Is There an Association Between Sleep and Memory?

While extensive research has been conducted on the relationship between hours slept per night and academic performance in young adults, the literature is surprisingly silent on the relationship, if any exists, between hours slept and memory ability (Okano, et al.). This report examines the determinants of memory ability (as measured by time taken to complete a memory game) for high school students in Massachusetts. An initial linear model was created with all predictor variables, but diagnostics indicated that this was a poor fit for the data. After transforming the dependent variable, a final multiple linear regression model was created that predicts the square root of memory score using a student's grade, sleep hours on a school night, gender, favorite subject, and hours spent on homework. The only significant predictor of memory ability was a student's favorite subject; there is no significant relationship between memory ability and hours slept when we adjust for the other variables in the model. The lack of a relationship between amount of sleep and memory ability rebutted our primary hypothesis that getting more sleep increases memory ability. If we were to conduct further research, we would see if these results hold for students of other ages, such as young children and/or college students.

I. Background and Introduction

Across the United States, young adults in both high school and college perpetually strive for the perfect balance between academic work, extracurricular activity, and personal life. Striking this balance inevitably comes with sacrifices, especially for students at prestigious institutions such as Williams, who hold themselves to a very high academic standard. As college students, we are interested in learning about how our previous habits in high school might have affected our performance in high school. Our high school times were some of the busiest times of our lives; accordingly, our sleep during those four years fell compared to during our college years. Given the prevalence of studies that highlight the relationship of sleep quality and duration to academic performance, as well as studies linking academic stress to the national mental health crisis, we intend to look into the impact of sleep and other factors on a particular aspect of academic performance: an individual's working memory capacity, which, in this study, is measured by the time, in seconds, it takes an individual to complete a visual memory task.

The research questions of interest in this study are threefold. First, how does the average number of hours of sleep on a school night for a high school student influence memory scores? Second, does sleeping for fewer hours on average influence a student's average memory scores? Third, is there an association between one's favorite subject in school and memory scores? It is hypothesized that, perhaps, less sleep is associated with worse scores on the memory game. It is also hypothesized that students whose favorite subjects are STEM have better scores on the memory game because these students may practice their memorization skills more frequently in these favorite subjects.

II. Data and Exploratory Analysis

A. Data and Variables

The data collected for this study was obtained from the American Statistical Association Census at Schools Database. Information regarding student scores in the United States for grades 4-12 from 2010-2022 are available. This study in particular looked at data sourced from a random sample of 500 high schoolers (grades 9-12) in the state of Massachusetts from 2010 to 2022. This report looked specifically at eleven variables. There was one response variable—memory score—and ten predictor variables (grade, gender, age, languages spoken, finger length, birth month, favorite subject in school, average hours of sleep on a school night, average hours per week spent on homework, and average number of hours spent outdoors per week). For a more descriptive summary of each variable, see Appendix A. This dataset can be assumed to contain a representative sample of Massachusetts high school students since the sample was obtained randomly. However, conclusions drawn in this analysis should not be extrapolated to other grades or states. Additionally, issues with data collection include cautious and thorough data cleaning because these data were self-reported. There appeared to be many data entry errors as well as responses that did not appear realistic. (For example, one student reported spending 100 hours per week on homework.) These data points were removed, but consider that it is hard to distinguish the truth of self-report data.

Additionally, certain categorical variables were adjusted to maintain stability among the groups during the analysis. For the favorite subject variable, we grouped similar subjects together into three main categories: STEM, humanities, and other. Computers and technology, mathematics and statistics, and science fell into STEM; art, geography, social studies, history, English, languages, and music fell into Humanities; and physical education, other, and missing entries fell into other. For details about the grouping of other categorical variables, see Appendix A.

