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The Effects of Sleep Restriction On Visual Working Memory in Teenage Students in Southern California

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ABSTRACT

This paper explores the effects of 2 hours of sleep restriction on a subject pool that normally gets the full recommended 8 hours of sleep. After administering a visual working memory assessment and survey tool, the researcher found that sleep restriction negatively impacts visual working memory in teenage participants.

Introduction

Sleep is an essential component of human life that enables the biological processes required for everyday human functionality, such as appetite, blood pressure, breathing, and cardiovascular health (National Institutes of Health [NIH], 2013). As humans enter adolescence and begin puberty, sleep duration and waking times shift to later than they previously were (Foster, 2013). This change may disrupt sleep cycles, as school starting times do not often change with the biological clock of their students, leading to a circadian rhythm shift, which is widely acknowledged as a difference of 2 hours later in the sleep duration for adolescents (Foster, 2013). To demonstrate, an alarm call at 7 a.m. for an adolescent is the equivalent of an alarm call at 5 a.m. for a middle-aged person. Such circumstances are the perfect conditions in which one, as an adolescent, may experience sleep deprivation, a state that arises when one does not get enough sleep on a 24-hour basis (NIH, 2013).

Sleep deprivation is a broad concept of study that the public commonly acknowledges as a concern worth addressing in the youth (Jackson & Cooper, 2020). The effects of acute or short-term sleep deprivation include irritability, lack of focus, reduced vigilance, higher risk of accidents, and overall fatigue (Picard, 2020). These effects indicate reduced levels of cognitive functioning, which have implications for long-term sleep deprivation. Prolonged sleep deprivation can lead to memory lapses, hallucinations, delusional thinking, and paranoia, with extreme cases leading to physical damage to the brain (Picard, 2020).

Literature Review

Reports from the Rhode Island High School Youth Risk Behavior Survey conducted by the Centers for Disease Control and Prevention show that about 80% of teenage students receive less than the recommended sleep duration of about 8 hours, showing how American teenage students struggle with their sleep (Jackson & Cooper, 2020). A demographic analysis of the factors determining this statistic shows a consistent trend in sleep duration in 14 to 18-year-olds, with 27% of 14-year-olds receiving adequate sleep compared to 14% of 18-year-olds (Jackson & Cooper, 2020). These findings suggest that as teens age and are challenged with a change in their lifestyles, they begin to experience a decrease in their sleep duration, which has various implications for their cognitive function and working (short-term) memory. Discussed in the following sections are these implications.

Sleep Deprivation and Cognitive Function

Before examining the current research on sleep deprivation and its effects on the cognitive function of the human brain, it is imperative to consider earlier research. Historical findings paved the way for new studies that review the results of their preceding research. However, the results of these earlier studies must be taken with a grain of salt, as research methods and experimental designs have evolved over the years. Despite this, the study published by Professors Patrick and Gilbert in 1896 famously aimed to determine any psychological and mental effects of sleep abstinence for an extended period. In this study, researchers analyzed the participants' cognitive function through memory, motor function, and reaction time tests. The study focused on three adult male subjects who abstained from sleep for 90 hours (Patrick & Gilbert, 1896). At regular intervals of 6 hours, the subjects' reaction time, memory, motor ability, and other such measures were recorded (Patrick & Gilbert, 1896). Results concluded that each of these cognitive abilities deteriorated in their accuracy throughout the experiment, which had implications for the function of sleep in psychological recovery (Patrick & Gilbert, 1896). In fact, towards the end of the study, one of the subjects took an astounding 20 minutes to commit a series of 18 figures to memory, demonstrating the importance of sleep in memory consolidation (Patrick & Gilbert, 1896).

To demonstrate how research has changed over time, another peer-reviewed study by researchers from Loughborough University studied the effects of sleep deprivation on temporal memory, or recency. Researchers deprived 40 adults of sleep for 30 hours and conducted facial recognition examinations on the sleep-deprived participants (Harrison & Horne, 2000). Like Patrick and Gilbert's study, the results found noticeable cognitive impairment with the progression of sleep loss, stating, "Whereas sleep deprivation did not significantly affect the recognition of faces, it did produce a significant impairment of the temporal memory" (Harrison & Horne, 2000). Upon further analysis, the researchers concluded that sleep deprivation had a specific impact on the subjects' cognitive abilities rather than having a generalized sense of sleepiness, demonstrating the importance of adequate sleep (Harrison & Horne, 2000).

