Short persistent sleep duration is associated with poor receptive vocabulary performance in middle childhood

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Abbreviations:

BIC: Bayesian Information Criterion; CI: Confidence Interval; OR: Odds Ratio; PPVT-R: Peabody Picture Language Test – Revised (a receptive language test); SD: Standard Deviation; χ^2: Pearson Chi Square Test; df: degrees of freedom

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ABSTRACT

The aim of this study was to examine whether short sleep duration is associated with poor receptive vocabulary at age 10 years. In the Quebec Longitudinal Study of Child Development, parents reported their children's nocturnal sleep duration annually from age 2.5 to 10 years, and children were assessed for receptive vocabulary using the Peabody Picture Vocabulary Test – Revised (PPVT-R) at ages 4 and 10 years. Groups with distinct nocturnal sleep duration trajectories were identified and the relationships between sleep trajectories and poor PPVT-R performance were characterized. In all, 1192 children with available sleep duration and PPVT-R data participated in this epidemiological study. We identified four longitudinal nocturnal sleep trajectories: short persistent sleepers (n=72, 6.0%), short increasing sleepers (n=47, 3.9%), 10-hour persistent sleepers (n=628, 52.7%), and 11-hour persistent sleepers (n=445, 37.3%). In all, 14.8% of the children were showed poor PPVT-R performance at age 10 years. Nocturnal sleep trajectories and poor PPVT-R performance at age 10 were associated significantly ($P = 0.003$). After adjusting for baseline receptive vocabulary performance at age 4 and other potential confounding variables, logistic regression analyses suggest that, compared to 11-hour persistent sleepers, the odds ratio of presenting poor receptive vocabulary at age 10 was 2.67 (95% CI=1.24–5.74, $P = 0.012$) for short persistent sleepers and 1.66 (95% CI=1.06–2.59, $P = 0.026$) for 10-hour persistent sleepers. These results corroborate previous findings in early childhood, and indicate that short sleep duration is associated with poor receptive vocabulary during middle childhood.

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INTRODUCTION

Adequate sleep duration contributes to children's well-being and cognitive development (Touchette et al., 2009). Dahl proposed a developmental model of sleep and arousal regulation in which inadequate sleep affects various cognitive functions required for performing abstract or complex goal-oriented tasks (Dahl, 1996). Short sleep duration at night affects prefrontal cortex functioning (Bernier et al., 2010), resulting in poorer performance on executive tasks, such as learning a new language, and on creativity, emotional regulation, short-term memory, and working memory (Horne, 1993, Vriend et al., 2013). In school-age children, disrupted sleep, including short sleep duration and/or fragmented sleep, impairs cognitive performance on neuropsychological tests (Geoffroy et al., 2010, Fallone et al., 2005, Sadeh et al., 2003, Steenari et al., 2003, Wolfson and Carskadon, 2003, Randazzo et al., 1998).

To achieve social adaptation at school and academic success, children must acquire and use complex communication systems, including receptive vocabulary (i.e., words that they understand) and expressive vocabulary (i.e., words that they use to communicate). Children with larger receptive vocabulary have greater sublexical skills and can express more words (Gray, 2006). Little is known about the links between sleep and word learning in childhood (Bernier et al., 2013). In early childhood, Dionne et al. suggested that good sleep consolidation may enhance the memorization of phoneme sequences and facilitate the storage of their meaning in long-term memory (Dionne et al., 2011). Among twins during the first 2 years of life, poor sleep consolidation (incapacity to have uninterrupted sleep periods, defined as the number of consecutive hours slept during the day over that slept

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during the night) may be a risk factor for poor language learning up to age 5 years. On the other hand, good sleep consolidation appears to foster language learning through successive genetic and environmental influences (Dionne et al., 2011). Bernier et al. (2010) showed that 1-year-olds with a greater percentage of night-time sleep had larger expressive vocabulary at age 2.

