The Effect of Sleep Duration on Emotional N-back Performance in Children

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Abstract

Adolescence is a period of time where individuals experience biological and psychological changes, and sleep is a physiological process that provides support for some of these changes. Prior research has shown that adolescents sleep less than the CDC recommended average, and that the lack of sleep has a negative impact on different cognitive domains such as executive functioning, sustained attention, and long-term memory (Lowe et al., 2017). However, there is little information whether these effects are present in a younger age group, and there are a few large observational studies that take actigraphy data to study this relationship. We used baseline and year-2 data from the Adolescent Brain Cognitive Development study to investigate the relationship between sleep duration measured via actigraphy and performance in the emotional 2-back task among 5,897 participants. Results of a linear mixed regression model showed that there was a very small but significant relationship between sleep duration and rate of correct responses (p=0.007). For each additional hour slept, 2-back proportion correct increased by 0.007. Because we found a significant relationship, we utilized the co-twin control method to control for unmeasured confounds within families that could contribute to sleep duration. There was no significant relationship between twin differences in sleep duration and 2-back in 244 twin pairs and no significant interaction of zygosity with that relationship. These results indicated that there is a very small relationship between sleep duration and 2-back accuracy, but the data are not consistent with a causal or genetic relationship. We think this is because of a small sample size for the twin analysis which resulted in low power to detect the small relationship we saw in the full sample. The small but significant relationship between sleep and 2-back performance is important because it suggests that we need to do more research to further investigate how and why a lack of sleep is associated with different cognitive abilities in contexts such as school and extracurricular activities.

Introduction

Adolescence is one of the most crucial time periods a young adult endures as significant changes in the body occur. The brain, specifically, undergoes one of the most complex transformations in structure, cognition, emotional regulation, learning, attention, and intelligence. During this period, sleep is one function that provides substantial support for these changes. However, adolescence is a period often characterized by sleep duration averages well under the CDC recommended 8-10 hours (CDC, 2019). One review found many adolescents sleep less than 7 hours on school nights and less than 8 hours on the weekend (Galvan, 2020). Because adolescents are sleeping less, there can be negative effects on different cognitive functions, academics, mental health, and other behavioral implications. Due to these consequences, it is vital that the relationship between sleep and cognitive functioning is further studied to inform best practices and outcomes for this population.

According to a review, there is both social and biological reasoning as to why adolescents sleep less compared to other populations (Galvan, 2020). Socially, adolescents in middle and high school often have the compounded stress of extracurricular activities, academics, balancing social lives, and navigating the dynamics of different friend groups. Biologically, when puberty starts, there are changes in the body's internal clock that alter when melatonin is released, therefore shifting the bedtime and wake-up times to be approximately 2 hours later (Galvan, 2020). There are also changes in the homeostatic system of the body as well, where sleep pressure, which is the drive for sleep, is negatively affected and adolescents take longer to build up that drive to sleep, therefore having an urge to stay awake for longer and therefore sleeping less (Galvan, 2020). There are also neurobiological consequences of sleep deprivation in adolescence, where the prefrontal cortex of the brain undergoes structural changes, and a lack of sleep can weaken connections between important structures that are crucial for the adult brain. Due to these consequences, this can negatively affect important cognitive functions such as learning performance, attentional skills, and have memory impairments as well, which circles back to why sleep is significant for adolescents.

Within the literature, there are sleep restriction and sleep deprivation studies and while both studies are conducted experimentally, the difference is how extreme the sleep manipulation is. Sleep restriction is less extreme where experimenters give participants a limited number of hours to sleep and sleep deprivation is more extreme where experimenters make participants stay up longer than they are used to. Both examine the quantity of sleep in relation to cognition to correlate a positive, negative, or no effect with cognitive performance.

