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Original Article

Habitual sleep variability, not sleep duration, is associated with caloric intake in adolescents

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ABSTRACT

Objective: The objective of this study was to investigate the associations between objectively measured habitual sleep duration (HSD), habitual sleep variability (HSV), and energy and snack intake in adolescents.
Methods: We used data from 324 adolescents who participated in the Penn State Child Cohort follow-up examination. Actigraphy was used over seven consecutive nights to estimate nightly sleep duration. The seven-night mean and standard deviation of sleep duration were used to represent HSD and HSV, respectively. The Youth/Adolescent Food Frequency Questionnaire was used to obtain the daily average total energy, protein, fat, and carbohydrate intake, and number of snacks consumed. Linear regression models were used to investigate the associations between habitual sleep patterns and caloric, protein, fat, and carbohydrate intake. Proportional odds models were used to associate habitual sleep patterns with snack consumption.
Results: After adjusting for age, sex, race, body mass index (BMI) percentile, and smoking status, an increased HSV was associated with a higher energy intake, particularly from fat and carbohydrate. For example, with a 1-h increase in HSV, there was a 170 (66)-kcal increase in the daily total energy intake. An increased HSV was also related to increased snack consumption, especially snacks consumed after dinner. For instance, a 1-h increase in HSV was associated with 65% and 94% higher odds of consuming more snacks after dinner during school/workdays and weekends/vacation days, respectively. Neither energy intake nor snack consumption was significantly related to HSD.
Conclusion: High habitual sleep variability, not habitual sleep duration, is related to increased energy and food consumption in adolescents. Maintaining a regular sleep pattern may decrease the risk of obesity in adolescents.

1. Introduction

Pediatric obesity is becoming a global epidemic [1]. In 2010, 43 million children were estimated to be overweight and obese worldwide. The worldwide prevalence of childhood overweight and obesity increased from 4.2% in 1990 to 6.7% in 2010, and this is projected to reach 9.1% in 2020 [2]. Not only is childhood obesity prevalent, but it is also a risk factor for increased morbidity and premature mortality in adulthood [3]. Concurrent with the epidemic of childhood obesity is a marked increase in sleep disturbances and deprivation. Therefore, sleep duration has attracted attention as a potential novel risk factor for obesity in children. However, the majority of the previous studies reported the association between subjectively reported sleep duration and obesity [4–7]. As subjectively measured sleep duration is weakly correlated to objectively measured sleep duration [8], it may not represent the actual sleep duration but it may serve as a surrogate marker of stress and depression [9]. Therefore, the observed association between subjectively measured short sleep duration and obesity may be partially confounded by participants' psychological profiles [10,11]. On the other hand, previous literature reported an inconsistent relationship

Abbreviations: BMI, body mass index; HSD, habitual sleep duration; HSV, habitual sleep variability; OR, odds ratio; POMs, proportional odds models; PSCC, Penn State Child Cohort; PSG, Polysomnography; SD, standard deviation; YAQ, Youth/Adolescent Questionnaire.

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between objectively measured sleep duration, a quantitative assessment of the actual sleep duration, and obesity [10–15].

Meanwhile, excessive food consumption is considered as a primary behavioral contributing factor to the pediatric obesity epidemic. As energy intake is in excess of energy expenditure, a positive energy balance occurs. The cumulative impact of sustained positive energy balance results in weight gain, and this may lead to obesity [16]. In the last decade, several short-term interventional studies have consistently found a significant association between objectively measured sleep duration and energy intake [17–19]. However, these studies may not be generalized to real life.

With the increasing availability of actigraphy for multiple nights of sleep measurements, objectively measured habitual sleep pattern, including both sleep duration and sleep duration variability, has been used in observational sleep studies [20–23]. Among these studies, Kjeldsen and coworkers reported that both sleep duration and sleep duration variability were related to the dietary risk factor for obesity in Danish schoolchildren [23]. Therefore, it is plausible that an increased variability in sleep duration may contribute to an unhealthy food consumption behavior. To date, it is the only study that examined the relationship between objectively measured sleep duration variability and food intake.

Therefore, we carried out this study to investigate the association between objectively measured habitual sleep duration (HSD), habitual sleep variability (HSV), and energy intake and snack consumption in a population-based sample of healthy adolescents.

