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Original Article

Effects of sleep extension on cognitive/motor performance and motivation in military tactical athletes

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ABSTRACT

Objective: Investigate the immediate and residual impacts of sleep extension in tactical athletes.
Methods: A randomized controlled trial (Sleep extension = EXT vs Control = CON) was conducted on 50 (EXT: 20.12 ± 2.01 years vs CON: 19.76 ± 1.09 years) tactical athletes enrolled in the Reserve Officers' Training Corps (ROTC). Participants wore actigraphs for 15 consecutive nights and completed a cognitive/motor battery after seven habitual sleep nights, after four sleep extension nights, and after the resumption of habitual sleep for four nights. The CON group remained on habitual sleep schedules for the entire study.
Results: During the intervention, the EXT group significantly increased mean sleep time (1.36 ± 0.71 h, $p < 0.001$). After sleep extension, there were significant between-group differences on the mean score change since baseline in Psychomotor Vigilance Test (PVT) reaction time ($p = 0.026$), Trail Making Test (TMT) − B time ($p = 0.027$), standing broad jump (SBJ) distance ($p < 0.001$), and motivation levels [to perform the cognitive tasks ($p = 0.003$) and the SBJ ($p = 0.009$)]; with the EXT group showing a greater enhancement in performance/motivation. After resuming habitual sleep schedules, significant between-group differences on the mean score change since baseline persisted on SBJ distance ($p = 0.001$) and motivation to perform the SBJ ($p = 0.035$), with the EXT showing greater enhancement in performance/motivation.
Conclusion: Increasing sleep duration in military tactical athletes resulted in immediate performance benefits in psychomotor vigilance, executive functioning, standing broad jump distance, and motivation levels. Benefits on motor performance were evident four days after resumption of habitual sleep schedules. Military tactical athletes aiming to optimize their overall performance should consider the impact of longer sleep durations when feasible.

1. Introduction

Sleep extension, which is the intentional increase of habitual sleep duration, has been shown to confer a number of positive benefits in athletes. A recent systematic review of sleep interventions and athletic performance revealed that sleep extension enhances subsequent performance [1]. For instance, sleep extension resulted in significant improvements in serving accuracy and subjective sleepiness in college tennis players [2] and significant improvements in sprint time, basketball shooting percentage (free-throw and three-point percentage), Psychomotor Vigilance Test (PVT) reaction time, as well as subjective sleepiness and mood in male college basketball players [3]. Aside from the aforementioned cognitive, motor, and mood benefits in athletes, sleep extension has also revealed improvements in executive function performance on working memory tasks that tested visuospatial processing and divided attention [4]. While the mechanisms

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underlying the effects of sleep extension on subsequent performance, mood, and sleepiness are complex, one study revealed positive effects on fronto-central brain regions and their associated functions after sleep extension [5]. Furthermore, another hypothesized that sleep extension may optimize mood regulation by enhancing the functional connectivity between the amygdala and the prefrontal cortex (PFC), which sends inhibitory input to the amygdala [6]. Consequently, waking functions more reliant on fronto-central brain regions such as the PFC, including attention [7], executive functions [8], or motivation [9] may benefit when extending sleep beyond habitual amounts.

Sleep extension provides a potential strategy for sustaining operational effectiveness in professions with unique sleep circumstances and work demands (eg, military, law enforcement, fire response, etc.) considering sleep extension prior to periods of sleep restriction/deprivation has shown to provide cognitive and motor performance benefits [10,11]. Personnel in such professions have been termed “tactical athletes”, reflecting the nature of the training required to prepare/condition individuals for challenges that they are likely to encounter in the operational environment [12]. In the military, one source responsible for such training is the Reserve Officers' Training Corps (ROTC), which prepares tactical athletes for their future leadership role in the military. To date, there have been no well-controlled studies on the immediate and residual effects of sleep extension on performance and motivation in this population.

The primary aim of this study was to investigate the immediate effects of sleep extension on the cognitive/motor performance and motivation of tactical athletes enrolled in the ROTC. The second aim was to determine whether any effects of sleep extension remained detectable four days after participants 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 sleep extension. It was also 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.

