Published in final edited form as:

Ann Epidemiol. 2015 October ; 25(10): 773–778. doi:10.1016/j.annepidem.2015.05.001.

Association between actigraphic sleep metrics and body composition

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Abstract

Purpose—Determine if individuals with poor sleep characteristics (i.e., late sleep onset or wake times, short sleep duration, long sleep latency, low sleep efficiency, high wake-after-sleep-onset [WASO]) have greater body mass index (BMI=kg/m²) or body fat.

Methods—Data for these cross-sectional analyses were from the Energy Balance Study (University of South Carolina). Participants were between 21 and 35 years of age and had a BMI of 20–35 kg/m². Body fat percent was measured by dual X-ray absorptiometry. Sleep and physical activity were measured by actigraphy (BodyMedia's SenseWear® physical activity armband). General linear models were used to estimate mean BMI and body fat percent by sleep metric categories.

Results—Greater BMI and body fat percent were associated with low sleep efficiency (BMI=25.5 vs. 24.8kg/m², p<0.01; body fat=27.7 vs. 26.5%, p=0.04) and high WASO (BMI=25.6

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vs. 25.0 kg/m², $p=0.02$; body fat=28.0 vs. 26.7%, $p=0.03$). Elevated BMI or body fat percent also were observed for later wake times, shorter sleep duration, and longer sleep latency. Sex modified the association between wake times and body composition.

Conclusions—Understanding the complex relationships between sleep and health outcomes could help reduce chronic disease burden by incorporating sleep components, measured through novel non-invasive techniques (SenseWear® armband), into weight loss interventions.

Keywords

sleep; actigraphy; body mass index; abdominal fat; absorptiometry

Introduction

Sleep is a physiological necessity and its restorative properties are important for mental, emotional and physical health [1]. Disrupted sleep has been associated with respiratory illnesses, gastrointestinal disorders, diabetes, cardiovascular disease, depression, abnormal hormone and immune functioning, and cancer [2, 3]. Potential pathways linking disrupted sleep to abnormal health outcomes may work through overweight or obesity (as often assessed with body mass index [BMI kg/m²] or having higher body fat).

Various reviews have found a U-shaped or negative-linear trend association between sleep duration with BMI [4, 5]. A meta-analysis of 17 studies by Cappuccio and colleagues found an odds of obesity of 1.55 (95% confidence interval [95%CI]=1.43–1.68) for short sleepers (i.e., 5 hours of self-reported sleep per night) compared to longer sleepers [6]. More recent studies also found associations of BMI with short- or long-sleep duration and reductions in sleep duration over time [7–12]. However, some studies found no association [13, 14]. A majority of studies examining these relationships utilized self-reported sleep duration, though several found associations of BMI with actigraphic-measured sleep [1, 9, 15, 16] or self-reported sleep quality [17]. However, more research is needed to fully understand how other actigraphic-based sleep measures are associated with body composition (e.g., sleep onset, wake time, wake-after-sleep-onset [WASO]), as these may represent different aspects of sleep compared to sleep duration.

BodyMedia's SenseWear® physical activity armband (SWA, Pittsburgh, Pennsylvania) is a commercially available lightweight physical activity monitor. The four internal sensors (i.e., triaxial accelerometer, thermistor-based skin surface sensor, heat flux sensor, and galvanic skin response sensor) measure wear-time, energy expenditure, steps, sleep, posture (standing, lying down) and physical activity (e.g., intensity, duration, and frequency) [18]. Few studies have reported the use of the SenseWear® armband to describe minute-by-minute sleep epochs, which has a sleep/wake designation, in order to characterize sleep. Compared to other actigraphy devices (e.g., wrist-actigraphy) or polysomnography (PSG), SenseWear® armband-derived sleep duration, WASO and sleep efficiency showed high correlation, percent agreement, or intraclass correlation [19–21]. Although there are several reports demonstrating the use of the SenseWear® armband among those with a chronic disease [20–22], SenseWear® armband-derived sleep metrics have yet to be fully examined with respect to body composition.