Sleep restriction studies have found a generally negative effect between a lack of sleep and different cognitive domains, but there is a gap in the literature due to a lack of studies done on children aged between 10-12 years old. A meta-analytic review looking at different experimental studies found that sleep restriction has a negative effect on certain cognitive domains and the largest negative effect was on executive functioning (Lowe et al., 2017). Specifically, a negative effect of sleep restriction was found on executive functioning, sustained attention, and long-term memory; there was no significant effect on other domains of attention, multitasking, impulsive decision making, and intelligence (Lowe et al., 2017). Executive functioning is a general set of mental processes needed to perform daily life activities like learning, following directions, working memory functionalities, etc. Attention is focusing on a specific stimulus and, impulsive decision making is quickly evaluating given scenarios. Most of the studies examined by this review conducted experiments with participants aged between 14-20, 20-40, and 40-60 years old. Another study found that sleep restriction, or shorter sleep, has a negative impact on the most challenging working memory task, but again the mean age range of the adolescents is 17 years old (Stefansdottir et al., 2020).

The problem with just looking at children's sleep times and their scores on different cognitive games is that there are different confounds that can also be the reason why they sleep less and affect cognitive performance on the games they play. To control for those confounds, a co-twin study design will be applied so that when comparing the twin's sleep times and their scores on the games, other factors that can affect their sleep will be controlled for since they are from the same household.

Another problem with these studies is that they are only sleep restrictions and sleep deprivation studies, meaning that the association between sleeping less and cognition are investigated and there are no studies about how sleeping more impacts cognition. It is not known whether longer sleep is associated with better or worse performance on different cognitive tasks.

Here we use the Adolescent Brain Cognitive Development Study's data to further investigate the negative effect of poor quantity of sleep on cognitive function within children between 10-12 years old. Then, we will use a co-twin study design to examine whether the relationship found from the first analysis is consistent with poor sleeping causing cognitive impairment. Specifically, Fitbit sleep accelerometer data from the second year's protocol and data from the 2-Back version of the N-back task will be used to investigate the relationship between sleep and cognitive function. First, we will test whether there is an association between sleep times and 2-Back scores within the whole sample. We think that children in the protocol who sleep within the CDC average will perform better on the 2-Back task and those who sleep less than the CDC average will perform worse on the 2-Back task. We will also examine the association between sleeping more than the CDC average and how that impacts scores on the 2-

Back task. If there is an association, then we will use the co-twin study design to control for unmeasured confounds and examine the results for a causal explanation.

Methods:

Participants

The Adolescent Brain Cognitive Development study is a 10-year longitudinal study that investigates the impact of different factors in adolescents' lives such as substance use, school, family structure and more on brain development. We used data from the ABCD study at baseline and the 2-year follow up to investigate the effect of sleep duration on emotional n-back scores. The number of participants with either sleep or n-back data were 5,897 (2,880 females, 3,017 males, mean age= 9.93 years old). See Table 1 for descriptive statistics of the sample.

Measures

Sleep Measure

The sleep data were collected via accelerometer data as part of the Mobile and Wearable Technologies data collection (Bagot et al., 2015). Participants who were selected (thus far only a subset of the sample due the cost of the technology) wore a FitBit on their wrist for 21 days. A FitBit was used as a measure of accelerometer data due to the ease of use by the participants and their parents and the similarity of data collection between a low-cost accelerometer device and a research-based polysomnography (Bagot et al., 2015). Among other parameters, daily amount of sleep was collected for each participant for the number of days they complied with wearing the FitBit. The time point with the most data was year 2 follow up, where there was sleep data for 5,901 participants. The number of nights data were collected for each participant ranged from 1 to 159, but the average number of nights was 13.68.

We grouped the data by participant and calculated the average hours slept over the collection period for each participant (M=7.40 hours). We checked the data for non-linearity to see whether we should treat average daily sleep as a categorical or continuous variable. We grouped participants into short sleepers (sleeping < 8 hours per night on average), good sleepers (sleeping 8-10 hours per night on average) and long sleepers (sleeping > 10 hours per night on average) and found 4,840 were short sleepers, 1,089 were good sleepers, and 8 were long sleepers. The small number of participants in the long sleep bin indicated we would not have much power to detect statistical differences between long sleepers and short/good sleepers. Further, we ran a model where average daily sleep and the square of average daily sleep predicted n-back performance, and mainly, the relationship between the square of average daily sleep and n-back was not significant. Therefore, there was no evidence of non-linearity, and sleep duration was treated as a continuous variable. See Figure 1 for a histogram of average hours slept per night.