To our knowledge, the long-term effects of short persistent sleep on receptive vocabulary have never been studied during middle childhood. This article builds on previous work (Touchette et al., 2007) that identified associations between nocturnal sleep trajectories in children aged 2.5 to 6 years and receptive vocabulary at school entry. The aim of the present study was to examine the associations between nocturnal sleep duration trajectories and receptive vocabulary at age 10. We also wanted to verify whether this association persists after controlling for preschool receptive vocabulary and significant potential confounding factors. We hypothesized that a greater proportion of persistent short sleepers would have poorer receptive vocabulary at age 10.

METHODS

Setting

This study was conducted as part of the Quebec Longitudinal Study of Child Development (QLSCD) initiated by the Institut de la Statistique du Québec (Quebec Institute of Statistics). The QLSCD is a longitudinal study of a large (2,120) cohort of Quebec children. The main objectives were to identify factors that affect social adjustment and academic performance, including precursors, paths, and medium-and long-term effects. Phase 1 covered age 5 months to about 4 years, and Phase 2 and 3 monitored social and school adjustment in elementary school and high school, respectively. Expected outcomes include the identification of risk or protective factors for adjustment so as to provide Quebec with the means to prevent extremely costly human and social problems such as school dropout, delinquency, suicide, drug addiction, and domestic violence. All children were recruited from the Quebec Master Birth Registry managed by the Ministry of Health and Social Services, using a stratified procedure based on geographic area and birth rate. Families were included if the pregnancy lasted 24 to 42 weeks and the mother spoke French or English. Data were collected by trained interviewers using home interviews with the person most knowledgeable about the child (the mother in 98% of cases) to obtain information about child, parent, and family characteristics and behaviours. Written informed consent was obtained from all participating families at each assessment. Assessments were conducted at the following ages: 5 times over the preschool years (i.e., at age 5 months and at 1.5, 2.5, 3.5, and 4 years) and 5 times during the elementary school years (i.e.., at age 5, 6, 7, 8, and 10 years). Attrition rate and cohort characteristics are presented on the QLSCD website (http://www.iamillbe.stat.gouv.qc.ca/default_an.htm) along with technical documentation on the concepts, definitions, operational aspects, and tools used for the QLSCD study.

Participants

A total of 2,223 infants aged 5 months (4.5±0.6 months) were enrolled in the study and assessed annually starting in 1997. Children with known neurological conditions or developmental disorders were excluded from the study. In all, 1,192 children (53.4%) had

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both receptive language measured at age 10 and adequate nocturnal sleep duration reports (as described below), and were therefore included in the present study. All families were mailed detailed information about the aims and procedures of the research program, and all parents signed a consent form before each assessment.

Procedures

Nocturnal sleep duration

Nocturnal sleep duration was assessed at age 2.5, 3.5, 4, 5, 6, 7, 8, 9, and 10 years using the following open question: “Indicate how long in total your child sleeps during the night (on average). Do not count the hours that your child is awake”. For purposes of this study, only children with 2 or more sleep duration assessments were included, because at least 2 measures are needed to plot a sleep trajectory.

Receptive vocabulary

Receptive vocabulary was assessed during a home visit using the Peabody Picture Vocabulary Test – Revised (PPVT-R) in either of Canada’s two official languages: French or English (Dunn and Theriault-Whalen, 1993). The PPVT-R assesses receptive verbal ability by tapping into the cognitive processes involved in matching a verbal cue to a picture, where no immediate memory or recall component is involved. A trained interviewer presented a series of 4 drawings from a test booklet to the child in one session. Next, the interviewer pronounced a word for the child (receptive component), for example, “house”. The child then pointed to one of the four pictures and the item was scored as pass or fail if it matched the picture or not, respectively. No verbal answer was required. This

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test is valid across a wide age range (age 2 and up), with items adjusted for developmental stage. We used the normalized scores, which take age into account. At both the 4- and 10-year assessments, we considered children to have poor PPVT-R performance when they scored one standard deviation (SD) or more below the sample mean (mean-1 SD). No significant differences were found in baseline characteristics (sex, mother's immigrant status, parental high school diplomas, breastfed or not, parental income) between children assessed with the French version (n=1220) and the English version (n=98) of the PPVT-R. However, for 62 of the 98 children (63.3%) assessed with the English version, English was not their first language. In comparison, only 4% of children assessed with the French version had another mother tongue ($p<0.001$). It is well known that word learning is critically dependent on the linguistic and cultural context. We therefore included only children who completed the PPVT-R in French.

