



## Original Article

## Shorter sleep duration is associated with reduced cognitive development at two years of age



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## ABSTRACT

**Background:** Both short sleep duration and sleep-disordered breathing (SDB) are associated with poor neurocognitive development. However, the co-contributions of short sleep duration and SDB on neurodevelopment in pre-school children are relatively unknown.

**Methods:** We assessed both sleep duration and SDB by quarterly questionnaire from three months to two years of age among Canadian Healthy Infant Longitudinal Development (CHILD) birth cohort participants. Group-based modeling determined trajectories of total, daytime, and nighttime sleep duration and SDB. Linear regression was used to assess the impact of sleep duration and SDB trajectories on cognitive (primary outcome) and language (secondary) development at two years of age as assessed by the Bayley Scale of Infant Development (BSID-III) (mean 100; standard deviation of 15).

**Results:** Of the 822 CHILD Edmonton participants, 703 (86%) were still enrolled at two years of age with 593 having BSID-III data at two years of age. Trajectory analysis identified four total sleep durations phenotypes [short sleepers (17.9%), decline to short sleepers (21.1%), intermediate sleepers (36.9%) and long sleepers (24.1%)]. Compared to children with intermediate sleep durations, short sleepers had a 5.2-point lower cognitive development score at two years of age [standard error (SE) 1.7;  $p = 0.002$ ]. Nocturnal sleep duration, compared to daytime sleep duration had the greatest effect on cognitive development. We also identified three SDB symptom trajectories [early-onset SDB (15.7%), late-onset SDB (14.2%), and persistent SDB (5.3%)] and 79.5% of children had no SDB symptoms. Children with persistent SDB also had a 5.3-point lower language score (SE 2.7;  $p = 0.05$ ) compared to children with no SDB. SDB trajectories were not associated with cognitive development.

**Conclusion:** In a population-representative birth cohort study, both short sleep duration and SDB were associated with adverse neurodevelopment at two years of age. Children with short nighttime sleep duration had lowered cognitive and language scores and children with persistent SDB also had lower language scores.

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## 1. Introduction

Insufficient sleep duration and sleep-disordered breathing (SDB), from snoring to sleep apnea [1], are each associated with adverse cognitive development in children, adolescents [2] and

adults. Among adults, nocturnal sleep has been found to be more beneficial than daytime sleep for the encoding of verbal information [3] and motor sequences [4]. Reduced nighttime sleep at one year of age was associated with reduced executive functioning performance at four years of age [5]. Similarly, shorter nighttime sleep was associated with reduced attention among preschool children [6]. Infants with shorter sleep duration also displayed reduced memory retention [7]. Reduced childhood nighttime sleep is associated with worse new-word memory recall [8]. Poor sleep–wake consolidation by two years of age was associated with language delay by five years of age [9].

Longitudinal patterns of sleep duration, modeled using growth mixture modeling, have demonstrated how sleep duration over time [10] was associated with neurocognitive development [11,12]. Four sleep-duration patterns (typical sleepers, initially short sleepers, poor sleepers, and persistent short sleepers) were identified among children with biennial sleep duration data from birth to seven years of age [11,12]. Persistent short sleep in children was associated with lower physical, social, and emotional health compared to typical sleepers [11]. In a separate study, persistent short sleep duration between 2.5 and 10 years of age was associated with poor receptive vocabulary performance at 10 years of age [13].

SDB has been associated with negative consequences for children's cognitive development [14]. Several longitudinal cohort studies have shown associations between SDB in school-age children (five years of age or older) and adverse executive function [15,16] and behavior [17] difficulties. The Tucson children's assessment of sleep apnea (TuCASA) study reported an increased prevalence of learning difficulties [16] and behavior problems [18] among 5- and 12-year-old children with SDB. In the Dunedin longitudinal birth cohort, persistent sleep problems between five and nine years of age were associated with lower neuropsychological function at 13 years of age [19]. The Cleveland Children's Sleep and Health study showed that 8- to 11-year-old children with SDB already demonstrate a higher prevalence of behavioral problems [20].

SDB disrupts sleep architecture [21] and may confound the relationship between sleep duration and cognitive development [22]. Snoring but not sleep duration was associated with performance on cognitive and language assessments among preschool aged children (aged 3–6 years) [23]. We present findings from the Canadian Healthy Infant Longitudinal Development (CHILD) study Edmonton site in which we explored whether the co-contributions of sleep duration and SDB were associated with cognitive (primary) and language (secondary) development at two years of age. We hypothesized that children with reduced sleep duration (primary exposure variable) up to two years of age would present with reduced cognitive and language outcomes at two years of age. Additional analysis will examine the impact of SDB (secondary exposure variable) on neurobehavioral development at two years of age.

## 2. Methods

### 2.1. Study participants

CHILD is a longitudinal birth cohort study designed to assess the influence of gene–environment interactions on the development of allergy and asthma. CHILD Edmonton families ( $N = 822$ ), recruited between 2008 and 2012, participated in an add-on study examining the longitudinal relationship between SDB and cognitive development. Mothers were seen at recruitment during pregnancy and infants were seen at in-clinic visits at one and two years of age. Informed consent was obtained from all mothers as well as consenting fathers when available. Approval for this research study was obtained from the Research Ethics Board (REB) at the University of Alberta (Pro00002099).

