

# Associations Between Sleep Duration Patterns and Behavioral/Cognitive Functioning at School Entry

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**Objective:** The aim of the study was to investigate the associations between longitudinal sleep duration patterns and behavioral/cognitive functioning at school entry.

**Design, Setting, and Participants:** Hyperactivity-impulsivity (HI), inattention, and daytime sleepiness scores were measured by questionnaire at 6 years of age in a sample of births from 1997 to 1998 in a Canadian province (N=1492). The Peabody Picture Vocabulary Test - Revised (PPVT-R) was administered at 5 years of age and the Block Design subtest (WISC-III) was administered at 6 years of age. Sleep duration was reported yearly by the children's mothers from age 2.5 to 6 years. A group-based semi-parametric mixture model was used to estimate developmental patterns of sleep duration. The relationships between sleep duration patterns and both behavioral items and neurodevelopmental tasks were tested using weighted multivariate logistic regression models to control for potentially confounding psychosocial factors.

**Results:** Four sleep duration patterns were identified: short persistent

(6.0%), short increasing (4.8%), 10-hour persistent (50.3%), and 11-hour persistent (38.9%). The association of short sleep duration patterns with high HI scores (P=0.001), low PPVT-R performance (P=0.002), and low Block Design subtest performance (P=0.004) remained significant after adjusting for potentially confounding variables.

**Conclusions:** Shortened sleep duration, especially before the age of 41 months, is associated with externalizing problems such as HI and lower cognitive performance on neurodevelopmental tests. Results highlight the importance of giving a child the opportunity to sleep at least 10 hours per night throughout early childhood.

**Keywords:** Sleep duration patterns, hyperactivity, impulsivity, inattention, daytime sleepiness, cognitive functioning

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## INTRODUCTION

SLEEP IS IMPORTANT FOR BEHAVIORAL AND COGNITIVE DEVELOPMENT IN THE EARLY YEARS OF LIFE.<sup>1</sup> DAHL<sup>2</sup> DEFINES SUFFICIENT SLEEP AS THE AMOUNT necessary to permit optimal daytime functioning. Large-scale epidemiological surveys have reported that children from 2 to 6 years of age sleep an average of 10 to 11 hours a night.<sup>3,4</sup> A comparison of 3 birth cohorts (1974, 1979, and 1986) of the same Swiss population revealed that time spent in bed shortened (~40 minutes) across cohorts.<sup>5</sup> This raises an important question for clinicians and parents alike: how much sleep do children really need for optimal behavioral and cognitive functioning?

### Disclosure Statement

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It is well-known that short sleep duration induces sleepiness in children and adolescents.<sup>6</sup> However, the manifestations of sleepiness are varied in children and range from the classical signs of sleepiness (e.g., yawning) to externalizing behaviors (e.g., hyperactivity).<sup>7</sup> Dahl reports that "many toddlers and elementary school children respond to insufficient sleep with irritability, crankiness, low frustration tolerance, and short attention span."<sup>8</sup> In addition, numerous authors have noted a potential link between insufficient sleep and attention deficit hyperactivity disorder (ADHD) in children.<sup>9,10</sup>

Shortened sleep may also result in observable neurocognitive performance deficits.<sup>8</sup> Sleep deprivation is known to impact cognitive functions in adults, as revealed by a meta-analysis<sup>11</sup> of 56 studies on sleep deprivation. However, only a few studies<sup>12-15</sup> investigating different degrees of sleep deprivation in children have been conducted, generally on a single night, and their conclusions were not consistent.

Moreover, to our knowledge, the long-term effects of shortened sleep have never been studied in children. The aim of this study was to identify whether sleep duration is an independent risk factor for behavioral and cognitive functioning after adjusting for potentially confounding factors. We predicted that a short sleep duration pattern would significantly increase the risk for daytime externalizing problems and lower cognitive performance on neurodevelopmental tests.

