American Journal of Epidemiology

Vol. 173, No. 6
DOI: 10.1093/aje/kwq389
Advance Access publication:
February 8, 2011

Original Contribution

Short Sleep Duration and Body Mass Index: A Prospective Longitudinal Study in Preadolescence

Valérie Seegers, Dominique Petit, Bruno Falissard, Frank Vitaro, Richard E. Tremblay, Jacques Montplaisir, and Evelyne Touchette*

* Correspondence to Dr. Evelyne Touchette, 97 Boulevard de Port Royal, 75679 Paris cedex 14, France (e-mail: eveline.touchette@umontreal.ca).

Initially submitted April 14, 2010; accepted for publication October 19, 2010.

Short sleep duration is associated with incidence of overweight and obesity in preadolescent children. The authors performed regression analyses on data from the Quebec Longitudinal Study of Kindergarten Children (1986–1987), a prospective cohort study comprising 1,916 preadolescent children in Canada. The aim was to assess associations between time spent in bed and body mass index reported by mothers after adjusting for numerous confounding factors, such as pubertal status. Time-in-bed and body mass index trajectories were computed using a semiparametric model mixture. Time-in-bed trajectories were classified as short (15% of the preadolescents), 10.5-hour (68%), and 11-hour (17%) sleep-duration trajectories, decreasing over time. Body mass index trajectories were classified as normal weight (68% of the preadolescents), overweight (27%), and obese (5%). The short sleep trajectory was associated with an increased odds ratio of being in the overweight body mass index trajectory (odds ratio (OR) = 1.55, 95% confidence interval (CI): 1.39, 1.71) or in the obese body mass index trajectory (OR = 3.26, 95% CI: 3.20, 3.29) compared with the 11-hour trajectory. One hour less of sleep per night at 10 years of age was associated with an increased odds ratio of being overweight (OR = 1.51, 95% CI: 1.28, 1.76) or obese (OR = 2.07; 95% CI: 1.51, 2.84) at 13 years of age.

adolescent; obesity; overweight; public health; sleep

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio; SD, standard deviation; TIB, time spent in bed.

The prevalence of overweight and obesity in children and adolescents has risen greatly worldwide in the past 2 decades. In the United States, around 17% of children and adolescents between 2 and 19 years of age had a body mass index (BMI, measured as weight in kilograms divided by height in meters squared) above the 95th percentile of the 2000 growth charts (Centers for Disease Control and Prevention sex-specific BMI curves for age) in 2007–2008 (1–6). Obesity is associated with short- and long-term adverse consequences, such as diabetes or insulin resistance, sleep apnea syndrome or other respiratory disorders, cardiovascular diseases, hypertension, and several cancers (7–10).

The identification of modifiable risk factors for developing obesity during childhood and adolescence is key for prevention. In a recent meta-analysis that included 12 epidemiologic studies from different countries, Cappuccio et al. (11) found an association between short sleep duration and obesity, with an odds ratio around 2, among 30,002 children. Conversely, long sleep duration was reported to have beneficial effects on obesity rates (12–14).

It has been suggested that short sleep duration may lead to obesity through different pathways (15–20). First, sleep deprivation increases drowsiness and could alter thermoregulation functions through the hypothalamic-pituitary-adrenocortical secretion of growth hormone during slow-wave sleep, which leads to reduced energy expenditure (15). In addition, sleep deprivation could increase opportunities to eat and boost appetite and caloric intake by increasing levels of circulating ghrelin and decreasing levels of leptin, both of which are implicated in appetite regulation (17, 18).

Researchers assessed the association between sleep duration and BMI in childhood in several prospective longitudinal studies (21–25). In these studies, sleep duration was measured between 6 months and 2 years of age (21), as an average of repeated measures between 2 and 5 years of age (22), at 2.5 years of age (23), or between 2 and 7 years of age (24), and BMI was measured 1.5–5 years later. Sleep duration was analyzed for the first time longitudinally by Touchette et al. (25). They found that short sleep duration during childhood (from 2.5 to 6 years of age) was associated with an increased risk of overweight or obesity at 6 years of age. Gupta et al. (26) assessed the relation between sleep duration and BMI (between 11 and 16 years of age) and adjusted for puberty status. The association between sleep duration and BMI was also reported in adulthood (27–31).

To our knowledge, no prospective longitudinal sleep study has shown an association between sleep duration and BMI in preadolescent children. During this developmental period, the association between sleep duration and BMI could be mediated by hormonal and socioenvironmental changes. It has been reported that pubertal status shows marked variability among preadolescents (32, 33). It is well known that pubertal modifications influence sleep timing (phase delay in bedtime and waking time) and changes in lifestyle (including time spent watching television or level of physical activity out of school).

In the present study, we aimed to evaluate the association between sleep duration and BMI (overweight/obesity) among preadolescents in a prospective longitudinal study. The objective was to evaluate longitudinally the relation between sleep duration and BMI by using repeated measures through preadolescence (10–13 years of age), taking into account pubertal status and lifestyle changes observed in preadolescence. Our underlying hypothesis was that there was an association between short sleep duration and higher BMI.

