Combat Effectiveness and Sleep Patterns in US Marines

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The goal of this study was to examine the effects of sleep on both the cognitive and physiological performance of warfighters approximately two hours after wakeup. Participants were active duty Unites States Marines (N=61). Dependent variables included wrist-worn actigraphy, Stanford Sleepiness Scale scores, marksmanship scores, obstacle course performance, and the switching task from the Automated Neuropsychological Assessment Metric (ANAM) battery. Results showed no statistically significant associations between sleep metrics and the mean radius of impact in the marksmanship test. In contrast, short sleep duration and elevated sleepiness were associated with worse (higher) completion times in the obstacle course. Elevated sleepiness was also associated with lower cognitive throughput, i.e., the number of correct responses per minute, as measured by the ANAM Switching Task. Increased sleep duration was associated with increased throughput, however the trend was not statistically significant. These results suggest that sleep-deprived Marines experienced poorer executive decision making as measured using the ANAM.

INTRODUCTION

Any degradation in performance during military combat may have dire consequences. The timeliness and accuracy of warfighters' decisions may determine not only their survival but also the success of the entire operation. Despite the overwhelming evidence regarding the negative effects of reduced sleep on performance, military populations are chronically sleep deprived (Miller, Matsangas, & Kenney, 2012; Miller, Matsangas, & Shattuck, 2008; Miller, Shattuck, & Matsangas, 2011). Sleep deprivation can be described as sleeping less than what is physiologically acceptable. A recent joint consensus statement by the American Academy of Sleep Medicine and Sleep Research Society recommended 7 or more hours per night on a regular basis to promote optimal health (Watson et al., 2015). This amount increases to 9 or more hours of sleep per night for young adults. Research has also shown the existence of individual differences in sleep requirements (Grant & Van Dongen, 2013; Kuna et al., 2012; Rupp, Wesensten, & Balkin, 2012; Van Dongen, 2012). Some individuals need less sleep while others appear less vulnerable to the effects of sleep deprivation.

The goal of this study was to examine the effects of sleep on both the cognitive and physiological performance of warfighters approximately two hours after wakeup. This work was part of a larger study to assess combat efficiency of embarked infantry within 30 minutes of a forced amphibious assault beach landing (Chaidez et al., 2011; Shattuck, Shattuck, Smith, & Matsangas, 2013). In the context of this study, combat efficiency referred to factors affecting an infantryman's ability to conduct combat operations.

In warfighting, there are three mission essential functions (MEFs) that must accomplished successfully for a system to be considered operational: move, shoot, and communicate (Chaidez et al., 2011). Three factors directly related to infantry tasks were assessed: physical coordination, (i.e., the ability to move swiftly and efficiently); marksmanship (i.e., the ability to effectively focus, aim at, and hit a distant target) and, cognitive performance (i.e., the ability to receive, process, transmit, and act on information).

METHOD

Participants

A total of 61 active duty members of the Unites States Marine Corps (USMC) volunteered to participate in the study. Participants were randomly assigned to four squads (15 Marines in squads A to C, and 16 in D). The age range of the participants was 18 to 28 years with a median of 22. Participants were enlisted (5 were E2, 27 E3, 26 E4, and 3 E5) with on average 3.51 ± 1.79 years in service.

Measures and Apparatus

Actigraphic estimates of crewmembers' sleep were obtained using the Philips Respironics actiwatches (46 participants with Actiwatch Spectrum and 15 participants with Actiwatch 64). Actigraphic data were scored using Actiware software version 6.0.0 (Phillips Respironics, Bend, OR). The medium sensitivity threshold (40 counts per epoch) was used with 10 immobile minutes the criterion for sleep onset and sleep end (all values are set to the default for this software). Participants were instructed to wear the wrist activity monitors (WAMs) on their non-dominant hand, and completed a sleep log to indicate their sleep periods throughout day.

The Stanford Sleepiness Scale (SSS) (Hoddes, Dement, & Zarcone, 1972) was used to assess alertness. The participant assesses his sleepiness by choosing one from eight states, ranging from "feeling active, vital, alert, or wide awake" to "asleep."

