Evidence for a Possible Link between Bedtime and Change in Body Mass Index

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Objectives: The aim of the current study was to examine the longitudinal relationship between bedtimes and body mass index (BMI) from adolescence to adulthood in a nationally representative sample.

Design: Three waves of data from the National Longitudinal Study of Adolescent Health were used to assess the bedtimes and BMI of 3,342 adolescents between 1994 and 2009. Hypotheses were tested with hierarchical linear models using a two-level, random intercept and slopes model.

Results: Later average bedtime during the workweek, in hours, from adolescence to adulthood was associated with an increase in BMI over time (b = 0.035 kg/m^2 per min later bedtime per 6 years; standard error = 0.016; t = 2.12, degrees of freedom = 3,238, $P < 0.05$). These results remained significant after controlling for demographic characteristics and baseline BMI. Although sleep duration, screen time, and exercise frequency did not attenuate the relationship between workday bedtime and BMI over time, fast-food consumption was recognized as a significant partial mediator of the relationship between bedtimes and BMI longitudinally.

Conclusions: The results highlight bedtimes as a potential target for weight management during adolescence and during the transition to adulthood.

Keywords: bedtime, BMI, longitudinal, obesity, sleep

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INTRODUCTION

The World Health Organization has identified obesity as a global epidemic[1] with rates of obesity, poor diet, and inadequate exercise rapidly rising in children, adolescents, and adults.[2–4] Obesity is a multisystem disease with potentially devastating consequences for physical[5–10] and emotional health[11–14] across the lifespan.

In adolescence, circadian timing is of critical importance. Approximately 40% of teens select later bedtimes, a pattern of behavior often referred to as an evening circadian preference or eveningness.[15–17] With the onset and progression of puberty, evening preference adolescents exhibit a delayed sleep schedule, whereby they increase activity later in the day and both go to sleep and get up later.[18] Indeed, Price et al.[19] reported that 60% of 11th and 12th graders who were surveyed reported that they "enjoyed staying up late."

An eveningness circadian pattern has been linked to risk for obesity in a handful of studies. Gonnissen et al.[20] reported that, in a sample of 13 adults who were experimentally induced into either phase advanced or phase delayed circadian misalignment, eating and sleeping at unusual times of day resulted in a disturbed glucose and insulin metabolism. A study by Spaeth et al.,[21] in a large sample of adults, provides direct experimental evidence that delaying bedtimes for 5 nights (and thereby reducing sleep duration) results in significant weight gain within a single week. Moreover, in a sample of 52 adults, Baron et al.[22] showed that individuals with later bedtimes tended to consume meals later in the day than those with earlier bedtimes. Compared to those with earlier bedtimes, individuals with later bedtimes ate fewer fruits and vegetables and consumed an average of 248 more calories, most of which were consumed at dinner or after 20:00. Fleig and Randler[23] found that later sleep timing in adolescents on non-school days was associated with greater "fast food" consumption. In a large sample of Australian adolescents, those with late bedtimes were 1.47 times more likely to be overweight or obese than those with early bedtimes and more than twice as likely to be obese.[24] Moreover, later bedtimes are associated with more screen time,[25] which is associated with obesity[26] and increased daytime sleepiness, which is associated with decreased physical activity. [27] The cross-sectional and experimental data indicate that bedtime is important to consider when identifying risks for obesity.

Regular insufficient sleep and excessive daytime sleepiness is another serious epidemic among adolescents. In several studies with large samples of adolescents, researchers reported that between 45% and 80% of adolescents experience insufficient sleep on school nights.[28,16]

Although the evidence is inconsistent, there is growing literature indicating a relationship between risk for obesity and both insufficient sleep in adults and children and too much sleep in adults. In a meta-analysis, Cappuccio et al.[29] concluded that cross-sectional studies from around the world show a consistent increased risk of obesity amongst children who are sleep deprived, and also a 60% to 80% increase in the odds of being sleep deprived for obese children. Other researchers have found that the relationship between sleep and risk for obesity in adults holds to a curvilinear relationship, where both too much sleep and too little sleep is associated with adverse impacts on metabolic health.[30,31] Thus, sleep is a plausible partial mediator of the association between bedtime and weight gain.[32]

To the best of our knowledge, there have been no longitudinal observational studies examining the relationship between

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bedtime and change in body mass index (BMI). We endeavored to explore whether later bedtimes would be associated with an increase in BMI from adolescence to adulthood and whether the relationship would be partially mediated by sleep duration, fast-food consumption, screen time, and exercise frequency in a longitudinal nationally representative data set.

