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Associations of Infant Sleep Characteristics with Childhood Cognitive Outcomes

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Abstract

Objective: To quantify associations of infant 24-hour sleep duration and nighttime sleep consolidation with later child cognition.

Method: This study included children from Project Viva, a prospective cohort in Massachusetts with (1) sleep measures in infancy (median age 6.4 months) and (2) child cognition in early childhood (median age 3.2 years) or mid-childhood (median age 7.7 years). Main exposures were parental report of infant 24-hour sleep duration and nighttime sleep consolidation (% of total daily sleep occurring at nighttime). Cognitive outcomes were (1) early childhood vocabulary and visual-motor abilities and (2) mid-childhood verbal and nonverbal IQ, memory, and visual-motor abilities. We examined associations of infant sleep with childhood cognition using linear

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Ethical Standards Disclosure: This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the Harvard Pilgrim Health Care Institutional Review Board and exempt from review by the Columbia University Medical Center Institutional Review Board. Participating mothers provided written informed consent on behalf of themselves and their children.

regression models adjusted for child sex, age, and race or ethnicity; maternal age, education, and parity; and household income.

Results: Early and mid-childhood analyses included 1102 and 969 children, respectively. Most mothers reported infant race or ethnicity as White (69%) and were college graduates (71%). Mean infant 24-hour sleep duration was 12.2±2.0 hours and mean nighttime sleep consolidation was 76.8±8.8%. Infant 24-hour sleep duration was not associated with any early or mid-childhood outcomes. Higher infant nighttime sleep consolidation was associated with higher mid-childhood verbal intelligence (β: 0.12 points per % nighttime sleep; 95% CI: 0.01, 0.22), but not with any early childhood cognitive measures.

Conclusions: In this cohort, higher infant nighttime sleep consolidation was associated with higher verbal IQ in mid-childhood. Future studies should investigate causal relationships of infant sleep consolidation with child cognition among diverse populations.

Keywords

infant sleep duration; infant sleep consolidation; child cognition; verbal intelligence

INTRODUCTION

Childhood cognition (*i.e.,* mental abilities including memory and intelligence) is linked to long-term academic attainment[1], socioeconomic outcomes[2], and adult mental health.[3] Longer 24-hour sleep duration in school age children and adolescents is associated with higher intelligence and better memory, learning, executive functioning, and academic performance.[4–6] Relationships of earlier sleep characteristics and later child cognition are poorly understood.

In the first year of life, sleep duration and patterns are dynamic and individually variable, but mature on predictable trajectories. [7] In the newborn period (age 0–2 months), sleep is evenly divided between daytime and nighttime.[7] By age 12 months, most infants have established 24-hour sleep cycles and sleep is mostly consolidated to nighttime.[7] During this first year, sleep disturbances are among the most common concerns parents raise at pediatric visits.[8] Moreover, over 40% of infants (age 4–12 months) in the United States do not meet the American Academy of Sleep Medicine recommendation of 12–16 hours of daily sleep.[9]

Despite the high prevalence of infant short sleep duration and parent-reported sleep problems, relationships of infant sleep characteristics with later child cognitive outcomes are unclear. The most recent pediatric sleep guidelines from 2016 focus solely on 24-hour sleep duration and do not address nighttime sleep consolidation or nap duration.[10] Cross-sectional studies of infant sleep suggest daytime naps correlate with memory consolidation and language learning.[11] The few prospective studies among toddlers[12,13] and infants[5,14–17] document inconsistent associations between infant sleep "maturity" (*i.e.*, shorter daytime sleep, higher nighttime consolidation, longer nighttime sleep, fewer nighttime arousals) and advanced cognition in toddlerhood and childhood. Prior studies longitudinally investigating infant sleep and later child cognition are limited by small sample size[14,15] and lack of population diversity[14–17], and only assess outcomes until toddlerhood.[14,15,17] Among participants in Project Viva—a longitudinal pre-birth cohort of women and children recruited in eastern Massachusetts—infant (median age 6.4 months) 24-hour sleep duration and executive function in mid-childhood (median age 7.7 years) were not associated.[5] However, relationships between infant nighttime sleep consolidation and other cognitive measures were not assessed.

This study assesses the relationship between infant sleep and later childhood cognition. Utilizing the Project Viva cohort, we tested the hypothesis that longer infant 24-hour sleep duration and higher nighttime sleep consolidation are associated with higher vocabulary and visual-motor skills in early childhood (median age 3.2 years), and verbal and non-verbal IQ, memory and visual-motor skills in mid-childhood. Secondarily, we assessed whether additional measures of infant sleep (daytime sleep and nighttime sleep duration) are associated with the same cognitive outcomes.

