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The Relationship Between Sleep and Weight in a Sample of Adolescents

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Abstract

Research to date in young children and adults shows a strong, inverse relationship between sleep duration and risk for overweight and obesity. Fewer studies examining this relationship have been conducted in adolescents. The purpose of the article is to describe the relationship between sleep and weight in a population of adolescents, controlling for demographics, energy intake, energy expenditure, and depression. This is a cross-sectional study of 723 adolescents participating in population-based studies of the etiologic factors related to obesity. We examined the relationship between three weight-related dependent variables obtained through a clinical assessment and three sleep variables obtained through self-report. Average caloric intake from dietary recalls, average activity counts based on accelerometers, and depression were included as covariates and the analysis was stratified by gender and grade level. Our results show that the relationship between sleep duration and BMI is evident in middle-school boys ($\beta = -0.32$, s.e. = 0.06: $P < 0.001$) and girls ($\beta = -0.18$, s.e. = 0.08: $P = 0.02$) but largely absent in high-school students. Differences in sleep patterns have little association with weight in males, but in high-school girls, waking up late on weekends as compared to weekdays is associated with lower body fat ($\beta = -0.80$, s.e. = 0.40: $P = 0.05$) and a healthy weight status ($\beta = -0.28$, s.e. = 0.14: $P = 0.05$). This study adds to the evidence that, particularly for middle-school boys and girls, inadequate sleep is a risk factor for early adolescent obesity. Future research needs to examine the relationship longitudinally and to study potential mediators of the relationship.

INTRODUCTION

There is a growing literature documenting the relationship between sleep and obesity risk in adults and children. The link between sleep duration and obesity has been well established in adults although differential associations are often seen by gender. In men, the relationship appears to be negative and linear while in women the relationship between sleep duration and obesity risk appears to be more U-shaped (1–3).

The evidence in children is more limited and not so definitive. A recent meta-analysis by Chen *et al.* (4) reported on findings across 17 studies examining the relationship between sleep and childhood overweight and obesity in general pediatric populations. This analysis included studies from the United States ($n = 6$) and outside of the United States ($n = 11$). Only three longitudinal cohort studies (two in the United States and one in the United

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DISCLOSURE

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Kingdom) were included in the meta-analysis. The conclusions of this meta-analysis were that, across the ages, for each hour increase in sleep the risk of overweight/obesity was reduced on average by 9%. However, a dose-response between sleep and overweight/obesity risk was seen only in children under the age of 10 and a stronger inverse relationship between sleep duration and overweight/obesity risk was seen in boys as compared to girls.

The meta-analysis also revealed that although the relationship between sleep and overweight appears strong in young children (even established through a longitudinal study showing short sleep duration at age 3 associated with obesity at age 7; ref. 5), the association in adolescents is much less clear. The meta-analysis by Chen *et al.* (4) included eight studies examining the relationship in children aged 10 years and older. In three of the studies, the relationship between sleep and overweight/obesity was seen in boys but not in girls (6–8) and in two studies (9,10) the relationship appeared to be strong only when sleep duration was at very low levels (≤6 h).

The meta-analysis documented some limitations in the current empirical research. Most of the research was cross-sectional, used convenience samples, used different approaches for classifying youth as overweight and obese, and relied on self-report assessment of sleep. In addition, although studies with adults examined sleep patterns and sleep problems, the majority of the research in youth focused on duration of sleep. Some of these limitations are inherent in population-based research, particularly the use of a self-report assessment of sleep. And some of the limitations, particularly the reliance on cross-sectional data, reflect the nascent nature of the research.

Another important limitation of the research is the lack of consistency with which covariates are examined. Because the mechanisms by which sleep and body weight might be related are poorly understood, consideration of potential covariates and confounders is very important. To date, there is little consistency with regard to the important covariates that should be examined as factors on the causal pathway between sleep and overweight or as moderators of the relationship. Previous studies have examined gender, socioeconomic factors, age, race, sexual maturity, caffeine, and being breastfed as an infant as covariates. Although energy intake and energy expenditure are the most proximal factors related to weight, most studies to date have used behavioral proxies representing intake and expenditure such as screen time or eating snacks and none have used objective measures of activity. Chen *et al.* (4) suggested that little attention has been paid to how depression may be related to the association. Depression is well known to affect sleep (11), obesity risk (12) and is a documented mental health issue for adolescents (13,14).

Taheri (15) suggests a conceptual model showing the potential mechanisms through which sleep loss might result in obesity. Representing the energy expenditure side of the equation, this model shows sleep loss linked with obesity through a pathway that follows from low sleep to tiredness to reduced activity. Representing the energy intake side of the equation, the model suggests that sleep loss leads to more opportunities to eat and hence, higher caloric intake. Links between sleep loss, hormonal levels, satiety cues, and energy expenditure are also made in Taheri’s model. Research that focuses on the mechanisms linking sleep with weight outcomes in youth is needed.