B. Exploratory Data Analysis

Many of our predictor variables (especially those measured in hours) contained only integer values, and so were not truly continuous. Because of the self-reported nature of the data, many of the variables also followed abnormal distributions (e.g., several peaks and troughs, extreme outliers), adding uncertainty to their reliability. However our two main variables of focus—score on the memory test and average hours of sleep on a school night—had smooth, mostly-uniform distributions. Appendix B contains the summary statistics for MemoryScore and SleepHoursSchoolNight, and Appendix C shows graphical distributions of all independent variables as well as the dependent variable. Looking at the bar plots in Appendix C, Favorite Subject was left as is. Grade was combined into two categories. One category was grade 12 and the other category was grades 9-11, as seniors may have different sleep habits from freshmen, sophomores, and juniors, and there were far more grade 12 responses than grades 9-11. Gender Missing was left as its own group because even though there are very few entries, it doesn't make contextual sense to group it with either Male or Female.

For the histograms, MemoryScore (mean = 45.46, median = 44.00) and SleepHoursSchoolNight (mean = 6.55, median = 7) are both unimodal and fairly symmetric, although MemoryScore is slightly right-skewed and SleepHoursSchoolNight is slightly left-skewed. Neither variable appears to have any extreme outliers, although MemoryScore notably has values at 0 (which is an impossible score on the test), but because they were not extreme outliers we did not remove them from our data. We must keep in mind that these scores are self-reported. We also explore potential multicollinearity between our predictor variables. Based on the pairs plot of continuous variables and side-by-side boxplot between FavSubCat (favorite subject broken into three categories: Humanities, STEM, and Other) in Appendix D, there does not appear to be any multicollinearity between our predictor variables or our response.

III. Model and Results

A. Analytic Methods

To attempt to answer our research question, we constructed a multiple linear regression normal error model. We started by regressing memory score on school night sleep hours as well as all the variables listed in the previous section. When checking the diagnostics of this initial model, we saw a few violations of the assumptions of a normal error linear model, as shown in Appendix E. First, the residuals of the memory scores predicted by our model exhibited non-constant variance: residual variance was smaller at low predicted scores and greater at medium and high predicted scores. Second, the residuals were not normally distributed as the normal probability plot did not appear linear.

To adjust our model in response to these issues, we used the Box-Cox procedure to find a suggested transformation of our response variable. Since the 95% confidence interval displayed on the Box-Cox plot was centered near 0.5, we decided to carry out a power transformation of memory score accordingly (i.e., a square root transformation), as shown in Appendix E. After transformation, we observed homoscedasticity of the residuals and a normal probability plot of the residuals that looked much closer to linear than before as shown in Appendix F. As such, we proceeded with this transformation.

When we regressed the square root of memory scores on all our predictor variables, we conducted t-tests on individual predictor variables and partial F-tests on groups of predictor variables to find that, when adjusting for all the other predictors, the only variable that had a significant effect on transformed memory score significant at the 5% level was students' favorite subjects. As such, we omitted all the initial predictors from our model other than sleep hours (our primary research interest), favorite subject (a significant predictor of memory score), homework hours (a potential confounding variable), gender, and age (control variables).

B. Final Model and Results

Despite fulfilling the assumptions of a normal error linear model, our model does not explain a great deal of the variation in the square root of memory score as the adjusted R-squared statistic of the model is 0.026. In other words, our model explains only 2.6% in the variation of Massachusetts high school students' sleep hours. For a summary table of the results of our final model, see Appendix G. Even when omitting some variables, we find once again that only favorite subject is a significant predictor of the square root of memory score. In particular, we are 95% confident that the interval (-0.46, -0.08) contains the average difference in the square root of memory score between students whose favorite subject is in STEM rather than in humanities. In reference to our research question, we find that the amount of sleep students get on a school night is not a significant predictor of their memory score. We are 95% confident that the interval (-0.05, 0.08) contains the average change in the square root of memory score for each additional hour of sleep students receive on a school night. As shown in the summary table, the other predictors we opted to include remain insignificant. See Appendix H for the final model and its corresponding coefficients.

