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Prospective Study of Insufficient Sleep and Neurobehavioral Functioning among School-Age Children

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Abstract

Objective—To examine associations between insufficient sleep and neurobehavioral functioning in childhood as reported by mothers and teachers.

Methods—Participants were 1046 children in a pre-birth cohort study. Main exposures were insufficient sleep durations at three time points: 6 months to 2 years, defined as sleep < 11 hours/day, 11-<12 hours/day (v. ≥ 12); 3 to 4 years, defined as sleep < 10 hours/day, 10-<11 hours/day (v. ≥11); and 5 to 7 years, sleep < 9 hours/day, 9-<10 hours/day (v. ≥ 10). Outcomes at age 7 were executive function, behavior, and social-emotional functioning, assessed by the Behavior Rating Inventory of Executive Function (BRIEF) and the Strengths and Difficulties Questionnaire (SDQ). Higher scores indicate poorer functioning. Mothers and teachers completed both instruments independently.

Results—At age 7, mean (SD) mother and teacher report of the BRIEF global executive composite scale were 48.3 (7.9) and 50.7 (9.4) points, respectively, and of the SDQ total difficulties score was 6.5 (4.7) and 6.2 (5.7). In multivariable models, children who slept <10 hours/day at 3–4 years had worse maternal-reported scores for the BRIEF (2.11 points; 95% CI: 0.17, 4.05) and SDQ (1.91 points; 95% CI: 0.78, 3.05) than those with age-appropriate sleep. Children who slept <9 hours/day at 5–7 years also had worse scores. At both ages, associations with teacher-reported results were consistent with mothers'. Infants who slept 11-<12 hours/day had higher teacher- but not mother-reported scores.

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Conclusions—Insufficient sleep in the preschool and early school years is associated with poorer mother- and teacher-reported neurobehavioral processes in mid-childhood.

Keywords

Sleep; behavior; executive function; neurobehavior

INTRODUCTION

Across infancy, childhood, and adolescence, evidence from multiple US and international studies suggests a consistent decline in average sleep duration of about 30 to 60 minutes over the last 20 years.[1] Multiple observational studies in children demonstrate that shorter sleep duration and chronic insufficient sleep are associated with a range of adverse health and developmental outcomes.[2–6.] Yet, major questions remain regarding the mechanisms and behaviors that may underlie the relationship between insufficient sleep and adverse health outcomes. One potential answer is the role of sleep in influencing neurobehavioral processes including executive function, behavior, or social-emotional functioning.

It is well known that sleep loss adversely affects neurobehavioral functioning in adults, manifested as poor attention, memory, and cognitive dysfunction, but few studies have been conducted with young children.[7,8] In older children, sleep has been associated with behavioral self-regulation which encompasses executive function, or the cognitive processes of attention shifting, working memory, and inhibitory control.[9,10] For example, in a study by Gruber et al. of 35 children ages 7–11 years, shorter sleep duration, measured objectively using polysomnography, was associated with higher levels of teacher-reported cognitive problems and inattention assessed using the Conners Teacher Rating Scale.[11] Insufficient sleep may also affect emotional regulation, which represents attempts by an individual to modify his/her emotional response to a situation. Thus, mounting evidence suggests associations between sleep and neurobehavioral functioning across early childhood.[10]

The purpose of this study was to examine sleep duration from infancy onwards and neurobehavioral functioning in a prospective, cohort of children in which neurobehavioral functioning was assessed in mid-childhood. We hypothesized that insufficient sleep at multiple time points throughout childhood would be associated with poorer child executive function, behavior, and social-emotional functioning as independently reported by mothers and teachers.

PARTICIPANTS and METHODS

Subjects/Study Design

Study subjects were participants in Project Viva, a prospective, pre-birth cohort study that recruited women during early pregnancy from Atrius Health, a multi-specialty group practice in eastern Massachusetts. Details of recruitment and retention procedures are available elsewhere.[12] Of the 2128 women who delivered a live infant, 1683 children were eligible for 7–10 year (‘mid-childhood”) follow-up of whom 1116 attended a mid-childhood in-person visit. Since our main exposure was insufficient sleep from 6 months to 7 years, we excluded 70 participants who did not have sleep data for these time points. Thus, our sample size for analysis was 1046 children. Compared with the 1046 participants in this analysis, non-participants were less likely to have college-educated mothers (59% v. 71%) and to have annual household income exceeding $70,000 (52% v. 63%). Parity (48% v. 48% nulliparous) and mean maternal age (31.3 v. 32.3 years), however, were fairly similar.

