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The influence of sleep and exercise on cognitive function in college-aged students

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THE INFLUENCE OF SLEEP AND EXERCISE ON COGNITIVE FUNCTION IN COLLEGE-AGED STUDENTS

A Masters Thesis presented to the Faculty of the Graduate Program in Exercise and Sport Sciences
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In partial fulfillment of the requirements for the degree
Master of Science

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by

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Thesis of

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submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Health Sciences and Human Performance at Ithaca College has been approved.

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ABSTRACT

This study investigated how low intensity exercise affects sleep deprivation induced cognitive deficit in college-aged students. In order to investigate this relationship, three testing sessions were conducted. The first session included a VO_2max test to determine the subjects heart rate at 40% of HRmax, which corresponded to low exercise intensity. One of the next two sessions included a night of sleep deprivation (24 h) while the other involved a night of normal sleep. Subjects were 27 males aged 18-26 years who devoted two nights and the following mornings for the sleep deprivation and normal sleep data collection. The groups were assigned to either an exercise or a non-exercise activity. Cognitive testing was performed immediately following the exercise (40% HRmax) or non-exercise activity and again one hour later. The three cognitive tests were the Stroop test, serial arithmetic test, and Raven's Advanced Progressive Matrices. The results of the study showed sleep deprivation (24 h) to have a nominal effect on cognitive performance. A cognitive deficit was found in two of the five sub-tests of the Stroop test (other congruent and other incongruent) with sleep deprivation. All other variables were not affected by the imposed sleep loss. Exercise did not alter the sleep loss induced deficit on these two aspects of Stroop performance. Results also revealed that repeated trials improved performance in almost all tests meaning that learning likely occurred. In the absence of a substantial sleep deprivation effect, the results neither challenge nor support the contention that low intensity exercise has a positive effect on cognitive performance after sleep loss. Future studies must ensure that a meaningful sleep loss induced cognitive deficit occurs before the effects of exercise can be properly determined.

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Chapter 1

INTRODUCTION

Many individuals are not familiar with the stages of sleep, the importance of getting the proper amount of sleep, and the effects of improper sleep. Unfortunately, one of the first things an individual will give up due to managing a busy schedule is sleep (National Sleep Foundation, 1999). College students, especially, tend to go to sleep late and wake-up early in order to keep up with academic responsibilities, work, and social activities. The easy access and availability of the internet also presents new allure that challenges college and secondary-school students to get the proper amount of sleep. The students that are not getting proper sleep are often late to or fall asleep in class. They may also experience memory loss and perform worse than their counterparts who get normal sleep (Mitru, Millrood, & Mateika, 2002). When an individual is not getting proper sleep and specific vulnerable periods of sleep are interrupted, it may cause a significant deficit in ability to recall learned tasks (Sandys-Wunsch & Smith, 1991).

Research has focused on the effects of chronic and acute sleep deprivation on cognition (Carskadon, Harvey, & Dement, 1981; Linde & Bergström, 1992; Pilcher & Huffcutt, 1996). Moreover, there is great concern for the sleep needs and patterns of students, especially the link between their lack of sleep and emotional, intellectual, and social lives (Banks, 2001). However, to the author's knowledge there is no research on the effect of exercise following sleep deprivation on cognition.

Empirical research provides evidence that exercise often improves cognitive functioning. It appears that submaximal aerobic exercise performed for durations between 20 and 60 min may facilitate multiple cognitive processes which are critical to optimal performance and adaptive behavior (Adam, Teeken, Ypelaar, Verstappen, & Paas, 1998; Arcelin, Delignieres, & Brisswalter, 1998; Davey, 1973; Fleury & Bard, 1987; Gondola, 1987; Hancock & McNaughton, 1986; Heckler & Croce, 1992; Hogervorst, Riedel, Jeukendrup, & Jolles 1996; Lichtman & Poser, 1983; Paas & Adam, 1991). Therefore, it can be hypothesized that exercise may positively impact the cognitive effects of sleep deprivation knowing the potential impact that sleep deprivation has on students and cognitive performance. It is imperative to gather information on these topics.

Statement of Purpose

The purpose of this study was to determine how low intensity exercise affects sleep deprivation induced cognitive deficit in college-aged students.

Hypothesis

The hypothesis for this study was that low intensity exercise positively affects cognitive function following total sleep deprivation as measured by the Stroop test, serial arithmetic test, and Raven's Advanced Progressive Matrices.

Assumptions of the Study

For the purpose of this study, the following assumptions were made at the beginning of the investigation:

1. The subjects represented typical college-aged students, specifically in the areas of cognitive function and average sleep time.
2. The subjects provided accurate information in their sleep/activity log.
3. Total sleep deprivation in a 24 h period, as applied in this study, had potential to impact circadian rhythms and cognitive performance.

4. Subjects acquired their average amount of quality sleep, which was calculated from the sleep/activity log, on the night sent home for a normal night of sleep.

Definition of Terms

The following terms are defined for the purpose of this research:

1. Average cardiovascular fitness level: males 20 to 29 years of age that are within 42.6 – 49.0 ($mL \cdot kg^{-1} \cdot min^{-1}$) maximal aerobic capacity (American College of Sports Medicine, 2005).
2. Cognitive function: ability to receive, understand, evaluate, and interpret information.
3. Good sleep: a normal 7 to 8 h sleep period.
4. High cardiovascular fitness level: males 20 to 29 years of age that are above 55.1 $mL \cdot kg^{-1} \cdot min^{-1}$ of maximal aerobic power (ACSM, 2005).
5. Low intensity exercise: 20 to 39% of heart rate reserve (HRR) or 35 to 54% heart rate max (HRmax). In this study the exercise used was of low intensity (40% HRmax).
6. Sleep: a state of unconsciousness in which the brain is relatively more responsive to internal than to external stimuli.
7. Sedentary: persons not participating in a regular exercise program or meeting the minimal physical activity recommendations from the U.S. Surgeon General's Report (ACSM, 2005).
8. Total sleep deprivation: a period of at least 24 h without sleep.

Delimitations

The delimitations of this study are as follows:

1. Only moderately active 18-26 year old male students from Ithaca College were used as subjects.
2. Only the effects of total sleep deprivation in a 24 h period was studied.
3. The type of exercise used was low intensity for a duration of 20 min.
4. The Stroop test, serial arithmetic test, and the Raven's Advanced Progressive Matrices were used as measures for cognitive function.

Limitations

The limitations of this study are as follows:

1. The results may only be applicable to college-aged male students.
2. The results may only apply to total sleep deprivation conditions as studied.
3. The results may only apply to cognitive performance capabilities on the specific tests administered.
4. The results may only apply to exercise of low intensity and moderate duration.

Chapter 2

REVIEW OF LITERATURE

Sleep and cognitive function are highly interdependent functions that are impacted by many factors. Sleep effects on cognitive function vary with factors such as the time sleep was acquired, the quantity and quality of sleep, the type of sleep, and circadian events. As one matures, these factors are influenced by a variety of behavioral factors (e.g., academic, social, and employment responsibilities), which often have a negative impact on sleep. The present study examines the effect of exercise on the relationship between sleep and cognition. This review chapter outlines the nature of sleep, sleep deprivation and students, and effects of sleep on cognitive function. The final section emphasizes the effects of exercise on cognition and is followed by a summary.

Nature of Sleep

Many individuals are not aware of the significance of the cyclic nature of sleep, the stages of sleep and the role that each primary sleep stage might have in human development, behavior, and learning (Mitru et al., 2002). The lack of knowledge about sleep may be the very reason why sleep is the first thing a person will give up in order to keep up with today's busy lifestyle. Sleep is a state of unconsciousness from which a person can be aroused by appropriate sensory or other stimuli (Guyton, 1986). During a normal seven to eight hour sleep period, there are five sleep cycles of about 90 min in duration that consist of non-rapid eye movement (NREM) sleep followed by rapid-eye movement (REM) sleep (Dotto, 1996). Each cycle contains different stages of sleep: stage one and two are comparatively a light sleep; stage three and four, also known as slow-wave sleep or deep sleep, is believed to be most important for physical and psychological restoration; and REM sleep, during which the sleeper is very near consciousness and likely to be dreaming (Dotto, 1996).

Several studies have demonstrated a link between memory and REM sleep (Dahl, 1996; Dotto, 1996; Sandys-Wunsch & Smith, 1991). In humans, increases in REM density (the number of rapid eye movements per minute of REM sleep) can be observed on the first night after complex information is learned, but interestingly not on the second night nor for several nights afterwards (Dotto, 1996). Interrupting sleep during specific vulnerable periods of increased REM activity can cause substantial deficits in the ability to recall learned tasks (Sandys-Wunsch & Smith, 1991). REM sleep appears to hold a critical role in consolidation of memory and cognitive development required for the completion of goal-directed behaviors (Dahl, 1996; Dotto, 1996). However, REM sleep can be interrupted during periods other than the vulnerable periods without memory impairment. When a person is extremely tired, REM sleep may be very short or absent. The duration of REM sleep will increase as the night progresses and the person is more rested. While REM is linked to memory, it has been suggested that the function of NREM sleep is to restore or synthesize neuronal processes that are necessary for optimal daytime mental and physical performance (Dahl, 1996; Dotto, 1996).

The quality and quantity of the sleep pattern described above is influenced by internal biological mechanisms that are referred to as circadian rhythms (Dijk, 1999). The circadian timing system mediates numerous systems and functions that include hormonal output, body core temperature, rest and activity, sleep and wakefulness, and motor and cognitive function (Murphy & Campbell, 1996). Circadian rhythms are developed during early childhood and are generated primarily by a specialized structure in the brain (i.e., the suprachiasmatic nuclei of the hypothalamus) (Murphy & Campbell, 1996). Human circadian rhythms oscillate approximately every 25 h which can be reduced to 24 h under the influence of changes in light intensity associated with the day-night cycle (Mitru et al., 2002). During maturation, there is a tendency for sleep patterns to change, which may alter circadian rhythms. This phenomenon is referred to as the sleep phase delay or delayed phase preference, which is the technical term to describe the tendency to go to sleep later and wake up later the following morning (Carskadon, 1999). The sleep phase delay occurs more typically on the weekends when there may be less behavioral or occupational time constraints.

Wolfson & Carskadon (1996) surveyed students on self-reported sleeping patterns and academic performance. The results showed an association with students who were struggling or failing at school and sleeping significantly less on the weekends. Those students also reported later bedtime and woke up later on week days than their counterparts who were achieving A's and B's. A serious case is that of an individual unable to fall asleep before 5:00 or 6:00 in the morning and has a hard time waking up before 2:00 or 3:00 in the afternoon (Carskadon, 1990). A pattern such as this will usually require special attention from a sleep disorder clinic. It is important to understand that excessive sleepiness is a potentially serious problem, which is ironically often unrecognized. This may be because sleepiness is so prevalent among young adults that it almost seems to be ordinary.

Sleep Deprivation and Students

Young adults need for sleep is similar to, or greater than, that of children (Banks, 2001). Young adults may require an increase in sleep duration, however these biological needs are often not met (Carskadon, 1982; Carskadon & Dement, 1982; Mitru et al., 2002; Wolfson & Carskadon, 1996). Many students experience a reduction in sleep as a consequence of behavioral factors such as academic workload, social, and employment opportunities (Carskadon, 1999; Mitru et al., 2002). Insufficient sleep in teens and young adults is linked to increased risk of unintentional injuries and fatal accidents, poor school performance, difficulty controlling emotions and behavior problems, and increased likelihood of stimulant use (National Sleep Foundation, 2000). Busy students who are heavily involved in school, community activities, jobs and other responsibilities appear to be at greater risk due to the serious detrimental effects of sleepiness than those who are less involved in these activities (Carskadon, 1990).

Young adults require at least as much sleep as they did as pre-adolescents, which is about nine hour each night (Carskadon, Harvey, Duke, Anders, Litt, & Dement, 1980). In adults, sleep of eight to nine hours is considered fully restorative (Russo, 2002). However, the function of sleep has not been completely determined and the absolute number of hours necessary to fulfill its function is unknown. Some individuals will only need three to five hours of sleep per night, while others claim they need at least eight hours of sleep per night (or more) to perform effectively (Russo, 2002). On average, adults sleep 6.54 h during the work week and compensate their sleep loss by sleeping longer on the weekend, with sleep time increasing by an average of 40 min (National Sleep Foundation, 2000). Students sleep patterns tend to shift toward later times for both sleeping and waking. Wolfson and Carskadon (1996) found that 40 percent of 3,000 students surveyed reported going to bed after 11:00 p.m. on school nights. In addition, 91 percent of those students reported going to sleep after 11:00 p.m. on weekends. Only 15 percent of those students reported sleeping 8.5 h or more, and 26 percent of students reported typically sleeping 6.5 h or less. The contrast between pre-pubertal adolescents and a group of typical college students sleep schedule is rather interesting. Children are maximally alert throughout the day, whereas a combination of factors including chronic insufficient sleep often puts the college student in an impaired performance state lasting nearly all day (Carskadon, 1990).

According to the National Sleep Foundation (2000), one out of five (20%) adults reported that daytime sleepiness interferes with their daily activities at least a few days per week or more. Daytime sleepiness has been found to be more common among young adults (33% of 18-29 year-olds vs. 16% of 30-64 year-olds and 15% of those ≥ 65 years old). The symptoms of daytime fatigue (e.g., lack of attention and falling asleep in class) often observed in students may not be due to laziness or lack of motivation as traditionally perceived, but rather may be due to insufficient sleep (National Sleep Foundation, 1999).

Sleep and Cognitive Function

Students might not be able to learn according to national expectations in part because they are too tired during the day (National Sleep Foundation, 1999). An individual, who is not getting enough sleep and is feeling the consequence of sleep loss often wakes up later, is late to and/or sleeps during class time, and has memory loss (Mitru et al., 2002). According to Dahl (1999), tasks requiring planning, strategy, or complex sequences of activities are more difficult when one is tired. Consequently, those students that are sleep deprived may have more difficulty with these tasks, which are very similar to tasks in a classroom environment.

The prefrontal cortex is responsible for the regulatory integration of sleep/arousal and affection/attention. A prefrontal cortex function is to integrate cognition and emotion into goal-directed behaviors (Dahl, 1996; George, Ketter, & Post, 1994; Horne, 1993). Sleep deprivation causes dysfunction of the prefrontal cortex, which is similar to various neurophysiologic disorders; however, this dysfunction is fortunately reversible with sleep recovery (Horne, 1993). This deficiency in prefrontal cortex function may be responsible for the impact of sleep deprivation on emotions, attention, and intellectual performance of young adults (Mitru et al., 2002). The prefrontal cortex continues to develop throughout childhood and adolescence with important neurobiological changes occurring during puberty (Dahl, 1996). Therefore, puberty is an important period during which sleep and behavioral regulation are coupled with developing cognitive processes (Mitru et al., 2002). According to this information, it is essential to reduce or eliminate behavioral factors that challenge sleep and to ensure that students obtain the required amount of sleep. The effects of sleep deprivation on cognition are demonstrated both in acute (short-term) as well as chronic (long-term) conditions.

Acute Sleep Deprivation

According to Smith (1995), cognitive performance can be affected not only by quantity of sleep, but also by type and timing of sleep. Smith has conducted several studies to investigate the relationship between sleep loss on memory and learning. One particular study looked at REM sleep deprivation and memory in college students (Smith, 1995). The subjects were tested using both verbal and nonverbal declarative tasks (e.g., word lists and paired associates) and verbal and nonverbal procedural tasks (e.g., puzzles). The study had five groups consisting of two control groups that had normal sleep after learning a task, one group slept at home and the other in the sleep lab; a third group that stayed awake all night; a fourth group that was selectively deprived of REM sleep during the last two sleep cycles of the night, when most REM sleep occurs; and a fifth group that was awakened the same number of times as the group deprived of REM sleep, but during non-REM sleep stages. The study showed that when tested a week later on a cognitive procedural task, the two control groups and the non-REM sleep deprived group improved their baseline performance. The total sleep deprived group and the group deprived of REM sleep performed significantly worse. Smith indicated in his studies that the performance of cognitive procedural tasks by subjects deprived of REM sleep shows a deficit of roughly 20% to 30% compared with that of rested subjects or with their own baseline performance (Smith & Whittaker, 1987; Smith, 1995). Following the declarative tasks, neither of the groups showed impairment when tested a week later. This suggests that tasks such as memorization or verbatim repetition of explicit information seem to be resistant to sleep deprivation.

Linde and Bergström (1992) investigated the effect of one night without sleep on the performance of complex cognitive tasks, such as problem-solving, in comparison with a purely short-term memory tasks (immediate free recall and reasoning). Sixteen undergraduate students participated in the study and were randomly assigned to an experimental or control group. All subjects were allowed normal sleep (up to eight hours) on the first testing day. The second testing day, the experimental group was totally sleep deprived, while the control group slept at home. The results showed a significant decline in the number of correct items due to sleep loss on problem solving (i.e., Raven's Progressive Matrices). Linde and Bergström (1992) conducted a second experiment to investigate if the significant decline on problem solving was due to the order of the tests. In addition, the generalizability of the effect obtained in the first experiment by using a different problem-solving task (number-series inductions) was tested. Also, the number of hours without sleep was increased to 30 h. Twenty-two undergraduate students took part in experiment two. These results again showed that sleep deprivation had a significant effect on performance of Raven's Progressive Matrices and that this effect may occur regardless of the position of the task in a 1.5 h long test session. There were no effects of sleep loss on the other tasks (i.e., Baddeley's logical- reasoning test, immediate recall: number span, attention power: effortful information-processing, and number-series inductions) of cognitive function.

According to a meta-analysis of 19 research studies (Pilcher & Huffcutt, 1996), overall sleep deprivation strongly impairs human functioning, and partial sleep deprivation appears to have a greater impact on subjects compared to short-term or long-term deprivation. When Pilcher and Huffcutt (1996) assessed the type of measurement, sleep deprivation had the greatest effect on mood, then cognitive tasks, and the least on motor tasks. However, there were no studies included in the analysis that examined short-term deprivation on mood. The second assessment investigated was the effects of test duration and type of task (simple vs. complex) on sleep deprivation. For short-term deprivation (≤15 h), performances on complex and long tasks were worse than on simple and short tasks. For partial sleep deprivation (sleep period of <5 h in a 24 h period), subjects did worse when the test were longer (motor, ≥8 min; cognitive, ≥10 min) and performed worse on simple tasks than those that were complex. For long-term deprivation (>45 h), performance was worse on short tasks than on long tasks and slightly worse on simple tasks than on complex tasks.