A study at the University of California, Irvine focused on another aspect of cognitive function. With the renowned Elizabeth Loftus, this study aimed to investigate the effect of sleep deprivation on forming false memories (Frenda et al., 2014). After depriving participants of sleep for 24 hours and conducting a misinformation task, results showed that restricted sleep is related to memory suggestibility (Frenda et al., 2014). However, results were inconsistent, showing that although there is a correlation between sleep deprivation and false memory formation, real-world stimuli would be more effective in concluding the psychological function of memory consolidation under sleep-deprived conditions (Frenda et al., 2014). Comparably, a study conducted by Duke-NUS Medical School found that "…sleep-deprived individuals were more likely than well-rested persons to incorporate misleading post-event information into their responses during memory retrieval" (Lo et al., 2015). This study used a different measure to determine the extent to which the formation of false memories was affected by sleep deprivation. Rather than having participants conduct a misinformation task as done by Frenda et al., these researchers used framing misinformation to prime the participants' minds, leading them to question their interpretations of the events that passed (Lo et al., 2015). The various methods used to research the effect of sleep deprivation and susceptibility to false memory encoding suggest that cognitive function is impaired when one does not consistently attain adequate levels of sleep. Previously mentioned research detailing the effects of sleep deprivation on facial recognition and motor function also supports this conclusion.

Sleep Deprivation and Working Memory

As already established, sleep deprivation profoundly affects the cognitive function of humans. However, working memory, the retention of a small amount of information in a readily accessible form, is also influenced by this decreased cognitive function (Cowan, 2015). Working memory is a form of short-term memory that stores information from visual, auditory, or spatial inputs for a short time, and it is a specific aspect of the brain's cognitive function (Cowan, 2019). By examining the existing research on the effects of sleep deprivation on working memory, one may better understand the importance of sleep in a specific subcategory of the brain's function.

A study published in 1978 by Glenville et al. sought to examine the effects of sleep deprivation on working memory. After 24 hours without sleep, participants aged 20-46 completed a short-term memory task that involved memorizing a string of 8 numbers (Glenville et al., 1978). The results showed that "The short-term memory test failed to show any adverse effects of sleep loss" (Glenville et al., 1978). However, the researchers did not consider the time at which the participants took the test, which may have influenced its results, as the study conducted by Patrick and Gilbert shows that even when participants are sleep deprived, the circadian rhythm still dictates sleepiness levels, which influences short-term, or working, memory (Patrick & Gilbert, 1896).

Another study by Yin et al. sought to determine whether cognitive load moderates the effects of sleep deprivation on working memory, using an experimental design to meet their needs (Yin et al., 2023). After analyzing electroencephalography recordings of their adult participants while they took visual working memory tests, the researchers concluded that cognitive load does moderate the effect of sleep deprivation on working memory, as there was a positive correlation between less sleep and worse memory performance (Yin et al., 2023). A study conducted at the University of California, San Diego also found that "… components of visual working memory are differentially vulnerable to the effects of sleep deprivation, and different types of sleep deprivation impact visual working memory to different degrees" (Drummond et al., 2012). These findings have implications for people who work in environments that require visual filtering for long periods, where sleep deprivation may be an issue.