### 2.2. Study variables

#### 2.2.1. Cognitive (primary outcome) at two years of age

Cognitive development was assessed using the Bayley Scale of Infant Development (BSID-III) at two years of age. The BSID-III is a standardized, reliable and validated developmental assessment of infants between 6 and 42 months of age [24,25]. A trained research assistant conducted testing in an examination room with a primary caregiver present. A registered educational psychologist completed annual or semi-annual assessments of the research assistant's administration of the BSID-III to ensure reliability. All subtests were completed in a single 45-min session, although only the results from the cognitive subtest will be addressed in the current study. Breaks were provided if infants displayed signs of boredom or inattentiveness. The research assistants were not blinded to the infant's sleep or snoring symptoms at the time of BSID-III testing. Two individuals scored the BSID-III and the results compared for consistency. Raw cognitive scores were converted to a composite score (population mean 100 and standard deviation of 15).

#### 2.2.2. Language development (secondary outcome)

The BSID-III language scale assesses both receptive and expressive communication. Receptive communication includes how well the child is able to recognize sounds and understand orally presented words and sentences such as following simple directions or identifying an object by pointing to its picture or following simple directions. Expressive communication includes how well the child is able to communicate using sound, words or gestures; tasks include asking the child to identify pictures using words and answering questions. The BSID-III total language scores, the sum of the receptive and expressive language scales, were converted to a composite score (population mean 100 and standard deviation of 15).

#### 2.2.3. Sleep duration (primary exposure variable)

The 13-item parent-completed Brief Infant Sleep Questionnaire (BISQ) [26], was administered quarterly from three months of age. Parents reported the amount of time that their infants slept during the day and night separately. Total sleep was calculated by summing day and night sleep times.

#### 2.2.4. SDB (secondary exposure variable)

A 22-item sleep-related breathing disorder (SRBD) scale was completed by parents quarterly from three months to two years of age. The SRBD ratio is obtained by dividing the sum of all 'yes' responses by the total number of non-missing items (yes or no). Infants with a SRBD ratio greater than 0.33 were considered to have SDB at that quarterly assessment [27].

### 2.3. Confounding variables

Please see the Supplementary Material for a more in-depth assessment of covariates. These covariates include maternal age, birth weight (kg), first born, ethnicity, family income, marital status, highest education achieved, maternal depression, maternal stress, season of birth, and control, for which a research assistant completed the BSID-III testing at two years of age.

#### 2.3.1. Family history of language delay

The primary care giver completed the Language Development Survey (LDS) [28] when children were two years of age. Children were classified as having a family history of language delay if their parent/guardian reported that someone in the family had been slow in learning to talk.

### 2.3.2. Sleep efficiency, apnea–hypopnea index, desaturation index

A single-night level-three home polysomnography study (PSG; NOX-T3) was completed at a mean age of 13.2 months [95% confidence interval (CI) 9.5, 22.2]. Home PSG was not completed at any other time point. Staff installed the PSG equipment in the infant's bedroom approximately 30 min before their bedtime. The NOX-T3 PSG recorded pulse oximetry, real-time audio, and chest/abdominal respiratory inductance plethysmography [29]. PSG scoring was completed by trained PSG technicians (Sleep Strategies). The scoring rubric (Supplementary Material), based on the AASM pediatric scoring guidelines [30], was modified to reflect the channels available for the NOX-T3. Measures of apneas, hypopneas, sleep duration, total time in bed, and sleep efficiency were obtained from the PSG. Sleep efficiency was calculated as the number of minutes of sleep divided by the number of minutes the infant was in bed.

### 2.3.3. Duration of breastfeeding

Breastfeeding is associated with increased nighttime waking [12]. Mothers reported whether they were breastfeeding, formula feeding, or provided solid food for their infants at 3, 6, 12, and 24 months of age.

### 2.3.4. Gestational age at delivery

Gestational age at delivery was obtained from the hospital birth chart.

### 2.3.5. Environmental tobacco smoke

Exposure to household smoke was obtained from maternal reporting during pregnancy, at three months and 12 months of age.

## 2.4. Statistical analysis

Children with known neurodevelopmental delays were excluded from all analyses. Group-based trajectory modeling, using finite mixture modeling (STATA Proc Traj – January 2017 download [31,32]), was used to determine (1) trajectories of sleep duration to two years of age (daytime, nighttime, and total) using quarterly BISQ assessments, and (2) trajectories of SDB to two years of age using quarterly SRDB assessments. Participants were assigned to a trajectory based on the group trajectory for which they had the highest probability of membership. Linear, quadratic, and cubic trajectory models were considered for model development [33]. Participants had to have at least one PSQ ratio and one completed BISQ to be included in each trajectory analysis. The model with the best-fit [lowest Bayesian information criterion (BIC)] and significant group percentage was selected.

Chi-squared tests (categorical predictors) and *t*-tests (continuous predictors) were used to compare demographic variables between participants with and without BSID-III cognitive scores at two years of age. Univariate linear regression analyses identified factors associated with cognitive performance on the BSID-III at two years of age (primary outcome). Measures of SDB assessed by PSG, including sleep efficiency, apnea and hypopnea index, and desaturation index, were considered as univariate predictors of cognition. Predictors significant in univariate analysis ( $p < 0.05$ ), such as SDB trajectories, were included in multivariate analyses. The BIC were compared among the daytime, nighttime, and total sleep trajectory models to determine which sleep trajectories to use in the multivariate analyses. For multivariate analyses, missing values on all variables other than BSID-III (including BISQ and SDB questionnaires) were replaced with the mean or reference (for continuous and categorical variables, respectively) and a dummy variable was included in the analysis in order to account for the replacement. Variables not statistically significant ( $p < 0.05$ ) in the multivariate analyses were excluded. Interactions between SDB and

sleep trajectories were also explored and kept in the model if significant ( $p < 0.05$ ). Analysis controlled for which research staff completed the BSID-III testing at two years of age. Similar statistical analyses were used to identify factors associated with language performance on the BSID-III at two years of age. Stata 14 (STATA corp.) was used for all analyses.