METHODS

Participants/Study Design

We performed a secondary data analysis of participants enrolled in Project Viva, a prospective, longitudinal pre-birth cohort of women and their children. Pregnant women were recruited between 1999 and 2002 from obstetrics offices of Atrius Harvard Vanguard Medical Associates, a multispecialty urban/suburban practice in eastern Massachusetts. Exclusion criteria included multiple gestation, non-English speaking, gestational age >22 weeks at recruitment, and plans to relocate before delivery. The cohort included 2,128 women with live singleton births. More details regarding Project Viva's recruitment, inclusion/exclusion criteria, study instruments, and retention were previously published.[18]

For this analysis, we included children born ≥34 weeks gestation with (1) parent-reported infant sleep measures (median age 6.4 months) and (2) child cognition measures in early childhood (median age 3.2 years) and/or mid-childhood (median age 7.7 years). We excluded infants born <34 weeks gestation since premature infants have different sleep and developmental trajectories.[19]

Study staff conducted in-person visits in infancy, early childhood, and mid-childhood. Mothers provided written informed consent at enrollment and at each postnatal follow-up visit. Children provided assent at the mid-childhood visit. The Harvard Pilgrim Health Care IRB approved the study protocol. The Columbia University IRB deemed the study exempt from approval given its non-human subjects designation.

Exposure Measures

During the infancy visit, mothers responded to the following interview questions about their child's sleep. In the past month, on average: (1) for how long does your baby nap during the morning, (2) for how long does your baby nap during the afternoon, and (3) how many hours does your baby sleep during the night? Parents provided responses in hours and minutes. Responses were converted to hours for analysis. Primary exposures were 24-hour sleep duration (Question 1 + 2 + 3) and nighttime sleep consolidation measured by percentage of total 24-hour sleep occurring at nighttime (Question 3 / [Question 1 + 2 + 3] x 100).

Secondary exposures were daytime sleep duration (Question 1 + 2) and nighttime sleep duration (Question 3).

Outcome Measures

Early childhood cognition.—During early childhood visits, research assistants measured receptive vocabulary with the Peabody Picture Vocabulary Test Revised Version 3 (PPVT-3).[20] PPVT-3 scores correlate with measures of IQ, and estimate verbal and scholastic ability. Visual-motor skills were measured with the Wide Range Assessment of Visual Motor Abilities (WRAVMA).[21] The WRAVMA composite score includes assessments of drawing (visual-motor), matching (visual-spatial), and pegboard (fine motor). WRAVMA scores are moderately correlated with IQ. PPVT-3 and WRAVMA scores are standardized and age norm-referenced (population mean=100±15).

Mid-childhood cognition.—During mid-childhood visits, research assistants assessed verbal and nonverbal intelligence with the Kaufman Brief Intelligence Test Second Edition (KBIT-2)[22] and visual-motor skills with the Wide Range Assessment of Visual Motor Abilities (WRAVMA)[21] Drawing Subscale. WRAVMA Drawing and KBIT-2 Verbal and Nonverbal scores are standardized and age norm-referenced (population mean=100±15). Memory was measured with the Wide Range Assessment of Memory and Learning Visual Memory Index (WRAML2-VMI).[23] WRAML2-VMI measures how individuals learn and recall meaningful (pictorial) and minimally related (design) visual information. Scores are standardized and age norm-referenced (population mean=10±3).

Other Measures

At enrollment mothers reported demographic characteristics which we categorized as follows: age (years), education level (less than college degree; college degree or higher), marital status (married/cohabitating; other), household income (>$70,000; ≤$70,000 [United States dollars] per year) and parity (primiparous; multiparous). At infancy visits mothers reported breastfeeding status (formula only; breast milk only; mixed; weaned), and child TV viewing (hours per day). We calculated child age at the infancy visit using the child's birthday and visit date. We collected infant sex from child medical records and derived gestational age from last maternal menstrual period or second trimester ultrasounds if estimates differed by more than 10 days. For child race and ethnicity, mothers were asked, "Which of the following best describes your child's race or ethnicity?" Mothers could choose one or more of the following racial or ethnic groups: American Indian or Alaskan Native, Asian or Pacific Islander, Black or African American, Hispanic or Latino, White or Caucasian, and Other (please specify). If a participant endorsed >1 race or ethnicity, we categorized them as ">1 race or ethnicity." Three participants who chose "Other," had their responses reclassified based on U.S. census definitions for the other five races and ethnicities.[36] One participant who responded "Other" was unable to be reclassified and was grouped with the >1 race or ethnicity category. If child race or ethnicity was missing, we used maternal race or ethnicity reported at enrollment. No mother reported American Indian or Alaskan Native child race or ethnicity.

Statistical Analysis

First, we examined descriptive statistics and distributions for the exposures, outcomes, and potential covariates, and assessed for missingness. As missingness for covariates was minimal, an available-case analysis was done. Our primary exposures of interest were (1) 24-hour sleep duration (hours) and (2) nighttime sleep consolidation (percentage) in infancy. Secondary exposures were (1) daytime sleep duration (hours) and (2) nighttime sleep duration (hours). Outcomes of interest in early childhood were receptive vocabulary (PPVT-3) and visual-motor skills (WRAVMA Composite). Outcomes of interest in mid-childhood were verbal and nonverbal IQ (KBIT-2), visual motor skills (WRAVMA-drawing subscale), and memory (WRAML2-VMI).