The Gap in the Research

The American Academy of Sleep Medicine recommends that teenagers aged 13 to 18 should secure about 8 to 10 hours of sleep every night (Jackson & Cooper, 2020). However, an observational study of Rhode Island teenage students found that four out of five students reported getting less sleep than the recommended duration, with one out of four students sleeping for less than 5 hours every night, a trend reflected throughout the rest of the United States of America (Jackson & Cooper, 2020). With this in mind, as well as the unfavorable effects of sleep deprivation, it is imperative to consider the consequences of sleep deprivation on the mental functions of teenagers. Since the American teenage population generally does not meet the standards for sleep duration, research in the area is valuable since it seeks to better the health and mental function of the given population. All the experimental studies mentioned in previous sections did not consider adolescents or teenagers in their methods, as they entirely focused on adults. Existing research on the effects of experimental sleep deprivation on adolescents is limited to areas outside of the United States (Kiriş, 2022). Geographic region is significant to consider because one's environment profoundly impacts the quality of one's sleep (Foster, 2013). This gap in the research prompts the question: What is the effect of sleep restriction on visual working memory in teenage students in Southern California? Based on the scholarly discussion, the results of this study will likely confirm that visual working memory is negatively impacted by sleep restriction.

Methodology

Study Design

This study aims to analyze the relationship between sleep restriction and visual working memory in teenage college-going students in Southern California. Spreading awareness about the importance of sleep and its effects on the physiological functions of teenagers is significant because the increasing percentages of sleep-deprived students may result in an unhealthy population that becomes the dominant age cohort in a democratic country. The goal is that the intended population, teenage students, implement better sleep schedules into their lives to attain a better, more healthy physiological state.

This study is a two-part, mixed methods study. This approach allows for a quantitative analysis of the results. Such an approach is significant because using a mixed-methods approach, compared to a single-approach analysis, permits the study to reveal more about how sleep restriction impacts visual working memory (Leedy & Ormrod, 2010). The two parts of the methodology are the N-Back Test and the Pittsburgh Sleep Quality Index (PSQI), the former being a digital assessment of working memory and the latter being a questionnaire (see Figure 1). These instruments are discussed later in this section. As mentioned in the literature review, researchers have conducted experiments involving these instruments in separate studies. However, this study pairs the use of the digital assessment and questionnaire, a method distinct from the preexisting research. This significant design allows the study to present a new perspective on how sleep restriction affects visual working memory by using methods previously not considered by researchers in the field.