N-back Measure

Emotional n-back is a cognitive task that assesses working memory. There are two versions of this task, 0-Back and 2-Back. In 0-Back, participants are presented with an image, which is either a face or a place, that is the target picture. Then, they are presented with subsequent images which they need to decide whether the new image matches the target picture or not. They indicate “yes” whether it matches the picture or “no” if it does not match the picture by pressing one of two buttons on a button box. In 2-Back, participants are presented with a series of images, and they need to indicate whether the image they are currently viewing matches the image shown 2 positions ago. If it is a match, they press one of the buttons to indicate “yes” and press the other button to indicate “no” if it doesn’t match. The 2-back version of the task is more difficult compared to 0-back. Based on evidence from the literature where other studies have found a relationship between poor sleep and 2-Back performance, 2-Back scores were used for this project (Freis et al., 2022).

The n-back data were transformed and scored according to Freis et al., 2022. We removed non responders and those who did not score better than chance, then calculated the rate of correct responses from the 2-Back data to indicate performance. A correct response means that the participant correctly indicated yes when the picture presented matched the old picture presented 2 positions back. An incorrect response means the current picture did not match the old picture and the participant indicated that it did match.

Analyses

Before conducting analyses, we regressed out sex and age from n-back performance. We subtracted out the effects of age and sex values from n-back, equating participants on sex and age but not standardizing n-back. We ran linear regression models with mixed effects to control for family to assess whether there was a significant relationship between average daily sleep and n-back performance. Finally, we applied the co-twin control method to see if the data are consistent with a causal relationship between average daily sleep and n-back performance if there was a significant relationship between sleep and n-back in the regression model.

Within the co-twin control method, twin differences between average daily sleep and n-back scores were computed by subtracting twin 1's and twin 2's scores to see whether twin sleep differences predicted twin n-back differences. We also examined whether zygosity interacted with the effect of sleep difference on n-back differences to evaluate genetic influences on sleep predicting n-back.

Results:

We found average daily sleep significantly predicted n-back performance (Beta= 0.007, *p*=0.007). As average sleep increases 1 hour, the predicted n-back proportion correct also increases 0.007. After plotting the linear relationship, we discovered an outlier was present in this model as one participant slept more than 14 hours on average per night, which is not realistic. We removed the outlier and re-ran the analysis. The relationship between the average daily sleep and n-back performance became slightly more significant, but was largely the same (Beta= 0.0081, *p*=0.003). See Figure 2 for the scatterplot depicting the linear relationship between sleep duration and n-back.

Because we found a significant relationship between sleep and n-back, we subsetted the data to contain only the twin sample and ran several twin analyses. There were 936 twins with sleep or n-back data (371 monozygotic and 565 dizygotic twins). We computed twin differences of average daily sleep and n-back performance by subtracting twin 1's scores from twin 2's scores. These twin difference score variables act as within-twin pair measures of sleep and n-back, and if a significant relationship is found, it would be consistent with a causal relationship between sleep duration and n-back. Then, we computed whether these twin differences depended on zygosity by letting the sleep difference score, zygosity, and their interaction predict the n-back difference scores. When putting this data into "wide format" for the within-twin pair analyses, there were 247 pairs who both had N-back, and 407 pairs who both had sleep measures, and 244 pairs with complete data for both n-back and sleep measures. Thus, we ended up with only 244 twin pairs for this analysis.

We found all relationships in this model to be non-significant. See Table 2 below for the twin-analyses statistics. For monozygotic twin pairs, the predicted n-back difference is 0.027

when the sleep difference is 0 hours between the twins, and as the difference in average hours per night increases 1 hour, the difference between twin pair n-back scores increases .004 (*p*=0.896). For dizygotic twin pairs, the predicted n-back difference is -0.008 when the sleep difference is 0 hours between the twins, and as the difference in average hours per night increases 1 hour, the difference between twin pair n-back scores increases -0.003 (p=0.863).

