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Longitudinal associations between sleep and weight status in infants and toddlers

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Abstract

Background: The limited research assessing relationships between sleep duration and weight status in infants and toddlers relies primarily on parent-reported sleep and cross-sectional studies.

Objectives: Examine whether average sleep duration and changes in sleep duration among 6–24-month-old children were associated with weight-for-length z-scores, and whether these associations varied by race/ethnicity, socioeconomic status, and sex.

Methods: Data were collected when children were approximately 6, 12, 18, and 24 months old (N=116). Sleep duration was measured using actigraphy. Weight-for-length z-scores were calculated using children's height and weight. Physical activity was assessed using accelerometry. Diet was assessed using a feeding frequency questionnaire. Demographic characteristics included sex, race/ethnicity, and socioeconomic status. Separate associations of between- and within-person changes in sleep duration were estimated with weight-for-length z-score treated as the outcome variable in linear mixed model analyses. Additional models were assessed that included interactions between sleep and demographic characteristics.

Results: At time points where children slept longer at night compared to their own average, their weight-for-length z-score was lower. This relationship was attenuated by physical activity levels.

Conclusions: Increasing nighttime sleep duration can improve weight status outcomes in very young children who have low physical activity levels.

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Keywords

sleep; weight status; physical activity; diet; infant

Introduction

Childhood overweight and obesity are associated with negative health outcomes, including cardiovascular disease, asthma, and chronic inflammation.[1] Nearly 10% of children under the age of 2 years have a weight-for-length value that is at or above the 95th percentile of the sex-specific weight-for-recumbent length 2000 Centers for Disease Control and Prevention (CDC) growth charts,[2] which is the percentile cut off value for overweight. This makes it imperative to develop effective prevention strategies for childhood overweight or obesity in this very young age group. Obesity is associated with modifiable health behaviors, including nutrition and physical activity (PA).[3] Obesity prevention strategies that have shown the most success include a sleep component, suggesting sleep duration is an important factor to include to improve weight status outcomes among young of children.[4]

The National Sleep Foundation (NSF) recommends that infants between 4–11 months old sleep 12–15 hours per 24-hour day, while toddlers 1–2 years old sleep 11–14 hours per 24-hour day.[5] The NSF recommendations do not provide any additional detail on the proportion of sleep that should come from daytime naps compared to nighttime sleep, although most children under 2 years of age partake in daytime naps in addition to sleeping at night.[6] Although longer sleep duration is inversely associated with weight status among older youth, the direction and magnitude of the association among infants and very young children (i.e. ≤2 years of age) is not as consistent,[7] and it is still unclear whether the associations between infant's sleep duration and outcomes such as weight status vary depending on whether sleep is measured during the day, at night, or over a 24-hour period. Studies vary in terms of design and measures used to assess both sleep and weight status. Understanding whether short sleep duration is associated with higher weight status using objective measures among young children can inform early prevention efforts.[8]

Longitudinal studies assessing the relationship between sleep duration and weight in very young children have primarily relied on parent-reported sleep.[9,10] Few studies have adjusted for factors related to weight, including PA or diet.[11] Additionally, few longitudinal studies disaggregate the within-person and between-person effects of sleep over time, which would help determine the extent to which changes in an individual's sleep duration are associated with changes in weight status.[12] Finally, there is some evidence to suggest that low-income and minority status children are less likely to meet sleep duration guidelines,[13] and that these children are also at a higher risk of overweight and obesity.[14] In a study by Taveras et.al. (2013), 7-year-old black and Hispanic children had a significantly higher prevalence of overweight and obesity compared to white children. Some of these differences could be explained by modifiable, early childhood risk factors, including sleep duration.[15] Therefore, higher rates of poor sleep duration may help explain why minoritized populations are at a higher risk of negative health outcomes such as overweight and obesity.

In light of the above limitations, the goal of this study was to determine whether overall (i.e., average) or changes in sleep duration are associated with weight-for-length z-scores in longitudinal data from children 6 to 24 months old. Additionally, the study assessed whether associations between sleep duration and weight-for-length z-score vary based on the child's race/ethnicity, socioeconomic status, or sex. The authors hypothesized that there would be inverse associations between both overall sleep duration and changes in sleep duration with weight-for-length z-scores, which would exist for both 24-hour and nighttime sleep durations.

Methods

Participants and study design.