IV. Discussion and Conclusions

In conclusion, there is no statistically significant relationship between the amount of sleep a high schooler receives and their score on the memory game. The only statistically significant predictor of memory score, at α = 0.05, is the indicator variable associated with a student favoring STEM courses. Favoring STEM courses is associated with an expected score that is, on average, 0.073 seconds faster than a student favoring humanities courses, holding all other factors constant. A possible explanation for this is that STEM courses involve more memorization than Humanities courses. Therefore, if a participant favors STEM courses, they may take more STEM courses and practice the skill of memorization more than kids who favor Humanities courses.

While this study was informative, multiple potential sources of error ingrained in its design and methodology make it difficult to draw extensive conclusions. As mentioned previously, students self-reported all of the data and may have reported data erroneously either by accident or to portray themselves in a better light (ie reporting a higher number of hours slept to appear healthier). Another limitation of this study was that students reported which subject was their favorite, rather than what subjects students studied the most or had the highest test scores in. Because we did not explore the relationship between a student's self-reported favorite subject and their 'best' subject, we cannot draw conclusions about a student's best subject or college major and their memory score.

In light of these limitations, there are numerous avenues that future researchers should consider exploring in order to draw more salient conclusions. First, student performance should be assessed on other mentally-stimulating cognitive tests, perhaps a test similar to a "concussion baseline" where there are several shorter-term and longer-term memory assessments based on shapes, colors, words, etc. While this study examined student performance on one particular memory game, it is entirely plausible that this game is not entirely indicative of mental cognition because it doesn't test sensory or long term memory, for example. Second, further research should be conducted as to how college students perform on the memory test. Study habits and cognitive ability may change as teenagers mature into young adults; examining exactly to what degree this change occurs may be of utmost importance to researchers.

References

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Deng, Yuwei, et al. “Family and Academic Stress and Their Impact on Students' Depression Level and Academic Performance.” *Frontiers in Psychiatry*, U.S. National Library of Medicine, 16 June 2022, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9243415/.

Okano, K., Kaczmarzyk, J.R., Dave, N. *et al.* Sleep quality, duration, and consistency are associated with better academic performance in college students. *npj Sci. Learn.* 4, 16 (2019). https://doi.org/10.1038/s41539-019-0055-z.

Appendix

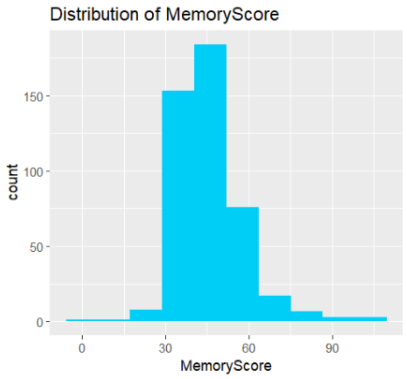
A. Variable Descriptions and Corresponding Categories (if applicable)

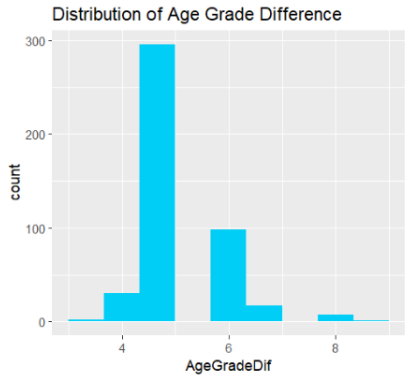
Variable	Description
MemoryScore	Memory score accounts for the time it takes, in seconds, for someone to solve a 4x5 memory puzzle. A lower time/score indicates faster/better performance. This is a continuous variable.
SleepHoursSchool Night	The average number of hours of sleep a student gets per night during the week. This is a continuous variable.
Grade	What grade the participant is in. This is an ordered categorical variable.
Gender	What gender the participant identifies as. This is a categorical variable.
AgeGradeDif	The participant's Age minus Grade. This is a continuous variable.
LanguagesSpoken	How many languages the participant is fluent in. This is a categorical variable. One of the categories is if you speak one language and the other category is if you speak 2+ languages.
LongerFinger	There is a myth that having a longer ring finger (compared to index finger) indicates a higher level of academic performance. This is a categorical variable with 0 = same length, 1 = ring finger longer.
BirthMonth	The month the participant was born in. This is a categorical variable.
FavoriteSubject	What the participant's favorite subject was. This is a categorical variable with STEM, Humanities, and Other being the categories.
HomeworkHours	How many hours a participant spends on homework per week, on average. This is a continuous variable.
OutdoorHours	How many hours a participant spends outdoors per week, on average. This is a continuous variable.