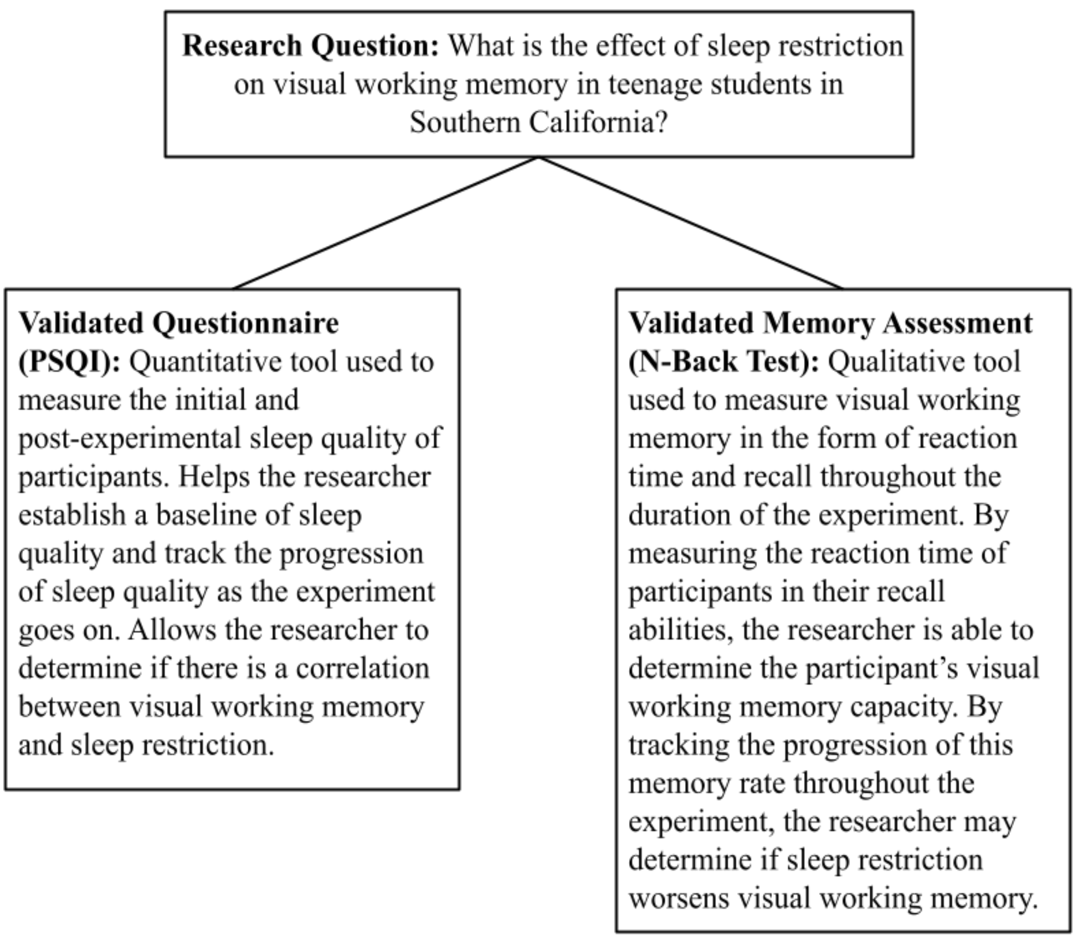

Figure 1. Demonstrating the 2-Part Method Design's Alignment with the Research Question

Subjects

The subjects who chose to participate in the study were ten students attending a large public university in Southern California. They studied various subjects and majored in diverse fields, with half male students and the other half female students. They were all between the ages of 18 and 19 years. The demographic of chosen participants aligned with the study's aims since they are in their teen years and attend an educational institution, with their demographic characteristics being diverse enough to represent a large population. They had a firsthand understanding of how significant cognitive ability, including visual working memory, in an academic setting is, as they experience its effects in their daily lives.

Additionally, previous research lacked detailed information on the demographics mentioned, including geographic region and age cohort (Jackson & Cooper, 2020). During various financial club meetings at the university, the researcher informed prospective subjects of the aims and objectives of this study, with the consent of the organization's president. These qualifying prospects signed a consent form and chose to participate in the study.

Research Instruments

The study made use of two methods to answer the research question, the first being a questionnaire and the second being a digital test. The questionnaire used in the study is the Pittsburgh Sleep Quality Index (PSQI) from Buysse et al. (1988). The authors granted permission to reproduce the scale for researchers to use in non-industry studies such as this one (Buysse et al., 1988). The PSQI assesses overall sleep conditions and quality, allowing the researcher to track the progress of sleep quality throughout the experiment. Espie et al. consider the validity of the questionnaire, concluding that it accurately assesses sleep quality (2014). This instrument is significant to the study because it will permit the researcher to evaluate the subjects' sleep quality before and after the experiment while providing a basis for the quantitative analysis of the subjects' visual working memory. This questionnaire's questions are on the left side, and the right side are the areas where the subject may respond (see Appendix A). The scoring criteria are different for the various questions, with each question resulting in a different number, to sum up the final score of the questionnaire. A score of greater than 5 indicates severe sleep difficulties, while a score of 5 or less indicates average sleep quality (Buysse et al., 1988). The questionnaire asks nine questions about the subjects' sleep habits throughout the past month. The questionnaire was modified to fit within the 1-week scope of the study the second time it was administered, with approval from the IRB. The modifications included changing the phrases "in the past month" to "in the past week" and changing "... times a week" to "... times a day." The researcher made no modifications the first time the participants took the questionnaire, allowing the researcher to establish a baseline level of sleep quality.

The N-Back Test was the second research instrument used. It is a validated instrument that assesses working memory, particularly visual working memory, available for public use (Yin et al., 2023). The N-Back Test presented subjects with a sequence of letters one by one, and the subject's goal was to determine whether the current letter was the same one presented two trials ago, with a two-second delay between each letter. If the subject recognized the letter, they pressed a button on their computer. At the end of the N-Back, the test presented the subject's amount of correctly and incorrectly identified items. These scores indicate how efficient the subject's visual working memory was at the time, providing a basis for the researcher to analyze the change in visual working memory efficiency throughout the study (Yin et al., 2023).