2. Methods

2.1. Population

We used the available data from 421 adolescents who completed the follow-up examination of the Penn State Child Cohort (PSCC) study. Recruitment methods and examination procedures for the PSCC baseline study have been published elsewhere [24]. A total of 700 children aged 6–12 years participated in the baseline examination conducted in 2002–2006. Among the 700 subjects, 421 returned and completed the follow-up examination during 2010–2013, yielding a response rate of 60%. The loss to follow-up was mainly due to subjects moving out of the central Pennsylvania area. However, no major difference in the baseline demographic characteristics was observed between subjects who participated in the follow-up study examination and those who did not. The participants were examined at the Clinical Research Center in the Pennsylvania State University College of Medicine. After undergoing a whole-body dual-energy X-ray absorptiometry scan, a detailed physical examination and questionnaire-based data collection protocol were performed. An actigraph tri-axis accelerometer monitor (GT3X+, Actigraph LLC, Pensacola, FL, USA) was used to measure the sleep duration. The participants stayed overnight in a sleep laboratory to complete a standardized polysomnographic (PSG) recording. After collecting morning blood, saliva, and urine samples, the participants were allowed to proceed with their daily routine with the actigraphy and a set of questionnaires about their habitual behaviors, including food consumption. The study protocol was approved by the Penn State University College of Medicine Institutional Review Board. Written informed consent was obtained from participants and their parents or legal guardians if younger than 18 years.

2.2. Sleep variables

The actigraphy worn on the wrist of a nondominant hand during bedtime was used to assess the sleep duration for eight consecutive nights over the study period, in combination with the sleep diary that recorded "bedtime" and "out of bedtime" on a nightly basis. The actigraphy data were exported to a designated computer for analysis. After removing artifacts, the actual sleep duration was obtained using ActLife 6 software (Actigraph LLC, Pensacola, FL, USA). Sleep data for the first night were excluded from the calculation, as these were measured under a 9-h sleep protocol in a laboratory environment. HSD and HSV were computed to assess participants' habitual sleep patterns. The average of sleep duration across seven nights in the free-living environment was used to represent HSD. The intra-subject standard deviation (SD) of the seven-night sleep duration was used to represent HSV. Participants with less than five (<5) nights, that is, <70% of seven nights, of sleep data were excluded from the analysis.

2.3. Food intake variables

A self-administered Youth/Adolescent Questionnaire (YAQ) was used to assess participants' daily nutrition and food intake behavior. Briefly, the participants were asked to report the frequency of consumption of 152 food items over one year prior to the study. Frequencies for each of the 152 food items were analyzed and converted into a series of nutrient indices representing the daily nutrition intake. The reproducibility and validity of the YAQ have been reported previously [25,26]. For this analysis, we used the daily total energy, total fat, protein, and carbohydrate intake to represent the participants' energy and nutrition intake. Subjects with a daily total energy intake <500 kcal or >5000 kcal were excluded from the analysis due to suspicion of implausible responses to the questionnaire.

To examine whether the association between habitual sleep pattern and nutrition intake can be attributed to snack-eating behavior, the number of snacks consumed daily obtained from YAQ was used directly. To facilitate this analysis, participants were asked to report the number of snacks eaten on school/workdays and on weekends/vacation days for each of the three segments, including between breakfast and lunch, between lunch and dinner, and after dinner. Five options, including "None," "1," "2," "3," and "4 or more," could be chosen for each segment.

2.4. Other covariates

Subjects' demographic information, such as age, race, gender, smoking status, and medical history, was collected via a self-administered questionnaire. Subjects' height and weight were measured to calculate their body mass index (BMI) percentile. BMI percentile was adjusted for age and gender based on the formula and data from the 2000 Centers for Disease Control and Prevention (CDC) growth charts. Subjects with BMI percentiles <85, ≥85 and <95, and ≥95 were categorized as "normal weight," "overweight," and "obese," respectively.

2.5. Statistical analysis

Among 421 subjects who completed the follow-up examination, 97 individuals were excluded from the analysis due to insufficient nights of sleep data ($n = 94$) and/or implausible daily total caloric intake ($n = 7$). Thus, the effective sample size for this report is 324. Summary statistics of the demographics were calculated as the mean (SD) for continuous variables and as proportions for categorical variables. No significant differences in demographic characteristics were observed between the analytical sample and those who were excluded. Analysis of variance and Cochran–Mantel–Haenszel tests were used to compare the distribution of demographic variables across the three BMI percentile groups. Linear regression models were used to assess the association between habitual sleep pattern and behavioral energy and nutrition intake. Initially, sleep variables were included in the models individually, in which only one sleep variable was entered into the model as the