THESIS

THE EFFECTS OF SLEEP EXTENSION ON PHYSICAL AND COGNITIVE PERFORMANCE IN AROTC CADETS

Submitted by

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ABSTRACT

THE EFFECTS OF SLEEP EXTENSION ON PHYSICAL AND COGNITIVE PERFORMANCE IN AROTC CADETS

College students and military personnel have limited sleep opportunities; Reserve Officer Training Corps (ROTC) cadets belong to both groups. Thus, cadets are at a heightened risk of insufficient sleep. Sleep loss can have deleterious effects on physical and cognitive health (Halson et al., 2014). In military professions, these impairments have potentially fatal consequences, as decreased performance will result in diminished operational readiness. Recent evidence suggests that sleep extension is a valid intervention to increase sleep duration (Bonnar et al., 2018). Thus, we aim to identify if sleep extension improves performance in chronically sleep-deprived ROTC cadets. This study examines the impact of 1-week of sleep extension on physical and cognitive performance in Army ROTC cadets. We recruited 16 healthy, active male and female participants aged 18-35 from Colorado State University's ROTC program. Participants were equipped with Actiwatches and completed daily sleep questionnaires and diaries during the habitual and sleep extension periods. Sleep extension was achieved by asking participants to spend 10 hours in bed to increase sleep by at least 1 hour per night. Cadets then completed a series of physical and cognitive tests to measure performance on tactically relevant tasks. The physical testing consisted of a vertical jump, 3-repetition maximal hexagon deadlift, 300-meter shuttle, and a 1-mile run; and cognitive test consisted of a psychomotor vigilance test, the Purdue pegboard test Tiffin (1948), the STROOP color-word test Jensen (1965), and a simulated shooting exercise. Wilcoxon Signed rank-test and two samples paired t-test statistical analysis compared baseline, physical, and cognitive testing data to post-intervention testing data. Cognitive and physical testing occurred after 1-week of habitual sleep and 1-week of sleep extension. The mean objective Total Sleep Time (TST) was 6.07 ± 0.15 hours during the baseline period and 7.03 ± 0.17 hours during the sleep extension period (P=<0.0001). The mean Epworth Sleepiness Scale (ESS) rating was outside of normal limits at 10.47 ± 1.16 during the habitual sleep period; it decreased to fall within the normal limits during the sleep extension period at 7.10 ± 0.79 (P <0.005) (Shattuck & Matsangas. 2014). There were statistically significant differences found on 2 of the 4 Purdue pegboard tests and deadlift performance from habitual sleep to the sleep extension period. The mean hands and assembly scores significantly improved (P = 0.038 and P=0.003, respectively). Performance on the 3-repetition maximal hexagon deadlift increased significantly during the habitual sleep period and sleep extension period (p = .007). The limited sleep opportunities ROTC cadets encounter have negative implications on physical and cognitive performance; based on our findings in the current study, it is plausible that sleep was not extended to an adequate duration to elicit cognitive and physical performance improvements in all of the tested cognitive and physical measure. Thus, more research is needed to investigate the relationship between sleep duration and sleep quality and their effect on cognitive and physical performance in tactical population.

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CHAPTER 1

1.1. Introduction

Prevalence of Insufficient Sleep

The National Sleep Foundation (NSF) recommends sleeping seven hours per night for healthy function. However, approximately only two-thirds of the U.S. adult population report sufficient sleep durations (Watson et al., 2015). The recommendation for young adults (ages 18-25) is seven to nine hours of sleep per night (American Academy of Sleep Medicine and Sleep Research Society). However, the average nightly sleep for college students is less than the recommendations. College students are generally characterized as poor sleepers, which is defined as sleeping less than the recommended amount and having trouble falling or staying asleep (Lund et al., 2010). Students who participate in the Army Reserve Officer Training Corps (ROTC) may experience more demands on their time due to military obligations in addition to their academic and extracurricular responsibilities, and previous research suggests that they sleep less than the recommended amounts which can impair physical and cognitive performance, impacting the cadets' performance on the Army Combat Fitness Test (ACFT), and subsequently, their career trajectory (Ritland et al., 2019). After commissioning as an officer upon graduation, the inability to perform at a high level in various high-stress environments may result in severe consequences, including loss of life, be it their own or others. Therefore, insufficient sleeping habits must not compromise physical fitness, cognitive competency, and military readiness. Thus, understanding how to mitigate the lack of sleep in military populations is important for enhancing combat readiness and physical preparedness across all military branches.

As both college students and service members – two groups who tend towards poor sleep (Lund et al. 2010), ROTC cadets are likely to experience poor sleep quality, abbreviated sleep duration, or both. These cadets must meet high academic and physical standards. Hence, there must a focus on their sleep, as it impacts performance in both areas. The extra demands on their time increase the possibility of exposure to insufficient sleep, which is an abbreviated sleep duration and inadequate sleep opportunities that are less than what is required for the preservation of daytime wakefulness (Sankari, 2022). Those who do not reach the sleep recommendations are at an increased risk for reduced cognitive and physical performance, difficulties with mental health, diminished immunity, gaining weight, becoming obese, developing metabolic, cardiovascular, and renal disease, and increased morbidity and mortality (Walsh et al., 2020). Further, research suggests that accumulated sleep debt can reduce an individual's ability to be alert and attentive; the associated cognitive consequences of chronic insufficient sleep present themselves as decreases in reaction time, fine motor skill, memory consolidation, and decision-making (Alhola & Polo-Kantola, 2007). Additionally, accumulated insufficient sleep may impair physical performance, increase injury risk in athletes, and impair recovery (Milewski et al., 2014). Further, sleep loss is associated with decreases in mood states and affective functioning (Watling et al. 2017), functional mental toughness (Cooper, Wilson, & Jones, 2019), and resilience (Arora et al. 2022), which may have important implications for both mental health and physical performance.

Sleep Patterns in the United States Military and Military Academies

The Army Surgeon General's office and the U.S. Army Field manual-622.5 have placed an emphasis on identifying strategies to improve sleep following or prior to sleep disruptions and periods of insufficient sleep caused within operational environments (Good et al., 2020). A systematic review conducted by Good et al (2020), reported that young adults who chronically sleep less than the recommended amounts are at an increased risk for depression; further, those exposed to insufficient sleep durations prior to deployment are significantly more likely to develop post-deployment PTSD and suicidal ideations. Sleep health is the multifaceted pattern of the sleep-wake cycle, specifically adapted to the social, environmental, and individual demands that are necessary for the promotion of physical and mental health; according to Buysse et al (2014), “Good sleep health is characterized by subjective satisfaction, appropriate timing, adequate duration, high efficiency, and sustained alertness during waking hours.” Thus, we postulate that consistent positive health behaviors, explicitly obtaining sufficient amounts of sleep, will engender improvements in psychological health and performance physically and cognitively. This thesis project focuses on a subset of college tactical athletes training to become military service members. This population refers to Army Reserve Officer Training Corps (AROTC) cadets. A tactical athlete is defined as "personnel in law enforcement, military, and rescue professions who require unique physical training strategies to optimize occupational and physical performance" (Scofield et al., 2015). As an AROTC cadet, there is an opportunity for college students to develop technical and leadership skills, career training, and a structured path to an occupation following college during their time in the program. Not only are highly translatable and applicable skills developed and taught, but those who could not afford college financially can with the financial support provided by AROTC programs. Once graduated, cadets will commission into the United States Army; a commissioned officer's responsibilities include planning and organizing military exercises and leading soldiers, managing enlisted personnel, and operating and commanding aircraft, ships, or mobile convoys. In addition, officers can sometimes provide specialized services such as medical and legal aid and engineering. The wide range of responsibilities held by commissioned officer provide an explanation as to why physical fitness, cognitive competency, and military readiness must not be compromised due to insufficient sleeping habits.

When a teen enlists or applies to a military academy following high school, they are placed into an environment where habitually sleeping less than 6 hours and waking at 4:30 am is normal. Thus naturally, service members are often exposed to insufficient sleep durations within the training and the deployment cycle. Actigraphy data worn by soldiers in the Army reported they were attaining <5 h of sleep per night during training and deployment; often, soldiers did not sleep for a continuous <5 h per night but rather multiple bouts of <2 h (Good et al., 2020). The acute effects of insufficient sleep may be an early predictor of declining attention and vigilance, which could be detrimental to the entire unit. A robust linear relationship exists between the amount of nighttime sleep attained and performance on a military-specific task such as an artillery exercise (Good et al., 2020). As a consequence of insufficient sleep, a 15-25% decline in combat effectiveness was observed for every hour of sleep lost the night prior (Good et al., 2020). Belenky et al. (2003), recruited 66 participants for a 14-day protocol; first, participants underwent a three-day adaptation, training, and baseline period in which they were instructed to spend 8-h (TIB). On the fourth day, participants were then placed into one of four sleep conditions, 9-h TIB, 7-h TIB, 5-h TIB, and 3-h TIB, with sleep augmentation of one group and restriction of the other three. This study's sleep augmentation/restriction period lasted 7 days; on day eleven and the three days following, participants were instructed to spend 8-h TIB as recovery. The researcher's findings indicated a dose-response relationship between the Psychomotor Vigilance test (PVT) and TIB, with reaction time speed, increasing most significantly within the 3-h and 5-h TIB groups. Suggesting an impairment in vigilance during the experimental phase, whereas reaction time in the 7-h and 9-h TIB group was maintained through the experimental phase. The number of lapses also increased in the 3-h TIB and 5-h TIB groups during the sleep restriction phase, and there were no increases in the 7-h and 9-h TIB groups. Initially, performance declines were observed within the 5 and 7-h sleep restriction groups. However, during the experimental period, performance declines stabilized at reaction times lower than baseline, whereas in the 3-h TIB group, performance declined at a linear rate. Lastly, the 9-h TIB group saw no change in performance during the experimental period. The author suggests these findings are indicative of an "inflection point which is the minimum amount of nightly sleep required to achieve a state of equilibrium in which daytime alertness and performance can be maintained at a stable, albeit reduced, is approximately 4-h per night" (Belenky et. 2003).

Furthermore, Larsen et al. (2022), investigated the variability of sleep patterns and restriction in trainees at basic military training (BMT) and assessed trainees' subjective sleep quality prior to BMT. In a 12-week mixed modal design, participants were given wrist-worn actigraphy and completed the Pittsburgh Sleep Quality Index during the first week of BMT; so researchers had a subjective estimate of the participants' sleep patterns before BMT. During BMT, trainees progressed through 4 phases: (1) orientation, (2) physical training (PT) and military skills, (3) field training, and (4) ceremonial drill; it is important to note, during the four phases, the training demand increased. There was a scheduled sleep opportunity from 2200-0600, and the training day took place between 0600 and 2200; though, during field training, the sleep schedule of trainees varied. Therefore, researchers subjectively assessed pre-BMT sleep patterns using the PSQI with wrist-worn actigraphy-derived sleep parameters. In addition, sleep durations were categorized as sub-optimal and restricted sleep quantities based on the National Sleep Foundation's recommendations; a sleep duration of 06:00–07:00 h was "*uncertain"* and ≤06:00 h "was *not recommended"* (Larsen et al., 2022). The study's findings revealed that during 12-weeks of BMT, sleep duration in most recruits was less than 6-h per night for at least two consecutive weeks of BMT. Researchers also found that the prevalence of sleep restriction peaked during field training. Additionally, they observed a significant decrease in sleep duration of 15-18 minutes and efficiency of 7-8% throughout field training (06:06 ± 00:36h and 71 ± 6%; $p < 0.01$, respectively). Although, with respect to the objective sleep parameters, there were significant increases in sleep onset latency, wake after sleep onset, and awakenings during field training. Larsen et al. (2022), findings suggest that sub-optimal sleep and sleep restriction are prevalent during BMT, and as the demands of training increase, sleep disruption worsens.

Similarly, the office of the Army Surgeon General developed The Leaders Guide to Soldier Health and Fitness. In this guide, it is recommended that a soldier sleep a minimum of 7 hours per night. Additionally, in preparation for sleep loss, soldiers should attempt to sleep for 9 hours; yet the minimum amount of sleep recommended during field training exercises is less than 4 hours per night. Considering there is a 15-25% decline in combat effectiveness for every hour of sleep loss this recommendation will result in a combat effectiveness level of 15% within operational settings (Good et al., 2020).

One study examining habitual sleep health and its effect on performance in ROTC tactical athletes investigated 54 college-aged tactical athletes enrolled in ROTC (Ritland et al., 2019). Participants wore wrist actigraphy and completed 1- week of sleep diaries before completing a cognitive and motor test. Ritland et al, found that the habitual TST of this population was 6.17 ± 0.69 hours, but only 7.41% of the study subjects reported sleeping 7 hours or more per day. Additionally, the Karolinska Sleepiness Scale (KSS) and Epworth Sleepiness Scale (ESS) fall within pre-established norms with ratings of 4.70 ± 1.56 and 8.80 ± 3.24, respectively (Ritland et al. 2019).Thus, suggesting that subjective sleepiness subjective was lower or within normal ratings in those who had longer sleep durations, habitually. Ritland et al. findings accurately represent subjective sleepiness within collegiate athletic populations. Moreover, as previously mentioned, collegiate student-athletes are exposed to poor sleep quality and insufficient habitual sleep durations, providing a potential mechanism for the substantial prevalence of daytime sleepiness (Mah et al., 2018). Shattuck and Matsangas (2015) found that sailors with an elevated ESS score greater than 10 experienced a 60% slower reaction time when compared to sailors with normal ESS scores. Poor sleep quality, insufficient habitual sleep durations, and significant daytime sleepiness may have immense consequences on training, performance, academics, injury risk, and overall health within athletic populations.

Additionally, 4-year longitudinal study investigating sleep patterns of cadets enrolled in the United States Military Academy (USMA) revealed that cadets received the least nighttime sleep during the first year of the military academy (likely due to adjustment to rigorous schedules and standards at USMA) (Miller. 2010). Cadets then received significantly more sleep in the two years following their first year; subsequently, nighttime sleep decreased significantly in their final year. This change in sleep patterns is likely representative of the increased demand and obligations experienced by the cadets during their final year. Additional causes of insufficient sleep among USMA cadets have been identified as: time spent in bed on the nights before an early morning training session was significantly shorter (Miller, 2010). As a result, cadet populations participating in ROTC or enrolled in the USMA not only obtain less sleep than recommended amounts compared to their peers, but these cadets sleep less than their undergraduates' counterparts and other collegiate-student athlete populations (Miller, 2010).