The purpose of this research is to examine the relationship between three indicators of sleep patterns (duration, sleep problems/night eating, and differing sleep patterns from weekend to weekdays) and overweight and obesity in a sample of adolescents. In addition to demographic factors, age, and pubertal status, we include estimates of energy expenditure using objective activity data collected from accelerometers, estimates of energy intake using 24-h recalls and a measure of depressive symptomology as potential covariates.

METHODS AND PROCEDURES

Study design and sample

This research uses a cross-sectional design and two samples of adolescents. The adolescent samples are from the Identifying Determinants of Eating and Activity (IDEA) study (NIH #1U54 CA 116849) and the Etiology of Childhood Obesity (ECHO) study (NIH 5 R01 HL085978); both studies are etiologic, longitudinal studies examining factors that may be related to unhealthy weight gain in youth (16). Identical measurement protocol allowed us to combine these two samples increasing our potential power for understanding relationships.

For the IDEA study, 349 youth aged 10–16 years and one significant adult in their life (usually a parent) were recruited from within a seven-county metropolitan area from Minneapolis, St. Paul, Minnesota in 2006–2007. Youth were invited to participate regardless of weight status and were recruited from: (i) an existing cohort of youth participating in the Minnesota Adolescent Community Cohort (MACC) Tobacco Study (17), (ii) a Minnesota Department of Motor Vehicle (DMV) list restricted to the seven-county metro area, and (iii) a convenience sample drawn from local communities.

For the ECHO study, 374 youth/parent dyads were recruited from the membership of Health Partners (HP) health plan within the seven-county metropolitan area of Minneapolis, St. Paul, Minnesota between June 2007 and March 2008. We used a recruitment procedure that targeted a range of overweight and healthy weight youth and parent members and that oversampled minorities. To be eligible for enrollment, youth were required to be current HP members, in grades 6–11 in the fall of 2007, residing in one of the randomly selected middle- or high-school districts included in the sample, have a parent willing to participate, and be willing to allow their names and contact information to be sent from HP to the study team at University of Minnesota for further eligibility screening, consent, and measurement. In both the IDEA and ECHO studies, youth were excluded from eligibility if they planned to move from the area in the next 3 years, had a medical condition that affected their growth, were non-English speaking or otherwise had difficulty comprehending English, or had any other physical or emotional condition that would affect their diet/activity levels or make it difficult to complete measurements. The human subjects committee at the University of Minnesota approved the study.

Measures

Measures were collected in a number of ways. Anthropometric data were collected at a clinical visit attended by the child and parent. At that visit, the child completed the student survey (without input from the parent) and received an accelerometer to wear and return *via* the mail. Dietary recalls occurred after the clinical visit through scheduled phone calls. Parents also completed a survey at the clinic.

Sleep measures

Sleep duration was assessed on the student survey by asking the youth "what time they usually go to bed in the evening (i.e., turned out the lights in order to go to sleep) and "usually get out of bed in the morning" on a typical weekday and weekend. These items, adapted from the Night Eating Questionnaire (18), were used to compute average hours of weekday and weekend sleep and average hours of daily sleep reflecting sleep over the week. Similar sleep questions have been used successfully with adolescents in previous studies (19–21). Sleep pattern variables were also calculated from the usual bedtime and wake-time questions. Bedtime difference was calculated by subtracting the time the adolescent went to sleep on the weekdays from the time he/she went to sleep on the weekends. This variable then represented the bedtime shift from weekdays to weekends with a larger number indicating a later bedtime on weekends. Wake-time difference between weekdays and weekends was calculated by subtracting the time the adolescent woke up on the weekdays from the time he/she woke up on the weekends. This variable represented the wake-time shift from weekdays to weekends with a larger number indicating a later wake-time on weekends. The total sleep difference weekdays to weekends variable was calculated by subtracting average weekday sleep duration from average weekend sleep duration to represent the difference between sleep duration on the weekends and weekdays with a larger number indicating a greater difference between hours of sleep on the weekends and weekdays (with a more positive number indicating more sleep on the weekends). The variable sleep problems/night eating was created using a score (range = 0–3) where a positive response to the following questions equaled a “1”: Do you generally have trouble falling asleep?; Do you generally have trouble staying asleep?; and When you have trouble sleeping, how often do you eat something during the night? (0 = never or rarely; 1 = sometimes or often).