## 3. Results

Of the 822 participants recruited to CHILD Edmonton, 593 (72.1%) completed the two-year BSID-III assessment. Participants with cognitive outcomes at two years of age were more likely to be Caucasian (416/581; 71.6%, Table 1), come from households with an income of \$60,000 or more (506/569; 88.9%, Table 1) and have a mother that attended post-secondary education compared to individuals without cognitive data at two years of age ( $p < 0.001$  for all three outcomes). Average breastfeeding duration was 9.0 months (95% CI 8.5, 9.5) among mothers of infants with cognitive outcomes at two years. Participants with and without cognitive outcomes at two years did not differ with respect to gender, SDB symptoms, nighttime sleep duration, gestational age at delivery, and birth weight. See Table 1 for demographic information pertaining to categorical predictors and Table 2 for demographic information pertaining to continuous predictors.

### 3.1. Trajectories for sleep duration and SDB from 3 to 24 months

#### 3.1.1. Total sleep trajectories between 3 and 24 months

We identified four total infant sleep patterns throughout the first two years of life (Fig. 1): 'Short sleepers', 'Decline to short sleepers', 'Intermediate sleepers', and 'Long sleepers'. The short sleepers (17.9%) slept a total of 11.5 h at three months of age and 11.9 h at 24 months. The decline to short sleepers (21.1%) slept 15.5 h at three months of age and only 12.0 h at 24 months. The intermediate sleepers (36.9%) slept 13.4 h at three months of age and 12.9 h at 24 months. The long sleepers (24.1%) slept 16.0 h at three months of age and 13.3 h at 24 months. For comparison, population data as reported by Gelland et al., for mean hours of total sleep between three months and two years of age [34] are presented in Supplementary Table S2.

#### 3.1.2. Nighttime sleep trajectories between 3 and 24 months

We identified three nighttime sleep trajectories from three months to two years of age (Fig. 2): 'Short sleepers', 'Intermediate sleepers' and 'Long sleepers'. Short sleepers (9.7%) slept from 7.7 at three months of age to 9.0 h/night at two years of age, respectively; intermediate sleepers (39.2%) slept from 8.7 at three months of age to 10.0 h/night at two years and long sleepers (51.1%) from 10.1 at three months to 11.1 h/night at two years. Nighttime sleep duration from 3 to 24 months of age is presented in the Supplementary Table S3.

#### 3.1.3. Daytime sleep trajectories between 3 and 24 months

We identified four daytime infant sleep patterns throughout the first two years of life (Fig. 3): 'Short sleepers', 'Decrease to short sleepers', 'Intermediate sleepers' and 'Decrease to intermediate sleepers'. At three months of age, the short sleepers (29.5%) spent an average of 3.1 h asleep during the day and were asleep for 1.8 h throughout the day by 24 months. The decrease to short sleepers (34.4%) spent approximately 5.9 h asleep during the day at three months but only 1.9 h throughout the day by 24 months. The intermediate sleepers (23.8%) spent approximately 4.0 h asleep during the day at three months of age, and 2.6 h throughout the day by 24 months. The decrease to intermediate sleepers (12.2%) spent

**Table 1**  
Demographics describing the Canadian Healthy Infant Longitudinal Development (CHILD) Edmonton sample (categorical predictors).

	Cognitive data (two years) present, % (N/total)	Cognitive data absent, % (n/total)	<i>p</i> <sup>a</sup>
Categorical			
Female	48.4 (287/593)	50.7 (111/219)	0.06
Caucasian (child)	70.6 (416/581)	56.4 (110/195)	<0.01
Caucasian (mother)	78.7 (463/588)	68.2 (137/201)	<0.01
Income \$60,000 or more	88.9 (506/569)	73.0 (135/185)	<0.01
Mother attended post-secondary	93.5 (531/568)	84.3 (167/198)	<0.01
Maternal smoking	3.5 (20/571)	7.2 (14/195)	<0.01
SDB three months	4.0 (21/530)	4.8 (7/145)	0.64
SDB six months	4.6 (22/480)	8.6 (9/105)	0.10
SDB nine months	7.7 (39/505)	7.6 (10/131)	0.97
SDB 12 months	5.6 (30/522)	6.2 (6/97)	0.87
SDB 15 months	8.9 (42/474)	6.9 (6/48)	0.55
SDB 18 months	11.0 (54/491)	7.3 (5/69)	0.34
SDB 21 months	9.3 (47/504)	12.2 (6/49)	0.51
SDB 24 months	9.7 (50/515)	13.7 (7/51)	0.36

SDB, sleep-disordered breathing.