Tactical athletes can also be classified as elite athletes. Therefore, their training demands require similar sleep requirements for optimal performance. A study conducted on 175 elite athletes (n = 30 females, 22.2 ± 3.8 years) from 12 individual and team sports asked the question, "How many hours of sleep do you need to feel rested?" (Sargent et al., 2021). Participants kept a sleep diary and wore an activity monitor for approximately 12 nights during their general preparation phase of training. Each athlete’s sleep deprivation index was calculated by subtracting the average sleep duration from the self-reported sleep needs questionnaire. Researchers found that athlete’s feel most rested when 8.30 ± 0.90 hours of sleep is accumulated compared to a habitual sleep duration of 6.70 ± 0.80 hours yielding a sleep deprivation index of 96.0 ± 60.6 minutes. Only 3% of athletes got enough sleep to meet their individual sleep needs, compared to the 71% of athletes who were an hour or more insufficient.

Additionally, in a separate earlier study, Sargent et al. (2014), found that within elite college athletes, the onset of sleep and sleep duration were significantly reduced due to variations in sleep/wake behaviors on training and rest days. Specifically, participants experienced shorter sleep durations, earlier sleep onset and offset times on the nights prior to early morning training. Therefore, we posit the cadets’ training schedule heavily influences how much sleep a cadet will achieve. In concert with cadet's academic and military training schedule, ROTC tactical athletes are more likely to be exposed to behaviors promoting insufficient sleep. Additionally, due to the prevalence of insufficient sleep within the cadet population, they often compensate to some extent by an increase in daytime napping. However, depending on the duration of the nap, napping can potentially cause sleep inertia, which is the subjective feeling of grogginess, disorientation, drowsiness, and cognitive impairment that immediately follows waking, generally lasting to 15 to 60 minutes but may last for up to a few hours after waking (Balkin & Badia, 1988).

A study done by Miller et al. (2014), echoes what Sargent et al. (2021), found in tactical populations. A phase-delayed sleep schedule of 23:00 to 07:00 and a routine sleep schedule of 20:30-04:30 was implemented in two training companies. This quasi-experimental study compared trainees assigned to the phase-delay group or a routine sleep schedule; this was accomplished by scheduling sleep opportunities more aligned with adolescents' biologically driven sleep-wake patterns. Researchers found that army trainees who slept 8-h and had their sleep schedules aligned with their natural circadian rhythm report improved sleep quality, mood, marksmanship, subjective daytime sleepiness, and decreased reaction times (Miller et al., 2014). Mysliwiec et al. (2013) and Luxton et al. (2011), found that 72 and 69% of service members sleep insufficient amounts of ~6-h or less per night, respectively; whereas only 27 and 30% were reaching the recommended 7 – 8-h of sleep, respectively. Generally, an insufficient habitual sleep duration have a deleterious effect on a services members ability to optimally utilize the recuperative value of sleep necessary to meet the highly physical and cognitive demand of militarily relevant task within an operational setting (Good et al., 2020). Collectively, there are multiple contributions to the prevalence of insufficient sleep within military populations, such as deployment cycle, shift work, and combat operations (Good et al., 2020).

Effects of Insufficient Sleep on Cognitive and Physical Performance

A systematic review conducted by Owens (2014), detailed the effects of insufficient sleep, increased substance abuse, poor judgment, loss of motivation, and decreased attention, vigilance, and decision-making skills in young adults. Thus, since AROTC cadets are within the age demographic of 18-25, they are also included in this increased likelihood of exposure to adverse behavioral outcomes caused by insufficient sleep. According to Alhola and Polo-Kantola. (2017), sleep loss's cognitive consequences present as decreased reaction time, fine motor skills, memory consolidation, and decision-making. It is essential to note that the aforementioned decreases observed may also imply increases in impulsivity and inattention due to insufficient sleep (McGowan et al., 2020). Impairments to cognitive measures as a result of insufficient sleep may further contribute to impaired physical performance (Milewski, et al., 2014).

The current body of literature shows there are reductions in performance after only one night of restricted sleep; most notably, sport-specific skill development and acquisition, submaximal strength, and anaerobic power decrease, but performance on maximal efforts are often maintained following sleep restriction (Halson. 2014; Halson & Juliff. 2017;Thun et al,. 2018). In addition, the potential associated mechanism responsible for the decline in physical performance was observed after one night of sleep deprivation; researchers' findings indicated sleep disruption and reduced muscle glycogen as a consequence of insufficient sleep might result in reductions in exercise performance on a self-paced exercise test (Skein et al., 2011).

In a study conducted by Drummond et al (2006), 38 healthy adults who reported habitual sleep durations of 7-9 h completed a sleep diary and wore wrist-worn actigraphy for 1-week before the study to verify the sleep-wake schedule. Night one was an adaptation night to the laboratory, and on night two, participants slept based on their habitual sleep durations. The following night two participants were placed in a total sleep deprivation (TSD) protocol for 64 h, followed by two nights of recovery sleep predicated on their 1-week habitual sleep-wake schedule. Participants were administered a Go-NoGo task to assess response inhibition; the task was performed at 14:00 after one night of normal night sleep, each day of TSD, and twice during the recovery night sleep. The task was also conducted at 05:00am following the first night of TSD. Researchers found a significant increase in false positive responses during the TSD period; missed 'go' targets were significant only after the second night of TSD (Drummond et al., 2006). These findings suggest that inhibiting cognitive interference from sleep deprivation is difficult.

Furthermore, Service members are often exposed to insufficient sleep within operational environments when deployed (Luxton et al., 2011). A study investigating the effects of sleep restriction on marksmanship was conducted in 20 active-duty soldiers. Participants were placed in a 72-h sleep restriction protocol with 2-h sleep periods scheduled from 4:30 am – 6:30 am every

24-h. Soldier's marksmanship tests were conducted at 3, 20, 44, and 68-h of sleep restriction. Their findings indicate that soldier reaction time to identify friendly targets versus hostile targets was significantly slower over the sleep restriction period. In addition, to a significant decrease in the capacity to accurately differentiate between friendly and hostile targets, despite maintaining shooting accuracy (Smith et al., 2017).

Like the earlier findings, another sleep deprivation study conducted on 11 active, healthy males who had their VO_2 max measured 7-10 days before beginning the sleep deprivation protocol. Upon arrival, participants were euhydrated and reported to the lab following an overnight fast. In this randomized cross-over design, participants were placed into two experimental phases 7 days apart. Participants slept normally during the control trial, whereas the sleep deprivation trial consisted of one night without sleep. Participants performed a 30-minute treadmill run at 60% of their VO_2 max, followed by a 30 min self-paced distance run; before the 30 min self-paced distance test, participants were instructed to run as far as possible and had the autonomy to control the treadmill speed. Researchers found that participants covered less distance following 30-h of sleep deprivation, 6037 ± 759 meters, compared to the distance ran following habitual sleep, 6224 ± 818 meters. Further, the authors suggest reductions in endurance performance that are observed through the decrease in distance covered during the sleep deprivation period may be causal of changes to participants' perception of effort rather than self-pacing because there was no significance between participant speed and distance on their endurance test following TSD (Oliver et al., 2009). The mechanisms that influence physical performance concerning insufficient sleep duration are conjectural. Researchers suggest that the observed deleterious effects insufficient sleep has on cognitive performance, including declines in reaction time, fine motor dexterity, decision-making, and memory, could provide an explanatory mechanism for the deficits in physical performance (Fullagar et al., 2015)

In another study, 10 male team-sport athletes conducted a baseline session and two consecutive-day experimental trials; each session was split up by normal habitual sleep or TSD.

Participants performed 30 minute graded exercise test and a 50 minute intermittent sprint protocol. Researchers found increases in average sprint time on the second night of TSD (2.78 ± 0.17 s) compared to night one of TSD and control night two. Additionally, decreases in total distance covered on the self-paced submaximal graded exercise test were observed, but only during the first and last ten minutes of the test when comparing night two of TSD versus night one of TSD and control night two (Skein et al., 2011). The authors explain that their observations may be causal of significant reductions in muscle glycogen concentrations following 30-h of TSD when compared to habitual sleep. The reduction of glycogen availability is most prevalent on the second day of TSD, which suggests that, following sleep deprivation, athletes will have less muscle glycogen available to utilize (Skein et al., 2011). This acute maladaptation to insufficient sleep is plausible, considering sleep assists the body in the conservation of energy as it decreases its energy expenditure and reduces metabolic demand during rest; thus, these reductions of muscle glycogen are a result of the body's attempt to maintain its energy demand during wake which becomes especially concerning during extended durations of exercise (Skein et al., 2011).

Often militarily relevant tasks necessitate prolonged physical activity (i.e., rucking over long distances, land, and obstacle navigation), so it is critical for optimal combat performance that soldiers have a large capability to maintain aerobic endurance. Current research suggests that sleep loss may acutely compromise submaximal physiological function, resulting in performance declines on submaximal physical tasks (Grandou et al., 2019). Furthermore, in a study investigating the effect of one-night sleep deprivation on endurance performance, researchers found that acute sleep loss can severely impair performance on endurance tasks (Oliver, 2009). Martin (1981), reported the effects of acute sleep loss on exercise following 36-h of sleep deprivation compared to exercise following normal habitual sleep in 8 participants. Their findings showed that during a continuous submaximal treadmill test at 80% of the participants' VO_2 max, the loss of sleep significantly decreased the time to exhaustion (TTE) and changes in perceived effort during high-intensity exercise, resulting in a slower self-selected running pace, identifying a potential mechanism that may be causing the reduction in performance on endurance task. Overall, the studies mentioned above and their results indicate that short sleep durations can negatively impact next-day physical performance; however, the extent to which the impact may have, depends on the mode of exercise performed, along with the type of sleep loss that occurred. Such that the effects of TSD and an early wake have a more significant effect on exercise performance compared to the effects of a late bedtime; additionally, it is essential to note that physical performance is most impacted by sleep loss when exercise take occurs in the afternoon when compared to the morning. The time since awakening prior to exercise also influences performance outcomes (Craven et al., 2022). Previous studies have found that insufficient sleep durations can physiologically negatively impact physical and cognitive performance, as observed through decreases in muscle glycogen concentration, minute ventilation, and time to exhaustion, mood, vigor, and increased reaction time (Vitale et al., 2019). Insufficient sleep duration heavily impacts cognitive functions such as decision-making, reaction time, and judgment. Within elite sports and tactical populations, the differences between physical ability are minimal such that optimal cognitive function may have the potential to significantly influence performance outcomes competitively or operationally (Vitale et al., 2019).

Current and Potential/Promising Strategies to Target Insufficient sleep in AROTC Populations

The extension of sleep, using napping, and positive behavior changes in sleep hygiene promote sufficient and quality sleep during the nighttime. Sleep extension as an intervention is a targeted strategy to increase an individual's habitual sleep duration. As explained above, sleep is essential to cognitive and physical performance. Therefore, the directionality of an individual's performance can be influenced by the ability to obtain the sufficient amounts of sleep necessary at the individual level to reach one's habitual sleep need (Dement, 2005). In preparation for sleep loss, sleep extension as a strategy to increase sleep duration has been coined "sleep banking" and has been shown to improve performance and alertness (Rupp et al., 2009).

In order to combat the detrimental impacts of insufficient sleep on cognitive and physical health, it is important to understand the efficacy of sleep enhancement interventions on physical and cognitive performance. As previously stated, sleep extension as an intervention is targeted to increase sleep duration, and however, the effect of sleep extension on performance needs to be better understood. For example, Mah et al. (2014) found that increased sleep for 5-7 weeks, with 10 hours of in-bed time (8.5 hours of sleep) per night, elicited improvements in sprint times, shooting percentages, reaction time, and mood in collegiate basketball players. Other studies have found that even one week of sleep extension (~9 hours per night) improved accuracy and subjective sleepiness in tennis players (Schwartz & Simon, 2015).

One study investigated if sleep extension can improve performance and alertness succeeding sleep restriction; and to what extent are alertness and performance recovered following "post-restriction recovery sleep" (Rupp et al., 2009). Civilian and active duty military men and women were recruited and assigned randomly to a sleep extension group or habitual sleep group of 10-h TIB and 7.09-h TIB for one week, respectively. Following one week of 10-h TIB or habitual TIB, a night of baseline sleep was observed, then sleep was restricted to 3-h TIB for 7 nights, followed by 5 nights of recovery sleep which consisted of 8-h TIB. Participants underwent performance and alertness tests between 8 am and 6 pm. Performance on the Psychomotor Vigilance Test (PVT) showed an increase in the number of attentional lapses, and performance on the maintenance of the wakefulness sleep latency test was also decreased in the habitual group when compared to the sleep extension group during the sleep restriction protocol. Their findings indicated that when nighttime sleep is extended for one week, cognitive performance retains residual benefits during sleep restriction and recovery. Because PVT reaction time and the number of lapses improved at a faster rate and significantly during the recovery phase in the sleep extension group, it can be deduced that sleep banking through the extension of sleep prior to or following a period of sleep loss can be used as a strategy to ameliorate the potential impairments caused by insufficient sleep. The neurobiological mechanism underpinning cognitive performance may be causal to short habitual nighttime sleep durations, such that the behavioral consequences of chronic sleep restriction cause maladaptive changes to the brain's physiology. Chronic sleep restriction engenders deleterious effects of homeostatic sleep factors affecting an individual's propensity for sleep; specifically, alterations to the ratio of extracellular adenosine and the adenosine receptor provide a potential mechanism (Rupp et al., 2009).

Additionally, military researchers have found that decreases in performance can be mitigated through the supplementation and consumption of caffeine immediately following wake (Good et al., 2020). Van Dongen et al. (2001), conducted an in-lab sleep restriction study on 28 healthy subjects who reported moderate habitual caffeine use. Subjects were instructed not to consume caffeine two weeks before and during the 10-day study. Following a three-day adaptation and baseline period, subjects were placed in an 88-h sleep deprivation protocol where they were given 7 opportunities to take 2-h naps every 12-h. Subjects were then randomized into a sustained low-dose caffeine group(0.3 mg/kg per hour) and a placebo group. Subjects performed a PVT every two hours during their wake and immediately after their nap. Researchers found that the placebo group had a significantly higher number of lapses during the 88-h of wake compared to pre and post-nap PVT reaction times (Van Dongen et al., 2001). A continual low-level caffeine intake, paired with short naps, presents a feasible strategy to standardize and maintain performance and reduce sleep inertia when chronic sleep loss is prevalent, akin to a soldier's operational experiences (Van Dongen et al., 2001). Although, due to the increased likelihood of daytime napping within cadet and military populations immediately following wake, as a result of sleep inertia, impairments to PVT performance have been observed—moreover, the deleterious effects of sleep inertia after a daytime nap are ameliorated by supplementing caffeine.