Body composition measures

BMI was calculated using objectively measured height and weight and transformed into age- and sex-specific BMI *z*-scores using Centers for Disease Control/National Center fo Health Statistics 2000 growth charts (22). Overweight status was created from the BMI percentiles, and those adolescents at or above the 85th percentile were classified as overweight, while those below the 85th percentile were classified as nonoverweight. Percent body fat (PBF) was determined using a scale that measured bioelectrical impedance.

Energy intake

Each adolescent was asked to participate in three telephone-administered recalls that were collected using the Nutrition Data Systems software (Minneapolis, MN). Two recalls representing weekdays and one recall representing weekends were obtained from each adolescent. Two-dimensional portion size prompts were used to help the youth provide information on portion size consumed. The average number of kilocalories across the recalls (average daily calories) was used as a covariate.

Energy expenditure

Each adolescent was instructed to wear an accelerometer (model 7164; Actigraph, Pensacola, FL) for 7 days at all times during the day except when sleeping, swimming, or bathing. The monitor is an objective measure of physical activity and has been previously validated for use with children in laboratory and field settings (23–26). After data collection, each monitor was downloaded to a computer for subsequent data reduction and analysis. Average counts per minutes across the eligible days were used as a covariate.

Depression measure

Depressive symptoms were measured using the 6-item Kandel–Davies scale (27). These questions asked the students to respond “not at all,” “somewhat,” or “very much” to questions that ranged from the extent to which, in the past 12 months, they felt bothered or troubled by feeling too tired to do things, feeling hopeless about the future, and felt sad, unhappy, or depressed (range = 7–21). The Cronbach’s α for this scale was 0.78.

Demographic and pubertal measures

Data on socioeconomic status were obtained from a parent survey, and included the highest level of education for the parents who resided in the house and if the child qualified for free and reduced lunch at school. Race was reported by the child on the student survey. Pubertal development was measured with the 5-item self-report Pubertal Development Scale (28). Pubertal development has been associated with sleep and weight (29,30).

Analysis

Cross-sectional regression analyses were conducted to determine the association between the measures of obesity and measures of sleep using PROC GENMOD from SAS, version 9.1 (31) to account for the potential clustering by school. Interactions by gender and grade level (defined as 5–8th grade compared to 9–12th grade) were also tested and found to be significant; therefore the analysis was stratified by gender and grade level. All final models were adjusted for race, parent education, free and reduced lunch status, pubertal status, depression, energy intake, and energy expenditure.

RESULTS

Table 1 shows the univariate statistics for the total sample and by gender and grade level. Slightly >50% of the sample was female and in high school. It was primarily a white sample (85%) and ~25% of the sample were overweight or obese.

The total sample averaged 8.6 h of sleep per night over the week with more sleep (9.6 h) on weekends. Students went to bed and woke up late on weekends as compared to weekdays. The mean for the sleep problem/night eating variable was low at 0.9, with more than one-third (35.9%) of the sample reporting that they never had any sleep problems. On average, students had not reached sexual maturation but girls were more mature than boys. Girls reported significantly higher levels of depression, consumed fewer calories, and were less active as compared to boys.

There were many significant differences by grade level. The students in middle school were more likely to be classified as overweight or obese, reported longer sleep duration, more sleep problems/night eating, and higher levels of activity as compared to students in high school. Students in high school reported larger differences in their sleep patterns between weekdays and weekends, higher depressive symptoms and higher caloric intakes as compared to students in middle school.

Table 2 shows the descriptive statistic stratified by both gender and grade level. For both males and females, there were highly significant differences between grade levels for all of the sleep duration variables with the average amount of daily sleep dropping by an hour between middle and high school. Sleep patterns also changed for both sexes from middle to high school with later wake times and bed times on weekend as compared to weekdays. Reported sleep problems/night eating decreased in girls in older grades. Depressive symptoms and calorie intake increased in both girls and boys while activity levels dropped between middle- and high-school samples.

The multilevel analysis examining the relationship between the three weight-related variables and the sleep variables stratified by gender and grade level, adjusting for demographic variables, depression, energy intake and expenditure are shown in Table 3. After adjusting for covariates, a strong and consistent inverse relationship was seen between average daily sleep and weekday sleep duration across all three weight-related variables for boys in middle school. For PBF and BMI *z*-score the significant inverse relationship was also seen for weekend sleep duration in the middle-school boys. In addition, a greater difference in the time that middle-school boys woke up on weekends vs. weekdays was related to overweight status. No relationships were seen between any of the sleep-related variables and weight for boys in high school.

For females in middle school, an inverse relationship between average daily sleep and weekend and weekday sleep duration was seen only for BMI *z*-score. For girls in high school, the only statistically significant relationship seen between sleep duration and weight was a positive association between weekday sleep duration and risk for being overweight. In addition, high-school girls who woke up late on the weekends as compared to weekdays had lower PBF and were less likely to be overweight, while high-school girls whose sleep patterns differed the most between weekends and weekdays were more likely to have higher PBF and to be overweight.