MATERIALS AND METHODS

Setting and participants

All participants were part of the Quebec Longitudinal Study of Kindergarten Children, a prospective longitudinal study. A sample of 3,017 children was selected and recruited when they were 6 years of age from the French-speaking state schools of the province of Quebec, Canada, in 1986–1987. The subjects were chosen randomly and proportionally according to the 11 administrative regions of the province of Quebec and were representative of the general population of children entering school at 6 years of age. All families received detailed information on the aims and procedures of the research program and signed a consent form. The protocol was approved by the University of Montreal ethics committee. The present study assessed the preadolescent period between the ages of 10 and 13 years.

Measures

A sleep questionnaire and questions about both the weights and heights of children (between the ages of 10 and 13 years) were added to the annual questionnaire administered to mothers. In addition, preadolescents completed a questionnaire about their lifestyles and habits at 13 years of age. All variables used in the present study are presented in Table 1.

Sleep variables. Using open-ended questions, mothers were asked about their preadolescents' bedtimes and waking times on weekdays at 10, 11, 12, and 13 years of age. Sleep duration was estimated as the time spent in bed (TIB) between bedtime and waking time. For the cross-sectional analyses, TIB was considered as a continuous variable to evaluate the risk associated with a 1-hour reduction in TIB.

Body mass index. BMI, the most common and noninvasive measure of obesity, was calculated by using the preadolescents' weights and heights that were reported by their mothers when the children were between the ages of 10 and 13 years. The international definitions of overweight and obesity for preadolescents were based on BMI curves as a function of sex and age, as defined by Cole et al. (34). The overweight and obesity statuses were used for all cross-sectional analyses.

Confounding factors. The following sociodemographic characteristics were taken into account in the evaluation of the association between TIB and BMI: sex, maternal immigrant status, familial income (Can$ <40,000, Can$ 40,000–60,000, or Can$ >60,000), birth weight, and maternal and paternal educational levels. These data were obtained when the children were 6 years of age. Pubertal status was evaluated by the mother using the Pubertal Development Scale (35). Mothers rated growth spurts, body and facial hair development, and skin and voice changes when their preadolescents were 11, 12, and 13 years of age, and ratings were combined so as to yield 1 of the 5 categorical classifications: 1) prepubertal, 2) early pubertal, 3) midpubertal, 4) late pubertal, or 5) postpubertal. The validity of the instrument was measured by comparing the self-evaluation of preadolescents with the evaluation by the mothers. The correlation coefficients varied from 0.41 to 0.79, with a median correlation of 0.7. In the present study, the Spearman correlation between the self-evaluation of preadolescents and the evaluation by the mothers when the children were 13 years of age was 0.82. The self-administered questionnaire measured lifestyle and habits at age 13 years, including items such as time spent watching television per day (<3 hours/day vs. more) and frequency of physical activity out of school (once weekly or more vs. less than once weekly).

Description of samples at each age

Table 2 shows the comparisons of the sociodemographic characteristics between all cross-sectional samples (10 years of age, $n = 1{,}276$; 11 years of age, $n = 1{,}849$; 12 years of age, $n = 1{,}835$; and 13 years of age, $n = 957$) and the initial cohort at 6 years of age ($n = 3{,}017$). In the longitudinal analyses, 1,916 preadolescents for whom we had data on at least 2 out of the 4 measures of TIB and BMI were included. The initial sample was composed of 52.8% boys, and 4.2% of the children had an immigrant mother. About 12 years of education was reported for both parents in the initial sample. Over the years, the sample comprised fewer boys, fewer children with immigrant mothers (except at 13 years of age), and children with higher maternal and

Table 1. Sociodemographic and Sleep-Related Characteristics of Preadolescents Aged 10–13 Years in the Quebec Longitudinal Study of Kindergarten Children, 1986–1987

Variable	10 Years of Age (n = 1,276)			11 Years of Age (n = 1,849)			12 Years of Age (n = 1,835)			13 Years of Age (n = 957)		
	No.	%	Mean (SD)	No.	%	Mean (SD)	No.	%	Mean (SD)	No.	%	Mean (SD)
Continuous variables												
Time in bed, hours			10.5 (0.5)			10.2 (0.6)			9.9 (0.6)			9.5 (0.6)
Body mass index			18.2 (3.7)			18.8 (3.5)			19.4 (3.8)			20.3 (3.6)
Categorical variables												
Body mass index category												
Overweight[a]	244	19.1		351	19.0		329	17.9		194	20.3	
Obese[a]	75	5.9		101	5.5		82	4.5		41	4.3	
Pubertal status												
Prepubertal				774	42.2		434	24.0		104	11.0	
Early pubertal				436	23.7		475	26.3		175	18.6	
Midpubertal				539	29.4		615	34.1		294	31.2	
Late pubertal				72	3.9		243	13.5		303	32.2	
Postpubertal				15	0.8		38	2.1		66	7.0	
Data missing				13			30			15		
Time spent watching television daily												
>3 hours/day										511	53.7	
Data missing										6		
Physical activity out of school												
<2 hours/week										282	29.7	
Data missing										6		

Abbreviation: SD, standard deviation.
[a] Overweight and obesity statuses were defined by the international body mass index curves proposed by Cole et al. (34).

paternal educational levels. However, no significant difference was observed for family income or birth weight in any cross-sectional sample compared with the initial sample.