METHODS

Sample

The National Longitudinal Study of Adolescent Health (Add Health) is a longitudinal study in the United States that contains data on the health and behavior of adolescents who were in grades 7 to 12 in the first two waves of the study and 18 to 32 years of age in the third and fourth waves. Surveys were administered at home and in school to adolescents and their parents at wave I from September 1994 to April 1995. There were three follow-up interviews: wave II in April-August 1996, wave III in July 2001–April 2002, and wave IV in January 2008–February 2009. The current study only included data from participants in waves II through IV of data collection. A stratified random sampling of US high schools was included (79% of targeted schools agreed to participate). The collection of data followed informed consent procedures approved by the institutional review board at the University of North Carolina, Chapel Hill. The clustered sampling design was school based. Several eligible high schools were selected and stratified by region, urbanicity, school type, ethnic mix, and size, which resulted in a final sample of 132 discrete schools. The current analysis used the public-use data from the Add Health dataset. The public-use dataset consists of one half of the core sample that completed an in-home interview and includes an oversample of African-American adolescents with a parent with a college degree.

Measures

Sleep/circadian variables were determined via self-report measures at all three waves. In wave II, all participants were in school. Therefore, workday bedtime in wave II was defined by response to the question "During the school year, what time do you usually go to bed on week nights?" In waves III and IV, workday bedtime was defined by response to the question "On days when you go to work, school, or similar activities, what time do you usually go to bed?" Workday bedtime was a continuous variable; standard clock times were converted into variables representing the number of hours and minutes from noon, such that larger numbers indicate later bedtimes. For example, individuals going to bed at 01:30 have a bedtime of 13.5 and individuals going to bed at 23:30 have a bedtime of 11.5.

Sleep duration was investigated as a potential partial mediator. Rise times were not available at wave II; therefore, wave II workday estimated total sleep time (TST) was defined by response to the question "How many hours of sleep do you usually get?" In waves III and IV workday TST was calculated based on the workday bedtime and rise time reported at each wave. Workday TST was a continuous variable, formatted in hours with additional minutes as fractions of hours.

Investigators measured height and weight at each wave, from which BMI was calculated. BMI in adolescents and children is typically converted to a z-score because body fat percentage changes as a child develops and in growing children BMI also varies by sex. Therefore, BMI in children and adolescents is not age and sex adjusted and thereby does not accurately reflect norms unless converted to a z-score. However, in the current study, we are interested in change in an individuals' BMI over time, and the age-adjusted norms are less relevant. Moreover, in the current study age and sex have been included as covariates to account for age-related differences in BMI. Some previous studies that examined individual changes in BMI across this developmental period also did not use age-adjusted BMI values.[33–35]

Fast-food consumption, television viewing, and exercise were included as potential partial mediators. Fast-food consumption is a continuous variable, defined by the number of times the adolescent endorsed having consumed fast food in the past week. Fast-food consumption was collected at all three waves. Screen time per week is a continuous variable collected at each wave of data collection and was determined by response to the question "How many hours a week do you watch television?" Exercise frequency at wave II is a continuous variable and was defined by response to the question "During the past week, how many times did you exercise, such as jogging, walking, doing karate, jumping rope, doing gymnastics or dancing?" Questions assessing exercise frequency were inconsistent across waves, posing a methodological challenge in assessing exercise frequency across waves. Therefore, exercise frequency was based only on data from wave II in the current study.

Demographic characteristics controlled for included age (continuous; collected at all three waves), race/ethnicity (African American, Hispanic, Asian/Pacific Islander, Native American, or white), and welfare status (one parent receiving public assistance or no parent receiving public assistance).

A proxy for puberty was obtained via self-reported menarche for girls and levels of voice change for boys. Previous research has shown that voice change is a good indicator of puberty for boys.[36–38] For voice change, boys were asked, "Is your voice lower now than it was when you were in grade school?" We combined some responses to create three categories for boys' voice change (none, a little/somewhat, a lot/a whole lot of change). For menarche, girls were asked the following yes/no question: "Have you ever had a menstrual period (menstruated)?" Pubertal status data were only collected at wave II.

Statistical Analyses

We tested whether later bedtimes would be associated with an increase in BMI from adolescence to adulthood with hierarchical linear models (HLM) using a two-level, random intercept and slopes model. The HLM analyses were completed using maximum likelihood estimation with STATA 12 software (StatCorp, College Station, TX, 2011), utilizing methods for cluster design survey data. All measures were centered at the individual mean. Preliminary analyses determined that there was a linear trend in the repeated measures for BMI (intraclass correlation coefficient [ICC] = 0.75; $\chi^2 = 0$; degrees of freedom [df] = 3,238; $P < 0.001$) and workday bedtime (ICC 0.36; $\chi^2 = 0$; df = 3,238; $P < 0.001$).

Longitudinal mediation analyses were conducted to explore whether sleep duration, fast-food consumption, screen time,

Table 1—Predictor, covariate, and potential mediator variables by workday bedtime across waves.