Participants were children and their biological mothers recruited from communities in South Carolina participating in the Linking Activity, Nutrition and Child Health (LAUNCH) study.[16] This study was approved by the Institutional Review Board of the University of South Carolina. The present study used data collected at the first 4 time points, when children were approximately 6, 12, 18, and 24 months old.

Measures

Sleep.—Sleep was measured using an actigraph (MicroMini-Motionlogger, Ambulatory Monitoring, Inc.), worn on the left ankle for 24 hours/day for 7 days. Data were processed using the manufacturer software (Action4, Version 1.16, Ambulatory Monitoring, Inc., Ardsley, New York, USA). Sleep duration variables were assessed in 60-second epochs and computed using the Sadeh et al. algorithm.[17] Wear time was determined using the LIFE channel from the manufacturer software.[18] Only participants with ≥3 days/nights with ≥10 hours of data per night, or ≥3 24-hour days with ≥20 hours of data per night, were included in analyses assessing nighttime and 24-hour sleep duration, respectively. Nighttime sleep duration was operationalized as the average number of minutes spent sleeping between 7 PM and 7 AM. Twenty-four-hour sleep duration was the average number of minutes spent sleeping between 7 AM and 7 AM the following day. This definitions of nighttime sleep was based on research suggesting that very young children have an average bedtime between 6:30PM-9:00PM.[6] The nighttime and 24-hour sleep duration variables were normalized by dividing by wear time and extrapolated into 12 and 24 hours, respectively.

Weight status.—Age- and sex-specific weight-for-length percentiles and z-scores were calculated based on World Health Organization (WHO) growth charts. The definition of overweight for this age group is +2 z-scores, or a percentile of 97.7.[19] Trained data collectors measured weight and length at the 6-month time point. Due to COVID-19, 5% of weight status measures were collected by mothers and 2% of weight status measures were collected by the child's pediatrician during the child's checkup at the 12-month time point; 39% were collected by mothers and 1% was collected by the child's pediatrician during the child's checkup at the 18-month time point; and 87% were collected by mothers and 5% were collected by the child's pediatrician during the child's checkup at the 24-month time point. For time points where data were collected by trained data collectors, Seca Digital Baby Scales and measuring rods (model 334; Chino, CA) were used to measure supine length and weight in children until the age of 2 years old. Seca scales (model 869; Chino, CA) were used to measure weight in children who were able to stand independently at the time of measurement, and height was measured using a Shorr board (Shorr/Weigh and Measure, LLC, Olney, MD).

Physical activity.—Total PA was assessed using ActiGraph accelerometers (GT3X model, Pensacola, FL). Accelerometers were worn on the right ankle and were removed at night and during water-based activities. PA data were collected at the ankle rather than at the hip/waist, because hip/waist placement does not capture movement well when children are unable to walk, as was the case at the first time point.[20]

Accelerometers were initialized to begin collecting data at midnight following accelerometer distribution. Data were collected in raw data mode at 80 Hz and downloaded using 15-second intervals.[21] Any ≥60 minute period of consecutive zeros was considered non-wear time and was excluded from analyses.[22] Missing PA data were imputed for children who had >1 days of >8 hours of accelerometry data. This was done using the PROC MI command with 20 imputations to predict missing vector magnitude count values for each individual day. Predictor variables in the regression model used for imputation included the seven days of vector magnitude counts and the number of hours of wear time for each of the seven days. The mean vector magnitude counts over seven days were averaged for each child after imputation. The total PA counts variable was defined as the average number of vector magnitude counts per hour between 7 AM and 7 PM each day.

Diet.—At all 4 time points, mothers reported how often their child ate a list of 17 different foods derived from the Infant Feed Practices Study.[23] The following scores were applied to responses: more than once per day - 8; every day - 7; 5–6 days - 5.6; 3–4 days - 3.5; 1–2 days - 1.5; Not at all – 0. Scores for the following foods were summed to create a score for the “High quality” category: Breast milk, cow’s milk, other dairy, other soy foods, baby cereal, other cereals/starches, fruit, vegetables, meat/chicken/combo meals, fish or shellfish, peanut butter/other peanut foods/nuts, egg. Scores for the following foods were summed to create a score for the “Low quality” category: Formula, 100% fruit or vegetable juice, sweet drinks, French fries, sweet foods. The decisions for categorizing foods into low or high quality was based on the 2020–2025 US Dietary guidelines.[24] Low quality food scores were reverse scores and summed with the high quality food scores to create an overall food quality score. Higher food quality scores indicated better diet quality.

