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Associations of Executive Function with Sleepiness and Sleep Duration in Adolescents

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Abstract

Context—Sleep deprivation and sleepiness are associated with poorer school performance, impaired neurobehavioral functioning and behavioral problems.

Objective—To determine whether adolescents with high levels of sleepiness or short sleep duration have impaired executive functioning.

Design, Setting, and Participants—Cross-sectional analysis of data from 236 healthy adolescents in a community-based cohort study. Sleepiness was measured using a modified version of the Epworth Sleepiness Scale (ESS). Participants underwent 5–7 day wrist actigraphy at home prior to overnight polysomnography. Exposure variables were excessive sleepiness (ESS ≥ 11) and weekday mean sleep duration.

Main Outcome Measures—The Global Executive Composite (GEC) scale from the Behavior Rating Inventory of Executive Function (BRIEF) and the Tower Test – Total Achievement score from the Delis-Kaplan Executive Functioning System (D-KEFS).

Results—Participants (n=236) were 13.7 ± 0.8 years, 52.1% were male. Mean weekday sleep duration was 7.70 ± 1.03 hours; 11% slept < 6.5 hrs on average on weekdays and 26% reported excessive sleepiness. In unadjusted analyses, sleepy adolescents had poorer executive functioning on the BRIEF GEC (5.30 ± 1.67, p=0.002) and D-KEFS Tower Test Total Achievement (−1.11 ± 0.46, p=0.02). Analyses adjusted for potential confounders resulted in a modest attenuation of the association with the BRIEF and a larger attenuation for the D-KEFS. Caregiver education modified the association between sleepiness and the BRIEF outcomes; Among sleepy adolescents, those with less educated caregivers had greater impairment on the BRIEF-GEC. Sleep duration was not significantly associated with executive functioning outcomes.

Conclusions—Decrements in selected executive function scales are associated with subjective sleepiness, but not sleep duration, in adolescents. The association between sleepiness and

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executive functioning is strongest among adolescents with primary caregivers who have lower levels of education, suggesting an increased susceptibility. Pediatricians and public health officials should consider sleepiness as a potentially important contributor to adolescent functioning.

Keywords

Sleep; Adolescent; Sleepiness; Cognition

INTRODUCTION

Only 20% of adolescents receive the recommended 9 hours of sleep on school nights; 45% sleep less than 8 hours and more than half report daytime sleepiness (1). Many factors influence loss of sleep, including early school start times, social and extracurricular activities, and circadian timing changes (2, 3). The consequences of sleep deprivation and daytime sleepiness may include behavior problems, poorer school performance, mood disturbances, and inattentive driving (4).

Accumulating research has also found decreased quality or quantity of sleep, and increased sleepiness, to be associated with impaired neurobehavioral functioning in school aged children (5–10). Unfortunately, there has been a paucity of research that examines the association between sleep and executive functioning in large community-based samples of adolescents, or the confounding or moderating influences related to low socioeconomic status (SES). The latter may be of particular importance since children from low socioeconomic status (SES) households have a high prevalence of poor sleep habits, poor quality sleep, and short sleep durations (11–14)

Our hypothesis is that adolescents who report high levels of sleepiness or adolescents with shorter sleep duration will have greater impairment in executive functioning. We also explored the moderating effects of SES on sleepiness or short sleep duration, expecting that those who are from low SES households would have the greatest impairment.

METHODS

Subjects

The study sample was derived from the Cleveland Children's Sleep and Health Study, an ongoing longitudinal cohort (22). The first examination included 907 children recruited from the birth records of area hospitals and studied between 1998–2002, when the children were 8–11 years of age.. At the second examination from 2002–2006, we aimed to enroll at least 250 Cleveland Children's Sleep and Health Study participants aged 13–16, including all snorers and SDB cases identified at the first exam, and a stratified (sex, race, preterm (<37 weeks gestational age)) random sample of the remaining cohort (n=389) (15). Of the 292 participants studied, we excluded adolescents with sleep apnea, suspected narcolepsy, or cerebral palsy with physical limitations (n=31) and those without a minimum of 4 weekdays of actigraphy data (n=27), yielding an analytic sample of 236 adolescents. No appreciable differences in covariate distributions were observed between the observed and excluded adolescents.