Kjellberg (1975) studied the effects of sleep deprivation on a self-paced problem-solving task by lowering subjects' standard of performance, providing less performance feedback, and making failures less obvious and more acceptable. In the first experiment, one group was informed that there were unsolvable items and the other was not given this information. Subjects were randomly divided into two groups with each tested twice after a night of sleep deprivation and again following a night of normal sleep. The task consisted of 36 number series, three of the items were considered unsolvable. The time spent on a task, the number of items left unsolved, and the number of correct and incorrect solutions was observed. Less time was spent on task after sleep deprivation in both groups. The informed subjects left more items unsolved than uninformed subjects. This effect showed a consistent increasing difference between the sleep deprivation and control conditions for the first to the third part of the task, more items being left unsolved after deprivation. The number of correct solutions was lower after sleep deprivation for both groups but was lowest in the uninformed group. The results of the first experiment showed a decrease in standard performance following a night of sleep deprivation in both groups. This was understood as a result of the extreme difficulty of the task which, in itself, might make failures acceptable. This was tested in the next experiment, and the task was made easier. The task was made easier by exchanging the most difficult items with some very easy ones and by only including one unsolvable item on each page. As a result, less time was spent on task after sleep deprivation by informed subjects, whereas for uninformed subjects, the mean time was somewhat higher. The informed group left more items unsolved and the uninformed group had more incorrect solutions. The number of correct solutions was not significant. In conclusion, a lowered standard of performance only occurs when failures are accepted or the task is very difficult.

A study by Thomas et al. (2000) tested the hypothesis that negative effects of sleep deprivation on alertness and cognitive performance suggest decreases in brain activity and function. The decreases are primarily found in the thalamus, a subcortical structure involved in alertness and attention, and in the prefrontal cortex, a region sub-serving alertness, attention, and higher-order cognitive processes. The 17 participants were scanned for quantifiable brain activity changes during 85 h of sleep deprivation using positron emission tomography (PET) and ^{18}fluorine-2-deoxyglucose (^{18} FDG), a marker for regional cerebral glucose metabolic rate (CMRglu) and neuronal synaptic activity. Subjects were scanned prior to and at 24 h intervals during the sleep deprivation period, for a total of four scans per subject. During each 30 min scan, subjects performed a sleep deprivation-sensitive serial add/subtraction task. Polysomnographic monitoring confirmed that subjects were awake. The results showed that after 24 h of sleep deprivation, a significant decrease in global CMRglu, and significant decreases in absolute regional CMRglu in several cortical and subcortical structures. There was no evidence of a significant increase in absolute regional CMRglu in any area of the brain. Significant decreases in relative regional CMRglu, reflecting regional brain reductions greater than the global decrease, occurred predominantly in the thalamus and the prefrontal and posterior parietal cortices. Alertness and cognitive performance on the serial add/subtraction task declined in association with these brain deactivations. In the 24 h sleep deprivation session, there was a significant time-on-task decrease in performance (alertness, self-ratings of sleepiness, and serial add/subtraction task) when each subsequent five minute segment was compared with the first segment. These findings suggest that the neurobehavioral function of sleep in humans is to restore and sustain normal waking brain activity and behavior.

In 2001, Drummond and Brown further examined the effects of total sleep deprivation (TSD) on cerebral responses utilizing functional magnetic resonance imaging (FMRI) during verbal learning, arithmetic, and divided attention. Total sleep deprivation was associated with increased activation in the bilateral prefrontal cortex and parietal lobes when doing the verbal learning and divided attention tasks. Following TSD, increased sleepiness and lower levels of memory impairment were correlated with increased activation in specific regions of the prefrontal cortex and parietal lobes, respectively. A significant decrease of activation in the bilateral prefrontal cortex and parietal lobes was found for the arithmetic task. The verbal learning and divided attention tasks elicited greater responses following TSD in regions associated with working memory. The researchers suggested this may represent an adaptive cerebral compensatory response to the detrimental effects of TSD. However, these same regions did not show greater responsiveness to the arithmetic task following TSD, but these regions did respond during normal waking state. This double dissociation suggested the cognitive demands inherent in a task may in part determine the likelihood of an adaptive response after TSD.

Chronic Sleep Deprivation

Carskadon, Harvey, & Dement (1981) investigated the question, "What happens when sleep is chronically below an optimal level?" Ten college students were observed for ten nights. On the first three nights the subjects obtained 10 h of sleep. The next seven nights, sleep was reduced to five hours a night. The sleep restriction was measured using the multiple sleep latency test (MSLT). The MSLT is a diagnosing tool for sleep disorders, particularly narcolepsy. The test is administered in a quiet, darkened room to achieve a direct measure of the underlying tendency for sleep to occur in the absence of altering factors (e.g., light, noise, anxiety, and attention) (Carskadon & Dement, 1982). During the ten day study, the subjects got progressively sleepier every day. There was a reduction in nocturnal stage two and REM sleep, while slow wave sleep was not affected. All but one of the subjects hit the 'twilight zone' (i.e., five minutes or less on the MSLT) at some point, most for significant portions of the day. The twilight zone has been associated with impaired cognitive performance in Carskadon's previous research (Carskadon and Dement, 1979).

In 2000, Blagrove and Akehurst assessed the accuracy of self-assessment of overall performance on logical reasoning and Raven's Advanced Progressive Matrices. The relationships between confidence and accuracy for individual answers to the Gudjonsson Suggestibility Scale and Raven's Advanced Progressive Matrices were also evaluated. In addition, the researchers observed the effects of sleep loss on confidence for suggestible answers and on the confidence-accuracy correlations to indicate the reasons for the effects of sleep loss on suggestibility. The effects of sleep loss and the hypothesized increase in confidence resulting from question repetition were included in assessment. Ninety-three college students were randomly assigned to one of six groups, three groups assessing sleep loss and the other three as controls. These groups constituted three cohorts, each with a sleep loss and control group. All groups obtained baseline testing in the first session on day one. For the sleep loss groups, testing was administered following 29-32 h, 32-35 h, and 47-50 h without sleep, respectively. The main results of this study found that sleep loss participants responded with a level of confidence for suggestible answers insignificantly different from controls and from day one, despite significantly increased suggestibility. On the logical reasoning and Raven's Advanced Progressive Matrices, sleep loss participants significantly underestimated their performance. Confidence significantly increased when non-leading and leading questions were repeated and answered affirmatively, but did not occur for non-affirmative answers and did not interact with sleep loss. The results of the effects of sleep loss and cognition and self-assessment of performance were as follows: sleep loss led to significant deficits on logical reasoning and on logical reasoning self-assessed, with a significant effect in length of sleep loss; and to significant deficits on Raven's Advanced Progressive Matrices self-assessed; no significant deficits due to sleep loss on Raven's Advanced Progressive Matrices; significant underestimation due to sleep loss on logical reasoning and on Raven's Advanced Progressive Matrices, which increased with length of sleep loss. As shown in these studies, an individual's cognitive performance may be significantly impaired due to prolonged sleep deprivation.

Exercise and Cognitive Function

Empirical research has shown that researchers are unable to provide conclusive evidence that exercise persistently improves or impairs cognitive functioning (Etnier, Salazar, Landers, Petruzzello, Han, & Nowell, 1997; Tomporowski & Ellis, 1986; Tomporowski, 2003). The reason for this discrepancy may be due to the type and duration of exercise performed, the cognitive task used, the time at which cognitive function was evaluated relative to the exercise bout, as well as level of physical fitness and experience with the exercise modality. Researchers have reported (a) exercise had no effect on cognition (Fleury, Bard, Jobin, & Carriere, 1981; Isler, Asci, & Kosar, 2002; Marriott, Reilly, & Miles, 1993; Sparrow & Wright, 1993; Tomporowski, Ellis, & Robert, 1987; Travlos & Marisi, 1995), (b) exercise facilitated cognition (Adam et al., 1997; Arcelin, Delignieres, & Brisswalter, 1998; Davey, 1973; Fleury & Bard, 1987; Gondola, 1987; Hancock & McNaughton, 1986; Heckler & Croce, 1992; Hogervorst et al., 1996; Lichtman & Poser, 1983; Paas & Adam, 1991; Sibley, Etnier, & Le Masurier, 2006), or (c) exercise impaired cognition (Cian, Koulmann, Barraud, Raphel, Jimenez, & Melin, 2000; Cian, Barraud, Melin, & Raphel, 2001; Gopinathan, Pichan, & Sharma, 1988). These potential outcomes of exercise impact on cognition are discussed in the following subsections.

No Effect of Exercise on Cognition

Among those that found no exercise effect on cognition were Fluery and his colleagues (1981), who evaluated the effects of three different treadmill protocols on young men's visual perception. Each protocol induced a fatigue state. One protocol required participants to perform sprint type exercise for 20 s on a treadmill with 10%

grade with speed gradually increasing from seven to ten miles/hour. For the second protocol participants performed five 1.5 min bouts at a speed that elicited exertion comparable to 150% of VO_2max at five min intervals with a five min rest between periods of work. The third protocol required subjects to run continuously to voluntary exhaustion while the speed and grade of the treadmill was increased. The session started with the visual task, and then the subject performed one of the three types of exercise per session. The visual task was given again immediately after the exercise. Fatigue had no significant effect on the detection of letters according to their position in the display. Also, there were no significant differences found in either exercise protocol on letter detection between pre- and post-fatiguing performance.

Tomporowski et al. (1987) evaluated the effects of aerobic exercise on runners' free-recall memory. In the first of two experiments, 24 subjects constituting a non-exercise control group were given only the memory test. Another group of 24 college students of average cardiovascular fitness, the treatment group, ran on a treadmill for 50 min at a speed that corresponded to 80% of their VO_2max. Immediately following the exercise, the subjects completed a series of free-recall tests. Twelve lists of 15 words each were randomly presented and subjects were instructed to recall as many words as they could in any order during a 90 s period. The exercise subjects showed no significant deficit in the memory performances compared to the non-exercise control group. In the second experiment, 12 student-athletes with very high levels of cardiovascular fitness were compared to 12 subjects selected from the exercise group with the lowest VO_2max in the first study. The intensity of exercise given in the first study was the same demanded of each subject in the high fitness group prior to taking the free-recall test.

The duration of exercise was the same for each high fitness subject as their matched average fitness group partner. The memory performance of highly fit participants did not differ from the performance of individuals with average cardiovascular fitness. The results showed that fatigue-producing exercise does not influence the encoding or retrieval of information from short-term memory, regardless of level of cardiovascular fitness.

Marriott et al. (1993) assessed high- and low-skilled soccer players' decision-making performance on complex problem-solving tasks at rest, following an initial 45 min period of running and again following a second 45 min period of continuous running. The soccer players ran on a treadmill at a speed that elicited heart rates of approximately 157 beats min^{-1} in attempt to imitate the game-like exercise demands. Subjects were then presented a series of 20 slides that illustrated game scenarios for 20 s each while being asked a series of questions concerning the play. The only difference in performance that was statistically significant was found in the low-skilled players compared to the high-skilled players. Following 90 min of exercise, high-skilled players' decision making did not improve. However, the low-skilled players' level of decision making declined significantly from the first test compared to the test following 45 min of exercise. A similar study conducted by Travlos and Marisi (1995) evaluated young men classified as high or low fit individuals. Participants performed a 50 min cycling exercise regimen that progressed in intensity every ten minutes. A choice-reaction time test and a test of concentration were administered during and following exercise. The exercise protocol had no effect on either measure. The high- and low-fit individuals showed no substantial differences in test performances.

Sparrow and Wright (1993) investigated the nature of exercise effects on cognitive performance, Raven's Progressive Matrices (RPM), and an adaptation of the revised Wechsler Adult Intelligence Scale (WAIS) arithmetic subtest. A secondary purpose of the research was to test the inverted-U hypothesis of an interactive relation between exercise-induced arousal and cognitive performance, as proposed by Yerkes and Dodson (1908). According to Yerkes and Dodson (1908), when arousal is low performance will be poor. As arousal rises to a moderate intensity, performance will reach an optimal level, the top of the inverted-U. However, if arousal continues to rise, performance will begin to deteriorate until it eventually returns to a level equal to that shown during low levels of arousal. The subjects consisted of 50 physically active men with an average age of 24.8 years. These subjects were divided into five groups of similarly predicted maximal oxygen uptake. Three of the five groups made up the exercise groups, one group played bingo as a control group, and the other control group had no activity. The three exercise groups performed a bench stepping exercise at mean power outputs of 47, 72, 100 watts for six min at a cadence of 22.5 steps/min. Individual bench heights within a group were adjusted relative to the mean predicted VO_2max for that group. If a subject was 10% above the groups mean predicted VO_2max, the bench height was adjusted to demand 10% more work. The cognitive tests, RPM, and WAIS arithmetic subtest were conducted immediately following the exercise. Testing took approximately eight minutes. The results of the RPM showed no significant effects for groups, pre vs. post tests, or their interaction. Similar results were obtained for the arithmetic test scores except that the pre vs. post tests factor showed a significant effect. The investigators suggested that may be due to a testing effect. In absence of an exercise effect the results neither challenge nor support the hypothesized inverted-U relationship. Sparrow and Wright (1993) proclaimed that exercise effects are specific to either the type of exercise task or the cognitive task.

A study conducted by Isler et al. (2002) looked at the relationship between chronic physical activity, psychomotor, psychosocial, and cognitive development. A total of 293 students from three randomly selected schools in fourth to eighth grade participated in the study. Motor skill development was assessed by the Eurofit Test Battery (i.e., measures of flexibility, muscular endurance, muscular strength, agility, and cardio-respiratory endurance) and physical activity levels were determined by weekly activity checklists. Self-concept, athletic competence, and anxiety were taken as indicators of psychosocial development and examined via questionnaires. As a result, physical activity level was a significant factor in determining student motor skill development. Results on psychosocial development revealed physical activity level was a significant predictor for athletic competence, and trait anxiety only in girls. At the end of the semester, general academic records were obtained from the schools to determine cognitive development levels of students. The results indicated that physical activity level was not a significant predictor for academic achievement.

Possible reasons why these studies did not find any significant effects due to exercise may be that the tests used were not sensitive to changes in cognitive ability (Tomporowski et al. 1987; Travlos & Marisi, 1995). The exercise interventions may influence attention processes which facilitate the execution of previously learned responses other than the acquisition of new information (Tomporowski et al. 1987). Also, the exercise-induced activation for optimal mental performance may be evident at a lower VO_2max value (Travlos & Marisi, 1995). In addition, the duration of the study may play a significant role. For example, the Isler et al. (2002) study was a semester long but may have found different results if the study followed the students for several years.

Positive Exercise Effects on Cognition

Research provides evidence that aerobic-type exercise of moderate intensity lasting less than 90 min in duration provides a selective facilitative influence on cognitive functioning (Tomporowski, 2003). These data illustrate that aerobic exercise improves the operation of specific stages of information-processing, processes that are involved in complex problem solving, and attention processes that are involved in response inhibition (Tomporowski, 2003).

Davey (1973) noted a trend toward facilitation of cognition in response to exercise when exercise intensity was maintained at low to moderate levels; however, impairment was found as exertion was increased over longer periods of time. The subjects pedaled a bicycle ergometer for a sufficient time to ensure the attainment of an oxygen debt condition. They were then tested on various mental tasks including identifying a sequence of odd-even-odd digits from a continuous series presented orally at a rate of one per second.

Hancock and McNaughton (1986) found that intense exercise differentially affects low-level and high-level cognitive processes. The effects of intense exercise on abilities to evaluate and interpret topographical maps were assessed in this study. Six orienteering trained males, who had extensive experience in reading maps and plotting directions, interpreted a series of maps while running on a treadmill at near anaerobic threshold and at rest. The exercise produced selective effects on participants' cognitive performance. Compared to performance at rest, their ability to make global interpretations of the information presented on the maps decreased, but their short-term memory and time estimations improved.

In the early stages of information processing, submaximal bouts of exercise do not appear to affect perceptual mechanisms; however, exercise does seem to influence speed of decision making once information is encoded (Tomporowski, 2003). Paas and Adam (1991) evaluated the impact of two different 40 min submaximal exercise protocols on young adults' stimulus-identification and choice-reaction performances. Each protocol consisted of a baseline, warm-up, exercise, and cool-down period with cognitive tests administered at each period. The two exercise protocols had similar effects on participants' cognitive performance with choice-reaction times significantly shorter during exercise and cool-down periods compared to control conditions. Also, perceptual-task performance declined significantly during the exercise period but improved significantly during the cool-down period. Adam et al. (1997) replicated this study but employed a single exercise condition. Participants' choice-reaction times were again shorter during and following exercise. As a result, the speed of participants' perceptual-task performance was significantly faster during both exercise and cool-down periods than during baseline periods. The authors suggested that the results of these two studies provide evidence of the positive effects of exercise on the allocation of attention resources.

Several studies have found that bouts of aerobic exercise facilitate response preparation and activation of motor movement (Tomporowski, 2003). A study by Fleury and Bard (1987) evaluated the effects of four different exercise protocols on young men's perceptual processing, motor timing, and letter-detection ability. The protocols included both anaerobic and aerobic exercise regimens. Maximal anaerobic exercise showed a transient reduction in the subjects' letter-detection performance. However, the exercise protocol in which participants ran for 30 min at a moderate pace and then at a faster pace until voluntary exhaustion led to significant improvements of performance during a stimulus-detection task and during a motor timing task.

Gondola (1987) analyzed the effects of a single bout of aerobic exercise on higher-order thinking. A group of 21 young women were given three tests of problem solving and divergent thinking following a 20 min dance class. The control group consisted of 16 young women given the same three tests. A consequences test provided measures of idea expression and originality of thinking and an alternate use test provided flexibility of thinking measures. As a result, women who exercised had significantly higher scores on all three measures compared to the control group. The investigator inferred these findings as indicative of the beneficial effects of aerobic exercise on creativity. The results showed importance for evaluation in this review, even though this was a field-research study with methodological shortcomings (Tomporowski, 2003).

A study by Heckler and Croce (1992) presented a series of addition and subtraction problems to groups of young women who differed in their level of cardiorespriatory fitness. Participants performed the tests at rest, following a 20 min run, and following a 40 min run at speeds that corresponded to 55% VO_2max. Problem-solving tasks were administered 5 min and 15 min following each bout of exercise. The exercise protocols facilitated participants' problem-solving speed during three post-exercise test periods, with no loss in accuracy. The result showed that high-fit women's performance was improved following 20 and 40 min runs and low-fit women's performance was improved only following a 20 min run.

Arcelin et al. (1998) aimed to identify the effects of moderate intensity (60% of VO_2max) exercise on specific stages of information processing mechanisms. The subjects recruited completed three 10 min submaximal exercise bouts on a bicycle ergometer. Following exercise, subjects performed three manual choice-reaction tasks manipulating task variables (signal intensity, stimulus-response compatibility, and time uncertainty) on two levels of difficulty. The subjects were also tested for baseline performance at rest. A significant underadditive interaction between time uncertainty and exercise was found for the highest quartiles of the distribution of reaction times. No other interaction effects were found for the other variables. The results of the study support that moderate aerobic exercise showed selective rather than general influences on information processing.