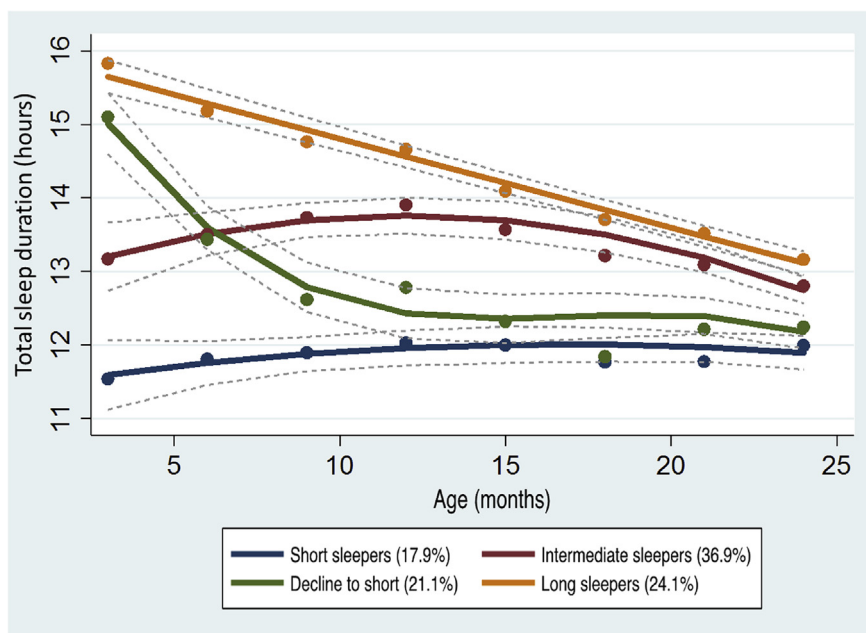
<sup>a</sup> Represents statistical significance of chi-squared.

**Table 2**  
Demographics describing the Canadian Healthy Infant Longitudinal Development (CHILD) Edmonton sample (continuous predictors).

Continuous	Cognitive data (two years) present, mean (95% CI)	Cognitive data absent, mean (95% CI)	<i>p</i> <sup>a</sup>
Nighttime sleep (h) (three months)	9.4 (9.2, 9.5) <i>N</i> = 529	9.3 (9.0, 9.5) <i>N</i> = 148	0.50
Nighttime sleep (h) (six months)	9.9 (9.8, 10.0) <i>N</i> = 502	9.9 (9.7, 10.2) <i>N</i> = 113	0.83
Nighttime sleep (h) (nine months)	10.4 (10.3, 10.5) <i>N</i> = 505	10.1 (9.9, 10.4) <i>N</i> = 130	0.03
Nighttime sleep (h) (12 months)	10.6 (10.5, 10.7) <i>N</i> = 530	10.5 (10.3, 10.8) <i>N</i> = 96	0.59
Nighttime sleep (h) (15 months)	10.7 (10.6, 10.8) <i>N</i> = 475	10.5 (10.3, 10.8) <i>N</i> = 87	0.24
Nighttime sleep (h) (18 months)	10.7 (10.6, 10.8) <i>N</i> = 510	10.3 (10.1, 10.6) <i>N</i> = 75	<0.01
Nighttime sleep (h) (21 months)	10.6 (10.5, 10.7) <i>N</i> = 502	10.2 (9.9, 10.6) <i>N</i> = 49	0.01
Nighttime sleep (h) (24 months)	10.5 (10.4, 10.6) <i>N</i> = 533	10.3 (10.1, 10.6) <i>N</i> = 68	0.20
Time in bed (min) (assessed using PSG at one year)	554.8 (546.2, 563.4) <i>N</i> = 473	534.1 (510.1, 558.1) <i>N</i> = 91	0.07
Sleep efficiency (min asleep/min in bed)	91.3 (90.8, 91.8) <i>N</i> = 473	91.7 (90.6, 92.8) <i>N</i> = 91	0.55
Gestational age (weeks)	39.5 (39.4, 39.6) <i>N</i> = 593	39.4 (39.2, 39.5) <i>N</i> = 216	0.21
Infant weight (kg)	3.4 (3.4, 3.5) <i>N</i> = 590	3.4 (3.3, 3.5) <i>N</i> = 212	0.66
Breastfeeding duration (months)	9.0 (8.5, 9.5) <i>N</i> = 532	6.5 (5.5, 7.5) <i>N</i> = 119	<0.01

PSG, polysomnography.

<sup>a</sup> Statistical significance of *t*-test.



**Fig. 1.** Trajectory groups characterizing total sleep patterns throughout the first two years of life.

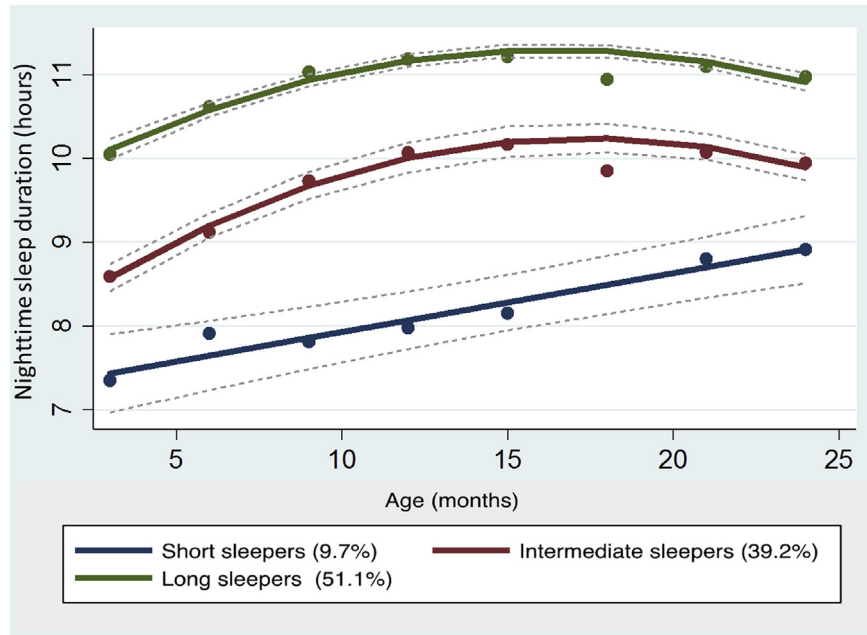


Fig. 2. Trajectory groups characterizing nighttime sleep patterns throughout the first two years of life.