2. Methods

2.1. Participants

Young adults (age 18–30 years) enrolled in any ROTC program (Air Force, Army, Navy) at the University of Maryland, College Park, were invited to participate in the study. Participants were recruited by word of mouth and advertisement flyers. During screening, participants were excluded if they self-reported any of the following: history of a psychiatric disorder; take medications with sleep-related side effects; use illicit drugs; an average of more than 8.5 h of sleep per 24-h; habitually extend their sleep by more than 90 min 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. A total of 57 participants provided written consent and started the study. However, 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). Therefore, 50 (25 in each group) tactical athletes completed the study.

2.2. Study design/Experimental timeline

A randomized controlled trial- sleep extension (EXT) versus control (CON) was conducted on tactical athletes enrolled in the ROTC. Fig. 1 provides an overview of the study timeline. Participants wore actigraphs for 15 consecutive nights. 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 h in bed each night. If participants were unable to spend 10 h in bed during the nighttime/morning hours, they were asked in spend any additional time in bed during the day to reach the 10 h. 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. The study took place during the academic year with participants actively engaged in coursework and ROTC training/responsibilities. To control for weekday/weekend sleep patterns, every participant started on a Monday. Participants were paid $50 at the end of the study if they successfully completed the entire study.

2.3. Sleep-wake monitoring

Participants wore actigraph watches (Actiwatch 2, Philips Respironics, Andover, MA) and completed consensus sleep diaries [13] in their own home environment for the entire duration of the study. Participants were instructed to wear the watch continuously for the duration of the study (15 nights) on their non-dominant arm. In addition to using the sleep diary to record their sleep-wake activity, they were asked to annotate any time 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.

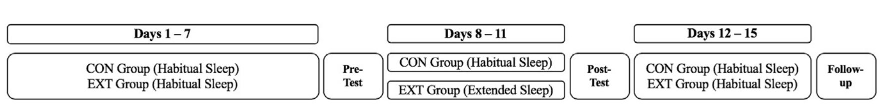

Fig. 1. Study timeline. Participant sleep/wake cycles were monitored continuously via actigraphs/sleep diaries for 15 nights and assessments were conducted on days 8 (Pre-Test), 11 (Post-Test), and 16 (Follow-up). The control group (CON) maintained habitual sleep patterns for the entire duration of the study. The extension group (EXT) maintained habitual sleep patterns for the first seven nights and the last four nights of the study. Between the pre-test and post-test, the EXT group performed four nights of sleep extension.

2.4. Performance testing

Every participant was tested on 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 h 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 h and completed questionnaires on their sleepiness and anxiety. After the questionnaires, the participants performed the Cognitive/Motor Test Battery (in order of performance): PVT – 5-min version, Flanker Task, the Trail Making Test (A and B), Symbol Digit Modalities Test (SDMT) (written and oral versions), and a maximum SBJ (three 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 Analog Scale (VAS) (anchors: No motivation, Highest possible motivation).

Daytime sleepiness was recorded using the Epworth Sleepiness Scale (ESS) [14] and the Karolinska Sleepiness Scale (KSS) [15]. The ESS measures sleep propensity in eight 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 [16]. 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 [17]. The State-Trait Anxiety Inventory (STAI) was used to measure anxiety [18] prior to performing the cognitive/motor battery.

A 5-min modified version of the PVT [19] was administered on the computer using the Psychology Experiment Building Language (PEBL) software program [20]. Each 5-min trial consisted of stimuli (red circle on computer monitor) occurring at intervals ranging from 2 to 5 s 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 ms).

A modified version of the Flanker Task [21] was administered on the computer using the PEBL software program [20]. 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, pointing in the right and left direction. The participant pressed the left-shift button if the target stimulus pointed to the left and the 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 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 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 measured. In addition, an interference score using the following equation,

$$\frac{\textit{incongruent mean RT} - \textit{congruent mean RT}}{\textit{congruent mean RT}} \times 100$$

was calculated as a metric of inhibitory control unbiased by differences in base reaction time [22].

The Trail Making Test A (TMT-A) and B (TMT-B) [23] 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 (ie, 1 to A to 2 to B) from 1 to 13. TMT-A and TMT-B were timed to completion events. Furthermore, the difference between TMT-B and TMT-A was calculated.