Sleep extension and performance

Athletes sleeping less than 8 hours experience significant negative impacts on exercise performance, most notably submaximal intensities (Vitale et al., 2019). Based on the aforementioned literature, sleep extension may be a feasible strategy to increase sleep duration in these populations. Additionally, positive correlations between various sleep parameters and attention, concentration, skill development, perception, memory, and executive function have been observed; thus, suggesting that adequate cognitive function is heavily reliant on sufficient sleep, which as a result, translates to improvements in athletic performance (Halson et al., 2014). Therefore, sleep extension may ameliorate performance through improved cognitive function (Arnal et al., 2015). Essentially, the extent to which sleep extension aids in the "compensation of" greater versus lesser degrees of prior sleep debt, may be dependent on an individuals' sleep needs.

One study investigated the effects of increased sleep for 5-7 weeks, with 10 hours TIB (8.5 hours of sleep) per night, which elicited improvements in sprint times, shooting percentages, reaction time, and mood in collegiate basketball players (Mah et al., 2011). In the study mentioned above, subjects maintained their habitual sleep-wake patterns for a 2–4-week baseline period during the NCAA basketball season and accumulated 6-9 h of subjective sleep time each night. Then, subjects had their nighttime sleep extended for 5-7 weeks, during which they were instructed to obtain as much extra sleep as possible and to spend at least 10-h in bed per night. Subjects were strongly encouraged to maintain a regular sleep-wake schedule and were allowed to take daytime naps. Sleep duration, athletic performance, reaction time, daytime sleepiness, and mood measure were recorded throughout the baseline period and during sleep extension. The study was concluded when subjects felt they could no longer accumulate extra sleep or the academic semester ended. Researchers reported in their findings that total sleep time increased from baseline to sleep extension, PVT reaction time improved, and the number of attentional lapses decreased following sleep extension; also, sprint time decreased significantly, with improved shooting accuracy and performance on sport-specific skills. Additionally, from baseline to sleep extension, daytime sleepiness and mood improved as measured by ESS scores and the Profile of Mood States questionnaire (POMS), indicating a substantial reduction in the level of daytime sleepiness and positive changes in vigor, fatigue, and total mood disturbance as reported on the POMS questionnaire (Mah, et al., 2014).

A more abbreviated sleep extension protocol was implemented in college tennis players. Participant serving accuracy was tested during the baseline period, which lasted 1-week as they maintained their regular sleep-wake schedule. Following the baseline week, sleep was extended for 1-week (~9 hours per night). Researchers observed improved serving accuracy from 35.7% at baseline to 41.8% following the intervention. Tennis players' subjective sleepiness on the ESS and Stanford Sleepiness Scale also improved significantly, from 12.15 and 3.56 at baseline to 5.67 and 2.67 following sleep extension, respectively. The observed sport-specific improvements may result from athletes feeling better rested during sleep extension, coinciding with Matsumoto et al. (2002), who found that subjective sleepiness negatively correlates with performance. Subject's habitual sleep increased by ~1.7-h during the sleep extension period; initially, the subject's habitual sleep duration was 7.14-h. After sleep extension, their sleep duration was 8.85-h. Thus, the performance improvement seen as a result of sleep extension within this population denotes that athletes may have a high demand for sleep to optimize performance (Schwartz, 2015). Therefore, athletes who exhibit habitually positive sleep behaviors are more likely to see occupational or sport-specific performance benefits from sufficient sleep.

The Effects of Sleep Extension on Physical and Cognitive Performance in Military Populations

In a study, 15 healthy college students who reported minimal daytime sleepiness were asked to sleep as much as possible. Kamdar et al., (2004), found that sleep extension is associated with improved alertness, reaction time, and mood on from baseline, to mid-sleep extension, and post-sleep extension test. The ameliorating improvements observed during wake as a result of sleep extension may suggest that sleep extension has a diminishing effect on sleep debt and, thus, optimizing cognitive performance (Kamdar et al., 2014).

Ritland et al. investigated habitual sleep in ROTC (tactical athletes) cadets using wrist-worn actigraphy. Their findings show a correlation between cadets who sleep more than the recommended 7 hours per night and increased motivation and cognitive processing speed when compared to their short-sleeping cadet peers. The same group then conducted a randomized control trial that investigated the effects of sleep extension on cognitive and gross motor performance; 50 ROTC cadets were recruited, and the study period consisted of 15 consecutive nights. During the first 7 days/nights, participants were instructed to maintain habitual sleep and to evaluate habitual sleep patterns (nights 1-7). On day 8 of the study, following the 7-night habitual sleep period, participants completed baseline cognitive and motor performance tests. That night, they began the sleep extension period for a total of 4 nights (nights 8-11). During the sleep extension period, participants within the intervention group were asked to sleep more than they do habitually, to be in bed for 10 hours per night. If unable to spend 10 hours in bed at night or in the morning, participants were instructed to spend any remaining time in bed during the day to achieve 10 hours. On day 12, following 4 days of extended sleep, participants were reassessed on their cognitive and motor performance. On the evening of the follow-up test, participants were instructed to return to their habitual sleep patterns for the remaining 4 nights of the study (nights 12-15). Following this period, on day 16, participants took the cognitive and motor assessments a third time. The control group was instructed to maintain their habitual sleep for the entirety of the study period, and the administration of performance testing was identical to the intervention group. The researchers observed significant increases in average sleep time of 1.36 ± .71 h following sleep extension. Additionally, the authors found decreases in PVT reaction time for the sleep extension group, and no decreases were found in the control group. Motivation did not significantly change for the sleep extension group, but there was a significant decrease in motivation for the control group. Notably, the mean post-test motivation to conduct gross motor movements increased significantly for the sleep extension group compared to the control group. Moreover, the beneficial residual effects of sleep extension were preserved for four days following sleep extension (Ritland et al., 2019).

Within an operational environment or a deployment setting, mild to severe sleep deprivation and disrupted sleep are common occurrences in some cases. As aforementioned, insufficient sleeping can significantly affect athletic performance, and athletes who sleep more than 7 hours during the nighttime may experience beneficial increases in physical performance (Craven et al., 2022). Hence, college tactical athletes may require 8 or more hours of sleep for optimal soldier preparedness and readiness. Further, soldiers who sleep sufficient amounts can better rely on their skills to make situationally informed, quick, and efficient decisions, thus, translating to their ability to perform occupational tasks under high levels of stress effectively. Bonnar et al. (2018), conducted a systematic review of sleep interventions and athletic performance; they found that sleep extension enhances components of physical performance. Though, to the authors' knowledge, more research is needed to explain the effects of sleep extension on tactical athletes, and what effect a sleep intervention has within an operational environment.

Limitations of the Prior Sleep Extension Studies

Unfortunately, the literature on sleep in tactical athletes is limited. Good et al. (2020), conducted a review which described the prevalence of sleep disruptions and insufficient sleep durations within service members. Only a select number of studies have access to this niche population of tactical athletes, yet few studies have accurately represented what improvements to sleep durations within military populations will yield on performance within an operation environment Instead, the body of literature is far more representative of athletes and non-athletic counterparts through epidemiological or observational research. Although, most studies investigating the effects of sleep loss on athletic populations do not reflect the sleep disruptions experienced by most athletes. To summarize, Sleep loss has been shown to have a minimal effect on maximal strength and aerobic performance. Whereas prolonged submaximal exercise, sport-specific skill acquisition and development, anaerobic power, and aerobic capacity are more vulnerable to impairment (Fullgar et al., 2015; Halson et al., 2014). Additionally, cognitive performance declines reflect negative implications on reaction time, executive function, fine motor dexterity, memory, perception, attention, mood, and decision-making (Fullgar et al., 2015). Currently, the implementation of supplementation, naps, positive behavior changes in sleep hygiene, and the extension of an individual's habitual sleep duration have been proven as feasible in the promotion of sufficient and quality sleep during the nighttime. Collectively, the effects of insufficient sleep can be mitigated through sleep extension. Sleep extension has been shown to elicit physical and cognitive performance improvements within healthy and athletic populations. Bonnar et al. (2018), conducted a systematic review of sleep interventions and athletic performance; they found that sleep extension enhances components of physical performance.Thus, more research is warranted to assess the effects of sleep enhancement strategies that will be most effective and applicable within operational environments and on tactically relevant task.

Hypothesis

This project aims to test the effects of acute sleep extension on college tactical athletes enrolled in AROTC. We hypothesize that increasing cadet habitual sleep duration through sleep extension will increase muscle power and strength, increase anaerobic power and aerobic capacity, reduce reaction times, improve cognitive interference inhibition and dexterity, and thus improve overall physical and cognitive performance in AROTC cadets.

CHAPTER 2

2.1. Methods

Overview

Young adults (age 18-35 years) were recruited from Colorado State University's Army Reserve Officer Training Corps (ROTC) program during the Fall and Spring semesters of the 2022-2023 academic year. The study took place within the homes of participants and the Sleep and Metabolism Laboratory within the Human Performance Clinical Research Laboratory at Colorado State University in Fort Collins, Colorado. Participants were recruited by word of mouth and an advertisement flyer. Participants underwent a screening process consisting of a health history questionnaire and body composition assessment (height and weight, waist girth). During screening participants were excluded if they: self-reported any medical conditions that may have impacted sleep (i.e. obstructive sleep apnea, known insomnia), took medication with sleep-related side-effects, did not have agency over sleep schedule, were not physically healthy enough to participate in physical performance testing, were under the age of 18 and over the age of 35, or were unable or unwilling to extend their habitual sleep duration. The study was approved by the Institutional Review Board and written informed consent was obtained from all participants.

Study Design/Experimental Timeline

This study was designed to investigate the impact of a sleep extension intervention on AROTC cadets' physical and cognitive performance. The first seven days/nights participants were instructed to sleep as they habitually do to establish habitual sleep-wake patterns. Performance testing took place after the first 7 nights of habitual sleep (Pre-Test). The cognitive battery assessed reaction time, the ability to inhibit cognitive interference, dexterity, and shooting accuracy. Following cognitive test, the physical battery assessed participants' muscular power and strength, anaerobic power, and aerobic capacity. During the intervention period, participants were instructed to sleep more than they habitually do, through the extension of their habitual sleep by at least 1 hour per night, every night for 7 days/nights with the goal of spending 10 hours in bed. The sleep manipulation/intervention lasted the next 7 days/nights (nights 7-14), then participants repeated the cognitive and physical batteries (Post-Test). All participants wore actigraphs for 14 consecutive nights and habitual sleep was monitored for one week, beginning on a Monday or Friday. If participants were unable to spend 10 h in bed during the nighttime and morning hours, participants were asked to return to bed during the day to accumulate any of the remaining 10 hours' time in bed.

Performance tests order and procedures were identical for all participants. Participants were asked to complete the following surveys to assess sleep quality, sleep preference, and sleepiness: Morningness-Eveningness Questionnaire (MEQ), Pittsburgh Sleep Quality Index (PSQI), and Epworth Sleepiness Scale (ESS). The MEQ and PSQI were only given during the screening process prior to the start of the habitual sleep period. Whereas the ESS was administered during the Pre and Post-test following habitual sleep and sleep extension. The study occurred during the academic year with participants actively engaged in course work and ROTC obligations, thus, to control for variable weekday/weekend sleep patterns, every participant began on either a Monday or Friday. Figure 1 depicts the study protocol.

Sleep-wake monitoring:

Participants were given their activity monitor (Actiwatch 2, Philips Respironics, and Andover, MA) and instructions for use. Sleep-wake monitoring took place within the home of participants; sleep patterns were monitored for the duration of the study 14 days/nights; participants were instructed to wear the watch continuously for the duration of the study on their non-dominant wrist. The baseline assessment period was used to understand habitual sleep patterns within their natural sleep environment. In addition, participants were also asked to complete a sleep diary to record sleep-wake patterns. This allowed us to measure their habitual sleep duration and allowed the participants to familiarize themselves with the watch and the sleep log before the intervention. Participants were sent daily text message reminders to use the Actiwatch event marker, to complete their sleep diary and ESS.

The raw actigraphy data (1min epoch length) was analyzed using a validated propriety algorithm within the commercial software. The use of wrist actigraphy for tracking objective measurements of sleep parameters such as sleep duration, efficiency, and quality, was a feasible and valid method for sleep-wake monitoring (Actiware software, Philips Respironics . 2004).

Performance testing:

All sleep-wake monitoring began on a Monday or Friday to ensure each cohort of participants were on the same weekday/weekend cycle leading up to performance testing. Performance tests were conducted following 7 days/nights of habitual sleep monitoring and 7 days/nights of sleep extension; in addition, participants were required to test within an hour of the initial performance battery pre-test. Testing order and procedures remained the same for each cohort. Cadets completed a testing battery designed to measure performance on tactically relevant tasks. The cognitive and physical battery was repeated at the end of the intervention, in the same order, within an hour of the pre-test. Daytime sleepiness was assessed using the Epworth Sleepiness Scale (ESS). The ESS measures sleep tendencies in 8 standardized situations on a 0-3 scale, with higher scores suggesting a greater propensity for sleep.