Demographic characteristics.—Mothers reported child demographic characteristics at baseline including biological sex and race/ethnicity. A proxy measure of socioeconomic status (SES) was assessed by asking whether the mother was enrolled in Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) and was collected at each time point

Statistical analyses

All analyses were conducted using SAS version 9.4 (SAS Institute Inc., Cary, NC). Skewness values between −2 and 2 and kurtosis values between −7 and 7 were the criteria used to determine whether data were normally distributed.[25] The intraclass correlation coefficient (ICC) was used to provide evidence that aggregating sleep data at the time point level for participants with ≥3 nights of sleep data was appropriate.[26] Continuous variables (age, total PA, nighttime, and 24-hour sleep duration, weight-for-length z-score, and total food quality) were summarized using means and standard deviations at each time point, and percentages were used to summarize categorical variables (sex, race/ethnicity, WIC status) at baseline.

We examined the independent variables of nighttime and 24-hour sleep duration in separate analyses. Data from each of the four time points was averaged for each child to create average nighttime and 24-hour sleep duration variables and represented the between-person effects of sleep. Nighttime and 24-hour sleep duration variables were also person mean-centered at each time point based on each child's individual data to create a variable representing the within-person effects of sleep. This allowed the variable to be interpreted as the deviation for a person's average sleep duration.[27] All sleep variables are in minutes/24-hour day or minutes/night divided by 10, because regression coefficients for the sleep duration variables were expressed in hundreds of minutes compared to the weight-for-length z-score variable, which was expressed in the single digits. For example, if a child slept 9 hours per night, their sleep variable would be expressed as 54, rather than 540 minutes per night. [((9*60)/10) = 54]. All models were analyzed using the PROC MIXED command and included a random intercept. Models included both average sleep and the mean-centered sleep as independent variables. We plotted residuals to check the assumptions of all models, and no violations were found. All models used all observed data and were likelihood based, which suggested their validity under the missing at random assumption.

Model 1 included only the within- and between-subject effect of sleep duration as independent variables, with separate models for 24-hour and nighttime sleep. Model 2 included these same within- and between-subject effect of sleep duration, as well as demographic characteristics including the child's race/ethnicity (Non-Hispanic Black, Non-Hispanic White, Hispanic, Other), sex (male, female), and WIC status (yes, no). Model 3 also included the within- and between-subject effect of sleep duration and demographic characteristics, as well as the additional effect of PA. Model 4 included the within- and between-subject effect of sleep duration, demographic characteristics, PA, and diet. Weight for length z-score was treated as the outcome variable in all models. The three adjustment strategies were used to assess variations in the relationship between weight-for-length z-score and 24-hour sleep or nighttime sleep. In interaction models, the sleep duration variables were not initially averaged or mean centered, and included total PA counts and overall food quality scores. In interaction models, a separate model was created for each of the demographic characteristics, and this demographic characteristic was included in the model along with a 2-way interaction between the demographic characteristic and the sleep duration variable. Comparisons between groups were made only if there was a significant overall effect of an interaction, with within and between subjects effects of sleep included in the analyses.

Results

A total of 150 mothers and their children were enrolled in the study. Observations that did not have a measure of weight-for-length z-score at any time point were removed, resulting in a sample size of 148 children with a weight-for-length z-score measure at >1 time point(s). Two children were missing data on WIC enrollment and three children were missing data on diet. Seven children did not meet inclusion criteria for PA, 36 children did not meet inclusion criteria for 24-hour sleep duration, and 28 children did not meet inclusion criteria for nighttime sleep duration. This resulted in a sample size of N=110 for adjusted analyses assessing relationships between 24-hour sleep duration and weight-for-length z-score, and a sample size of N=116 for adjusted analyses assessing nighttime sleep duration and weight-for-length z-score. Skewness for PA ranged from 0.58–0.74, and kurtosis ranged from 0.32–1.03. These values confirmed that PA data were normally distributed. Nighttime sleep duration ICCs ranged from 0.88 and 0.93 and 24 hour sleep duration ICCs ranged from 0.71 and 0.88, confirming the appropriateness of aggregating sleep data at the time point level for participants with >3 days of data.

Descriptive statistics

Table 1 shows children's baseline demographic characteristics. Most children (49.09%) were Non-Hispanic White and over half of the children were male (56.36%). Table 1 also provides data on the amount of children at each time point who met sleep guidelines, along with the amount of children with overweight or obesity at each time point. Table 2 provides means, standard deviations and ranges for children's ages, weight-for-length z-scores, sleep, PA, and diet data at each time point.