The Symbol Digit Modalities Test (SDMT) [24] was administered on pen and paper. At the top of the page, there was a key that paired nine numbers with nine corresponding geometric figures. Below the key, there were rows of only symbols and the participant was given 90 s to write as many numbers associated with symbols as possible. The total number of correctly completed numbers in 90 s 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 administered was a gross motor task: a ‘maximum effort’ standing broad jump. After receiving instructions and performing three practice 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 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.

2.5. 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). To assess the immediate impact of sleep extension (primary aim of study), a repeated measures ANOVA (Time × Group) using the pre-test and post-test scores was conducted. In addition, to assess the residual impact of sleep extension (secondary aim of study), a repeated measures ANOVA (Time × Group) using the pre-test and follow-up scores was conducted. Post hoc analysis of the repeated measures ANOVAs included performing paired t-tests to evaluate the within-group mean score changes between the pre-test and post-test (as well as between pre-test and follow-up) and independent sample t-tests were performed to compare between group mean pre-to post-test score changes (immediate impact) and mean pre-test to follow-up score changes (residual impact). P values < 0.05 were considered statistically significant. Standard deviations were recorded with mean values unless otherwise stated.

3. Results

3.1. Participants

Demographic information and characteristics of participants are reported in Table 1. There were no significant between-group differences on any baseline measurements/testing (Table 2).

Table 1
Demographic information of participants.

	Extension	Control	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	0.449
Height (m)	1.71 ± 0.09	1.70 ± 0.09	0.559
Weight (kg)	70.55 ± 9.70	66.37 ± 11.31	0.167
BMI (kg/m^2)	24.00 ± 2.47	22.95 ± 2.73	0.159
Trait Anxiety (STAI Y2)	33.92 ± 9.38	33.84 ± 9.78	0.977
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.

3.2. Sleep duration

Using actigraphy data, the mean habitual sleep durations during the first seven nights did not differ between groups (EXT = 6.19 ± 0.67 h vs CON = 6.20 ± 0.73 h, $p = 0.962$). Comparing the baseline average habitual sleep durations to the average sleep durations of the four-night intervention, the Group-by-Time interaction on total average sleep time was statistically significant, $p < 0.001$, $\eta_p^2 = 0.549$. During the four-night intervention period, compared to the baseline habitual sleep durations, the sleep extension (EXT) group significantly increased their average sleep time (1.36 ± 0.71 h, $p < 0.001$), but the control (CON) group did not (−0.25 ± 0.78 h, $p = 0.121$). There was a significant between-group difference of these mean changes ($p < 0.001$). These results indicate the EXT group successfully extended their sleep time, while the CON group maintained their habitual schedule.

Comparing the baseline average habitual sleep durations to the average sleep durations of the last four nights of the study, the Group-by-Time interaction on total average sleep time was not statistically significant, $p = 0.490$, $\eta_p^2 = 0.010$. 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 EXT group (0.08 ± 0.60 h, $p = 0.531$) or the CON group (0.21 ± 0.74 h, $p = 0.173$) and there were no significant between-group differences between these mean changes ($p = 0.490$). 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 EXT group (−0.16 ± 0.65 h, $p = 0.233$) or the CON group (0.09 ± 0.98 h, $p = 0.638$) and there were no significant between-group differences between these mean changes ($p = 0.490$). Taken together, these results show, as hypothesized, participants in the EXT group reverted back to their normal sleep schedule following the extension period, while the CON group maintained their habitual sleep time throughout the duration of the experiment.

Table 2
Baseline Measurements and Testing at Pre-Test. Between group comparison of baseline measurements and testing at pre-test (pre-intervention).