Study Protocol

Prior to an examination at a clinical research facility, participants wore a wrist actigraph for 5–7 days at home and completed daily sleep logs. The actigraph was worn 24 hours a day other than during activities that might damage the actigraph. Any removal of the actigraph was noted in the sleep diary. Examinations at the research center began at approximately 13:00 and ended the following day at 11:00, and included neurobehavioral testing (between 1400 and 1700) prior to overnight polysomnography, as well as physiological and anthropometric assessments. Informed consent was obtained from the child's parent or legal guardian and written assent was obtained from the child. The study was approved by the University Hospitals of Cleveland Institutional Review Board For Human Investigation.

Executive Functioning Outcomes

Two instruments were used: 1) the Behavior Rating Inventory of Executive Function (BRIEF), which provided parent reported measures of executive functioning (16); and 2) the Delis-Kaplan Executive Functioning System (D-KEFS) (17), which provided performance-based measures. The BRIEF consists of 86 questions with 8 subscales designed to measure a broad range of executive functioning. The Global Executive Composite (GEC) scale was our primary outcome measure from the BRIEF. The GEC is comprised of two subscales: the Metacognition Index, which assesses the ability to keep track of information and monitor one's actions in carrying out activities of daily living, and the Behavioral Regulation Index, which assesses the ability to maintain appropriate behavior and to self-regulate behavior). The Metacognition Index and Behavioral Regulation Index subscales were considered to be secondary outcome measures. Raw scores were converted to age and sex adjusted T-scores with a mean of 50 and standard deviation of 10, with higher scores indicating poorer executive functioning.

The D-KEFS includes 9 subtests designed to measure a broad array of executive functioning tasks. Participants completed 5 D-KEFS tests: *Trail Making Test*, *Verbal Fluency Test*, *Color-Word Interference Test*, *Sorting Test*, and *Tower Test*. The Tower Test (Total Achievement) was our primary performance based measure since it places demands on multiple aspects of executive functioning (e.g., planning ahead while keeping the rules in mind) and draws on several aspects of goal-directed behavior (self-guided action, planning, response inhibition, working memory for the rules). All other test results were considered secondary. Raw scores were converted to age and gender-specific scaled scores with a mean of 10 and standard deviation of 3, with lower scores signifying poorer performance.

Sleep Related Exposure Assessments

Our two primary exposures were excessive daytime sleepiness and weekday mean sleep duration measured by actigraphy. Other sleep exposure variables were considered secondary. Daytime sleepiness was measured using pediatric modification of the Epworth Sleepiness Scale (ESS). In this 8 item questionnaire, adolescents rate on a 4-point scale how likely they are to doze in different situations. Various modifications have been used in pediatric populations (18–21). For this study, the last item "in a car while stopped for a few minutes in traffic" was replaced with "doing homework or taking a test". Cronbach's alpha was 0.74 for this measure. Participants with a total ESS score ≥11 were considered to be excessively "sleepy". This cutoff has been used in prior adolescent research (20, 22, 23).

Mean sleep duration, coefficient of variation and sleep efficiency were estimated using 5 to 7 day wrist actigraphy (Octagonal Sleep Watch 2.01; Ambulatory Monitoring Inc., Ardsley, NY), analyzed using the Action-W software and the Time Above Threshold (TAT) algorithm as described previously (24). In sleep diaries, participants recorded a bedtime and waketime for each day. Actigraphy sleep data between bedtime and waketime was used for all variables. Given the greater number of weekdays compared to weekend days of data, we focused on weekday actigraphy as a potentially more reliable measure of sleep patterns. Sleep duration was examined as a continuous variable and a binary measure. Short sleep duration was considered weekday sleep duration below 6.5 hours, a threshold that approximated the lowest decile. Coefficient of variation was created by dividing mean sleep duration by the standard deviation, then multiplying by 100. A sleep efficiency measure was created for each day by dividing time asleep based on actigraphy by time in bed reported in the sleep diary. An average of all ratios was defined as average weekday sleep efficiency.