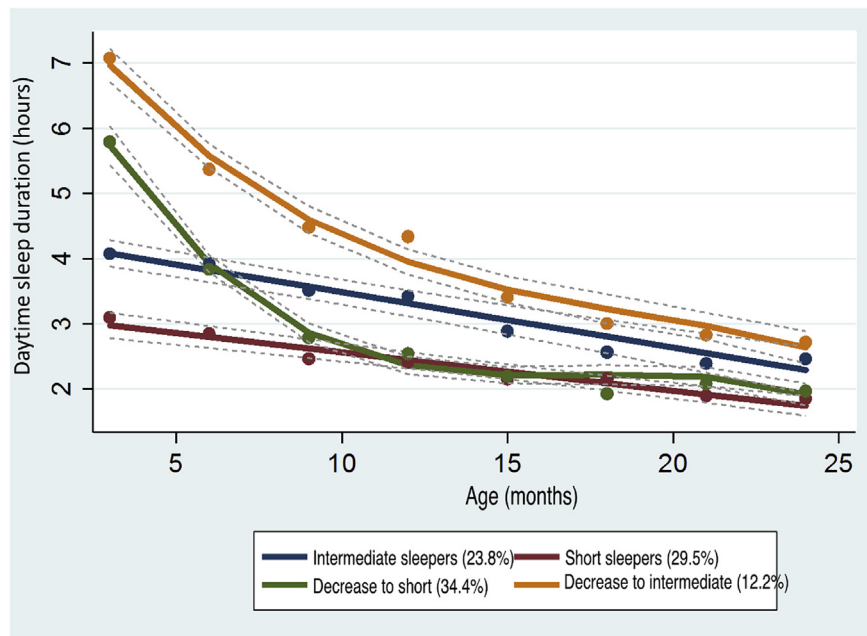


Fig. 3. Trajectory groups characterizing daytime sleep patterns throughout the first two years of life.

approximately 7.1 h asleep during the day at three months and 2.8 h asleep during the day at 24 months.

### 3.1.4. SDB trajectories between 3 and 24 months

Participants were categorized into four groups using the trajectory analysis (see [Supplementary Fig. S1](#)): 'No SDB', 'Late-onset SDB', 'Early-onset SDB with decline', and 'Persistent SDB'. The y-axis of [Supplementary Fig. S1](#) represents the proportion of participants with a positive SRBD in that category at that time-point. The description of the SDB trajectories including factors associated with each trajectory is detailed separately [35].

## 3.2. Cognitive development at two years of age (primary outcome)

### 3.2.1. Univariate analyses

Univariate analyses are presented in [Supplementary Table S1](#). Neither SDB trajectories based on the 22-item SRBD scale, nor children considered to have SDB based on a positive SRBD ratio at two years of age, were significantly associated with cognitive development at two years of age in univariate analyses. PSG measures [sleep efficiency, apnea–hypopnea index (AHI), and desaturation index] were not significantly associated with cognitive development at two years of age. Categorizing participants with



SDB based on an AHI greater than 1.5, 5 or 10 were not associated with cognitive development.

### 3.2.2. Multivariate analyses

Compared to children with intermediate total sleep durations, short sleepers had a 5.2-point lower cognitive development score at two years of age (SE 1.7;  $p = 0.002$ ). Neither decline to short sleep duration children, or long sleep duration children had a significant difference in cognitive development. Children born prior to 36.5 weeks had a 10.4-point lower BSID-III cognitive score compared to children born after 36.5 weeks (SE 3.3;  $p = 0.001$ ). Children with short total sleep duration continued to have a lower cognitive score at two years of age when controlling for cognitive development at one year of age.

The nighttime sleep trajectory resulted in a superior model fit, based on the lower BIC, compared to daytime sleep models (Table 3). Nighttime sleep trajectories predicted cognitive development even when controlling for concurrent total sleep duration at two years of age. Short nighttime sleep was associated with a 10.1-point decrease in cognitive development at two years of age (SE 2.2;  $p < 0.001$ ); while intermediate sleep was associated with a 3.7-point decrease in cognitive development (SE 1.2;  $p < 0.01$ ) compared to children in the long sleep group (reference). Children

born between 34 and 36.5 weeks' gestation had a 9.9-point lower cognitive score (SE 3.2;  $p < 0.005$ ) compared to children born after 36.5 weeks gestational age. Each month of any breastfeeding was also associated with a 0.3-point increase in cognitive development. Children of mothers who smoked during pregnancy had a 6.0 (SE 3.0;  $p = 0.05$ ) lower cognitive composite score. Multivariate analyses controlled for gender and ethnicity.

### 3.2.3. Sensitivity analyze

Short and intermediate nighttime sleep duration trajectories were still significantly associated with reduced cognitive development at two years of age in a sensitivity analysis including only participants with complete data. Shorter nocturnal sleep duration was similarly significantly associated with a reduced change in cognitive development between one and two years of age. There was no significant interaction between SDB and nighttime sleep trajectories.