Outcome/Assessment	Extension	Control	p-value
	Mean ± SD	Mean ± SD	
KSS	5.00 ± 1.44	4.48 ± 1.71	0.251
ESS	8.40 ± 2.69	9.12 ± 3.88	0.499
Motivation			
Cognitive Tests	85.72 ± 13.04	83.92 ± 12.12	0.616
Standing Broad Jump	87.32 ± 11.66	87.64 ± 9.61	0.916
STAI Y1	32.32 ± 8.57	31.04 ± 9.65	0.622
PVT			
Mean RT (ms)	306.10 ± 34.78	299.90 ± 39.40	0.558
Lapses (>500 ms)	0.92 ± 1.75	1.32 ± 3.01	0.569
Flanker Task			
Congruent RT (ms)	424.64 ± 43.33	421.38 ± 56.26	0.819
Incongruent RT (ms)	497.96 ± 54.42	492.29 ± 72.82	0.756
Interference Score	17.36 ± 6.39	16.74 ± 4.97	0.701
TMT			
TMT A (s)	25.86 ± 5.03	24.83 ± 4.75	0.462
TMT B (s)	52.05 ± 9.14	50.34 ± 11.10	0.553
TMT B-A (s)	26.19 ± 9.68	25.50 ± 10.72	0.812
SDMT			
Total (Written and Oral)	125.96 ± 22.30	130.48 ± 12.96	0.385
Standing Broad Jump			
Average Jump (cm)	170.10 ± 32.43	178.56 ± 37.28	0.369

Data are presented as mean ± standard deviation; KSS = Karolinska Sleepiness Scale; ESS = Epworth Sleepiness Scale; STAI = State-Trait Anxiety Inventory; PVT = Psychomotor Vigilance Test; TMT = Trail Making Test; SDMT = Symbol Digit Modalities Test.

3.3. Immediate impact of sleep extension

Group-by-Time interaction effects from the repeated measures ANOVA from the pre-test and post-test scores are reported in Table 3. Statistically significant Group-by-Time interactions were noted for KSS ratings ($p = 0.001$, $\eta_p^2 = 0.205$), ESS ratings ($p < 0.001$, $\eta_p^2 = 0.265$), mean PVT reaction time ($p = 0.026$, $\eta_p^2 = 0.099$), TMT-B performance ($p = 0.027$, $\eta_p^2 = 0.098$), average standing broad jump performance ($p < 0.001$, $\eta_p^2 = 0.307$), motivation to perform the cognitive tests ($p = 0.003$, $\eta_p^2 = 0.174$) and motivation to perform the standing broad jump ($p = 0.009$, $\eta_p^2 = 0.132$). There were no other statistically significant interactions noted (ie, for state anxiety, PVT lapses, Flanker task performance (congruent time, incongruent time, and interference score), TMT A performance, TMT B-A performance, and SDMT total performance).

3.3.1. Daytime sleepiness

The mean post-test KSS rating and ESS rating significantly decreased for the EXT group (KSS = −1.92 ± 1.47, $p < 0.001$; ESS = 2.28 ± 2.73, $p < 0.001$), but not for the CON group. There were significant between-group differences of these mean changes for the KSS rating ($p = 0.001$, $d = 0.99$) (Fig. 2) and the ESS rating ($p < 0.001$, $d = 1.18$).

3.3.2. Cognitive/Motor battery

The mean post-test PVT reaction time for the EXT group significantly decreased (−16.09 ± 26.07 ms, $p = 0.005$), but the CON group did not. There was a significant between-group difference of these mean changes ($p = 0.026$, $d = 0.65$) (Fig. 3).

The mean post-test TMT-B times significantly decreased for both the EXT group (−11.77 ± 6.67 s, $p < 0.001$) and the CON group (−7.07 ± 7.77 s, $p < 0.001$) and there was a significant between-group difference of these mean changes ($p = 0.027$, $d = 0.64$), such that the EXT group showed a greater enhancement in performance than the CON group (Fig. 3).

The mean post-test average jump distance significantly increased for the EXT group (9.07 ± 8.21 cm, $p < 0.001$), but not for

Table 3
Immediate Impact of Sleep Extension on Sleepiness, Motivation, Anxiety, and Cognitive/Motor Battery Between group comparison of mean pre-test to post-test score change.

