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Effects of Sleep Deprivation on Physiological and Cognitive Function

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Abstract

The importance of sleep to health is well known, but not well understood. Monitoring sleep deprivation of adolescents and college aged-students is an important area of research. Studying student sleep habits may lead to valuable insight in their overall academic success and physiological well-being. This research attempts to understand the effects that sleep deprivation has on cognitive and physiological function. Nineteen college students (19-24 years old) were asked how many hours of sleep they received the night prior to testing. The subjects were then placed into one of three bins, the first including students who received five hours of sleep or less, the second including students who received between five and seven hours, and the third including students who received seven hours or more. The resting heart rate and blood pressure were recorded for each participant. All subjects participated in a Stroop test and a reaction time test. The heart rate, blood pressure, Stroop test results, and reaction time test results of each bin were then compared to the results of other bins to determine statistically significant differences. The results showed a difference between each bin, but did not reach significance ($p<0.05$). Subjects with five hours of sleep or less (Bin 1) showed higher basal heart rate and blood pressure measurements coupled with hindered task performance on average compared to subjects with seven hours of sleep or more (Bin 3). Thus, the results of the study indicate that adequate amount of sleep may play an important role in cognitive task performance and cardiovascular function.

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Introduction

Sleep is an essential component of a lifestyle for the proper health and well-being of humankind. In today's society, sleep has become less of a priority. The National Sleep Foundation reports that adults are recommended to sleep 7-9 hours a day with 4-6 complete sleep cycles (Kryger 2006). The sleep cycle consists of a sequence of 5 stages alternating between two types of sleep, Non-Rapid Eye Movement (NREM) and Rapid Eye Movement (REM). NREM consists of stages 1-4 characterized by minimal physiological activity. In contrast, REM is stage 5 of the sleep cycle, which consists of increased physiological activity. Individuals deprived of a proper amount of sleep have shown to have a variety of detrimental cognitive and physiological effects (Kryger 2006).

Studies have shown that sleep loss can have negative effects on short-term memory and impede performance on newly learned tasks (Bonnet 2005). A recent study investigated brain activation during cognitive tasks using functional magnetic resonance imaging (fMRI) in sleep-deprived males (Mu 2005). The analysis of the fMRI scans of the sleep deprived subjects indicated decreased brain activation during a working-memory task correlating to decreased cognitive activity compared to the control (Mu 2005). The findings of the study indicate a possible relationship between inadequate amount of sleep and hindrance of cognitive abilities (Mu 2005).

In regards to working memory, a previous study examining the effects of sleep deprivation on the efficiency of visual working memory capacity showed that sleep deprivation had adverse consequences on task performance (Drummond 2012). In addition, a correlation between sleep deprivation and the body's ability to regulate temperature has been investigated (Romeijn 2012). The findings suggest that sleep deprivation disrupts coordination of skin temperature fluctuations. The study postulated that the disruption is caused by the coordination between skin blood flow fluctuations and cardiovascular regulations that prevent venous pooling of blood in the legs. The study further researched the relationship between the disrupted body temperature and vigilance through a reaction time test (Romeijn 2012). Vigilance was also found to be negatively affected, suggesting a relationship between the performance of the cardiovascular system and the performance of the individual in a reaction time test (Romeijn 2012). Incorporation of heart rate and blood pressure measurements and performance tasks such as a Stroop test can further indicate an association between sleep deprivation and its cognitive and physiological effects.

Sleep deprivation has also been shown to result in increased heart rate and blood pressure (Tochikubo 2012). A recent study sampled United States citizens averaging less than 5 hours of sleep per night. Researchers found that subjects below the age of 60 consistently experiencing inadequate sleep were at a higher risk of developing hypertension at a younger age than subjects over the age of 60 following a healthy lifestyle (Fang 2011). Researchers claim that the association between sleep deprivation and increased risk of hypertension is due to long-term elevated activity of the sympathetic nervous system and irregularity in the physiological circadian rhythm (Gangwisch 2006).