Full-channel overnight PSG was performed over a single recording night (E-Series, Compumedics Ltd., Abbotsford, Victoria, Australia). Sleep stages and arousal were scored using standard criteria(25, 26). Sleep variables derived from PSG included PSG-defined sleep efficiency, number of arousals per hour, and percentages of sleep times in stage 3–4 and in REM sleep.

Measures of Socioeconomic Status (SES)

We included three measures of SES: family income (measured on a 7-point scale ranging from <$5,000 to ≥$50,000), caregiver education (< high school, high school or equivalent, some college, ≥ college degree), and the median income of the child's neighborhood. Neighborhood income was ascertained by linking the participant's address to data from the 2000 US Bureau of the Census (27).

Other Measures

Body mass index (BMI) was calculated by dividing the weight in kilograms by height in meters squared and converted into age and sex adjusted percentiles (28). Standardized questionnaires were used to collect demographic, symptom, and medical history data.

Statistical Analysis

Bivariate analyses comparing sleepy and non-sleepy adolescents were assessed using the Pearson chi-square test for categorical variables, the two-sample t-test for normally distributed variables, and the Wilcoxon Rank-Sum test for non-normally distributed measures. Pearson correlations were used to examine the unadjusted association between mean sleep duration and each outcome measure. Multiple linear regressions were used to further assess the association between sleepiness and sleep duration to executive functioning. After examining the unadjusted associations (Model 1), two additional models were fitted to adjust for potential confounders: Model 2 was adjusted for subject characteristics (age, gender, term status) and Model 3 was adjusted for subject characteristics and measures of SES. Effect modification by SES was evaluated by fitting the two way interaction between each sleep exposure and each measure of SES, adjusting for subject characteristics.

Several secondary analyses were performed: First, we examined the association between each sleep exposure and the secondary D-KEFS and BRIEF outcomes. Second, we refitted the adjusted linear regression models (model 3) and included both sleep exposures. Third, model 3 with each sleep exposure was refitted after additionally adjusting for a sleep quality measure derived from actigraphy (coefficient of variation or sleep efficiency). Model 3 was then refitted after additionally including a sleep quality measure from PSG (percentage time in stage 3–4 sleep, percentage time in REM or sleep efficiency).

Results are summarized as adjusted mean differences and their standard errors for binary exposures. For exposures that are continuous variables, slopes and standard errors are presented. SAS version 9.1 was used for all analyses (SAS Institute, Inc., Cary, NC).

RESULTS

Sample characteristics are shown in Table 1. The average age of the participants was 13.7 years. Actigraphy data showed that adolescents slept less than 8 hours on weeknights (mean=7.70, SD=1.03, min=4.34, max=10.59) and that 11% had an average weekday sleep duration of <6.5 hours ("short sleep"). Sleep duration was 33 minutes longer on weekends. Approximate duration of sleeping during the day was 21 minutes. The mean ESS score was 7.8 (SD=4.4, min=0, max=19).

Associations with Sleepiness

Bivariate comparisons of the 62 adolescents who were sleepy (ESS ≥11) with the 174 adolescents who were non-sleepy revealed that the former group had a higher proportion of African-Americans and was heavier (Table 1). A higher proportion of sleepy adolescents lived in homes with lower household incomes and lower neighborhood incomes. Short weekday sleep duration (<6.5 hrs) was more prevalent among sleepy adolescents (i.e, sleepy adolescents had 2.7 times the odds of short weekday sleep duration). Sleepy adolescents also had shorter mean weekend sleep duration, greater night-to-night variability in sleep duration, and poorer sleep efficiency compared with non-sleepy adolescents. The results from the overnight PSG study show that sleepy and non-sleepy adolescents did not appreciably differ in the number arousals per hour, percent time in REM sleep or sleep efficiency. However, sleepy adolescents spent significantly less time in stage 3–4 sleep (slow wave sleep) compared with non-sleepy adolescents.