Outcome/Assessment	Extension	Control	Group × Time Effect
	Mean ± SD	Mean ± SD	p-value (η_p^2)
KSS	−1.92 ± 1.47	−0.20 ± 1.96	**0.001 (0.205)**
ESS	−2.28 ± 2.73	0.76 ± 2.42	**<0.001 (0.265)**
Motivation			
Cognitive Tests	4.44 ± 11.85	−7.04 ± 13.63	**0.003 (0.174)**
Standing Broad Jump	4.36 ± 6.78	−1.60 ± 8.69	**0.009 (0.132)**
STAI Y1	−3.36 ± 6.78	−0.04 ± 6.33	0.080 (0.063)
PVT			
Mean RT (ms)	−16.09 ± 26.07	−1.75 ± 17.16	**0.026 (0.099)**
Lapses (>500 ms)	−0.40 ± 2.14	−0.20 ± 0.96	0.672 (0.004)
Flanker Task			
Congruent RT (ms)	−33.02 ± 26.31	−21.38 ± 35.51	0.194 (0.035)
Incongruent RT (ms)	−38.72 ± 28.50	−24.55 ± 53.99	0.251 (0.027)
Interference Score	−0.01 ± 4.76	0.47 ± 5.26	0.740 (0.002)
TMT			
TMT A (s)	−5.90 ± 5.04	−4.70 ± 4.38	0.373 (0.017)
TMT B (s)	−11.77 ± 6.67	−7.07 ± 7.77	**0.027 (0.098)**
TMT B-A (s)	−5.86 ± 8.74	−2.37 ± 9.14	0.173 (0.038)
SDMT			
Total (Written and Oral)	10.92 ± 10.12	10.76 ± 10.49	0.956 (0.000)
Standing Broad Jump			
Average Jump (cm)	9.07 ± 1.64	−2.31 ± 1.84	**<0.001 (0.307)**

p-values and effect sizes (η_p^2) reflect the Group-by-Time interactions from the ANOVA. Bold p-values indicate significant group-by-time interaction, $p < 0.05$. KSS = Karolinska Sleepiness Scale; ESS = Epworth Sleepiness Scale; STAI = State-Trait Anxiety Inventory; PVT = Psychomotor Vigilance Test; TMT = Trail Making Test; SDMT = Symbol Digit Modalities Test.

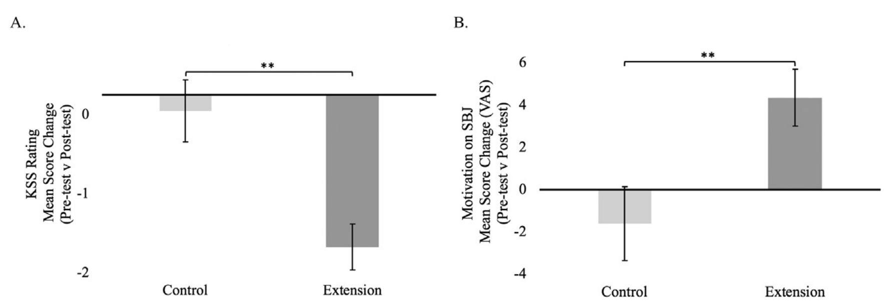

Fig. 2. Immediate impact of sleep extension on subjective sleepiness (A) and motivation (B) at post-test, significant between-group mean score differences noted for both. (A) The extension group's Karolinska Sleepiness Scale (KSS) rating significantly improved by approximately two, from a baseline value around five, which equates to “Neither alert nor sleepy”, to a value around three, which equates to “Alert”. (B) The extension group's motivation to perform the standing broad jump (SBJ) significantly improved by approximately 4%. Mean ± standard error. ** = $p < 0.01$.

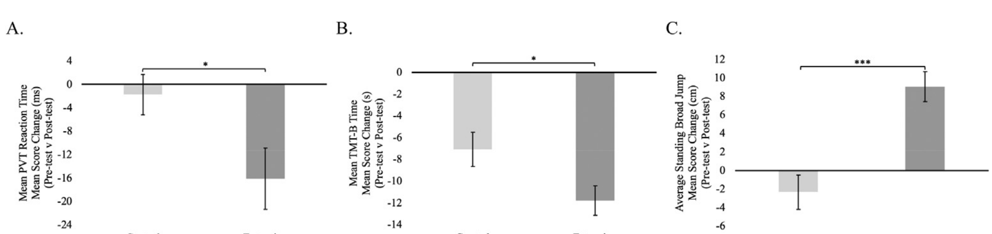

Fig. 3. Immediate impact of sleep extension on mean Psychomotor Vigilance Test (PVT) reaction time (A), Trail Making Test – B (TMT-B) time (B), and standing broad jump performance (C) at post-test, significant between-group mean score differences were noted for all. Mean ± standard error. * = $p < 0.05$; *** = $p < 0.001$.

the CON group. There was a significant between-group difference of these mean changes ($p < 0.001$, $d = 1.31$) (Fig. 3).