There are several studies that demonstrate response inhibition resulting from aerobic exercises. Response inhibition is the ability to withhold making a response when one is expected to do so. It involves the ability to selectively suppress irrelevant information in working memory in order to respond adaptively to the context of the current situation (Zacks & Hasher, 1994). An applied research study conducted by Lichtman and Poser (1983) showed the effects of aerobic exercise on response-inhibition processes. The study used Stroop test performance to evaluate the effects of an aerobic jogging program on 64 young adults. The students were randomly assigned to 45 min of jogging and various other physical activities or a hobby class (control group). Testing took place before and after the sessions. During the pretest, there were no differences between the groups on performance (percent correct). However, participants of the exercise group performed significantly better on the Stroop test (neutral, congruent, and incongruent) following exercise compared to the control group.

Hogervorst et al. (1996) conducted a number of cognitive and psychomotor tasks in 15 highly competitive cyclists and trained triathletes prior to and following a 60 min. simulated time trial. Participants pedaled at rates ranging between 75 and 100 rev min^{-1} and maintained levels of exertion that ranged between 75% and 85% VO_2max. The cognitive tasks that were administered were a finger-tapping test, three reaction-time tests and a short version of the Stroop Color-Word test (i.e., 40 items of each of the three Stroop sub-tests). The findings showed that exercise had a positive facilitative effect on simple reaction time, but not on finger tapping rates or choice-reaction time measures. However, exercise improved response inhibition performance, and the time required to complete the Stroop Color-Word interference subtest decreased significantly. Data collected during a subsequent testing session reinforced the finding that improved Stroop performance was due to exercise.

In 2006, Sibley et al. (2006) assessed the impact of a 20 min moderate-intensity exercise on cognitive function in 76 male and female college students. Executive functioning and inhibition were measured using the Stroop color-word tests. Three conditions were used in this test: a color naming test (neutral), a color-word interference test (incongruent), and negative priming test. In the negative priming condition, the ink color of each word was the same as the color word stimulus on the previous item. Participants engaged in an exercise condition and a sedentary control condition. The exercise bout was a self-paced run and/or walk at a moderately intense workload on a treadmill. The control condition consisted of reading for 20 min. An Activation-Deactivation Adjective Checklist (measures arousal) was administered before and after the Stroop Test. Participants took less than ten min to complete testing. The response time was significantly longer on Stroop interference (incongruent) test for the exercise group. There were no significant differences on the other sub-tests. Overall, the Stroop tests revealed a practice effect with participants performing the task faster after the second condition. Sibley et al. (2006) concluded that exercise facilitates the processing of pertinent information on the Stroop color-word interference test rather than increasing inhibition on irrelevant stimuli.

The results of most of these studies recognize that submaximal aerobic exercise performed for durations between 20 and 60 min facilitates multiple cognitive processes which are critical to optimal performance and adaptive behavior. People are better prepared for action, concentration, and solving complex problems after engaging in aerobic exercise than prior to exercise. The results provide reasoning to explain why people often report that they can think and concentrate more clearly after bouts of exercise (Tomporowski, 2003).

Negative Exercise Effects on Cognition

Overall, laboratory tests of cognitive function appear to be quite immune to putative fatigue states produced by intense anaerobic exercise. Researchers have consistently failed to detect a clear relation between exhaustive exercise and processes involved in perception, sensory integration, or discrimination. In most cases, these studies are based on the a priori expectation that intense anaerobic exercise will produce a fatigue state in participants leading to declines in their cognitive performance (Tomporowski, 2003).

In 1988, Gopinathan et al. studied the variation in mental performance under different levels of heat stress-induced dehydration on 11 subjects that were heat acclimatized in the tropical regions of India. Body dehydration (1%, 2%, 3%, and 4%) was induced by a combination of water restriction and exercise (15 steps/min on a 38-cm high stool for two h) in heat. The word recognition test, serial addition test, and a trail making test (includes motor speed and attention) were administered in a thermoneutral room after the subjects recovered fully from the effects of exercise in heat. The results indicated that the short-term memory progressively deteriorated as the degree (critical level at 2%) of dehydration increased. The same findings were found for the serial addition test. For the trail marking test, speed decreased as the dehydration level increased. Accordingly, it seems that dehydration associated with exercise can hinder cognitive performance.

Cian and colleagues (2000) performed a series of experiments that were driven by their observation that thermal stress manipulations producing dehydration with more than a 2% loss in body weight resulted in significant declines in cognitive performance. An initial study resulted in different effects of passive thermal dehydration and exercise-inducted dehydration on eight young men's performance of multiple cognitive tasks. During separate sessions, participants body mass was lowered by 2.8% either by environmental heat exposure or by running on a treadmill at a speed equal to 60% VO_2max. The two sessions lasted approximately two hours in length. A control session required the participant to remain in a seated position while maintaining fluid hydration for two hours. The cognitive tests were conducted 30 min after the dehydration period. The dehydration phases compared to control phase, had no effect on participants' performance of a four-choice serial discrimination task or a long-term memory task that measured free-recall and recognition memory. Both dehydration sessions led to significantly poorer performance during a psychomotor tracking task and during a short-term memory digit-span test. During the perceptual-discrimination task, participants responded more slowly; however, accuracy of response was not impaired. About 60 min after the cognitive tasks were completed; participants performed an arm-crank exercise protocol corresponding to 85% of VO_2max until fatigue (15-20 min). A cognitive test battery was conducted 15 min after termination of the arm-crank exercise. As a result of the additional exercise, no effect was seen in performance of the perceptual-discrimination task, the serial-reaction task, or the short-term memory task. The participants showed a significant decline in psychomotor tracking when dehydrated. Further, the men's performance of the long-term, free-recall memory test was impaired more when dehydration was affected by exercise compared to passive exercise. The decline in the memory test may have resulted from either dehydration or due to the arm-crank exercise.

In a more recent study, Cian et al. (2001) isolated the effects of heat exposure, exercise induced dehydration and fluid ingestion on cognitive performance. The subjects were seven young men that participated in five experimental sessions. There were two trials of dehydration by controlled passive exposure to heat, two trials of dehydration by exercise on a treadmill, and a control session. Body mass decreased 2.8% by dehydration from controlled passive exposure to heat or exercise on a treadmill at 65% of VO_2max lasting approximately two hours. A cognitive test battery was administered 30 min following the first session and achieved the target body dehydration. Consistent with other studies, there was no effect found during long-term memory, psychomotor tracking, or reaction time. However, the response time for perceptual tasks lengthened, and memory impairment was observed in short-term memory. At the end of a one hour recovery phase, the subject drank two separate amounts of glucose solution taken at 30 min intervals. A cognitive test battery was administered two hours after the subjects drank the second amount of solution. Fluid replacement ameliorated the decline in short-term memory performance observed following the dehydration treatments. In addition, lack of fluid replacement resulted in significant declines in free-recall memory test performance. The researchers demonstrated that the dehydration produced by exercise or passive heat could impair men's memory performance and reaction time. However, it is not clear how fluid replacement psychologically impacts cognitive function.

Summary

In summary, many individuals give up sleep in order to meet the needs of their busy lifestyles. The lack of obtaining proper sleep causes NREM and REM disruptions and influences circadian rhythms. Sleep loss may minimize the restoration of neuronal processes that are necessary for optimal daytime mental and physical performance, as well as consolidating memory and cognitive development for goal-oriented behaviors. Inadequate sleep may explain why students are not performing as well as their counterparts who get a proper amount of sleep and achieve better grades. Therefore, studying all night for an exam may be the worst thing a student can do, and there are times when an athlete might be better off sleeping rather than hitting the skating rink or swimming pool at five in the morning.

Studies finding contrary results describing exercise effects on cognition may be due to the type and duration of exercise administered, as well as the sensitivity of the cognitive task. Submaximal aerobic exercise lasting between 20 and 60 min appears to facilitate multiple cognitive processes which are critical to optimal mental performance and adaptive behavior. However, exercise that is longer in duration and leads to dehydration and associated metabolic changes can impair information processing and cognition. The high physical fitness of an individual and their great experience on a particular modality may provide more favorable and correct results. For instance, an unfit individual may not physically perform as well on a treadmill due to lack of experience compared to a highly fit individual that is familiar with the modality. Overall, the results of the previous studies have implications for the academic and athletic performance of students and, indeed, for anyone whose work involves ongoing learning and demands high standards of performance (e.g., military, physicians, pilots, and rescue workers).

Chapter 3

METHODS

This chapter describes in detail the methodology of this study. The purpose of this study was to determine the effects of low intensity exercise and sleep deprivation on cognition among college-aged students. Baseline and sleep deprivation conditions were examined at two separate testing sessions. The Stroop test, serial arithmetic test, and Raven's Advanced Progressive Matrices were used as measures of cognitive function. A low-intensity exercise protocol was used, which corresponded to 40% of the subject's HRmax. This methods section is subdivided as follows: (a) subjects, (b) design and protocol, (c) measurements, and (d) statistical analysis.

Subjects

Twenty-seven college-aged male students from Ithaca College located in Ithaca, New York, gave their written consent (Appendix A) to participate in this study. The subjects ranged in age between 18 to 26 years ($M = 20.1$, $SD = 2.1$) and were recruited entirely on a voluntary basis. Prior to testing, participants were informed of the study protocol, potential risks, and benefits. The main risk associated with this type of study was possible sleepiness throughout and after the sleep deprivation testing day. Additional risks that could have occurred during the exercise tests included, but were not limited to, sprains, strains, abrasions, and contusions. All subjects were given the opportunity to ask questions about their role in the study and were informed that they could drop out of the study at any time.

During the preliminary subject recruitment meeting, interested participants were asked to complete a Medical History/Health Habit Questionnaire (Appendix B) and a sleep/activity log (Appendix C). The questionnaire and journal were used to determine regular nocturnal sleeping patterns and if exclusion criteria existed. Examples of exclusion criteria were a high level of cardiovascular training, sedentary lifestyle, sleep disorders, reliance on tobacco, alcohol, or caffeinated products, and any health conditions preventing exercise. In addition, subjects who took prescription medication or over-the-counter medication on a regular basis (more than four times per week) were excluded from participation. These criteria eliminated subjects with poor health and sleep patterns prior to the study.

Design and Protocol

The study was conducted in the Exercise Physiology Lab at Ithaca College. The same experimenters administered all sessions. Also, the same testing environment and procedures were used for all sessions. Participants (N=27) were randomly placed into a non-exercise group (n=13) and a low-intensity exercise group (n=14). Each participant took part in three sessions that involved a VO_2max test, cognitive assessments following normal sleep, and again following sleep deprivation. These sessions occurred on separate testing days. Participants were asked to devote two nights and the following mornings for the sleep deprivation and normal sleep data collection. The experimental design required subjects to serve as their own controls for sleep effects, but the non-exercise group served as a control for exercise effects. The exercise group was asked to wear appropriate attire and footwear for exercise. The exercise group exercised at a low intensity (40% of HRmax) for 20 min prior to the cognitive tests. Previous studies have indicated that optimal exercise for subsequent maximal cognitive performance may be between 40% and 60% VO_2max (Davey, 1973; Travlos & Marisi, 1995). In addition, previous research showed that problem-solving performance of both high and low fit women improved following a 20 min run compared to a 40 min run (Heckler & Croce, 1992).

The first visit was a scheduled VO_2max test in the Exercise Physiology Lab, which took approximately one hour. Completion of the VO_2max test allowed determination of the subject's heart rate at 40% of HRmax, which corresponded to low intensity exercise. The VO_2max test required participants to run on a treadmill at a self-selected speed. The grade of the treadmill started at 0%, and then increased by 2% every two min. The test was terminated when participants felt they could no longer continue. During the test, participants were required to wear a headgear device with a breathing valve to allow collection of expired gases. Heart rate and rating of perceived exertion were monitored throughout the test. At this time, participants were asked to keep a daily sleep/activity log (Appendix C) for two weeks to obtain information on sleep/wake cycles, physical activity, and consumption of alcohol, caffeine, cigarettes, and medication/supplement use.

During the first data collection session, all participants were required to report to the Exercise Physiology Lab. Participants were asked to complete a 24 h history form (Appendix D) prior to each of the two subsequent data collection sessions. Refreshments were then provided (e.g., pizza and water/juice), and all participants had an opportunity to become familiar with the cognitive tests. All subjects, including exercise and non-exercise groups, were present at this time. After meeting for 1.5 h, subjects who were not to be deprived of sleep were dismissed (11:30 p.m.) from the lab to go home for a normal night of sleep (approximately seven hours). These subjects were required to report back to the lab the following morning for cognitive assessment. The sleep deprived subjects were required to remain awake in the Exercise Physiology Lab through the entire night. To ensure that participants obtained 24 h of sleep deprivation, they were required to report their previous morning's wake time and refrain from napping through the day. Sleep restriction for an entire night has been found to significantly impair memory performance (Carskadon et al., 1981). To prevent participants from sleeping, they had the opportunity to engage in non-exercise activities (e.g., watching movies, playing games, or socializing) and were provided with a snack (e.g., fruit and water/juice). If a participant happened to fall asleep, a researcher woke them up by getting their attention, such as tapping them or calling their name. The researcher then was more attentive to the participant to ensure he remained awake. In the morning, participants in the exercise group performed a five min warm-up followed by a 20 min bout of cardiovascular exercise and then the cognitive assessments. Prior to cognitive assessments, the non-exercise group participated in light stretching activity. Subjects remained in the Exercise Physiology Lab for one h to repeat cognitive assessments. Participants were allowed to leave following completion of the second cognitive assessment.

The second data collection session occurred two weeks after the first testing session, to allow sleep deprived subjects to return to their normal sleep/wake cycle. As with the first testing session, half of the exercise and non-exercise group were assessed following a normal night of sleep (approximately seven hours) and the other half were assessed following one night of total sleep deprivation. The only difference during the second session was that those subjects who were sleep deprived during the first data collection session received a normal night of sleep and those who had normal sleep were sleep deprived. All other methods during the second data collection session were the same as during the first session.

Measurements

VO_2max Test

All subjects in the exercise group were given a test of cardiovascular fitness approximately two weeks prior to attending the two data collection sessions. A Precor treadmill (model C954) was used as the exercise modality, and a maximal treadmill run was conducted to obtain measures of cardiovascular fitness. The protocol required subjects to warm up at a slow pace for five min. The warm-up pace was then increased by one to one and a half mph to establish a self-selected test pace. The test began at 0% grade with grade increasing by 2% every two min until volitional exhaustion at the predetermined test pace. After the warm-up, the two-way valve affixed to the subject's headgear was attached to the metabolic measurement cart (Parvomedics, Sandy,UT) via a hose connection. Expired gas was collected continuously and analyzed to provide a measure of oxygen consumption ($ml/kg/min^{-1}$) and a measure of the subject's respiratory quotient every 30 s. Heart rate (HR) measures, through telemetry, were recorded at the end of each stage. After the test, the subject actively cooled down by walking on the treadmill at a comfortable speed until heart rate was within ten beats of the warm-up heart rate. Information from this maximal test was used to select the exercise intensity (40% of HRmax) for exercise during the data collection sessions.

Cognitive Measures

All subjects attended two data collection sessions to examine the effects of either normal sleep or total sleep deprivation on several measures of cognitive function. The cognitive tests administered following the exercise or non-exercise activities were the Stroop test (Appendix E), a computerized serial arithmetic test (Appendix F), and Raven's Advanced Progressive Matrices (RAPM; Appendix G). Each test provides challenging and exasperating measures of cognitive ability. The cognitive assessments took approximately 25 min and were administered in the same order each time.

The first test administered was the Stroop test (Appendix E), which has been widely recognized for over 70 years as the "gold standard" of attention measures (Bower, 1992). The Stroop effect is consistent under a variety of experimental conditions, especially when considering complex cognitive function (i.e., task involving both hemispheres of the brain). This test contains elements of selective attention, response inhibition, word reading, and color-naming processes. Previous research has used this test to investigate exercise effects on cognitive function (Hogervorst et al. 1996; Lichtman & Poser, 1983). The Stroop test is based on the observation that individuals can read words much faster than they can identify and name colors. For this test, a computer program randomly generated words that were highlighted in red, green, or blue. The subjects were to depress number one, two, or three respectively, on the number key pad in response to the color highlighted. There were five sections containing 24 words each that included neutral (different words presented in a different color (e.g., house, red; gun, green; and door, blue), congruent (color word presented in the same color), incongruent (color word presented in a different color), other congruent (color-related word as the color (e.g., blew, blue; greed, green; and read, red), and other incongruent (color-related word presented in a different color (e.g., blew, red). The neutral subtest is used as a measure for baseline performance. The congruent and other congruent subtests are used to measure facilitation effect, with a relatively automatic cognitive process (word reading) having that same effect on a relatively controlled cognitive process (color naming). The incongruent, and other incongruent subtests, are used to measure interference effect, with a relatively automatic cognitive process (word reading) opposing a relatively controlled cognitive process (color naming). The difference between congruent/incongruent and other congruent/other incongruent are the use of color words v. color-related words, respectively. The color-related words cause greater interference (other incongruent) than color words. The test took approximately five minutes to administer. Participant performance on time and percent correct were evaluated. The reliability and validity of the Stroop effect is highly consistent across different variations of the test (MacLeod, 1991).

The serial arithmetic test (Appendix F), a task from the Walter Reed Performance Assessment Battery, was used as a mental serial add/subtract task requiring sustained attention, working memory, and arithmetic processing (Thorne, Genser, Sing, & Hegge, 1985). Previous research has used problem solving to investigate effects of total sleep deprivation (Drummond & Brown, 2001; Kjellberg, 1975) and exercise (Heckler & Croce, 1992). In the present study, a computer program generated two randomly selected single digits (zero-nine) and an operator (either – or + sign) displayed sequentially in the same center-screen location, followed by a blank box for the answer. The subject performed the indicated addition or subtraction and, if the result was positive, entered the least significant digit of the result. If the result was negative, the subject added 10 and entered the positive single digit result. The digits and operator were each presented for 250 msec, with a 200 msec interdigit/operator interval. The next trial began 200 msec after a key entry, or response, was made by the subject. Thus, there was no opportunity for an omission or lack of response. This test took approximately 10 min to administer. Participant performance on time and percent correct were evaluated. The computer program necessary to assess speed and accuracy of the task was developed by the investigators at Ithaca College.

The third test, the Raven's Advanced Progressive Matrices (Appendix G) is a multiple choice test of abstract reasoning. RAPM measures two main components of general intelligence, eductive (to think clearly and make sense of complexity) and reproductive (to store and reproduce information) ability (Wilkipedia, 2008). Previous research has used the RAPM to investigate effects of total sleep deprivation (Blagrove & Akehurst, 2000; Linde & Bergstrom, 1992) and the effects of exercise (Etiner et al., 1997) on logical reasoning. This test can be timed to obtain a rapid index of educated ability or efficiency. The test consisted of two sets: set I contained 12 problems; set II contained 36 problems arranged in ascending order of difficulty. Each problem contained a missing piece that was to be identified by a set of alternative pieces to complete the figure. This test took approximately 10 min to administer. Participant performance on time and percent correct was evaluated.