Cognitive Test:

First, participants completed a series of four cognitive tests, a 10-minute computerized psychomotor vigilance test (Inquisit software program), a computerized STROOP word-color test (Jensen, 1965), the Purdue Pegboard (Tiffin, 1948), a simulated target engagement simulation using computer software, and a modified M4 assault rifle (Smokeless Range). The 10-minute modified version of the PVT was administered on the computer using the Inquisit software program. Each 10-minute trial consisted of a stimulus (Red box on a computer monitor), then participants were instructed to respond to the stimuli by pressing the spacebar on the keyboard as fast as possible. The primary outcome of interest was reaction time. In the STROOP test, participants are presented with incongruent information by having the color of a word differ from the word printed. The Purdue PEG board was used to assess manual dexterity. In this test participants were given a rectangular board with 2 sets of 25 holes running vertically with 4 concave cups at the top. Using the small metal pegs, participants were first instructed to use their dominant hand to place the pegs in holes from the concave cup on the same side being tested (i.e., using the right hand, right concave cup, and right side 25 holes). Participants were then asked to remove the pegs and repeat the same test with their left hand. Following the individual left and right-hand tests, participants were instructed to use both hands simultaneously to fill the 2 sets of 25 holes vertically. Subjects were given an assembly task, which consisted of the alternation of dominant and non-dominant hands, using the metal pegs on their dominant side, washers, and collars which reside in the neighboring cups. It is of note that participants were allowed to practice before each of the four Purdue Pegboard tests and all four tests consisted of three trials. Participants were given 30 seconds to complete the dominant, non-dominant, and simultaneous conditions as quickly as possible, then participants were given 1 min to complete the assembly task as quickly as possible. Participants' accuracy was assessed using a target engagement simulator, which used computerized software and a mock M4 gas-powered rifle to identify and shoot targets.

Physical Test:

Following cognitive testing, cadets performed a physical testing battery consisting of a vertical jump for maximum height, a 3-repetition hex bar deadlift for maximum weight, a 300-meter timed shuttle run, and a 1-mile run for time. Following instructions, participants stepped on a jump pad, and were told to "jump as high as possible" while landing on both feet, they then performed three trial jumps for maximum vertical height with two minutes of rest between each trial. Additionally, they were instructed to keep their leg straight during the jump. The 60-pound hex bar and weighted plates were used to demonstrate strength through the maximal deadlift (MDL), while executing a 3-repetition maximum deadlift to assess the participant's ability to safely and effectively lift heavy loads from the ground. After receiving instruction and performing three warm-up sets, participants conducted a 3-repetition maximum deadlift. During the 300m shuttle run, cones were set 25m apart, participants were asked to run from cone to cone, touching the line at each turnaround. In the last test of the physical battery, participants were instructed to run one mile continuously; walking was allowed although strongly discouraged. Participants were given 10 minutes to warm up for the test and were allowed up to 5 minutes of rest between events.

Statistical Analyses

Data are reported as means ± standard error mean (SEM). Prior to statistical analysis all data underwent a Wilks-Shapiro normality test. A two-sided paired *t*-test analysis was utilized to test statistically significant differences between the habitual and sleep extension condition on normally distributed data. All non-normal distributed data was analyzed using the Wilcoxon-Signed Rank test. Significance was set *a priori* at an α level of p=0.05, and all analyses were conducted using IBM SPSS Statistics.

CHAPTER 3

3.1. Results

Participant

Sixteen participants (21 ± 4 years, 7 female, 9 male) Army Reserve Officer Training Corps (AROTC) cadets at Colorado State University provided written consents and participated in the study. For participant anthropometric measurement, body mass index and waist-to-hip ratio were calculated using height and weight and waist-to-hip measurements (height 172.4 ± 9.2 cm, weight 69.55 ± 10.68 kg, hip 97.9 ± 8.0 cm, BMI 24.83 ± 3.71 kg/m^2, WHR 0.80 ± 0.10). Table 1 provides demographic information and characteristics of the study population.

Sleep Duration

Sleep quantity parameters were determined by wrist-worn actigraphy. The group mean change for Time in bed (TIB) increased by approximately 31% and the TST increased by approximately 17% from the habitual sleep period to the sleep extension period. TIB was 7.19 ± 0.22 hours during the baseline period and 9.35 ± 0.34 hours during the sleep extension period ($p<0.001$). Additionally, habitual total sleep time (TST) was 6.07 ± 0.15, but increased to 7.03 ± 0.17 during the sleep extension period ($p<0.001$). Figure 2a and b shows participants average TIB and TST during habitual sleep and sleep extension. Participants habitual midpoint of sleep during was 2.66 ± 0.20 and decreased significantly to 2.13 ± 0.22 hours (<0.01). Figure 2d shows participants average midpoint of sleep during habitual sleep and sleep extension. Table 2 show objective sleep parameters.

Sleep Quality

Sleep quality parameters was determined by wrist-worn actigraphy. The time it took the subject to fall asleep or Sleep Onset Latency (SOL), was 11.96 ± 4.26 minutes during the baseline period and 36.49 ± 6.25 minutes during the sleep extension period. The percentage that the subject slept versus their attempts to sleep or Sleep Efficiency (SE) was 84.41 ± 1.30 minutes during the baseline period and 76.47 ± 1.64 minutes during the sleep extension period. The amount of time in scored as 'awake' after falling asleep or Wake after Sleep Onset (WASO) was 46.93 ± 5.16 minutes during the baseline period and 70.35 ± 7.19 minutes during the sleep extension period. The number of times a participant woke during sleep or Awakenings, was 24.00 ± 1.00 hours during the baseline period and 31.00 ± 1.00 hours during the sleep extension period. Figures 2c-f show participants average SOL, SE, WASO, Awakenings habitual sleep and sleep extension ($P<0.0001$). Table 2 shows objective sleep parameters.

Subjective Daytime Sleepiness and Morningness-Eveningness Questionnaire

The mean Epworth Sleepiness Scale (ESS) rating was 10.47 ± 1.16 (i.e., outside of normal limits) during the habitual sleep period indicating significant sleepiness. Whereas the mean ESS rating during the sleep extension period was 7.10 ± 0.79 ($P = 0.005$; i.e., within the normal limits). One participant was excluded from data reported due to not completing habitual ESS, therefore their sleep extension ESS was excluded from analysis. Another participant was excluded from MEQ data due to not completing MEQ during the habitual sleep period. 47% of participants reported a morning wake preference, compared to the 53% reporting an evening preference. Figure 2g shows the participants' mean ESS ratings at during habitual sleep and sleep extension and Table 2 shows participants levels of subjective sleepiness.

Cognitive Performance Test

The Wilcoxon-Signed Rank analyses indicates total sleep time (TST) was not significantly associated with performance on mean PVT reaction time and response speed {[1/mean reaction time (RT)*1000]} during the habitual sleep period which was 333.51 ± 6.76 milliseconds and 3.02 ± 0.06 ms, respectively; compared to the intervention which was 328.75 ± 5.95 and 3.06 ± .05 milliseconds ($P= 0.62$ and 0.65, respectively). Paired T-test analysis indicates the number of lapses also not significantly associated with increased TST when compared to the habitual sleep period and sleep extension which were 3.56 ± 0.89 and 2.00 ± 0.62, respectively ($P= 0.23$). Through paired sample analysis there was no statistical significance on the Purdue Peg board for the Right-hand and Left-hand conditions, but there was statistical significance in the both hand and assembly task conditions. The mean Purdue Peg board scores are reported by condition. The mean Right-Hand score was 15.79 ± 0.78 pegs during the habitual sleep period and increased to 17.13 ± 0.57 pegs during the sleep extension period (P = 0.06), the mean Left-Hand score was 14.52 ± 0.68 during the habitual sleep period and 15.54 ± 0.16 pegs during the sleep extension period (P = .08). The mean Right and Left hand (both hands) scores was 12.29 ± 0.52 during the habitual sleep period and significantly increased to 13.04 ± 0.48 pegs during the sleep extension period (P = 0.038). The mean assembly sore was 42.60 ± 1.84 assembled pieces during the habitual sleep period and increased significantly to 45.71 ± 1.60 assembled pieces (P = 0.003) during the sleep extension period. The smokeless range shooting test and STROOP color-word test were excluded from analysis due to a change in range protocol between cohorts and a voice record recognition software error, respectively. Figures 2h-n show participant performance on the PVT and Purdue Pegboard following 1-week habitual sleep and 1-week sleep extension.

Physical Performance Test

The average maximal vertical jump height was 18.50 ± 0.74 inches during the habitual sleep period and decreased to 18.19 ± 0.04 inches during the sleep extension period (p=0.90). One participant's maximal vertical jump height was excluded from the data due to human error. For the 3-repetition maximal hexagon deadlift, the average maximal load lifted three times increased significantly from 237.50 ± 19.55 pounds during the habitual sleep period to 245.31 ± 16.61 pounds during the sleep extension period (p = 0.007). The average run time on the 300-meter shuttle run test was 1.35 ± 0.06 minutes during the habitual sleep period v 1.37 ± 0.06 minutes during sleep extension period (p = 0.221). The mean run time for the 1-mile run was 8.07 ± 0.40 during the habitual sleep period and decreased to 7.81 ± 0.34 (p = 0.09) minutes during sleep extension. Figures 2o-q show participant performance on the vertical jump, 3 repetition maximal hex deadlift, 300m shuttle, and 1-mile run following 1-week habitual sleep and 1-week sleep extension.

CHAPTER 4

4.1. Discussion

Objective Sleep parameters

The current study assessed the effects of acute sleep extension on cognitive and physical performance in AROTC cadets at a large state university. Consistent with other sleep extension studies, we found a significant and consistent effect on performance when compared to other sleep enhancement strategies, akin to a systematic review conducted by Bonnar et al. (2018). A cadet's ability to reach peak physical and cognitive performance depends on many factors. Sleep extension has been shown to benefit psychological and physical health in young adult populations (Owens, 2014).

In the current study, the habitual mean objective Time in Bed (TIB) increased significantly during the sleep extension period; as for Total Sleep Time (TST), habitually, it was recorded that cadets were obtaining, on average less than the recommended amounts and increased by ~ 0.96-h during the sleep extension period. However, in the present study, habitual sleep time was approximately 1-h shorter in duration compared to the habitual TST in a larger sample of collegiate athletes, reported by Mah et al. (2018), which was 6.98 ± 1.15 h, and a smaller college student population reported by Lund et al. (2010), 7.02 ± 1.15. The observed discrepancy in TST from the present study regarding the previously mentioned literature may be due to the increasingly high academic demand and military obligations prevalent in college tactical athletes compared to their collegiate-athlete counterparts. Additionally, the increased academic and military demand may play a role in elevated levels of subjective sleepiness, further shortening cadets' habitual TST. Therefore, we observed that the mean habitual objective sleep duration was less than the recommendations for optimal health (Watson et al. 2015), with over 93% of the participants sleeping less than 7-h per night. Additionally, the present study's average habitual TST in ROTC cadets was closer to that of deployed service members, which was ~6.5h per night (Lagoy et al., 2022). One study found that increasing sleep duration by 2.4 h per night for 13-48 days by asking 15 healthy college students to sleep as much as possible significantly affected daytime function and cognitive performance by improving alertness, reaction time, and mood (Kamdar et al., 2004). Thus, in the current study, it is plausible that not enough extra sleep was accumulated during the sleep extension period to engender an adequate reduction in sleep debt in order for cognitive performance can be optimized.

It is important to note that sleep quality was reduced during the sleep extension period, as assessed by sleep efficiency (SE). Reduced sleep quality in already poor sleeping populations may engender long-term consequences to sleep and physical and psychological health. Thus sleep extension in populations with pre-existing poor sleep quality is worth further study. Reed and Sacco (2016), have described a typical SE as ≥85%; notably, both the baseline and sleep extension SE is less than the average SE of 83% in Deployed Service members (Peterson et al., 2008). In the present study, habitual Sleep onset Latency (SOL) was increased significantly during the sleep extension period, consistent with the ~32-minute average SOL revealed in the Peterson et al. (2008), study which evaluated sleep disturbance and insomnia symptoms in deployed service members. Once commissioned as officers, in general, a cadet’s daily work schedule may reflect that of shift-working individuals. Specifically those shift working individuals transitioning between daytime and nighttime work, have been shown to have a significantly lower SE and increased SOL (Good et al., 2020). Within shift-working individuals, reductions in SE and SOL have been associated with the prevalence of insomnia (Peterson et al., 2008). Considering that SE and SOL in our study were within the range that reflects the presence of insomnia during habitual sleep and sleep extension, we would deduce that increasing sleep duration further imposed deleterious effects on cadet sleep quality. Though, depending on the timing of the onset of sleep, if it were earlier, then there may not have been an adequate or sufficient enough sleep pressure accumulated.Wake after sleep onset (WASO) is the time spent awake after sleep has begun and before morning wake. In the present study, the mean objective habitual WASO significantly increased during sleep extension. Additionally, the number of times a participant woke during sleep, also known as awakenings, significantly increased from the habitual sleep period compared to the sleep extension. These findings are consistent with the systematic review by Ohayon et al. (2017), the authors categorized a WASO of 20 minutes or less suggests a good quality of sleep, whereas a WASO of 51 minutes or more indicates poor sleep quality. Moreover, the authors suggest that 1 or fewer awakenings per night indicate good sleep quality for all ages. However, 4 or more awakenings per night would indicate poor sleep quality (Ohayon et al., 2017). Thus, although we observed an increase in sleep duration, cadet SE, SOL, WASO, and Awakenings seems to have been compromised further causing a reduction in sleep quality.

Subjective Sleep

Additionally, the mean Epworth Sleepiness Scale (ESS) rating was elevated during the habitual sleep period, which is outside normal limits in this present study and indicates significant daytime sleepiness (Johns, 1986). Whereas, during the sleep extension period, the ESS rating decreased significantly, which fall back within the normal limits. The habitual mean ESS scores of the present study are aligned with the subsequent studies investigating daytime sleepiness within military populations. Lagoy et al. (2022), which found in an observational study that longer habitual sleep durations were associated with lower daytime sleepiness.

Additionally, the ESS has been used to evaluate potential indicators of impaired performance on tasks requiring attention and psychomotor vigilance (Shattuck and Matsanga, 2014). Furthermore, the authors suggest that "ESS scores indicate personal sleep debt that varies depending on the current opportunity for sleep combined with an individual's sleep requirement" (Shattuck and Matsangas, 2014). Therefore, we posit that although habitual sleep duration was increased and subjective sleepiness improved during the sleep extension period, collectively, the objective sleep quality measures in the present study suggest that there may be an impairment to sleep quality causal of sleep extension. Consequently, imposing "poor sleep quality" on already poor sleeping populations. Additionally, it is plausible that habitual TST was not low enough to elicit performance improvements, in concert to reductions in objective sleep quality further illuminates the potential determinants of decreased cognitive and physical performance on tactically relevant tasks.