	Wave II				Wave III				Wave IV			
	Early < 22:00	Middle 22:15–23:00	Late < 23:15	P[a]	Early < 23:00	Middle 23:01–24:00	Late < 24:00	P[a]	Early < 22:30	Middle 22:39–23:45	Late < 24:00	P[a]
Sex, % male[b]	42%	46%	47%	0.03	38%	45%	53%	< 0.001	38%	43%	53%	< 0.001
Age, y	15.8 (0.04)	16.07 (0.05)	16.17 (0.04)	< 0.001	21.39 (0.04)	21.51 (0.06)	21.44 (0.05)	0.39	27.90 (0.05)	28.03 (0.06)	28.01 (0.05)	0.05
Welfare status, % receiving welfare[b]	9%	6%	8%	0.001	8%	6%	7%	0.30	8%	6%	9%	0.08
Race/ethnicity, % Caucasian[b]	63%	64%	56%	0.001	62%	61%	61%	0.004	64%	60%	59%	0.002
Pubertal status, % post-pubertal[b]	72%	78%	79%	0.01	77%	76%	75%	0.18	79%	77%	71%	< 0.001
Physical activity, times/w[b]	1.69 (0.03)	1.68 (0.03)	1.58 (0.04)	0.10	1.64 (0.03)	1.71 (0.04)	1.63 (0.03)	0.42	1.66 (0.03)	1.64 (0.03)	1.67 (0.03)	0.91
Screen time, h/w	14.20 (0.35)	14.65 (0.43)	14.14 (0.51)	0.55	11.87 (0.32)	12.77 (0.45)	12.66 (0.39)	0.31	12.73 (0.33)	13.27 (0.47)	13.21 (0.38)	0.48
Fast food, times/w	2.14 (0.05)	2.19 (0.05)	2.19 (0.06)	0.63	2.36 (0.06)	2.46 (0.08)	2.45 (0.07)	0.79	1.97 (0.05)	1.90 (.07)	1.86 (0.06)	0.35
Workday TST, h	7.61 (0.04)	7.61 (0.04)	7.59 (0.06)	0.85	8.30 (0.08)	8.23 (0.10)	8.09 (0.08)	0.14	8.06 (0.08)	7.93 (0.09)	8.05 (0.08)	0.42
Workday bedtime, time	21:23 (3 min)	22:47 (0.6 min)	24:35 (5 min)	< 0.001	21:40 (2 min)	23:52 (0.6 min)	02:26 (5 min)	< 0.001	21:23 (4 min)	23:07 (0.6 min)	01:58 (5 min)	< 0.001
BMI, kg/m^2	23.0 (0.14)	23.25 (0.15)	23.2 (0.19)	0.56	26.5 (0.17)	26.27 (0.23)	26.22 (0.20)	0.37	29.3 (0.21)	29.18 (0.26)	28.8 (0.24)	0.39

Data are expressed as the mean (standard deviation) or as percentages. Bedtimes were divided into tertiles. The bottom tertile was categorized as "early", the middle tertile as "middle", and the top tertile as "late" bedtimes. The categorization of bedtimes serves to illustrate the change in the variables by bedtime over time. In the hierarchical linear models used in the study bedtime was a continuous variable. All time values are hours and minutes (hh:mm). [a]P value comparison across sleep duration groups using analysis of variance for continuous variables and the chi-squared test for dichotomous variables. [b]Variables were only assessed at wave II. All other variables were assessed at all waves.

Table 2—Hierarchical linear models assessing the relationship between bedtime and body mass index and models assessing the contribution of potential mediators.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Bedtime	0.048 (0.017)*	0.046 (0.017)*	0.040 (0.016)*	0.045 (0.017)*	0.047 (0.017)*	0.035 (0.017)*
Total sleep time	–	−0.012 (0.016)	–	–	–	−0.014 (0.016)
Fast food	–	–	0.026 (0.013)*	–	–	0.028 (0.013)*
Screen time	–	–	–	0.002 (0.002)	–	0.002 (0.002)
Exercise frequency	–	–	–	–	−0.0001 (0.024)	−0.004 (0.025)

Data are expressed as betas (standard error). All models include bedtime as the predictor variable. Model 1, adjusted for age, wave II BMI, race/ethnicity pubertal status, welfare status, and biological sex. Model 2, adjusted for variables in Model 1 plus total sleep time. Model 3, adjusted for variables in Model 1 plus fast food consumption. Model 4, adjusted for variables in Model 1 plus screen time. Model 5, adjusted for variables in Model 1 plus exercise frequency. Model 6, adjusted for variables in Model 1 plus total sleep time, fast food consumption, screen time and exercise frequency. *P < 0.05.

and exercise frequency acted as partial mediators of the relationship between bedtimes and BMI. The first multivariate model (model 1) included age, wave II BMI, race/ethnicity pubertal status, welfare status, and biological sex. The theorized mediating variables of sleep duration, fast-food consumption, screen time, and exercise frequency were progressively added in subsequent models (models 2, 3, 4, and 5) to test whether these variables acted as mediators of the relationship between bedtime and BMI. We considered an attenuation of 10% in the beta between bedtimes and BMI after including TST as a covariate to be consistent with mediation on an *a priori* basis.

