep durations increase task motivation levels, which may result in an increased "attentional effort" during a cognitive task (Sarter et al., 2006), which results in improved cognitive performance. No other tests in the cognitive motor battery, including the psychomotor vigilance test (PVT), the flanker task, and the standing broad jump, or the motivation to perform the standing broad jump were associated with longer baseline habitual sleep durations.

During the four-night sleep extension intervention, the sleep manipulation was successful in increasing the mean sleep duration by an average of about 1.4 hours per 24-hour period. The 1.4 hour per night/day increase appears to be more than the 0.4

hour per night/day increase observed in female track athletes (Famodu et al., 2017) and less than the 1.7-1.8 hour per night/day increase observed in basketball and tennis players (Mah et al., 2011; Schwartz & Simon, 2015). The mentioned studies utilized a sleep extension intervention that lasted at least 1 week and as long as 7 weeks. The sleep intervention used in this dissertation lasted for only four nights, which may be more feasible for individuals with schedules less flexible with longer intervention durations.

Immediately following the sleep extension intervention, the sleep extension group mean score changes were significantly better than the control group on mean PVT reaction time, TMT-B performance, and the average standing broad jump distance. The PVT is viewed as a “gold standard” for assessing the effects of sleep on cognition because of its high reliability, sensitivity to circadian rhythm influences, and minimal learning effects (Dinges et al., 1997; Killgore, 2010; Van Dongen, Maislin, et al., 2003). As such, the PVT is one of the most common cognitive tests utilized in sleep research to assess vigilant attention. After the sleep extension, the college tactical athletes improved in their vigilant attention. As previously mentioned, the TMT-B is more reflective of executive functions of task-set inhibition ability, cognitive flexibility, and set-shifting, which may mean that tasks that rely on these abilities may improve after sleep extension. Only one other study has shown benefits in executive functions, which were working memory tasks that measured visuospatial processing and divided attention, following a sleep extension intervention that was a gradual extension intervention over 2 weeks (Dewald-Kaufmann et al., 2013). Executive functions have been hypothesized to be the vital for other athletic performance (Simpson et al., 2017) and it is plausible that executive functions are equally important in tactical athletes. Thus, it is noteworthy that extending sleep for a short period of time can potentially have a positive impact on some executive functions in college tactical athletes. The standing broad jump is considered a general index of muscular fitness (Castro-Pinero et al., 2010) and in collegiate athletes, it has been highly related/correlated to muscular strength, peak power output, vertical jumping ability, agility, sprint acceleration, and sprint velocity (Peterson et al., 2006). Because of this relationship, sleep extension may provide benefits in these other parameters of motor performance. Supportive of this, previous research has found improvements in sprint times in basketball players following sleep extension (Mah et al., 2011). In addition, sleep extension has shown to significantly increase time to exhaustion while performing a submaximal isometric knee extensor exercise (Arnal et al., 2016). More research is needed to determine what other parameters of motor performance, like agility, are positively impacted by sleep extension.

Immediately following the sleep extension, the sleep extension group mean score changes in subjective sleepiness and motivation levels to perform the cognitive tasks and the standing broad jump were also significantly better than the control group. While the findings in subjective sleepiness were consistent with prior research, this was the first study to demonstrate improvements in motivation following a sleep extension intervention, which provides a potential contributing mechanism behind the aforementioned performance improvements. There is a chance that motivation levels were confounded by the participant's perceived performance because participants were asked to annotate their motivation levels after they performed all of the tasks.

Collectively, the sleep extension intervention resulted in both immediate performance improvements in cognitive and motor tasks, as well as alertness and motivation levels. Considering the cognitive and motor performance improvements noted following sleep extension, a four-night intervention could be useful tool for tactical athletes looking to enhance their overall performance.