Cognitive Performance Test

Lagoy et al. (2022), conducted a study investigating the role of habitual sleep on physical performance and effects of a 5-day simulated military operational stress protocol (SMOS), where sleep was disrupted or restricted for 2-consecutive days. Researchers administered the ESS and a tactical mobility test daily and determined that there is a relationship between lower daytime subjective sleepiness and a higher capacity for aerobic fitness. The present study assessed cognitive performance following an acute bout of sleep extension via the Psychomotor Vigilance Test (PVT) and the Purdue Pegboard. Despite an increase in TST and improved subjective sleepiness there was no significant association between habitual sleep and sleep extension on PVT performance with respect to reaction time, response speed and number of lapses. Shattuck and Matsangas (2014), suggest that the ESS score predicts impaired psychomotor performance. Therefore, high levels of subjective sleepiness may engender decreases in performance on PVT mean reaction times (Shattuck & Matsangas. 2014). Considering that subjective sleepiness improved during our sleep extension period, and there were no significant improvements in cadet reaction time, it is plausible that a cadet's sleep duration with respect to the completion a full sleep cycle and obtaining a sufficient amount of nighttime sleep may provide a potential mechanism to explain our findings.

The present findings are inconsistent with Mah et al. (2011), and Ritland et al. (2019), who reported significant improvements in mean PVT reaction time and the number of lapses during a sleep extension protocol. According to Ritland et al. (2019), "longer sleep increases (around 1.4 h per night for this study) may be needed to observe vigilant attention (reaction time) improvements," which is consistent with improved PVT reaction times observed following a 5-7 week sleep extension protocol where TST was increased to 1.8 h per night (Mah et al., 2019).

However, TST was increased by ~1 h in the present study, and it did not significantly affect PVT performance, akin to Famodu et al. (2017) findings. Famodu et al. (2017), revealed that increasing sleep duration for 1 week at 0.4 h per night is insufficient to prompt performance improvements. The Purdue Pegboard test (PPT) assesses fine motor dexterity and compares it to normative data (Lawson, 2019). The ability to implement complex, meticulous movements by coordinating small muscle groups is intertwined with cognitive performance within an operational setting (Knufinke et al., 2018). The current study's findings show that increased TST had no significant effect on fine motor skills in 2 of the 4 conditions of the PPT (Right hand and Left hand). The lack of significance may result from the subjects falling within the normative values for young adults 35 and younger. Though, there was a significant effect on the 'both hand' and 'assembly task' conditions. Considering these findings and their inconsistency with the literature, performance improvements may be predicated on a potential learning effect rather than improved fine motor dexterity causal of increased TST.

Physical Performance Test

The findings of this study suggest that components of physical performance pertinent to militarily relevant tasks and soldier preparedness/readiness may not benefit from sleep extension, if sleep extension is less than 1.4 to 1.8-h (Ritland et al., 2019 and Mah et al., 2014). Considering the vertical jump, 3 repetition maximal deadlift, 300-meter shuttle, and 1-mile run are measures of muscular power, strength, anaerobic capacity, and aerobic power, respectively (Peterson et al., 2006). The literature did not support cadet performance on the 300m shuttle in the current study; Mah et al. (2011), reported improved sprint times due to sleep extension of 1.8-h. Additionally, Schwartz et al. (2015), reported improved sport-specific skill performance following the increase of TST by 2-h per night for 1-week. Further, the present study reveals sleep extension had no significant effect on the vertical jump when compared to baseline, which is also not in agreement with Ritland et al. (2019), findings that sleep extension had a significant effect on vertical jump ability assessed via the standing broad jump and the motivation to execute the movement. Although we did not measure motivation to perform a vertical jump, Ritland et al. (2019), revealed improvements in motivation following sleep extension. Thus, considering our findings on subjective sleepiness were consistent with previous sleep extension research, the observed improvement in subjective sleepiness in concert with the unknown effect of increased sleep duration by ~ 1-h on motivation may explain a potential contributing mechanism behind the non-significant changes in vertical jump performance. The literature is limited on the effect of sleep extension on endurance performance. However, we found in the current study that sleep extension had no significant effect on 1-mile run time. Congruently, Spencer et al. (2019), found that, following three nights of sleep extension, endurance performance was maintained when compared to normal and restricted sleep. As previously mentioned, 7-h of sleep per night habitually engenders optimal health; our findings imply that 7-h may not be adequate enough to ensure optimal endurance performance within this population. In fact, during the sleep extension period, cadets did obtain the recommended 7-h of sleep per night, but there may not be enough nighttime sleep accumulated to observe similar improvements to endurance performance as seen in the aforementioned sleep extension studies (Mah et al., 2011; Schwartz et al., 2015; Spencer et al., 2019). Whereas there was a significant effect on 3 repetition maximal deadlift, we concur with Ritland et al. (2019), who reported improvements in performance on gross motor tasks may be causal of differences in motivation to perform the task. Similar to the present study, significant improvement in the 3-repetition maximal deadlift from baseline to sleep extension, may be explained as a result of increased motivation of the participants to outperform their baseline result although motivation was not measured. The majority of existent evidence on sleep duration, the health span and performance are comprised of extensive observational or epidemiological studies of the general population. The results from the studies mentioned above are encouraging, though the utilization of more interventional sleep studies, specifically investigating the effects of sleep extension on cognitive and physical performance in tactical populations, is necessary.

CHAPTER 5

5.1. Strengths and Limitations

This study included several strengths (1) limiting of caffeine 6 hours prior to cognitive and physical testing; The literature suggests caffeine can have ameliorating effects on attention, alertness, and vigilance in sleep deprived states; therefore, caffeine consumption prior to testing will increase study variability (Walsh et al., 2020). (2) Circadian rhythm has been shown to influence performance (Thun et al., 2015), so cognitive and physical post-test were conducted within an hour of the baseline pre-test; The study started on a Friday for cohorts 1-3 and on a Monday for cohort 4 in order to control for weekday/weekend sleep pattern variability; (3) In addition, testing on a Monday or Friday allowed us to better control for any potential carryover effect of weekend behaviors such as weekend oversleeping or increased drinking; (4) On test days, participants were excused from their 6am physical training to avoid fatigue or other training effects which may hinder performance on the performance batteries; (5) The utilization of varying cognitive and physical test and questionnaires aided in delineating which types of tactically relevant tasks are impacted by sleep extension and (6) The recruitment of AROTC cadets developing technical, physical, and cognitive and leadership skills to lead the U.S Army offers a perspective on how to implement strategies that may potentially enhance performance by improving habitual sleep patterns.

It is important to also mention the limitations of the present study. (1) The use of a 1- week intervention implemented may be burdensome for individuals with busy schedules. (2) The age range for the study population was 18-32 years, and to our knowledge limited evidence is available on the effect of a sleep extension intervention in older tactical athletes. (3) In addition, we could not control for all potential learning effects exhibited on the cognitive test; (4) nor did we control for proper hydration and nutrition during habitual and intervention periods. (5) Menstrual phase was not taken into consideration during the study. (6) The use of a consecutive design study may have introduced a learning effect. Future research should widen their inclusion criteria for age to better elucidate the effects of sleep extension across the lifespan within tactical populations. In addition, future researchers should consider time management/planning specifically for extending time in bed. Collectively, future researchers should identify strategies that promote sleep health through the assessment of the various factors impeding or supporting adequate sleep duration and quality

CHAPTER 6

6.1. Conclusion

This study aimed to assess the effect of acute sleep extension on cognitive and physical performance in Army Reserve Officer Training Corps cadets. Time in bed was increased by approximately 2 hours, which resulted in an increase in sleep time by approximately 1 hour per night for 1-week, which resulted in improved subjective sleepiness, performance on the assembly task, both hand conditions on the Purdue Peg Board test, and 3-repetition maximal hexagon deadlift. Although habitual sleep improved in duration it may have had a deleterious effect on objective sleep quality, which decreased significantly during the sleep extension period. Considering the lack of statistical significance on the psychomotor vigilance test, the right- and left-hand conditions of the Purdue Peg Board test, vertical jump, 300-meter shuttle and 1-mile run, further research in warranted in this population. Although the majority of research done on tactical populations investigate the effect of sleep restriction or deprivation on performance, more evidence is needed to identify which approach should be taken to improve sleep health within these populations. Specifically, additional research should focus on the effects of sleep enhancement strategies on sleep duration and quality in tactical populations enrolled in ROTC programs to aid in performance within operational environments.

Table 1. Participant Characteristics.

Variable		Mean ± SD
Age, y		21 ± 4
Sex		
	Female, n (%)	7 (43.8%)
	Male, n (%)	9 (56.3%)
Race		
	African American, n (%)	0 (0)
	Asian, n (%)	1 (6.25%)
	White, n (%)	14 (87.5%)
	Hispanic, n (%)	1 (6.25%)
	American Indian/Alaskan Native, n (%)	0 (0)
	More than one race, n (%)	0 (0)
BMI, kg/m^2		26.2 ±5.5
MEQ		
	Morningness	8
	Eveningness	7

Table 2. Subjective Sleepiness and Objective Sleep Parameters.

Variable	1-week habitual sleep	1-week sleep extension	P value
	Mean ± SEM	**Mean ± SEM**	
Time in Bed, hours	7.19 ± 0.22	9.35 ± 0.34	<0.001
Total Sleep Time, hours	6.07 ± 0.15	7.03 ± 0.17	<0.001
Sleep midpoint	2.66 ± 0.20	2.13 ± 0.22	<0.01
Sleep Onset Latency, minutes	11.96 ± 4.26	36.49 ± 6.25	<0.003
Sleep Efficiency, %	84.41 ± 1.3	76.47 ± 1.64	<0.001
Wake After Sleep Onset, minutes	46.93 ± 5.16	70.35 ± 7.19	<0.001
Awakenings, # of wakes	7.19 ± 0.22	9.35 ± 0.34	<0.001
Epworth Sleepiness Scale	10.47 ±1.16	7.10 ±0.79	<0.005

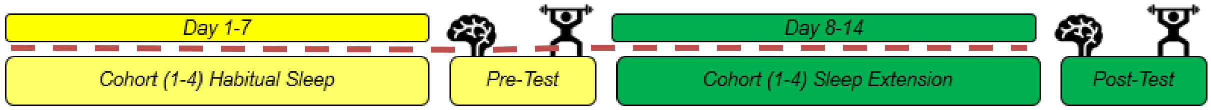
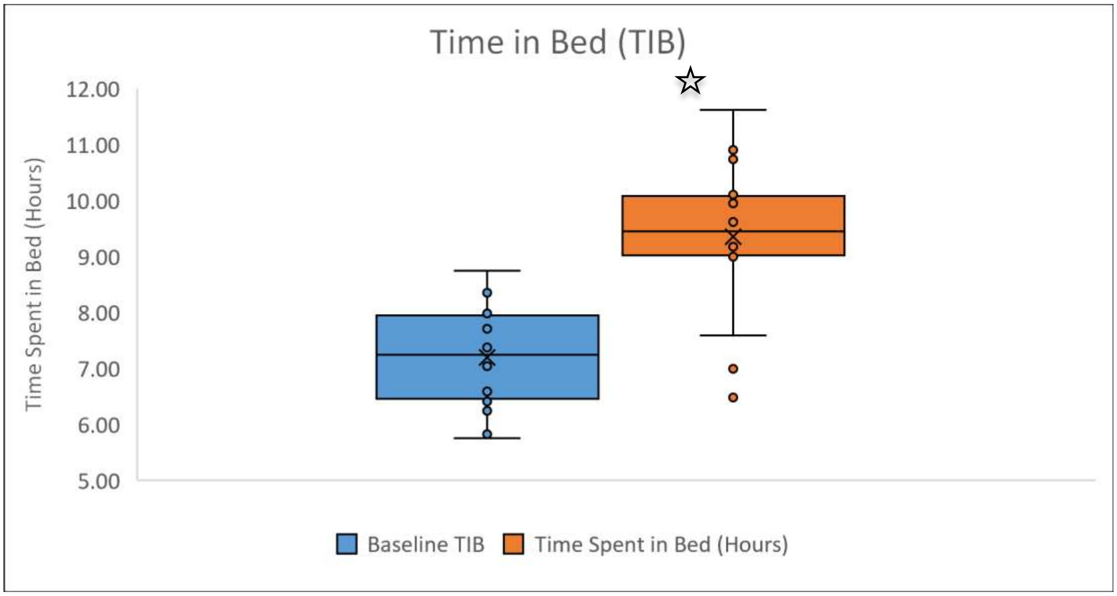
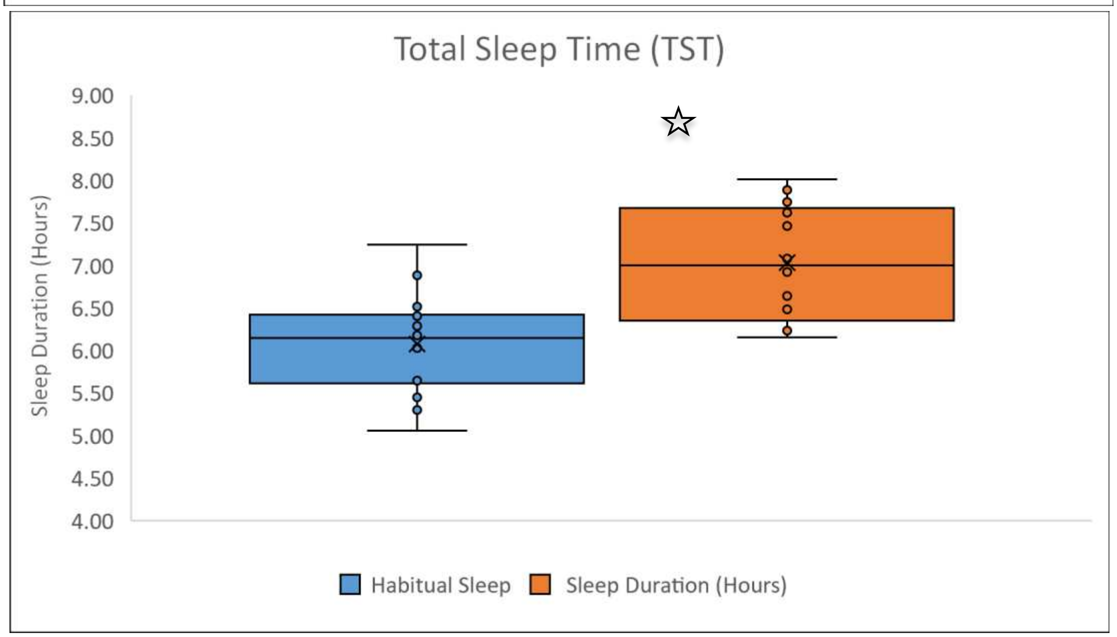


Figure 1. Study Protocol. For 1-week, habitual sleep was recorded (day 1-7); following the habitual sleep period, participants began the sleep extension protocol (day 8-14). Red dashes indicate Actiwatch data collection. Cognitive and physical testing will occur after 1 week of habitual sleep and 1 week of sleep extension (indicated by brain and weightlifting icons on Days 7 and 14). Sleep extension will be achieved by asking participants to spend 10 hours in bed with the goal of increasing sleep by at least 1 hour per night.