The University of South Carolina Energy Balance Study obtained sleep and physical activity through objective measures (SenseWear® armband) and characterized diet using a 24-hour recall (24HR), a gold standard in diet assessment [23]. The Energy Balance Study provided an excellent opportunity to examine the association between sleep and body composition. We hypothesized that individuals with poor sleep characteristics (i.e., late sleep onset/wake times, short sleep duration, low sleep efficiency, long sleep latency, or high WASO) would have greater BMI and body fat percent (a potentially stronger predictor of cardio-metabolic risk) [24] compared to individuals with healthier sleep. Although we expected similar relationships for males and females separately, body composition levels and sleep differ by sex [25, 26]; therefore, we explored potential effect modification by sex because examining both sexes combined may lead to a masking of effects. Lastly, increased sleep quality can increase participation in daytime physical activity [27–29] and improve diet [30]; whereas poor sleep may reduce levels of physical activity [29, 31] and is associated with poorer diet [30]. It is well known that physical activity and diet influence body composition [32, 33]. Therefore, physical activity or diet may act as a mediator because they lie on the causal pathway between sleep and body composition [34]. Several physical activity and dietary measures were tested as potential mediators.

Methods

Design and Sample

The Energy Balance Study is an on-going prospective cohort study designed to examine the impact of energy intake and expenditure on changes in body weight and composition. A full description of the Energy Balance Study can be found elsewhere [23]. Briefly, participants had to be between 21 and 35 years of age and have a BMI of 20–35 kg/m²; most lived in or near Columbia, South Carolina. Individuals who were excluded included those: with major acute or chronic health conditions; who had large changes in health or body composition in the previous months; or who would not be in the study area for the duration of the study. Follow-up visits continue to occur every 3 months or until the participant exits the study. However, only the baseline visit was utilized for this cross-sectional analysis. The Energy Balance Study was approved by the Institutional Review Board at the University of South Carolina and all participants provided written informed consent.

Body Composition Outcome Measures

BMI was calculated from two averaged height (stadiometer to the nearest 0.1 centimeter) and weight (electronic scale to the nearest 0.1 kg) measurements. Body fat percent was estimated using a Lunar fan-beam dual X-ray absorptiometry scanner (GE Healthcare model, Waukesha, WI).

Sleep Exposure Measures

Sleep metrics derived from the SenseWear® armband minute-by-minute sleep epochs served as the primary exposures. The SenseWear® armband is worn halfway between the acromion and olecranon of the upper left arm and activates when the sensors contact the skin. All armband data were analyzed by computer-based software (SenseWear® Professional software version 7.0; BodyMedia Inc.) using demographic information (i.e., smoking status,

handedness, sex, age, height, and weight) applied to proprietary algorithms. Participants wore the SenseWear® armband for 7–10 days and recorded activities and duration of any non-wear periods. Information on energy expenditure and sleep during the non-wear periods were filled by matching activities to the 2011 Compendium of Physical Activity [35] and multiplying the corresponding metabolic equivalent (MET) with the individual's measured resting metabolic rate. Participants had to have at least 4 days of sleep data to be eligible for this analysis.

Average nighttime sleep measures included sleep/wake times; sleep duration, efficiency, and latency; and WASO. Time of sleep onset was the first of three consecutive minutes spent asleep, coinciding with at least ten minutes lying down. Sleep latency was the time between lying down and sleep onset. WASO was the sum of wake periods at least two minutes in length after the onset of sleep until the final wake time. Sleep duration was the sum of all sleep-designated minutes during the sleep bout. Morning wake time was the first of 90 consecutive minutes spent awake. Sleep efficiency was the total sleep time divided by the length of the nighttime sleep bout. Naps were removed (considered to be sleep bouts <4 hours ending between noon and 10PM or bouts lasting <45 minutes), as nighttime sleep was the primary exposure of interest. However, it should be noted that *post-hoc* adjustments for naps had no effect on the analyses. Except for sleep duration, all sleep metrics were categorized based on values that were near the median and increased ease of interpretation and to maximize the sample size for the *a priori* hypothesized comparisons (see Table 1).