Procedures

After the researcher informed the subjects of the study's methods, the subjects signed a consent form and confidentiality statement. The confidentiality statement stated that the names of the subjects and their results would remain private. All 10 participants completed the study, with no dropouts. The IRB approved the following procedures.

This study lasted for one week, from Day 1 to Day 7. For the entire week, the subjects were not allowed to nap, drink excessive amounts of caffeinated beverages, drink alcoholic beverages, or use any medications or drugs to help them fall asleep, ensuring that the participants' sleep restriction would not be tampered with, as energizing substances may impact visual working memory (Snel & Lorist, 2011). The researcher randomly divided the subjects into control and experimental groups via an online group generator, each with 5 participants. On Day 1, every participant took the PSQI, taking the modified version of the PSQI on Day 7 before nighttime, tracking sleep quality. Every participant also took the N-Back Test once a day right after waking from sleep, from Day 1 to Day 7, tracking working memory. The control group slept as they usually would, 8 hours a night, every day. The experimental group slept 8 hours on Day 1 to establish a baseline, but from Day 2 to Day 6, they slept 2 hours less than usual, about 6 hours. The experimental group was allowed to sleep 8 hours at nighttime on Day 7 to allow for a recovery period, ensuring that they took the modified PSQI before sleeping, providing a final assessment of sleep quality after sleep restriction.

Delimitations

Delimitations were established before the study to ensure efficiency. Only the subjects with a regular sleep schedule of at least 8 hours a night were allowed to participate in the study. Exclusions included those who consume large amounts of caffeine or alcohol regularly. The researcher informed all the subjects that their participation was optional and that they could leave at any time during the study. None of the subjects dropped out of the study. Another limitation is that the researcher only investigated a small sample of teenage students at a large public university in Southern California.

Results

A preliminary data analysis showed that visual working memory functioned best on Day 1 and Day 7, as assessed by the N-Back Test. Day 1 had the highest scores of accuracy. When the sleep restriction began, accuracy scores on the N-Back Test scores dropped significantly but steadily increased. By Day 7, the experimental group's accuracy scores were less than the control group's, but by a much lower value than on Day 2, when the sleep restriction began. However, sleep quality steadily deteriorated throughout the experiment, as assessed by the PSQI. On Day 1, the experimental and control groups had low average PSQI scores of 3.8 and 3.4, respectively, indicating that their sleep quality was acceptable. As mentioned earlier, a score of >5 indicates poor sleep quality. On Day 7, the control group retained their sleep quality, with their average being 3. In contrast, the experimental group's PSQI score on Day 7 more than doubled to 8.2, indicating their sleep quality was well below the average.

PSQI Results

As seen in Figure 2, the control and experimental groups had relatively similar PSQI averages of around 3-4. At the end of the experiment, on Day 7, the control group had a similar average score of 3. However, the experimental group had a much higher average score of 8.2, indicating that the experimental group had a decline in sleep quality since a PSQI score of greater than 5 indicates substandard sleep quality. Despite this, a 2-sample t-test of the control and experimental groups on Day 7 resulted in a p-value of 1, meaning there was no statistically significant difference between the PSQI scores on Day 7. A second 2-sample t-test conducted to compare the PSQI results of the experimental group from Day 1 to Day 7 resulted in another p-value of 1, indicating a statistically insignificant difference between the scores.