Because our primary and secondary exposures and all outcomes were normally distributed, we used multivariable linear regression modelling to examine associations between exposures and outcomes in separate models. In multivariable models, we included only covariates of *a priori* interest or those that statistically confounded associations between infant sleep measures and cognitive outcomes (β change of >10%). First, in sex-adjusted models, we adjusted for child sex. Next, confounder-adjusted models additionally adjusted the sex-adjusted model for *a priori* confounders of child age at the infancy visit, maternal age, maternal education, parity, and household income. To build final fully-adjusted model, we individually added hypothesized confounders (*i.e.,* child race and ethnicity, breastfeeding status, child TV viewing, gestational age) to the confounder-adjusted model to determine if their inclusion impacted the observed relationships between predictor and outcome variables. If an additional variable caused a β change of >10% to the confounder-adjusted variable, it was included in the fully-adjusted model. Only child race and ethnicity met this criterion. Final fully-adjusted models included child sex, child age at infancy visit, maternal age, maternal education, parity, household income, and child race and ethnicity. Child race and ethnicity is a social—not biological—construct that served as an imperfect proxy for structural racism and systemic inequities that account for racial and ethnic disparities in child cognition and infant sleep duration.[24,25] Therefore, we included child race and ethnicity as a potential confounder in our models.

We performed two sensitivity analyses to exclude 1) clinical outliers (participants with parent-reported infant 24-hour sleep duration <5 hours, n=4) and 2) statistical outliers (potentially influential points determined by Cook's distance with a threshold of 4/n).[26] We also examined whether child sex modified relationships of exposures and outcomes for all models using an interaction term (child sex*sleep variable). We considered p-interaction < 0.1 as significant. All statistical analyses used SAS on Demand for Academics.

RESULTS

Participants

Of the 2128 singleton infants enrolled in Project Viva, 1215 mother-infant dyads were included in our early and/or mid-childhood analyses (Figure 1). A total of 1102 dyads were included in the analysis for early childhood cognitive outcomes and 969 for mid-childhood cognitive outcomes. Dyads lost to follow-up between early and mid-childhood did not differ significantly from those retained in average PPVT-3 (104.6±13.9 vs. 104.2±14.3, p=0.71), WRAVMA (102.2±11.7 vs. 102.5±11.2, p=0.67), or maternal education (71.8% vs. 74.2% college graduates, p=0.47). Most mothers reported their child's race or ethnicity as White (69.0%), and most mothers were college graduates (71.2%) (Table 1).

Mean infant 24-hour sleep duration was 12.2±2.0 hours and mean nighttime sleep consolidation was 76.8±8.8% (Table 2). 53.7% of infants had 24-hour sleep durations below the minimum recommendation of 12 hours.[27] Mean cognitive scores were generally above U.S. population averages (Table 2).

Early Childhood Multivariable Results (Table 3)

Infant 24-hour sleep duration was not associated with any early childhood outcomes. Higher infant nighttime sleep consolidation was associated with higher early childhood receptive vocabulary and higher visual-motor skills in sex-adjusted and confounder-adjusted models. Results were no longer statistically significant after additionally adjusting for child race and ethnicity in fully-adjusted models.

For the secondary exposures, longer infant daytime sleep duration was associated with lower early childhood receptive vocabulary and lower visual-motor skills in sex-adjusted and confounder-adjusted models, but results were no longer statistically significant after additionally adjusting for child race and ethnicity in fully-adjusted models. Longer infant nighttime sleep duration was associated with higher early childhood receptive vocabulary and higher visual-motor skills in sex-adjusted models. Neither relationship was significant in confounder- and fully-adjusted models.

Mid-Childhood Multivariable Results (Table 4)

Longer infant 24-hour sleep duration was associated with higher mid-childhood verbal IQ in the sex-adjusted model, but not in confounder- and fully-adjusted models. Infant 24-hour sleep duration was not associated with any of the other mid-childhood outcomes.

Higher infant nighttime sleep consolidation was associated with higher mid-childhood verbal IQ in sex-adjusted and confounder-adjusted models. This association decreased in magnitude but remained significant in the fully-adjusted model (β: 0.12 KBIT-2 points per nighttime sleep percentage point; 95% CI: 0.01, 0.22). Higher infant nighttime sleep consolidation was also associated with higher mid-childhood non-verbal IQ in the sex-adjusted model, but results were attenuated in confounder- and fully-adjusted models. Infant nighttime sleep consolidation was not associated with mid-childhood visual-motor skills or memory in any models.