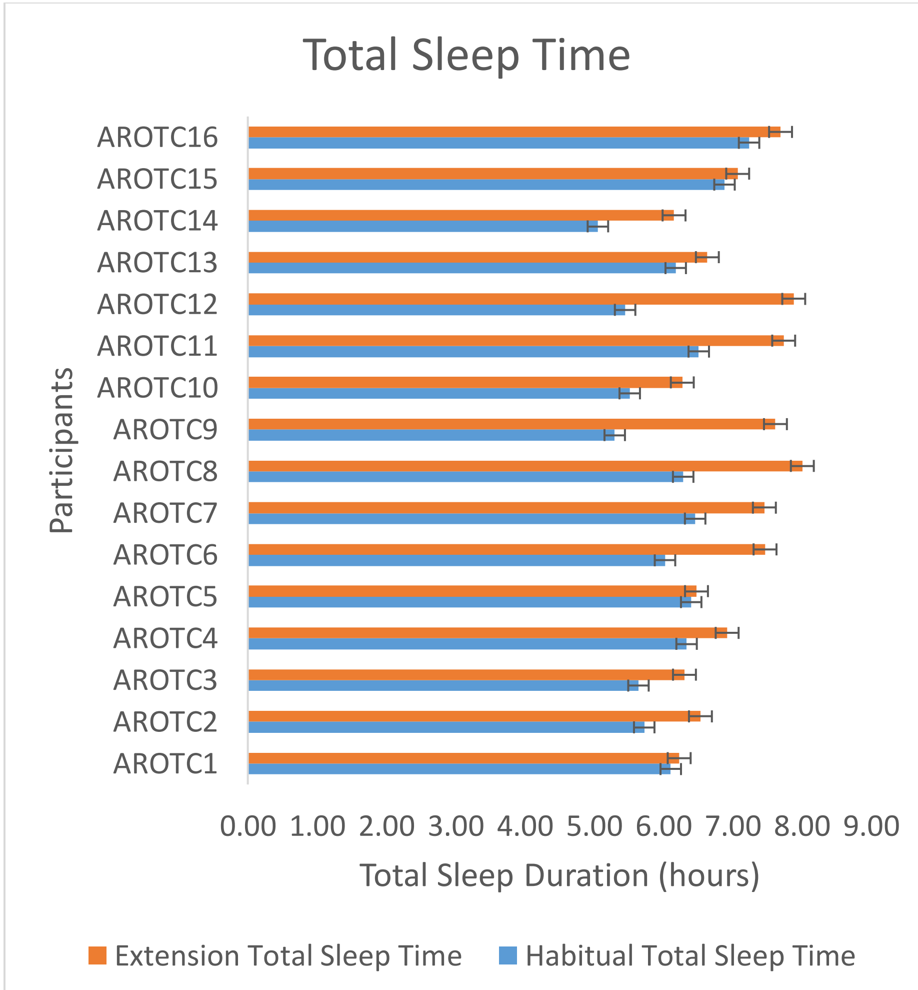


a.



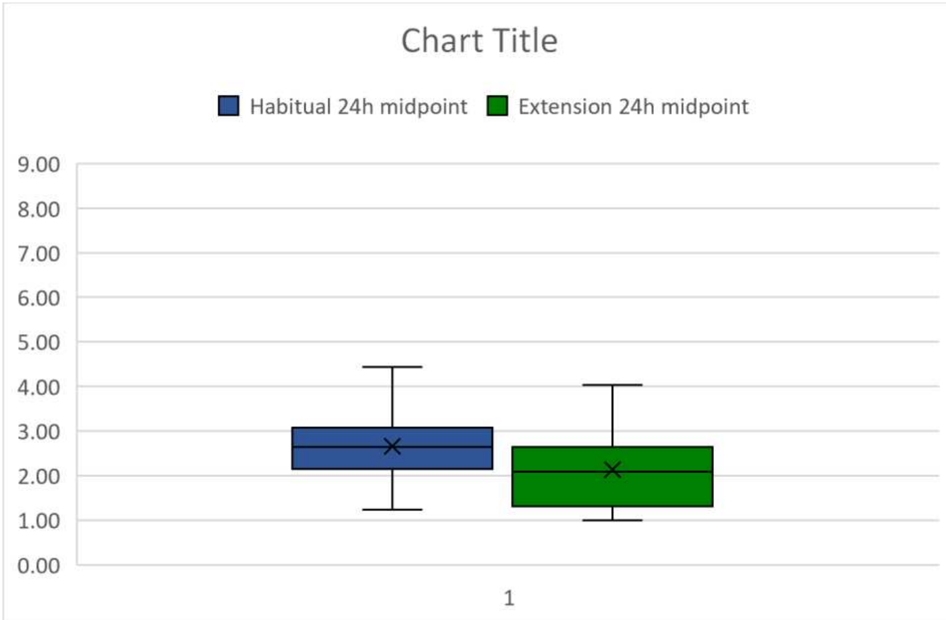
b.

Figure 2 a & b Sleep Duration Figures 2 a & b show the sleep duration parameters recorded from the Actiwatch. The blue boxes indicate mean baseline TIB and TST during the habitual sleep period, while the orange boxes indicate mean TIB and TST during the intervention. The white star indicates statistically significant differences were found between baseline and intervention in TST and TIB; orange indicates that TIB ($p<0.01$) and TST ($p<0.001$) significantly increased from baseline throughout the intervention. This is expected of a sleep extension protocol and exhibits that the protocol was effective in extending sleep duration.



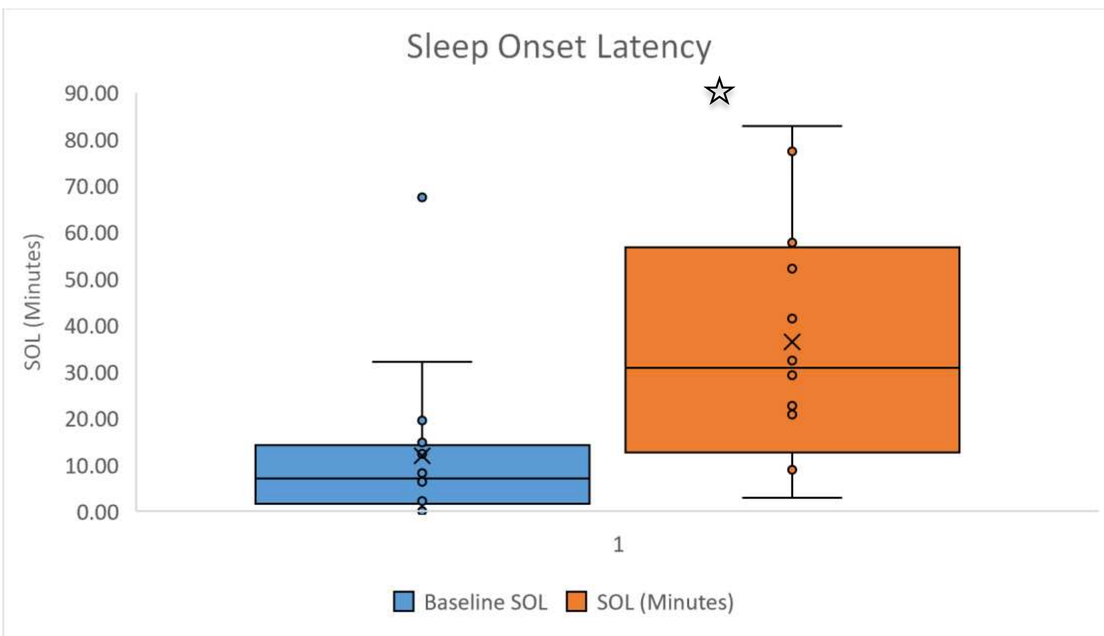
c.

Figure 2 c show the sleep duration of each participant during the habitual sleep period and the sleep extension period. The blue bar indicate participant average sleep duration during the habitual period and the orange bar indicates average sleep duration during the sleep extension period.

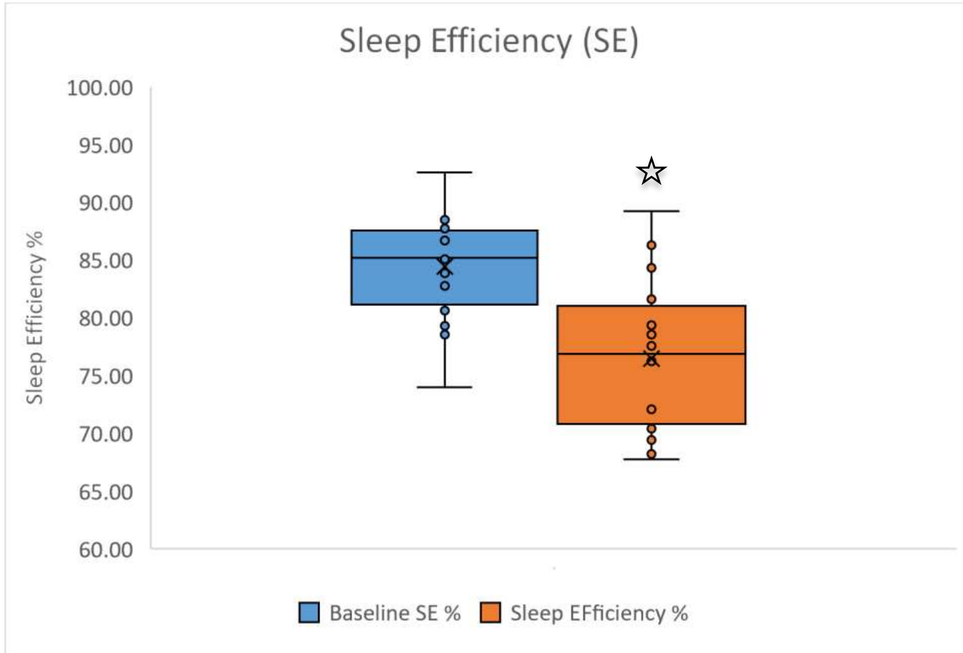


d.

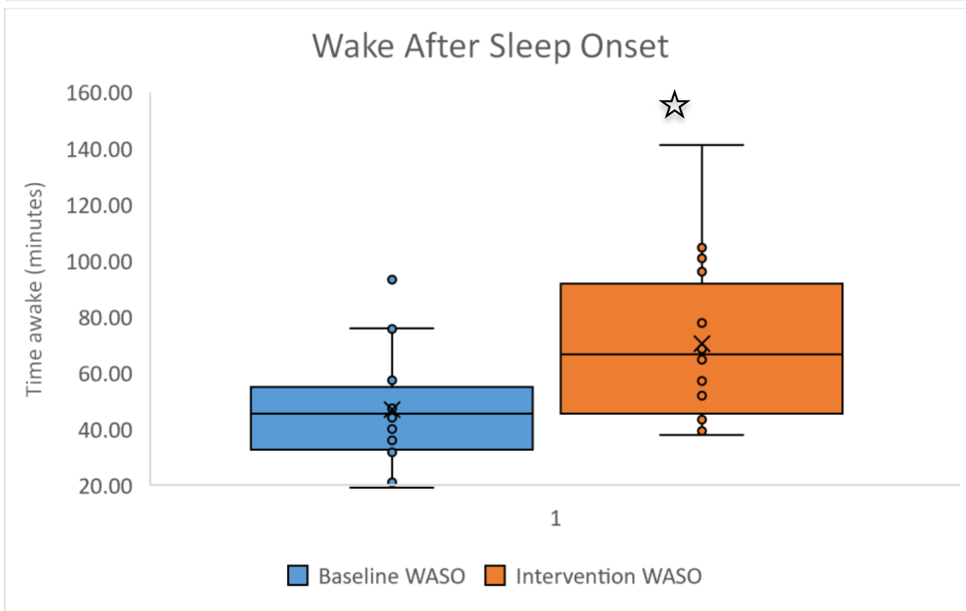
Figure 2 d show the sleep timing of each participant during the habitual sleep period and sleep extension period. The blue box indicate participant average habitual midpoint of sleep during the habitual period; the green box indicate participant average midpoint of sleep during sleep extension.



e.


Sleep Efficiency (SE)
100.00
95.00
90.00
85.00
80.00
75.00
70.00
65.00
60.00
Sleep Efficiency %
Baseline SE %
Sleep EFficiency %

f.


Wake After Sleep Onset
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
Time awake (minutes)
1
Baseline WASO
Intervention WASO

g.

h.