Statistical Analysis

Descriptive statistics and analysis of variance (ANOVA) were used to analyze the dependent variables. The primary dependent variables were scores from the Stroop test, serial arithmetic test and Raven's Advanced Progressive Matrices. A three-way ANOVA (2 x 2 x 2) with repeated measures on two factors (sleep and trial) with the third factor being exercise/non-exercise group was applied to all dependent variables. Alpha level of

.05 was used to determine significant effects of sleep and exercise on cognition. The time factor was analyzed to determine if there were lasting effects of sleep and/or exercise on cognition one hour from completion of the first battery of test.

Summary

The purpose of this study was to determine the influence of sleep deprivation and exercise on cognitive function among college-aged students. The subjects provided information on their sleep and physical activity for two weeks prior to data collection. The subjects VO_2max and running speed at 40% HRmax was determined during an initial exercise testing session. Baseline and sleep deprivation data were collected during sessions one and two. Food was provided to control what the subjects ate during data collection. Following the exercise or non-exercise activities, the cognitive tests administered were the Stroop test, serial arithmetic test, and Raven's Advanced Progressive Matrices. Statistical analyses were performed on cognitive test results to determine if there was any significant effect of sleep deprivation and/or exercise on cognitive function.

Chapter 4

RESULTS

This study was conducted to investigate how low intensity exercise affects sleep deprivation induced cognitive deficit in college-aged students. Descriptive statistics and analysis of variance (ANOVA) were used to analyze the dependent variables (Stroop test, serial arithmetic test, and Raven's Advanced Progressive Matrices). Exercise, sleep, and time were the factors used in a three-way ANOVA (2 x 2 x 2) with repeated measures on two factors (sleep and time). In total, 14 analyses of variance were completed. Sections in this chapter describe the resulting data by dependent variable and include: (a) Stroop analysis, (b) serial arithmetic analysis, (c) Raven's Advanced Progressive Matrices analysis, and (d) summary. Each variable was analyzed for both percent correct (%) and response time (s).

Stroop Test Analysis

The Stroop test is a psychological test of selective attention and response inhibition. The Stroop test assesses the subject's ability to selectively suppress irrelevant information in working memory in order to respond adaptively to the context of the current situation. Percent correct and response time for each of the five subgroup test (i.e., neutral, congruent, incongruent, other congruent and other incongruent) of the Stroop were recorded for each subject after a night of sleep and a night of sleep deprivation. These data were collected immediately following the exercise or non-exercise activity and again after 1 h recovery. Raw data for the Stroop test can be found in Appendix H through Q.

Stroop Test Neutral

The Stroop neutral test presents a different word in a different color. This test measures the subject's baseline (control) performance of coloring naming. The raw data for this test can be found in Appendix H for percent correct and Appendix I for average response time. The three-way interaction (sleep x trial x exercise) for neutral (% correct) was not significant ($p > .05$) (Table 1). There were also no significant findings in the two-way interaction for sleep and exercise. The two-way interaction of trial x exercise was not significant ($p > .05$), nor were differences found for sleep x trial. There were no significant differences in neutral performance (% correct) caused by the main effect of sleep (i.e., percent correct was the same after a good night of sleep and sleep deprivation) ($p > .05$). There were no significant differences for main effect trial ($p > .05$) or the main effect of exercise ($p > .05$). The Stroop neutral test (% correct) descriptive data can be found in Table 2.

The following are the results for Stroop neutral test response time. The three-way interaction (sleep x trial x exercise) for response time was not significant ($p > .05$) (Table 3). There were no significant findings in the two-way interaction for sleep and exercise ($p > .05$). The two-way interaction of trial and exercise was also not signiificant ($p > .05$). No differences were found for the two-way interaction of sleep and trial ($p > .05$). There were no significant differences in response time caused by the main effect of sleep (i.e., average response time in the Stroop neutral test was the same after a good night of sleep and sleep deprivation) ($p > .05$). As shown in Table 3, there was a significant difference in response time for main effect of trial. Stroop neutral response times were initially longer than seen 1 h later ($p < .05$). This may indicate a learning effect with subjects

Table 1

Stroop Neutral Test (% Correct) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	13.37	1.00	13.37	0.21	.65
Error	1560.71	25.00	62.43		
Trial	184.47	1.00	184.47	3.63	.06
Error	1271.18	25.00	50.85		
Exercise	4.72	1.00	4.72	0.08	.77
Error	1395.24	25.00	55.81		
Sleep x Trial	3.97	1.00	3.97	0.06	.81
Error	1710.40	25.00	68.42		
Trial x Exercise	1.21	1.00	1.21	0.02	.88
Sleep x Exercise	89.86	1.00	89.87	1.44	.24
Sleep x Trial x Exercise	124.26	1.00	124.26	1.82	.19

Note. Significance was determined at an alpha level of .05.

Table 2

Stroop Neutral Test (% Correct) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	38.00	100.00	93.15	16.64
No Sleep Trial 2	14	92.00	100.00	98.51	2.64
Sleep Trial 1	14	92.00	100.00	98.21	2.69
Sleep Trial 2	14	96.00	100.00	98.51	2.07
Control Group					
No Sleep Trial 1	13	83.00	100.00	97.76	4.99
No Sleep Trial 2	13	96.00	100.00	98.40	2.71
Sleep Trial 1	13	67.00	100.00	94.87	11.68
Sleep Trial 2	13	92.00	100.00	99.04	2.50

Note. Scores are percent correct.

Table 3

Stroop Neutral Test Response Time (s) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	0.49	1.00	0.49	0.02	.88
Error	515.47	25.00	20.62		
Trial	513.57	1.00	513.57	43.64	.00[a]
Error	294.19	25.00	11.77		
Exercise	47.69	1.00	47.69	1.22	.28
Error	975.07	25.00	39.00		
Sleep x Trial	7.94	1.00	7.94	0.99	.33
Error	199.57	25.00	7.98		
Trial x Exercise	6.65	1.00	6.65	0.57	.46
Sleep x Exercise	19.55	1.00	19.55	0.95	.34
Sleep x Trial x Exercise	8.24	1.00	8.42	1.03	.32

Note. Significance was determined at an alpha level of .05.

[a] There was a significant (main effect) decrease in performance from first trial to second trial.

improving test time due to familiarity with the test. There were no significant differences for main effect of exercise ($p > .05$). The Stroop neutral test response time descriptive data can be found in Table 4.

Stroop Test Congruent

The Stroop congruent test presents a color word that is shown in the same color. This test measures the subject's performance on Stroop facilitation. The raw data for this test are presented in Appendix J for percent correct and Appendix K for response time. As demonstrated in Table 5, there were no significant differences found in the three-way interaction sleep, trial, and exercise ($p > .05$) for Stroop congruent (% correct). The two-way interaction sleep and exercise was not significant ($p > .05$). There were also no differences found in the two-way interactions for trial x exercise and for sleep x trial ($p > .05$). There no significant findings in congruent response time caused by the main effect of sleep ($p > .05$) A significant difference was found in performance for main effect trial ($p < .05$). This may indicate a learning effect with scores generally getting faster on the second trial. There were no significant findings for the main effect exercise ($p > .05$). The Stroop congruent test (% correct) descriptive data are shown in Table 6.

The following are the results for Stroop congruent test response time. There were no significant differences found in the three-way interaction sleep, trial, and exercise for response time ($p > .05$) (Table 7). The two-way interaction within sleep and exercise was not significant ($p > .05$). There were also no differences found in the two-way interactions for trial x exercise and for sleep x trial ($p > .05$). There were no significant findings in response time for main effect sleep ($p > .05$) and the main effect of trial ($p > .05$). There were no significant differences found in congruent response time for

Table 4

Stroop Neutral Test Response Time (s) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	15.78	28.41	21.76	4.77
No Sleep Trial 2	14	12.87	26.28	17.88	3.73
Sleep Trial 1	14	15.42	28.56	21.03	3.63
Sleep Trial 2	14	12.98	24.81	17.17	3.59
Control Group					
No Sleep Trial 1	13	15.59	32.44	22.18	5.44
No Sleep Trial 2	13	14.12	22.81	18.41	3.62
Sleep Trial 1	13	16.93	36.16	24.26	6.12
Sleep Trial 2	13	13.34	27.77	18.31	4.15

Note. Data are times expressed in seconds.

Table 5

Stroop Congruent Test (% Correct) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	173.39	1.00	173.39	2.74	.11
Error	1580.74	25.00	63.23		
Trial	219.91	1.00	219.91	4.36	.05[a]
Error	1259.94	25.00	50.40		
Exercise	42.40	1.00	42.40	0.39	.54
Error	2721.25	25.00	108.85		
Sleep x Trial	85.41	1.00	85.41	2.18	.15
Error	977.85	25.00	39.11		
Trial x Exercise	0.02	1.00	0.02	0.00	.98
Sleep x Exercise	2.29	1.00	2.29	0.04	.85
Sleep x Trials x Exercise	0.56	1.00	0.56	0.01	.91

Note. Significance was determined at an alpha level of .05.

[a] There was a significant (main effect) increase in performance from first trial to second trial.

Table 6

Stroop Congruent Test (% Correct) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	33.00	100.00	92.86	18.38
No Sleep Trial 2	14	83.00	100.00	97.32	4.51
Sleep Trial 1	14	88.00	100.00	97.32	3.51
Sleep Trial 2	14	88.00	100.00	98.51	3.51
Control Group					
No Sleep Trial 1	13	63.00	100.00	94.23	10.70
No Sleep Trial 2	13	96.00	100.00	99.04	1.83
Sleep Trial 1	13	92.00	100.00	98.40	3.20
Sleep Trial 2	13	96.00	100.00	99.36	1.57

Note. Scores are percent correct.

Table 7

Stroop Congruent Test Response Time (s) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	218.68	1.00	218.68	0.97	.33
Error	5616.27	25.00	224.65		
Trial	2.67	1.00	2.67	0.01	.91
Error	5570.72	25.00	222.83		
Exercise	42.35	1.00	42.35	0.20	.66
Error	5346.66	25.00	213.87		
Sleep x Trial	118.74	1.00	118.74	0.55	.47
Error	5435.50	25.00	217.42		
Trial x Exercise	213.39	1.00	213.39	0.96	.34
Sleep x Exercise	148.86	1.00	148.86	0.66	.42
Sleep x Trial x Exercise	257.25	1.00	257.25	1.18	.29

Note. Significance was determined at an alpha level of .05.

main effect exercise ($p < .05$). The Stroop congruent response time descriptive data are shown in Table 8.

Stroop Test Incongruent

The Stroop incongruent test presents a random color word shown in a different color. This test measures the subject's performance on Stroop interference. The raw data for this test are presented in Appendix L for percent correct and Appendix M for response time. As shown in Table 9, the three-way interaction (sleep x trial x exercise) for incongruent (% correct) was not significant ($p > .05$). There were no significant findings for the two-way interaction sleep and exercise ($p > .05$). No significant differences were found for the two-way interaction trial and exercise ($p > .05$). The two-way interaction between sleep and trial was not significant ($p > .5$). There were no significant differences found for (% correct) main effect sleep ($p > .05$). There were no significant differences for main effect trial and the main effect of exercise ($p > .05$). The Stroop incongruent test (% correct) descriptive data are shown in Table 10.

For Stroop incongruent response time, the three-way interaction (sleep x trial x exercise) was not significant ($p > .05$) (Table 11). There were no significant findings for the two-way interaction sleep x exercise and for trial x exercise ($p > .05$). The two-way interaction for sleep and trial were not significant ($p > .5$). There were no significant differences in response time caused by the main effect of sleep ($p > .05$). However, there was a significant finding in response time for main effect trial ($p < .05$). Again, this may indicate a learning effect with subjects completing the test faster due to familiarity. The main effect for exercise did not show any significant differences ($p > .05$). The Stroop incongruent response time descriptive data are shown in Table 12.

Table 8

Stroop Congruent Test Response Time (s) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	14.46	30.68	19.25	4.66
No Sleep Trial 2	14	12.61	24.27	16.85	3.45
Sleep Trial 1	14	14.07	24.79	19.24	3.22
Sleep Trial 2	14	12.25	24.14	17.18	3.71
Control Group					
No Sleep Trial 1	13	15.04	31.81	21.55	5.64
No Sleep Trial 2	13	12.95	24.97	18.06	3.74
Sleep Trial 1	13	13.46	29.51	20.06	4.95
Sleep Trial 2	13	11.96	35.65	18.55	6.54

Note. Data are times expressed in seconds.

Table 9

Stroop Incongruent Test (% Correct) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	0.16	1.00	0.16	0.01	.94
Error	686.45	25.00	27.46		
Trial	146.64	1.00	146.64	3.20	.09
Error	1145.08	25.00	45.80		
Exercise	74.53	1.00	74.53	0.52	.48
Error	3597.18	25.00	143.89		
Sleep x Trial	0.01	1.00	0.01	0.00	.99
Error	1401.65	25.00	56.06		
Trial x Exercise	16.98	1.00	16.98	0.37	.55
Sleep x Exercise	18.14	1.00	18.14	0.66	.42
Sleep x Trial x Exercise	170.50	1.00	170.50	3.04	.09

Note. Significance was determined at an alpha level of .05.

Table 10

Stroop Incongruent Test (% Correct) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	38.00	100.00	91.96	16.22
No Sleep Trial 2	14	88.00	100.00	97.62	4.23
Sleep Trial 1	14	83.33	100.00	95.24	6.30
Sleep Trial 2	14	75.00	100.00	95.83	7.31
Control Group					
No Sleep Trial 1	13	83.00	100.00	97.76	4.70
No Sleep Trial 2	13	92.00	100.00	96.79	3.02
Sleep Trial 1	13	58.33	100.00	94.36	11.20
Sleep Trial 2	13	91.67	100.00	98.40	2.71

Note. Scores are percent correct.

Table 11

Stroop Incongruent Test Response Time (s) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	50.87	1.00	50.87	2.65	.12
Error	479.08	25.00	19.16		
Trial	75.35	1.00	75.35	5.66	.03[a]
Error	332.63	25.00	13.31		
Exercise	26.17	1.00	26.17	0.39	.54
Error	1668.27	25.00	66.73		
Sleep x Trial	34.93	1.00	34.93	2.84	.11
Error	307.86	25.00	12.31		
Trial x Exercise	7.03	1.00	7.03	0.53	.47
Sleep x Exercise	13.64	1.00	13.64	0.71	.41
Sleep x Trial x Exercise	8.66	1.00	8.66	0.70	.12

Note. Significance was determined at an alpha level of .05.

[a] There was a significant (main effect) decrease in performance from the first trial to the second trial.

Table 12

Stroop Incongruent Test Response Time (s) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	17.95	32.56	23.29	3.91
No Sleep Trial 2	14	15.63	26.83	20.42	3.68
Sleep Trial 1	14	16.66	31.19	22.25	4.11
Sleep Trial 2	14	15.39	32.39	22.79	5.10
Control Group					
No Sleep Trial 1	13	18.34	37.62	23.51	5.61
No Sleep Trial 2	13	15.73	26.88	20.75	3.12
Sleep Trial 1	13	18.10	31.66	25.02	4.51
Sleep Trial 2	13	13.80	52.22	23.41	9.67

Note. Data are times expressed in seconds.

Stroop Test Other Congruent

The Stroop other congruent test presents a color-related word in the color (i.e., blew; blue). This test measures the subject's performance on Stroop facilitation. This is a similar measurement as congruent except other congruent are color-related words and congruent are color words. The raw data for this test is presented in Appendix N for percent correct and Appendix O for response time. As shown in Table 13, there were no significant findings for the three-way interaction between sleep, trial, and exercise for Stroop other congruent (% correct) ($p > .05$). There were no significant differences found in the two-way interaction within sleep and exercise ($p > .05$). No significant differences were found for two-way interaction trial x exercise and for sleep x trial ($p > .05$). There were no significant differences found for main effect sleep ($p > .05$). No significant differences were found for main effect trial or the main effect of exercise ($p > .05$). The Stroop other congruent test (% correct) descriptive data are shown in Table 14.

The following are the results for Stroop other congruent response time. As shown in Table 15, there were no significant findings in the three-way interaction for sleep, trial, and exercise in Stroop other congruent response time ($p > .05$). There were no significant differences found in the two-way interaction sleep and exercise ($p > .05$). However, a significant difference was found for other congruent response time in the two-way interaction of trial and exercise ($p < .05$) (Table 15). To explore this interaction, paired t-tests were used to compare trial one to trial two scores for both groups and an unpaired t-test was used to compare the exercise to non-exercise group scores for trial one and trial two. There was a significant difference found between trials ($p < .05$), but not for exercise vs. non-exercise group ($p > .05$). The two-way interaction for sleep and trial was

Table 13

Stroop Other Congruent Test (% Correct) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	59.46	1.00	59.46	0.74	.40
Error	1999.90	25.00	80.00		
Trial	192.45	1.00	192.45	2.82	.11
Error	1705.29	25.00	68.21		
Exercise	7.05	1.00	7.05	0.07	.79
Error	2457.21	25.00	98.29		
Sleep x Trial	1.66	1.00	1.66	0.03	.87
Error	1412.44	25.00	56.50		
Trial x Exercise	13.01	1.00	13.01	0.19	.67
Sleep x Exercise	27.15	1.00	27.15	0.34	.57
Sleep x Trial x Exercise	29.67	1.00	29.67	0.53	.48

Note. Significance was determined at an alpha level of .05.

Table 14

Stroop Other Congruent Test (% Correct) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	91.67	100.00	98.13	2.65
No Sleep Trial 2	14	91.67	100.00	98.81	3.02
Sleep Trial 1	14	33.33	100.00	94.34	17.65
Sleep Trial 2	14	87.50	100.00	97.62	4.54
Control Group					
No Sleep Trial 1	13	54.17	100.00	94.87	12.52
No Sleep Trial 2	13	91.67	100.00	99.04	2.50
Sleep Trial 1	13	70.83	100.00	95.19	8.13
Sleep Trial 2	13	83.33	100.00	97.76	4.99

Note. Scores are percent correct.

Table 15

Stroop Other Congruent Test Response Time (s) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	51.72	1.00	51.72	9.94	.00[a]
Error	130.02	25.00	5.20		
Trial	161.62	1.00	161.62	36.30	.00[b]
Error	111.32	25.00	4.45		
Exercise	31.75	1.00	31.75	0.75	.40
Error	1059.80	25.00	42.39		
Sleep x Trial	4.30	1.00	4.30	0.72	.41
Error	150.38	25.00	6.02		
Trial x Exercise	19.24	1.00	19.24	4.32	.05[c]
Sleep x Exercise	18.39	1.00	18.39	3.54	.07
Sleep x Trial x Exercise	3.41	1.00	3.41	0.57	.46

Note. Significance was determined at an alpha level of .05.

[a] There was a significant (main effect) increase in performance from the no sleep condition to the sleep condition.

[b] There was a significant (main effect) increase in performance from the first trial to the second trial.