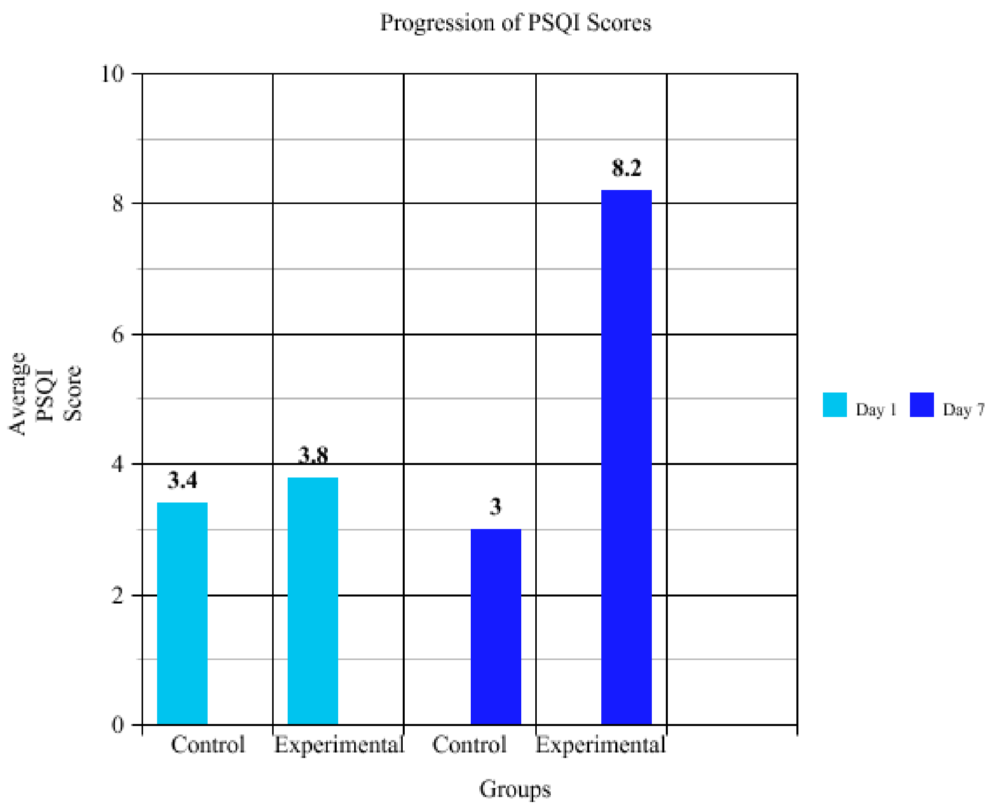

Figure 2. Demonstrating the Progression of PSQI Scores from Day 1 and Day 7

N-Back Test Results

Figure 3 depicts the average scores of the N-Back Test for the control and experimental groups on each day of the experiment. The steep drop in the scores of the experimental group reflects the beginning of the sleep restriction period. The graph shows that while the control group's scores remained relatively constant, the experimental group's scores dropped steeply but began to climb back up as the experiment progressed. A possible explanation for this peculiarity is that the brain became accustomed to the lack of sleep in the experimental group, therefore beginning to accommodate and adapt. A 2-sample t-test of the control and experimental group's scores resulted in a p-value of 0.029, indicating a statistically significant difference, showing that the sleep restriction period significantly impacted the experimental group's visual working memory.

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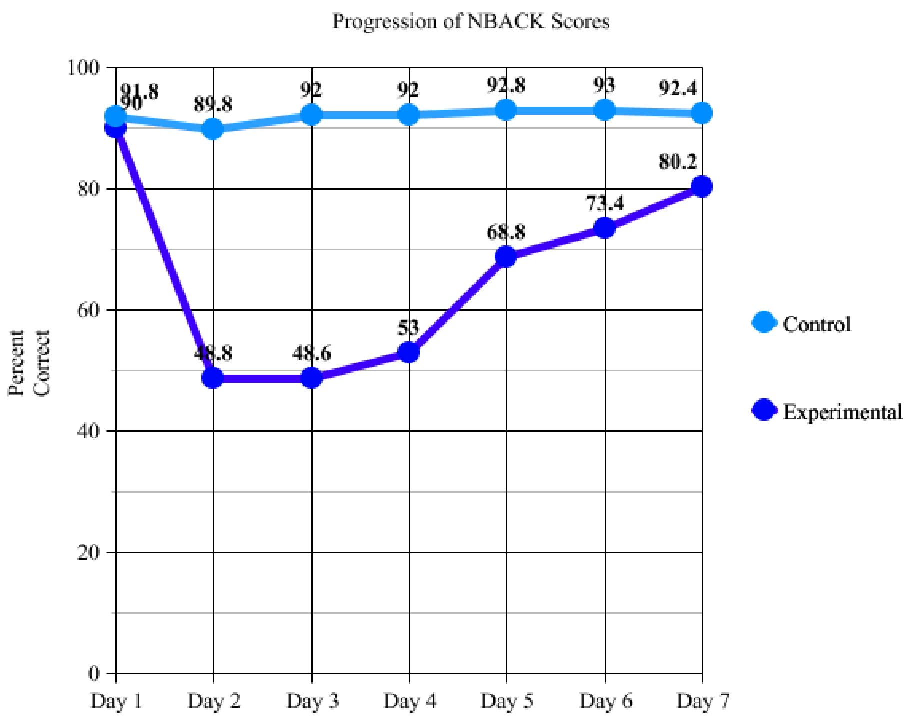