Participants performed the Switching task from the Automated Neuropsychological Assessment Metrics (ANAM), a computer-based battery for assessing human performance and neuropsychological function (Reeves, Kane, & Winter, 1995; Reeves, Winter, Bleiberg, & Kane, 2007). The Switching task is a combination of the Manikin and Mathematical Processing tasks displayed simultaneously on the screen (Figure 1). The participant is required to respond to the task indicated by a red arrow on the screen. When arrow changes direction, the participants must switch to respond to the designated task. The Manikin task, a visual-spatial test, requires the participant to identify the hand in which a manikin is holding an object. The Manikin test assesses an individual's ability to discern three-dimensional spatial rotation, left-right orientation, problem solving and attention. The mathematical task requires the test participant to solve a basic three step mathematical equation (e.g., $5 + 3 - 6 =$) and determine if the result is greater or less than five. The mathematical test assesses an individual's basic computational skills, concentration and working memory. Overall, the Switching task assesses the participant's executive function and directed attention.
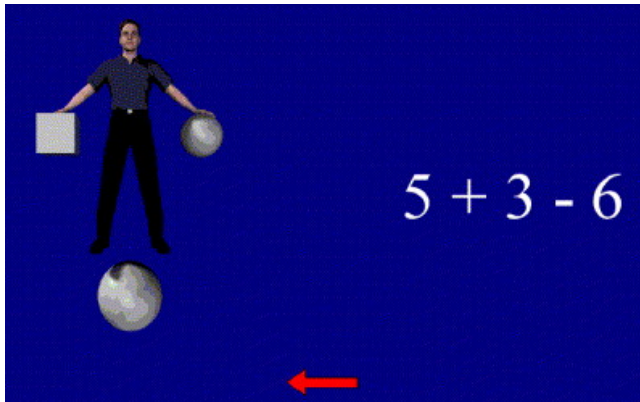

Figure 1. ANAM Switching Task.

Participants also completed the obstacle and the marksmanship courses. The obstacle course (Figure 2) is a modification of the US Marine Corps' Load Effects Assessment Program (MC-LEAP) described by Tack, Kelly, Richter, and Bray-Miner (2012). The obstacle course is designed to challenge the participant's balance and agility.

Figure 2. Obstacle course (Chaidez et al., 2011).

To evaluate precision in the employment of a standard USMC issued small arm, participants were tested in marksmanship using the Laser Marksmanship Training System (LMTS). Participants were required to fire five rounds within a 30-second time limit, from the standing position, at a target 15 yards away. As shown in Figure 3, participants conducted the marksmanship test in pairs and always in the same order.

Figure 3. Marksmanship range (Chaidez et al., 2011).

Procedures

The study protocol was approved by the Naval Postgraduate School Institutional Review Board and participants provided written informed consent before enrolling in the study.

The data collection occurred at Camp Pendleton, CA. Participants received a week of training to reach steady-state performance levels before the actual testing period commenced. Environmental conditions during data collection

were mild with ambient air temperatures ranging between 61°F and 70°F, and relative humidity between 76% and 94%.

The field experiment was based on a repeated measures quasi-experimental design. This procedure allowed participants to serve as their own control and partially accounted for time-of-day effects since participants always commenced testing early in the morning. At the start of the study, participants were issued actiwatches and were asked to fill out daily activity logs to indicate sleep and nap times. All participants mustered at 0700 and the daily test battery was administered. This battery always started with the marksmanship test (conducted with pairs of individuals always in the same order), followed by the obstacle course, the cognitive test battery, the daily study questionnaire, and finally, a second marksmanship test. Each participant was tested on four separate occasions, i.e., four test days with approximately one hour of testing each day.

Initially, all variables underwent descriptive statistical analysis to identify anomalous entries and to determine demographic characteristics of the study population. Three dependent variables were used in this study, a) the length of time required to complete the obstacle course in minutes, b) performance in the marksmanship course derived from five shots with the Laser Marksmanship Training System (LMTS) converted to a mean radius of impact (MRI - the spread of five shots) measured in millimeters; and d) cognitive throughput (correct answers per minute) on the ANAM Switching Task. Given that cognitive throughput combines both accuracy of responses and response speed, it reflects an individual's performance efficiency.

Mixed model analysis of variance was used to assess the association between the dependent variables, sleep duration, and ESS scores. Squad, day, time of day, sleep duration, and SSS scores were fixed factors, whereas the random factor was participants. Statistical analysis was conducted with a statistical software package (JMP Pro 12; SAS Institute; Cary, North Carolina). Data are presented as mean (M) ± standard deviation (SD). Significance level was set at $p < 0.05$. To account for multiple comparisons, statistical significance was adjusted by applying the Benjamini–Hochberg False Discovery Rate (BH-FDR) controlling procedure (Benjamini & Hochberg, 1995).

RESULTS

Aggregated by participant, the average daily sleep duration was 5.42 ± 0.833 hours ranging from 3.31 to 7.02 hours; the average sleep efficiency was $85.9\% \pm 3.74\%$ ranging from 76.7% to 94.2%. Approximately 74% of the participants slept on average less than 6 hours daily.