Covariates

The following potential confounding factors usually associated with receptive language were also assessed at inclusion in the cohort: child's sex (girl vs. boy) (Livesey and Intili, 1996), whether or not the child was breastfed (breastfed vs. not breastfed) (Mahurin-Smith, 2015), whether or not the mother smoked during pregnancy (yes/no) (Huijbregts et al., 2007), mother's immigrant status (immigrant vs. non-immigrant) (Farver et al., 1995), and parental income (insufficient vs. sufficient, calculated from family income, family size, and geographic area based on National Census data) (Statistics Canada, 2009). Other confounding variables usually associated with receptive language were also collected at age 4: inattention (inability to concentrate, easy distraction) was

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assessed at age 4 years from parental reports on 3 items from the Social Behaviour Questionnaire (SBQ) (Gagnon et al., 1995) (>1SD above the mean), and parental education level (both parents without a high school diploma vs. one or both parents with a high school diploma) (Dollaghan et al., 1999).

Analysed sample

Compared with the initial overall cohort (n=2,223), the analysed sample (n=1,192) comprised a lower proportion of children with an immigrant mother (6.9% vs. 9.1%, χ^2=20.03, df=1, p<0.001) and included more girls (53.0% vs. 48.8%, χ^2=17.89, df=1, p<0.001). No significant differences were found in other covariates.

Statistical analyses

A group-based trajectory analysis, using a semi-parametric mixture model developed by Nagin (Nagin, 1999), was used to identify nocturnal sleep duration trajectories from age 2.5 to 10 years. Based on posterior probabilities, this strategy assigns the children to the sleep duration trajectory group of the highest probability, independently of *a priori* cut-off points reported in the literature. To choose the best model, the maximum value of the Bayesian information criterion (BIC) was used to determine the optimal number of groups with shapes that best fit the data. This procedure allows including cases with some missing data. Therefore, we chose the model which enabled including the greatest number of participants (n=1,877) with 2 or more sleep duration assessments. Trajectory models with 2 to 5 trajectories and varied shapes (e.g., intercept, linear,

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quadratic, or cubic) were compared using PROC TRAJ (Jones et al., 2001), an SAS® procedure (SAS Institute Inc., Cary, NC).

Univariate analyses were run to test associations between potential confounding factors and the two main criteria of interest: (i) PPVT-R performance and (ii) nocturnal sleep duration trajectories at age 10 using chi-square tests for categorical variables or Fisher tests for continuous variables. A multivariate logistic regression model was then performed to test associations between nocturnal sleep duration trajectories and poor receptive vocabulary at age 10, while taking into account poor PPVT-R performance at age 4 and the covariates. Analyses were performed using R version 2.8.1 (Venables et al., 2010).

RESULTS

Sample description

The sample comprised 1,192 children who were assessed with the PPVT-R at age 10 and had at least 2 sleep duration assessments from age 2.5 to 10 years. Table 1 shows that 53.0% of the sample were girls (n=632), 6.9% had an immigrant mother (n=78), 18.6% had parents who did not complete high school (n=182), 25.2% had a mother who smoked during pregnancy (n=285), 26.2% were not breastfed (n=298), 15.2% had parents with insufficient income (n=173), and 9.9% were inattentive at age 4 years (n=172).