For the secondary exposures, longer infant daytime sleep duration was associated with lower mid-childhood verbal IQ in sex-adjusted and confounder-adjusted models. This association decreased in magnitude but remained significant in the fully-adjusted model (β: −0.86 KBIT-2 points per hour of daytime sleep; 95% CI: −1.62, −0.10). Infant daytime sleep duration was not associated with any of the other mid-childhood outcomes.

Longer infant nighttime sleep duration was associated with higher mid-childhood verbal IQ in sex-adjusted and confounder-adjusted models, but results were no longer statistically significant in fully-adjusted models. Longer infant nighttime sleep duration was also associated with higher mid-childhood non-verbal IQ in sex-adjusted models but not in confounder- and fully-adjusted models. Infant nighttime sleep duration was not associated with mid-childhood drawing or memory in any models.

Sensitivity analyses that excluded clinical and statistical outliers did not change our conclusions, therefore outliers were retained in all models. In addition, the interaction term of child sex*sleep variable was not significant in any models so they were not included.

DISCUSSION

This study, assessing the association between infant sleep and early and mid-childhood cognitive measures, found a significant association between higher infant nighttime sleep consolidation and higher mid-childhood verbal IQ. These results translate into a four-point mid-childhood verbal IQ differential between infants that were two standard deviations below the mean for nighttime sleep consolidation (59.2% of sleep occurring at night) and those two standard deviations above the mean (94.4% of sleep occurring at night). Comparatively, studies of lead exposure—a topic of high public health priority—find four-point IQ differentials in mid-childhood for increases in blood lead from 2.4 to 10 µg/dL, a level deemed unacceptable by today's standards.[28] Verbal intelligence is a complex measure determined by many biological and environmental factors.[29] Thus, we believe that a four point difference associated with one variable, nighttime sleep consolidation, is clinically relevant. Additionally, we found that longer infant daytime sleep duration was associated with lower mid-childhood verbal IQ. Collectively, these results suggest that infants with more mature sleep patterns (larger percentage of nighttime than daytime sleep) had improved verbal skills in mid-childhood. Although the observational nature of this study precludes conclusions regarding causality, to our knowledge, this is the first study to examine relationships of sleep characteristics before age 12 months with cognition in mid-childhood.

There are explanations for why early sleep consolidation may be associated with improved childhood verbal intelligence. First, sleep may promote synaptic consolidation (strengthening of neuronal connections in the brain) that are important for learning.[30] Consolidated sleep patterns may have beneficial "sleep architecture" (time spent in different stages of sleep) that supports neuronal connections and improves language learning. Second, consolidated nighttime sleep may promote daytime alertness, when infants are exposed to language-rich environments that facilitate learning.[31] Third, infant nighttime sleep consolidation may lay the groundwork for healthy sleep patterns in later childhood that bolster brain development. Fourth, infants' abilities to regulate their circadian rhythms may serve as a developmental milestone that precedes advanced processes like cognition.[32] Thus, nighttime sleep consolidation may be a marker, rather than an accelerant, of brain development. Fifth, the resource-rich environments that support improved child cognition may also support infant nighttime sleep consolidation.[33] Infants with improved nighttime sleep consolidation may have less stressed, better rested parents to support their verbal development.[34] Lastly, there may be unmeasured confounders, like parental work schedules or daycare attendance, that influence napping and account for this relationship.

Our results include outcomes at mid-childhood, extending previous research findings. The only other large, prospective study investigating the relationship between infant sleep patterns and later child cognition, Dionne et al., found that poor nighttime sleep consolidation at age 6-months was a risk factor for poor verbal abilities as measured by the PPVT at age 2.5 years among Canadian children.[17] We found that nighttime sleep consolidation at age 6-months was associated with mid-childhood verbal IQ (median age 7.7 years), but not early childhood receptive vocabulary (median age 3.2 years). This variance may be attributable to population specific differences in exposures, outcomes, or other characteristics. Unlike the study by Dionne et al., we found that racial and ethnic inequities confound relationships between infant sleep and both early and mid-childhood cognitive outcomes. Our findings are consistent with other longitudinal studies that identify associations between mature sleep patterns among toddlers[12,13] and infants[14–16] and advanced cognition in later childhood. Our study is unique because we examine associations at a later age and adjust for child race and ethnicity.

We did not find that infant 24-hour sleep duration or nighttime sleep duration were associated with later child cognition. Our results highlight the unique features of infant sleep, as studies among toddlers, school-aged children, and adolescents consistently document positive associations between total and nighttime sleep duration and child cognition.[4–6,12] Multiple longitudinal studies have found that longer total and nighttime sleep trajectories from infancy to later childhood are associated with better verbal cognition.[16,35] Taken together, these results with ours suggest that shorter 24-hour and nighttime sleep duration in infancy alone may not be associated with poorer childhood cognition, but that persistent short sleep duration into later childhood is a risk factor for poorer outcomes.

Although higher infant nighttime sleep consolidation was associated with higher mid-childhood verbal IQ, we did not find relationships between infant sleep and early childhood cognitive outcomes. Small differences in verbal abilities may be difficult to detect in early childhood when children have a smaller range of verbal abilities. Alternatively, differing results by age may be attributable to different assessment tools that measure divergent areas of verbal cognition.