Figure 3. Demonstrating the Progression of N-Back Test Scores from Day 1 to Day 7 (Percent Correct)

Correlation Analysis

To assess whether or not the PSQI and N-Back Test are correlated, the researcher calculated the correlation coefficient between the N-Back Test scores and the PSQI scores in the experimental group. Since there was no sleep restriction on Day 1, the correlation coefficient between the Day 1 PSQI results and Day 1 N-Back Test results provided a stable baseline to assess the correlation between these scores. The result of the correlation analysis was $r = 0.76$, indicating a strong positive correlation between the N-Back Test and PSQI results on Day 1. However, the correlation analysis between the N-Back Test scores and PSQI results on Day 7 revealed that $r = 0.467$, indicating that although there was a positive correlation between the two sets of values, it was less significant than the correlation on Day 1. This peculiarity could have resulted from how the N-Back Test scores, after the initial drop, increased in value as the experiment progressed, leading to a looser correlation with the PSQI results. The researcher analyzed other data within the PSQI and N-Back Test scores for correlation, but these results discussed were the most significant and representative of the overall correlation analysis.

Discussion

The researcher designed the study to examine the effect of sleep restriction on visual working memory in teenage students in Southern California.

Findings

Upon analysis of the results obtained, the researcher concluded that a sleep restriction period of two hours negatively impacts visual working memory in teenage students. The graphs shown in Figure 2 and Figure 3 support this conclusion, as they both show a decrease in cognitive function and sleep quality as the experimental group experiences sleep loss. The results of the PSQI show that as the experimental group experienced sleep restriction, their overall sleep quality drastically deteriorated, indicating a decrease in restfulness and restoration in their sleep, as compared to the control group, who maintained adequate sleep quality. The N-Back Test's results showed that as the experimental group experienced sleep restriction, their visual working memory function upon waking deteriorated, as compared to the control group, whose visual working memory remained constantly accurate, serving as the foundation for this study.

The researcher found that as the experiment progressed, the initial drop in visual working memory efficiency experienced by the experimental group was followed by a steady incline in the accuracy of the experimental group's N-Back Test scores. By Day 7, visual working memory accuracy in the experimental group was nearly equal to the scores on Day 1, indicating that the experimental group became accustomed to the sleep restriction that they were experiencing. Therefore, the data shows that as subjects experience sleep restrictions for an extended period, they become used to the lack of restful sleep, causing their brains to adapt to the circumstances and eventually overcome the sleep restriction's negative effects.

In addition, the data revealed that at the end of the experiment, on Day 7, the control group experienced a decrease in average PSQI scores, indicating that they improved their sleep quality. This phenomenon could be due to the sleep requirements of the experiment, meaning that the control group had no room to delay their sleep for any purpose, ensuring that they slept for a complete 8 hours. This adherence could have influenced better sleep quality at the end of the experiment, implying that paying attention to one's sleep schedule and putting measures in place to ensure one adheres to it will result in overall better sleep.