Description of sleep duration trajectories from age 2.5 to 10 years

The selected model included four sleep duration trajectories. The 4-trajectory model showed a better goodness of fit (BIC=-13352.88) than the 3-trajectory model (BIC=-

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13372.76). The two criteria for the optimal model were met by the 4-trajectory model: 1) it provided the best BIC; and 2) the percentage of individuals in each trajectory was above 5% of the whole sample. The four trajectories are illustrated in Figure 1: *short persistent sleepers* (6.0%, n=72), who consistently had the shortest mean sleep duration (8.5–9 hours) during the study period; *short increasing sleepers* (3.9%, n=47) with short sleep duration in early childhood, but with increasing duration from age 2.5 to 3.5 years (from 7.5 to 10 hours), peaking at 11 hours at age 6, and decreasing thereafter to 10 hours from age 7 to 10; *10-hour persistent sleepers* (52.7%, n=628) who slept persistently for about 10 hours per night; and *11-hour persistent sleepers* (37.3%, n=445) who slept persistently for about 11 hours per night. Although the sleep trajectories in this study and in a previous study by Touchette and colleagues (Touchette et al., 2007) were derived independently, 91% of children were classified into the same trajectory at age 10 as they were at age 6.

Selection of covariates

Tables 1 and 2 present significant associations between many covariates related to sleep duration trajectories and language performance in the analysed sample. The covariates that were significantly associated with sleep duration trajectories include mother's immigrant status (χ^2=27.72, df=3, p<0.001), parents without a high school diploma (χ^2=10.12, df=3, p=0.018), and mother smoked during pregnancy (χ^2=8.04, df=3, p=0.045). More specifically, we found a greater proportion of immigrant mothers among short persistent sleepers (18.1%) and short increasing sleepers (8.5%) compared to 10-hour persistent sleepers (7.3%) and 11-hour persistent sleepers (3.4%). The 10-hour persistent sleepers also had fewer parents without a high school diploma (16.1%) compared with short persistent sleepers (26.6%), 11-hour persistent sleepers (22.2%), and short increasing sleepers (27.7%). Moreover, higher proportions of short increasing sleepers (27.7%) and 11-hour persistent sleepers (27.6%) were exposed to tobacco *in utero* compared with short persistent sleepers (13.9%) and 10-hour persistent sleepers (22.1%).

Several covariates were significantly associated with poor language performance at age 10: not breastfed (χ^2=6.99, df=1, p=0.008), inattention at age 4 (χ^2=6.26, df=1, p=0.012), and poor PPVT-R performance at age 4 (χ^2=31.71, df=1, p<0.001). More specifically, a higher proportion of children with poor language performance at age 10 were not breastfed compared with the normal performance group (32.4% vs. 23.7%), and children with poorer language performance at age 10 had higher inattention (15.3% vs. 8.9%) and poorer PPVT-R performance at age 4 (26.7% vs. 11.2%) compared with the normal performance group at age 10.

Association between short persistent sleep and poor receptive vocabulary

The proportion of children with poor PPVT-R performance at age 10 differed as a function of sleep trajectories: 27.8% were short persistent sleepers, with 21.3% short increasing sleepers, 14.8% 10-hour persistent sleepers, and 11.9% 11-hour persistent sleepers (χ^2=14.15, df=3, p=0.003, Table 1).

Figure 2 depicts the results of a multivariate logistic regression used to predict poor receptive vocabulary performance from sleep duration trajectories and covariates (n=901, due to missing values for covariates). Four factors predicted receptive vocabulary performance at

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age 10: Compared to the 11-hour persistent sleepers, short persistent sleepers had an odds ratio (OR) of 2.67 (95% CI=1.24–5.74, p=0.012) for belonging to the poor receptive vocabulary performance group, and 10-hour persistent sleepers had an OD of 1.66 (95% CI=1.06-2.59, p=0.026). Children with poor receptive vocabulary performance at age 4 had an OD of 3.12 (95% CI=1.93-5.06, p<0.001) for belonging to the poor receptive vocabulary performance group at age 10 compared to children with good receptive vocabulary performance at age 4. Other significant predictors of poor receptive vocabulary performance were not breastfed (OR=1.87, 95%CI=1.22-2.86, p=0.004) and inattention at age 4 (OR=2.57, 95%CI=1.46-4.52, p=0.001).