Like previous studies documenting racial and ethnic disparities in infant sleep duration,[36] we found disparities in infant nighttime sleep consolidation. Child race and ethnicity confounded associations between infant nighttime sleep consolidation and some cognitive measures in early and mid-childhood. We used child race and ethnicity as imperfect proxies for systemic inequities and structural racism that account for child cognition and academic achievement gaps.[25] Structural racism leads to housing and neighborhood inequities that may play roles in infant sleep consolidation disparities.[37] Individual experiences of racial discrimination may also impact sleep—a Project Viva study found associations between maternal personal experiences of racism and infant sleep duration.[24] Our study uniquely adjusted for child race and ethnicity, which may explain some discrepancies between our conclusions and studies like Dionne et al.[17] Future studies should include more diverse cohorts, examine modifiable structural and environmental drivers of racial and ethnic differences in sleep to inform interventions, and use consistent measures of race and ethnicity in participants to allow comparability between cohorts.

Our study has many strengths. It is among the first to prospectively investigate associations between sleep duration and consolidation under age one year—when parental sleep concerns are common—and child cognition during elementary school—when cognition predicts long-term academic and socio-economic attainment.[1,2] High retention over time in a large sample size allowed us to control for important confounders including race, ethnicity, and socioeconomic status. We examined multiple infant sleep characteristics to provide additional information about potentially modifiable intervention targets for future research.

Despite these strengths, our study has limitations. The Project Viva population is primarily White and may not be generalizable to all populations. However, the cohort is more diverse than most infant sleep studies.[14–17] We used subjective reports of infant sleep which overestimate infant sleep duration, and are influenced by parental proximity to the infant during sleep.[38,39] However, since parental report of sleep overestimates both daytime and nighttime sleep duration,[39] this bias should have less impact on nighttime sleep consolidation. Also, subjective measures cannot capture physiologic sleep stages that may influence cognitive functioning. Studies using subjective sleep measures may yield different results than those using objective measures like actigraphy, or physiological measures like EEG. Likewise, although the brief KBIT-2 intelligence screening test is highly correlated with full scale IQ measures like the Wechsler Intelligence Scale for Children-Third Edition (WISC-III), it less accurately predicts WISC-III scores in intellectually-gifted and learning-disabled populations.[22,40] These inaccuracies at the extremes make null results more likely. Unfortunately, most existing large cohort studies are limited to subjective measures of sleep and cognitive screening tests given cost and time limitations. Although we examined prospective relationships of infant sleep duration and nighttime consolidation with later child cognition, we could not assess other infant sleep characteristics like overnight awakenings or uninterrupted sleep length, which have been found to be influential for cognition in toddlerhood.[15] Due to the observational nature of our study and analysis, we could not conclude causal relationships between sleep and cognitive measures.

In a large prospective cohort of children from Project Viva, we found that parental reports of higher infant nighttime sleep consolidation and shorter infant daytime sleep duration were associated with higher verbal IQ in mid-childhood. Future studies should include more racially, ethically, and socioeconomically diverse participants, use both subjective and objective measures of infant sleep, and compare changes in sleep and cognition longitudinally to consider causality. Current sleep guidelines from 2016 only include recommendations for 24-hour sleep duration and do not focus on other sleep pattern measures like sleep consolidation.[10] Researchers should continue to examine infant sleep patterns in detail to inform updated clinical recommendations to promote optimal child cognitive outcomes. Infant sleep is influenced by environmental factors, including parental behaviors and sleep arrangement. Therefore, infant sleep patterns may be an appropriate modifiable target for interventions aimed at improving child cognition.

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Abbreviations:

PPVT-3	Peabody Picture Vocabulary Test Revised Version 3
WRAVMA	Wide Range Assessment of Visual Motor Abilities
KBIT-2	Kaufman Brief Intelligence Test Second Edition
WRAML2-VMI	Wide Range Assessment of Memory and Learning Visual Memory Index