[c] There was a significant (two-way interaction) increase in performance from the no sleep condition to the sleep condition and first trial to the second trial.

not significant ($p > .05$). A significant main effect for sleep was found ($p < .05$): Stroop other congruent response time was faster in the sleep condition compared to the no sleep condition. This may indicate that the subjects were more alert than following the no sleep condition. A significant difference also was found for main effect trial ($p < .05$), which may indicate that there was a learning effect. No differences were found for main effect exercise ($p > .05$). The Stroop other congruent test response time descriptive data are shown in Table 16.

Stroop Test Other Incongruent

The Stroop other incongruent test presents a color-related word shown in a different color (i.e., blew; red). This test measures performance on Stroop interference. This is a similar measurement as incongruent except other incongruent are color-related words and incongruent are color words. The raw data for this test is presented in Appendix P for total correct in percent and Appendix Q for completion time. As shown in Table 17, the three-way interaction (sleep x trial x exercise) for Stroop other incongruent (% correct) was not significant ($p > .05$). The two-way interactions for sleep x exercise and for trial x exercise were not significant ($p > .05$). There were no significant differences found in the two-way interaction for sleep and trial. There were no significant differences in Stroop other incongruent (% correct) caused by the main effect of sleep ($p > .05$). There were no significant differences for main effect trial or the main effect of exercise ($p < .05$). The Stroop other incongruent test (% correct) descriptive data can be found in Table 18.

The following are the results for Stroop other incongruent response time. The three-way interaction (sleep x time x exercise) for response time was not significant

Table 16

Stroop Other Congruent Test Response Time (s) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	14.62	30.67	21.12	4.01
No Sleep Trial 2	14	14.02	22.42	18.76	2.61
Sleep Trial 1	14	13.16	24.41	18.15	3.28
Sleep Trial 2	14	12.77	22.46	17.31	3.25
Control Group					
No Sleep Trial 1	13	15.97	30.09	21.87	4.45
No Sleep Trial 2	13	14.15	24.06	18.53	3.29
Sleep Trial 1	13	12.64	30.68	21.27	5.61
Sleep Trial 2	13	12.78	22.45	18.02	3.31

Note. Data are times expressed in seconds.

Table 17

Stroop Other Incongruent Test (% Correct) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	93.53	1.00	93.53	2.31	.14
Error	1010.64	25.00	40.43		
Trial	0.76	1.00	0.76	0.02	.90
Error	1120.56	25.00	44.82		
Exercise	106.09	1.00	106.09	1.43	.24
Error	1852.83	25.00	74.11		
Sleep x Trial	14.79	1.00	14.79	0.27	.61
Error	1360.72	25.00	54.43		
Trial x Exercise	56.72	1.00	56.72	1.27	.27
Sleep x Exercise	64.15	1.00	64.15	1.59	.22
Sleep x Trial x Exercise	60.94	1.00	60.94	1.12	.30

Note. Significance was determined at an alpha level of .05.

Table 18

Stroop Other Incongruent Test (% Correct) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	91.67	100.00	97.58	2.72
No Sleep Trial 2	14	87.50	100.00	96.73	4.38
Sleep Trial 1	14	33.33	100.00	92.56	17.61
Sleep Trial 2	14	87.50	100.00	94.94	4.38
Control Group					
No Sleep Trial 1	13	87.50	100.00	98.08	3.65
No Sleep Trial 2	13	87.50	100.00	97.11	3.95
Sleep Trial 1	13	91.67	100.00	99.04	2.50
Sleep Trial 2	13	83.33	100.00	95.51	4.95

Note. Scores are percent correct.

($p > .05$) (Table 19). The two-way interaction sleep x exercise was not significant nor were differences found for the two-way interaction of trial x exercise ($p > .05$). There were also no significant differences found for other incongruent response time in the two-way interaction of sleep and trial. There were no significant findings for main effect exercise ($p > .05$). There was a significant finding for response time for main effect of sleep ($p < .05$). The total time to take the test was faster following normal sleep compared to sleep deprivation. This may indicate that the subjects were more attentive following normal sleep. The main effect trial was also significant ($p < .05$). The response time to take the test was faster in the second trial compared to the first, which may indicate that there was a learning effect. The main effect exercise was not significant ($p > .05$). The Stroop other incongruent test response time descriptive data are shown in Table 20.

Serial Arithmetic Analysis

The serial arithmetic test was used to assess the subject's ability to problem solve as accurately and quickly as possible. Percent correct and response time for the serial arithmetic test were recorded for each subject on the sleep and sleep deprived sessions. The test was administered immediately following the Stroop test and again 1 h later. Raw data for the serial arithmetic test can be found in Appendix R for percent correct and Appendix S for response time.

The following are the results of the serial arithmetic test (% correct). As shown in Table 21, the three-way interaction for sleep, time, and exercise was not significant ($p > .05$). There were no significant findings for the two-way interactions of sleep x exercise ($p > .05$), trial x exercise ($p > .05$), or sleep x trial ($p > .05$). There were also no

Table 19

Stroop Other Incongruent Test Response Time (s) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	97.93	1.00	97.93	14.02	.00[a]
Error	174.61	25.00	6.99		
Trial	50.40	1.00	50.40	10.11	.00[b]
Error	124.63	25.00	4.99		
Exercise	0.71	1.00	0.71	0.01	.91
Error	1234.68	25.00	49.39		
Sleep x Trial	1.23	1.00	1.23	0.37	.55
Error	82.64	25.00	3.31		
Trial x Exercise	7.54	1.00	7.54	1.51	.23
Sleep x Exercise	2.93	1.00	2.93	0.42	.52
Sleep x Trial x Exercise	0.00	1.00	0.00	0.00	.98

Note. Significance was determined at an alpha level of .05.

[a] There was a significant (main effect) increase in performance from the no sleep condition to the sleep condition.

[b] There was a significant (main effect) increase in performance from the first trial to the second trial.

Table 20

Stroop Other Incongruent Test Response Time (s) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	91.67	100.00	22.08	3.07
No Sleep Trial 2	14	87.50	100.00	21.04	3.59
Sleep Trial 1	14	33.33	100.00	19.64	3.28
Sleep Trial 2	14	87.50	100.00	19.01	3.49
Control Group					
No Sleep Trial 1	13	87.50	100.00	22.45	5.58
No Sleep Trial 2	13	87.50	100.00	20.33	3.96
Sleep Trial 1	13	91.67	100.00	20.66	4.66
Sleep Trial 2	13	83.33	100.00	18.98	4.14

Note. Data are times expressed in seconds.

Table 21

Serial Arithmetic Test (% Correct) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	0.67	1.00	0.67	0.02	.89
Error	720.42	25.00	28.82		
Trial	109.46	1.00	109.46	4.96	.04[a]
Error	551.29	25.00	22.05		
Exercise	263.17	1.00	263.17	0.44	.52
Error	15064.15	25.00	602.57		
Sleep x Trial	0.77	1.00	0.77	0.03	.86
Error	570.08	25.00	22.80		
Trial x Exercise	23.72	1.00	23.72	1.08	.31
Sleep x Exercise	82.23	1.00	82.23	2.85	.10
Sleep x Trial x Exercise	39.86	1.00	39.86	1.75	.20

Note. Significance was determined at an alpha level of .05.

[a] There was a significant (main effect) increase in performance from the first trial to the second trial.

significant differences for main effect sleep ($p >.05$) or main effect of exercise ($p > .05$). There was a significant difference for main effect trial ($p < .05$). The scores improved possibly due to a learning effect on the second trial. The serial arithmetic test (% correct) descriptive data are shown in Table 22.

The following are the results of the serial arithmetic test for response time. The three-way interaction for sleep, time, and exercise was not significant ($p > .05$) (Table 23). There were no significant findings in the two-way interactions of sleep x exercise ($p > .05$), trial x exercise ($p > .05$), or sleep x trial ($p > .05$). There were no significant differences for main effect sleep ($p >.05$) or main effect of exercise ($p > .05$). There was a significant difference in response time for main effect trial ($p < .05$). The total response time to complete the test was faster in the second trial compared to the first. This finding was probably due to a learning effect. The serial arithmetic test response time descriptive are shown in Table 24.

<u>Raven's Advanced Progressive Matrices Test Analysis</u>

The Raven's Advanced Progressive Matrices (RAPM) test was used to assess logical reasoning. This tests the subject's creativity and ability to recognize patterns. Percent correct and response time for the RAPM test was recorded for each subject on a night with sleep and a night of sleep deprivation. These data were collected immediately following the serial arithmetic test and again 1 h later. Raw data for this test can be found in Appendix T for percent correct and Appendix U for average response time.

For RAPM (% correct), the three-way interaction of sleep, trial, and exercise was not significant ($p > .05$) (Table 25). There were no significant findings found in the two-way interactions of sleep x exercise ($p > .05$), trial x exercise ($p > .05$), or sleep and trial

Table 22

Serial Arithmetic Test (% Correct) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	64.00	97.33	87.43	9.20
No Sleep Trial 2	14	70.67	100.00	91.43	7.24
Sleep Trial 1	14	74.66	100.00	90.38	7.73
Sleep Trial 2	14	65.33	100.00	92.29	8.39
Control Group					
No Sleep Trial 1	13	54.67	100.00	88.20	15.15
No Sleep Trial 2	13	49.33	97.33	87.90	16.41
Sleep Trial 1	13	37.33	100.00	85.23	17.30
Sleep Trial 2	13	44.00	98.67	87.69	17.91

Note. Scores are percent correct.

Table 23

Serial Arithmetic Test Response Time (s) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	0.01	1.00	0.01	0.00	1.00
Error	35979.32	25.00	1439.17		
Trial	15835.34	1.00	15835.34	37.32	0.00[a]
Error	10607.99	25.00	424.32		
Exercise	8404.37	1.00	8404.37	1.11	0.30
Error	188873.52	25.00	7554.94		
Sleep x Trial	80.78	1.00	80.78	0.28	0.60
Error	7179.59	25.00	287.18		
Trial x Exercise	596.82	1.00	56.82	1.41	0.25
Sleep x Exercise	591.28	1.00	591.28	0.41	0.53
Sleep x Trial x Exercise	15.03	1.00	15.03	0.05	0.82

Note. Significance was determined at an alpha level of .05.

[a] There was a significant (main effect) decrease in performance from the first trial to the second trial.

Table 24

Serial Arithmetic Test Response Time (s) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	148.39	294.40	221.33	49.32
No Sleep Trial 2	14	157.39	289.34	202.78	39.59
Sleep Trial 1	14	165.32	290.24	217.65	38.28
Sleep Trial 2	14	149.25	247.15	197.14	30.03
Control Group					
No Sleep Trial 1	13	154.75	412.87	238.26	66.75
No Sleep Trial 2	13	169.52	368.33	211.80	51.61
Sleep Trial 1	13	163.46	363.30	245.44	62.00
Sleep Trial 2	13	164.62	327.35	214.03	48.59

Note. Data are times expressed in seconds.

Table 25

RAPM[a] Test (% Correct) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	9.53	1.00	9.53	0.05	.83
Error	4783.46	25.00	191.34		
Trial	1993.09	1.00	1993.09	7.77	.01[b]
Error	6415.13	25.00	256.61		
Exercise	350.56	1.00	350.56	0.27	.61
Error	32556.95	25.00	1302.28		
Sleep x Trial	91.59	1.00	91.59	0.35	.56
Error	6579.56	25.00	263.18		
Trial x Exercise	235.39	1.00	235.39	0.92	.35
Sleep x Exercise	405.78	1.00	405.78	2.12	.16
Sleep x Trial x Exercise	413.03	1.00	413.03	1.57	.22

Note. Significance was determined at an alpha level of .05.

[a] RAPM = Raven's Advanced Progressive Matrices.

[b] There was a significant (main effect) decrease in performance from the first trial to the second trial.

($p > .05$). There were no significant differences found for main of effect sleep or the main effect of exercise ($p > .05$). There was a significant difference for main effect trial ($p < .05$). Interestingly, the subject's (% correct) scores went down after the first trial. This may be because the test was administered last and the subjects were not as motivated compared to the first test. The RAPM test (% correct) descriptive data are shown in Table 26.

The RAPM response time three-way interaction of sleep, trial, and exercise did not show a significant difference in response time ($p > .05$) (Table 27). There were no significant findings for the two-way interactions of sleep x exercise ($p > .05$), trial x exercise ($p > .05$), or sleep x trial ($p > .05$). There were no significant differences found in main effect sleep ($p > .05$) or main effect of exercise ($p > .05$). There was a significant difference in main effect trial ($p < .05$). The subjects completed the test faster in the second trial compared to the first trial. The RAPM test response time descriptive data are shown in Table 28.

Summary

The statistical information in this section presents the effect of low intensity exercise following two sleep conditions (sleep deprivation and normal sleep) on cognitive function. A summary of statistical results can be found in Table 29. Of note there was a significant difference by main effect trial for both percent correct and response time in most of the tests (Stroop, serial arithmetic, and RAPM). This may signify the need for more trial tests before conducting such a study to eliminate repeated bouts of a learning effect. In addition, the main effect of sleep was found to be significant in two subtests of the Stroop test. The subjects may have been more attentive following the normal night of

Table 26

RAPM[a] Test (% Correct) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	50.00	100.00	73.21	17.04
No Sleep Trial 2	14	33.00	92.00	65.50	17.83
Sleep Trial 1	14	33.33	100.00	67.86	20.63
Sleep Trial 2	14	16.67	91.67	64.29	30.03
Control Group					
No Sleep Trial 1	13	16.67	92.00	64.77	22.89
No Sleep Trial 2[b]	13	16.67	100.00	62.50	28.35
Sleep Trial 1	13	41.67	100.00	75.00	20.69
Sleep Trial 2[c]	13	8.33	91.67	63.89	23.12

Note. Scores are percent correct.

[a] RAPM = Raven's Advanced Progressive Matrices.

[b] One score not reported.

[c] One score not reported.

Table 27

RAPM[a] Response Time (s) ANOVA Summary Table

Source of Variation	SS	*df*	MS	*F*	*p*
Sleep	9154.67	1.00	1594.67	1.83	.19
Error	1098767.83	22.00	4943.99		
Trial	262762.50	1.00	262762.50	10.33	.00[b]
Error	559800.00	22.00	25445.46		
Exercise	145548.51	1.00	145548.51	2.69	.12
Error	1191813.99	22.00	54173.36		
Sleep x Trial	19259.00	1.00	19259.00	0.88	.36
Error	481103.50	22.00	21868.34		
Trial x Exercise	48262.50	1.00	48262.50	1.90	.18
Sleep x Exercise	36094.67	1.00	36094.67	0.72	.40
Sleep x Trial x Exercise	359.00	1.00	359.00	0.02	.90

Note. Significance was determined at an alpha level of .05.

[a] RAPM = Raven's Advanced Progressive Matrices

[b] There was a significant (main effect) decrease in performance from the first trial to the second trial.

Table 28

RAPM[a] Test Response Time (s) Descriptive Data

Test	N	Min	Max	Mean	SD
Exercise Group					
No Sleep Trial 1	14	120.00	960.00	475.71	212.41
No Sleep Trial 2	14	240.00	840.00	454.29	160.85
Sleep Trial 1	14	240.00	1200.00	527.14	256.92
Sleep Trial 2[b]	14	240.00	780.00	447.69	169.02
Control Group					
No Sleep Trial 1	13	300.00	900.00	540.00	189.74
No Sleep Trial 2[c]	13	120.00	660.00	430.00	159.43
Sleep Trial 1[d]	13	300.00	1080.00	665.00	235.12
Sleep Trial 2	13	360.00	840.00	503.08	139.73

Note. Data are times expressed in seconds.

[a] RAPM = Raven's Advanced Progressive Matrices.

[b] One score not reported.

[c] One score not reported.

[d] One score not reported.

Table 29

Summary of Statistical Results

Test	$S^a \times T^b \times E^c$	Two-Way Interactions S x E	T x E	S x T	Main Effects S	T	E
Stroop Test							
Neutral							
Percent	NS	NS	NS	NS	NS	NS	NS
Time	NS	NS	NS	NS	NS	*	NS
Congruent							
Percent	NS	NS	NS	NS	NS	*	NS
Time	NS	NS	NS	NS	NS	NS	NS
Incongruent							
Percent	NS	NS	NS	NS	NS	NS	NS
Time	NS	NS	NS	NS	NS	*	NS
Other Congruent							
Percent	NS	NS	NS	NS	NS	NS	NS
Time	NS	NS	*	NS	*	*	NS
Other Incongruent							
Percent	NS	NS	NS	NS	NS	NS	NS
Time	NS	NS	NS	NS	*	*	NS
Serial Arithmetic							
Percent	NS	NS	NS	NS	NS	*	NS
Time	NS	NS	NS	NS	NS	*	NS
RAPM[d]							
Percent	NS	NS	NS	NS	NS	*	NS
Time	NS	NS	NS	NS	NS	*	NS

Note. * $p < .05$. NS = not significant.

[a] S = sleep; [b] T = trial; [c] E = exercise; [d] RAPM = Raven's Advanced Progressive Matrices.

sleep compared to sleep deprivation. The RAPM test may have indicated by the significant finding for main effect trial that the order of the test administered could have a negative effect on performance.

Chapter 5

DISCUSSION

The purpose of this study was to investigate how low intensity exercise affects sleep deprivation induced cognitive deficit in college-aged students. Cognitive testing, following a night of total sleep deprivation and exercise, was used to analyze this relationship. This chapter contains a discussion of the results reported in chapter 4. Sections in this chapter include the following: (a) the effect of sleep on cognitive function, (b) the effect of exercise on cognitive function, (c) the effect of repeated trials on cognitive function, (d) practical application, and (e) summary.

Effect of Sleep on Cognitive Function

The results of the present study generally contradict that overall sleep deprivation has a significant negative effect on human cognitive performance. This is the first study to examine the effects of 24 h sleep deprivation on the Stroop test. According to the results the Stroop test has limited sensitivity to 24 h sleep deprivation. Only 2 of 10 Stroop dependent variables (other congruent and other incongruent) showed a significant sleep deprivation effect. Subjects were more alert with faster response times on these items following a night of normal sleep. The importance of these limited findings is questionable. There has been considerable debate in Stroop literature as to what represents an appropriate control (neutral) item (e.g., color patches, strings of symbols, pseudowords, or non-color name words) for measuring color-naming (Lindsay & Jacoby, 1994). The control items alone may have some interference with color naming (MacLeod, 1991) and the amount of interference is unclear. The mixed reviews on appropriate control items makes reasoning behind the present results difficult.