Statistical analyses

Descriptive analyses were performed for categorical variables (sex, maternal immigrant status, familial income, pubertal status, daily time spent watching television, and level of physical activity out of school) and for continuous variables (birth weight and maternal and paternal educational levels). For comparisons with the initial sample, chi-square tests were used for categorical data and t tests were used for continuous data for all samples.

TIB and BMI trajectories. Distinct trajectories were identified for TIB and BMI by using the semiparametric mixture model described by Nagin (36). For each trajectory, the model defined its shape and the estimated proportion of the sample it represented. Trajectory models with 2–4 trajectories were computed. Selection of the optimal number of trajectories was determined by using the model that best fitted the data on the basis of the lowest value for the Bayesian Information Criterion. Subjects for whom at least 2 years' worth of data were available were taken into account in the modeling of TIB and BMI trajectories. We used posterior probabilities to estimate each individual's probability of belonging to each trajectory, independent of a priori cutoff points reported in the literature. The TIB and BMI trajectories were computed using the PROC TRAJ procedure in SAS, version 9.1 (SAS Institute, Inc., Cary, North Carolina).

Cross-sectional analyses. At each age, the associations between TIB and BMI as continuous variables were estimated using linear regression. Results are presented as β coefficients and 95% confidence intervals. Multinomial regressions analyses were performed to estimate the associations between TIB and BMI categories (normal, overweight, and obese) at each age. Results are presented as odds ratios and 95% confidence intervals. Multinomial regression was used to test the associations between TIB and BMI trajectories after adjusting for confounding factors.

Longitudinal analyses. The association between TIB trajectories and BMI at 13 years of age was analyzed by using linear regression for continuous BMI and multinomial regression for categorical BMI at 13 years of age. Regression analyses (linear for BMI as a continuous variable and

Table 2. Sociodemographic Characteristics for Each Sample at Ages 10, 11, 12, and 13 Years and for the Longitudinal Sample Compared With the Initial Sample at Age 6 Years in the Quebec Longitudinal Study of Kindergarten Children, 1986–1987

Variable	Initial Sample (*n* = 3,017)			Cross-Sectional Samples																Longitudinal Sample (*n* = 1,916)			
				10 Years of Age (*n* = 1,276)				11 Years of Age (*n* = 1,849)				12 Years of Age (*n* = 1,835)				13 Years of Age (*n* = 957)							
	No.	%	Mean (SD)	No.	%	Mean (SD)	*P* Value	No.	%	Mean (SD)	*P* Value	No.	%	Mean (SD)	*P* Value	No.	%	Mean (SD)	*P* Value	No.	%	Mean (SD)	*P* Value
Categorical variables[a]																							
Sex							0.001				0.06				0.03				0.06				0.07
Male	1,594	52.8		602	47.2			925	50.0			908	49.5			472	49.3			960	50.1		
Female	1423	47.2		674	52.8			924	50.0			927	50.5			485	20.7			956	49.9		
Maternal immigration status	125	4.2		17	1.3		<0.001	50	2.7		0.009	50	2.7		0.01	26	2.7		0.05	43	2.3		<0.001
Nonimmigrant	2,867	95.8		1,253	98.7			1,788	97.3			1,772	97.3			924	97.3			1,860	97.7		
Data missing	24			6				11				13				7				13			
Familial income, Can$							0.74				0.55				0.87				0.30				0.51
<40,000	827	59.3		545	58.1			573	57.1			583	58.2				55.3			600	57.0		
40,000–60,000	432	31.0		293	31.2			327	32.6			316	31.6			154	34.8			340	32.3		
>60,000	136	9.7		100	10.7			104	10.4			102	10.2			44	9.9			112	10.7		
Data missing	1,622			338				845				834				514				864			
Continuous variables[b]																							
Birth weight, g							0.50																
Cohort members			3,282 (551)			3,296 (546)				3,293 (538)	0.53			3,290 (558)	0.64			3,311 (538)	0.20			3,290 (553)	0.54
Data missing			1,021			224				213				273				185				283	
Parental educational level, years																							
Maternal			11.71 (2.6)			12.0 (2.5)	0.001			12.0 (2.6)	0.002			12.0 (2.6)	<0.001			12.1 (2.5)	<0.001			12.1 (2.6)	<0.001
Maternal data missing			102			37				51								18				51	
Paternal			11.9 (3.4)			12.2 (3.4)	0.01			12.0 (3.4)	0.10			12.1 (3.4)	0.02			12.2 (3.1)	0.02			12.1 (3.4)	0.001
Paternal data missing			345			148				171				184				66				185	

Abbreviation: SD, standard deviation.