Weight-for-length z-score and sleep duration

The within-subject effect of nighttime sleep duration was significantly associated with weight for length z-score ($P < .05$) in unadjusted analyses, and approached significance in models adjusting for demographic characteristics ($P = .07$). The between-subject effect of nighttime sleep duration approached significance with weight for length z-score in adjusted models ($p < .10$). In models where 24-hour sleep duration was treated as the primary independent variable of interest, none of the variables were significantly associated with weight-for-length z-score. Details on these analyses can be found in Table 3.

Interactions between sleep and demographic characteristics

In models assessing interactions, none of the 24-hour sleep by demographic characteristic interactions were associated with weight-for-length z-score ($P < .05$) (Results not shown). There was a significant interaction between nighttime sleep and race/ethnicity, which showed that children in the "Other" race/ethnicity category slept significantly less than White and Hispanic children. It is important to note, though, that there were only 7 children in this category. Therefore, these results were not interpreted further.

Discussion

This study examined the longitudinal relationship between sleep and weight status in children in the first two years of life. No significant relationship was found for the "between-children" association, however there was a "within-child" association shown for nighttime sleep duration and weight status in unadjusted models. Specifically, when children in the present study slept 10 minutes longer at night compared to their own average nighttime sleep duration, they had a 0.2 unit decrease in weight-for-length z-score. These results are consistent with the limited amount of longitudinal research showing an inverse association between sleep duration and weight status in very young children.[8,10] The present study expands on this work by using a unique analytic strategy which considered both the effect of inter-child differences in average sleep duration on weight status, as well as the effect of intra-individual changes in sleep duration on weight status.

In the present study, the inverse relationship between sleep and weight-for-length z-score was seen for nighttime sleep duration and not for 24-hour sleep duration. Although daytime naps are considered to be a potential tool for combatting sleep deprivation and are associated with greater cognitive health outcomes, it is still unclear whether daytime and nighttime sleep are both associated with weight status.[28]. Much of the research has assessed 24-hour sleep rather than looking at nighttime and daytime sleep separately,[28] and the NSF provides sleep recommendations over a 24 hour period without any detail on specific nighttime sleep duration recommendations.[5] The results of this study suggest that the development of weight status may have a specific relationship with nighttime sleep duration in this age group. Considering that short sleep is associated with higher weight status in adolescence[7] and adulthood when sleep is fully consolidated into the nighttime,[29] future research should explore whether biological events that occur only during nighttime sleep are the potential mechanisms driving this relationship.

Some of the biological mechanisms used to explain the association between sleep and the development of weight status consider the way sleep regulates hormones associated with appetite and metabolism, and inflammation. In other words, poor sleep can potentially lead to a higher appetite, a slower metabolism, and greater inflammation, all of which can lead to unhealthy weight gain.[10] It is important to note that many of these mechanisms have been studied primarily in older children and adults, and the research exploring these potential biological pathways among younger children is highly inconstant and limited.[11]

Another mechanism proposed to explain the inverse relationship between sleep and weight status considers the potential role of PA,[30] which was a significant factor in analyses for the present study. It is hypothesized that better sleep leads to less fatigue, which in turn results in higher PA levels, lessening unhealthy weight gain.[30] It is important to note, though, that this pathway is not yet supported by research in infants and young children.[11] Even so, the within-subject effect of sleep was only associated with weight status in the present study when PA was not included in analyses. Once models adjusted for PA, the within-subject effect of sleep was no longer significant. In other words, the nighttime sleep and weight status relationship was confounded by PA. PA is associated with weight status in children of all ages.[31] This study suggests that either the effect of daytime PA overrode the effect short nighttime sleep had on weight status, or it potentially eliminated some of the influence of sleep such that it was no longer significantly associated with weight status. Regardless of the exact mechanism, the results of this study show that daytime PA has a protective effect on the development of weight status.