Covariates

Total daily physical activity minutes measured by the SenseWear® armband and supplemented with 2011 Compendium of Physical Activity for non-wear periods were defined as any activity ≥ 1.5 METs. Dietary information was collected through one to three, telephone-administered 24HRs. The Nutrient Data System for Research (version 2012, Nutrition Coordinating Center, University of Minnesota) was used to estimate energy, nutrient, and individual food intakes from the 24HR. Potential covariates included age, sex, race, education, income, employment, marital status, number of children, smoking status, exposure to secondhand smoke, perceived and ideal body image, dieting status, social approval and desirability, and several validated questionnaires (i.e., Perceived Stress Scale [36], Eating Disorder Inventory [37]).

Analyses

All analyses were performed using SAS® (version 9.3, Cary, NC). Means and standard deviations were used to characterize crude sleep metrics for the total population. Prior to variable selections, dietary factors (i.e., calorie intake, percent calories from fat, and caffeine) and total daily physical activity were examined as potential mediators. The Sobel test for mediation was performed for each exposure-outcome relationship presented in Table 2 for each mediator [38]. Variable selections began as a series of bivariate analyses (i.e., exposure + potential covariate) where covariates with a p-value ≤ 0.20 were added to a 'full' model. Backward elimination procedures were used to develop 'final' models that included all covariates that were statistically significant (p<0.05) or, when removed, changed the beta coefficient of the exposure by ≥ 10%. Least square means and 95% CIs of BMI and body fat

percent were calculated among categories of each sleep metric using general linear models. These models were then stratified by sex. Additionally, linear regression analyses were run using the continuous form of each sleep metric.

Results

The baseline statistics for the Energy Balance Study have already been described [23]. Briefly, there was roughly an equal number of males ($n=212$) and females ($n=218$). The participants were, on average, young (mean age: 27.7 ± 3.8 years) and overweight (mean BMI: 25.4 ± 3.8 kg/m²), and participated in 5.9 ± 1.5 hours of total physical activity per day. Most participants completed college (84%), were European-American (67%), had an income <\$60,000 (72%), and were non-smokers (75%). The Sobel test for mediation indicated that average total daily physical activity mediated the relationships including wake time, sleep latency and WASO for both BMI and body fat percent; therefore, physical activity was not included in these adjusted models. The examined dietary factors were not statistical mediators and after adjustment did not change the interpretation of the results and, therefore, were not included in final models.

The mean time of sleep onset and wake time were near midnight and 8:00AM, respectively. Participants spent an average of 8 hours in bed, but slept an average of only ≈ 6.5 hours. The average sleep efficiency was 82% with an average WASO of 55 minutes. When the crude sleep characteristics were compared by sex, females had statistically significantly earlier bed and wake times, longer sleep duration, and shorter sleep latency than males. However, no differences were observed for WASO or sleep efficiency (Table 1).

Table 2 displays adjusted mean BMI and body fat percent by categories of the SenseWear® armband-derived sleep metrics. Individuals with these characteristics had higher BMI values: an average sleep duration of 6–7 hours compared to >7 hours (24.8 vs. 25.5 kg/m², $p=0.01$); a sleep latency ≥ 12 minutes compared to less (25.1 vs. 25.6 kg/m², $p=0.05$); a WASO of ≥ 50 minutes compared to less (25.6 vs. 25.0 kg/m², $p=0.02$); and a sleep efficiency <85% compared to more (25.5 vs. 24.8 kg/m², $p<0.01$). Similar associations were found between percent body fat and sleep latency, WASO, and sleep efficiency. Additionally, participants with a wake time after 8:00AM had higher body fat percent compared with participants with a wake time before 8:00AM (28.2% vs. 26.6%, $p=0.01$). Statistically significant linear associations between BMI and the continuous form of sleep duration ($p=0.01$), latency ($p=0.02$), and efficiency ($p<0.01$) were shown. For body fat percent, linear associations were observed for sleep onset ($p=0.05$) and wake time ($p<0.01$).