3.3.3. Motivation levels

The mean post-test motivation to perform the cognitive tests did not significantly change for the EXT group, but significantly decreased for the CON group (−7.04 ± 13.63 mm, $p = 0.016$). There was a significant between-group difference of these mean changes ($p = 0.003$, $d = 0.90$). The mean post-test motivation to perform the standing broad jump significantly increased for the EXT group (4.36 ± 6.78 mm, $p = 0.004$), but not for the CON group. There was a significant between-group difference of these mean changes ($p = 0.009$, $d = 0.76$) (Fig. 2).

Table 4
Residual Impact of Sleep Extension on Sleepiness, Motivation, Anxiety, and Cognitive/Motor Battery Between group comparison of mean pre-test to follow-up score change.

Outcome/Assessment	Extension	Control	Group × Time Effect
	Mean ± SD	Mean ± SD	p-value (η_p^2)
KSS	−1.28 ± 1.77	−0.60 ± 1.68	0.170 (0.039)
ESS	−0.80 ± 2.55	0.08 ± 1.91	0.174 (0.038)
Motivation			
Cognitive Tests	2.60 ± 10.82	−3.48 ± 12.41	0.071 (0.066)
Standing Broad Jump	1.92 ± 6.11	−3.28 ± 10.32	**0.035 (0.089)**
STAI Y1	−0.60 ± 5.04	2.60 ± 8.67	0.117 (0.050)
PVT			
Mean RT (ms)	−9.48 ± 28.49	−0.88 ± 26.84	0.227 (0.025)
Lapses (>500 ms)	0.08 ± 2.25	0.32 ± 1.75	0.676 (0.004)
Flanker Task			
Congruent RT (ms)	−33.91 ± 31.75	−26.65 ± 41.38	0.489 (0.010)
Incongruent RT (ms)	−37.14 ± 32.03	−39.17 ± 54.46	0.873 (0.001)
Interference Score	0.53 ± 4.37	−1.79 ± 4.03	0.056 (0.074)
TMT			
TMT A (s)	−7.17 ± 5.01	−5.69 ± 4.60	0.282 (0.024)
TMT B (s)	−15.68 ± 6.98	−12.27 ± 8.24	0.120 (0.050)
TMT B-A (s)	−8.51 ± 8.67	−6.57 ± 9.85	0.464 (0.011)
SDMT			
Total (Written and Oral)	21.08 ± 11.53	19.04 ± 12.81	0.557 (0.007)
Standing Broad Jump			
Average Jump (cm)	9.47 ± 12.86	−1.59 ± 9.48	**0.001 (0.200)**

p-values and effect sizes (η_p^2) reflect the Group-by-Time interactions from the ANOVA. Bold p-values indicate significant group-by-time interaction, $p < 0.05$. KSS = Karolinska Sleepiness Scale; ESS = Epworth Sleepiness Scale; STAI = State-Trait Anxiety Inventory; PVT = Psychomotor Vigilance Test; TMT = Trail Making Test; SDMT = Symbol Digit Modalities Test.

3.4. Residual impact of sleep extension after returning to habitual sleep

Group-by-Time interaction effects from the repeated measures ANOVA from the pre-test and follow-up scores are reported in Table 4. Statistically significant Group-by-Time interactions were noted on average standing broad jump performance ($p = 0.001$, $\eta_p^2 = 0.200$) and motivation to perform the standing broad jump ($p = 0.035$, $\eta_p^2 = 0.089$). There were no other statistically significant interactions noted (ie, for KSS rating, ESS rating, state anxiety, mean PVT reaction time, PVT lapses, Flanker Task performance (congruent time, incongruent time, and interference score), TMT performance (TMT A, TMT B, TMT B-A), SDMT total performance, and motivation to perform cognitive tests).

Compared to baseline, the mean follow-up average jump distance significantly increased for the EXT group (9.47 ± 12.86 cm, $p = 0.001$), but not for the CON group. There was a significant between-group difference of these mean changes ($p = 0.001$, $d = 0.98$) (Fig. 4).