DISCUSSION

This research adds support to the growing evidence that sleep is related to weight in youth. Our data further suggest that the relationships are moderated both by gender and grade level and that the relationship between sleep duration and weight is stronger in middle-school boys as compared to boys in high school. For girls in middle school, sleep duration is inversely related only to BMI *z*-score and there is minimal evidence for a relationship between sleep duration and weight in high-school girls. Sleep problems/night eating do not show up as being significantly related to any of the weight-related variables for any of the sample strata and differences in sleep patterns between weekends and weekdays seem to be most important in girls in high school.

To our knowledge, this is one of the first studies to control for both energy expenditure and energy intake in examining the relationship between sleep and weight, to examine multiple variables representing sleep and weight and to examine gender and grade level as moderators. We found that controlling for energy balance, depression, and demographic variables did not mitigate the relationship between sleep and weight. Also, although sleep patterns and sleep problems showed some relationships with weight, sleep duration emerged as a more robust sleep variable. Assessing PBF and weight status allowed us to pick up some associations with sleep patterns that did not show up with BMI *z*-score as our weight variable.

Our data showed a moderating effect by both gender and grade level. An inverse relationship in sleep duration and weight was seen in middle-school boys and girls but largely absent in high-school boys and girls. In middle-school boys, the relationship between sleep duration and weight was robust as evidenced by a statistically significant inverse relationship between average sleep duration and PBF, BMI *z*-score, and overweight status. In middle-school girls, sleep duration was negatively related to BMI but not PBF or overweight status. There were no statistically significant relationships between sleep duration and any of the weight-related variables in high-school boys. In high-school girls, we found a statistically significant and positive relationship between weekday sleep duration and overweight status. In addition, the only significant relationships between sleep patterns and weight was seen in high-school females. Significant sleep pattern differences and weight were largely absent in boys except for a positive relationship between wake-time differences and weight status in middle-school boys.

The mechanisms to explain these gender- and grade-level differences are not clear. The conceptual model proposed by Taheri (15) suggests that reduced activity caused by tiredness, increased food intake caused by more opportunity to eat, and metabolic hormones impacting hunger and appetite are the important factors linking sleep with obesity. The finding that the relationship between sleep and weight is robust even after adjusting for energy intake and expenditure suggests that there may be some metabolic factors at play that are independent of energy balance. Research documents a relationship between sleep loss and leptin, ghrelin, insulin, cortisol, interleukin 6, and growth hormones but it is not clear whether these hormones have a direct effect on metabolism or whether they impact food selection or activity choices (15). It may be that lack of sleep is experienced as a biological stressor and that the body responds by conserving energy or that adequate sleep increases metabolic rate. Our research did not assess metabolic or stress hormones and future research with adolescents should add this assessment.

In support of the hypothesis that lack of sleep is experienced as a stressor, Chen *et al.* (4) report that a number of other youth-based studies have noted that the association between sleep and weight is stronger in boys than girls. They speculate that, from an evolutionary perspective, girls might be more resilient to environmental challenges as compared to boys and may better able to cope with reduced sleep without negatively compromising their health. Our differences by grade levels may suggest that older youth have adapted to the stress of lack of sleep better than their younger counterparts.

To date, the evidence linking sleep and weight is strong for younger children and adults and in this research we have found more evidence for younger adolescents as compared to the older adolescents suggesting a nonmonotonic relationship over the lifespan. Other research in adolescents also documented that the relationship between sleep duration and weight was stronger in boys than girls (5–8) but none has documented that the relationships between sleep and weight seems to attenuate in high-school samples. Our findings need to be added to the evidence base that is accumulating on this important topic and further examination of these relationships is needed. Although the patterns and mechanisms are not clear, the results do suggest that sleep is important for a healthy weight in younger adolescents and because overweight and obesity are fairly intractable after puberty, adequate sleep during this critical time period is important.

There are some important limitations to this research. We examined the relationship cross-sectionally but we believe that poor sleep patterns are risk factors for developing overweight and obesity. Also, in this analysis we control for the covariates rather than study their effects in a causal pathway. An important next step will be to examine whether energy intake and expenditure have mediating effects on the relationship between sleep and weight and whether depression acts as a moderator for the relationship. Future research should also include measurement of metabolic hormones and elements of the diet beyond total calories that may be related to sleep. Finally, this research has limited generalizability and depends on self-report measures of sleep that are available in population-based research.

In a recent review of research examining predictors of unhealthy weight gain in youth, Must *et al.* (32) suggest that examining sleep patterns is an important new area of exploration. Although the biological mechanisms are far from clear, sleep has long been identified as an important health behavior (33); we are just now recognizing its relationship to overweight and obesity.