## 3.3. Language development at two years of age (secondary outcome)

### 3.3.1. Multivariate analyses

Compared to children with intermediate total sleep durations, short sleepers had a 3.2-point lower language development score at

**Table 3**  
Multivariate regression analysis for cognitive development at two years of age.

Variable	Total sleep		Model 1: nighttime sleep		Model 2: daytime sleep	
	$r^2$ 0.19		BIC: 4838	$r^2$ 0.20	BIC: 4860	$r^2$ 0.18
Trajectories	Coefficient (SE)	$p$	Coefficient (SE)	$p$	Coefficient (SE)	$p$
Total sleep						
Intermediate sleepers (ref.)						
Short sleepers	-5.2 (1.7)	0.002				
Decline to short sleepers	-1.6 (1.6)	0.321				
Long sleepers	-0.3 (1.4)	0.859				
Missing sleep data	-5.7 (13.4)	0.669				
Nighttime sleep						
Long sleepers (ref.)						
Short sleepers			-10.1 (2.2)	<0.001		
Intermediate sleepers			-3.7 (1.2)	0.003		
Missing sleep data			-7.2 (13.2)	0.584		
Daytime sleep						
Decrease to short (ref.)						
Intermediate sleepers					-2.8 (1.5)	0.064
Short sleepers					0.7 (1.4)	0.615
Decrease to intermediate sleepers					-2.8 (1.9)	0.129
Missing sleep data					-4.6 (13.4)	0.733
Categorical						
Male (ref.)						
Female	3.8 (1.1)	0.001	3.8 (1.1)	<0.001	3.7 (1.1)	0.001
Caucasian (ref.)						
Non-caucasian	-3.6 (1.2)	0.004	-2.8 (1.2)	0.027	-3.4 (1.2)	0.007
Missing ethnicity data	3.5 (4.3)	0.407	4.4 (4.2)	0.297	2.7 (4.3)	0.523
Maternal not smoking during pregnancy (ref.)						
Maternal smoking during pregnancy	-6.7 (3.1)	0.028	-6 (3)	0.046	-6.2 (3)	0.042
Missing pregnancy smoking data	-1.9 (2.1)	0.38	-0.9 (2.1)	0.658	-1.3 (2.1)	0.539
Season of birth: Winter (ref.)						
Spring	1.9 (1.6)	0.224	1.5 (1.6)	0.34	2 (1.6)	0.207
Summer	-3.4 (1.6)	0.031	-3.8 (1.6)	0.014	-3.3 (1.6)	0.036
Fall	-4.9 (1.6)	0.003	-5.2 (1.6)	0.001	-4.9 (1.6)	0.003
Born after 36.5 weeks gestational age (ref.)						
Born prior to 36.5 weeks gestational age	-10.4 (3.3)	0.001	-9.9 (3.2)	0.002	-10.4 (3.3)	0.001
Individual completing BSID-III testing:						
Research coordinator (ref.)						
Research assistant 1	-10.8 (9.4)	0.254	-9.7 (9.3)	0.298	-11.8 (9.4)	0.211
Research assistant 2	5.4 (1.5)	<0.001	5.5 (1.5)	<0.001	5.5 (1.5)	<0.001
Research assistant 3	-9.8 (3.5)	0.005	-11.2 (3.5)	0.001	-9.9 (3.5)	0.005
Research assistant 4	2.1 (2.8)	0.451	0.1 (2.8)	0.967	0.8 (2.9)	0.768
Research assistant 5	-1.6 (1.4)	0.255	-1.8 (1.4)	0.184	-1.9 (1.4)	0.181
Continuous						
Breastfeeding duration	0.3 (0.1)	0.001	0.3 (0.1)	0.002	0.3 (0.1)	0.002
Missing breastfeeding data	-4.5 (1.9)	0.017	-5.5 (1.9)	0.003	-4 (1.9)	0.035
Total sleep duration at two years	-0.1 (0.6)	0.796	-0.3 (0.5)	0.529	0.8 (0.5)	0.088
Missing sleep duration at 24 months data	1.7 (1.8)	0.352	1.8 (1.8)	0.319	1.9 (1.8)	0.295

BIC, Bayesian information criterion; SE, standard error.

two years of age (SE 1.75;  $p = 0.03$ ). Neither decline to short sleep duration children, or long sleep duration children had a significant difference in language scores. Similar to cognitive development, children with short total sleep duration had a lower language score at two years of age when controlling for language development at one year of age.

The nighttime sleep trajectory resulted in a superior model fit on language development, based on the lower BIC, compared to daytime sleep models (Table 4) on language development. Children with short nighttime sleep ( $-10.3$ , SE 1.8,  $p < 0.001$ ; Table 3) and intermediate night sleep ( $-2.8$ , SE 1.0;  $p < 0.01$ ) had lower BSID-III composite language scores compared to the long nighttime sleep group. Children with persistent SDB symptoms had a 5.3-point lower language score (SE 2.7;  $p = 0.05$ ) compared to those

children without SDB symptoms. Neither children with early- nor late-onset SDB symptoms had a change in their language score. A family history of language delay resulted in a 3.8-point decrease in the language score compared to those children with no family history of language delay (SE 1.2,  $p = 0.001$ ). Children of mothers who smoked during pregnancy had a lower BSID-III language score ( $-5.4$ , SE 2.4  $p = 0.03$ ). Children born between 34 and 36.5 weeks gestational age scored 6.9 points lower compared to children born after 36.5 weeks gestational age (SE 2.6,  $p < 0.01$ ). Each month of breastfeeding was again associated with a 0.3-point increase in language score (SE 0.08;  $p < 0.001$ ). In a sensitivity analysis, persistent SDB was still associated with a lower language score when controlling for treatment for rhinitis with either nasal steroid or saline rinse at 12 or 24 months of age.