[a] Chi-square tests were used for categorical variables.

[b] *t* tests were used for continuous variables.

multinomial for categorical BMI) were performed to evaluate the association between TIB at age 10 years and BMI at age 13 years. Finally, the same approach was used to evaluate the association between BMI trajectories and TIB at age 13 years and then between BMI at age 10 years and TIB at age 13 years.

Missing data. We used a multivariate imputation approach to treat the missing data for the following confounding factors: maternal immigrant status, familial income, birth weight, maternal and paternal educational levels, pubertal status, time spent watching television, and level of physical activity out of school. All statistical tests were 2-tailed, and the alpha level was set at $P < 0.05$. Analyses were performed using the R statistical programming language, version 2.8.1 (R Development Core Team, Vienna, Austria).

RESULTS

Table 1 shows the evolution of weekday TIB decreasing across time from a mean of 10 hours and 29 minutes (standard deviation (SD), 32 minutes) per day at 10 years of age to 9 hours and 29 minutes (SD, 37 minutes) per day at 13 years of age. BMI increased from a mean of 18.2 (SD, 3.7) at age 10 years to 20.3 (SD, 3.6) at age 13 years. The percentage of obese preadolescents varied from 4.3% to 5.9%, and the percentage of overweight/obese preadolescents varied from 17.9% to 20.3% between ages 10 and 13 years. At 13 years of age, 53.7% of the preadolescents watched television for ≥3 hours daily. In addition, 29.7% of the preadolescents reported having <2 hours of physical activity out of school per week. The pubertal status changed between ages 11 and 13 years (65.9% began their puberty at 11 years of age and 70.4% reported a middle, advanced, or postpubertal status at 13 years of age).

Description of trajectories. Figure 1A shows 3 trajectories of TIB for children at 10–13 years of age. The prevalence of study participants with a short sleep duration at 10 years of age was 14.5%, with their sleeping time decreasing further over the years. The prevalence of children who slept around 10.5 hours per night at 10 years of age was 68.2%, with that amount decreasing gradually over the years. The prevalence of children who slept about 11 hours per night at 10 years of age was 17.3%, with that amount decreasing gradually over the years. Figure 1B presents 3 trajectories for BMI evolution for ages 10–13 years. The most prevalent trajectory (67.9%) represents children with a normal BMI that increased progressively from 16.6 to 17.6 over the years. The second most prevalent trajectory (26.7%) represents overweight children with a BMI increasing progressively from 20.8 to 23.0 over the years. Finally, the third trajectory (5.4%) represents obese children with a BMI that varied from 26.2 to 27.0 over the years.

Cross-sectional analyses

Associations between TIB and BMI at each age. Table 3 presents the results of the associations between TIB and BMI at each age after adjusting for confounding factors. At each age, TIB and BMI were significantly and negatively associated (except for age 13 years); shorter sleep duration

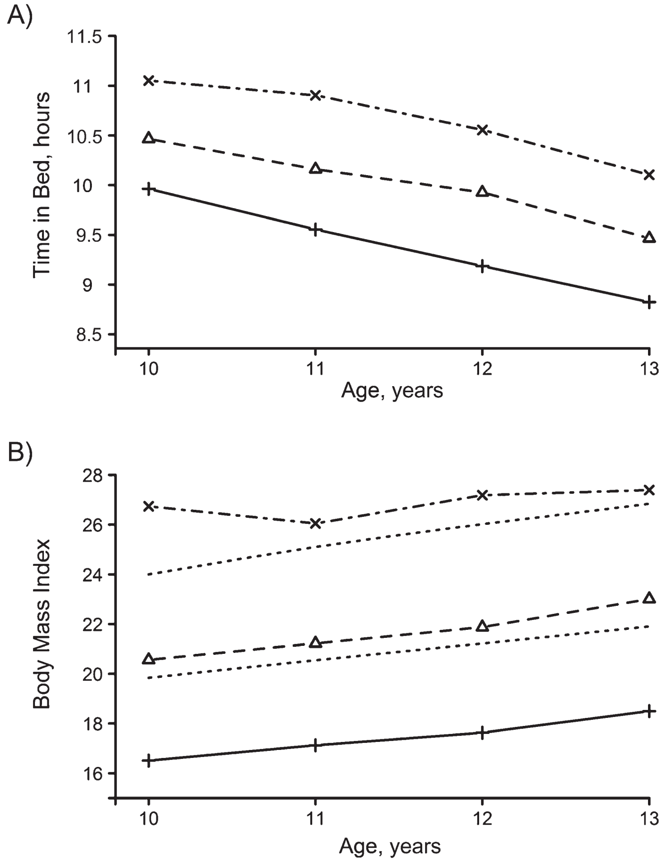

Figure 1. Developmental trajectories, represented by means of time in bed and body mass index (BMI) from 10 to 13 years of age, in the Quebec Longitudinal Study of Kindergarten Children, 1986–1987. A) Three time-in-bed trajectories were defined: short sleepers (+; $n = 316$, 14.5%), 10.5-hour sleepers (△; $n = 1,486$, 68.2%), and 11-hour sleepers (x; $n = 376$, 17.3%). B) Three BMI trajectories were also computed: normal BMI (+; $n = 1,315$, 67.9%), overweight (△; $n = 518$, 26.7%), and obese (x; $n = 104$, 5.4%). Dotted lines in part B illustrate the international boundaries proposed by Cole et al. (34) to define overweight and obesity between the ages of 10 and 13 years (merged means for girls and boys at each age).