RESULTS

A total of 3,342 participants comprised the sample for the current study. Table 1 displays analyses on the relationship between weekday bedtime, covariates, and potential mediators across waves.

Results for the tests of whether later bedtimes were associated with an increase in BMI from adolescence to adulthood are shown in Table 2. Later average workday bedtime (b = 0.048; standard error [SE] = 0.017; t = 2.80, df = 3,238, P < 0.05) was associated with an increase in BMI controlling for age, wave II BMI, pubertal status, welfare status, and sex. In addition, even after controlling for covariates and potential mediators (sleep duration, fast food consumption, exercise frequency, and screen time) later average workday bedtime was associated with an increase in BMI (b = 0.035; SE = 0.016; t = 2.12, df = 3,238, P < 0.05).

Results for the tests to evaluate sleep duration, fast-food consumption, exercise frequency, and screen time as potential mediators in the relationship between bedtimes and BMI longitudinally are displayed in Table 2. The relationship between bedtime and BMI was not appreciably attenuated with the inclusion of sleep duration, exercise frequency, and screen time in subsequent models 2, 4, and 5, indicating that these variables did not act as mediators of the relationship between bedtime and BMI. However, the relationship between bedtime and BMI was appreciably attenuated with the inclusion of fast-food consumption (model 3).

No significant interactions were found between age and sleep duration and age and bedtime during the workweek (all Ps > 0.28).

DISCUSSION

To the best of our knowledge, this is the first study to investigate the longitudinal relationship between bedtimes and BMI in any age group in an observational study. Our results indicate that later average bedtime during the workweek from adolescence to adulthood was associated with an increase in BMI over time in a nationally representative sample of more than 3,000 participants. Going to bed during the workweek each additional hour later is associated with an increase of 2.1 BMI kg/m^2 (calculated by multiplying the beta (0.035) from the fully adjusted model by 60 min/h). Indeed, a chronic pattern of late sleep timing (over a period of 13–15 years) has been previously demonstrated to contribute to metabolic disturbance,[20] which in turn may contribute to the physiologic processes underlying the steeper increase in BMI observed in this study.

Our results were not consistent with sleep duration, screen time, or exercise acting as partial mediators of the relationship between bedtimes and BMI longitudinally. Although surprising that these factors were not significant mediators, this finding supports the importance of considering bedtime in future research regarding the relationship between sleep and BMI. Conversely, fast-food consumption was a significant partial mediator of the relationship between bedtimes and BMI longitudinally. The effect of later bedtimes upon dietary habits therefore represents a potential target for future research and intervention.

The results of the current study should be interpreted within the confines of several limitations. First, "gold standard" measures for sleep and circadian rhythms such as sleep diary, actigraphy,[39] and forced desynchrony protocols[40] were not used. However, the Add Health questions used as proxies are often used as an index of TST and bedtime preference.[41,42] Second, all of the sleep data included in this study are based on self-report. Although adolescents appear to be largely accurate and reliable on self-report measures,[43] it can be difficult to accurately estimate one's sleep duration, bedtime, and wake times. For example, participants may have been influenced by biases such as most recent night or most salient night sleep[44] and adolescents may have incorporated their weekend bedtimes and total sleep times into their assessment of what is "usual." Although impractical in large epidemiological studies, future research in smaller samples should endeavor to use the "gold standard" tools to improve the contribution to knowledge.[45] Third, measurements of waist circumference would have been valuable. Unfortunately, waist circumference measurements were not available at all three waves. Although BMI is a ratiometric measurement that accounts for variation in height over weight,[46] it cannot distinguish between lean muscle and abdominal fat. Fourth, Add Health questions assessing exercise frequency were inconsistent across waves and therefore exercise frequency across waves was not available. Instead, exercise frequency at wave II was included as a covariate. Future research should investigate how exercise frequency over time may contribute to the relationship between bedtime and BMI. Last, loss to follow-up (n = 52) was related to baseline levels of BMI in the current study ($t = 3.62$, P = 0). The reasons for this pattern of findings are unknown. No other variables were related to loss to follow-up.

In conclusion, to our knowledge, this is the first study to investigate the relationship between bedtime and BMI longitudinally in an observational study. Later average bedtime during the workweek in the years from adolescence to adulthood was associated with an increase in BMI across that period. These results remained significant even after controlling for sleep duration, baseline BMI, demographic characteristics, screen time, exercise frequency, and fast-food consumption. Our results highlight adolescent bedtimes as a potential target for weight management concurrently and in the transition to adulthood.

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