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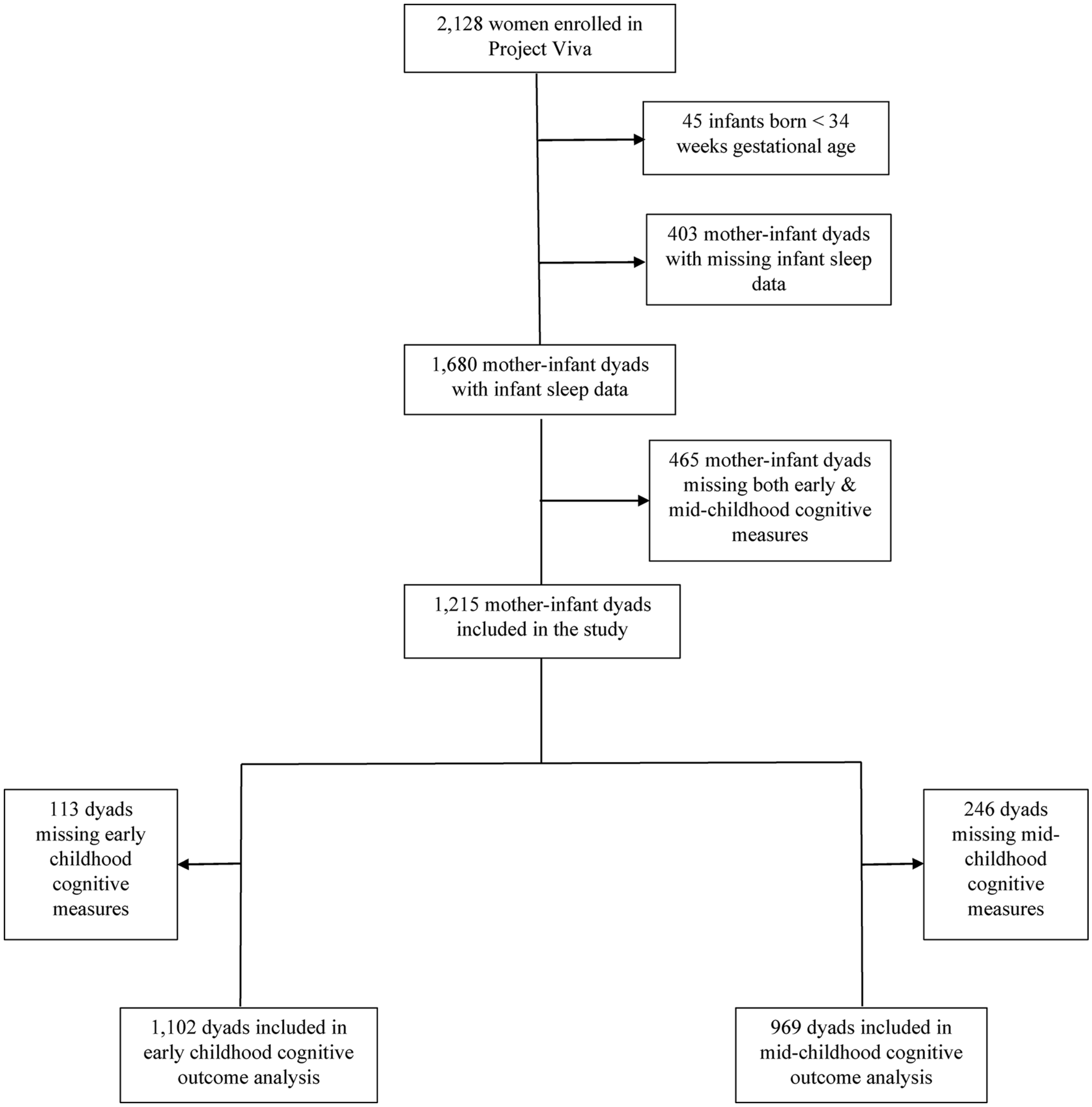

Figure 1.

Participant Inclusion and Exclusion Flow Diagram for Project Viva Study on Infant Sleep and Child Cognition in Early and Mid-Childhood

Table 1.

Characteristics and Infant Sleep Data of N=1215 Participants in Project Viva with Infant Sleep Data and Early and/or Mid-Childhood Cognitive Data

Characteristics	Total Sample (N=1215)		Mean (SD)	
			24-hour sleep duration (h)	Nighttime sleep consolidation[a] (%)
Child				
Age at infancy visit, median (IQR), m	6.4	(6.1–7.0)	-	-
Sex				
Female, n (%)	603	(49.6)	12.26 (2.1)	77.01 (8.6)
Male, n (%)	612	(50.4)	12.15 (2.0)	76.68 (9.0)
Race or ethnicity[b], n (%)				
American Indian or Alaskan Native	0	(0)	-	-
Asian/Pacific Islander	38	(3.1)	12.01 (1.9)	73.55 (7.7)
Black/African American	160	(13.2)	11.39 (2.7)	72.02 (12.9)
Hispanic/Latino	50	(4.1)	11.69 (2.5)	73.41 (9.8)
White	837	(69.0)	12.44 (1.8)	78.25 (7.0)
More than 1 race or ethnicity	129	(10.6)	12.06 (1.9)	75.94 (10.3)
Breastfeeding status at 6 months, n (%)				
Formula only	120	(9.9)	12.27 (2.1)	77.46 (9.1)
Breast milk only	329	(27.1)	12.28 (2.1)	77.41 (8.1)
Mixed	323	(26.6)	12.11 (2.0)	76.51 (9.4)
Weaned	443	(36.5)	12.21 (2.0)	76.50 (8.8)
Infancy television viewing[b], median (IQR), h/d	0.4	(0.1–1.1)	-	-
Gestational age at delivery, mean (SD), wks	39.6	(1.4)	-	-
Maternal				
Age, mean (SD), y	32.4	(5.1)	-	-
Education[b]				
Less than college, n (%)	349	(28.8)	11.94 (2.3)	75.23 (10.8)
College graduate or more, n (%)	862	(71.2)	12.33 (1.9)	77.50 (7.8)
Parity				
Primipara, n (%)	580	(47.7)	12.21 (1.9)	77.64 (7.9)
Multipara, n (%)	635	(52.3)	12.20 (2.2)	76.12 (9.5)
Household income[b]				
≤$70,000, n (%)	381	(33.7)	11.89 (2.2)	75.56 (9.2)
>$70,000, n (%)	749	(66.3)	12.39 (1.8)	77.86 (7.7)
Marital Status[b]				
Married/Cohabitating, n (%)	1131	(93.5)	12.24 (2.0)	76.97 (8.7)
Not married/Cohabitating, n (%)	79	(6.5)	11.89 (2.2)	75.13 (10.6)