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REFERENCES

1. Vorona RD, Winn MP, Babineau TW, et al. Overweight and obese patients in a primary care population report less sleep than patients with a normal body mass index. Arch Intern Med. 2005; 165:25–30. [PubMed: 15642870]

2. Gangwisch JE, Malaspina D, Boden-Albala B, Heymsfield SB. Inadequate sleep as a risk factor for obesity: analyses of the NHANES I. Sleep. 2005; 28:1289–1296. [PubMed: 16295214]
3. 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; 27:661–666. [PubMed: 15283000]
4. Chen X, Beydoun MA, Wang Y. Is sleep duration associated with childhood obesity? A systematic review and meta-analysis. Obesity (Silver Spring). 2008; 16:265–274. [PubMed: 18239632]
5. Reilly JJ, Armstrong J, Dorosty AR, et al. Avon Longitudinal Study of Parents and Children Study Team. Early life risk factors for obesity in childhood: cohort study. BMJ. 2005; 330:1357. [PubMed: 15908441]
6. Gibson S, Lambert J, Neate D. Associations between weight status, physical activity, and consumption of biscuits, cakes and confectionery among young people in Britian. Nutr Bull. 2004; 29:301–309.
7. Knutson KL. Sex differences in the association between sleep and body mass index in adolescents. J Pediatr. 2005; 147:830–834. [PubMed: 16356441]
8. Eisenmann JC, Ekkekakis P, Holmes M. Sleep duration and overweight among Australian children and adolescents. Acta Paediatr. 2006; 95:956–963. [PubMed: 16882569]
9. Chen MY, Wang EK, Jeng YJ. Adequate sleep among adolescents is positively associated with health status and health-related behaviors. BMC Public Health. 2006; 6:59. [PubMed: 16524482]
10. Seicean A, Redline S, Seicean S, et al. Association between short sleeping hours and overweight in adolescents: results from a US Suburban High School survey. Sleep Breath. 2007; 11:285–293. [PubMed: 17440761]
11. Perlis ML, Giles DE, Buysse DJ, Tu X, Kupfer DJ. Self-reported sleep disturbance as a prodromal symptom in recurrent depression. J Affect Disord. 1997; 42:209–212. [PubMed: 9105962]
12. Herva A, Laitinen J, Miettunen J, et al. Obesity and depression: results from the longitudinal Northern Finland 1966 Birth Cohort Study. Int J Obes (Lond). 2006; 30:520–527. [PubMed: 16302014]
13. Rushton JL, Forcier M, Schectman RM. Epidemiology of depressive symptoms in the National Longitudinal Study of Adolescent Health. J Am Acad Child Adolesc Psychiatry. 2002; 41:199–205. [PubMed: 11837410]
14. Kubik MY, Lytle LA, Birnbaum AS, Murray DM, Perry CL. Prevalence and correlates of depressive symptoms in young adolescents. Am J Health Behav. 2003; 27:546–553. [PubMed: 14521250]
15. Taheri S. The link between short sleep duration and obesity: we should recommend more sleep to prevent obesity. Arch Dis Child. 2006; 91:881–884. [PubMed: 17056861]
16. Lytle LA. Examining the etiology of childhood obesity: the IDEA study. Am J Community Psychol. 2009; 44:338–349. [PubMed: 19838791]
17. Widome R, Forster JL, Hannan PJ, Perry CL. Longitudinal patterns of youth access to cigarettes and smoking progression: Minnesota Adolescent Community Cohort (MACC) study (2000–2003). Prev Med. 2007; 45:442–446. [PubMed: 17719080]
18. Gluck ME, Geliebter A, Satov T. Night eating syndrome is associated with depression, low self-esteem, reduced daytime hunger, and less weight loss in obese outpatients. Obes Res. 2001; 9:264–267. [PubMed: 11331430]
19. Laberge L, Petit D, Simard C, et al. Development of sleep patterns in early adolescence. J Sleep Res. 2001; 10:59–67. [PubMed: 11285056]
20. Lee KA, McEnany G, Weekes D. Gender differences in sleep patterns for early adolescents. J Adolesc Health. 1999; 24:16–20. [PubMed: 9890360]
21. Wolfson AR. Sleeping patterns of children and adolescents: developmental trends, disruptions, and adaptations. Child Adolesc Psychiatr Clin N Am. 1996; 5:549–568.
22. Kuczmarksi RJ, Ogden CL, Grummer-Strawn LM, et al. 2000 CDC growth charts for the United States: methods and development. Vital Health Stat. 2002; 11:1–190.
23. Eston RG, Rowlands AV, Ingledew DK. Validity of heart rate, pedometry, and accelerometry for predicting the energy cost of children's activities. J Appl Physiol. 1998; 84:362–371. [PubMed: 9451658]

24. Louie L, Eston RG, Rowlands AV, et al. Validity of heart rate, pedometry, and accelerometry for estimating the energy cost of activity in Hong Kong Chinese boys. Pediatr Exerc Sci. 1999; 11:229–239.