Researchers have acknowledged a possible relationship between sleep deprivation and hypertension. One study, in particular, focused on the impact that age and gender have on this association (Fang 2011). The study used data from the

National Health Interview Surveys, first stratifying by age and gender and then researching the hours of sleep and prevalence of hypertension. The findings exhibited a higher prevalence of hypertension for individuals who slept less than 7 hours per night or more than 10 hours per night. However, the study did find a variance in how much sleep could be defined as deprived based on age and gender. The age groups were 18-44, 45-64, and ≥65 years (Fang 2011). However, this study did not specifically target young adults such as college students. Further research can be done on students ages 19 to 24 to investigate whether the results fit this specific age group. Therefore, additional studies must be conducted before a direct association relating sleep deprivation and its detrimental effects on physiological and cognitive functions can be validated (Yang 2012).

How does sleep deprivation in young adults (age 19-24) have adverse effects on cognitive and physiological functions? The objective of our study is to investigate whether loss of sleep has an effect on blood pressure and heart rate, and the possible resulting negative effects on task performance. We will be measuring blood pressure and heart rate to investigate the possible effects that the number of hours of sleep a night has on cardiovascular function. A Stroop test and a reaction time test will examine task performance, representative of cognitive processing and motor reflex. We hypothesize that reduced sleep will result in increased blood pressure and heart rate with hindered cognitive task and motor reflex performance.

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Methods

Pilot Study

A survey was handed to 30 students enrolled in the Physiology 435 course at University of Wisconsin-Madison. The survey gathered information on the average number of hours of sleep students receive per weeknight. In addition, the survey asked students to state the number of hours of sleep they received the night prior to completing the questionnaire. We formulated bins to categorize subjects based on the number of hours of sleep reported in the survey. The following three bins were created to group subjects: ≤5 hours (Bin 1), 5-7 hours (Bin 2), ≥7 hours (Bin 3).

Subjects

All data was collected between February-April 2013. Inclusion criteria were subjects enrolled in the Physiology 435 course as an undergraduate, graduate, or special student at the University of Wisconsin-Madison between the ages of 19-24. This study included a total of 19 individuals (10 males, 9 females). All subjects were asked to state the number of hours they slept the night before testing. To minimize confounding variables in our study, all subjects were asked whether they are currently taking any medication for pre-existing heart conditions. All subjects that participated in the study gave informed consent for the experimental protocol. Subject demographic information is displayed in **Table 1**.

Table 1. Demographics of subjects and results of tasks.

	Bin 1 Subjects (≤5 hours of sleep)	Bin 2 Subjects (5-7 hours of sleep)	Bin 3 Subjects (≥7 hours of sleep)
Number of Subjects (n=19)	5	9	5
Number of Females	3	3	3
Number of Males	2	6	2
Average Heart Rate (HR)	79	73	68
Average Sitting Blood Pressure (mmHg)	117/78.4	114/75.9	112.6/70.2
Average Correct Responses on Stroop Test out of 20 possible	18	19	19
Average amount of time taken to complete Stroop Test (sec)	29	28	27
Average Reaction Time (sec.)	0.240	0.230	0.223

Cardiovascular Data Acquisition Paradigm

Blood pressure and heart rate are considered to be standardized measures to assess cardiac output (Vasan 2001).Therefore, we measured blood pressure and heart rate to investigate the possible effects that the number of hours of sleep the participant received the night prior to testing has on the cardiovascular system. A Discovery Channel deluxe wrist heart rate monitor was placed the subject’s left wrist to record resting heart rate and blood pressure before any cognitive tests were performed.

Cognitive Task Paradigms

A Stroop test and a reaction time test were used to measure cognitive task and motor reflex performance.The focus of the Stroop test was to investigate the relationship between the amount of sleep and higher order executive function and cognitive processing (Stroop 1935). The purpose of the reaction time test was to examine the relationship between the amount of sleep and the time it takes the brain to recognize and interpret an external stimulus. The Stroop test used in this experiment was created using Microsoft Powerpoint. Subjects were shown 20 different slides during the Stroop test. Each of the 20 slides had a color written on it in a specific font color against a black background. The colors used were red, orange, yellow, green, blue, and purple. Participants were instructed to state the color of the font of the word, without reading the word that is written. For example, subjects were presented with a slide reading “blue” in red font. A correct response was noted when the subjects stated, “red”. The number of correct responses in a 30 second time period was recorded. Hesitation and multiple answers to one slide were noted as incorrect responses.