Table 1. Descriptive Statistics of Variables

Variable	N	Mean/ Count	Standard Deviation	Min	Max	Skewness	Kurtosis
Sex	5897	M=3,017; F=2,880	–	1.00	3.00	-0.05	-1.96
Age	5899	9.93 years	0.62 years	9 years	10.9 years	0.02	-1.28
Average Daily Sleep	5901	7.40 hrs	3.80 hrs	2.70 hrs	14.11 hrs	-0.91	5.11
n-back Performance	4041	0.76	0.12	0.15	1	-0.51	0.38

Table 2. Model Results from Regression Analyses

Model 1. Sleep predicting n-back (*N*=4040)		
Predictor Variable:	Beta	p
Average Daily Sleep	0.007	0.007
Model 2. Twin sleep differences predicting twin n-back differences (*N*=244 pairs)		
Predictor variable:	Beta	p
Intercept (MZ=0)	0.027	0.096
Sleep Differences	0.004	0.896
Zygosity	-0.034	0.091
Sleep Differences x Zygosity	-0.007	0.843

Figure 1

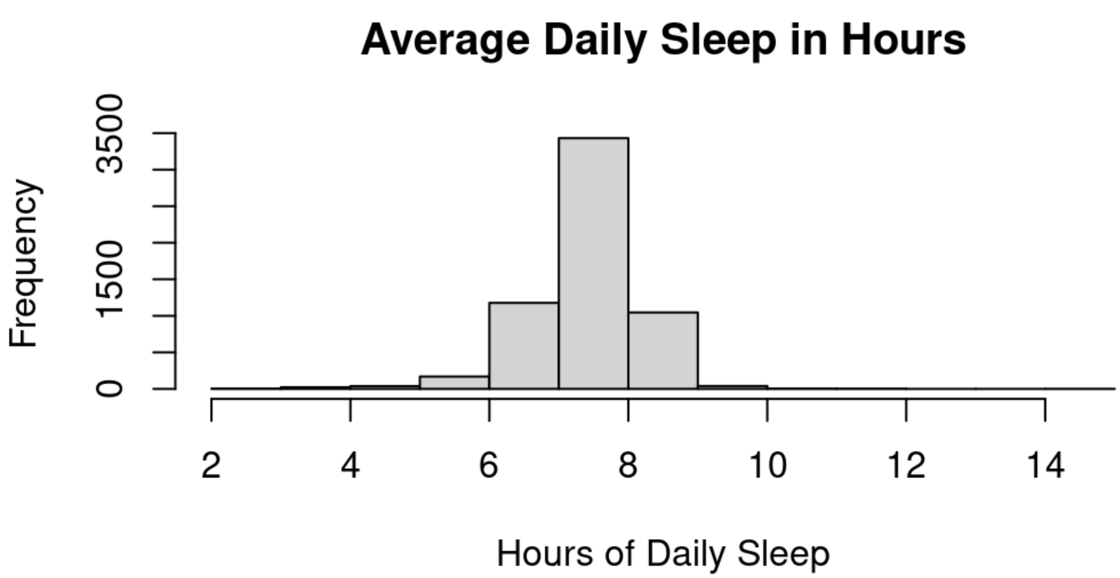
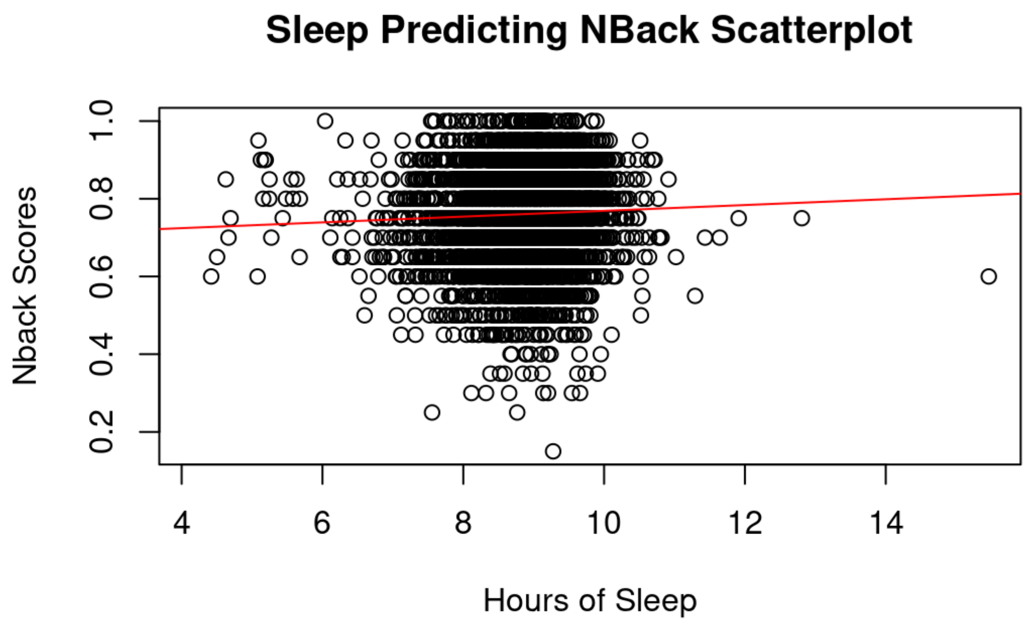