DISCUSSION

This study is the first to investigate associations between sleep duration trajectories and receptive vocabulary performance in middle childhood. As previously found by Touchette and colleagues (Touchette et al., 2007) in children aged 2.5 to 6 years, we identified four sleep duration trajectories from age 2.5 to 10 years. This suggests highly stable sleep patterns from early to middle childhood. Furthermore, the present results indicate that children in the short persistent sleep trajectory have higher odds of belonging to the poor receptive vocabulary group at age 10 compared to children in the 11-hour persistent sleep trajectory, even after controlling for receptive vocabulary at age 4. Moreover, this study is the first, to our knowledge, to control for prior receptive vocabulary. Finally, no differences in receptive vocabulary were found between short increasing sleepers and 11-hour persistent sleepers. However, the small sample size of the short increasing sleepers may have prevented detecting significant differences.

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Dionne and colleagues (Dionne et al., 2011) have offered several explanations for the association between sleep duration and language acquisition. Short sleep duration may impede brain maturation and memory consolidation (Pilcher and Huffcutt, 1996), which are required in early language learning (Bernier et al., 2010). Sleep helps focus and sustain attention on an intended object, which may affect the language stimulation process, such that children who sleep longer develop better language skills. Future studies could explore whether (and which) sleep characteristics mediate the association between sleep duration and receptive vocabulary. As suggested by Bernier et al., the observed associations between sleep and cognition might be explained by a "common environmental influence of stable and harmonious parent-child interactions" (Bernier et al., 2013).

We found an association between not being breastfed and poor receptive vocabulary at age 10. This association has been described in previous observational and interventional studies (Jain et al., 2002; Kramer et al., 2008), in which cognitive testing was done in early childhood. A number of mechanisms have been proposed to explain the association between breastfeeding and optimum cognitive development (Mahurin-Smith, 2015). For instance, human milk may affect later brain structure, gene expression within cells, and the immune system, all of which can exert a positive influence on learning and memory (Makrides et al., 1995, Helland et al., 2001). Inattention at age 4 was also associated with poor PPVT-R performance at age 10 over and above its concurrent association with PPVT-R performance at age 4. Warner-Rogers (2000) demonstrated that children with inattentive behaviour (without a hyperactivity component) were more likely to have general cognitive delays, particularly in word learning.

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Our study has several limitations. First, the prospective epidemiological design does not allow inferring causality or investigating underlying mechanisms. Although it allows us to understand which factors are associated with receptive vocabulary, experimental studies are needed to confirm these findings. Second, our sample comprised French-speaking families exclusively, limiting the generalizability of the results. Another limitation is the subjective measure of sleep quantity, which may slightly overestimate actual sleep duration (Dayyat et al., 2011). Although it is unlikely that this measure can provide a complete and accurate account of sleep duration, parental reports of sleep behaviours have considerable validity and reliability compared with objective actigraphy measures, even though parents of school-aged children are less accurate at identifying night wakings in their child (Holley et al., 2010, Sadeh, 1996, Sekine et al., 2002). Therefore, information provided by parents may have led to an underestimated prevalence of short-duration sleepers, at worst, and consequently of the role of short sleep duration in receptive vocabulary performance. This is a noninvasive, economical method for detecting sleep behaviours in healthy children, and can be used to explore sleep over extended periods of time (Sadeh, 2015).

In summary, the present study corroborates and extends the previous findings on the association between short-duration sleep and poor receptive vocabulary performance in early childhood by demonstrating that the association between sleep duration and receptive vocabulary persists over time. Several hypotheses have been proposed to explain the association between reported sleep duration and vocabulary acquisition, especially in early childhood (Bernier et al., 2010, Decker and Rye, 2002, Dionne et al., 2011), and further investigations are needed to understand the underlying mechanisms.