A secondary aim of this dissertation was to determine the extent to which effects of sleep extension persist following resumption of habitual sleep schedules for four nights. Following the sleep extension intervention, during the last four nights of the study, the sleep extension group returned to their habitual normal sleep durations levels, which were similar to the control group. After returning to habitual sleep amounts, there were significant between-group differences in mean score changes from pre-test to follow-up in the standing broad jump. The extension group essentially maintained the same nine-centimeter improvement that was observed immediately following the sleep extension intervention. As predicted, for the rest of the cognitive motor battery, there were no other significant between-group differences in mean score changes from pre-test to follow-up. The only other significant between-group difference in mean score change from pre-test to follow-up was the motivation to perform the standing broad jump. Consistent with what has been previously hypothesized, the change in motivation levels between groups possibly elucidates the reason for the difference in performance during the standing broad jump. The results reveal potential residual benefits four days after a short-term sleep extension intervention on a gross motor task and motivation to perform the gross motor task, but not on the cognitive tasks, when participants return to their habitual sleep amounts. These results may provide a tactical athlete with an ability to maintain their enhanced performance on gross motor tasks days after they have returned to their habitual sleep amounts, which may encourage them to take the time to invest in the intervention.

Some of the strengths of the dissertation include a larger sample size and the utilization of a control group, both of which are largely lacking in sleep extension research, especially in an athlete population. The study measured sleep objectively with actigraphs and controlled for measures such as caffeine intake, testing times, and testing days. In addition, a diverse battery of tests and questionnaires were utilized to help test the hypotheses and to determine which types of performance are impacted by extending sleep amount. Lastly, the utilization of a sample of college tactical athletes that are training to become future leaders in all three services of the U.S. military helps provide some insight on their habitual sleep patterns and how to potentially enhance their performance in the future.

The dissertation provides recommendations for future research. Future research should include neuroimaging during the testing to further understand how a short-term sleep extension intervention may impact the neural dynamics during performance. Future research should expand the cognitive motor battery, such as other executive function tasks, like decision making, or other motor/physical tasks, like endurance tasks or agility tasks, in order to better understand what types of tasks are enhanced with increased sleep amounts. Increasing test frequency may also provide a way to determine a dose-response to the intervention and for how long they last. Lastly, investigating other tactical athlete populations and using job specific outcome measures or utilizing the intervention in an operational environment may help determine if sleep extension is a tool that could potentially be used by other professions and/or in the operational environment where cognitive and motor performance is vital.

Overall, this dissertation addressed a knowledge gap in how a short-term sleep extension intervention effects performance, both cognitively and physically, and motivation in college tactical athletes. Because of the design, this dissertation provides awareness of sleep health in young adults training to become future leaders of the U.S military and how performance and motivation are positively impacted by longer sleep durations. The dissertation revealed immediate benefits of a four-night sleep extension intervention in alertness, psychomotor vigilance/attention, executive function performance, standing broad jump performance, and motivation levels. Lastly, the benefits of sleep extension on broad jump performance and motivation level were shown to be evident four days after resumption of habitual sleep schedules. These findings are encouraging for those in professions, like tactical athletes and other athletes, that regularly train to enhance their overall performance.

Appendices

Appendix A.

Average Total Sleep Time, Mean ± SD

	Habitual Sleep (Nights 1-7)		**Intervention Sleep (Nights 8-11)**		**Habitual Sleep (Nights 12-15)**	
	Extension	**Control**	**Extension**	**Control**	**Extension**	**Control**
Actigraphy (hours)	6.19 ± 0.67	6.20 ± 0.73	7.55 ± 0.72	5.95 ± 0.85	6.27 ± 0.82	6.41 ± 0.88
Sleep Diary (hours)	6.50 ± 0.93	6.38 ± 0.76	8.55 ± 1.02	6.20 ± 0.92	6.84 ± 1.02	6.66 ± 0.96

Appendix B.