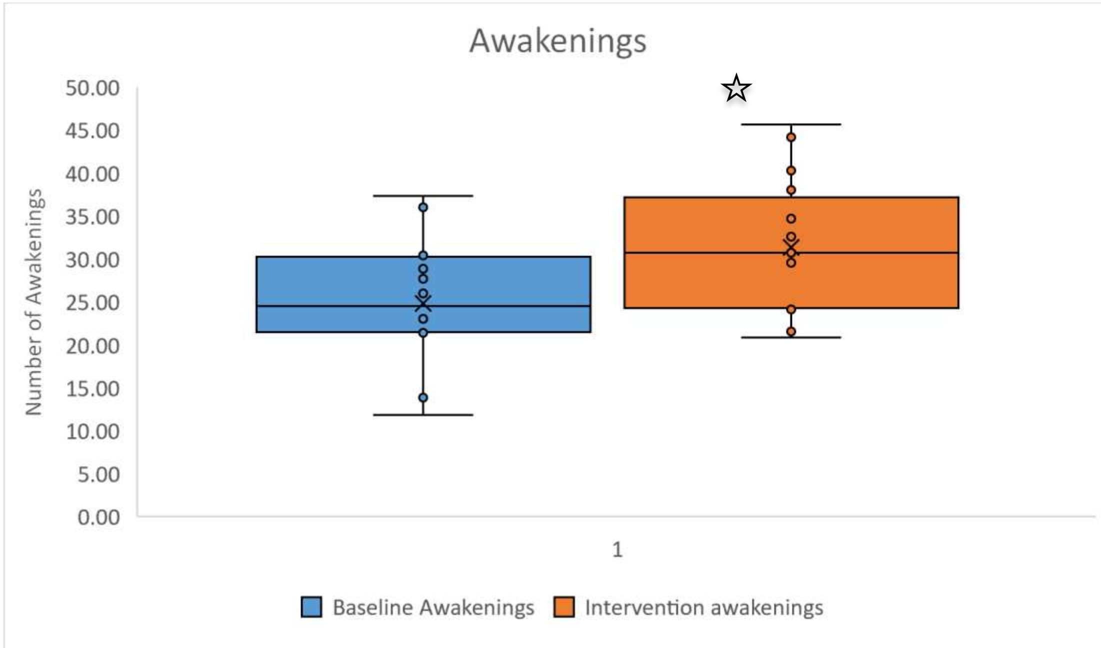
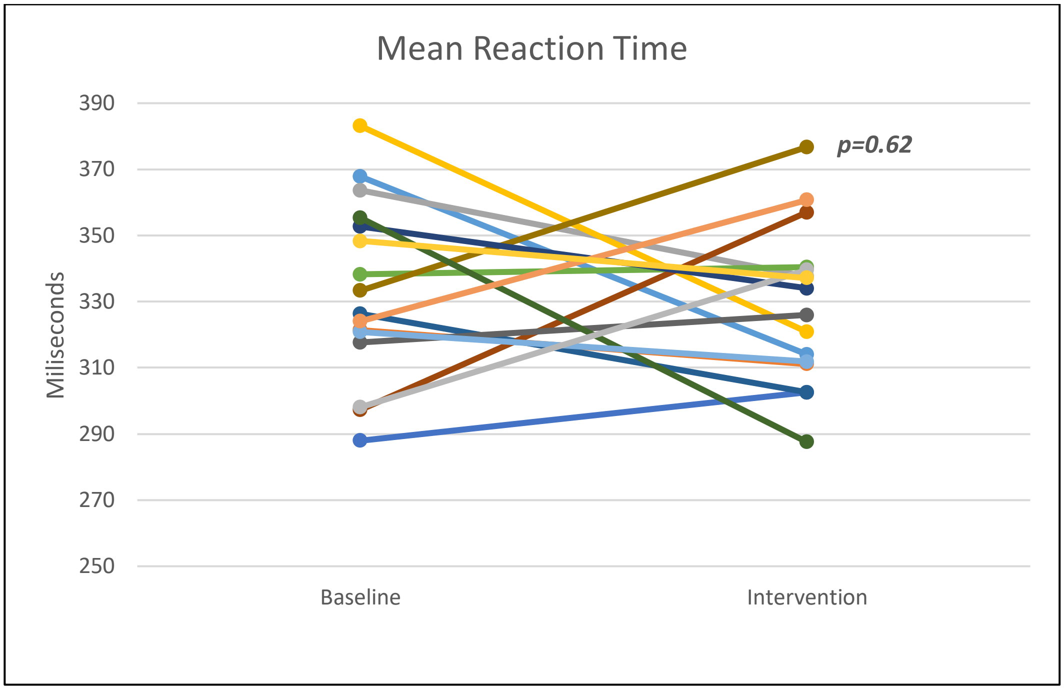
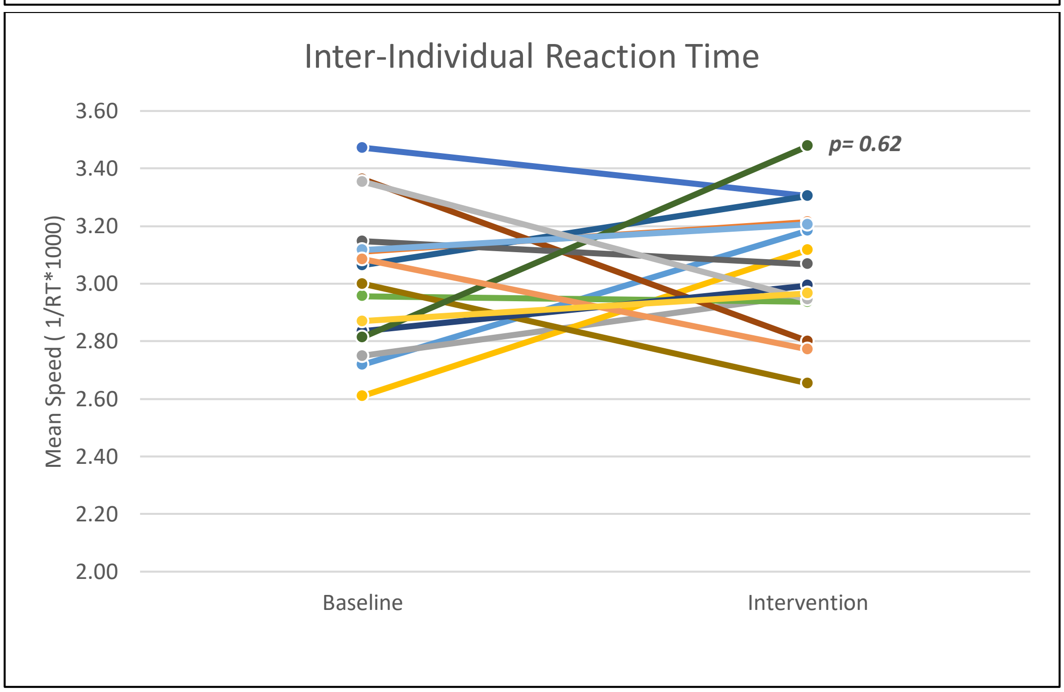


Figure 2. f – i Objective Sleep Qualities. Shown above are the sleep quality parameters recorded from the Actiwatch. Figures 2c – 2f indicate SOL, SE, WASO, and Awakenings, respectively. The blue boxes indicate mean baseline, SOL, SE, WASO, and Awakenings during the habitual sleep period, while the orange boxes indicate mean SOL, SE, WASO, and Awakenings during the intervention. Significant differences were found between baseline and intervention; Fig. 2c indicates an increase from baseline throughout the intervention of SOL ($p<0.003$). Fig. 2d suggests a reduction in SE % during the intervention ($p<0.001$). Fig. 2e indicates an increase in WASO during the intervention ($p<0.001$). Fig. 2f indicates an increase in awakenings from baseline to intervention ($p<0.001$). As a result of sleep extension and increasing sleep duration, sleep quality was negatively affected.


Mean Reaction Time
390
370
350
330
310
290
270
250
Miliseconds
p=0.62
Baseline
Intervention

i.


Inter-Individual Reaction Time
3.60
3.40
3.20
3.00
2.80
2.60
2.40
2.20
2.00
Mean Speed (1/RT*1000)
p= 0.62
Baseline
Intervention

j.

k.

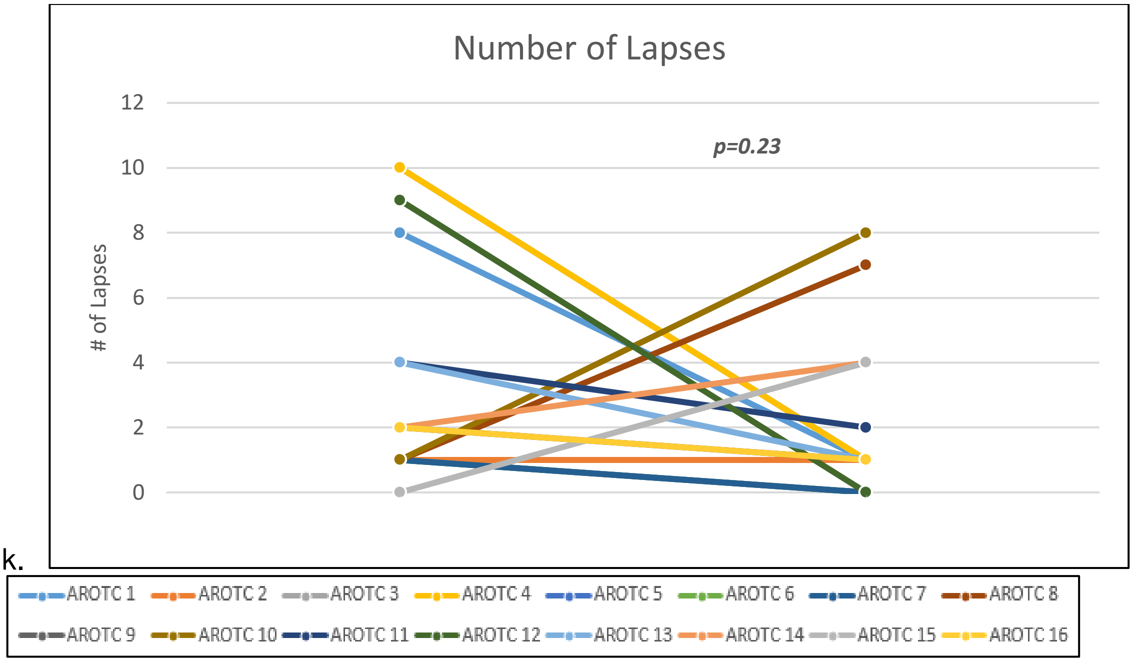
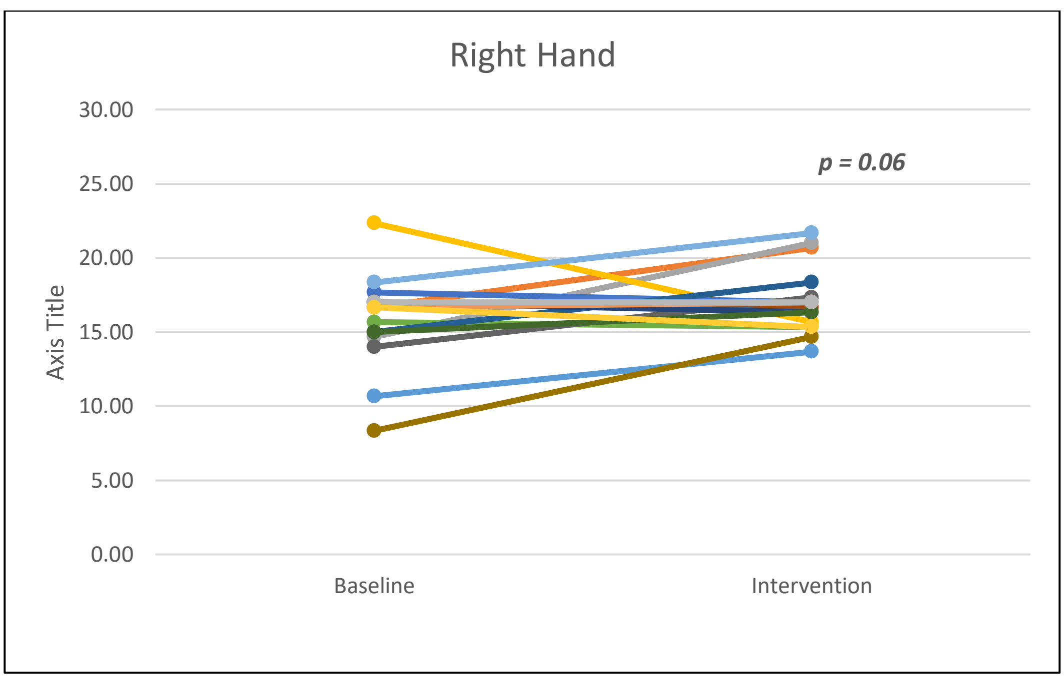
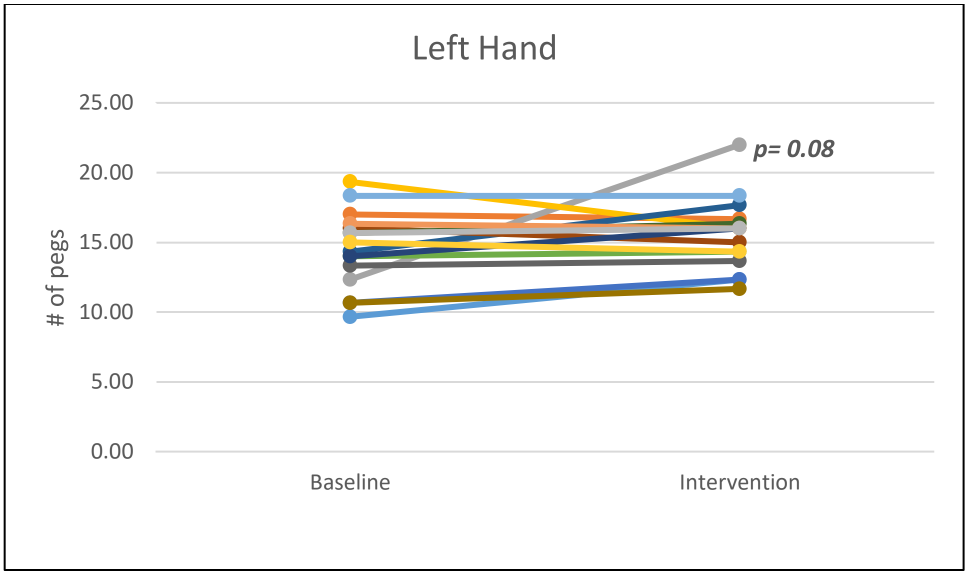


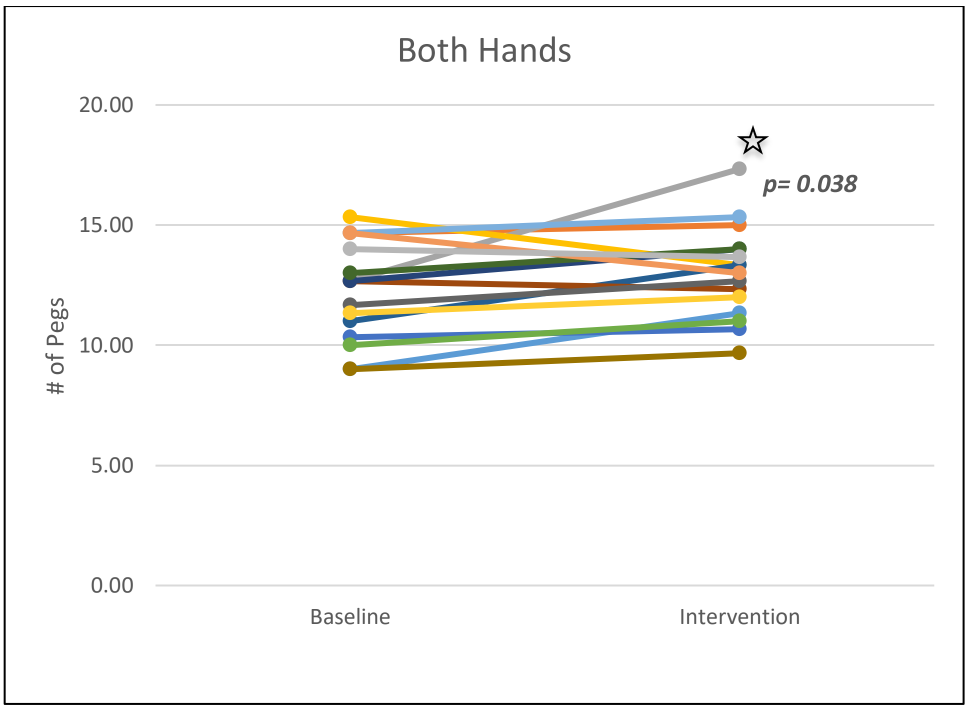
Figure 2 j - l Psychomotor Vigilance Motor Test. Shown above are the performance results from the PVT. Figures 2 g – i indicate the mean reaction time, mean PVT response speed, and number of lapses, respectively. The Blue boxes indicate PVT performance during the habitual sleep period, while the orange boxes indicate PVT performance during the Sleep extension. No significant differences were found between baseline and intervention (P=0.62, 0.65, P=0.23, respectively).

l.