**Table 4**  
Factors associated with BSID-III composite language scores in multivariate analysis.

Variable	Total sleep		Model 1: nighttime sleep		Model 2: daytime sleep	
	$r^2$ 0.24		BIC: 4616		$r^2$ 0.27	
Trajectories	Coefficient (SE)	p-value	Coefficient (SE)	p-value	Coefficient (SE)	p-value
Total sleep						
Intermediate sleepers (ref.)						
Short sleepers	-3.2 (1.5)	0.032				
Decline to short sleepers	-0.3 (1.3)	0.838				
Long sleepers	0.2 (1.5)	0.896				
Missing sleep data	-8.1 (11.4)	0.479				
Nighttime sleep						
Long sleepers (ref.)						
Short sleepers			-10.3 (1.8)	<0.001		
Intermediate sleepers			-2.8 (1)	0.007		
Missing sleep data			-10.1 (11.1)	0.363		
Daytime sleep						
Decrease to short (ref.)						
Intermediate sleepers					-0.7 (1.2)	0.545
Short sleepers					-0.4 (1.1)	0.736
Decrease to intermediate sleepers					-2.6 (1.5)	0.084
Missing sleep data					-8 (11.4)	0.485
SDB						
No SDB symptoms (ref.)						
Persistent SDB	-6.2 (2.8)	0.026	-5.3 (2.7)	0.052	-6.6 (2.8)	0.019
Early SDB	0.3 (1.7)	0.836	-0.1 (1.6)	0.955	0.5 (1.7)	0.751
Late SDB	2.4 (2)	0.243	1.3 (2)	0.525	2.3 (2)	0.25
Categorical						
Male (ref.)						
Female	5.3 (0.9)	<0.001	5.4 (0.9)	<0.001	5.2 (0.9)	<0.001
Caucasian (ref.)						
Non-caucasian	-4.4 (1)	<0.001	-3.3 (1)	0.001	-4.1 (1)	<0.001
Missing ethnicity data	-4.2 (3.5)	0.231	-2.8 (3.5)	0.417	-4.7 (3.5)	0.181
Maternal not smoking during pregnancy (ref.)						
Maternal smoking during pregnancy	-5.9 (2.5)	0.019	-5.5 (2.4)	0.025	-5.6 (2.5)	0.025
Missing pregnancy smoking data	-3.1 (2.5)	0.209	-2.5 (2.4)	0.31	-2.9 (2.5)	0.24
Season of birth: Winter (ref.)						
Spring	0.4 (1.3)	0.758	-0.1 (1.3)	0.954	0.5 (1.3)	0.714
Summer	-1.7 (1.3)	0.196	-2.2 (1.3)	0.084	-1.7 (1.3)	0.182
Fall	-3.4 (1.3)	0.012	-3.8 (1.3)	0.005	-3.5 (1.4)	0.011
Born after 36.5 gestational age (ref.)						
Born prior to 36.5 weeks gestational age	-6.8 (2.7)	0.011	-6.9 (2.6)	0.009	-6.8 (2.7)	0.011
Individual completing BSID-III testing:						
Research coordinator (ref.)						
Research assistant 1	-5.4 (7.9)	0.491	-3.5 (7.7)	0.655	-6.6 (7.9)	0.407
Research assistant 2	4.7 (1.2)	<0.001	4.9 (1.2)	<0.001	4.7 (1.2)	<0.001
Research assistant 3	1.5 (2.9)	0.604	0.3 (2.8)	0.918	1.3 (2.9)	0.663
Research assistant 4	6.9 (2.4)	0.005	5.2 (2.4)	0.031	6.2 (2.5)	0.013
Research assistant 5	1.4 (1.1)	0.215	1.3 (1.1)	0.246	1.3 (1.1)	0.267
Continuous						
Breastfeeding duration	0.3 (0.1)	0	0.3 (0.1)	0	0.3 (0.1)	0
Missing breastfeeding data	-4.3 (1.6)	0.006	-5.3 (1.5)	0	-4.2 (1.6)	0.007
Total sleep duration at two years	0.5 (0.5)	0.252	0.1 (0.4)	0.787	1 (0.4)	0.014
Missing sleep duration at 24 months data	0.4 (1.5)	0.808	0.5 (1.4)	0.71	0.4 (1.5)	0.78
No family history of speech or language delay (ref)						
Family history of speech or language delay	-3.9 (1.2)	0.001	-3.9 (1.2)	0.001	-3.9 (1.2)	0.001
Missing family history of speech or language delay	-0.1 (1.8)	0.945	0.3 (1.8)	0.885	-0.3 (1.8)	0.878
Fruit during pregnancy	0.7 (0.3)	0.015	0.6 (0.3)	0.018	0.7 (0.3)	0.011
Missing fruit intake during pregnancy	-2.5 (2.6)	0.339	-2.3 (2.5)	0.359	-2.6 (2.6)	0.312

SDB, sleep-disordered breathing.