was significantly associated with higher BMI values. One hour less of TIB was associated with increased odds ratios for being overweight at 10 (odds ratio (OR) = 1.47, 95% CI: 1.33, 1.62) and 13 (OR = 1.24, 95% CI: 1.10, 1.40) years of age. In addition, 1 hour less of TIB was associated with increased odds ratios for being obese at 10 (OR = 1.78, 95% CI: 1.53, 2.08), 11 (OR = 1.41, 95% CI: 1.24, 1.61), and 12 (OR = 1.17, 95% CI: 1.01, 1.35) years of age.

Association between TIB and BMI trajectories. Table 4 presents the results of the multinomial logistic regression for the association between TIB and BMI trajectories. After adjusting for confounding factors, the short-sleeper trajectory was associated with a higher odds ratio for being in the overweight trajectory (OR = 1.55, 95% CI: 1.39, 1.71) and in the obese trajectory (OR = 3.26, 95% CI: 3.20, 3.29) compared with the 11-hour sleeper trajectory. The 10.5-hour sleeper trajectory was associated with a higher odds ratio for

Table 3. Associations Between Time in Bed and Body Mass Index at Each Age, Adjusted for Confounding Factors[a], in the Quebec Longitudinal Study of Kindergarten Children, 1986–1987

	10 Years of Age (n = 1,276)		11 Years of Age (n = 1,849)		12 Years of Age (n = 1,835)		13 Years of Age (n = 957)	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
BMI, continuous[b]	−0.87	−1.26, −0.49	−0.45	−0.74, −0.16	−0.32	−0.61, −0.03	−0.32	−0.68, 0.05
BMI, categorical								
Overweight vs. normal BMI	1.47	1.33, 1.62	1.08	1.00, 1.17	1.06	0.98, 1.15	1.24	1.10, 1.40
Obesity vs. normal BMI	1.78	1.53, 2.08	1.41	1.24, 1.61	1.17	1.01, 1.35	1.02	0.83, 1.25

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio.
[a] Adjustments were performed for sex, immigrant status, familial income, birth weight, and maternal and paternal education, for all ages, for pubertal status at ages 11–13 years, and for time spent watching television and physical activity out of school at age 13 years.
[b] Values are β coefficients rather than ORs.

being in the obese trajectory compared with the 11-hour sleeper trajectory only (OR = 1.32, 95% CI: 1.29, 1.35) after adjusting for confounding factors.

Longitudinal associations between TIB trajectories and TIB at 10 years of age and BMI at 13 years of age. Table 5 presents results of the longitudinal associations between the TIB trajectories/TIB at 10 years of age and BMI at 13 years of age after adjusting for confounding factors. The short-sleeper trajectory was associated with a higher odds ratios for being overweight (OR = 1.99, 95% CI: 1.67, 2.37) and obese (OR = 2.23, 95% CI: 2.18, 2.27) at 13 years of age compared with the 11-hour sleeper trajectory. The 10.5-hour sleeper trajectory was associated with a higher odds ratios for being overweight (OR = 1.56, 95% CI: 1.22, 1.99) and obese (OR = 1.26, 95% CI: 1.23, 1.29) at age 13 years compared with the 11-hour sleeper trajectory. Finally, TIB at 10 years of age was significantly and negatively associated with BMI at 13 years of age ($\beta = -0.71$, 95% CI: −1.18, −0.14). Furthermore, a 1-hour decrease in TIB at age 10 years was associated with increased odds ratios for being overweight (OR = 1.51, 95% CI: 1.28, 1.76) and obese (OR = 2.07, 95% CI: 1.51, 2.84) at age 13 years.

Longitudinal associations between BMI trajectories and BMI at 10 years of age and TIB at 13 years of age. Table 5 also presents the results of longitudinal associations between BMI trajectories and BMI at 10 years of age and TIB at 13 years of age after adjusting for confounding factors. No significant association was found between either BMI trajectories or BMI at age 10 years and TIB at age 13 years.