After obtaining written informed consent from mothers, we performed in-person study visits with the mother at the end of the first and second trimesters of pregnancy, and with mother and child in the first few days after delivery and in infancy (median 6.2 months), early childhood (median 3.3 years) and mid-childhood (median 7.7 years). Mothers completed mailed questionnaires at 1, 2, 4, 5, and 6 years after birth. Institutional Review Boards of participating institutions approved the study protocols.

Measurements

Main Exposures—At 6 months and yearly from 1 to 7 years, mothers reported their children's sleep duration in a usual 24-hour period.[5] The main exposure was insufficient sleep at three age periods, 6 months to 2 years, 3 to 4 years, and 5 to 7 years. We first averaged sleep hours/day during each of these three age periods. Based on age-specific sleep recommendations from the National Sleep Foundation,[13] we then categorized sleep in each period and defined insufficient sleep duration at each time period as follows: from 6 months to 2 years, sleep < 11 hours/day or 11-<12 vs. ≥ 12; from 3 to 4 years, sleep < 10 hours/day or 10-<11 v. ≥11; and from 5 to 7 years, sleep < 9 hours/day or 9-<10 v. ≥ 10.

Outcome Measures—The main outcomes were mother- and teacher-reports of child executive function, behavior, and social-emotional functioning in mid-childhood (median 7.7 years). To assess executive function, mothers and teachers were mailed the self-administered Behavioral Rating Inventory of Executive Function (BRIEF),[14] a validated 86-item questionnaire designed to assess executive function behaviors in home and school environments. The BRIEF includes the following sub-scales: inhibit, shift, emotional control, initiate, working memory, plan/organize, organization of materials, and monitor. The sub-scales form 2 broadband indexes: (1) the behavioral regulation index, which indicates the ability of the child "to shift cognitive set and modulate emotions and behavior via appropriate inhibitory control" and (2) the metacognition index, which reflects the child's ability to "initiate, plan, organize, and sustain future-oriented problem-solving in working memory." The BRIEF indices are each scaled to a mean of 50 and standard deviation of 10. The global executive composite is the average of the 2 indices, representing a summary measure of executive function. Higher BRIEF scores represent poorer executive function.

To assess child behavior and social-emotional functioning also in mid-childhood, mothers and teachers were mailed the self-administered Strengths and Difficulties Questionnaire (SDQ), a validated 25-item questionnaire designed to assess children's social, emotional, and behavioral functioning.[15] The SDQ is used widely in research and clinical settings,[16] and has five subscales: prosocial behavior, hyperactivity/inattention, emotional symptoms, conduct problems, and peer relationship problems. Possible scores range from 0–40 points.

Higher total difficulties scores (with the exclusion of the prosocial scale) indicate greater difficulties. Normative data for the SDQ derive from a representative sample of US children.[17]

Other measures—At enrollment, we collected information about maternal age, education, parity, and household income. We collected child's race and ethnicity in early childhood. In mid-childhood (median 7.7 years), we administered the Home Observation Measurement of the Environment short form (HOME-SF),[18] which assesses cognitive stimulation and emotional support in the environment. Possible scores range from 0 to 22. Higher scores indicate environments more supportive of development. In mid-childhood, we also asked parents to report the number of hours their children watched TV/videos on an average weekday and weekend day in the past month. Response categories included, "none, < 1 hour a day, 1–3 hours a day, 4–6 hours a day, 7–9 hours a day, and ≥10 hours a day". We did not ask specifically about the content of the programming viewed.

Statistical Analysis—We first examined bivariate relationships of children's sleep duration in each age period with each covariate and with our neurobehavioral outcomes. We also examined the correlation of sleep in infancy (6 months to 2 years) with sleep at 3–4 years and 5–7 years using Pearson correlation. We then used multivariable linear regression models to examine the associations of insufficient sleep in each age period with the neurobehavioral outcomes with and without the inclusion of potential confounders. Our first model, Model 1, was adjusted for child age and sex only. We then additionally adjusted the multivariable models for potential confounders including sociodemographic factors (maternal age, parity; parental education, household income, and HOME-SF score; and child race/ethnicity) and child television viewing at mid-childhood (Model 2). The multivariate models from 3 to 4 years were adjusted for sleep from 6 months to 2 years; models from 5 to 7 years were adjusted for sleep from 6 months to 2 years and 3 to 4 years.