In conclusion, sleep restriction negatively impacts sleep quality and visual working memory function in teens. Participants gave feedback to the researcher, saying they felt that sleep had risen in their priorities since the experiment. The control group stated that as the experiment progressed, they felt better rested and grateful for the opportunity to solidify their sleep habits. The experimental group said that the sleep restriction helped them realize the importance of prioritizing their restful sleep. One of the subjects even stated that they would change their study habits to accommodate their sleep schedule, rather than the other way around, to ensure that their cognitive function is at its best for their academics. All the participants agreed that the experiment made them realize the importance of their sleep, and how it can help them in their endeavors as teenage students.

Fulfillment of the Gaps in the Research

This study filled multiple gaps in the previously existing research. To begin with, the age cohort of teenage adults aged 18 and 19 was not mentioned in any of the studies covered in the literature review. Previous research focused on adults older than this cohort to ensure their participants were fully post-pubescent. This study, however, focused on teenage, college-going adults to fill the mentioned gap in research. In addition, previous research covered geographic regions typically outside of the United States of America, exempting the study by Jackson and Cooper, which took place in Rhode Island (Jackson & Cooper, 2020). Existing research excluded information on Californian subjects, another gap filled by this study. As mentioned in the literature review, this geographic region is important to consider when understanding the environment where subjects participate in the study. The final gap in the research was the duration for which participants were restricted from sleep. A significantly established restriction duration of 2 hours was not included in the methodology of pre-existing research, rather those studies focused on total sleep deprivation periods for up to 72 hours. These gaps served as the foundation for the study.

Limitations

When using this data to conclude, it is imperative to consider that sleep restriction affects visual working memory to a varying degree, as the results section depicts daily averages rather than individual differences throughout the experimental period. Therefore, the findings of this study apply to a general population rather than a particular group that experiences abnormal sleep patterns. Had either the PSQI or the N-Back Test been used in this study exclusively, then the accuracy of the results would have been compromised. Since the researcher used the PSQI coupled with the N-Back Test, proper analysis of the relationship between sleep quality and visual working memory occurred after sleep restriction.

In addition, the initial population the researcher intended to study was teenagers aged 13-18, but California law prohibited sleep restriction in minors. Therefore, the research question was pivoted to focus on teenage adults to ensure that a gap in research was filled. However, as adults, the subjects live in a completely different environment than high school teens. Not only does independence play a role in their sleep patterns, but their living conditions do as well. These environmental factors weaken the generalizability of the results of this study to high school teens since these teens typically live in a home environment without the responsibilities of a full-grown adult. However, the underlying biological principles still apply, strengthening the generalizability of this study to high school teens, despite the onset of puberty affecting sleep cycles (Lucien et al., 2021).

Finally, the sample size of the study, consisting of only 10 participants, was rather small. There was much difficulty in finding participants willing to sacrifice their sleep, and time constraints made it difficult for the researcher to collect a larger sample size. Therefore, the generalizability of the study is again limited.

Implications

The results of this study can influence the scheduling and deprioritization of homework and other school-related activities in college and high school students. Realizing the importance of sleep and rest can help the affected population prioritize their sleep above all else, as memory functions much better when one has adequate sleep. The related population of teenage students may implement better lifestyle habits that cater to a healthy sleep schedule, making sacrifices where needed.

Additionally, the findings of this study are consistent with the existing research. Previous research found that total sleep deprivation negatively impacts visual working memory (Yin et al., 2023). This study also concludes that sleep restriction impacts visual working memory in the same way, which is supported by the idea that different types of sleep deprivation or restriction impact visual working memory in various ways (Drummond et al., 2012). Although the sleep restriction lasted only 2 hours, its effect on visual working memory was still significant, highlighting the importance of adequate sleep.

Areas for Future Research

The study's limitations are areas where new research could explore. Expanding the study's subject pool to include multiple universities instead of just one could add to the validity of the results, increasing its generalizability. In addition, the study may gain more accurate data on all teens if it were conducted somewhere the law does not prohibit sleep restrictions on minors. Finally, the researcher may look into the effects of longer sleep restriction periods on other kinds of memory, including auditory and temporal memory. Overall, this study leaves many areas where future research may explore, expanding the valuable pool of knowledge on the importance of sleep and how it is necessary for optimal cognitive performance.

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