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Tables and Figures

Table 1. Selected potential covariates associated with low PPVT-R Receptive Language at age 10 (one standard deviation (SD) below the mean), Chi-Square Statistic (χ^2), Degrees of Freedom (df), and p-value (p)

	Analysed Sample (N=1192)	PPVT-R Receptive Language: Poor (≤-1 SD) (n=176, 14.8%)	PPVT-R Receptive Language: Good (> -1 SD) (n=1016, 85.2%)	
Measures at 5 months				
Girl (vs. Boy)	632 (53.0%)	99 (56.3%)	533 (52.5%)	χ^2=0.72, df=1 p=0.396
Mother's immigrant status	78 (6.9%)	14 (8.0%)	64 (6.3%)	χ^2=0.63, df=1 p=0.427
No parental high school diploma	182 (18.6%)	40 (22.7%)	181 (17.8%)	χ^2=2.85, df=1 p=0.091
In utero tobacco exposure	285 (25.2%)	47 (26.7%)	238 (23.4%)	χ^2=1.35, df=1 p=0.245
Not breastfed	298 (26.2%)	57 (32.4%)	241 (23.7%)	χ^2=6.99, df=1 **p=0.008**
Measures at 4 years				
Inattention	172 (9.9%)	27 (15.3%)	90 (8.9%)	χ^2=6.26, df=1 **p=0.012**
Insufficient parental income	173 (15.2%)	31 (17.6%)	142 (14.0%)	χ^2=1.80, df=1 p=0.179
Poor PPVT-R (-1 SD)	161 (15.0%)	47 (26.7%)	114 (11.2%)	χ^2=31.71, df=1 **p=<0.001**

Note: Data courtesy of the Quebec Institute of Statistics.

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Table 2. Selected potential covariates associated with nocturnal sleep duration trajectories from age 2.5 to 10 years, Chi-Square Statistic (χ^2), Degrees of Freedom (df), and p-values (p)

	Nocturnal sleep duration trajectories		
Measures	Short persistent sleepers (n=72, 6.0%)	Short increasing sleepers (n=47, 3.9%)	10-hour sleepers (n=628, 52.7%)
At 5 months			
Girl (vs. Boy)	34 (47.2%)	24 (51.1%)	317 (50.5%)
Mother's immigrant status	13 (18.1%)	4 (8.5%)	46 (7.3%)
No parental high school diploma	16 (22.2%)	13 (27.7%)	101 (16.1%)
In utero tobacco exposure	10 (13.9%)	13 (27.7%)	139 (22.1%)
Not breastfed	18 (25%)	16 (34%)	143 (22.8%)
At 4 years			
Inattention	11 (15.3%)	3 (6.4%)	58 (9.2%)
Insufficient parental income	15 (20.8%)	11 (23.4%)	80 (12.7%)
Poor PPVT-R (-1 SD)	20 (27.8%)	12 (25.5%)	67 (10.7%)
At 10 years			
Poor PPVT-R (-1 SD)	20 (27.8%)	10 (21.3%)	93 (14.8%)

Note: Data courtesy of the Quebec Institute of Statistics

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Figure 1. Nocturnal sleep duration trajectories from age 2.5 to 10 years
Note: Data courtesy of the Quebec Institute of Statistics.
(cf attached file)