25. Trost SG, Ward DS, Moorehead SM, et al. Validity of the computer science and applications (CSA) activity monitor in children. Med Sci Sports Exerc. 1998; 30:629–633. [PubMed: 9565947]

26. Computer Science and Applications I. Wrist Activity Monitor Technical Manual. Shalimar, FL: Computer Science and Applications; 1991.

27. Kandel DB, Davies M. Epidemiology of depressive mood in adolescents: an empirical study. Arch Gen Psychiatry. 1982; 39:1205–1212. [PubMed: 7125850]

28. Peterson AC, Crockett L, Richards M, et al. A self report measure of pubertal status: reliability, validity, and initial norms. J Youth Adolesc. 1988; 17:117–133.

29. Dahl RE, Lewin DS. Pathways to adolescent health sleep regulation and behavior. J Adolesc Health. 2002; 31:175–184. [PubMed: 12470913]

30. Carskadon MA, Vieira C, Acebo C. Association between puberty and delayed phase preference. Sleep. 1993; 16:258–262. [PubMed: 8506460]

31. SAS/STAT 9.1 User's Guide. Cary, NC: SAS Institute; 2004.

32. Must A, Barish EE, Bandini LG. Modifiable risk factors in relation to changes in BMI and fatness: what have we learned from prospective studies of school-aged children? Int J Obes (Lond). 2009; 33:705–715. [PubMed: 19399020]

33. Belloc NB, Breslow L. Relationship of physical health status and health practices. Prev Med. 1972; 1:409–421. [PubMed: 5085007]

Table 1

Descriptive statistics: overall and by gender and grade level

Characteristic	Total sample; mean (s.d.), (*n* = 723)	Gender			Grade level		
		Males; mean (s.d.) (*n* = 353)	Females; mean (s.d.) (*n* = 370)	*P*[a]	5th to 8th; mean (s.d.) (*n* = 336)	9th to 12th; mean (s.d.) (*n* = 387)	*P*[a]
Gender							
Boys	48.8 (50.0)				51.5 (50.1)	46.5 (49.9)	0.20
Grade level[b]							
5th to 8th	46.5 (49.9)	49.0 (50.1)	44.1 (49.7)	0.20			
9th to 12th	53.5 (49.9)	51.0 (50.1)	55.9 (49.7)	0.20			
Age, years	14.7 (1.8)	14.7 (1.8)	14.7 (1.8)	0.98	**13.0 (1.0)**	**16.1 (0.7)**	**<0.001**
Race/ethnicity							
White	84.6 (36.1)	85.8 (34.9)	83.5 (37.2)	0.37	81.8 (38.6)	87.1 (33.6)	0.12
Highest household education							
College graduate or beyond	74.0 (43.9)	76.5 (42.5)	71.6 (45.1)	0.19	73.2 (44.4)	74.7 (43.5)	0.70
Free/reduced price lunch	11.9 (32.4)	11.0 (31.4)	12.7 (33.3)	0.55	**15.5 (36.2)**	**8.8 (2.8)**	**0.02**
Percent body fat	21.5 (10.5)	**16.3 (9.7)**	**26.4 (8.8)**	**<0.001**	21.1 (10.8)	21.8 (10.2)	0.48
BMI percentile	60.8 (28.1)	61.6 (28.9)	60.1 (27.3)	0.44	60.5 (30.1)	61.1 (26.3)	0.80
Percent overweight/obese	25.6 (43.7)	27.2 (44.6)	24.1 (42.8)	0.35	**29.8 (45.8)**	**22.0 (41.5)**	**0.02**
Average hours of daily sleep	8.6 (1.0)	8.7 (1.0)	8.6 (1.0)	0.81	**9.2 (0.9)**	**8.2 (0.9)**	**<0.001**
Average hours of weekday sleep	8.3 (1.1)	8.3 (1.1)	8.2 (1.1)	0.32	**8.9 (1.0)**	**7.7 (0.9)**	**<0.001**
Average hours of weekend sleep	9.6 (1.4)	9.5 (1.5)	9.7 (1.4)	0.17	**9.9 (1.4)**	**9.3 (1.4)**	**<0.001**
Bedtime difference weekday to weekend	1.5 (1.1)	**1.6 (1.2)**	**1.4 (1.0)**	**0.04**	**1.3 (1.1)**	**1.7 (1.1)**	**<0.001**
Wake-time difference weekday to weekend	2.9 (1.5)	2.9 (1.7)	2.9 (1.4)	0.65	**2.3 (1.4)**	**3.4 (1.5)**	**<0.001**
Total sleep difference weekday to weekend	−1.4 (1.5)	**−1.2 (1.5)**	**−1.5 (1.4)**	**0.03**	**−1.0 (1.4)**	**−1.6 (1.5)**	**<0.001**
Sleep problems/night eating	0.9 (0.8)	0.9 (0.8)	1.0 (1.8)	0.25	**1.0 (0.8)**	**0.9 (0.9)**	**0.04**
Pubertal status	2.9 (0.7)	**2.6 (0.7)**	**3.2 (0.7)**	**<0.001**	**2.4 (0.7)**	**3.3 (0.5)**	**<0.001**
Depression score	15.6 (4.0)	**14.9 (3.7)**	**16.3 (4.3)**	**<0.001**	**14.8 (3.6)**	**16.3 (4.3)**	**<0.001**
Average daily calories	1,979.7 (635.0)	**2,192.1 (671.4)**	**1,774.9 (522.4)**	**<0.001**	**1,862.7 (568.3)**	**2,082.4 (672.3)**	**<0.001**
Average activity counts per min	371.9 (157.5)	**405.8 (175.9)**	**339.9 (130.2)**	**<0.001**	**411.6 (154.4)**	**336.3 (151.8)**	**<0.001**