The confounding variables in our analyses were not available for all subjects. We therefore used multiple imputation to generate plausible values for each missing value.[19,20] We used a chained equations approach with predictive mean matching based on linear regressions for approximately continuous variables and logistic or generalized logistic regression for dichotomous or more generally categorical variables. The "completed" data set comprises the observed data and one imputed value for each missing value. We replicated this analysis across completed data sets and then combined them in a structured fashion that accurately reflects the true amount of information in the observed data, i.e., without erroneously presuming that the imputed values are known true values, but recovering the information in partially observed subjects. We generated 50 complete data sets[21] and combined multivariable modeling results (Proc MI ANALYZE) in SAS version 9.3 (SAS Institute, Cary NC). From these multiple imputation results, we report adjusted effect estimates from regressions and 95% confidence intervals for each sleep category with the lowest risk sleep category as the reference group.

Given differences in participant characteristics by sleep duration, we also considered whether a lack of covariate overlap between exposed (sleep duration 3 to 4 years <10 hours/day) and unexposed (sleep duration >=10 hours/day) drove our results. We used propensity scores to define overlapping covariate values, or "common support." We ran common-support regression after excluding 16 participants where one or the other exposure group provided few data; results were similar so we do not report them.[22]

RESULTS

From 6 months to 2 years, 14% of infants slept <11 hours/day, 25% slept 11-<12 hours/day, and 61% slept the recommended amount of ≥ 12 hours/day. From 3–4 years, 12% of children slept < 10 hours/day, 31% slept 10-<11 hours/day, and 56% slept the recommended amount of ≥ 11 hours/day. From 5–7 years, 6% of children slept <9 hours/day, 23% slept 9-<10 hours/day, and 71% slept the recommended amount of ≥ 10 hours/day. Characteristics of study participants overall, and by sleep duration at ages 5 to 7 years when we also measured neurobehavioral functioning, are shown in Table 1. Pearson correlations between sleep at 6 months-2 years with sleep at 3–4 years and 5–7 years were 0.46 and 0.42, respectively.

As we previously reported, children who lived in homes with lower household incomes and lower maternal educational attainment were more likely to sleep < 9 hours per day vs. longer hours per day at 5 to 7 years (Table 1).[5] In addition, black children were more likely than white children to have insufficient sleep (Table 1). In mid-childhood, insufficient sleep was also associated with greater hours of television viewing and higher BMI z-scores. In mid-childhood, mean (SD) mother and teacher report of the BRIEF global executive composite scale were 48.3 (7.9) and 50.7 (9.4) points, respectively, and of the SDQ total difficulties score were 6.5 (4.7) and 6.2 (5.7), respectively (Table 2). Pearson correlation between mother and teacher BRIEF global executive composite scale scores was 0.35. Teacher reported BRIEF scores were consistently poorer (higher) than mother's ratings, although associations with sleep duration were similar for mother and teacher report. In bivariate analyses (Table 2), children who slept < 9 hours/day compared to those who slept ≥ 10 hours/day at 5 to 7 years had higher mother- and teacher-report of the BRIEF and SDQ indices, indicating poorer function.

In multivariable models adjusted for maternal and child sociodemographic characteristics as well as child TV viewing in mid-childhood, we found that infants who slept <11 hours/day (v. ≥12) did not have worse mother- (Table 3) or teacher (Table 4) reported BRIEF or SDQ scores in mid-childhood. However, infants who slept 11 to <12 hours (v. ≥12) had worse teacher (BRIEF 2.02 points; 95% CI: 0.55, 3.48 and SDQ 1.06; 95% CI: 0.19, 1.92) but not mother-reported BRIEF or SDQ scores.