#### 4. Discussion

Using data from a population-representative birth cohort study, we found that children with short total sleep duration had lower cognitive and language development to two years of age. Nighttime sleep duration resulted in better explanation of cognitive and language development than daytime sleep duration. Short and intermediate nighttime sleep duration across the first two years of life displayed significantly lower cognitive and language development scores at two years of age in comparison to infants who had long nighttime sleep durations. Children with persistent SDB symptoms had a lower language score compared to those children without SDB symptoms. SDB was not associated with cognitive development. Each month of any breastfeeding was also associated with increased cognitive and language development.

Short sleep duration has been associated with a wide range of adverse health outcomes [36]. A recent meta-analysis found that short sleep duration between 0 and 4 years of age was associated with obesity and worse emotional regulation. The association between short sleep duration and adverse cognitive development was unclear from the longitudinal studies included in the meta-analysis. Children with longer sleep duration had higher general conceptual ability at three years [37]. Conversely, total sleep duration was not associated with executive functioning or working memory in a separate study. However, children with higher proportions of total sleep occurring at nighttime performed better on executive tasks [5,38]. These results highlight the importance of nighttime sleep as a component of total sleep duration.

Our results are consistent with the literature supporting a positive association between nighttime sleep duration and cognitive outcomes in preschool children. Increasing nighttime sleep is positively correlated with improved attention among toddlers [6] and improved executive functioning outcomes at four years of age [5]. Good-quality nighttime sleep has been shown to improve children's memory for word learning [1] whereas poor sleep consolidation at 6 and 18 months was found to be associated with stable or late-onset language delays by five years of age. Three sleep-duration patterns were identified among children aged 2.5–6 years of age, (short persistent duration, short increasing duration, 10-h persistent duration) [39]. Children with short sleep duration showed lower cognitive measure scores [39].

We found an association between persistent SDB phenotype and language but not cognitive development at two years of age. The association between SDB and language delay may be the result of (1) both SDB and language delay being associated with rhinitis and otitis media, and (2) language acquisition being more sensitive to sleep disruption. The relationship between SDB and language delay may be the result of confounding by rhinitis. Otitis media has been associated with language delay among pre-school children [40] while rhinitis has been associated with otitis media [41–43]. We have shown that rhinitis is associated with all three SDB symptom trajectories [35]. In a sensitivity analysis, persistent SDB was still associated with a lower language score when controlling for treatment for rhinitis at 12 or 24 months of age. Additionally, the first two years of life are the most intensive period for language acquisition, a skill interdependent with cognitive development [44]. Our findings may indicate that higher-level processes, such as language, are more sensitive to interruption by SDB than the core cognitive processes on which language is constructed.

Childhood SDB may represent multiple overlapping phenotypes distinguished by age of onset and duration of symptoms. Not all SDB phenotypes may be associated with cognitive impairment. Treatment for SDB symptoms, not systematically recorded as part of the study record, may limit our ability to determine whether SDB is associated with adverse cognitive development. Future studies

will examine the impact of persistent SDB and later-onset childhood SDB on neurodevelopment in childhood.

The CHILD sample size provides a high degree of power to differentiate the impact of daytime versus nighttime sleep and the co-contributing role of SDB on cognitive development. We used objective measures of infant sleep and sleep disruption to help validate parental reports. Quarterly measures of sleep quality and quantity allowed for trajectory modeling of infant sleep patterns as well as SDB patterns throughout the first two years of life. The CHILD study allowed assessments of many potential confounders associated with the development of cognition, including breastfeeding duration and family socioeconomic status (SES).

The observational nature of our study precludes us from making causal associations between sleep duration and cognitive development. Although our analyses excluded children with known neurodevelopmental delays, children with low and intermediate nighttime sleep durations may have undetected or undetermined neurodevelopment abnormalities that predispose them to lower cognitive performance. Our study was not designed to determine the mechanism by which sleep duration is associated with cognitive development. Finally, the trajectory models for SDB, daytime, nighttime and total sleep are based on sleep and symptom estimates captured via parental report completed quarterly during the first two years of life. The error introduced via parent-report estimates may have reduced our ability to detect some associations between sleep duration or SDB and cognitive outcomes.

Home-based PSG has not been validated as a measure of SDB symptoms in children. Similarly, the PSQ has not been validated for children under two-years of age. We chose to present both methods of assessing children for the presence of SDB symptoms (PSQ and home PSG) as in-hospital PSG (the gold standard) was not feasible for this study. Formal reliability assessments of the PSG scoring were not performed.

Future research may identify factors associated with each of the sleep duration trajectories identified. Isolated bed sharing and breastfeeding were associated with sleep duration among infants from 6 to 18 months [12]. We were not able to perform trajectory analyses on cognitive development as the BSID-III was completed at only two time points. Multiple assessments of cognitive development from six months to two years of age would allow researchers to pinpoint the specific age at which reduced nighttime sleep affects cognitive performance outcomes.

#### 5. Conclusion

To our knowledge, this is the first study to assess cognitive development during the first two years of life in relation to phenotypes of SDB, daytime, nighttime, and total sleep duration. Short total sleep duration was associated with lower cognitive and language development to two years of age. Nighttime sleep had a greater impact on cognitive and language development compared to daytime sleep. Infants with low and intermediate nighttime sleep duration throughout the first two years of life have reduced cognitive and language outcomes at two years in comparison to long-sleeper infants. Persistent SDB was associated with language but not cognitive development. Future research is required to determine the directionality of the association between nighttime sleep and cognitive development as well as the mechanism(s) responsible for this association.

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### Conflict of interest

The authors have no conflicts of interest to declare related to this manuscript.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: <https://doi.org/10.1016/j.sleep.2018.04.005>.

### Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.sleep.2018.04.005>.

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