P < 0.05 is highlighted in boldface.

[a]Accounting for clustering at the school level.

[b]Two students in community college are included in 9th to 12th grade group.

Table 2

Descriptive statistics: stratified by gender and grade level

	Males			Females		
	5th to 8th; mean (s.d.) (*n* = 173)	**9th to 12th, mean (s.d.) (*n* = 180)**	***P*[a]**	**5th to 8th; mean (s.d.) (*n* = 163)**	**9th to 12th; mean (s.d.) (*n* = 207)**	***P*[a]**
Age, years	**13.0 (0.9)**	**16.2 (0.9)**	**<0.001**	**12.9 (1.0)**	**16.1 (0.9)**	**<0.001**
Race/ethnicity						
White	84.4 (36.4)	87.2 (33.5)	0.49	79.1 (40.8)	87.0 (33.8)	0.07
Highest household education						
College graduate or beyond	78.0 (41.5)	75.0 (43.4)	0.55	68.1 (46.8)	75.0 (43.4)	0.22
Free/reduced price lunch	12.1 (32.8)	10.0 (30.1)	0.58	**19.0 (39.4)**	**7.7 (26.8)**	**0.01**
Percent body fat	17.1 (10.5)	15.6 (8.7)	0.20	**25.4 (9.4)**	**27.1 (8.2)**	**0.05**
BMI percentile	60.3 (31.3)	63.0 (26.5)	0.44	60.7 (28.8)	59.5 (26.2)	0.69
Percent overweight/obese	31.2 (46.5)	23.3 (42.4)	0.12	28.2 (45.1)	20.8 (40.7)	0.07
Average hours of daily sleep	**9.2 (1.0)**	**8.2 (1.0)**	**<0.001**	**9.2 (0.9)**	**8.2 (0.9)**	**<0.001**
Average hours of weekday sleep	**8.9 (1.0)**	**7.7 (1.0)**	**<0.001**	**8.9 (1.0)**	**7.7 (0.9)**	**<0.001**
Average hours of weekend sleep	**9.8 (1.5)**	**9.3 (1.4)**	**0.005**	**10.1 (1.2)**	**9.4 (1.5)**	**<0.001**
Bedtime difference weekday to weekend	**1.4 (1.2)**	**1.9 (1.1)**	**<0.001**	**1.2 (1.0)**	**1.6 (1.0)**	**<0.001**
Wake-time difference weekday to weekend	**2.2 (1.5)**	**3.5 (1.6)**	**<0.001**	**2.4 (1.4)**	**3.3 (1.4)**	**<0.001**
Total sleep difference weekday to weekend	**−0.9 (1.5)**	**−1.6 (1.5)**	**<0.001**	**−1.2 (1.3)**	**−1.7 (1.5)**	**0.002**
Sleep problems/night eating	0.9 (0.8)	0.8 (0.9)	0.50	**1.1 (0.8)**	**0.9 (0.9)**	**0.02**
Pubertal status	**2.1 (0.6)**	**3.0 (0.4)**	**<0.001**	**2.7 (0.7)**	**3.6 (0.4)**	**<0.001**
Depression score	**14.3 (3.2)**	**15.4 (4.0)**	**0.003**	**15.3 (3.9)**	**17.1 (4.4)**	**<0.001**
Average daily calories	**2,006.9 (602.4)**	**2,371.1 (687.5)**	**<0.001**	**1,708.6 (485.9)**	**1,827.8 (545.1)**	**0.02**
Average activity counts per min	**458.8 (167.7)**	**353.5 (168.5)**	**<0.001**	**362.4 (121.5)**	**321.5 (134.5)**	**0.002**

$P < 0.05$ is highlighted in boldface.