Marksmanship

The average MRI was 13.7 ± 3.44 millimeters, ranging from 6.20 to 24.1 millimeters. Based on their rifle qualification system used in the USMC, participants had been qualified as experts (n=31, the highest qualification), sharpshooters (n=16), and marksmen (n=11). Adjusted for

squad, day, time of day, and marksmanship qualification, a mixed model analysis failed to identify a statistically significant effect of either sleep duration or SSS scores on marksmanship performance ($p>0.30$).

Obstacle Course

The average completion time in the obstacle course was 1.23 ± 0.139 minutes, ranging from 0.937 to 1.52 minutes. Mixed model analysis was used to assess the association between obstacle course completion times, sleep duration, and ESS scores. Squad, day, time of day, sleep duration, and SSS scores were fixed factors, whereas the random factor was participants. After adjusting for squad, day, and time of day, sleep duration ($F(1, 219.1)=5.03$, $p=0.026$) and SSS scores ($F(6, 218.0)=2.47$, $p=0.025$) were identified as significant predictors of obstacle course completion time (statistically significant based on post-hoc analysis with the BH-FDR controlling procedure).

Specifically, short sleep duration and elevated sleepiness were associated with worse (longer) completion times on the obstacle course. The results are shown in Figures 2 and 3 with accompanying regression lines. Obstacle course completion times were adjusted for squad, day, time of day, and individual differences.
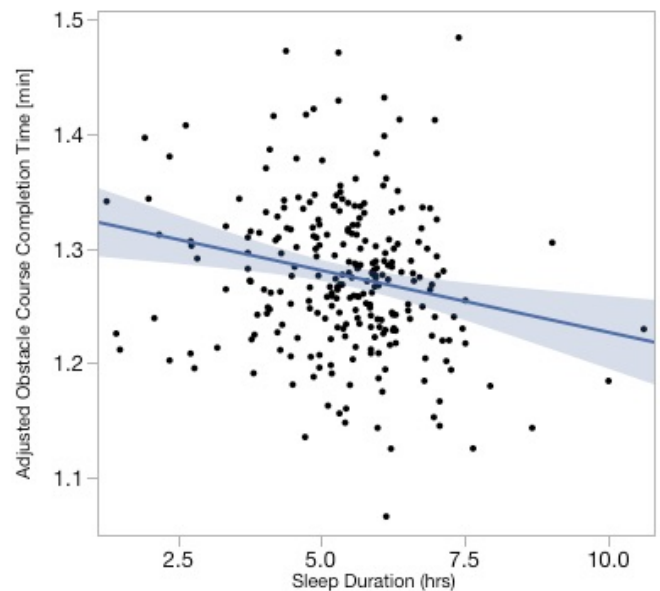

Figure 2. Scatterplot of obstacle course completion time by sleep duration.
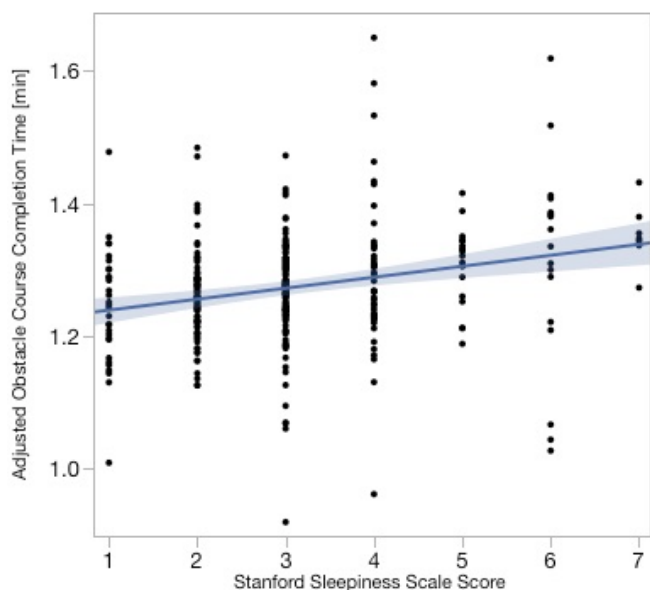
Figure 3. Scatterplot of obstacle course completion time by Stanford Sleepiness Scale (SSS) scores.
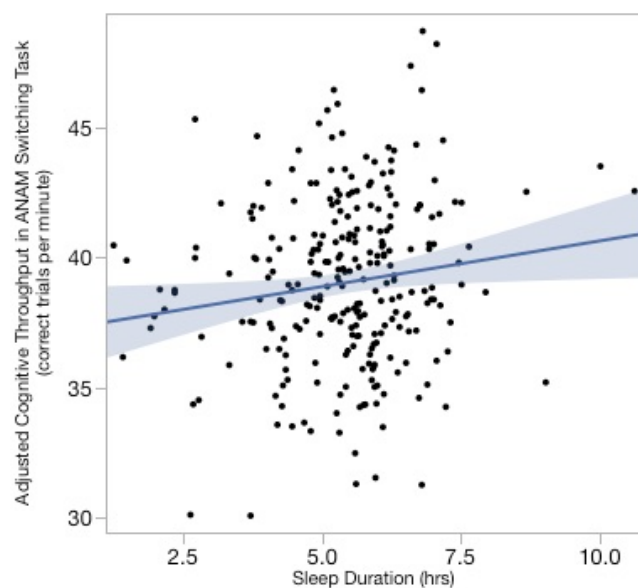

Figure 4. Scatterplot of cognitive throughput (errors per minute in ANAM Switching task) by sleep duration.