Abbreviations: IQR: interquartile range, d: days, SD: standard deviation, h/d: hours per day, wks: weeks, y: years

[a]Calculated as percentage of total 24-hour sleep hours occurring at nighttime

[b]Missing values for child race and ethnicity (n=1), child television viewing (n=4), maternal education (n=4), household income (n=85), marital status (n=5)

Table 2.

Infant Sleep Measures and Early and Mid-Childhood Cognitive Measures for Participants in Project Viva

Measure	N	Mean	(SD)	Range
Infant sleep measures[a]				
24-hour sleep duration (h)	1215	12.2	(2.0)	3–19
Nighttime sleep consolidation[b] (%)	1215	76.8	(8.8)	0–100
Daytime sleep duration (h)	1215	2.82	(1.2)	0–8
Nighttime sleep duration (h)	1215	9.4	(1.8)	0–14
Early Childhood Cognitive Measures				
Receptive Vocabulary (PPVT-3)	1081	104.3	(14.2)	64–148
Visual-motor skills (WRAVMA Composite)	1049	102.5	(11.3)	57–151
Mid-Childhood Cognitive Measures				
Verbal Intelligence (KBIT-2 Verbal)	960	112.9	(14.7)	44–147
Nonverbal Intelligence (KBIT-2 Nonverbal)	969	106.7	(16.9)	40–147
Visual-motor skills (WRAVMA Drawing)	963	92.3	(16.8)	45–155
Memory (WRAML2 VMI)	964	16.9	(4.4)	2–29

Abbreviations: h: hours, PPVT-3: Peabody Picture Vocabulary Test Revised Version 3, WRAVMA: Wide Range Assessment of Visual Motor Abilities, KBIT-2: Kaufman Brief Intelligence Test Second Edition, WRAML2 VMI: Wide Range Assessment of Memory and Learning Visual Memory Index

[a] N=1215 includes all subjects with infant sleep measures and at least one early or mid-childhood cognitive measure

[b] Calculated as percentage of total 24-hour sleep hours occurring at nighttime

Table 3.

Multivariable-Adjusted Difference in Early Childhood Cognitive Scores Associated with Increment in Infant Sleep Measures[a]

	Difference in Early Childhood Cognitive Score per 1-unit increase in infant sleep measure, β (95% CI)	
Models[b]	**Receptive Vocabulary[c]**	**Visual-motor Skills[d]**
24-hour sleep duration (h)		
Sex-adjusted model	0.13 (−0.30, 0.56)	0.20 (−0.14, 0.54)
Confounder-adjusted model	−0.12 (−0.54, 0.31)	0.02 (−0.33, 0.37)
Fully-adjusted model	−0.36 (−0.78, 0.05)	−0.08 (−0.43, 0.27)
Nighttime sleep consolidation[e] (%)		
Sex-adjusted model	0.20 (0.10, 0.30) **	0.13 (0.05, 0.21) **
Confounder-adjusted model	0.15 (0.04, 0.25) **	0.12 (0.04, 0.20) **
Fully-adjusted model	0.04 (−0.06, 0.14)	0.08 (−0.002, 0.17)
Daytime sleep duration (h)		
Sex-adjusted model	−1.29 (−2.04, -0.54) **	−0.61 (−1.20, -0.02) *
Confounder-adjusted model	−1.09 (−1.84, -0.33) **	−0.66 (−1.28, -0.04) *
Fully-adjusted model	−0.57 (−1.31, 0.16)	−0.47 (−1.10, 0.15)
Nighttime sleep duration (h)		
Sex-adjusted model	0.72 (0.22, 1.21) **	0.52 (0.13, 0.90) **
Confounder-adjusted model	0.30 (−0.19, 0.79)	0.31 (−0.10, 0.71)
Fully-adjusted model	−0.26 (−0.75, 0.23)	0.09 (−0.32, 0.51)