Table 4. Associations Between Time in Bed and Body Mass Index Trajectories, Adjusted for Confounding Factors[a], in the Quebec Longitudinal Study of Kindergarten Children, 1986–1987

Trajectory (n = 1,931)	Short vs. 11-Hour Trajectories		10.5-Hour vs. 11-Hour Trajectories	
	OR	95% CI	OR	95% CI
Overweight BMI vs. normal BMI trajectory	1.55	1.39, 1.71	1.00	0.86, 1.16
Obese BMI vs. normal BMI trajectory	3.26	3.20, 3.29	1.32	1.29, 1.35

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio.
[a] Adjustments were performed for sex, immigrant status, familial income, birth weight, and maternal and paternal education, for all ages, for pubertal status at ages 11–13 years, and for time spent watching television and physical activity out of school at age 13 years.

DISCUSSION

The results of the present study support the hypothesis that there is an association between short sleep duration and high BMI. We found that a 1-hour decrease in TIB at 10 years of age was associated with an increased risk (about 2 times' higher) of being obese at age 13 years, whereas 1 unit lower of BMI at 10 years of age was not related to TIB at 13 years of age. The results also show that the short-sleeper trajectory was associated with an increased risk (about 2 times' higher) of being overweight or obese at age 13 years compared with the 11-hour trajectory. The present results corroborate previous results of longitudinal studies during childhood (21–24) and cross-sectional studies during adolescence (26, 37) that support the hypothesis that short sleep duration increases the risk of obesity.

In the present study, weekday TIB trajectories showed a marked decrease between the ages of 10 and 13 years as a result of progressively later bedtimes and unchanged waking times corresponding to the start of school. It is well known that preadolescence is a developmental cornerstone in the maturation of sleep patterns (33). Pubertal status is associated with more drowsiness among adolescents (32). Indeed, a biologic trend is associated with later bedtimes during adolescence, possibly caused by a greater tolerance to homeostatic drive. This could be explained by biologic changes in sleep regulation mechanisms occurring at puberty and causing the sleep phase delay experienced by adolescents, as demonstrated by studies on sleep patterns among adolescents (33, 38).

We found that 22.4%–25.0% of the preadolescents were overweight or obese between the ages of 10 and 13 years, 4.3%–5.9% of whom were obese according to the international definition of Cole et al. (34). This prevalence is concordant with national data; according to Statistics Canada, 26% of children and adolescents were overweight (39). Our developmental BMI trajectories obtained independently from cutoff points suggested in the literature were also

Table 5. Longitudinal Associations Between Time-in-Bed Trajectories and Body Mass Index, Adjusted for Confounding Factors[a], in the Quebec Longitudinal Study of Kindergarten Children, 1986–1987

Measures	TIB Trajectory				TIB at 10 Years of Age (Continuous)	
	Short Sleepers vs. 11-Hour Sleepers		10.5-Hour Sleepers vs. 11-Hour Sleepers			
	β or OR	95% CI	β or OR	95% CI	β or OR	95% CI
BMI at 13 years of age, continuous[b]	1.24	0.38, 2.09	0.62	−0.01, 1.26	−0.71	−1.28, −0.14
BMI at 13 years of age, categorical[c]						
Overweight vs. normal[c]	1.99	1.67, 2.37	1.56	1.22, 1.99	1.51	1.28, 1.76
Obesity vs. normal	2.23	2.18, 2.27	1.26	1.23, 1.29	2.07	1.51, 2.84
	BMI Trajectory				**BMI at 10 Years of age (Continuous)**	
	Overweight Trajectory vs. Normal BMI		**Obese Trajectory vs. Normal BMI**			
	β or OR	**95% CI**	**β or OR**	**95% CI**	**β or OR**	**95% CI**
TIB at 13 years, continuous[b]	−0.09	−0.18, 0.00	0.02	−0.15, 0.20	−0.00	−0.02, 0.01

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio; TIB, time in bed.
[a] Adjustments were performed for sex, immigrant status, familial income, birth weight, and maternal and paternal education, for all ages, for pubertal status at ages 11–13 years, and for time spent watching television and physical activity out of school at age 13 years.
[b] Values are expressed as β coefficients.
[c] Values are expressed as odds ratios.

concordant with this distribution: 5.4% of the preadolescents studied here were in the obese trajectory and 26.7% were in the overweight trajectory.

To our knowledge, this is the first study of longitudinal sleep durations and longitudinal BMI trajectories among preadolescents. Our study has many strengths. First, the design was based on a prospective longitudinal study with a large representative sample of the population of Quebec. Second, estimating developmental sleep trajectories is an approach that is particularly indicated in the context of considerable physiologic changes over time. Third, preadolescence is an interesting developmental period to study because there are concomitant pubertal changes and lifestyle modifications, including sleeping habits, and these were all taken into account as potentially confounding factors.

The study also has some limitations. First, assessments for both BMI and TIB at 10, 11, 12, and 13 years of age were reported by mothers. Self-reported height and weight were not validated in this or similar populations. TIB normally overestimates true sleep duration because it includes the time taken to fall asleep and any time spent awake during the night. Nevertheless, previous studies have shown a good correlation between TIB reported by parents and sleep duration reported by children and early adolescents (40–42). Second, as this was a prospective longitudinal cohort, there were missing data for some variables. For the adjustment factors, we used a multivariate imputation method to retain the majority of the subjects in the analyses. Third, neither biologic mechanisms nor important behaviors like dietary habits and snacking were assessed in the present study. Finally, we could not infer a causal relation between TIB and BMI.