Unlike infancy, children at 3–4 years and 5–7 years with only the shortest duration of sleep had neurobehavioral deficits as reported by mothers (Table 3) and teachers (Table 4). For example, children with sleep durations <10 hours/day at 3–4 years had worse maternal-reported mid-childhood scores for both the BRIEF general executive composite (2.11 points; 95% CI: 0.17, 4.05) and SDQ total difficulties (1.91 points; 95% CI: 0.78, 3.05) scores than those with age-appropriate sleep durations. Children with sleep duration <9 hours/day at 5–7 years also had worse maternal-reported scores: (BRIEF 2.90; 95% CI: 0.16, 5.63; SDQ total difficulties 1.74 points; 95% CI: 0.21, 3.27). At both ages, associations with teacher-reported results (Table 4) were consistent with mothers' reports (Table 3).

DISCUSSION

In this prospective cohort, insufficient sleep in the preschool (ages 3–4 years) and early school age years (ages 5 to 7) was associated with poorer mother– and teacher-report of a range of neurobehavioral processes in mid-childhood. The associations between insufficient sleep and overall poorer functioning was moderately attenuated (~30%) but persisted even after adjustment for many potential confounders of the relationship between sleep and neurobehavior and in propensity-adjusted analyses. In contrast to the preschool and early school age results, associations between insufficient sleep in infancy and later neurobehavioral functioning were inconsistent. We did not find a lasting effect of the shortest durations of sleep (<11 hours/day) in infancy with adverse neurobehavioral functioning in mid-childhood. However, sleep in infancy is moderately correlated with sleep later in childhood and thus promotion of good sleep quality and quantity beginning in infancy is warranted.

In this study, we assessed a summary measure of executive function (BRIEF Global Executive Composite) as well as subcomponents of executive functioning including behavioral regulation and metacognition. Insufficient sleep at ages 3–4 and 5–7 was associated with both mother- and teacher reported BRIEF Global Executive Composite scores that were 2–3 points higher (less favorable) than scores of children who achieved the recommended, age-specific amount of sleep. Our findings are consistent with those of a study by Gruber et al. in which shorter sleep duration, assessed using actigraphy, was associated with cognitive problems and inattention assessed using the Connors Teacher Rating Scale.[11] Deficits in executive function are clinically relevant in that they underlie academic success[23] and social competence [24] later in life. Differences in 2–3 points may also have relevance on a population level. [25] Research is also increasingly showing that executive dysfunction can influence chronic disease-related behaviors.[26]

In addition to evaluating aspects of executive function we also assessed behavioral difficulties reported in the SDQ which reflects inattention/hyperactivity, emotional symptoms (anxiety and depression), peer problems, and conduct problems (aggressiveness and rule breaking). We found that insufficient sleep at ages 3–4 and 5–7 was associated with both mother- and teacher reported total difficulties scores that were 1–2 points higher (less favorable) than scores of children who achieved the recommended, age-specific amount of sleep. Some but not all previous studies have also found associations of sleep disturbances with social-emotional development and behavior. In one study of 591 7 year-old children participating in the Auckland Birthweight Collaborative (ABC) Study,[27] short sleep duration, assessed using actigraphy and defined as sleep < 9 hours/day, was not associated with contemporaneous adverse behavior assessed using the SDQ. In another study,[28] 8098 parents of children, age 7 years, participating in the Avon Longitudinal Study of Parents and Children (ALSPAC) completed the SDQ and reported on children's sleep-disordered breathing symptoms. Sleep-disordered breathing from 6 months to 7 years was associated with adverse behavioral outcomes defined as having a total difficulties score in the SDQ in the top 10th percentile. Our findings support those of the ALSPAC study indicating neurobehavioral morbidity as a result of impaired sleep.