Abbreviations: CI: confidence interval, h: hours

[a] Longitudinal data from mother-child pairs from Project Viva. Sample sizes for models of Receptive Vocabulary: Model 1, N=1081, Model 2 & 3, N=1022; Visual-motor skills: Model 1, N=1049, Model 2 & 3, N=993

[b] Sex-adjusted model: Adjusted for child sex; Confounder-adjusted model: Model 1 + child age at exposure, maternal age, education, parity, household income; Fully-adjusted model: Model 2 + child race/ethnicity

[c] Receptive vocabulary as measured by Peabody Picture Vocabulary Test Revised Version 3

[d] Visual-motor skills as measured by Wide Range Assessment of Visual Motor Abilities Composite Score

[e] Calculated as percentage of total 24-hour sleep hours occurring at nighttime

* $p<0.05$

** $p< 0.01$

Table 4.

Multivariable-Adjusted Difference in Mid-Childhood Cognitive Scores Associated with Increment in Infant Sleep Measures[a]

	Difference in Mid-Childhood Cognitive Score per 1-unit increase in infant sleep measure, β (95% CI)			
Models[b]	**Verbal IQ[c]**	**Non-verbal IQ[d]**	**Visual-motor Skills[e]**	**Memory[f]**
24-hour sleep duration (h)				
Sex-adjusted model	0.46 (0.01, 0.92) *	0.51 (−0.01, 1.04)	−0.11 (−0.63, 0.41)	0.05 (−0.08, 0.19)
Confounder-adjusted model	0.07 (−0.37, 0.51)	0.30 (−0.27, 0.86)	−0.11 (−0.68, 0.46)	−0.03 (−0.18, 0.12)
Fully-adjusted model	−0.09 (−0.52, 0.35)	0.21 (−0.35, 0.77)	−0.12 (−0.69, 0.46)	−0.03 (−0.18, 0.11)
Nighttime sleep consolidation[g] (%)				
Sex-adjusted model	0.28 (0.18, 0.38) **	0.16 (0.04, 0.28) **	0.05 (−0.06, 0.17)	0.01 (−0.02, 0.04)
Confounder-adjusted model	0.20 (0.10, 0.30) **	0.06 (−0.07, 0.19)	0.06 (−0.07, 0.19)	0.00 (−0.04, 0.03)
Fully-adjusted model	0.12 (0.01, 0.22) *	0.02 (−0.11, 0.16)	0.05 (−0.09, 0.19)	0.00 (−0.04, 0.03)
Daytime sleep duration (h)				
Sex-adjusted model	−1.65 (−2.44, -0.86) **	−0.61 (−1.53, 0.30)	−0.43 (−1.34, 0.48)	−0.04 (−0.27, 0.20)
Confounder-adjusted model	−1.32 (−2.08, -0.56) **	−0.26 (−1.24, 0.71)	−0.39 (−1.38, 0.60)	−0.02 (−0.28, 0.23)
Fully-adjusted model	−0.86 (−1.62,-0.10) *	−0.04 (−1.02, 0.94)	−0.32 (−1.33, 0.69)	−0.02 (−0.28, 0.24)
Nighttime sleep duration (h)				
Sex-adjusted model	1.35 (0.83, 1.87) **	0.95 (0.35, 1.56) **	0.04 (−0.56, 0.65)	0.09 (−0.07, 0.24)
Confounder-adjusted model	0.70 (0.18, 1.21) **	0.52 (−0.13, 1.17)	0.03 (−0.64, 0.70)	−0.03 (−0.20, 0.14)
Fully-adjusted model	0.28 (−0.24, 0.80)	0.33 (−0.35, 1.00)	−0.02 (−0.71, 0.67)	−0.04 (−0.22, 0.14)

Abbreviations: CI: confidence interval, h: hours, IQ: intelligence quotient

[a] Longitudinal data from mother-child pairs from Project Viva. Sample sizes for models of Verbal IQ: Model 1, N=960, Models 2 & 3, N=888, Non-verbal IQ: Model 1, N=969, Model 2 & 3, N=897, Memory: Model 1, N=964, Model 2 & 3, N=893, Drawing: Model 1, N=963, Model 2 & 3, N=892

[b] Sex-adjusted model: Adjusted for child sex; Confounder-adjusted model: Model 1 + child age at exposure, maternal age, education, parity, household income; Fully-adjusted model: Model 2 + child race/ethnicity

[c] Verbal IQ as measured by the Kaufman Brief Intelligence Test Second Edition Verbal Subtest

[d] Non-verbal IQ as measured by the Kaufman Brief Intelligence Test Second Edition Non-Verbal Subtest

[e] Visual-motor skills as measured by the Wide Range Assessment of Visual Motor Abilities Drawing Subscale

[f] Memory as measured by the Wide Range Assessment of Memory and Learning Visual Memory Index

[g] Calculated as percentage of total 24-hour sleep hours occurring at nighttime

* $p<0.05$

** $p< 0.01$