ANAM Switching Task

Averaged by participants, cognitive throughput was 36.5 ± 8.82 correct responses per minute, ranging from 20.7 to 55.2. Mixed model analysis was used to assess the predictors of Switching Task cognitive throughput, i.e., correct responses per minute. Squad, day, time of day, sleep duration, SSS scores were the fixed factors, while the random factor was participants. After adjusting for squad, day, and time of day, SSS scores ($F_{(6, 211.0)}$=2.51, p=0.023) were a significant predictor of cognitive throughput (i.e., statistically significant based on post-hoc analysis with the BH-FDR controlling procedure). Specifically, higher scores on the Stanford Sleepiness Scale were associated with lower throughput. Even though not statistically significant ($F_{(1, 211.4)}$=2.44, p=0.120), increased sleep was associated with increased throughput. The results are shown in Figures 4 and 5 with accompanying regression lines. Throughput has been adjusted for squad, day, time of day, and individual differences.
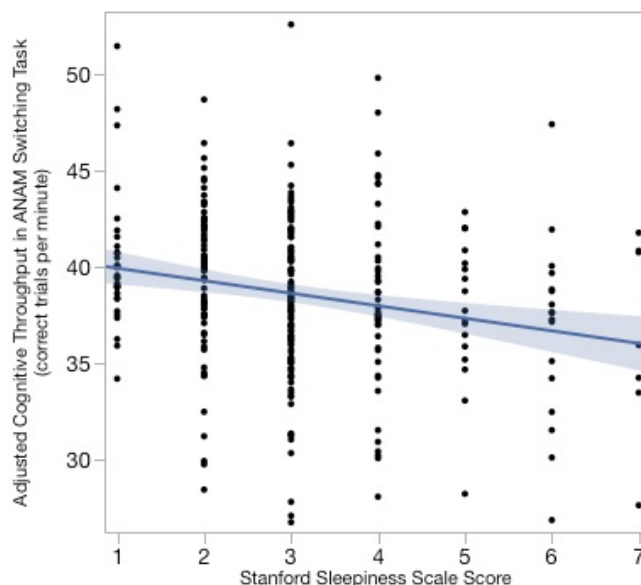

Figure 5. Scatterplot of cognitive throughput (errors per minute in ANAM Switching task) by SSS score.

Further analysis showed that the trend in sleep-related predictors, i.e., the effect of SSS scores, was consistent in the throughput of the Mathematical task, the Manikin task, as well as in the switching transition trials (in all cases, p<0.05).

DISCUSSION

Even though our analysis did not identify any performance reduction in marksmanship, short sleep duration and elevated sleepiness were associated with worse (higher) completion times on the obstacle course. Elevated sleepiness was also associated with lower cognitive throughput, i.e., the

number of correct responses per minute, as measured by the ANAM Switching Task. Increased sleep duration was associated with increased throughput; however, the trend was not statistically significant. These results clearly show that detrimental effect of sleep deprivation on aspects of combat efficiency.

It is also notable that our sample of Marines was significantly sleep deprived, even though the study was not conducted during operational conditions. Specifically, the average daily sleep duration was 5.42 ± 0.833 hours with approximately 74% of the participants sleeping on average less than 6 hours daily. Our results should be contrasted to physiologically acceptable amount of 7 or more hours per night on a regular basis to promote optimal health (Watson et al., 2015). The severity of sleep deprivation by this sample becomes even more pronounced if we consider the age of our sample (median age 22 years). For this age group, sleeping 8.5 to 9.25 hours per night is recommended(Watson et al., 2015). Consequently, most of the individuals in the study were operating in a significant sleep debt.

Since their first day in USMC Boot Camp, these young Marines have been required to work at varying times of the day and night. As such, they have been classified as shift workers. There is a growing concern about circadian scarring and the concomitant inability to maintain healthy sleep habits in shift workers (Monk, Buysse, Billy, Fletcher, & Kennedy, 2013). In addition to showing decrements in combat effectiveness that are associated with their sleep patterns, the current study may provide an early indication of circadian scarring in these young Marines.

Limitations

Limitations of the study include the need for queuing in the marksmanship and obstacle courses.

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