Figure 2- Scatterplot with Outlier



Discussion

Sleep is an incredibly important process for the human body as it provides substantial support for biological changes that occur during adolescence. However, adolescence is well characterized by sleeping less than the recommended amount due to social factors such as school, extracurricular activities, etc., and biological factors such as a shift in the internal clock and a shift in sleep drive, which lead adolescents to sleep later and take more time to build the sleep drive (Galvan, 2020). Because of these shifts, adolescents generally sleep less, which can have a negative impact on their cognitive abilities. Therefore, it is important to study this relationship to better understand how to mitigate this problem.

We used the baseline and 2-year follow up assessments from the ABCD study to investigate the relationship between number of hours slept and accuracy on the emotional n-back cognitive task. Our results showed that there was a significant relationship between sleep duration and n-back scores, such that more sleep was associated with better n-back accuracy. This association indicates that sleep could influence cognitive abilities in adolescence. It is a very small effect though, where for each additional hour of sleep, the predicted n-back proportion correct increases only 0.007. Nevertheless, this small effect may be important because it suggests there may need to be further research into how a lack of sleep can impact different cognitive abilities in contexts such as school and extracurricular activities.

Because we found a significant relationship between sleep duration and emotional n-back, we utilized the co-twin control method to evaluate whether the data are consistent with a causal relationship between sleep duration and n-back scores. Our results showed that there was no significant relationship between twin differences in sleep duration and twin differences in n-back scores. Thus, we have no evidence to conclude there is a causal relationship between sleep duration and n-back accuracy in these data. However, this result is inconclusive because of a small sample size in the twin analyses, which means there was low power to detect small effects that could be detected in the full sample.

Despite limited findings, these results are useful because we used a large sample of young participants (mean age= 9.93 years old). Using data from the Adolescent Brain Cognitive Development Study is useful because of its longitudinal design; we can investigate different relationships between the factors studied and see how this relationship changes over time as the children get older. Because we had such a large sample to analyze, our power to detect relationships between these variables was good. Further, the co-twin control method allowed us to control for external confounds that might affect how adolescents sleep because of the assumptions that monozygotic twins match completely on genetic and shared environmental influences, and dizygotic twins match 50% on genetic and completely on shared environmental influences.

Although one of the strengths of this study was the sample size, it is also one of the limitations. A study with as many participants as the ABCD sample has high power, meaning that even small effects can be detected as significant. But, when we analyzed the twin subsample, we had fewer participants with nonmissing data than in the main sample, which greatly reduced power for the statistical analysis. Although the association did not significantly interact with zygosity, numerically, we found the association between twin differences in sleep and n-back was a little stronger in monozygotic twins than dizygotic twins, which is the opposite of what we would have expected if the association is genetic. The association should be stronger in dizygotic twins than monozygotic twins to indicate a genetic influence because dizygotic twins differ genetically. The reduction of power could be due to the small sample size; therefore, the results are inconclusive.

In summary, our results show there is a small, but significant, relationship between sleep duration and emotional n-back accuracy, but results were inconclusive as to whether this association reflected a causal relationship. This needs to be investigated further or replicated in other samples where the twin sample size is bigger to avoid the power issue and for reliability to get consistent results across other studies. The regression model and the co-twin control method could be applied again to a different sample with more twins, or other methods could be used to decompose the variance on these traits into genetic and environmental influences. Additional work could also study relationships between other sleep variables and cognitive tasks to see how results compare and we can also study the same relationship when the children are older and see if there are differences. This is an important finding because adolescents go through a period where they are generally sleeping less. If sleep and cognitive abilities are associated, even in a small way, we should do more research on this association and work with adolescents to develop better sleep habits so that they can do better in school and other contexts.

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