Our study had several strengths. First, whereas most prior studies assessed executive function, behavior, and social-emotional development based on either parent or teacher[11] report, our study is the only one to examine relationships of sleep duration with these outcomes reported by both mothers and teachers. A discrepancy between parent and teacher ratings of the same child may occur for difficulties that are situation-specific; having multiple raters across different settings increases the sensitivity for detecting true difficulties;[29] we found consistent results with mother and teacher reports. Second, we collected longitudinal data on sleep duration beginning in early infancy through 7 years of age and adjusted later models of sleep and neurobehavior for sleep at earlier ages. Third, we used well-validated screening measures of social-emotional development, behavior, and executive function. Our study also had limitations. We estimated sleep duration by mother's report on questionnaires as opposed to using a more objective measure of sleep such as accelerometers or diaries. Additionally, we examined only sleep duration as the exposure. It is possible that patterns of sleep other than short sleep duration including sleep consolidation/fragmentation, day-to-day variability, and sleep timing may be more strongly predictive of neurobehavioral outcomes as has been found in a previous study. [30,31] We measured neurobehavioral functioning only at age 7 years. Thus, it is possible that other conditions related to poor neurobehavioral functioning such as anxiety or depression could have preceded or even predicted poor sleep in our sample which in turn could further exacerbate executive function. Another limitation is that our cohort is of relatively high socio-economic status, potentially limiting generalizability to lower socioeconomic environments; it is possible that insufficient sleep may have a greater impact on neurobehavioral functioning in lower socioeconomic groups. Finally, in any observational study it is possible that unmeasured characteristics and residual confounding might explain the observed associations between exposure and outcome. However, results were robust to adjustment for a number of measured characteristics by statistical adjustment and also propensity-score matching.

CONCLUSION

Insufficient sleep in the preschool and early school years is associated with mother- and teacher-reports of poorer function on a range of neurobehavioral processes in mid-childhood. Additional studies are needed to examine the mediating role of neurobehavioral functioning in the relationship between sleep and adverse health outcomes. Nevertheless, our results indicate that interventions to promote optimal sleep duration in early childhood could have positive effects on cognitive and behavioral functioning.

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What's New

Impaired neurobehavioral functioning is associated with adverse child health and development. In this study we found that insufficient sleep in the preschool and early school years is associated with poorer mother- and teacher-reported neurobehavioral processes in mid-childhood.

Table 1

Characteristics of 1046 Children from Project Viva, Overall and by Sleep Duration at 5 – 7 Years.

Characteristics	**Overall**	**Sleep Duration at 5 – 7 Years of Age, Hours/Day**		
		< 9	**9 to < 10**	**≥ 10**
Sample size	**N=1046**	61	239	746
Maternal and Household	**Mean (SD) or %**			
Maternal age (y)	32.3 (5.1)	30.3 (6.1)	31.9 (5.7)	32.6 (4.8)
Parity, nulliparous, %	47.9	30.7	42.9	50.9
Maternal Education, ≥ College graduate, %	70.8	38.8	59.9	77.0
Paternal Education, ≥ College graduate, %	65.7	30.4	53.4	72.4
Household income >$70,000/y, %	63.4	31.4	54.7	68.9
Married or cohabitating, %	92.9	78.7	89.6	95.1
Home Observation Measurement of the Environment, Short Form Score	18.4 (2.2)	17.0 (2.6)	17.8 (2.3)	18.7 (2.0)
Child				
Girl, %	50.3	45.8	46.1	52.0
Race/ethnicity, %				
White	66.4	18.7	54.2	74.2
Black	14.9	42.8	24.7	9.5
Hispanic	3.6	9.1	4.2	2.9
Asian	3.3	4.1	4.6	2.8
Other	11.9	25.3	12.2	10.6
Television viewing at age 7 y (h/d)	1.5 (1.0)	2.3 (1.3)	1.8 (1.1)	1.4 (0.9)

Table 2

Mid-Childhood Neurobehavioral Functioning Outcomes, Overall and by Sleep Duration at 5 – 7 Years.

Mid-Childhood Neurobehavioral Functioning Outcomes	Overall	Sleep Duration at 5 – 7 Years of Age, Hours/Day		
		< 9	9 to < 10	≥ 10
BRIEF Global Executive Composite				
Mother	48.3 (7.9)	52.0 (9.0)	49.6 (8.7)	47.6 (7.3)
Teacher	50.7 (9.4)	56.9 (11.3)	52.6 (10.9)	49.6 (8.3)
BRIEF Behavioral Regulation Index				
Mother	48.2 (8.7)	51.1 (9.9)	49.3 (10.0)	47.6 (8.1)
Teacher	50.5 (9.9)	56.6 (13.3)	52.3 (12.0)	49.4 (8.6)
BRIEF Metacognition Index				
Mother	48.4 (8.6)	53.0 (9.5)	50.0 (8.9)	47.5 (8.2)
Teacher	50.9 (10.6)	57.3 (11.9)	52.8 (11.6)	49.7 (9.8)
SDQ Total Difficulties				
Mother	6.5 (4.7)	9.5 (5.1)	7.4 (5.4)	5.9 (4.3)
Teacher	6.2 (5.7)	9.5 (6.9)	7.2 (6.3)	5.7 (5.2)
SDQ Prosocial Behavior Scale				
Mother	8.6 (1.7)	8.3 (1.7)	8.4 (1.7)	8.6 (1.6)
Teacher	8.1 (2.2)	7.4 (2.3)	7.7 (2.3)	8.2 (2.1)

* BRIEF is Behavioral Rating Inventory of Executive Function. BRIEF scores are standardized to mean 50 and standard deviation (SD) 10, with higher scores representing greater executive function problems.