Left Hand
25.00
20.00
15.00
10.00
5.00
0.00
# of pegs
Baseline
Intervention
p= 0.08

m.


Both Hands
20.00
15.00
10.00
5.00
0.00
# of Pegs
Baseline
Intervention
p= 0.038

n.

o.

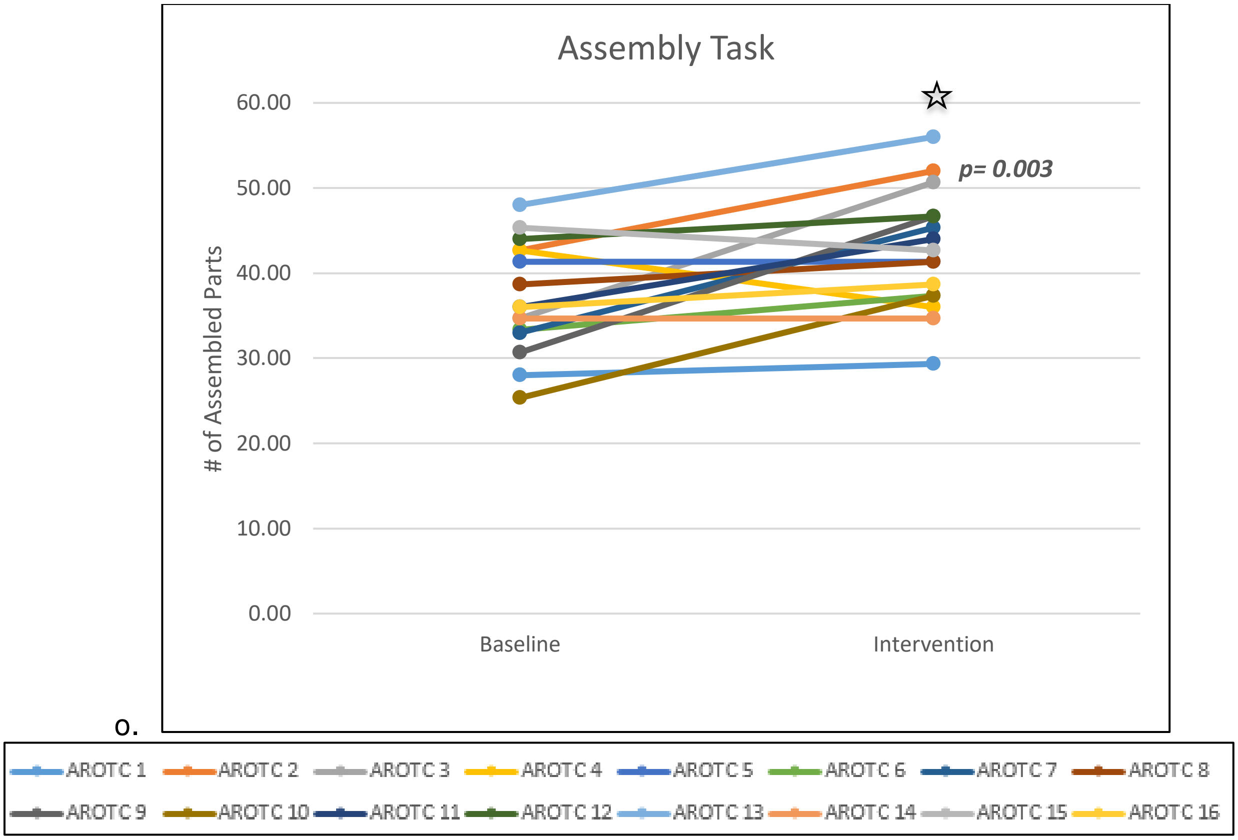
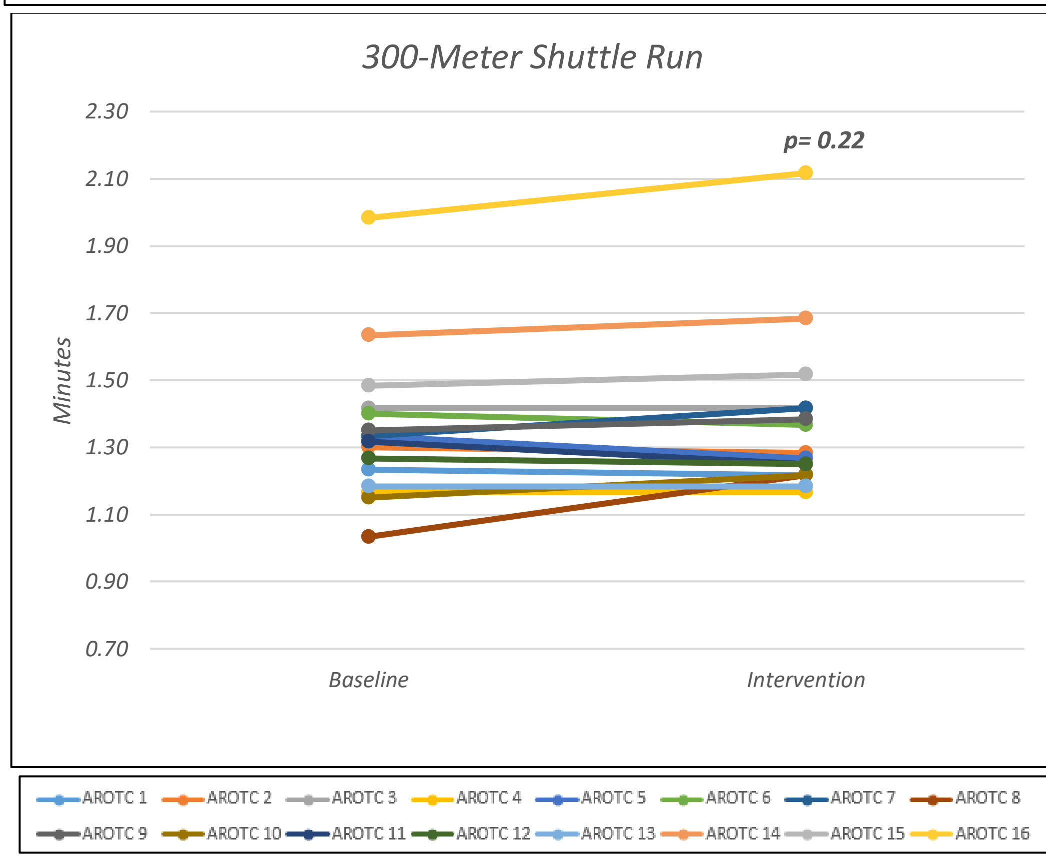


Figure 2. m-p Purdue Pegboard Test. The performance results from the Purdue Pegboard Test (PPT) are shown above. Figures 2 j – m indicates the right hand, left hand, both hands, and assembly task, respectively. Each colored line indicates individual cadet performance on the PPT from the habitual sleep period pre-test to the sleep extension period post-test. No significant differences were found between habitual sleep and sleep extension on the right and left hand conditions (P=0. 06 and P=0.08, respectively). The white star indicates statistically significant differences were revealed in both hand and assembly task conditions, P=0.038 and P=0.003, respectively).

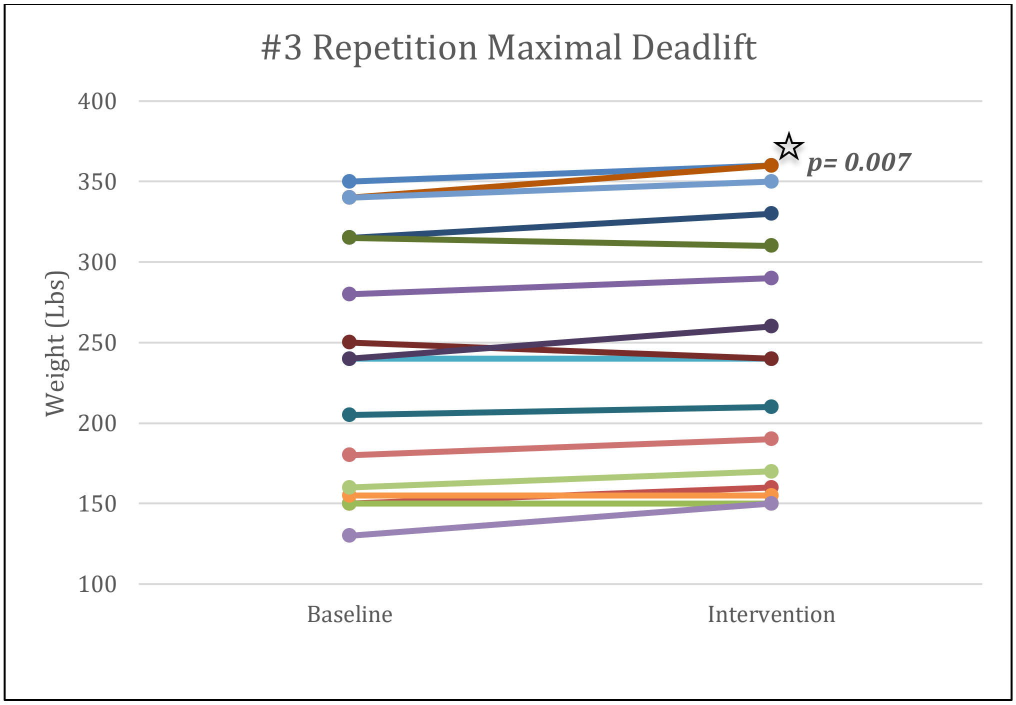
1 Mile Run
p= 0.09
Minutes
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Baseline
Intervention

p.

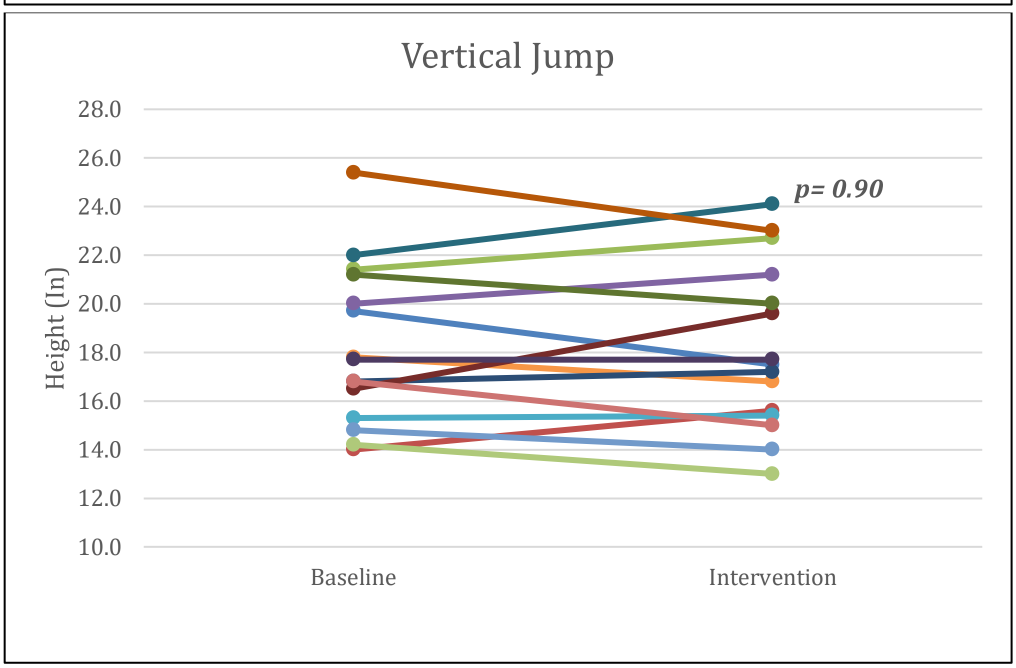


300-Meter Shuttle Run
p= 0.22
Minutes
2.30
2.10
1.90
1.70
1.50
1.30
1.10
0.90
0.70
Baseline
Intervention
AROTC 1
AROTC 2
AROTC 3
AROTC 4
AROTC 5
AROTC 6
AROTC 7
AROTC 8
AROTC 9
AROTC 10
AROTC 11
AROTC 12
AROTC 13
AROTC 14
AROTC 15
AROTC 16

q.



r.



s.

Figure 2 q – t. Physical Test Performance. Shown above are the performance results from the physical test Figures 2 n – q indicates the 1- mile run, 300 meter shuttle, 3-repetition maximal deadlift and the vertical jump, respectively. Each colored line indicates individual cadet performance on the physical test during from the habitual sleep period and the sleep extension period. No significant differences were found between baseline and intervention on the 1- mile run (P=0.09), 300 meter shuttle (P=0.22), and vertical jump (P=0.90); although significant differences were revealed in the 3 repetition maximal deadlift (P=0.007).

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