## METHODS

### Setting

This study was conducted as part of the Quebec Longitudinal Study of Child Development (Canada) initiated by the Quebec

Institute of Statistics. All children were recruited from the Quebec Master Birth Registry managed by the Ministry of Health and Social Services. The main procedures and instruments of this study have been previously described.<sup>16</sup>

## Participants

Initially, 2,223 families participated in the study when the children were approximately 5 months old ( $4.5 \pm 0.6$  months). The children were seen yearly thereafter until they started elementary school. In all, 1,492 families (67.1%) participated in the study until the children were 6 years old ( $73.8 \pm 3.1$  months). All families received detailed information by mail on the aims and procedures of the research program and signed a consent form. The protocol was approved by the Sacre-Coeur Hospital ethics committee and the Quebec Institute of Statistics.

## Outcome Variables

### SLEEP MEASURES

Nocturnal sleep duration was measured at 2.5, 3.5, 4, 5, and 6 years of age by an open question on the *Self-Administered Questionnaire for the Mother* (SAQM): "Indicate how long in total your child sleeps during the night (on average). Do not count the hours that your child is awake." Daytime sleep was measured at 29 months of age to assess a potential between-trajectory difference. In addition, at 6 years of age, time in bed was measured for both weekdays and weekends to assess an eventual sleep duration difference indicative of a needed compensation.

### BEHAVIORAL MEASURES

Hyperactivity-impulsivity (HI), inattention, and daytime sleepiness were assessed by the mothers through an *Interviewer Completed Computerized Questionnaire*. Children's HI was measured by a set of 6 questions on 1,442 children: "In the past three months, how often would you say your child: 1) couldn't sit still, was restless or hyperactive, 2) couldn't stop fidgeting, 3) was impulsive or acted without thinking, 4) had difficulty waiting for his/her turn at games, 5) couldn't settle down to do anything for more than a few moments, and 6) couldn't wait when you promised something." The inattention variable comprised 5 questions and was assessed on 1,442 children: "In the past three months, how often would you say your child: 1) was easily distracted, 2) had trouble sticking to any activity, 3) was unable to concentrate, 4) could not pay attention for long, and 5) was inattentive." Answers were categorized as "never," "sometimes," or "often." The Quebec Institute of Statistics standardized all behavioral variables on a scale of 0 ("not at all") to 10 ("exactly"). To select children with high HI or inattention scores, cutoff was set at over 1 standard deviation (SD) above the mean. Daytime sleepiness was measured on 1,267 children by the SAQM: "In general, is your child sleepy during the day?" This question was dichotomized into absence ("never") versus presence ("sometimes"/"often"/"always") of daytime sleepiness.

### COGNITIVE TASKS

Verbal and nonverbal cognitive abilities were measured by 2 neurodevelopmental assessments. First, 948 children were tested

with a Canadian translation of the Peabody Picture Vocabulary test – Revised (PPVT-R)<sup>17</sup> at  $5.1 \pm 0.3$  years of age to measure receptive vocabulary. The children were asked to point out one picture among 4 that best represented a word pronounced by the interviewer. Second, the Block Design subtest of the Wechsler Intelligence Scale for Children (WISC-III)<sup>18</sup> was administered to 1,124 children at  $6.2 \pm 0.3$  years of age to evaluate nonverbal intellectual skills. For both tests, low performance was defined as a score lower than 1 SD below the mean and high performance corresponded to a score higher than 1 SD above the mean.

### POTENTIALLY CONFOUNDING PSYCHOSOCIAL VARIABLES

The following potentially confounding factors that were found to be associated with behavioral or cognitive functioning were also assessed:

- Sex of the child – boy / girl<sup>19</sup>
- Low birth weight – yes ( $<2.5$  kg) / no ( $\geq 2.5$  kg)<sup>20</sup>
- No breastfeeding – never / yes (previously breastfed)<sup>21</sup>
- Maternal smoking during pregnancy – yes / no<sup>22,23</sup>
- Maternal immigrant status when the child was 5 months of age – yes / no (non-immigrant)<sup>24</sup>
- Young maternal age when the child was 5 months of age –  $<20$  years of age / no ( $\geq 20$  years of age)<sup>25</sup>
- Low parental education when the child was 6 years of age – both parents without a college diploma / high parental education – one or both parents with a college diploma<sup>26</sup>
- Inadequate income status when the child was 5 months of age / sufficient based on 3 indicators: family income, family size, and regional area based on national census data<sup>27</sup>
- Napping at 29 months of age – no nap or nap  $\leq 45$  minutes /  $\geq 1$ h<sup>14</sup>
- HI at 17 months of age –  $>1$  SD over the mean /  $\leq 1$  SD<sup>28</sup>
- Inattention at 17 months of age –  $>1$  SD above the mean /  $\leq 1$  SD<sup>29</sup>