** SDQ is Strengths and Difficulties Questionnaire. Possible scores range from 0–40. On the total difficulties scale, higher scores represent more difficulties; on the prosocial scale, higher scores represent more favorable prosocial behavior.

Table 3

Multivariable Associations of Insufficient Sleep at Each Age Period with Neurobehavioral Outcomes at Mid- Childhood Reported by Mothers. Data from 1046 children in Project Viva.

Neurobehavioral Outcomes & Multivariable Models*	Sleep Duration at Each Age Period					
	6 months to 2 years		3 years to 4 years		5 years to 7 years	
	< 11 hours v. ≥ 12 (reference)	11 to <12 v. ≥ 12 (reference)	< 10 hours v. ≥ 11 (reference)	10 to <11 v. ≥ 11 (reference)	< 9 hours v. ≥ 10 (reference)	9 to <10 v. ≥ 10 (reference)
BRIEF Global Executive Composite Score	***Effect Estimate (95% Confidence Interval)***					
Adjusted for child age & sex	**1.82 (0.24, 3.39)**	0.59 (−0.65, 1.83)	**3.09 (1.17, 5.01)**	0.51 (−0.67, 1.70)	**3.60 (0.90, 6.30)**	**1.72 (0.20, 3.24)**
Multivariable adjusted*	1.09 (−0.55, 2.73)	0.14 (−1.07, 1.35)	**2.11 (0.17, 4.05)**	0.30 (−0.86, 1.47)	**2.90 (0.16, 5.63)**	1.40 (−0.11, 2.92)
BRIEF Behavioral Regulation Index						
Adjusted for child age & sex	1.77 (0.00, 3.55)	0.87 (−0.51, 2.24)	**2.23 (0.13, 4.33)**	−0.06 (−1.37, 1.25)	2.69 (−0.34, 5.72)	1.42 (−0.26, 3.11)
Multivariable adjusted*	1.06 (−0.81, 2.92)	0.51 (−0.85, 1.86)	1.22 (−0.92, 3.36)	−0.22 (−1.51, 1.07)	1.84 (−1.21, 4.89)	1.11 (−0.60, 2.81)
BRIEF Metacognition Index						
Adjusted for child age & sex	**1.86 (0.17, 3.56)**	0.32 (−1.05, 1.68)	**3.96 (1.87, 6.05)**	1.09 (−0.20, 2.38)	**4.51 (1.60, 7.42)**	**2.01 (0.36, 3.66)**
Multivariable adjusted*	1.12 (−0.65, 2.89)	−0.23 (−1.56, 1.10)	**3.00 (0.89, 5.11)**	0.83 (−0.44, 2.10)	**3.96 (0.98, 6.93)**	**1.70 (0.07, 3.34)**
SDQ Total Difficulties						
Adjusted for child age & sex	**1.07 (0.13, 2.02)**	0.59 (−0.14, 1.32)	**2.90 (1.75, 4.05)**	0.37 (−0.35, 1.09)	**2.68 (1.15, 4.22)**	**1.07 (0.19, 1.95)**
Multivariable adjusted*	0.03 (−0.93, 0.99)	0.16 (−0.54, 0.86)	**1.91 (0.78, 3.05)**	0.22 (−0.47, 0.91)	**1.74 (0.21, 3.27)**	0.70 (−0.19, 1.58)
SDQ Prosocial						
Adjusted for child age & sex	−0.04 (−0.35, 0.26)	0.00 (−0.25, 0.25)	−0.44 (−0.82, −0.06)	−0.22 (−0.46, 0.02)	−0.20 (−0.73, 0.34)	−0.09 (−0.39, 0.20)
Multivariable adjusted*	0.06 (−0.27, 0.39)	0.10 (−0.16, 0.35)	−0.28 (−0.67, 0.10)	−0.19 (−0.43, 0.05)	−0.05 (−0.60, 0.50)	−0.01 (−0.31, 0.29)

*Adjusted for child age & sex, plus maternal age, parity, parental education, household income, HOME score; child race/ethnicity, and child television viewing at mid-childhood. All models additionally adjusted for sleep in previous time period.