Increasing the opportunity for sufficient sleep duration could be fostered through educational programs in elementary schools, during medical visits, and through later school starting times in high school (37). Studies are needed to test the effectiveness of programs aiming to optimize sleep duration and to decrease the prevalence of overweight and obesity in preadolescents. Finally, twin studies are also needed to understand the contribution of environmental and genetic factors to the association between sleep duration and BMI during development.

ACKNOWLEDGMENTS

Author affiliations: INSERM U669, Université Paris-Sud and Université Paris Descartes, Paris, France (Valérie Seegers, Bruno Falissard, Evelyne Touchette); Sleep Disorders Centre, Sacré-Coeur Hospital, Montreal, Canada (Dominique Petit, Jacques Montplaisir); Groupe de recherche en inadaptation psychosociale, University of Montreal, Montreal, Canada (Bruno Falissard, Frank Vitaro, Richard E. Tremblay, Evelyne Touchette); School of Psychoeducation, University of Montreal, Montreal, Canada (Frank Vitaro); Departments of Pediatrics, Psychology and Psychiatry, University of Montreal, Montreal, Canada (Richard E. Tremblay); School of Public Health and Population Sciences, University College Dublin, Dublin, Ireland (Richard E. Tremblay); and Department of Psychiatry, University of Montreal, Montreal, Canada (Jacques Montplaisir).

The research has been supported by research grants from the Fonds pour la Formation de Chercheurs et l'Aide à la Recherche, the Conseil Québécois de la Recherche Sociale, the Fonds de la Recherche en Santé du Québec, the National Health Research Development Program Canada, the Social Sciences and Humanities Research Counsil of Canada, the Molson Foundation, and the Canadian Institute of Advanced Research.

The authors thank Nathalie Fréchette, Hélène Beauchesne, Lyse Desmarais-Gervais, and Muriel Rorive for their assistance in data collection and administration of the project.

Conflict of interest: none declared.