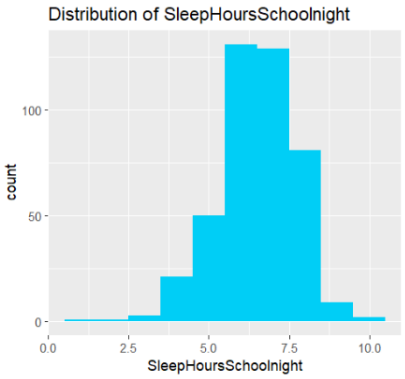
B. Summary Statistics for the Numerical Variables (Response Variable and Numerical Predictor Variables)

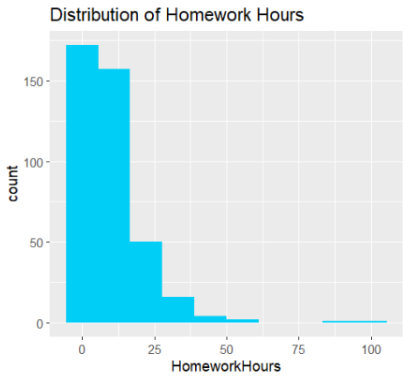
Variable	Mean	Variance	Median	IQR
MemoryScore	45.46	163.44	44.00	15.00
SleepHoursSchoolNight	6.55	1.55	7.00	1.00
AgeGradeDif	5.27	0.55	5.00	1.00
HomeworkHours	10.14	118.43	7.00	11.00
OutdoorHours	7.10	72.48	5.00	9.00