### Statistical Analyses

Although sleep duration throughout childhood is generally stable at approximately 10 to 11 hours per night,<sup>3,4</sup> this pattern may not be typical for all children. Rather than assume that all children follow the same developmental pattern of sleep duration over time, a semiparametric model was used to identify subgroups of children who followed different developmental trajectories.<sup>30</sup> Briefly, trajectory methodology uses all available developmental data points and assigns individuals to trajectories based on a posterior probability rule. The identified groups represent approximations of an underlying continuous process. For each trajectory group, this probability measures the likelihood of an individual belonging to that group based on observations across assessments. In other words, 100% classification accuracy is neither assumed nor required. Participants are assigned to the trajectory group to which they show the highest probability of belonging and analyses are weighted by posterior probabilities. A censored normal model was used; this model is considered appropriate for continuous data that are normally distributed, such as sleep duration. Trajectory models with 2 to 5 trajectories and varied shapes (e.g., intercept, linear, quadratic, or cubic) were compared by PROC TRAJ,<sup>31</sup> an SAS procedure (SAS Institute Inc., Cary, NC). To choose the best model, the maximum Bayesian informa-

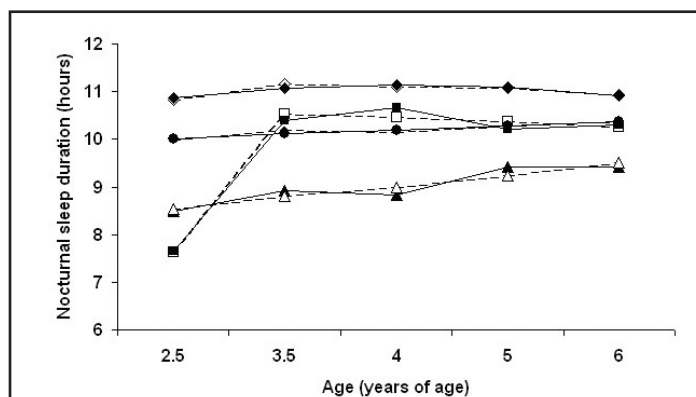
tion criterion (BIC) was used to determine the optimal number of groups with shapes that best fit the data. This procedure allows the inclusion of cases with some missing data. Models with either zero, 1 or 2 missing data points for a given subject (over the 5 data points) were tested; the same results were obtained regardless of missing status. Therefore, we chose the model which permitted the inclusion of the greater number of subjects (N=1829 with up to 2 missing data points).

Two types of analyses were conducted to measure the associations between sleep duration trajectories and the behavioral/cognitive variables using SPSS for Windows (version 14; SPSS Inc, Chicago, IL). Statistical significance was set at  $P < 0.05$ . First, chi-squared tests were used to measure the associations between sleep patterns and behavioral/cognitive scores ( $\pm 1$  SD). Second, weighted multivariate logistic regressions were performed to estimate the relative risk of sleep duration for low behavioral/cognitive scores without (unadjusted model) and while (adjusted model) controlling for a variety of potentially confounding psychosocial factors, using a stepwise selection approach based on likelihood ratio.