REFERENCES

1. Ogden CL, Carroll MD, Curtin LR, et al. Prevalence of high body mass index in US children and adolescents, 2007–2008. *JAMA*. 2010;303(3):242–249.
2. Ogden CL, Carroll MD, Flegal KM. High body mass index for age among US children and adolescents, 2003–2006. *JAMA*. 2008;299(20):2401–2405.
3. Ogden CL, Carroll MD, Curtin LR, et al. Prevalence of overweight and obesity in the United States, 1999–2004. *JAMA*. 2006;295(13):1549–1555.
4. Strauss RS, Pollack HA. Epidemic increase in childhood overweight, 1986–1998. *JAMA*. 2001;286(22): 2845–2848.
5. Troiano RP, Flegal KM. Overweight children and adolescents: description, epidemiology, and demographics. *Pediatrics*. 1998;101(3):497–504.
6. Wang Y, Lobstein T. Worldwide trends in childhood overweight and obesity. *Int J Pediatr Obes*. 2006;1(1): 11–25.
7. Puhl RM, Latner JD. Stigma, obesity, and the health of the nation's children. *Psychol Bull*. 2007;133(4): 557–580.
8. Weiss R, Caprio S. The metabolic consequences of childhood obesity. *Best Pract Res Clin Endocrinol Metab*. 2005;19(3): 405–419.
9. Daniels J. Obesity: America's epidemic. *Am J Nurs*. 2006; 106(1):40–49.
10. Ebbeling CB, Pawlak DB, Ludwig DS. Childhood obesity: public-health crisis, common sense cure. *Lancet*. 2002; 360(9331):473–482.
11. Cappuccio FP, Taggart FM, Kandala NB, et al. Meta-analysis of short sleep duration and obesity in children and adults. *Sleep*. 2008;31(5):619–626.
12. Chaput JP, Brunet M, Tremblay A. Relationship between short sleeping hours and childhood overweight/obesity: results from the 'Québec en Forme' Project. *Int J Obes (Lond)*. 2006; 30(7):1080–1085.
13. Locard E, Mamelle N, Billette A, et al. Risk factors of obesity in a five year old population. Parental versus environmental factors. *Int J Obes Relat Metab Disord*. 1992;16(10): 721–729.
14. von Kries R, Toschke AM, Wurmser H, et al. Reduced risk for overweight and obesity in 5- and 6-y-old children by duration of sleep—a cross-sectional study. *Int J Obes Relat Metab Disord*. 2002;26(5):710–716.
15. Van Cauter E, Latta F, Nedeltcheva A, et al. Reciprocal interactions between the GH axis and sleep. *Growth Horm IGF Res*. 2004;14(suppl A):S10–S17.
16. Van Cauter E, Holmback U, Knutson K, et al. Impact of sleep and sleep loss on neuroendocrine and metabolic function. *Horm Res*. 2007;67(suppl 1):2–9.
17. Spiegel K, Leproult R, L'hermite-Balériaux M, et al. Leptin levels are dependent on sleep duration: relationships with sympathovagal balance, carbohydrate regulation, cortisol, and thyrotropin. *J Clin Endocrinol Metab*. 2004;89(1133): 5762–5771.
18. Spiegel K, Tasali E, Penev P, et al. Brief communication: sleep curtailment in healthy young men is associated with decreased leptin levels, elevated ghrelin levels, and increased hunger and appetite. *Ann Intern Med*. 2004;141(11): 846–850.
19. Schoeller DA, Cella LK, Sinha MK, et al. Entrainment of the diurnal rhythm of plasma leptin to meal timing. *J Clin Invest*. 1997;100(7):1882–1887.
20. Shea SA, Hilton MF, Orlova C, et al. Independent circadian and sleep/wake regulation of adipokines and glucose in humans. *J Clin Endocrinol Metab*. 2005;90(5): 2537–2544.
21. Taveras EM, Rifas-Shiman SL, Oken E, et al. Short sleep duration in infancy and risk of childhood overweight. *Arch Pediatr Adolesc Med*. 2008;162(4):305–311.
22. Agras WS, Hammer LD, McNicholas F, et al. Risk factors for childhood overweight: a prospective study from birth to 9.5 years. *J Pediatr*. 2004;145(1):20–25.
23. Reilly JJ, Armstrong J, Dorosty AR, et al. Early life risk factors for obesity in childhood: cohort study. *BMJ*. 2005; 330(7504):1357.
24. Snell EK, Adam EK, Duncan GJ. Sleep and the body mass index and overweight status of children and adolescents. *Child Dev*. 2007;78(1):309–323.
25. Touchette E, Petit D, Tremblay RE, et al. Associations between sleep duration patterns and overweight/obesity at age 6. *Sleep*. 2008;31(11):1507–1514.
26. Gupta NK, Mueller WH, Chan W, et al. Is obesity associated with poor sleep quality in adolescents? *Am J Hum Biol*. 2002;14(6):762–768.
27. Patel SR, Malhotra A, White DP, et al. Association between reduced sleep and weight gain in women. *Am J Epidemiol*. 2006;164(10):947–954.
28. Björkelund C, Bondyr-Carlsson D, Lapidus L, et al. Sleep disturbances in midlife unrelated to 32-year diabetes incidence: the prospective population study of women in Gothenburg. *Diabetes Care*. 2005;28(11): 2739–2744.
29. Gangwisch JE, Malaspina D, Boden-Albala B, et al. Inadequate sleep as a risk factor for obesity: analyses of the NHANES I. *Sleep*. 2005;28(10):1289–1296.
30. Hasler G, Buysse DJ, Klaghofer R, et al. The association between short sleep duration and obesity in young adults: a 13-year prospective study. *Sleep*. 2004;27(4):661–666.
31. Landhuis CE, Poulton R, Welch D, et al. Childhood sleep time and long-term risk for obesity: a 32-year prospective birth cohort study. *Pediatrics*. 2008;122(5):955–960.
32. Carskadon MA, Vieira C, Acebo C. Association between puberty and delayed phase preference. *Sleep*. 1993;16(3): 258–262.
33. Carskadon MA, Harvey K, Duke P, et al. Pubertal changes in daytime sleepiness. *Sleep*. 1980;2(4):453–460.
34. Cole TJ, Bellizzi MC, Flegal KM, et al. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ*. 2000;320(7244): 1240–1243.
35. Peterson AC, Crockett L, Richards M, et al. A self-report measure of pubertal status: reliability, validity, and initial norms. *J Youth Adolesc*. 1988;17(2):117–133.
36. Nagin DS. Analyzing developmental trajectories: a semiparametric, group-based approach. *Psychol Methods*. 1999;4(2): 139–157.

37. Lumeng JC, Somashekar D, Appugliese D, et al. Shorter sleep duration is associated with increased risk for being overweight at ages 9 to 12 years. *Pediatrics*. 2007;120(5):1020–1029.
38. Laberge L, Petit D, Simard C, et al. Development of sleep patterns in early adolescence. *J Sleep Res.* 2001;10(1):59–67.
39. Willows ND, Johnson MS, Ball GD. Prevalence estimates of overweight and obesity in Cree preschool children in northern Quebec according to international and US reference criteria. *Am J Public Health*. 2007;97(2):311–316.
40. Epstein R, Chillag N, Lavie P. Starting times of school: effects on daytime functioning of fifth-grade children in Israel. *Sleep*. 1998;21(3):250–256.
41. Saarenpää-Heikkilä OA, Rintahaka PJ, Laippala PJ, et al. Sleep habits and disorders in Finnish schoolchildren. *J Sleep Res.* 1995;4(3):173–182.
42. Knutson KL, Lauderdale DS. Sleep duration and overweight in adolescents: self-reported sleep hours versus time diaries. *Pediatrics*. 2007;119(5):e1056–e1062.