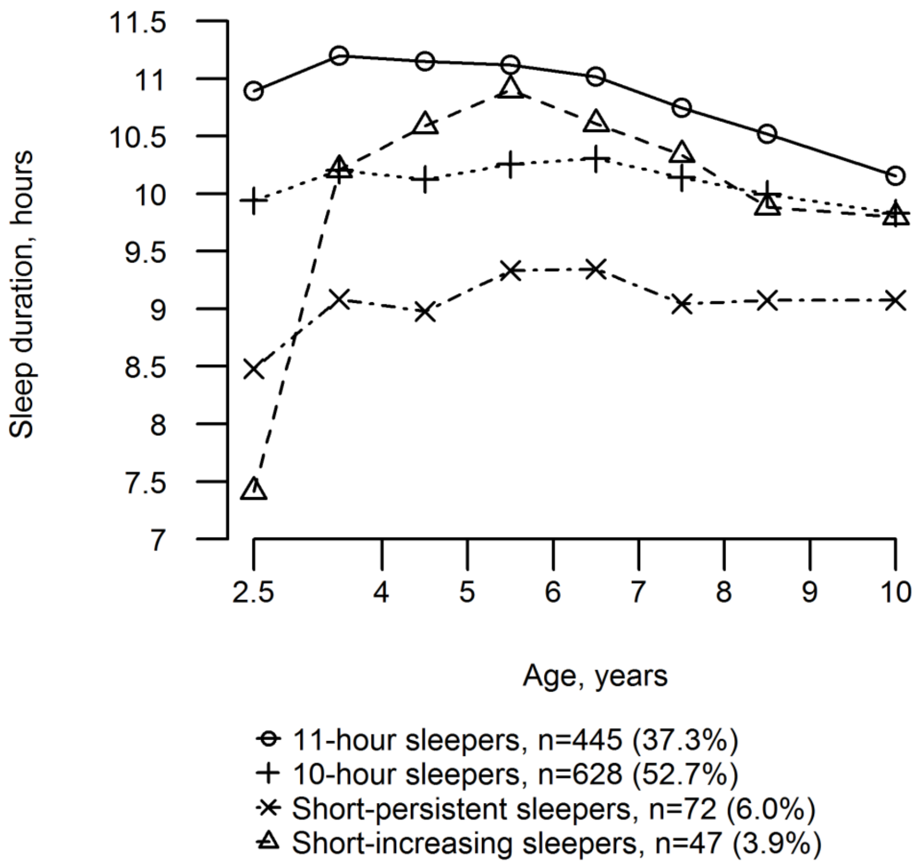

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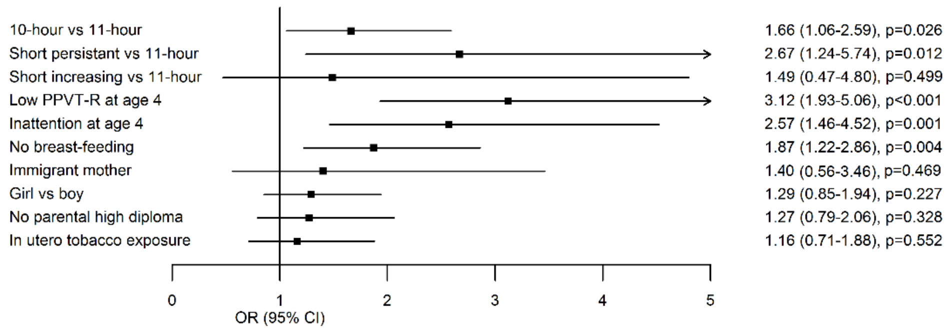
Figure 2: Odds ratios (OR) and 95% confidence interval (CI) for nocturnal sleep duration trajectories and covariates obtained in a multivariate logistic regression predicting receptive vocabulary at age 10.
Note: Data courtesy of the Quebec Institute of Statistics.
(cf attached file)



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Contributors' Statement Page

Valerie Seegers conceptualized and designed the study, analysed and interpreted the data, drafted the initial manuscript, and approved the final manuscript as submitted.

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Frank Vitaro conceptualized and designed the study, performed data acquisition, critically reviewed the manuscript, and approved the final manuscript as submitted.

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Bruno Falissard supervised the data analysis, critically reviewed the manuscript, and approved the final manuscript as submitted.

Michel Boivin conceptualized and designed the study, performed data acquisition, critically reviewed the manuscript, and approved the final manuscript as submitted.

Richard E. Tremblay conceptualized and designed the study, performed data acquisition, provided administrative, technical, and material support, and approved the final manuscript as submitted.