There was little evidence of effect modification by sex on the relationships between body composition and sleep. Only three statistically significant sex-sleep interactions were observed (interaction p -values not tabulated). The interaction between wake time and sex was statistically significant for both BMI and body fat percent. Specifically, the effect of wake time on these body composition measures was only observed among women. However, the interaction between sex and sleep efficiency revealed that higher body fat percent was observed for those with lower sleep efficiency (18.7% vs. 21.1%, $p<0.01$), but only among males. The only significant linear associations among males were observed

between BMI and sleep duration ($p=0.02$) and efficiency ($p=0.03$). Among females, only linear relationships between BMI and sleep onset ($p=0.03$) and body fat percent and wake time ($p<0.01$) and sleep duration ($p=0.05$) were significant.

Discussion

Individuals in sleep metric categories, derived from a relatively novel method for characterizing sleep using the SWA, representing ‘unhealthy’ sleep (i.e., later wake time, shorter sleep duration, longer sleep latency, lower sleep efficiency, or greater WASO) had significantly elevated BMI or body fat percent. Although some of these differences in BMI or body fat percent between the various sleep categories defined in the tables were small in magnitude, small differences in body composition have been associated with a variety of health outcomes including type II diabetes mellitus [39, 40].

Sleep-related findings from this study, which are among the first to utilize the SWA minute-by-minute data to characterize sleep, are generally consistent with findings from previous studies utilizing self-report or other actigraphy devices to characterize sleep, in that markers of poor sleep quality or sleep disruption have been associated with increased BMI or visceral adipose tissue [4, 5, 24, 41]. The association of wake times with BMI and body fat percent, in the current study, is a novel finding. In fact, the only SWA-measured sleep metric not associated with BMI or body fat percent, in the present study, was time of sleep onset which was previously associated with BMI (odds ratio for one-hour delay=2.59, 95%CI=1.61=4.16) [42].

With respect to sleep duration, a review by Marshall and colleagues noted that there have been three different relationships reported in the literature between sleep duration and obesity: 1) a u-shape association, 2) a negative linear association, 3) or no association [4]. In the current analysis, results were more consistent with a negative linear association in which longer sleepers (i.e., >7 hours per night) had lower BMI compared to participants who slept 6–7 or <6 hours per night. This was confirmed, partially, by the statistically significant linear relationship between sleep duration and BMI observed in the current study. Marshall and colleagues observed that studies among younger populations tended to show a negative linear association between sleep duration and BMI, whereas studies among middle-aged individuals tended to show a u-shape association [4]. Although this observation has not been consistent across all studies, it may partially explain the association between sleep duration and BMI in the present study of relatively younger adults (mean age ≈ 28 years).

Sleep efficiency, sleep latency, and WASO also were associated with body composition in the current study. Van den Berg and colleagues found that for every standard deviation increase in sleep fragmentation, analogous to WASO in the current study, BMI increased by 0.59kg/m^2 [16]. However, it is difficult to delineate the effects of poor sleep quality and short sleep duration, because poor sleep quality often results in short sleep duration [1]. Using structural equation modeling, Bailey and colleagues found that models including sleep efficiency, measures of sleep pattern inconsistency (i.e., 7-day standard deviations of sleep/wake times, and sleep duration), and physical activity best predicted body fat percent. For every standard deviation increase in sleep efficiency (e.g., 97.0 to 98.1%), body fat

percent decreased by 1.2% [1]. Other studies also noted associations between sleep efficiency and body composition [9, 15]. Associations between sleep latency and body composition have been less consistent. Sleep latency was not associated with BMI among younger populations, roughly similar to the age of the current study [43]; whereas, sleep latency was associated with body composition in the current study, although results were only marginally statistically significant. Caution is warranted when comparing these results to past studies, as this is one of the first studies to use the SWA to examine associations between sleep and body composition.