Both sleep and PA were associated with weight status in the present study, yet research on interventions targeting weight status by improving these two behaviors is still limited among infants and very young children. A review by Yoong and colleagues (2016) examined the effect of interventions that included a sleep component had on weight status, and found that most interventions showed null results. They hypothesized that this was most likely due to the inability to significantly improve sleep in most of the interventions included in the review.[4] Of the few interventions that have shown promise in improving some features of sleep among infants and young children, nearly no follow-up work was has been conducted to understand whether these changes in sleep had an effect on weight status.[30] Based on the results of the present study, obesity prevention interventions should focus in increasing both sleep duration and PA levels. These interventions should be incorporated into the home as well as in the childcare setting, if applicable. For example, parents can learn about optimal bedtime routines and what behaviors they and their children should avoid before bedtime.[30]

The association between sleep duration and weight-for-length z-score in children from 6 months old to 24 months old did not vary over time by race/ethnicity, socioeconomic status, or sex. Research has shown that low-income and minority youth are at a higher risk of not meeting sleep guidelines, and that the prevalence of overweight and obesity is higher among low income and minority youth.[11] Although some research has identified differences in sleep duration by race/ethnicity and socio-economic status in this age group,[13] it is still not clear how early the relationship between sleep and weight status may appear. Future research should address this gap so that interventions are implemented at a suitable age.

Although there is a clear need for research assessing the relationship between other sleep metrics, such as sleep quality, and weight status in children, there is currently a lack of standardized, best-practices for measuring sleep quality in this age group. For example, the National Sleep Foundation's report on sleep quality recommendations suggests that sleep quality can be measured by an infant's number of nighttime awakenings.[32] It is important to consider, though, that device-based measures of sleep such as actigraphy are not very accurate at discriminating between sleep and wake periods among infants (i.e. when the child is inactive during a wake period or moving during a sleep period).[33] Therefore, while the number of nighttime awakenings may be an appropriate measure of sleep quality, the ability to measure this variable in infants is still in need of improvement. Therefore, the current study focused on sleep duration exclusively, rather than assessing other sleep metrics.

The major strength of this study was the use of device-based measures for sleep and PA and objective measures of weight and length to calculate weight-for-length z-scores in a longitudinal study with a diverse population of infants and toddlers. An additional strength was the analysis method that allowed for the assessment of differences between children's sleep durations along with changes in individual children's sleep durations and their association with weight status over time, as opposed to only looking at differences between children. It is important to note, though, that there are limitations to the use of actigraphs in this age group. Actigraphs are less accurate at differentiating between sleep and wake classifications when very young children are either inactive during a wake period or moving during a sleep period, compared to older children and adults.[33] This accuracy could be improved with the use of sleep diaries, but parents were not asked to complete sleep diaries in order to reduce participant burden and avoid the risk of additional data loss from non-compliance.[34] Because of this limitation, it is difficult to accurately measure sleep quality in infants and very young children,[34] which limits studies that assess relationships between sleep quality and the development of weight status. Future research should find ways to better assess sleep quality in this age group. Furthermore, there are a number of other factors related to very young children's sleep duration that were not explored in this analysis. Cultural, social, and environmental factors all influence very young children's sleep, and can affect bedtime and waketime, the location the child sleeps, the amount of time parents spend on bedtime behaviors and soothing the child after waking, or the amount of screen time exposure a child has before bed or in bed.[35]

In conclusion, children's weight-for-length z-scores were lower at time points where they slept longer compared to their own average nighttime sleep durations. This relationship was attenuated by their daytime PA levels. These results suggest that the underlying mechanisms driving this relationship may be specifically related to the biological events that occur during nighttime sleep, and that PA may also have a protective effect on the development of weight status in very young children.

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Table 1.

Demographic characteristics of the study sample.

	N	%
Race/Ethnicity *	110	
Non-Hispanic White	54	49.09
Non-Hispanic Black	34	30.91
Hispanic	17	15.45
Other	5	4.55
Sex *	110	
Female	48	43.64
Male	62	56.36
WIC status		
Time point 1	105	
No assistance	63	60.00
WIC assistance	42	40.00
Time point 2	103	
No assistance	66	64.08
WIC assistance	37	35.92
Time point 3	79	
No assistance	62	78.48
WIC assistance	17	21.52
Time point 4	84	
No assistance	67	79.76
WIC assistance	17	20.24
Sleep guidelines		
Time point 1 [a]	88	
Met guidelines	52	59.09
Did not meet guidelines	36	40.91
Time point 2 [b]	74	
Met guidelines	67	90.54
Did not meet guidelines	7	9.46
Time point 3 [b]	53	
Met guidelines	49	85.96
Did not meet guidelines	8	14.04
Time point 4 [b]	55	
Met guidelines	49	89.09
Did not meet guidelines	6	10.91
High weight-for-length z-score		
Time point 1	107	

	N	%
< 2	97	90.65
≥ 2 (overweight)	10	9.35
Time point 2	98	
< 2	91	92.86
≥ 2 (overweight)	7	7.14
Time point 3	78	
< 2	66	84.62
≥ 2 (overweight)	12	15.38
Time point 4	74	
< 2	64	86.49
≥ 2 (overweight)	10	13.51

[*] Data reported at baseline

[a] Participants slept >12 hours per night

[b] Participants slept >11 hours per night

Table 2.