The reaction time test used in this experiment was a BIOPAC Reaction Time system. This system provided a series of audio clicks through headphones. Before the test started, the participants were instructed to use their dominant hand to maintain steady control of the clicker and close their eyes for the duration of the test. Immediately after hearing each click, the subject was instructed to press a push button hand switch. The system monitored and recorded reaction times for further data analysis.

Data Analysis

Data was analyzed based on the number of hours of sleep the subject received the night before testing. Statistical t-test analysis was conducted to determine significant differences of task performance based on the results of the Stroop test and reaction time test. Statistical comparisons were made between bins (Five hours of sleep or less, between five and seven hours of sleep, seven hours of sleep or more) to determine significant differences of task performance between subjects who received varying amounts of sleep. In addition, average heart rate and blood pressure measurements were compared between bins to determine the effects that sleep deprivation has on cardiovascular function. Normal physiological systolic/diastolic measurements of 120/80 mmHg were utilized as a control for blood pressure comparisons. The healthy physiological heart rate measurement of 60-70 beats per minute was used as a control for heart rate comparison (Vasan 2001). These measurements and comparisons were utilized to investigate the effect that sleep deprivation has on cardiovascular and cognitive function (task performance and motor reflex).

Results

Participants were grouped into 3 bins based on the amount of sleep received the night prior to testing. Bin 1 consisted of participants who received 5 hours of sleep or less. Bin 2 consisted of participants who received between 5-7 hours of sleep. Bin 3 consisted of participants who received 7 hours of sleep or more. All numerical results of tests are presented in **Table 1.** Subjects placed in bin 1 were observed to have a higher average basal heart rate compared to subjects in bins 2 and 3, indicating a notable trend between sleep and heart rate (**Figure 1**). However, the two-sample t-tests did not indicate a significant difference ($p<0.05$) between the average heart rates of each bin (**Table 2**). Although blood pressure measured for bin 1 subjects (117/78.4 mmHg) was higher than blood pressure measurements for bins 2 (114/75.8 mmHg) and 3 (112.6/70.2 mmHg), these values were within normal physiological limits (Vasan 2001).

In addition to cardiovascular measurements, the results of the Stroop test and reaction time test provided information on cognitive function. The accuracy rate on the

Stroop test across all bins was found to be at ninety percent (i.e. 18 questions correct out of 20 possible). Although the accuracy rate was consistent across all bins, the time required to complete the task differed. Bin 1 subjects took longer to complete the Stroop test compared to bin 2 and 3, showing a notable trend between sleep and time taken to complete the Stroop test. Again, the two sample t-test did not display a statistical significant difference ($p<0.05$) (**Figure 2, Table 2**). The results of the reaction time test followed a similar pattern to the results of the Stroop test. Bin 1 subjects were observed to have a longer reaction time compared to subjects in bin 2 or 3, displaying a less noticeable trend between amount of sleep and reaction time (**Figure 3**). The difference of average reaction time between each bin did not reach statistical significance ($p<0.05$) (**Table 2**).