Several biological pathways may link disrupted sleep to obesity. Shorter sleep duration and sleep restriction were previously associated with higher caloric intake [44], with no coinciding increase in energy expenditure, possibly due to fatigue [5, 11, 44]. Inadequate sleep could increase sympathetic nervous system and hypothalamic-pituitary-adrenal axis activity decreasing leptin and insulin secretion and increasing evening cortisol leading to increased hunger and insulin resistance [5, 45]. Long or short time-in-bed could disrupt circadian rhythmicity [46]. This could influence secretion of metabolic and appetite hormones and eating and physical activity patterns [46, 47]. Although recent studies adjusted for physical activity or diet-related measures [1, 7, 8, 10, 12, 15, 24, 48], these had not previously been examined as potential mediators of the relationship between sleep and body composition. Physical activity was found to mediate several relationships between sleep and body composition. However, *post-hoc* adjustment for physical activity within these models revealed that the overall interpretation only changed for two models. The difference in BMI between sleep latency medians was no longer significant (mean BMI: 25.1 vs. 25.5, $p=0.15$). The same was true for the relationship between WASO and body fat percent (26.9% vs. 27.8%, $p=0.10$). This may indicate that physical activity is only a partial mediator, as most models were unchanged with additional adjustment for physical activity.

Effect modification by sex mainly affected the relationships between wake times and body composition. Several recent studies examined the relationship between sleep and body composition by sex; however, results have been inconsistent [8, 10, 15, 48]. Data from the National Survey of Midlife Development in the United States (MIDUS) indicated that as actigraphy-measured sleep duration and efficiency increased, BMI and waist circumference decreased, among women only [15]. However, studies utilizing the NIH-AARP Diet and Health Study and National Health and Nutrition Examination Survey (NHANES) data found no differences in the relationship between sleep and body composition by sex [8, 48]. Differences between study populations or method of sleep assessment may explain lack of consistency in sex-stratified results. For example, the Energy Balance study population is generally younger than the MIDUS, NIH-AARP, and NHANES populations. Nonetheless, the finding that the associations of wake times with body fat percent and BMI were modified by sex is novel and warrants further attention.

Due to the cross-sectional nature of this study, it is not possible to determine the temporal ordering of these relationships. Though it has been shown that overweight or obesity can lead to sleep disruptions [49], we can only say our results are consistent. Several studies have shown that short or long sleepers or those with disrupted sleep are more likely to gain weight or become obese after several years (e.g., >6 years) [8, 11]. Medically diagnosed

sleep disorder diagnoses or indices of sleep apnea that have been associated with obesity were not available [50]. Other unmeasured factors (e.g., clock gene polymorphisms), which have been associated with sleep and obesity [51], also were not characterized. This sample was a relatively homogeneous group of educated young adults and may not be generalizable to other populations. An average sleep efficiency of only 82% in this sample suggests that the SWA overestimated wakefulness during the sleep period. As seen with other actigraph devices, it has been reported that the ability of the SWA to differentiate between wakefulness and sleep becomes attenuated as sleep efficiency decreases [20, 21]. Nonetheless, differences in BMI and body fat percent were distinguished by our *a priori* definition of low vs. high sleep efficiency.

Despite its limitations, this study had numerous strengths. Physical activity and sleep were assessed using non-invasive objective measures. This was one of the first studies to characterize and examine sleep metrics using minute-by-minute data from the SWA in relationship to body composition [20, 21]. Study protocols ‘back-filled’ any missing SWA time; this accounted for every minute of the day. Lastly, many covariates were examined as potential mediators or confounders, including psychosocial measures (e.g., social desirability and approval) which may influence dietary reports and potentially affect participation in physical activity [52].

Conclusions

This study showed that relatively non-invasive objective measures of sleep were associated with BMI or body fat percent. Improving one’s sleep is a potential avenue to increase the effectiveness of weight loss programs. For example, several recent studies observed significantly increased odds of success in weight-loss programs among those with better subjective sleep quality or >7 hours of reported sleep per night [17, 53]. However, more research is needed to fully understand the complex web of associations between sleep and health outcomes including body composition measures and intermediate endpoints, especially in consideration of other lifestyle factors (e.g., physical activity and diet). Understanding these complex associations could be an important step in combating and reducing the risk of numerous chronic diseases.

Acknowledgments

Funding for this project was provided through an unrestricted grant from The Coca-Cola Company. The Coca-Cola Company played no role in the study design, collection, analysis and interpretation of data, or preparation and submission of this manuscript. Dr. Hébert is supported by an Established Investigator Award in Cancer Prevention and Control from the Cancer Training Branch of the National Cancer Institute (K05 CA136975). Dr. Youngstedt is supported by an NIH grant (R01HL095799). Steven N. Blair serves on the scientific advisory boards of Technogym, Clarity, and Santech. He has received research funding from BodyMedia, Technogym, the U.S. Department of Defense, and the National Institutes of Health. He receives book royalties from Human Kinetics. The authors thank the participants, the Energy Balance staff, and the External Advisory Board for their participation in this study.