Following a night of sleep deprivation, the present study did not find the expected significant decrease on serial arithmetic performance predicted by limited previous literature (Drummond & Brown, 2001; Kjellberg, 1975; Thomas et. al. 2000). Thomas et al. (2000) found a significant reduction in cognitive performance on the Serial Add/Subtraction (Walter Reed Performance Assessment Battery) task to accuracy, speed, and correct responses/min following 24 h sleep deprivation. A difference between Thomas et al. and the present study is the monitoring of sleep schedules prior to experimental phase. Thomas et al. had subjects wear a wrist movement activity device for 7 to 10 days to document adherence to a nightly sleep schedule (7.45 h). Subjects then stayed at a research center for the residential portion of the study and the same sleep schedule was followed for two more days. In the present study, subjects kept a sleep and activity log for two weeks before testing and averaged 7.7 h sleep time. The same sleep and wake schedule for 10 to 13 days prior to the experimental phase, in the Thomas et al. (2000) study, may have provided subjects with optimal rest. Thus, sleep deprivation had a detrimental effect on subject's performance. The sleep and wake patterns, as documented in the sleep logs, in the present study were erratic which may explain why subjects' performance was not affected by one night of sleep deprivation.

Kjellberg (1975) found a lower standard of performance following sleep deprivation, provided that the task was such that subjects found failures acceptable. This study was similar to the present study in testing students following 24 h of sleep deprivation and a night of normal sleep. Moreover, Kjellberg was able to increase the measured sleep deprivation impairment in a second study by making adjustments to the testing protocol by using an easier problem solving task. In the present study, it was not feasible to conduct a second experiment following the first. As demonstrated by Kjellberg, the serial arithmetic task in the present study may have needed to be more difficult, or subjects could have been informed that it was not solvable. This was not done, and serial arithmetic testing in the present study did not prove to be sensitive to 24 h of sleep deprivation.

The results of the Raven's Advance Progressive Matrices test did not coincide with the findings of previous literature (Linde and Bergström, 1992). Presently, 24 h of sleep deprivation had no significant effects on RAPM performance. Linde and Bergström (1992) showed a significant decrease in the number of RAPM correct items as a function of one night of sleep loss. The same findings were obtained when the order of the test was reversed and sleep deprivation was increased from 24 h to 30 h. Linde and Bergstrom (1992) tested subjects for 1.5 h while the present study took 25 min to complete the battery of tests. Linde and Bergström (1992) suggested their results may have been due to sleep deprived subjects not being willing to spend time and effort on a difficult task. They found, however, that the sleep-deprived group and the control group left almost an equal number of items unsolved in the 20 min RAPM test. They also suggested that the decline in performance after sleep deprivation may be due to impairment in feature-selection functions rather than to mental computation functions. In other words, a lowered arousal may have been an important factor for the results. According to Yerkes and Dodson (1908), when arousal is low, performance will be poor. The subjects of the present study did not seem to be affected by poor arousal and performed well on the RAPM despite lack of sleep. Although both the previous and present study allowed subjects to play cards and watch movies during sleep deprivation, perhaps the activity performed through the night provided more stimulation to maintain arousal and cognitive performance in this study. Neither study reported a high level of control over this time period. Future studies in this area should more carefully control and report activities during the 24 h sleep deprivation period.

As indicated in a meta-analysis (Pilcher and Huffcutt, 1996), cognitive performance was considerably more decremented with restricted sleep of less than 5 h in a 24 h period than following long-term (> 45 hr) or short-term (≤ 45 hr) deprivation. However, previous research disagrees on the number of hours and days of sleep deprivation necessary for significant differences on cognitive, motor, and mood performance (Carskadon and Dement, 1981). In any event, it seems that 24 h of sleep deprivation causes a limited decrement in Stroop performance (other congruent and other incongruent response time), but generally the 24 h sleep deprivation used presently did not have a substantial negative impact on cognitive performance.

Effect of Exercise on Cognitive Function

The sleep intervention in the present study had only a nominal impact on cognitive function and when it did, exercise had no effect on cognitive function. Therefore the hypothesis that exercise can improve cognitive functioning after sleep deprivation could not be supported. Lichtman and Poser (1983) found exercise group scores significantly higher on the Stroop test after 45 min of jogging compared to a hobby (control) group. However, Litchman and Poser did not explain their intensity of exercise except that subjects jogged or did other physical activity exercises for 45 min. The present study had subjects perform low-intensity exercise for 20 min after a five minute warm-up. Sibley et al. (2006) found a small but significant improvement on the

Stroop test following a self-paced moderate-intensity run and/or walk for 20 min. In the Sibley et al. study, participants were instructed to select a moderately intense workload according to a rating perceived exertion scale, whereas the present study used low-intensity exercise (40% HRmax). Moreover, Sibley et al. used a negative priming condition to add an extra inhibitory influence which was not used in the Stroop test of the present study. Stroop performance of the present study may have been different if a longer exercise session and/or greater intensity were used. However, sleep deprivation was not a condition studied by Lichtman and Poser or Sibley et al., and even a longer exercise duration may have not produced desired results in the present study. Future studies on exercise with sleep deprivation should consider longer exercise durations.

The present results of the serial arithmetic test did not coincide with the findings by Heckler and Croce (1992). They found a significant improvement in response time on problem solving following 20 and 40 min of exercise by a fit group. Their low-fit group only showed an increase on math speed following 20 min of exercise. In the present study, exercise did not have a significant effect on performance of the serial arithmetic test. The exercise intensity of the previous study was equal to 70% of the subject's maximal age-predicted heart rate (~55% VO_2max), whereas this study was equal to low-intensity exercise (40% HRmax). A study by Sparrow and Wright (1993) had similar findings to the present study on arithmetic performance following exercise. Sparrow and Wright (1993) used 50 physically active men assigned to five groups of ten. The cognitive task was an arithmetic subtest of the Wechsler Adult Intelligence Scale-revised administered after a bench stepping exercise Three of the groups performed a bench stepping exercise at mean power outputs of 47 (low) , 72 (moderate), 100 (high) watts for six min at a cadence of 22.5 steps/min. Two other groups consisted of a bingo group and a non-activity group. No significant differences were found between groups. Their findings suggest that a short duration aerobic exercise has no effect on cognitive function. Further research on moderate-intensity and longer duration exercise effects following sleep deprivation may reveal different results then seen presently.

Etnier and his collegues (1997) indicated that an acute bout of exercise may not have a meaningful impact on cognition. In the present study, exercise did not have a significant effect on the RAPM test. The study by Sparrow and Wright (1993) also used the standard test of RAPM immediately following three intensities of bench stepping exercise. Similarly, there were no significant differences in RAPM performance following exercise. Sparrow and Wright (1993) proclaimed that exercise effects are specific to either the type of exercise or the cognitive task. Taken together, these results suggest that a low-intensity exercise may not stimulate arousal enough to produce an effect on RAPM performance.

There are mixed reviews on whether exercise does influence cognition. This is due to the variety of cognitive tests, subject population, and exercise protocol used, which makes reasoning behind the results difficult to determine. The intensity and/or duration of exercise in the present study may not have been enough to stimulate an affect on cognition. The exercise did not have a significant main effect on performance in all three cognitive tests. Furthermore, the present study did not meet the assumption that sleep deprivation would impair cognitive function. This, in combination with the lack of an exercise effect on cognition, makes it impossible to conclude that exercise impacts sleep-induced cognitive deficit.

Effect of Repeated Trials on Cognitive Function

The Stroop test generally showed a consistent trial effect particularly for response time. This may have been due to a learning effect since performance improved with familiarity on the test. Hogervorst et al. (1996) found a learning effect with Stroop neutral and congruent sub-tests. Response time was significantly longer before than after endurance exercise. The subjects in the Hogervorst et al. study were familiarized with the cognitive tests and procedures before the testing day, as done in the present study. The Sibley et al. (2006) study also found a practice effect in all three conditions (neutral, incongruent, and negative priming) used of the Stroop test. Subject's response time was significantly faster after the second testing session. Sibley et al. did not discuss a practice or familiarization of the Stroop test, which was implemented in the present study. On the other hand, Lichtman and Poser (1983) did not have a Stroop learning effect in either experimental or control groups. Interestingly, no practice or familiarization of the Stroop test prior to testing was described in their study.

The serial arithmetic test also showed a substantial trial effect for percent correct and response time. Sparrow and Wright (1993) also found a significant trial effect from pre to post test scores with improvement due to familiarity of an arithmetic test. No practice or familiarization prior to testing was described in their study. Thomas et al. (2000) had subjects pre-trained on the serial arithmetic test for three days for 25 min. On the third day, subjects practiced the serial arithmetic test again for 30 min in the afternoon. Heckler and Croce (1992) did not find a trial effect on the serial arithmetic test administered at baseline, 5 min, and 15 min post exercise. That study had subjects solve several practice sets of addition and subtraction problems on a computer. The present study may have needed more practice trials to hold learning constant.

The RAPM test also showed a trial effect for both percent correct and response time. Time to complete the test was faster; however, the percent correct worsened on the second trial for both exercise and control groups. This may have been due to the fact that this test was taken last, and the subjects may have lost interest. They were interested simply in completing the test as soon as possible. The study by Linde and Bergström (1992) did not find a learning effect on RAPM after providing 12 training items of the RAPM right before taking the test. Subjects in the present study were familiarized with RAPM items at night before being tested in the morning and these trials may not have been intense or recent enough to ensure subject familiarization.

Practical Application

The reason for this study was to assess whether low intensity exercise would improve cognitive performance following 24 h of sleep deprivation. For example, if a college student stayed up all night to study for an exam, would some exercise (e.g., a walk) the next day improve the cognitive deficit expected from sleep loss? This study did not support the assumption that sleep deprivation impairs cognitive function. In the absence of a sleep deprivation effect, the hypothesis claiming that low intensity exercise would have a positive effect on cognitive performance could not be adequately tested. These findings do not imply that cognitive performance is not hindered by sleep deprivation, but the 24 h sleep deprivation used in the study did not impact the specific cognitive challenges presented. Future studies on exercise of college-aged males should use alternative means of sleep deprivation, and cognitive challenge, to ensure a sleep loss effect on cognitive function.

Summary

In summary, this chapter discussed the effect of sleep deprivation and low-intensity exercise on cognitive performance. The sleep intervention had only nominal impact on cognitive function, and subsequent exercise had no clear beneficial effects. These findings question the nature of sleep deprivation needed to impair cognitive performance among college-aged males. Without seeing a negative effect from sleep deprivation, the current study was unable to better determine the effects of exercise under these conditions. However, the findings of this study may have been influenced by the duration and intensity of the exercise, difficulty of test, and/or the subject population. The possible learning effect observed may have been prevented by implementing a longer practice session to better familiarize subjects to the cognitive tests. Alternatively, keeping subjects motivated throughout all testing sessions may be another factor of concern for sleep deprivation studies. It is difficult to speculate what the effect of exercise might have been if a sleep deprivation-induced cognitive deficit had occurred. Future research is necessary to determine if exercise can help the effects of sleep deprivation when it occurs.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to investigate how low intensity exercise affects sleep deprivation induced cognitive deficit in college-aged students. Subjects were males (N = 27) aged 18-26 years who participated in three testing sessions. The first session was a maximal treadmill test to measure VO_2max. Information from this maximal test was used to select the exercise intensity (40% HRmax) for exercise during the data collection sessions. The subjects were randomly divided into the exercise and non-exercise groups. The next two sessions cognitively assessed subjects following a night of normal sleep and a night of sleep deprivation. The subjects were tested following the exercise or non-exercise activity and then again one hour later.

Descriptive statistics and analysis of variance (ANOVA) were used to analyze the dependent variables (Stroop test, serial arithmetic test, and the Raven's Advanced Progressive Matrices). A three-way ANOVA (2 x 2 x 2) with repeated measures on two factors (sleep and trial) was used to investigate the effects of exercise and sleep deprivation on cognitive performance. Results showed that neither exercise nor sleep consistently and significantly affect cognitive performance. Sleep (main effect) had an effect on two Stroop subtests but no impact on the 12 other dependent variables. The most consistent finding was that trial (main effect) improved cognitive performance. In other words, a learning effect and faster performance was observed for most of the tests on the second trial.

Conclusions

The results of the study support the following conclusions:

1. Sleep deprivation (24 h) in college-aged males did not have an affect on cognitive performance as measured in this study.
2. Low intensity exercise (40% HRmax) in college-aged males did not affect cognitive performance as measured in this study.
3. Trial did consistently affect cognitive performance as measured in this study. A longer practice session or greater control over participant motivation may help to prevent this testing effect.

Recommendations for Further Study

This investigation leads to these recommendations for further study:

1. Use of a higher intensity of exercise may stimulate arousal that will differently influence cognitive function.
2. Use of alternative testing procedures that challenge the subjects cognitive performance and may be more sensitive to 24 h sleep deprivation
3. Use of a longer practice session for the cognitive tests to better familiarize subjects and prevent a learning effect.
4. Use of restricted sleep (five hours or less) to determine whether a greater effect is seen on cognitive performance than with 24 h sleep deprivation.

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APPENDIX A

INFORMED CONSENT FORM

Influence of Exercise upon Sleep Induced Cognitive Deficits among College-Aged Students

1. Purpose of Study

The purpose of this study is to determine the influence of exercise and sleep deprivation on cognitive function. Many college students are experiencing a reduction in sleep as a consequence of a variety of behavioral factors (e.g., academic, social, and employment responsibilities). Cognitive tasks required for optimal academic performance such as planning, strategy, or complex sequences of activities are more difficult following sleep deprivation. Therefore, this study is being conducted to determine how exercise affects sleep-induced cognitive deficit.

2. Benefits of the Study

By participating in the study you will learn your maximum level of oxygen consumption (VO_2max). VO_2max is commonly used index of cardiorespiratory training status and a test which can normally cost hundreds of dollars. However, the primary goal of this study is to expand the current knowledge base on the effects of sleep deprivation and exercise on cognitive function. This information may also benefit those that work in environments that demand high standards of performance (e.g., pilots and doctors). As a participant, you are welcome to have a copy of the results once the study is completed (contact information can be found on the following page).

3. What You Will Be Asked to Do

If you agree to participate you will be involved in three testing sessions. The study will be explained to you and if you are in good health and do not rely on tobacco, alcohol, or other drugs, including caffeinated products that prohibit participation, you can sign this informed consent form. The total participation time in the study will be approximately 21h. The first testing session will involve a VO_2max test in the Exercise Physiology Laboratory. This test will require you to run on a treadmill at a self selected speed with the incline increasing every two minutes. The test will be terminated when you feel you can no longer continue (approximately 10-15 min). During the test you will be required to wear a headgear device with a breathing valve so that we can measure your expired gases. Your heart rate and breathing will be monitored throughout the test. The VO_2max test session will take approximately 1h. You will also be asked to keep a sleep/activity log for two weeks to obtain information concerning your daily sleeping/activity cycles.

*Initial*____

The two subsequent testing sessions will also take place in the Exercise Physiology Laboratory. One testing session will involve some cognitive testing following a normal night of sleep and the other session will involve assessment following sleep deprivation. To ensure you obtain 24h of sleep deprivation, you will be asked to report your wake-up time of the previous morning and to avoid taking naps on the day of data collection. You will be randomly assigned to either a low or moderate exercise intensity condition. Within each condition, you will be randomly assigned into either group A or group B. On the first night you will be required to report to the lab for cognitive test familiarization, and refreshments will be provided. On the night of sleep deprivation you will have the opportunity to engage in non-exercise activities (e.g., watching movies, playing games, or socializing) and be provided with a snack. You will remain awake all night. If you happen to fall asleep, a researcher will awaken you by getting your attention, such as tapping or calling your name. The researcher will then be more attentative to you, to ensure you remain awake. The morning testing session will include a 20 min bout of exercise for group A followed by cognitive assessments. Group B will participate in a recreational activity, such as playing catch and cognitive assessment thereafter. The cognitive assessment is a battery of three tests that takes around 50 min. .

On the night of normal sleep you will be asked to return home to sleep in your own bed, but must report to the lab the following morning for testing. The same morning procedures will be conducted as the first testing session. Total participation time during each session will be 5h with normal sleep and 15h with sleep deprivation.

4. Risks

The risks of participating in this study are minimal but include standard risks associated with physical activity. These include injury, fatigue, soreness, musculoskeletal injury, or cardiac event. You may feel tired or fatigued during the exercise sessions and may experience soreness 24 to 48 h following the sessions. You may also experience feelings of fatigue, sleepiness, or a decrease of motivation or cognitive function following the sleep deprivation testing day. However, sleep deprivation symptoms can be alleviated with sleep. No special medical arrangements have been made regarding your participation in this study. In the event that your participation in this research results in injury, standard first aid will be provided and appropriate emergency personnel will be contacted.

5. Compensation for Injury

There is no compensation available for injury; you are responsible for all medical costs.

6. If You Would Like More Information about the Study

For more information at any time prior to, during, or after the study contact either Erica Anderson at (315) 269-3775, e-mail: eanders2@ithaca.edu; Thomasita Collins at (607) 256-2059, e-mail: tcollin2@ithaca.edu; Dr. King at (607) 274-1479, email: dking@ithaca.edu, Dr. Sforzo at (607) 274-3359, e-mail: sforzo@ithaca.edu, or Dr. Swensen at (607) 274-3114, e-mail: tswensen@ithaca.edu.

*Initial*____

7. Withdrawal from the Study
I understand that I may stop participating or withdraw from this study at any time without any reasoning or penalty. If I withdraw, any of my data collected will be discarded and will not be used in the study.

8. How the Data will be Maintained in Confidence
All data collected will be confidential. Any data files will be kept in the Graduate Studies office at Ithaca College, which is a secure room with lockable cabinets. Computer files will be accessed through a password known only by the investigators. Your data will be identified by alphanumeric code. Only the investigators will have access to this code. Your name will not be used in reports connected with any part of this study.

I have read and understood the above document. I agree to participate in this study and realize that I can withdraw at anytime. I understand that I can and should address questions related to this study at any time to the researchers involved. I acknowledge that I am 18 of age or older. I have received a copy of this consent form for my own records.

Name of Subject (PRINT):________________________________

Signature of Subject (SIGN): _______________________________

Date: __________

*Initial*____

APPENDIX B

MEDICAL HISTORY FORM

Name: ______________________________________ ID Number ______________
(Last, First)

DOB: _____/_____/_____ Height __________ *Ft./In.* Weight__________ *Lbs.*

Address: ____
street *city* *state* *zip*

Phone # : ( ) - ________ Email Address: ______________________

Academic Year: FR SO JR SR
(circle one)

Family History: Check if any blood relatives (parents, siblings, etc.) ever had any of the following:

_____ Heart Disease
_____ Diabetes
_____ High Cholesterol
_____ Stroke
_____ High Blood Pressure

Other Conditions or Comments:

____
____
____

Medical History:
If you have ever experienced or been diagnosed with any of the following please place an "X" next to that item.