Compared to baseline, the follow-up motivation to perform the standing jump did not significantly change for either group. However, the combination of extension group's minimal increase and the control group's minimal decrease revealed a significant between-group difference of the follow-up mean changes of the motivation to perform the standing broad jump ($p = 0.035$, $d = 0.61$) (Fig. 4).

4. Discussion

The primary aim of this study was to investigate the immediate impact of a short-term, four night, sleep extension intervention on the cognitive and motor performance of tactical athletes enrolled in ROTC. Prior to this work, the effect of sleep extension on this population was unknown. As hypothesized, this study found sleep extension provided an immediate enhancement of both cognitive, including attention/vigilance and executive function, and motor performance, as well as improved alertness and motivation.

The sleep extension group, relative to controls, exhibited significantly better post-test mean score changes in performance on mean PVT reaction time. 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 [25–27] and is used extensively in sleep-related research to assess attention/vigilance. This study provides further evidence that longer sleep increases (around 1.4 h per night for this

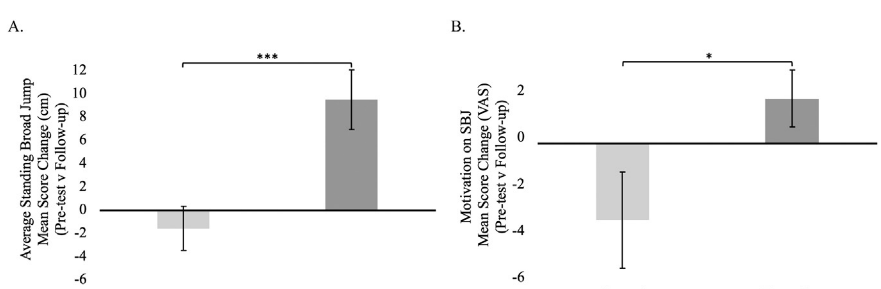

Fig. 4. Residual impact of sleep extension on average standing broad jump (SBJ) performance (A) and motivation to perform the SBJ (B) at follow-up compared to pre-test, significant between-group mean score differences noted for both. While the extension group significantly improved their standing broad jump distance by approximately 9 cm (A), of note, follow-up motivation to perform the standing jump did not significantly change for either group. Rather, it was the opposing trends of the motivation changes that precipitated that between-group score differences (B). Mean ± standard error. * = $p < 0.05$; *** = $p < 0.001$.

study) may be needed to observe vigilant attention (reaction time) improvements considering previous research in athletes has shown that an average sleep increase of 0.4 h per night over one week did not improve PVT reaction times [28], but an increase of 1.8 h per night over 5–7 weeks did [3].

Sleep extension also conferred positive benefits on TMT-B performance. Considering TMT-B performance requires executive functions of task-set inhibition ability, cognitive flexibility, and set-shifting [29,30], extending sleep may assist tactical athletes performing in more complex situations where mental flexibility is critical. Sleep extension has also revealed improvements in other executive function performance on working memory tasks that tested visuospatial processing and divided attention [4].

In addition to the cognitive benefits, the sleep extension group showed significant improvements in the standing broad jump, which is highly related/correlated to muscular strength, peak power output, vertical jumping ability, agility, sprint acceleration, and sprint velocity [31]. This result provides evidence that sleep extension can also influence a functional gross motor task. Other sleep extension research has shown motor improvements in sprint speed and basketball shooting accuracy [3], tennis serving accuracy [2], and endurance while performing a submaximal isometric knee extensor exercise [11].

The sleep extension group, relative to controls, exhibited significantly better post-test mean score changes on subjective sleepiness and motivation levels to perform the SBJ. While subjective sleepiness improvements have been previously observed [3,2], this is the first study to report improvements in motivation levels following sleep extension. The improved motivation to perform a task may be a potential pathway by which sleep extension benefits motor performance. It is possible that increased motivation levels leads to increased “attentional effort” during a task [32], resulting in improved performance. Notably, for the cognitive tasks, the extension group maintained their level of motivation, however, the control group's motivation significantly decreased. It is unclear why the control group's motivation levels for the cognitive tests decreased. One possibility could be that individuals in the control group became less engaged with the study once they knew they had not been assigned to the intervention group. Although in that scenario, decreased motivation to perform the SBJ should have also been expected. It is possible that sleep extension may actually result in the maintenance of motivation levels during cognitive tasks, which may be considered more mundane compared to physical tasks. Collectively, the changes in subjectively sleepiness and motivation levels likely contributed to the performance benefits following sleep extension.