Abbreviations

BMI   body mass index

SWA	Bodymedia's SenseWear® armband
PSG	polysomnography
WASO	wake-after-sleep-onset
24HR	24-hour dietary recall
MET	metabolic equivalent
95%CI	95% confidence interval
MIDUS	National Survey of Midlife Development in the United States
NHANES	National Health and Nutritional Examination Survey

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Table 1

Mean Baseline Sleep Metric Values Measured by Bodymedia's Sensewear® Physical Activity Monitor by Sex

Sleep Metric	All Subjects	Males	Females	p-value
Average Sleep Onset (time ± min)	12:04 AM ± 80	12:17 AM ± 88	11:52 PM ± 69	<0.01
Average Wake Time (time ± min)	7:51 AM ± 80	7:59 AM ± 89	6:42 AM ± 69	0.03
Average Time-in-Bed (min)	480 ± 59	473 ± 58	486 ± 59	0.02
Average Night Time Sleep (min)	392 ± 55	385 ± 53	399 ± 56	0.01
Average Sleep Latency (min)	13 ± 7	14 ± 8	12 ± 6	0.04
Average Wake After Sleep Onset (min)	55 ± 32	55 ± 33	55 ± 30	0.97
Average Sleep Efficiency (%)	82 ± 7	82 ± 7	82 ± 7	0.88

p-value represents the differences between males and females.

Table 2
Adjusted BMI and Body Fat Percent by SWA-Derived Sleep Metrics Among All Subjects

SWA Sleep Metrics	BMI (kg/m ²)	p-value	Cont. p	Body Fat %	p-value	Cont. p
Sleep Onset			0.23			0.05
<12:00AM	25.4 (24.9–25.9)	REF		27.0 (26.1–27.9)	REF	
12:00AM	25.6 (25.1–26.2)	0.41		27.5 (26.7–28.4)	0.38	
Wake Time			0.07			<0.01
<8:00AM	25.4 (24.9–25.9)	REF		26.6 (25.8–27.5)	REF	
8:00AM	25.7 (25.2–26.3)	0.28		28.2 (27.2–29.2)	0.01	
Sleep Duration			0.01			0.55
<6 Hours	25.5 (25.0–26.0)	0.89		27.5 (26.3–28.7)	0.78	
6 – 7 Hours	25.5 (25.0–26.0)	REF		27.7 (26.6–28.8)	REF	
>7 Hours	24.8 (24.3–25.4)	0.01		27.3 (26.0–28.6)	0.58	
Sleep Latency			0.02			0.07
<12 Minutes	25.1 (24.7–25.5)	REF		26.6 (24.7–27.4)	REF	
12 Minutes	25.6 (25.1–26.0)	0.05		28.0 (27.1–28.9)	0.01	
WASO			0.07			0.08
<50 Minutes	25.0 (24.5–25.5)	REF		26.7 (25.8–27.5)	REF	
50 Minutes	25.6 (25.1–26.0)	0.02		28.0 (27.1–28.8)	0.03	
Sleep Efficiency			<0.01			0.16
<85%	25.5 (25.1–26.0)	<0.01		27.7 (27.0–28.5)	0.04	
85%	24.8 (24.3–25.3)	REF		26.5 (25.5–27.5)	REF	

Cont. p: represents the p-value for the continuous form of the sleep metrics. **BMI adjustments:** All models adjusted for employment, race, perceived body image, current dieting, and social approval and bulimia scores. Bedtime and wake time models also were adjusted for children in household. **Body Fat % adjustments:** All models adjusted for sex, employment, perceived body image, and ideal body image. Sleep duration model was also adjusted for race. **Abbreviations:** BMI = body mass index; SWA = Bodymedia's Sensewear® physical activity monitor; WASO = wake after sleep onset; REF = reference category.