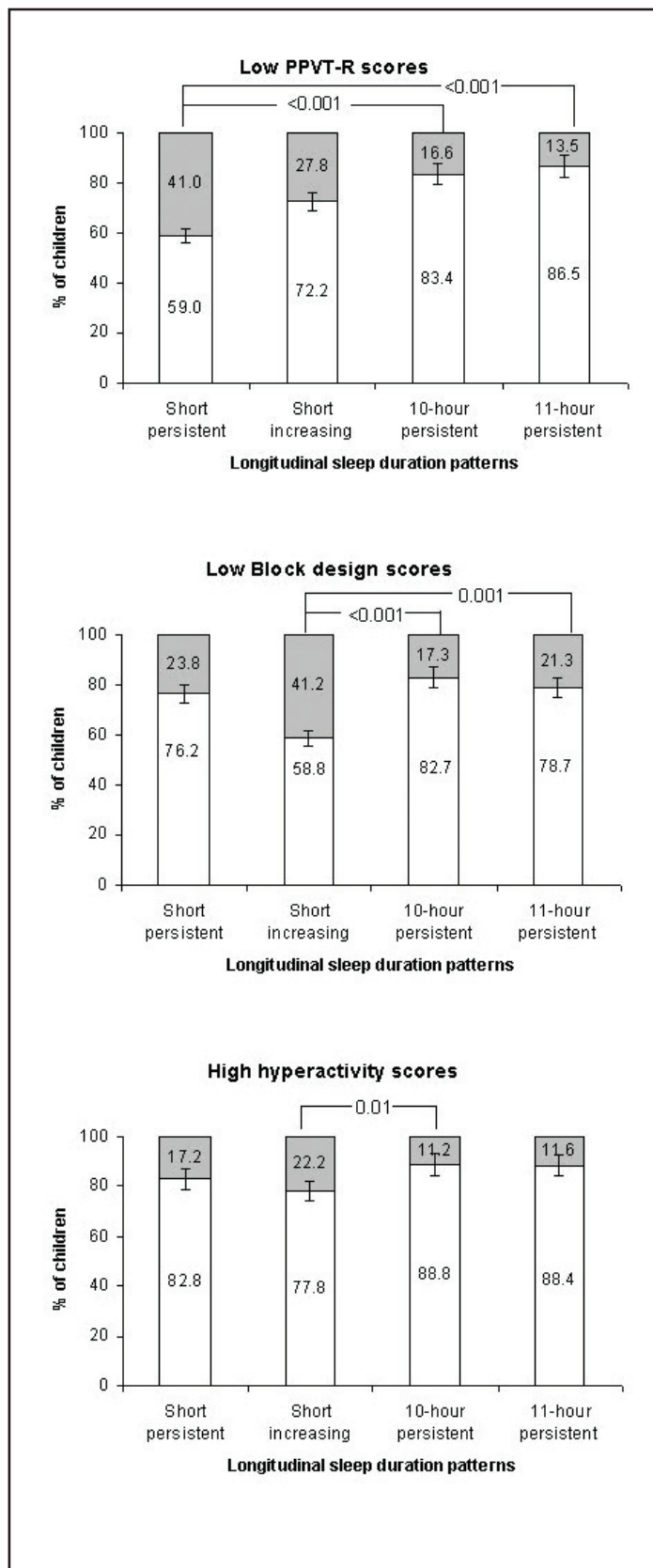
## RESULTS

The sample of children at 6 years of age was comprised of 91.6% ( $n=1,492$ ) having a Canadian (non-immigrant) mother and 8.4% having a first-generation immigrant mother. The majority of the sample was Caucasian (93.8%). Black Africans, Native Amerindians, Arabs, and Asians represented 1.7%, 0.2%, 1.0%, and 1.5% of the sample, respectively. Most mothers were interviewed in French (89.1%); the remainder were interviewed in English (10.9%).

We obtained 4 developmental sleep duration patterns, as illustrated in Figure 1: a *short persistent* pattern (6.0%,  $n=109$ ) composed of children sleeping less than 10 hours per night until age 6; a *short increasing* pattern (4.8%,  $n=88$ ) composed of children who slept fewer hours in early childhood but whose sleep duration increased around 41 months of age, a *10-hour persistent* pattern (50.3%,  $n=920$ ) composed of children who slept persistently approximately 10 hours per night; and an *11-hour persistent* pattern (38.9%,  $n=712$ ) composed of children who slept persistently around 11 hours per night. Mean probability estimates (of being classified



**Figure 1**—Patterns of sleep duration at 2.5, 3.5, 4, 5 and 6 years of age: : short persistent sleepers ( $n=109$ ; 6.0%), : short increasing sleepers ( $n=88$ ; 4.8%), : 10-hour persistent sleepers ( $n=920$ ; 50.3%), and : 11-hour persistent sleepers ( $n=712$ ; 38.9%). Predicted (dashed lines) versus observed (solid lines) trajectories. Data courtesy of the Quebec Institute of Statistics.