_____ Heart Disease
_____ Lung Disease
_____ Stroke
_____ Chest Pain
_____ Heart Murmur
_____ Asthma
_____ Diabetes
_____ Anxiety
_____ Allergies
_____ Cancer
_____ Thyroid
_____ High Blood Pressure
_____ High Cholesterol
_____ Ulcers
_____ Hypoglycemia
_____ Headaches
_____ Eating disorders
_____ Learning Problems
_____ Sleep Disorders
_____ Muscle Weakness
_____ Memory Problems
_____ Shortness of Breath
_____ Skipped Beats/Irregular rhythms
_____ Hearing problems/Deafness
_____ Lightheadedness/fainting
_____ Loss of Consciousness
_____ Bone/Joint Problems
_____ Musculoskeletal Problems
_____ Gait Unsteadiness
_____ Ankle/Leg swelling
_____ Injuries to back, hip, knees, or ankles
_____ Major surgery of any kind

Please List Any Additional Health Conditions or Comments:

____
____
____

Present Symptoms: Have you recently (within last few months) had any of the following:

_____ Chest Pain
_____ Shortness of Breath
_____ Lightheadedness
_____ Blood Clots
_____ Heart Palpitations
_____ Loss of Consciouness
_____ Ankle/Leg Swelling
_____ Joint/Muscle Pain
_____ Illness/Hospitalization/Injury
_____ Abnormal ECG/GXT Test

Other Conditions/Comments:

____
____
____

List all prescribed and over-the-counter medication currently taking:

____
____
____
____

Health Habits

Smoking History:

Do You Smoke? _____ Yes _____ No _____ Quit _____ Never

What do (did) you smoke? _____ Cigarettes _____ Pipe _____ Cigars _____ Chewing Tobacco

Amount per day? ______________________________

How long have (had) you been smoking? ______________________________

If you quit, when? ______________________________

Alcohol Consumption:

Do you presently consume any alcohol? _____Yes _____ No

If yes, what? ______________________________

Number of drinks per week? ______________________________

Caffiene Consumption:

Do you presently consume any caffiene? _____ Yes _____ No

If yes, what? ______________________________

Amount per day? ______________________________

Exercise Habits:
Have you ever been told by a physician that you shouldn't exercise? _____Yes _____No

Level of Current Physical Activity:
_____ Sedentary (Do Not Exercise)
_____ Mild Exercise (i.e. climb stairs, walk, golf)
_____ Occasional Exercise (≤ 3x/week for 30 minutes)
_____ Regular Exercise (> 3x/week for 30 minutes)
_____ Heavy Exercise (>3x/week in excess of 30 minutes)

Type of Exercise: ____________________
Frequency: ____________________
Intensity: _____ Light _____ Moderate _____ Heavy
Duration: ____________________

Do you have discomfort, shortness of breath, or pain with exercise? _____Yes _____No
If yes, what type of pain and what type of exercise?
____
____
____

Sleep:
On average, how many hours of sleep do you get per night? ____________________
Is your sleep sound? _____Yes _____No
If no, describe:
____
____
____

Additional Pertinent Information:
____
____
____

Signature____________________ Date__________

APPENDIX C

DAILY SLEEP/ACTIVITY LOG

ID Number: ______________________________ Date: ___________________________

Please record information every day for two weeks. Try to be as accurate as possible. When uncertain, please give your best estimate. Thank you!

1. What exercise did you do?

	Exercise:	Exercise Intensity:	How long:	Time of day:
S				
M				
T				
W				
Th				
F				
Sa				

2. How many caffeinated or alcoholic beverages did you consume?

	Beverage:	Amount:	Time of day:
S			
M			
T			
W			
Th			
F			
Sa			

3. How many cigarettes did you smoke?

	Number of cigarettes:	Time of day:
S		
M		
T		
W		
Th		
F		
Sa		

4. What medications or supplements* did you take?
   *(*e.g., Creatine, Twin Lab products, Glucosamine, etc.)*

	Medication/Supplements:	Dosage:	Time of day:
S			
M			
T			
W			
Th			
F			
Sa			

5. What time did you go to bed and wake up?

	Bedtime:	Time took to fall asleep (min):	Wake up time:
S			
M			
T			
W			
Th			
F			
Sa			

6. Did you wake up during the night?

	How many times you woke up:	Time you woke up:	What woke you up:	How long were you awake:
S				
M				
T				
W				
Th				
F				
Sa				

7. How would you rate the quality of your sleep? Please check the one that applies

	1 Poor/Disturbed	2	3 Fair	4	5 Good/Solid
S					
M					
T					
W					
Th					
F					
Sa					

8. In general, how was your alertness and performance during the day? (e.g., energetic, fatigue, etc.)

	Describe alertness and/or performance:	# of naps:	Time of day:
S			
M			
T			
W			
Th			
F			
Sa			

9. Other comments or observations:

APPENDIX D

24-HOUR HISTORY

ID NUMBER ______________________________ Date: ___________________________

HOW MUCH SLEEP DID YOU GET LAST NIGHT? (please circle one)

1 2 3 4 5 6 7 8 9 10 11 12 hours

HOW MUCH SLEEP DO YOU NORMALLY GET? (please circle one)

1 2 3 4 5 6 7 8 9 10 11 12 hours

HOW LONG HAS IT BEEN SINCE YOUR LAST MEAL OR SNACK? (please circle one)

1 2 3 4 5 6 7 8 9 10 11 12 hours

LIST ITEMS EATEN BELOW:

____

WHEN DID YOU LAST:
Have a cup of coffee, tea, or other caffeine product

____

Smoke a cigar, cigarette, pipe, or use chewing tobacco

____

Take drugs (including aspirin) ____________________

Drink alcohol ___________________________________

Have an illness _________________________________

Suffer from respiratory problems

____

WHAT SORT OF PHYSICAL EXERCISE DID YOU PERFORM YESTERDAY?

WHAT SORT OF PHYSICAL EXERCISE DID YOU PERFORM TODAY?

DESCRIBE YOUR GENERAL FEELINGS BY CHECKING ONE OF THE FOLLOWING:

____ Excellent
____ Very, Very Good
____ Very Good
____ Neither Bad or Good

___ Bad
___ Very Bad
___ Very, Very Bad
___ Terrible

APPENDIX E

SAMPLE OF STROOP TEST

Description: The Stroop test is a computerized test that is divided into sub-sections. These are Neutral (different word presented in a different color); Congruent (color word presented in the same color); Incongruent (color word presented in a different color); Other Congruent (color-related word in the same color (e.g., blew; blue, greed; green, and read; red); Other Incongruent (color-related word presented in a different color (e.g., blew; red). This test is timed to determine speed performance and percent correct was evaluated.

Sample of Stroop Test: The customized computer program generated randomly colored words that were highlighted in red, green, or blue, which the subject were to depress number 1, 2, or 3 respectively, on the number key pad in response to the color highlighted.

RED	**ORANGE**
YELLOW	**BLUE**
GREEN	**RED**
ORANGE	**YELLOW**
BLUE	**GREEN**
GREEN	**BLUE**
YELLOW	**ORANGE**
RED	**GREEN**
BLUE	**RED**
ORANGE	**YELLOW**

APPENDIX F

SAMPLE OF SERIAL ARITHMETIC TEST

Description: The serial arithmetic test is a computerized test that consists of serial addition/subtraction tasks. The test is timed to determine speed performance and percent correct was evaluated.

Sample of serial addition/subtraction task: This task consists of two randomly generated digits followed by either a plus or minus sign. The subject performs the indicated addition or subtraction and enters the least significant digit of the result (e.g., 8 + 6 equals 14 so, subject enters 4). If the result is negative the subject adds 10 and enters the positive single digit remainder (e.g., 3 – 9 = -6, so the subject enters 4).

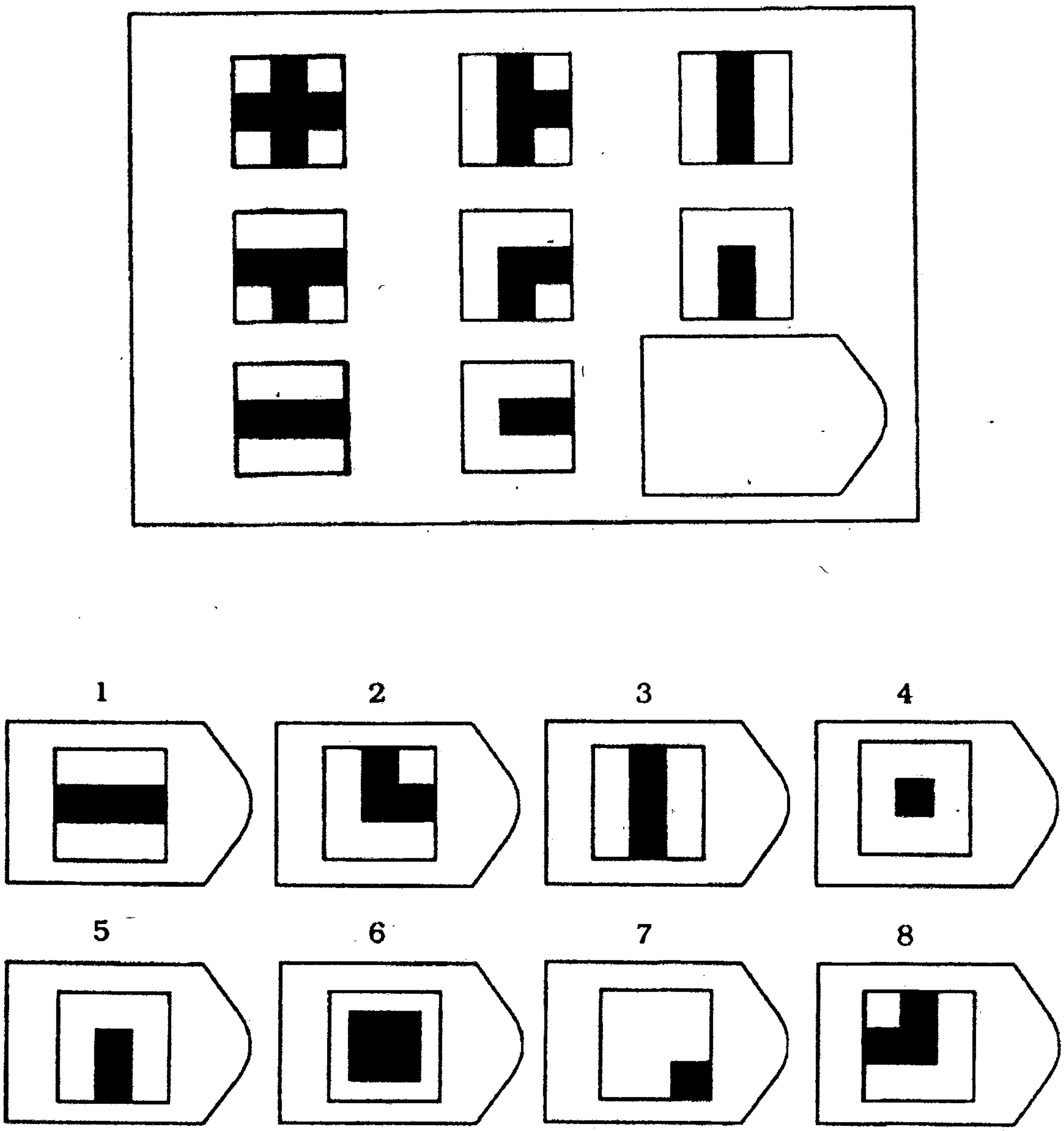
8 + 5 = _____	3 + 9 = _____	3 + 6 = _____	7 + 5 = _____
2 + 6 = _____	4 + 8 = _____	7 + 8 = _____	9 + 9 = _____
3 – 9 = _____	8 – 6 = _____	5 – 7 = _____	4 – 2 = _____
7 – 8 = _____	1 – 5 = _____	9 – 3 = _____	2 – 6 = _____

APPENDIX G

SAMPLE OF RAPM TEST

Description: The Raven's Advanced Progressive Matrices is a written test. The test was timed to determine speed performance and percent correct was evaluated.

Sample of Raven's Advanced Progressive Matrices: The test consists of two sets: set I contains 12 problems; set II contains 36 problems arranged in ascending order of difficulty. Each problem contains a missing piece that is to be identified by a set of alternative pieces to complete the figure.



APPENDIX H

RAW DATA: STROOP (NEUTRAL % CORRECT)

Subject #	SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1 No Exercise	100.00	100.00	95.83	100.00
2 No Exercise	100.00	100.00	100.00	91.67
3 No Exercise	100.00	100.00	100.00	100.00
4 No Exercise	100.00	100.00	100.00	100.00
5 No Exercise	95.83	95.83	100.00	100.00
6 No Exercise	100.00	100.00	100.00	95.83
7 No Exercise	100.00	100.00	70.83	100.00
8 No Exercise	100.00	100.00	100.00	100.00
9 No Exercise	91.67	91.67	100.00	100.00
10 No Exercise	100.00	95.83	66.67	100.00
11 No Exercise	100.00	100.00	100.00	100.00
12 No Exercise	100.00	100.00	100.00	100.00
13 No Exercise	83.33	95.83	100.00	100.00
14 Exercise	95.83	95.83	100.00	95.83
15 Exercise	100.00	100.00	100.00	100.00
16 Exercise	100.00	100.00	91.67	100.00
17 Exercise	100.00	100.00	100.00	95.83
18 Exercise	95.83	100.00	100.00	100.00
19 Exercise	100.00	100.00	100.00	100.00
20 Exercise	83.33	95.83	100.00	100.00
21 Exercise	100.00	100.00	95.83	100.00
22 Exercise	100.00	91.67	100.00	100.00
23 Exercise	37.50	100.00	100.00	95.83
24 Exercise	95.83	100.00	95.83	100.00
25 Exercise	95.83	95.83	95.83	95.83
26 Exercise	100.00	100.00	95.83	100.00
27 Exercise	100.00	100.00	100.00	95.83

Note. Data are expressed in percent correct.

[a] SD T1 = sleep deprivation trial 1;

[b] SD T2 = sleep deprivation trial 2;

[c] S T1 = sleep trial 1; and

[d] S T2 = sleep trial 2.

APPENDIX I

RAW DATA: STROOP (NEUTRAL RESPONSE TIME)

Subject #	SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1 No Exercise	32.44	21.74	27.81	19.97
2 No Exercise	27.05	21.78	35.54	21.23
3 No Exercise	18.47	15.22	16.93	15.56
4 No Exercise	18.67	14.12	21.76	13.34
5 No Exercise	26.88	22.81	24.32	21.03
6 No Exercise	19.50	20.30	18.19	19.62
7 No Exercise	22.04	21.73	26.05	22.44
8 No Exercise	30.92	19.97	22.08	14.95
9 No Exercise	15.59	18.20	25.88	16.94
10 No Exercise	20.50	21.31	36.16	27.77
11 No Exercise	15.82	12.22	22.79	16.00
12 No Exercise	20.00	15.01	17.87	13.81
13 No Exercise	20.46	14.98	20.02	15.31
14 Exercise	18.96	13.45	17.52	13.88
15 Exercise	15.78	20.44	21.13	16.41
16 Exercise	19.98	20.96	24.07	24.81
17 Exercise	15.07	13.94	26.53	14.37
18 Exercise	28.22	20.06	20.32	15.59
19 Exercise	20.00	20.58	17.08	15.29
20 Exercise	23.20	19.00	23.21	17.08
21 Exercise	28.41	16.94	20.21	14.09
22 Exercise	23.11	26.28	21.35	18.21
23 Exercise	26.18	14.30	20.55	15.43
24 Exercise	18.39	12.87	18.00	12.98
25 Exercise	23.14	15.56	28.56	21.25
26 Exercise	28.34	18.79	15.42	17.94
27 Exercise	15.83	17.15	20.48	23.10

Note. Data are expressed in seconds for time.

[a] SD T1 = sleep deprivation first trial;

[b] SD T2 = sleep deprivation second trial;

[c] S T1 = sleep first trial; and

[d] S T2 = sleep second trial.

APPENDIX J

RAW DATA: STROOP (CONGRUENT % CORRECT)

Subject #		SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1	No Exercise	91.67	100.00	95.83	100.00
2	No Exercise	83.33	100.00	91.67	100.00
3	No Exercise	100.00	100.00	100.00	100.00
4	No Exercise	100.00	95.83	100.00	100.00
5	No Exercise	95.83	100.00	100.00	100.00
6	No Exercise	100.00	95.83	100.00	100.00
7	No Exercise	95.83	100.00	91.67	95.83
8	No Exercise	100.00	100.00	100.00	100.00
9	No Exercise	95.83	100.00	100.00	100.00
10	No Exercise	62.50	95.83	100.00	95.83
11	No Exercise	100.00	100.00	100.00	100.00
12	No Exercise	100.00	100.00	100.00	100.00
13	No Exercise	100.00	100.00	100.00	100.00
14	Exercise	100.00	95.83	95.83	100.00
15	Exercise	100.00	95.83	100.00	100.00
16	Exercise	100.00	100.00	100.00	100.00
17	Exercise	100.00	100.00	100.00	100.00
18	Exercise	100.00	95.83	95.83	95.83
19	Exercise	95.83	100.00	95.83	100.00
20	Exercise	100.00	100.00	100.00	100.00
21	Exercise	100.00	100.00	95.83	100.00
22	Exercise	100.00	95.83	100.00	100.00
23	Exercise	33.33	83.33	87.50	100.00
24	Exercise	100.00	100.00	100.00	100.00
25	Exercise	75.00	95.83	100.00	87.50
26	Exercise	95.83	100.00	95.83	95.83
27	Exercise	100.00	100.00	95.83	100.00

Note. Data are expressed in percent correct.

[a] SD T1 = sleep deprivation trial 1;

[b] SD T2 = sleep deprivation trial 2;

[c] S T1 = sleep trial 1; and

[d] S T2 = sleep trial 2.

APPENDIX K

RAW DATA: STROOP (CONGRUENT RESPONSE TIME)

Subject #	SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1 No Exercise	23.92	21.06	22.04	15.96
2 No Exercise	28.36	19.32	20.52	20.49
3 No Exercise	15.85	12.95	15.58	13.79
4 No Exercise	19.82	17.54	14.71	13.58
5 No Exercise	24.76	16.35	25.32	19.16
6 No Exercise	22.29	17.92	17.41	17.93
7 No Exercise	31.81	24.09	26.54	35.65
8 No Exercise	26.74	24.97	18.82	15.19
9 No Exercise	13.81	17.80	18.23	15.90
10 No Exercise	23.96	19.27	29.51	28.09
11 No Exercise	16.69	14.70	15.77	18.06
12 No Exercise	17.08	15.88	13.46	11.96
13 No Exercise	15.04	12.93	22.87	15.42
14 Exercise	17.90	12.61	17.41	12.25
15 Exercise	16.05	15.41	19.10	19.72
16 Exercise	20.34	19.34	24.79	24.14
17 Exercise	14.81	12.39	18.74	20.06
18 Exercise	23.78	20.57	18.99	21.50
19 Exercise	14.46	13.41	14.85	13.59
20 Exercise	16.39	14.73	16.96	14.44
21 Exercise	30.68	19.10	23.87	13.27
22 Exercise	22.64	24.27	21.99	20.05
23 Exercise	14.72	18.20	19.58	15.29
24 Exercise	19.96	13.60	16.13	12.83
25 Exercise	17.15	15.69	20.93	18.80
26 Exercise	24.08	17.85	14.07	15.96
27 Exercise	16.53	18.74	21.94	18.62

Note. Data are expressed in seconds for time.