Table 3
Adjusted BMI and Body Fat Percent by SWA-Derived Sleep Metrics Among by Sex

SWA Sleep Metrics	BMI (kg/m ²)	p-value	Cont. p	Body Fat %	p-value	Cont. p
Males						
Sleep Onset			0.74			0.28
<12:00AM	25.6 (25.0–26.2)	REF		20.4 (19.1–21.6)	REF	
12:00AM	25.5 (24.9–26.1)	0.76		20.4 (19.2–21.6)	0.96	
Wake Time			0.30			0.10
<8:00AM	25.7 (25.1–26.3)	REF		20.1 (18.9–21.2)	REF	
8:00AM	25.4 (24.8–26.1)	0.57		20.8 (19.5–22.0)	0.43	
Sleep Duration			0.02			0.54
<6 Hours	25.5 (24.9–26.2)	0.79		20.9 (19.4–22.4)	0.91	
6 – 7 Hours	25.4 (24.8–26.0)	REF		20.8 (19.4–22.2)	REF	
>7 Hours	24.8 (24.0–25.6)	0.14		20.0 (18.2–21.8)	0.43	
Sleep Latency			0.12			0.35
<12 Minutes	25.3 (24.7–25.8)	REF		19.8 (18.5–21.0)	REF	
12 Minutes	25.4 (24.8–26.0)	0.67		20.9 (19.8–22.1)	0.16	
WASO			0.09			0.10
<50 Minutes	25.1 (24.5–25.6)	REF		19.6 (18.4–20.7)	REF	
50 Minutes	25.6 (25.0–26.1)	0.14		21.3 (20.1–22.5)	0.03	
Sleep Efficiency			0.03			0.12
<85%	25.9 (25.1–26.1)	0.02		21.1 (20.2–22.3)	<0.01	
85%	24.7 (24.1–25.4)	REF		18.7 (17.3–20.1)	REF	
Females						
Sleep Onset			0.03			0.09
<12:00AM	25.3 (24.7–25.9)	REF		33.7 (32.4–35.0)	REF	
12:00AM	25.8 (25.2–26.5)	0.15		34.7 (33.4–36.1)	0.23	
Wake Time			0.18			<0.01
<8:00AM	25.2 (24.7–25.8)	REF		33.3 (32.1–34.5)	REF	
8:00AM	26.0 (25.3–26.7)	0.03		35.8 (34.3–37.2)	<0.01	

SWA Sleep Metrics	BMI (kg/m ²)	p-value	Cont. p	Body Fat %	p-value	Cont. p
Sleep Duration						
<6 Hours	25.4 (24.6–26.2)	0.63	0.17	33.9 (31.9–35.8)	0.54	0.05
6 – 7 Hours	25.6 (25.0–26.2)	REF		34.6 (33.1–36.0)	REF	
>7 Hours	24.8 (24.2–25.4)	0.04		34.5 (32.9–36.1)	0.92	
Sleep Latency						
<12 Minutes	24.9 (24.4–25.5)	REF	0.09	33.4 (32.1–34.7)	REF	0.15
12 Minutes	25.7 (25.2–26.3)	0.02		35.1 (33.8–36.4)	0.04	
WASO						
<50 Minutes	25.0 (24.4–25.5)	REF	0.29	33.8 (32.5–35.1)	REF	0.23
50 Minutes	25.6 (25.1–26.2)	0.07		34.6 (33.3–35.9)	0.32	
Sleep Efficiency						
<85%	25.5 (25.0–26.0)	0.10	0.09	34.2 (33.0–35.4)	0.91	0.49
85%	24.9 (24.2–25.6)	REF		34.1 (32.7–35.5)	REF	

Cont. p: represents the p-value for the continuous form of the sleep metrics. **BMI adjustments:** All models adjusted for employment, race, perceived body image, current dieting, and social approval and bulimia scores. Bedtime and wake time models also were adjusted for children in household. **Body Fat % adjustments:** All models adjusted for sex, employment, perceived body image, and ideal body image. Sleep duration model was also adjusted for race. **Abbreviations:** BMI = body mass index; SWA = Bodymedia's Sensewear® physical activity monitor; WASO = wake after sleep onset; REF = reference category.