**Figure 2**—Grey areas indicate percentage of children who had low performances on the PPVT-R, on the Block design or high hyperactivity ratings as a function of sleep duration patterns. Chi-square tests (4 X 2) were used to measure the distribution of low performance on the PPVT-R ( $P < 0.001$ ) and on the Block design subtest ( $P = 0.001$ ) and high hyperactivity ratings ( $P = 0.04$ ) with different sleep duration patterns. Data courtesy of the Quebec Institute of Statistics.

**Table 1**—Multivariate Weighted Odds Ratios (OR) and 95% Confidence Interval (95% CI) for Behavioral Measures Based on Sleep Duration (Unadjusted Model) and After Controlling for Potentially Confounding Variables (Adjusted Model) in the Final Logistic Regression Model\*

Risk factors	Hyperactivity-impulsivity High (n=173†/n=129‡)			Inattention High (n=124†/n=124‡)			Daytime sleepiness Yes (n=266†/n=265‡)		
	OR	95% CI	P	OR	95% CI	P	OR	95% CI	P
<b>Unadjusted model†</b>									
Sleep duration patterns§									
Short persistent duration	1.6	(0.8 - 3.0)	0.16	1.2	(0.6 - 2.5)	0.68	1.3	(0.7 - 2.4)	0.41
Short increasing duration	2.4	(1.3 - 4.4)	0.008	0.7	(0.3 - 2.0)	0.56	1.1	(0.6 - 2.2)	0.75
10-h persistent duration	1.1	(0.7 - 1.5)	0.73	0.9	(0.6 - 1.3)	0.59	1.0	(0.7 - 1.3)	0.75
		n=1,391			n=1,391			n=1,258	
<b>Adjusted model‡</b>									
Sleep duration patterns§									
Short persistent duration	1.5	(0.7 - 3.2)	0.25	1.1	(0.5 - 2.4)	0.76	1.2	(0.7 - 2.2)	0.44
Short increasing duration	3.2	(1.6 - 6.6)	0.001	0.7	(0.3 - 2.0)	0.55	1.0	(0.5 - 2.0)	0.96
10-h persistent duration	1.2	(0.8 - 1.8)	0.46	0.9	(0.6 - 1.3)	0.47	0.9	(0.7 - 1.2)	0.57
		n=1,169			n=1,386			n=1,251	

Data courtesy of the Quebec Institute of Statistics.

\* Data are expressed as weighted odds ratio (95% confidence interval).

§ The reference for sleep duration patterns in the logistic regression was children who slept 11-hour persistently.

† Unadjusted odds ratio (95% CI) without controlling for potentially confounding factors.

‡ Adjusted odds ratio (95% CI) while controlling for sex of the child, low birth weight, breastfeeding status, maternal immigrant status, low parental education, young mother age, inadequate income, naptime at 29 months of age, hyperactivity-impulsivity and inattention at 17 months of age.

into the correct trajectory) were 0.85 for the *short persistent*, 0.79 for the *short increasing* pattern and 0.85 for both *10-hour* and *11-hour persistent* patterns. This indicates good fit of the model.

The short increasing trajectory did not show a longer daytime sleep duration at 29 months (97±47 min) than that of the 3 other trajectories (118±37 min, 109±41 min, 99±50 min for the short persistent, 10-hour persistent and 11-hour persistent sleepers, respectively). There was no between-trajectory difference either on sleep duration variation between weekdays and weekends at 6 years of age (P = 0.41). All children tended to sleep a little more on weekdays (10 minutes on average) in all 4 trajectories. In light of previous findings,<sup>16</sup> the percentages of children who were not sleeping 6 consecutive hours at night at both 5 and 17 months were calculated for the 4 trajectories and the highest percentages were found in the short increasing (5 months: 35.3%, 17: months: 19.5%), then in the short persistent trajectories (31.5%, 14.3%) compared to both the 10-hour (19.6%, 5.9%) and 11-hour (16.8%, 4.3%) persistent trajectories.