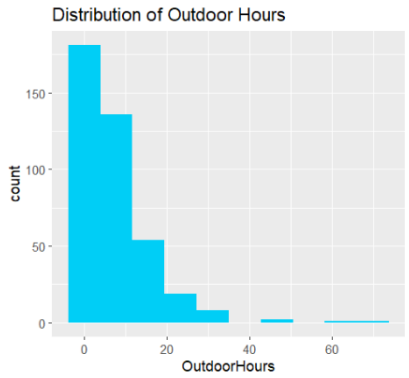
C. Histograms and Barplots of Variables

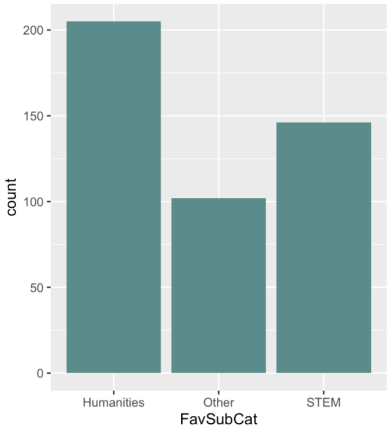


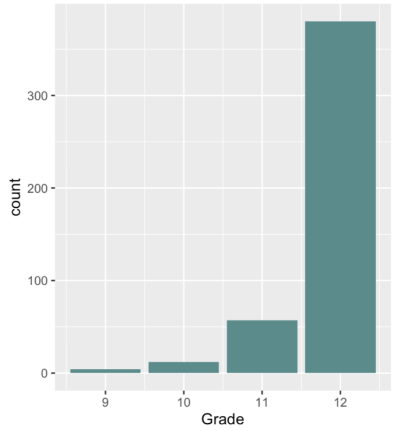


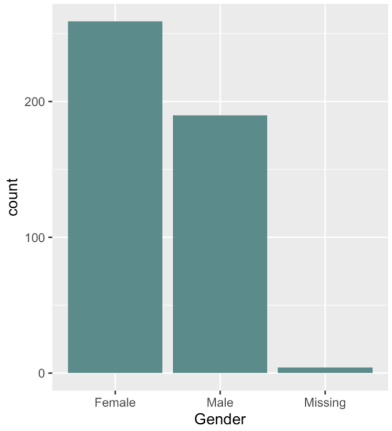




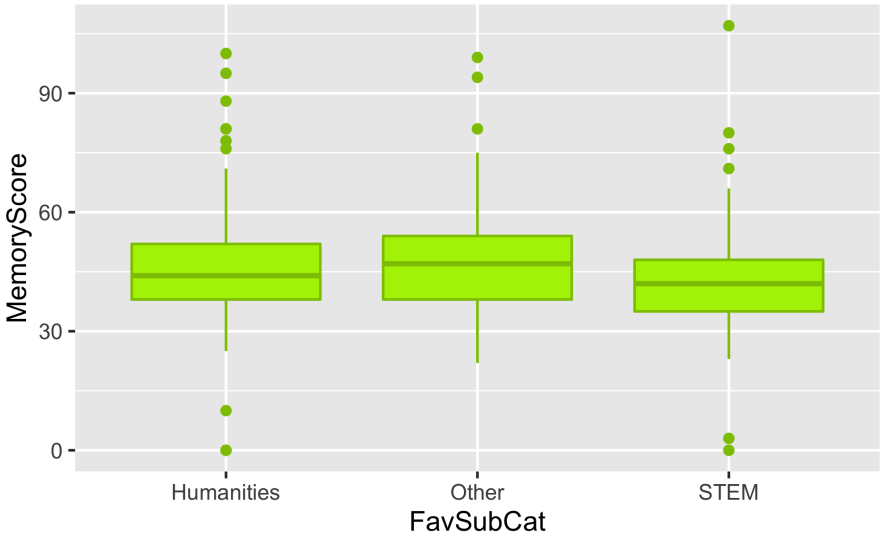


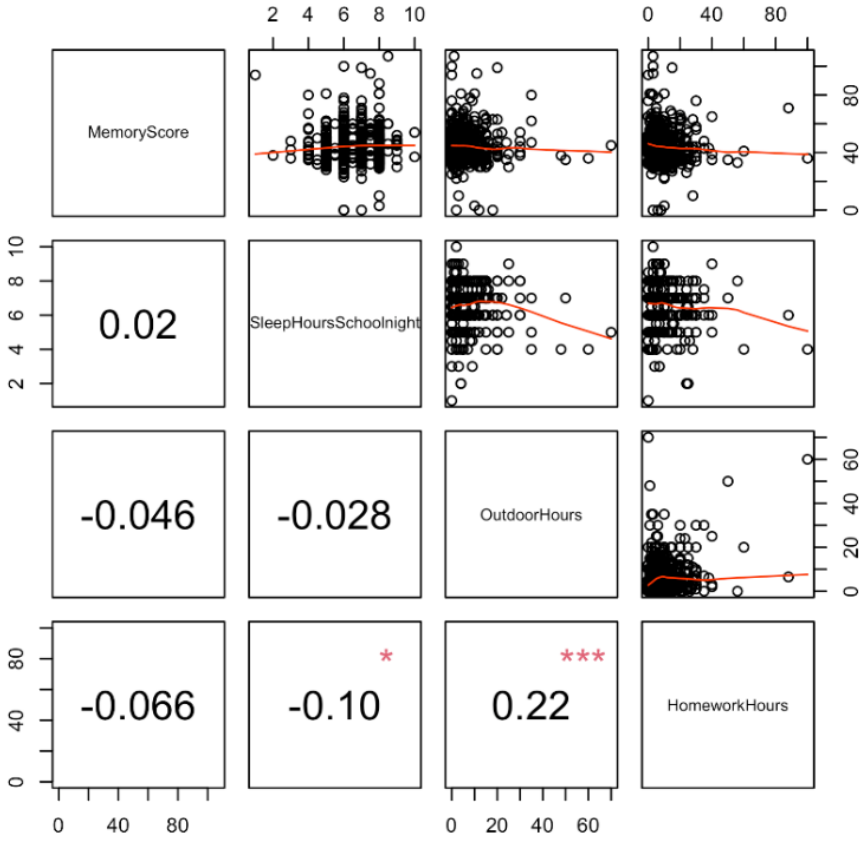




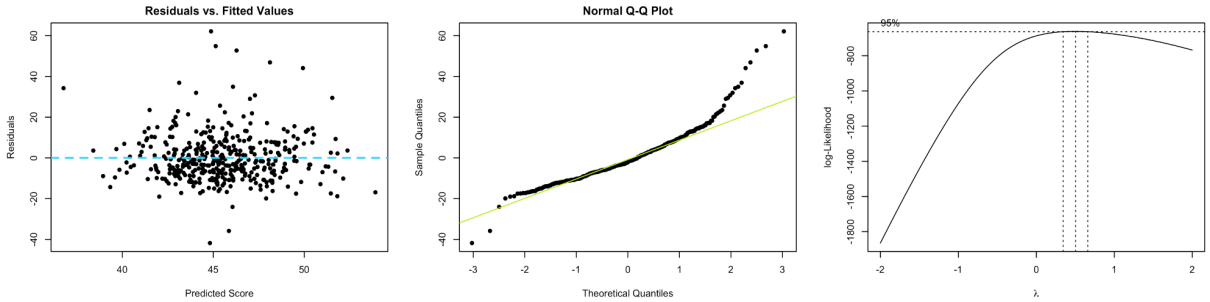


D. Relevant Bivariate Plots

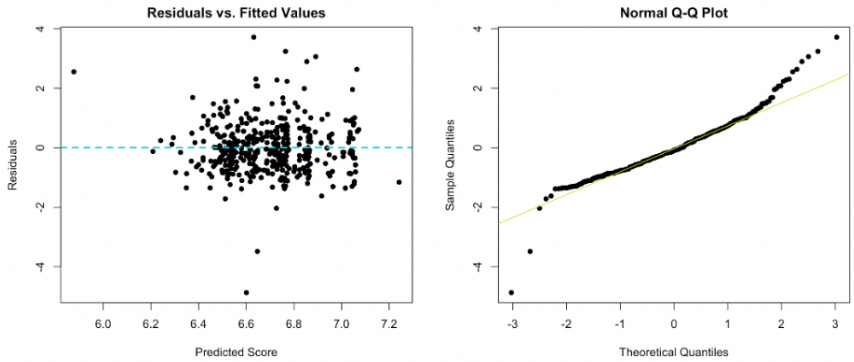




E. Initial Diagnostics



F. Diagnostics for the Final, Reduced Model



G. Summary Table of Final Model Coefficient Estimates

Variable	Estimate	Std. Error	P-Value	CI (95%)
Intercept	5.1917	1.0172	< 0.0001	(3.192, 7.191)
Grade	0.1212	0.0839	0.1467	(-0.0429, 0.287)
SleepHoursSchoolNight	0.0128	0.0347	0.7132	(-0.0554, 0.0809)
GenderMale	0.1415	0.0898	0.1158	(-0.0349, 0.3178)
GenderMissing	0.3464	0.5124	0.4994	(-0.6607, 1.3535)
FavSubSTEM	-0.2724	0.0966	0.0050	(-0.4622, -0.0826)
FavSubOther	0.1318	0.1213	0.2779	(-0.1066, 0.3703)

H. Final Model and Coefficients

$$\widehat{\sqrt{Memory}} = 5.1917 + 0.1212 Grade + 0.0128 SleepHoursSchoolNight + 0.1415 GenderMale + 0.3464 GenderMissing$$
$$- 0.27237 FavSubSTEM + 0.1318 FavSubOther$$