Associations with Sleep Duration

Bivariate analyses of child and caregiver characteristics stratified by short sleep duration on weekdays are also presented (Table 1). The proportion of African-American children and children with lower family household incomes was higher among children with short sleep duration Short sleep duration was associated with greater actigraphy-determined measures of night-to-night variability in sleep duration and poorer sleep efficiency.

Associations between Executive Function and Sleepiness

The unadjusted standardized scores on the measures of executive functioning, as well as the results of the multivariable linear regression analyses of the unadjusted and adjusted associations between sleepiness and executive functioning, are displayed in Table 2. Unadjusted analyses show that sleepy adolescents performed significantly worse on the BRIEF GEC (5.30 ± 1.67, p=0.002). This association was modestly attenuated after adjusting for subject characteristics and SES measures (Model 3: 4.77 ± 1.73, p=0.006; adjusted r^2 = 0.04). Examination of the two subscales that comprise the BRIEF GEC show that this association is largely driven by the Metacognition Index rather than the Behavioral Regulation Index. Unadjusted analyses show that sleepy adolescents performed significantly worse on the D-KEFS Tower Test (−1.11 ± 0.46, p=0.02). This association was moderately attenuated after adjusting for child characteristics and measures of SES (−0.87 ± 0.45, p=0.06; adjusted r^2 = 0.08).

Associations between Measures of Executive Function and Sleep Duration

The unadjusted and adjusted associations between mean sleep duration and the executive functioning outcomes are shown in Table 3. Neither mean sleep duration nor “short sleep” was significantly associated with either of the primary outcomes in unadjusted or adjusted analyses. For the secondary outcomes, mean sleep duration was significantly associated with D-KEFS Color-Word Interference; however, this association was diminished and was no longer statistically significant after adjusting for subject characteristics and SES measures.

Assessment of SES Measures as Effect Modifiers

The two-way interaction between each primary sleep exposure variable and each measure of SES was fitted for each outcome. Caregiver education modified the association between sleepiness and the BRIEF outcomes; the association between sleepiness and the BRIEF outcomes was strongest among adolescents who had caregivers with lower levels of education (Figure 1). Caregiver education did not modify the association between mean sleep duration and executive functioning. Neither household nor neighborhood income modified the association of executive functioning and sleepiness or sleep duration.

Exploratory Analyses: Sleep Quality and Executive Functioning

To gain insight about the association between sleep quality, sleepiness and executive functioning, multiple linear regression analyses (Model 3) were rerun additionally adjusting for various indicators of sleep quality. The association between sleepiness and executive functioning did not appreciably change after additionally adjusting for coefficient of variation in mean sleep duration or sleep efficiency based on the actigraphy data, or after additionally adjusting for sleep efficiency, percent time in stage 3–4 sleep or percent time in REM sleep from PSG. However, percent time in REM from PSG was positively associated with D-KEFS Trail Making Test (slope and standard error for each 1% increase in percent time in REM: 0.12 ± 0.05, p=0.02) and D-KEFS Verbal Fluency Test - Category Fluency (0.09 ± 0.04, p=0.02). Additionally, percent time in REM was marginally associated with D-KEFS Verbal Fluency Test - Letter Fluency (0.08 ± 0.05, p=0.07), Verbal Fluency Test - Category Switching Total Correct Responses (0.08 ± 0.04, p=0.07), Sorting Test - Free

Sorting Condition (0.07 ± 0.04, p=0.06), and the BRIEF Behavioral Regulation Index (−0.30 ± 0.17, p=0.07).

DISCUSSION

Despite the growing prevalence of insufficient sleep in adolescents, limited research has addressed the associations of sleep duration, sleepiness, and cognitive functioning in this population. We performed extensive analyses of indices of sleep and an aspect of cognitive function, executive functioning, in a community sample of adolescents. Our analyses identified important inter-relationships among sleep, subject characteristics, and executive functioning. First, we observed a high prevalence of sleepiness in adolescents and identified a number of possible risk factors for sleepiness, including higher BMI, lower SES, African American race, shorter sleep duration, and lower percentage of slow wave sleep. Second, in age, gender, and term/preterm adjusted analyses, we identified significant associations between sleepiness and two measures of executive functioning, one based on parent report and the second based on a performance measure.