Table 4

Multivariable Associations of Insufficient Sleep at Each Age Period with Neurobehavioral Outcomes at Mid- Childhood, Reported by Teachers. Data from children in Project Viva.

Neurobehavioral Outcomes & Multivariable Models*	Sleep Duration at Each Age Period					
	6 months to 2 years		3 years to 4 years		5 years to 7 years	
	< 11 hours v. ≥ 12 (reference)	11 to <12 v. ≥ 12 (reference)	< 10 hours v. ≥ 11 (reference)	10 to <11 v. ≥ 11 (reference)	< 9 hours v. ≥ 10 (reference)	9 to <10 v. ≥ 10 (reference)
BRIEF Global Executive	***Effect Estimate (95% Confidence Interval)***					
Composite Score						
Adjusted for child age & sex	**3.13 (1.24, 5.02)**	**2.69 (1.16, 4.22)**	**4.63 (2.29, 6.97)**	0.18 (−1.22, 1.59)	**5.22 (1.81, 8.62)**	**1.82 (0.06, 3.58)**
Multivariable adjusted*	1.08 (−0.93, 3.08)	2.02 (0.55, 3.48)	**2.85 (0.53, 5.17)**	0.05 (−1.31, 1.41)	3.35 (−0.06, 6.76)	1.05 (−0.74, 2.83)
BRIEF Behavioral Regulation Index						
Adjusted for child age & sex	**2.93 (0.85, 5.00)**	**3.07 (1.44, 4.70)**	**4.55 (1.95, 7.16)**	0.32 (−1.19, 1.82)	**5.12 (1.38, 8.86)**	1.78 (−0.11, 3.67)
Multivariable adjusted*	0.89 (−1.29, 3.07)	**2.36 (0.79, 3.94)**	**2.68 (0.12, 5.24)**	0.17 (−1.28, 1.63)	3.01 (−0.79, 6.81)	0.98 (−0.95, 2.90)
BRIEF Metacognition Index						
Adjusted for child age & sex	**3.34 (1.25, 5.43)**	**2.31 (0.56, 4.07)**	**4.71 (2.14, 7.28)**	0.05 (−1.52, 1.63)	**5.32 (1.42, 9.22)**	1.86 (−0.08, 3.80)
Multivariable adjusted*	1.26 (−0.99, 3.51)	1.67 (−0.03, 3.36)	**3.01 (0.42, 5.61)**	−0.07 (−1.61, 1.47)	3.70 (−0.22, 7.61)	1.12 (−0.84, 3.09)
SDQ Total Difficulties						
Adjusted for child age & sex	0.92 (−0.25, 2.08)	**1.36 (0.46, 2.25)**	**2.31 (0.94, 3.67)**	0.33 (−0.53, 1.20)	**3.11 (1.10, 5.11)**	**1.12 (0.05, 2.20)**
Multivariable adjusted*	−0.13 (−1.37, 1.12)	**1.06 (0.19, 1.92)**	1.32 (−0.03, 2.68)	0.25 (−0.60, 1.10)	**2.14 (0.15, 4.13)**	0.70 (−0.39, 1.79)
SDQ Prosocial						
Adjusted for child age & sex	−0.05 (−0.51, 0.41)	−0.24 (−0.59, 0.10)	−0.70 (−1.21, −0.18)	−0.34 (−0.68, 0.00)	−0.72 (−1.48, 0.03)	−0.43 (−0.83, −0.03)
Multivariable adjusted*	0.13 (−0.36, 0.62)	−0.15 (−0.49, 0.20)	−0.51 (−1.05, 0.02)	−0.30 (−0.65, 0.04)	−0.56 (−1.32, 0.20)	−0.36 (−0.78, 0.05)

*Adjusted for child age & sex, plus maternal age, parity, parental education, household income, HOME score; child race/ethnicity, and child television viewing at mid-childhood. All models additionally adjusted for sleep in previous time period.