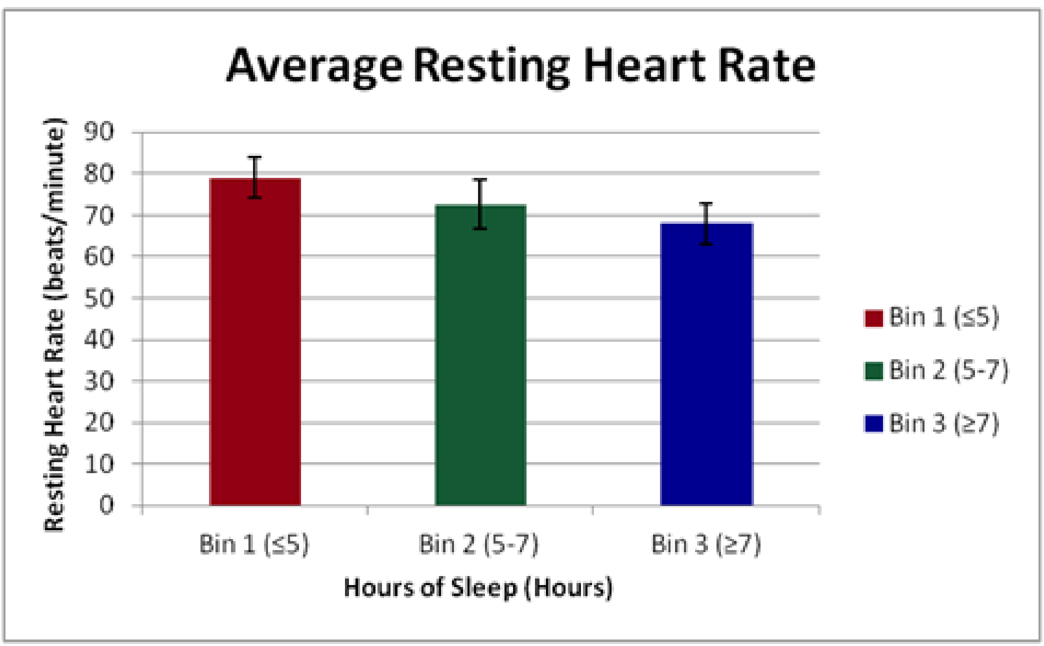

Figure 1: Hours of sleep vs. resting basal heart rate (beats/minute) were compared. An average resting heart rate was determined for each of the 3 bins. Participates placed into bin 1 (red) averaged a basal heart rate of 79.0 BPM. Those placed into bin 2 (green) averaged a basal heart rate of 72.6 BPM. Subjects placed into bin 3 (blue) averaged a basal heart rate of 68 BPM.

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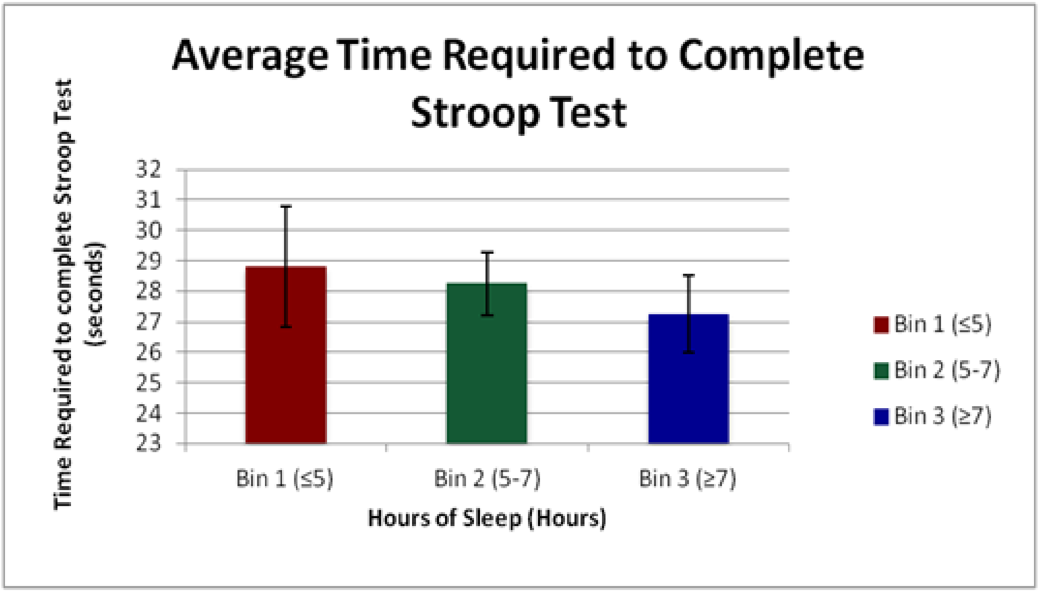

Figure 2: Hours of sleep vs. time required to complete a stroop test (seconds) were compared. An average time required to complete this task was calculated for each of the 3 bins. Participates placed into bin 1 (red) averaged a time of 28.8 seconds to complete the test. Those placed into bin 2 (green) averaged a time of 28.2 seconds. Subjects placed into bin 3 (blue) averaged a time of 27.6 seconds.