Whether or not the immediate cognitive and motor improvements noted in the extension group are operationally meaningful to tactical athletes is unknown. Depending on the situation a military tactical athlete is in (ie, combat versus non-combat), these cognitive/motor improvements may be critical. Likewise, a military tactical athlete who feels less tired and is more motivated may be more likely to achieve an optimal operational state. Future research is needed to ascertain the extent to which sleep extension impacts performance on operational relevant tasks and whether it is a viable technique in a combat environment.

The secondary aim of this study 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 normal habitual 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 improvement that was observed immediately following the sleep extension. 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. However, the significant difference was not due to a significant improvement of motivation from the extension group, rather it was because of the combination of an increased trend for the extension group and a decreased trend for the control group. There remains a possibility that the difference in motivation changes between the groups contributed to the difference in motor performance. Residual benefits of a short-term sleep extension intervention remain on a gross motor task, but not on the cognitive tasks when participants return to their habitual sleep amounts for four nights. Similar to the immediate impacts of sleep extension, whether or not these benefits are operationally meaningful is unknown.

It is noteworthy that the study population appears to habitually sleep insufficient amounts, just over six hours, as previously reported [33]. As such, the increased amount of sleep the participants received during the four nights of sleep extension increased their average sleep duration to approximately seven and a half hours, closer to the recommended amounts. This study provides further evidence on the importance of obtaining recommended amounts of sleep. Future research is needed to determine if sleep extension has performance benefits in those already habitually sleeping recommended amounts or if the effects are specific to populations where sleep opportunity is limited rather than sleep ability (eg, older adults, patients with insomnia, etc).

5. Strengths and limitations

The main limitation of this study was that both the researcher and the participants were not blinded to the group assignments. Furthermore, motivation levels were asked after the participant performed the tasks; therefore, the manner by which participants perceived their own performance on a task may have confounded how they reported their motivation. Finally, although this study utilized both actigraphy and sleep diaries, it did not utilize polysomnography to verify sleep duration.

Some of the strengths of the study include the utilization of a control group and a sample of 50 participants with an equal distribution of male and females. Caffeine intake was controlled for and 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 start on the same day of the week (Monday). The four-night intervention utilized may be more feasible than longer duration interventions for individuals with busier schedules. The utilization of a sample of tactical athletes that are training to become future leaders in all three services of the U.S. military helps provide insight on their habitual sleep patterns and how to potentially optimize their performance and motivation in the future.

Future research should include neuroimaging during the testing to further understand how a short-term sleep extension intervention may impact neural dynamics during performance. Expanding the cognitive/motor battery, including executive function tasks like decision making, or other motor/physical tasks, like agility tasks, will assist in fully understanding which tasks can be positively impacted by increased sleep amounts. Similarly, using occupation-specific outcome measures and investigating other tactical athlete populations would help determine if sleep extension is an effective tool for improving occupational performance across professions.

6. Conclusions

This study was the first to investigate the immediate and residual impacts of a short-term (four-night) sleep extension intervention in military tactical athletes. Increasing sleep duration resulted in immediate benefits in alertness, psychomotor vigilance/attention, executive function performance, standing broad jump performance, and motivation levels. The immediate cognitive and motor benefits, along with improvements in motivation, may be critical to optimizing occupational performance in professions that rely on both. While the majority of the benefits of sleep extension dissipate after the resumption of habitual sleep schedules for four nights, there appears to be ongoing motor benefits that persist, which may continue to contribute to physical performance in tactical athletes. Military tactical athletes looking to optimize their overall performance should consider the impact of longer sleep durations when feasible.

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Conflict of interest

None of the authors have any relevant conflicts of interest to report. Wording from ICMJE Conflict of Interest Forms: Dr. Ritland has nothing to disclose, Dr. Simonelli has nothing to disclose, Dr. Gentili has nothing to disclose, Dr. Smith has nothing to disclose, Dr. He has nothing to disclose, Dr. Mantua has nothing to disclose, Dr. Balkin has nothing to disclose, and Dr. Hatfield has nothing to disclose.

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