[a] Accounting for clustering at the school level.

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Table 3

Relationship between sleep and body fat percentage, BMI *z*-score, and being overweight

	Males[a]						**Females[a]**					
	Grade level						**Grade level**					
	5th to 8th (*n* = 173)			**9th to 12th (*n* = 180)**			**5th to 8th (*n* = 163)**			**9th to 12th (*n* = 207)**		
	Coef	**s.e.**	***P***	**Coef**	**s.e.**	***P***	**Coef**	**s.e.**	***P***	**Coef**	**s.e.**	***P***
Percent body fat												
Average daily sleep	**−1.91**	**0.68**	**0.005**	−0.67	0.76	0.38	−0.44	0.71	0.54	0.21	0.68	0.75
Weekday sleep duration	**−2.97**	**0.81**	**<0.001**	−0.83	0.51	0.10	−0.25	0.63	0.70	0.92	0.55	0.09
Weekend sleep duration	**−1.22**	**0.47**	**0.01**	−0.08	0.52	0.88	−0.36	0.50	0.48	−0.63	0.43	0.14
Sleep problems/night eating	−0.05	1.07	0.96	−0.77	0.72	0.29	1.03	0.74	0.17	1.05	0.66	0.11
Bedtime difference	0.45	0.75	0.55	0.40	0.65	0.54	0.03	0.55	0.95	0.56	0.59	0.34
Wake-time difference	0.25	0.56	0.65	0.32	0.47	0.50	−0.19	0.37	0.61	**−0.80**	**0.40**	**0.05**
Total sleep difference	−0.00	0.38	0.99	−0.17	0.40	0.67	0.22	0.47	0.64	**0.90**	**0.38**	**0.02**
BMI *z*-score												
Average daily sleep	**−0.32**	**0.06**	**<0.001**	−0.09	0.09	0.27	**−0.18**	**0.08**	**0.02**	−0.03	0.07	0.49
Weekday sleep duration	**−0.29**	**0.08**	**<0.001**	−0.09	0.06	0.14	**−0.13**	**0.07**	**0.05**	0.03	0.06	0.59
Weekend sleep duration	**−0.13**	**0.05**	**0.01**	0.00	0.06	0.95	**−0.11**	**0.05**	**0.02**	−0.07	0.05	0.16
Sleep problems/night eating	0.05	0.14	0.74	−0.06	0.08	0.47	0.10	0.10	0.32	−0.03	0.08	0.74
Bedtime difference	0.14	0.08	0.08	0.04	0.08	0.59	0.06	0.07	0.34	0.04	0.06	0.54
Wake-time difference	0.08	0.06	0.17	0.06	0.05	0.21	−0.01	0.04	0.83	−0.07	0.05	0.16
Total sleep difference	−0.00	0.05	0.95	−0.04	0.05	0.42	0.04	0.05	0.31	0.07	0.04	0.11
Weight status (overweight)												
Average daily sleep	**−0.52**	**0.20**	**0.01**	−0.15	0.20	0.47	−0.29	0.28	0.30	0.18	0.24	0.44
Weekday sleep duration	**−0.58**	**0.20**	**<0.01**	−0.19	0.21	0.36	−0.28	0.27	0.30	**0.45**	**0.22**	**0.04**
Weekend sleep duration	−0.10	0.11	0.36	0.14	0.15	0.38	−0.08	0.17	0.63	−0.15	0.12	0.21
Sleep problems/night eating	−0.04	0.29	0.89	−0.54	0.31	0.08	0.11	0.33	0.73	0.12	0.24	0.61
Bedtime difference	0.21	0.14	0.14	−0.16	0.22	0.46	−0.05	0.23	0.83	0.11	0.20	0.59
Wake-time difference	**0.27**	**0.12**	**0.03**	0.14	0.13	0.26	0.02	0.14	0.89	**−0.28**	**0.14**	**0.05**
Total sleep difference	−0.14	0.11	0.19	−0.24	0.17	0.16	−0.05	0.16	0.77	**0.26**	**0.12**	**0.03**

$P < 0.05$ is highlighted in boldface.

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Coef, coefficient.

[a]Adjusted for demographic variables and depression, energy intake (average daily calories), and energy expenditure (average counts per min).