Descriptive statistics at each time point.

	Time point 1			Time point 2		
	N (%)	Mean (SD)	Range	N (%)	Mean (SD)	Range
Age (in months)	107	6.86 (1.09)	5.00–10.24	104	12.75 (0.98)	10.53–16.26
Weight-for-length z-score	107	0.47 (1.11)	−2.13–2.92	98	0.68 (1.04)	−2.64–3.46
24-hour sleep duration[a]	88	741.45 (113.35)	460.05–1315.32	74	757.20 (81.01)	600.06–1055.92
Nighttime sleep duration[a]	90	552.26 (77.38)	319.00–717.71	79	567.77 (71.46)	393.80–691.17
Physical Activity (ankle)	103	79.76 (24.55)	32.40–166.67	86	92.07 (21.17)	41.49–159.48
Food quality score	104	8.63 (6.42)	−3.00–22.00	103	14.63 (5.95)	0.00–30.00
	Time point 3			**Time point 4**		
Age (in months)	81	19.62 (1.43)	17.45–22.65	82	25.58 (1.57)	23.30–29.26
Weight-for-length z-score	78	0.69 (1.16)	−1.57–4.27	74	0.65 (1.17)	−2.26–3.85
24-hour sleep duration	57	750.54 (107.36)	594.67–1378.15	55	739.64 (68.70)	552.77–892.31
Nighttime sleep duration	62	560.34 (86.76)	321.01–681.29	58	574.39 (61.48)	430.64–691.69
Physical Activity (ankle)	77	105.80 (25.13)	41.42–177.40	36	126.87 (40.57)	47.58–227.08
Food quality score	79	15.19 (4.71)	4.00–23.00	84	15.20 (4.44)	4.00–24.00

[a]Sleep duration is expressed as minutes per 24 hour day or 12 hour night.

Table 3.

Associations between weight-for-length z-score and 24-hour and nighttime sleep duration[a]

	Model 1 Unadjusted		Model 2 Demographic char.		Model 3 Physical activity		Model 4 Diet	
	Estimate (SE)	***P* - value**	**Estimate (SE)**	***P* - value**	**Estimate (SE)**	***P* - value**	**Estimate (SE)**	***P* - value**
24 HR Sleep[a]	N = 112		N = 111		N = 111		N = 110	
Intercept	0.72 (0.76)	.35	0.39 (0.81)	.63	0.41 (0.86)	.63	0.69 (0.88)	.43
Sleep - w/in subject effect	−0.008 (0.008)	.30	−0.009 (0.008)	.25	−0.005 (0.009)	.55	−0.005 (0.009)	.54
Sleep - b/w subject effect	−0.001 (0.01)	.89	−0.0001 (0.01)	.99	−0.003 (0.01)	.81	−0.007 (0.01)	.48
Physical activity (ankle)					0.002 (0.002)	.35	0.001 (0.002)	.63
Food Quality score							0.02 (0.01)	.11
Nighttime Sleep[a]	N = 120		N = 119		N = 117		N = 116	
Intercept	1.56 (0.69)	.03	1.62 (0.85)	.06	1.59 (0.88)	.07	1.57 (0.88)	.08
Sleep - w/in subject effect	−0.02 (0.01)	.05[b]	−0.03 (0.01)	.07	−0.02 (0.01)	.13	−0.02 (0.01)	.12
Sleep - b/w subject effect	−0.02 (0.01)	.18	−0.02 (0.01)	.15	−0.03 (0.01)	.08	−0.03 (0.01)	.06
Physical activity					0.003 (0.002)	.10	0.003 (0.002)	.18
Sum Quality food score							0.01 (0.01)	.20

w/in: within, b/w: between

[a]Nighttime sleep duration was normalized by dividing values by wear time and multiplying by 12. 24-hour sleep duration was normalized by dividing values by wear time and multiplying by 24

[b]P = .047; Cells that are empty do not have relevant data