Adjustments for SES modestly attenuated the association between sleepiness and parent-reported executive functioning (change in parameter estimate by 15%); a larger attenuation occurred in models of performance-based measures of executive function (change in parameter estimate by ~25%). The statistically stronger association between self-perceived daytime sleepiness and lower parent ratings of executive functioning is consonant with the view that weaknesses in executive functioning are more manifest under the less controlled conditions of everyday living than in highly structured test settings (16). Contrary to our hypothesis, sleep duration was not associated with executive functioning in adjusted models.

A higher prevalence of sleepiness and shorter sleep duration in adolescents from low SES households or poor neighborhoods is consistent with prior research (11–14). Low SES is a recognized risk factor for reduced cognitive functioning and academic performance (29) and may operate as a confounder. Our results show the general persistence, with some attenuation, of the association between sleepiness and executive function after accounting for caregiver education, household income, and poor neighborhoods, suggesting that confounding with SES does not completely explain the association between sleepiness and executive functioning. The mechanism through which SES influences cognitive function is not fully understood.

Recently, Buckhalt et al. identified an association between sleep duration and quality with academic performance in a group of third grade students. Moreover, SES was identified as an effect modifier in the association between academic achievement and sleep (the associations were stronger in children of low compared to high SES). Similar to Buckhalt et al. but in a different age group, our study found that caregiver education moderated the association between sleepiness and parent-reported executive functioning such that sleepy adolescents who had caregivers with lower levels of education had the greatest impairment in executive functioning.

Although sleepy adolescents were more likely to have shorter sleep duration, we did not observe a significant association between sleep duration and executive functioning. Although measurement of sleep duration using actigraphy has been validated in many populations, including adolescents, there is some degree of measurement error, which may have attenuated any real association (24). Additionally, sleep duration may not adequately capture individual sleep needs in adolescents. Previous research has suggested inter-individual differences in tolerance for sleep deprivation and sleep need (30, 31). If sleep duration needs are variable, then self-reported sleepiness may be a better indicator of sleep deprivation.

Our results need to be interpreted in light of several limitations. First, the clinical impact of small decrements in executive functioning on day to day functioning is not well established. Our findings also showed that only some of the subscales of executive functioning varied significantly with sleepiness. Such modest findings may be attributable to study of only a relatively small number of adolescents with very short sleep duration. Also, the more robust findings for parent-reported compared with performance-based measures raise the possibility of reporting biases. However, sleepiness was reported by the adolescent and executive function by the parent, mitigating this concern. Measurements other than actigraphy were collected on only a single occasion, which may reduce their reliability and bias findings toward the null. Finally, a number of comparisons were made, which may have increased the likelihood of falsely rejecting the null hypothesis.

In summary, this work underscores the high prevalence of self reported sleepiness in adolescents and provides evidence that sleepiness may contribute to mild impairments in tests of executive functioning. Further research is required to determine how to best identify the sleep needs of at-risk adolescents and identify those who are at most at risk for sleep related impairments.

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List of Abbreviations

BRIEF	Behavior Rating Inventory of Executive Function
D-KEFS	Delis-Kaplan Executive Functioning System
ESS	Epworth Sleepiness Scale
GEC	Global Executive Composite
SES	Socioeconomic Status

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Table 1

Sample Characteristics for the Entire Sample & Stratified by Sleepiness and Short Sleep Duration