Figure 2 shows significant differences between the distributions of low performance on the PPVT-R (P < 0.001), the Block design subtest (P = 0.001) and high HI scores (P = 0.04) as a function of sleep duration pattern. More precisely, more children with lower PPVT-R performance were assigned to the short persistent group (41.0%) compared to both the 10-hour (16.6%; P < 0.001) and 11-hour persistent groups (13.5%; P < 0.001). In addition, more children with lower Block design performance were assigned to the short increasing group (41.2%) than either the 10-hour (17.3%; P < 0.001) or 11-hour persistent (21.3%; P = 0.001) groups. Finally, we observed more HI in the short increasing group compared with the 10-hour persistent group (22.2% versus 11.2%; P = 0.01). No differences in the distributions of inattention scores or daytime sleepiness as a function of sleep duration pattern were found.

Weighted logistic regression models for behavioral measures are presented in Table 1. No significant effect of sleep duration pattern was found on inattention or daytime sleepiness. The effect

of sleep duration pattern on HI remained significant after adjusting for potentially confounding variables. Risk for HI was almost 3.2 times higher for short increasing sleepers compared with 11-hour persistent sleepers (P = 0.001). No significant risk for HI was found for other sleep patterns.

Other independent variables were significantly associated with high HI scores. Risk for HI at 6 years of age was almost 3 times higher for children who were also HI at 17 months of age (Odds Ratio [OR]: 3.2; 95% confidence interval [CI]: 2.1 – 4.8; P < 0.001). Risk for HI was almost 1.6 times higher for boys compared to girls (OR: 1.6; CI: 1.1 – 2.3; P = 0.02) and 1.9 times higher for children of parents without a college diploma (OR: 1.9; CI: 1.2 – 2.9; P = 0.004).

Other independent variables were significantly associated with high inattention scores. Risk for inattention was almost 2.1 times higher for boys than girls (OR: 2.1; CI: 1.4 – 3.1; P < 0.001). In addition, risk for inattention at 6 years was almost 1.7 times higher for children who showed inattention at 17 months of age (OR: 1.7; CI: 1.1 – 2.6; P = 0.02).

Weighted logistic regression models for neurocognitive tests are shown in Table 2. No effect of sleep duration pattern was found for high PPVT-R or Block Design subtest performance. The effect of short sleep duration pattern on low PPVT-R and Block Design subtest performance remained significant after adjusting for potentially confounding variables. Risk for low PPVT-R performance was almost 3.1 times higher for short persistent sleepers compared to 11-hour persistent sleepers (P = 0.002). No effect was found for other sleep patterns with low PPVT-R performance. Risk for low Block Design subtest performance was almost 2.4 times higher for short increasing sleepers compared with 11-hour persistent sleepers (P = 0.004). No effect was found for other sleep patterns with low Block Design subtest performance.

Other factors were significantly associated with low PPVT-R performance: immigrant status of the mother (OR: 3.6; CI: 2.0 – 6.6; P < 0.001), insufficient income (OR: 2.1; CI: 1.3 – 3.5;

**Table 2**— Multivariate Weighted Odds Ratios (OR) and 95% Confidence Interval (95% CI) for Cognitive Tasks Based on Patterns of Sleep Duration (Unadjusted Model) and After Controlling for Potentially Confounding Variables (Adjusted Model) in the Final Logistic Regression Model\*