Subjective Behavior Measures at Pre-Test, Post-Test, and Follow-up, Mean ± SD

	Pre-Test		Post-Test		Follow-Up	
	Extension	**Control**	**Extension**	**Control**	**Extension**	**Control**
KSS	5.00 ± 1.44	4.48 ± 1.71	3.08 ± 1.26	4.28 ± 1.54	3.72 ± 1.77	3.88 ± 1.69
ESS	8.40 ± 2.69	9.12 ± 3.88	6.12 ± 3.00	9.88 ± 3.42	7.60 ± 3.98	9.20 ± 4.18
Motivation						
Cognitive Tests	85.72 ± 13.04	83.92 ± 12.12	90.16 ± 13.01	76.88 ± 18.84	88.32 ± 13.53	80.44 ± 18.22
Standing Broad Jump	87.32 ± 11.66	87.64 ± 9.61	91.68 ± 9.71	86.04 ± 14.16	89.24 ± 11.39	84.36 ± 15.67
STAI						
Trait (Y2)	33.92 ± 9.38	33.84 ± 9.76			33.12 ± 9.10	33.04 ± 9.53
State (Y1)	32.32 ± 8.57	31.04 ± 9.65	28.96 ± 8.19	31.00 ± 8.62	31.72 ± 8.76	33.64 ± 9.69

KSS = Karolinska Sleepiness Scale; ESS = Epworth Sleepiness Scale; STAI = State-Trait Anxiety Inventory

Appendix C.

Performance at Pre-Test, Post-Test, and Follow-Up, Mean ± SD

	Pre-Test		**Post-Test**		**Follow-Up**	
	Extension	**Control**	**Extension**	**Control**	**Extension**	**Control**
PVT						
Mean RT (ms)	306.10 ± 34.78	299.90 ± 39.40	290.01 ± 30.07	298.16 ± 38.67	296.62 ± 32.40	299.03 ± 42.17
Lapses (>500 ms)	0.92 ± 1.75	1.32 ± 3.01	0.52 ± 1.05	1.12 ± 2.76	1.00 ± 1.55	1.64 ± 2.56
Flanker Task						
Congruent Accuracy	99.12 ± 1.27	99.08 ± 1.73	99.60 ± 0.65	99.44 ± 0.71	99.52 ± 0.65	99.24 ± 0.83
Congruent RT (sec)	424.64 ± 43.33	421.38 ± 56.26	391.62 ± 31.16	400.00 ± 36.96	390.73 ± 32.14	394.73 ± 31.19
Incongruent Accuracy	92.84 ± 5.86	93.72 ± 5.50	92.80 ± 8.01	91.92 ± 7.42	91.48 ± 9.58	92.08 ± 5.71
Incongruent RT (sec)	497.96 ± 54.42	492.29 ± 72.82	459.25 ± 35.41	467.74 ± 33.09	460.83 ± 44.23	453.11 ± 31.69
Interference Score	17.36 ± 6.39	16.74 ± 4.97	17.36 ± 4.09	17.21 ± 4.46	17.89 ± 4.61	14.95 ± 4.51
TMT						
TMT A (sec)	25.86 ± 5.03	24.83 ± 4.75	19.96 ± 5.02	20.13 ± 4.27	18.69 ± 5.13	19.14 ± 4.27
TMT B (sec)	52.05 ± 9.14	50.34 ± 11.10	40.29 ± 9.27	43.27 ± 8.49	36.37 ± 9.48	38.07 ± 7.20
TMT B-A (sec)	26.19 ± 1.94	25.50 ± 2.14	20.33 ± 2.02	23.14 ±1.78	17.68 ± 1.52	18.93 ± 1.30
SDMT						
Total	125.96 ± 22.30	130.48 ± 12.96	136.88 ± 21.63	141.24 ± 16.45	147.04 ± 28.28	149.52 ± 15.50
Written	60.24 ± 10.55	62.76 ± 7.75	66.08 ± 10.78	67.60 ± 8.00	69.80 ± 12.81	71.28 ± 7.56
Oral	65.72 ± 12.13	67.72 ± 6.84	70.80 ± 11.79	73.64 ± 10.07	77.24 ± 16.23	78.24 ± 9.96
Standing Broad Jump						
Average Jump (cm)	170.10 ± 32.43	178.56 ± 37.28	179.17 ± 34.19	176.25 ± 38.39	179.57 ± 36.30	176.97 ± 38.30
Best Jump (cm)	173.26 ± 32.59	183.74 ± 39.30	183.34 ± 34.71	180.34 ± 39.22	184.14 ± 37.08	182.14 ± 39.19

PVT = Psychomotor Vigilance Task; TMT = Trail Making Test; SDMT = Symbol Digit Modalities Test

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