	Entire Sample (n=236)	Not Sleepy: ESS < 11 (n=174)	Sleepy: ESS ≥ 11 (n=62)	Longer Sleep ≥ 6.5 hrs (n=210)	Short Sleep: < 6.5 hrs (n=26)
Child Characteristics					
Age	13.7 ± 0.8	13.7 ± 0.8	13.6 ± 0.7	13.7 ± 0.7	13.9 ± 1.0
Male Gender	123 (52.1%)	94 (54.0%)	29 (46.8%)	108 (51.4%)	15 (57.7%)
African-American Race	120 (50.9%)	75 (43.1%)	45 (72.6%) *B*	101 (48.1%)	19 (73.1%) *A*
Preterm Status	136 (57.6%)	101 (58.1%)	35 (56.5%)	122 (58.1%)	14 (53.9%)
BMI Percentile	67.9 ± 27.6	64.4 ± 28.6	77.7 ± 22.4 *B*	67.7 ± 27.6	69.7 ± 28.6
Overweight (BMI %tile ≥ 95th)	52 (22.4%)	34 (20.0%)	18 (29.0%)	45 (21.7%)	7 (28.0%)
Sleep Characteristics					
Actigraphy: mean weekday sleep duration (hrs)	7.70 ± 1.03	7.78 ± 0.96	7.47 ± 1.18	7.93 ± 0.83	5.88 ± 0.57 *B*
Actigraphy: mean weekend sleep duration (hrs)	8.25 ± 1.41	8.43 ± 1.36	7.71 ± 1.42 *B*	8.40 ± 1.29	6.96 ± 1.67 *B*
Actigraphy: mean weekday sleep duration < 6.5 hours (short sleep) 6.5 – 7.49 hours 7.5 – 8.49 hours ≥ 8.5 hours	 26 (11.0%) 72 (30.5%) 89 (37.7%) 49 (20.8%)	 14 (8.1%) 50 (28.7%) 73 (41.9%) 37 (21.3%)	 12 (19.4%) *A* 22 (35.5%) 16 (25.8%) 12 (19.3%)	 0 (0.0%) 72 (34.3%) 89 (42.4%) 49 (23.3%)	 26 (100.0%) *B* 0 (0.0%) 0 (0.0%) 0 (0.0%)
Actigraphy: Coefficient of Variation sleep duration weekdays (%)	13.30 ± 7.95	12.19 ± 7.77	16.41 ± 7.67 *B*	12.51 ± 7.39	19.70 ± 9.42 *B*
Actigraphy: weekday sleep efficiency (%)	89.7 (84.6, 93.6)	90.4 (86.4, 94.3)	86.3 *B* (80.8, 92.5)	90.3 (86.3, 93.8)	80.1 *B* (72.4, 85.5)
Actigraphy: weekday daytime sleep duration (min)	21.8 (8.0, 47.1)	21.4 (7.0, 43.3)	22.7 (8.0, 71.0)	24.3 (8.0, 47.4)	18.7 (7.0, 36.5)
Actigraphy: weekend daytime sleep duration (min)	18.0 (6.0, 63.0)	17.5 (6.0, 59.5)	22.0 (6.0, 77.0)	19.5 (6.0, 66.0)	12.5 (6.5, 26.0)
Self-report: weekday time in bed	8.66 ± 1.04	8.69 ± 1.07	8.57 ± 0.95	8.74 ± 0.96	8.01 ± 1.45 *A*
PSG: Arousal Index *	7.4 (6.1, 9.4)	7.4 (6.0, 9.4)	7.4 (6.2, 9.7)	7.3 (6.0, 9.4)	8.2 (6.3, 10.8)
PSG: % time stage 3–4 *	32.1 (25.2, 40.7)	33.5 (25.4, 41.2)	29.0 *A* (23.9, 36.9)	32.2 (25.3, 40.7)	29.5 (20.6, 40.3)
PSG: % time REM *	18.4 (15.1, 21.4)	18.3 (15.2, 21.4)	18.5 (15.0, 21.0)	18.2 (15.1, 21.4)	18.9 (16.1, 21.8)