Risk factors	PPVT-R						Block Design					
	Low (n=155† / n=136‡)			High (n=138† / n=123‡)			Low (n=225† / n=224‡)			High (n=191† / n=166‡)		
	OR	95% CI	P	OR	95% CI	P	OR	95% CI	P	OR	95% CI	P
<b>Unadjusted model†</b>												
Sleep duration patterns§												
Short persistent duration	3.6	(1.9 - 6.7)	<0.001	0.4	(0.1 - 1.1)	0.08	0.9	(0.5 - 1.8)	0.84	0.9	(0.4 - 1.9)	0.75
Short increasing duration	2.2	(1.0 - 6.7)	0.04	0.7	(0.2 - 1.9)	0.45	2.5	(1.4 - 4.5)	0.003	0.7	(0.3 - 1.7)	0.48
10-h persistent duration	1.2	(0.8 - 1.7)	0.45	1.0	(0.7 - 1.4)	0.90	0.8	(0.6 - 1.1)	0.19	1.1	(0.8 - 1.5)	0.76
		n=915			n=915			n=1099			n=1099	
<b>Adjusted model‡</b>												
Sleep duration patterns§												
Short persistent duration	3.1	(1.5 - 6.3)	0.002	0.4	(0.1 - 1.3)	0.11	0.9	(0.5 - 1.8)	0.77	0.6	(0.3 - 1.5)	0.31
Short increasing duration	1.6	(0.7 - 3.9)	0.31	0.8	(0.3 - 2.5)	0.68	2.4	(1.3 - 4.4)	0.004	0.7	(0.3 - 1.8)	0.43
10-h persistent duration	1.2	(0.8 - 1.9)	0.42	1.0	(0.7 - 1.5)	0.92	0.8	(0.6 - 1.1)	0.20	0.9	(0.7 - 1.3)	0.74
		n=800			n=807			n=1,098			n=924	

Data courtesy of the Quebec Institute of Statistics.

\* Data are expressed as weighted odds ratio (95% confidence interval).

§ The reference for sleep duration patterns in the logistic regression was children who slept 11-hour persistently.

† Unadjusted odds ratio (95% CI) without controlling for potentially confounding factors.

‡ Adjusted odds ratio (95% CI) while controlling for sex of the child, maternal immigrant status, low parental education, young mother age, inadequate income, low birth weight, breastfeeding status, naptime at 29 months of age, hyperactivity-impulsivity and inattention at 17 months of age.

P = 0.003), and low parental education (OR: 2.1; CI: 1.3 – 3.4; P = 0.002). We found 2 significant factors for low Block Design subtest performance: immigrant status of the mother (OR: 1.8; CI: 1.1 – 3.2; P = 0.03) and young mother (OR: 2.9; CI: 1.3 – 6.2; P = 0.006).

Low parental education reduced almost twofold the probability of high PPVT-R performance (OR: 0.5; CI: 0.2 – 0.9; P = 0.02) and high Block Design subtest performance (OR: 0.4; CI: 0.2 – 0.7; P = 0.001). Finally, probability of high PPVT-R performance was almost 5 times lower for children whose mothers were immigrants compared to children with nonimmigrant mothers (OR: 0.2; CI: 0.1 – 0.9; P = 0.03).

## COMMENT

This study represents the first investigation of developmental sleep duration patterns throughout childhood. The majority of the children studied (50.3%) slept persistently for 10 hours a night on average, whereas 38.9% slept persistently for 11 hours a night over the period studied, demonstrating that nighttime sleep duration is fairly stable from 2.5 years of age to 6 years of age. These sleep duration values are in good agreement with those reported elsewhere.<sup>3-</sup>

<sup>5</sup> Also, there was no difference in sleep duration between weekdays and weekends indicating that children were not compensating on the weekend for sleep loss occurring during the week, even in the group of short persistent sleepers. Short increasing sleepers, who had evidence of a nocturnal sleep consolidation problem before the age of 41 months, did not compensate their short nighttime sleep duration by more daytime sleep at 29 months.

## Sleep Duration and Cognitive Outcomes

More importantly, our results indicate that a modest but chronic reduction of just 1 hour of sleep nightly in early childhood can be associated with the child's cognitive performance at school entry.

Short sleep duration multiplied by 3.1 the risk of low performance on the PPVT-R. This suggests that language acquisition and the consolidation of new words into memory could be significantly impeded by chronically shortened sleep duration throughout childhood. Lower performance on the Block design subtest was also observed in the short increasing sleep group. This means that, although sleep duration improved at 3 years of age, the risk for scoring low on the Block design subtest at 6 years of age remained more than 2.4 times higher, independently of potentially confounding factors. This finding points to an early critical period for cognitive development that may be jeopardized by short sleep duration. Randazzo and colleagues<sup>17</sup> reported that a duration of 5 hours in bed results in significantly lower performance in verbal creativity and abstract thinking, compared with 11 hours of sleep. Moreover, studies on cumulative sleep restriction have shown negative effects on cognitive performance.<sup>32,33</sup> Sadeh and his team<sup>33</sup> reported that children who extended their sleep by 1 hour for 3 consecutive nights showed significantly improved digit forward memory test scores and reaction times on a performance test.