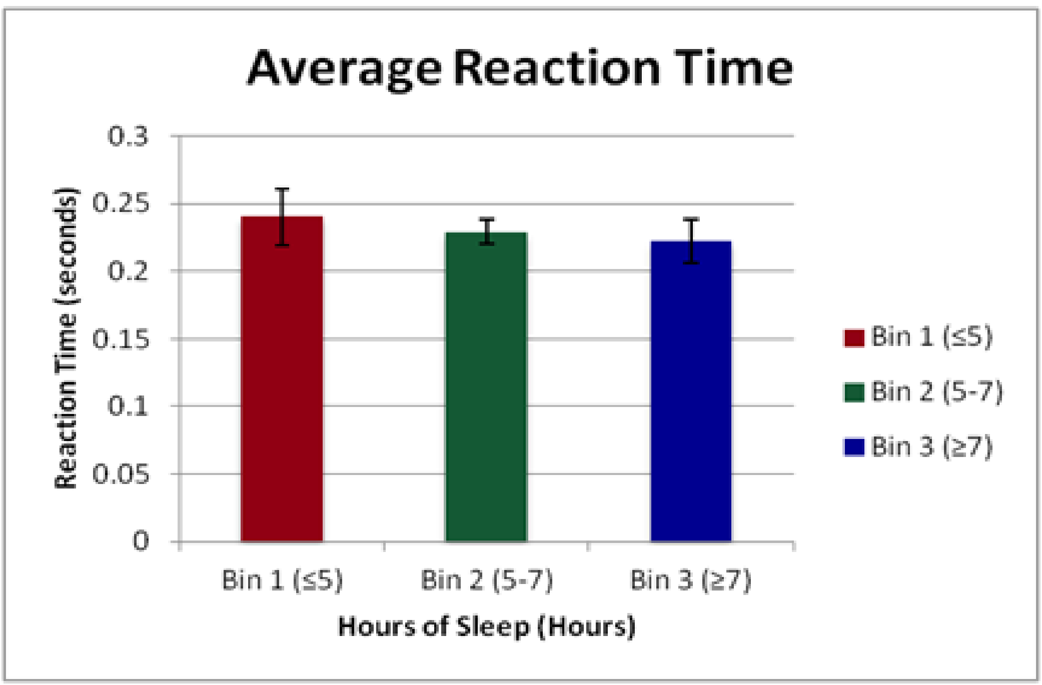

Figure 3: Hours of sleep vs. reaction time (seconds) were compared. An average reaction time was calculated for each bin. Participants placed into bin 1 (red) averaged a reaction time of 0.240 seconds. Those placed into bin 2 (green) averaged a reaction time of 0.229 seconds. Subjects placed into bin 3 (blue) averaged a reaction time of 0.222 seconds.

Table 2. **Paired t-test comparison of results from each bin. *Statistical significance was determined to be p<0.05.**

	Bin 1 vs. Bin 2 p-values	Bin 2 vs. Bin 3 p-values	Bin 1 vs. Bin 3 p-values
Average Heart Rate	0.456	0.581	0.118
Average Correct Responses on Stroop Test	0.348	0.959	0.291
Average amount of time taken to complete Stroop Test	0.773	0.537	0.486
Average Reaction Time	0.561	0.683	0.478