	Entire Sample (n=236)	Not Sleepy: ESS < 11 (n=174)	Sleepy: ESS ≥ 11 (n=62)	Longer Sleep ≥ 6.5 hrs (n=210)	Short Sleep: < 6.5 hrs (n=26)
PSG: Sleep Efficiency *	90.2 (85.5, 94.0)	90.6 (85.6, 94.2)	89.8 (85.5, 92.9)	90.2 (85.6, 93.8)	91.5 (82.6, 94.4)
ESS: Sleepiness	7.8 ± 4.4	5.8 ± 3.0	13.5 ± 2.4 [B]	7.6 ± 4.3	9.7 ± 5.1 [A]
Socioeconomic Measures					
Household Income					
<$20,000	58 (26.5%)	34 (21.2%)	24 (40.7%) [B]	47 (24.1%)	11 (45.8%) [A]
$20,000 – $49,999	64 (29.2%)	46 (28.8%)	18 (30.5%)	58 (29.7%)	6 (25.0%)
≥$50,000	97 (44.3%)	80 (50.0%)	17 (28.8%)	90 (46.2%)	7 (29.2%)
Neighborhood Median income Census Tract ($1000) *	39.5 (24.7, 53.8)	42.0 (25.5, 56.0)	29.2 [A] (23.2, 46.0)	41.0 (24.2, 55.3)	32.2 (26.1, 40.6)
Caregiver Education					
< High School	21 (9.1%)	14 (8.3%)	7 (11.5%)	17 (8.3%)	4 (15.4%)
High School or GED	47 (20.5%)	34 (20.1%)	13 (21.3%)	41 (20.1%)	6 (23.1%)
Some College	84 (36.5%)	61 (36.1%)	23 (37.7%)	77 (37.8%)	7 (26.9%)
College Degree or Higher	78 (33.9%)	60 (35.5%)	18 (29.5%)	69 (33.8%)	9 (34.6%)

* Test statistics from the pearson Chi-square test for categorical variables, two-sample t-test for normally distributed variables, and the Wilcoxon Rank-Sum test for non-normally distributed measures.

[A] Statistically significant at $p<0.05$

[B] Statistically significant at $p<0.01$

* Median (25^{th}, 75^{th} percentile);

ESS: Epworth Sleepiness Score; PSG: Polysomnograph

Table 2

Unadjusted and Adjusted Associations Of Sleepiness (ESS ≥ 11 vs. < 11) with Executive Functioning Measures

	Mean ± SD	Model 1 beta ± se p-value	Model 2 beta ± se p-value	Model 3 beta ± se p-value
Primary Outcomes				
BRIEF: GEC	52.0 ± 11.4	5.30 ± 1.67 P=0.002	5.60 ± 1.68 P=0.001	4.77 ± 1.73 P=0.006
D-KEFS: Tower Test, Total Achievement	9.20 ± 3.10	−1.11 ± 0.46 P=0.02	−1.13 ± 0.45 P=0.01	−0.87 ± 0.45 P=0.06
Secondary Outcomes				
BRIEF: Metacognition Index	52.4 ± 10.9	5.49 ± 1.58 P<0.001	5.77 ± 1.59 P<0.001	5.21 ± 1.65 P=0.002
BRIEF: Behavioral Regulation Index	50.9 ± 12.3	4.29 ± 1.82 P=0.02	4.55 ± 1.83 P=0.01	3.41 ± 1.87 P=0.07
D-KEFS: Trail Making Test, Number-Letter Switching	8.16 ± 3.69	−1.12 ± 0.54 P=0.04	−1.18 ± 0.54 P=0.03	−0.67 ± 0.53 P=0.21
D-KEFS: Verbal Fluency Test, Letter Fluency	10.13 ± 3.33	−0.55 ± 0.49 P=0.26	−0.57 ± 0.49 P=0.25	−0.52 ± 0.51 P=0.31
D-KEFS: Verbal Fluency Test, Category Fluency	11.36 ± 3.08	−0.07 ± 0.46 P=0.88	−0.12 ± 0.46 P=0.79	0.02 ± 0.47 P=0.97
D-KEFS: Verbal Fluency Test, Category Switching Total Correct Responses	10.23 ± 3.00	−0.35 ± 0.44 P=0.43	−0.46 ± 0.44 P=0.30	−0.46 ± 0.45 P=0.31
D-KEFS: Color-Word Interference Test, Inhibition/Switching	8.77 ± 2.75	−0.87 ± 0.40 P=0.03	−0.93 ± 0.40 P=0.02	−0.59 ± 0.40 P=0.14
D-KEFS: Sorting Test, Confirmed Correct Sorts	9.42 ± 2.67	−0.51 ± 0.40 P=0.20	−0.59 ± 0.39 P=0.13	−0.23 ± 0.38 P=0.55
D-KEFS: Sorting Test, Free Sorting Description	9.46 ± 2.75	−0.10 ± 0.41 P=0.80	−0.16 ± 0.41 P=0.69	0.23 ± 0.39 P=0.56