[a] SD T1 = sleep deprivation trial 1;

[b] SD T2 = sleep deprivation trial 2;

[c] S T1 = sleep trial 1; and

[d] S T2 = sleep trial 2.

APPENDIX L

RAW DATA: STROOP (INCONGRUENT % CORRECT)

Subject #	SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1 No Exercise	100.00	100.00	100.00	100.00
2 No Exercise	95.83	95.83	93.33	95.83
3 No Exercise	100.00	100.00	95.83	95.83
4 No Exercise	100.00	95.83	100.00	100.00
5 No Exercise	100.00	91.67	100.00	100.00
6 No Exercise	100.00	95.83	95.83	95.83
7 No Exercise	95.83	95.83	100.00	100.00
8 No Exercise	100.00	100.00	100.00	100.00
9 No Exercise	95.83	100.00	95.83	100.00
10 No Exercise	83.33	91.67	58.33	100.00
11 No Exercise	100.00	95.83	91.68	100.00
12 No Exercise	100.00	95.83	95.83	100.00
13 No Exercise	100.00	100.00	100.00	91.67
14 Exercise	91.67	100.00	95.83	100.00
15 Exercise	91.67	100.00	95.83	91.67
16 Exercise	100.00	100.00	100.00	100.00
17 Exercise	95.83	100.00	100.00	100.00
18 Exercise	87.50	100.00	100.00	95.83
19 Exercise	100.00	100.00	83.33	100.00
20 Exercise	95.83	91.67	100.00	100.00
21 Exercise	100.00	100.00	100.00	100.00
22 Exercise	100.00	95.83	100.00	100.00
23 Exercise	37.50	87.50	83.33	75.00
24 Exercise	91.67	100.00	100.00	100.00
25 Exercise	95.83	100.00	91.67	91.67
26 Exercise	100.00	100.00	95.83	87.50
27 Exercise	100.00	91.67	100.00	100.00

Note. Data are expressed in percent correct.

[a] SD T1 = sleep deprivation trial 1;

[b] SD T2 = sleep deprivation trial 2;

[c] S T1 = sleep trial 1; and

[d] S T2 = sleep trial 2.

APPENDIX M

RAW DATA: STROOP (INCONGRUENT RESPONSE TIME)

Subject #		SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1	No Exercise	22.83	20.76	25.81	23.91
2	No Exercise	26.12	21.20	29.71	52.22
3	No Exercise	18.55	16.27	22.05	17.99
4	No Exercise	21.28	19.04	21.79	23.19
5	No Exercise	37.62	26.88	31.66	25.57
6	No Exercise	20.78	22.67	19.82	21.02
7	No Exercise	31.12	24.46	28.91	29.40
8	No Exercise	26.32	21.95	27.25	19.78
9	No Exercise	19.30	21.32	20.17	18.84
10	No Exercise	23.09	21.37	30.89	24.99
11	No Exercise	18.34	17.43	26.06	16.14
12	No Exercise	19.65	20.70	18.10	13.80
13	No Exercise	20.58	15.73	23.03	17.46
14	Exercise	17.95	15.63	16.66	15.60
15	Exercise	24.86	16.62	22.82	25.66
16	Exercise	23.96	25.42	25.85	26.45
17	Exercise	17.79	18.30	15.35	19.92
18	Exercise	23.26	22.83	20.13	25.92
19	Exercise	20.20	18.50	21.30	15.39
20	Exercise	27.92	26.83	25.41	24.88
21	Exercise	22.77	20.45	22.16	20.20
22	Exercise	32.56	23.50	22.28	25.19
23	Exercise	21.17	16.68	23.38	20.74
24	Exercise	21.69	15.89	17.22	16.12
25	Exercise	24.04	20.53	31.19	28.16
26	Exercise	26.28	20.47	23.47	22.43
27	Exercise	21.59	24.26	24.22	32.39

Note. Data are expressed in seconds for time.

[a] SD T1 = sleep deprivation trial 1;

[b] SD T2 = sleep deprivation trial 2;

[c] S T1 = sleep trial 1; and

[d] S T2 = sleep trial 2.

APPENDIX N

RAW DATA: STROOP (OTHER CONGRUENT % CORRECT)

Subject #	SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1 No Exercise	95.83	100.00	100.00	100.00
2 No Exercise	100.00	100.00	100.00	95.83
3 No Exercise	100.00	100.00	95.83	100.00
4 No Exercise	100.00	100.00	100.00	100.00
5 No Exercise	100.00	100.00	95.83	100.00
6 No Exercise	95.83	100.00	70.83	100.00
7 No Exercise	100.00	100.00	95.83	83.33
8 No Exercise	100.00	100.00	100.00	100.00
9 No Exercise	91.67	91.67	95.83	100.00
10 No Exercise	54.17	100.00	87.50	91.67
11 No Exercise	100.00	100.00	100.00	100.00
12 No Exercise	100.00	100.00	100.00	100.00
13 No Exercise	95.83	95.83	95.83	100.00
14 Exercise	100.00	91.67	100.00	100.00
15 Exercise	95.83	100.00	95.83	100.00
16 Exercise	100.00	100.00	100.00	95.83
17 Exercise	100.00	100.00	100.00	100.00
18 Exercise	100.00	100.00	100.00	100.00
19 Exercise	95.83	100.00	100.00	100.00
20 Exercise	91.67	100.00	95.83	100.00
21 Exercise	100.00	100.00	100.00	100.00
22 Exercise	95.83	100.00	100.00	100.00
23 Exercise	98.83	100.00	33.33	87.50
24 Exercise	95.83	100.00	100.00	100.00
25 Exercise	100.00	100.00	100.00	87.50
26 Exercise	100.00	91.67	100.00	95.83
27 Exercise	100.00	100.00	95.83	100.00

Note. Data are expressed in percent correct.

[a] SD T1 = sleep deprivation trial 1;

[b] SD T2 = sleep deprivation trial 2;

[c] S T1 = sleep trial 1; and

[d] S T2 = sleep trial 2.

APPENDIX O

RAW DATA: STROOP (OTHER CONGRUENT RESPONSE TIME)

Subject #	SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1 No Exercise	28.57	21.01	19.13	19.40
2 No Exercise	20.09	21.48	27.46	20.77
3 No Exercise	16.93	15.88	20.56	15.51
4 No Exercise	20.61	15.24	19.10	16.66
5 No Exercise	21.47	22.89	28.23	18.41
6 No Exercise	20.18	20.15	20.85	17.00
7 No Exercise	24.81	20.42	30.68	20.52
8 No Exercise	27.21	17.83	24.69	22.45
9 No Exercise	21.06	17.00	16.00	21.20
10 No Exercise	30.09	24.06	25.27	21.74
11 No Exercise	18.77	14.15	14.32	12.78
12 No Exercise	15.97	15.18	12.64	13.19
13 No Exercise	18.54	15.63	17.53	14.59
14 Exercise	14.62	14.02	14.30	13.17
15 Exercise	20.13	20.74	18.46	17.77
16 Exercise	24.18	19.35	24.41	20.43
17 Exercise	22.00	18.07	14.20	15.62
18 Exercise	21.23	21.63	19.09	18.74
19 Exercise	18.90	16.36	15.63	13.18
20 Exercise	19.87	18.28	18.84	14.64
21 Exercise	23.27	16.68	17.53	15.97
22 Exercise	30.67	22.16	24.10	22.32
23 Exercise	19.86	19.09	18.73	22.46
24 Exercise	16.04	14.68	13.16	12.77
25 Exercise	24.94	19.49	18.06	16.94
26 Exercise	22.09	22.42	18.45	19.34
27 Exercise	17.89	19.70	19.21	18.94

Note. Data are expressed in seconds for time.

[a] SD T1 = sleep deprivation trial 1;

[b] SD T2 = sleep deprivation trial 2;

[c] S T1 = sleep trial 1; and

[d] S T2 = sleep trial 2.

APPENDIX P

RAW DATA: STROOP (OTHER INCONGRUENT % CORRECT)

Subject #	SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1 No Exercise	95.83	100.00	100.00	91.67
2 No Exercise	95.83	87.50	100.00	95.83
3 No Exercise	100.00	100.00	100.00	100.00
4 No Exercise	100.00	95.83	100.00	100.00
5 No Exercise	100.00	95.83	95.83	91.67
6 No Exercise	100.00	95.83	100.00	100.00
7 No Exercise	100.00	100.00	100.00	95.83
8 No Exercise	100.00	100.00	100.00	100.00
9 No Exercise	100.00	95.83	91.67	91.67
10 No Exercise	87.50	91.67	100.00	83.33
11 No Exercise	100.00	100.00	100.00	100.00
12 No Exercise	95.83	100.00	100.00	95.83
13 No Exercise	100.00	100.00	100.00	95.83
14 Exercise	100.00	100.00	100.00	95.83
15 Exercise	100.00	87.50	100.00	95.83
16 Exercise	100.00	100.00	100.00	91.67
17 Exercise	100.00	100.00	100.00	91.67
18 Exercise	95.83	91.67	100.00	100.00
19 Exercise	95.83	100.00	100.00	95.83
20 Exercise	95.33	95.83	95.83	87.50
21 Exercise	100.00	100.00	100.00	100.00
22 Exercise	100.00	100.00	100.00	100.00
23 Exercise	91.67	95.83	33.33	95.83
24 Exercise	95.83	91.67	87.50	91.67
25 Exercise	95.83	91.67	95.83	87.50
26 Exercise	100.00	100.00	87.50	95.83
27 Exercise	95.83	100.00	95.83	100.00

Note. Data are expressed in percent correct.

[a] SD T1 = sleep deprivation trial 1;

[b] SD T2 = sleep deprivation trial 2;

[c] S T1= sleep trial 1; and

[d] S T2 = sleep trial 2.

APPENDIX Q

RAW DATA: STROOP (OTHER INCONGRUENT RESPONSE TIME)

Subject #	SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1 No Exercise	32.98	23.66	24.72	24.07
2 No Exercise	22.80	22.03	20.37	19.05
3 No Exercise	16.52	15.22	18.14	16.55
4 No Exercise	21.69	17.44	19.05	15.83
5 No Exercise	21.76	20.89	27.65	21.23
6 No Exercise	24.52	21.41	21.95	18.19
7 No Exercise	26.20	27.10	28.78	28.47
8 No Exercise	27.21	24.76	20.84	21.78
9 No Exercise	19.55	19.28	15.84	20.58
10 No Exercise	30.11	24.23	23.86	16.41
11 No Exercise	16.01	14.74	14.92	14.96
12 No Exercise	16.29	17.01	13.66	14.74
13 No Exercise	16.25	16.59	18.74	14.89
14 Exercise	14.93	16.56	16.11	15.03
15 Exercise	19.60	22.45	19.12	19.83
16 Exercise	24.23	21.42	22.58	26.24
17 Exercise	22.05	22.48	14.12	16.15
18 Exercise	25.27	25.28	19.21	20.75
19 Exercise	22.06	15.40	16.91	16.96
20 Exercise	24.51	22.64	23.60	22.49
21 Exercise	21.20	18.51	16.86	16.35
22 Exercise	22.60	23.71	23.35	20.36
23 Exercise	22.67	16.73	21.97	16.64
24 Exercise	18.34	17.34	15.35	13.30
25 Exercise	26.61	23.59	23.19	22.55
26 Exercise	24.62	27.26	22.15	18.93
27 Exercise	20.47	21.18	20.47	20.55

Note. Data are expressed in seconds for time.

[a] SD T1 = sleep deprivation trial 1;

[b] SD T2 = sleep deprivation trial 2;

[c] S T1 = sleep trial 1; and

[d] S T2 = sleep trial 2.

APPENDIX R

RAW DATA: SERIAL ARITHMETIC (% CORRECT)

Subject #	SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1 No Exercise	93.33	97.33	88.00	94.67
2 No Exercise	80.00	86.67	80.00	88.00
3 No Exercise	98.67	97.33	86.67	94.67
4 No Exercise	97.33	97.33	96.00	96.00
5 No Exercise	85.33	92.00	90.67	97.33
6 No Exercise	96.00	94.67	90.67	96.00
7 No Exercise	85.33	86.67	96.00	94.67
8 No Exercise	98.67	97.33	100.00	97.33
9 No Exercise	54.67	49.33	62.67	52.00
10 No Exercise	60.00	54.67	37.33	44.00
11 No Exercise	100.00	96.00	89.33	90.67
12 No Exercise	100.00	97.33	98.67	98.67
13 No Exercise	97.33	96.00	92.00	96.00
14 Exercise	97.33	92.00	84.00	100.00
15 Exercise	90.67	89.33	84.00	90.67
16 Exercise	85.33	92.00	88.00	97.33
17 Exercise	97.33	94.67	96.00	94.67
18 Exercise	77.33	93.33	86.67	96.00
19 Exercise	96.00	92.00	100.00	96.00
20 Exercise	64.00	70.67	81.33	65.33
21 Exercise	94.67	98.67	100.00	98.67
22 Exercise	78.67	92.00	93.33	93.33
23 Exercise	88.00	85.33	89.33	89.33
24 Exercise	88.00	100.00	98.67	92.00
25 Exercise	86.67	93.33	92.00	96.00
26 Exercise	93.33	98.67	97.33	90.67
27 Exercise	86.67	88.00	74.66	92.00

Note. Data are expressed in percent correct.

[a] SD T1 = sleep deprivation trial 1;

[b] SD T2 = sleep deprivation trial 2;

[c] S T1 = sleep trial 1; and

[d] S T2 = sleep trial 2.

APPENDIX S

RAW DATA: SERIAL ARITHMETIC (RESPONSE TIME)

Subject #		SD T1[a]	SD T2[b]	S T1[c]	S T2[d]
1	No Exercise	412.87	368.33	344.13	327.35
2	No Exercise	308.18	250.07	319.24	207.50
3	No Exercise	212.89	188.63	207.05	179.17
4	No Exercise	243.16	212.82	219.22	203.31
5	No Exercise	262.55	194.36	225.58	199.65
6	No Exercise	257.78	218.44	265.24	238.16
7	No Exercise	184.86	193.51	202.58	173.67
8	No Exercise	247.54	183.81	163.46	164.62
9	No Exercise	154.75	169.52	240.09	212.87
10	No Exercise	209.56	195.69	363.30	288.43
11	No Exercise	218.48	211.79	251.67	238.52
12	No Exercise	215.94	195.59	206.68	173.24
13	No Exercise	168.81	170.81	182.50	175.84
14	Exercise	148.39	157.39	180.99	149.25
15	Exercise	169.54	165.37	236.30	183.01
16	Exercise	257.01	219.55	290.24	220.12
17	Exercise	167.90	164.65	200.92	190.00
18	Exercise	273.34	289.34	261.31	247.15
19	Exercise	185.86	179.74	165.32	185.86
20	Exercise	288.36	233.90	261.48	200.05
21	Exercise	262.57	212.82	199.12	176.41
22	Exercise	294.40	243.13	237.72	243.12
23	Exercise	176.60	156.59	175.80	165.32
24	Exercise	192.93	173.02	167.29	160.51
25	Exercise	208.32	189.92	229.16	197.59
26	Exercise	253.27	234.54	215.48	221.69
27	Exercise	220.12	219.01	226.00	219.86

Note. Data are expressed in seconds for time.

[a] SD T1 = sleep deprivation trial 1;

[b] SD T2 = sleep deprivation trial 2;

[c] S T1 = sleep trial 1; and

[d] S T2 = sleep trial 2.

APPENDIX T

RAW DATA: RAPM[a] (% CORRECT)

Subject #	SD T1[c]	SD T2[d]	S T1[e]	S T2[f]
1 No Exercise	66.67	58.33	91.67	8.33
2 No Exercise	41.67	66.67	41.67	41.67
3 No Exercise	83.33	75.00	91.67	91.67
4 No Exercise	83.33	100.00	100.00	75.00
5 No Exercise	58.33	58.33	91.67	66.66
6 No Exercise	92.00	58.33	58.33	75.00
7 No Exercise	50.00	58.33	50.00	66.66
8 No Exercise	91.67	66.67	100.00	83.33
9 No Exercise	41.67	33.33	58.33	58.33
10 No Exercise	16.67	b	83.33	b
11 No Exercise	75.00	83.33	75.00	75.00
12 No Exercise	83.30	91.67	83.33	75.00
13 No Exercise	58.33	16.67	50.00	33.33
14 Exercise	91.67	91.67	100.00	91.67
15 Exercise	75.00	58.33	83.33	58.33
16 Exercise	50.00	66.67	83.33	75.00
17 Exercise	83.33	75.00	75.00	75.00
18 Exercise	58.33	83.33	66.67	75.00
19 Exercise	91.67	58.33	33.33	66.67
20 Exercise	50.00	50.00	50.00	16.67
21 Exercise	83.33	50.00	66.67	83.33
22 Exercise	75.00	66.67	66.67	33.33
23 Exercise	50.00	33.33	41.67	41.67
24 Exercise	83.33	75.00	100.00	83.33
25 Exercise	75.00	91.67	66.67	75.00
26 Exercise	100.00	75.00	75.00	75.00
27 Exercise	58.33	42.00	41.67	50.00

Note. Data are expressed in percent correct.

[a] RAPM = Raven's Advanced Progressive Matrices.

[b] represents that no data was recorded.

[c] SD T1 = sleep deprivation trial 1;

[d] SD T2 = sleep deprivation trial 2;

[e] S T1 = sleep trial 1; and

[f] S T2 = sleep trial 2.

APPENDIX U

RAW DATA: RAPM[a] (RESPONSE TIME)

Subject #	SD T1[c]	SD T2[d]	S T1[e]	S T2[f]
1 No Exercise	420	660	480	420
2 No Exercise	360	420	480	360
3 No Exercise	720	120	720	480
4 No Exercise	420	b	300	420
5 No Exercise	900	480	960	600
6 No Exercise	360	600	420	360
7 No Exercise	480	540	1080	480
8 No Exercise	660	600	480	420
9 No Exercise	480	360	720	600
10 No Exercise	600	420	840	840
11 No Exercise	480	300	780	600
12 No Exercise	840	420	720	600
13 No Exercise	300	240	b	360
14 Exercise	960	600	600	540
15 Exercise	300	360	600	420
16 Exercise	360	420	360	b
17 Exercise	240	240	660	600
18 Exercise	540	480	480	660
19 Exercise	660	540	480	480
20 Exercise	420	420	300	300
21 Exercise	540	600	300	360
22 Exercise	600	540	360	300
23 Exercise	420	240	360	240
24 Exercise	600	840	600	780
25 Exercise	120	360	1200	540
26 Exercise	300	360	240	240
27 Exercise	600	360	840	360

Note. Data are expressed in seconds for time.

[a] RAPM = Raven's Advanced Progressive Matrices.

[b] represents that no data was recorded.

[c] SD T1 = sleep deprivation trial 1;

[d] SD T2 = sleep deprivation trial 2;

[e] S T1 = sleep trial 1; and

[f] S T2 = sleep trial 2.