Discussion

We observed an increased heart rate and blood pressure in individuals placed in bin 1 compared to bin 3. The two-sample t-tests do not indicate a significant difference ($p<0.05$) between the average heart rates of subjects placed in bin 1 compared to bin 3. Less amount of sleep was associated with increased cardiovascular function. Sleep deprivation has adverse health effects including chronic activation of the sympathetic nervous system (Spiegel 1999). Prolonged sympathetic nervous system activation links sleep deprivation to increased cardiovascular output and cardiac disorders (Gangwisch 2006). Sleep deprivation hinders biological processing and disrupts the circadian clock controlled in the suprachiasmatic nucleus (Oertel 2013). The sleep-arousal cycle governed by the ventrolateral preoptic nucleus of the hypothalamus and the reticular activating system is disturbed during sleep deprivation (Schwartz and Roth 2008). A non-consistent circadian rhythm elevates the stress level and activates the sympathetic nervous system. The cardio-acceleratory center of the medulla oblongata releases the neurotransmitter norepinephrine. Epinephrine, a neurohormone, is also released via the adrenal medulla (Lokuta 2013). Epinephrine and norepinephrine target all four chambers of the heart. High levels of epinephrine and norepinephrine increase heart rate, stroke volume, and cardiac output (Guyton 1957). Consequently, sleep deprivation is associated with increased heart rate and cardiovascular function, corresponding to the results of our study.

Subjects in bin 3 completed the Stroop test quicker than subjects in bin 1. Bin 3 was observed to have a quicker reaction time compared to bin 1. The two sample t-tests did not show a statistically significant difference ($p<0.05$) between the average time to complete the Stroop test or reaction time test in bin 1 compared to bin 3. Although accuracy of answers on the Stroop test remained constant across all three bins, the time required to complete the task changed. Less amount of sleep was associated with increased amount of time to complete the task. Sleep deprivation has been known to hinder cognitive task and motor reflex performance. The reaction time test is a type of sustained attention task to detect randomly occurring auditory stimuli, measuring psychomotor performance (Scott 2006). Drummond et al (2012) determined that prolonged attention and behavioral alertness tests have been a valid tool to measure effects of sleep deprivation because attention mechanisms localized in the prefrontal cortex (PFC) are most sensitive to a lack of sleep. Prolonged sleep deprivation has been associated with a slowing of the PFC-posterior parietal system (Drummond 2012). A slowing of the attention mechanism correlates with an increased reaction time. Consistent with the results of our study, sleep deprivation slows the PFC-posterior parietal system resulting in an increased reaction time. Slower cognitive function results in decreased motor reflex speed, lengthening the reaction time. Therefore, bin 3 subjects were observed to have a quicker reaction time compared to bin 1 subjects. The same pattern of results was seen in the Stroop test. The Stroop test measures working memory and mental flexibility, both of which are negatively affected with reduced sleep (Stroop 1935). Mechanisms governed in the PFC are slowed during sleep deprivation, requiring additional time to accurately perform a cognitive task. Consequently, sleep deprivation is associated with hindered cognitive task performance, corresponding to the results of our study.

There are a few limitations to this study. Foremost, we relied on self-reported sleep durations as opposed to measured sleep durations. However, previous self-reported sleep studies show that minimal discrepancies are observed between self-reported sleep durations versus experimentally measured sleep durations. Additionally, the amount of sleep participants receive varies on a nightly basis. Therefore, some subjects participated in our tests on multiple occasions. Prior exposure to the Stroop Test could have skewed data. Thus, further studies should increase their sample size and test each subject once to eliminate any bias. Also, males averaged a faster reaction time compared to females. Therefore, further studies should consider the different effects of sleep deprivation based on gender. During the course of this study, we did not account for lifestyle choices and external factors (i.e. illness, hunger, and external stress) that affect physiological and cognitive functions. The inclusion criteria for further research should account for lifestyle behaviors (diet, exercise, stress level). However, we eliminated outliers from the study during data analysis to prevent inaccurate results.

Further studies should consider accounting for confounding variables and its role in task performance.

Conclusion

Sleep deprivation has adverse effects on cardiovascular and cognitive function. Subjects with reduced amount of sleep had increased cardiovascular function with hindered cognitive task performance. Thus, college students should highly consider the importance of sleep for their academic success and biological well-being. Results of this study indicate the cognitive and physiological importance of adequate sleep in college students.

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