Each beta value represents the estimated difference in the value of the executive functioning outcome in those with and without sleepiness

Model 1: Unadjusted

Model 2: Adjusted for subject characteristics (age, gender and preterm status)

Model 3: Adjusted for subject characteristics and socio-economic measures (caregiver education, household income and neighborhood median income)

Table 3

Unadjusted and Adjusted Association Between Mean Sleep Duration and Executive Functioning Measures

	Mean ± SD	Model 1 Slope ± se p-value	Model 2 Slope ± se p-value	Model 3 Slope ± se p-value
Primary Outcomes				
BRIEF: GEC	52.0 ± 11.4	−0.79 ± 0.73 P=0.28	−0.66 ± 0.74 P=0.37	−0.31 ± 0.76 P=0.69
D-KEFS: Tower Test, Total Achievement	9.20 ± 3.10	0.15 ± 0.20 P=0.46	0.15 ± 0.20 P=0.44	0.05 ± 0.20 P=0.82
Secondary Outcomes				
BRIEF: Metacognition Index	52.4 ± 10.9	−0.81 ± 0.69 P=0.24	−0.69 ± 0.70 P=0.32	−0.42 ± 0.72 P=0.56
BRIEF: Behavioral Regulation Index	50.9 ± 12.3	−0.74 ± 0.78 P=0.34	−0.63 ± 0.80 P=0.43	−0.21 ± 0.81 P=0.80
D-KEFS: Trail Making Test, Number-Letter Switching	8.16 ± 3.69	0.29 ± 0.23 P=0.21	0.29 ± 0.23 P=0.21	0.13 ± 0.23 P=0.58
D-KEFS: Verbal Fluency Test, Letter Fluency	10.13 ± 3.33	0.10 ± 0.21 P=0.62	0.11 ± 0.21 P=0.61	0.11 ± 0.22 P=0.61
D-KEFS: Verbal Fluency Test, Category Fluency	11.36 ± 3.08	−0.13 ± 0.20 P=0.51	−0.17 ± 0.20 P=0.41	−0.18 ± 0.20 P=0.36
D-KEFS: Verbal Fluency Test, Category Switching Total Correct Responses	10.23 ± 3.00	0.04 ± 0.19 P=0.83	−0.03 ± 0.19 P=0.88	−0.06 ± 0.20 P=0.77
D-KEFS: Color-Word Interference Test, Inhibition/Switching	8.77 ± 2.75	0.37 ± 0.17 P=0.03	0.36 ± 0.17 P=0.04	0.25 ± 0.17 P=0.15
D-KEFS: Sorting Test, Confirmed Correct Sorts	9.42 ± 2.67	0.20 ± 0.17 P=0.23	0.16 ± 0.17 P=0.36	0.06 ± 0.16 P=0.72
D-KEFS: Sorting Test, Free Sorting Description	9.46 ± 2.75	0.09 ± 0.18 P=0.60	0.06 ± 0.18 P=0.75	−0.04 ± 0.17 P=0.83

Each beta value represents the estimated difference in the value of the executive functioning for each one hour increase in sleep duration

Model 1: Unadjusted

Model 2: Adjusted for subject characteristics (age, gender and preterm status)

Model 3: Adjusted for subject characteristics and socio-economic measures (caregiver education, household income and neighborhood median income)