We could posit other potential variables to explain the associations between sleep duration pattern and cognitive measures. For example, the PPVT-R Instruction Manual<sup>17</sup> reports that recent immigration, low parental education, and low socioeconomic status can influence PPVT-R results, as we found in this study. Likewise, immigrant status, and young age of the mother were associated with low performance on the Block design subtest of the WISC-III.<sup>34,35</sup> However, none of the other factors studied were able to explain the association observed between sleep pattern and cognitive performance.

## Sleep Duration and Behavioral Outcomes

Our results also demonstrate a significant relationship between high HI scores at 6 years of age and a short increasing sleep duration pattern. Although sleep duration improved at 3 years of age,

the risk for high HI scores at 6 years of age remained 3.2 times higher independent of potentially confounding factors. We believe that there is a critical period in early childhood where the lack of sleep is particularly detrimental to various aspects of development even if sleep duration normalizes later on. There was an inclination for children in the short persistent pattern to also show high HI scores at 6 years of age. However, the sleep duration in the critical period was even shorter (by 51 minutes) in the short increasing than in the short persistent pattern. Lavigne and colleagues<sup>10</sup> also associated less nocturnal sleep (<10 hours) in preschool children with increased daytime behavior problems, according to the Child Behavior Checklist. No association was found in the present study between daytime sleepiness and sleep patterns, whereas other studies on older children have reported that sleep-deprived children were sleepier than non-sleep-deprived children.<sup>12-15,36</sup> Our results support the notion that 6-year-old children are more likely to exhibit externalizing behaviors such as HI instead of the classical signs of sleepiness when they do not get sufficient nocturnal sleep.<sup>7,8</sup> These results also highlight the importance of giving a child the opportunity to sleep at least 10 hours a night throughout childhood, especially before the age of 3.5 years. No association was found between inattention and sleep duration pattern.

It might be argued that other variables might explain the association observed between sleep duration and behavioral outcomes. It is well-known in the literature that boys score higher on HI and inattention than girls.<sup>37</sup> The present study also shows that sex of the child is an independent risk factor for higher HI and inattention scores. High HI and inattention scores at 17 months increase the risks for HI and inattention, respectively, at 6 years of age. High behavioral scores in early childhood appear to persist over time.<sup>28,29</sup> However, despite these associations, short sleep duration was independently associated with high HI scores. Future studies could investigate the relationship between short sleep duration in early childhood and the predominantly hyperactive-impulsive subtype of ADHD.

## Limitations

Our study is limited by reliance on a subjective measure of sleep quantity, which may slightly overestimate the real sleep time. Fortunately, the parental reports and actigraphy measures show generally high agreement for sleep duration.<sup>38-40</sup> Further controlled studies are needed to better quantify the long-term effects of shortened sleep on cognitive tasks in young children, although verbal skills (e.g., PPVT-R, as used in this study) have been found to better predict school achievement than other types of cognitive tests. In future studies, it would also be interesting to use tests that involve neurocognitive executive functions, which are known to be under the control of the frontal lobe and thus affected by sleep reduction.<sup>41</sup> Furthermore, the odds ratio of logistic regression assesses risk but cannot be used to infer causality. Finally, since the participants were generally nonimmigrant French-speaking Caucasians, the results might not be generalizable to other populations. Nevertheless, this paper highlights the importance to give the child the opportunity to sleep at least 10 hours a night in early childhood, as supported by the findings of the National Sleep Foundation Poll.<sup>42</sup> It would be interesting to determine more precisely whether 10 hours (on average) represents a threshold for minimum required sleep duration in early childhood. One should keep in mind that the required amount

of sleep shows some inter-individual variation (short- and long-sleepers). Finally, future studies should look at the emergence of chronotypes (eveningness vs morningness) in relation to childhood sleep duration.

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