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No Evidence of Reciprocal Associations between Daily Sleep and Physical Activity

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Abstract

Purpose—To determine if physical activity patterns are associated with sleep later at night, and if nighttime sleep is associated with physical activity patterns the next day, among adult women.

Methods—Women (N=353) living throughout the U.S. wore a wrist and a hip accelerometer for 7 days. Total sleep time (TST, hrs/night) and sleep efficiency (SE, %) were estimated from the wrist accelerometer; and moderate to vigorous physical activity (MVPA, >1040 counts per minute [cpm], hrs/d) and sedentary behavior (SB, <100 cpm, hrs/d) were estimated from the hip accelerometer. Mixed-effects models adjusted for age, race, body mass index (BMI), education, employment, marital status, health status, and hip accelerometer wear time were used to analyze

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Conflicts of Interest

The results of the present study do not constitute endorsement by ACSM

the data. Follow-up analyses using quantile regression were used to investigate associations among women with below average TST and MVPA, and above average SB.

Results—The average age of our sample was 55.5 (SD = 10.2) years. The majority of participants were white (79%) and married (72%), and half were employed full-time (49%). The participants spent on average 8.9 and 1.1 hours per day in SB and MVPA, respectively, and 6.8 hours per night asleep. No associations were observed between MVPA and SB with nighttime TST or SE. There were no associations between nighttime TST and SE with MVPA or SB the next day. The findings were the same in the quantile regression analyses.

Conclusion—In free-living adult women, accelerometry-estimated nighttime sleep and physical activity patterns were not associated with one another. Based on our observational study involving a sample of adult women, higher physical activity will not necessarily improve sleep at night on a day-to-day basis (and vice versa).

Keywords

Accelerometry; actigraphy; female; sedentary behavior

Introduction

Sleep and physical activity are among the most important lifestyle factors that can help prevent the leading chronic diseases in adulthood (5, 6, 26). U.S. adults are recommended to sleep for 7–9 hours per night and to accumulate 150 minutes of moderate-to-vigorous physical activity (MVPA) each week (17, 29). However, 30% of U.S. adults sleep for ≤6 hours each night (16), and an estimated 57% of U.S. adults do not meet the physical activity guidelines (7). The self-reported physical inactivity prevalence is notably high among adult women (60%) (7), and accelerometry estimates indicate that up to 97% of U.S. adult women are physically inactive (33).

It has been hypothesized that nighttime sleep and daytime physical activity are linked in a reciprocal or bi-directional manner (11, 21). However, a review published in 2012 indicated that the association between TST and physical activity energy expenditure was unclear and limited (24). Establishing if this hypothesized relationship exists in adult women is particularly important given their high prevalence of short sleep and physical inactivity (7, 16, 33), high prevalence of chronic disease, and high use of medical services (8). Moderate intensity aerobic exercise training (typically involving four 30-minute sessions per week, for 16 weeks) has been shown to improve certain self-reported sleep outcomes among women, including: improved sleep quality, shorter sleep onset latency (SOL), longer total sleep time (TST), improved apnea-hypopnea index and a reduction in reported sleep disturbances (20, 22, 23, 30, 34). Conversely, short-term experimental sleep restriction, by 2 hours per night for 14 days, was found to lead to a reduction in physical activity levels in adult men and women (3). These experimental and intervention studies support a bi-directional relationship between sleep and physical activity. However, they do not necessarily provide insight into sleep and physical activity patterns in free-living populations. They also do not specifically address if sedentary behavior (SB) is bi-directionally associated with sleep. This is of importance given that SB is associated with chronic diseases in adult women, independent of

MVPA (32), and there is some evidence that SB (self-reported sitting and television viewing) is associated with poorer self-reported sleep outcomes in adult men and women (4).

It is feasible to prospectively collect objective measures of sleep, physical activity, and SB concurrently, in the free-living setting, on a day-to-day basis, using accelerometry. Studies dating back to 2003 have used accelerometry to test for daily associations between sleep and physical activity (38). However, to the best of our knowledge only one study has used accelerometry to prospectively measure both physical activity and sleep exclusively in free-living adult women (mean age 73 years) (25). In that study, more physical activity during the day was associated with shorter TST at night, and greater sleep efficiency at night was associated with higher physical activity during the day (25). Importantly, the sample size was relatively small (N=175) and SB was not measured (25). We therefore tested whether evening sleep was associated with physical activity and SB on the following day, and if physical activity and SB were associated with nighttime sleep, in a sample of 353 adult women who wore wrist and hip accelerometers concurrently over 7-days. We hypothesized that higher physical activity levels would be associated with improved actigraphy estimated sleep outcomes at night. Conversely, we hypothesized that longer and more efficient sleep at night would be associated with higher physical activity levels on the following day.

Methods

Participants

Our analytical sample was comprised of 353 adult women. This convenience sample comprised participants who were living in/near San Diego, CA (N=72), Philadelphia, PA (N=119), and St Louis, MO (N=71) at the time of recruitment (2012–2013). Investigators at the University of California San Diego (UCSD), the University of Pennsylvania (UPenn), and Washington University in St Louis (WUSTL) recruited these participants. In addition, investigators from Harvard University recruited adult women living throughout the U.S. (N=91). At all sites, the participants had to meet the following eligibility criteria: 21–75 years old, self-reported BMI between 21.0 and 39.9 kg/m^2, and be able to ambulate unassisted. Site-specific eligibility criteria included: currently employed full or part-time (WUSTL) and previously diagnosed with breast cancer (UPenn). The Harvard sample was selected from participants in the Nurses Health Study II with a BMI less than 40, and was sampled to evenly represent varying population densities and all Census regions of the US (African American were oversampled). Furthermore, 17% of the UCSD sample was comprised of confirmed breast cancer survivors. The measurement protocols were identical across all sites. The participants provided informed consent and IRB approval for this study was granted at each study site.

Accelerometer Protocol

Each participant received two accelerometers in the mail to wear for 7 days (ActiGraph GT3X+, ActiGraph, Pensacola, FL). They were instructed to wear one of the accelerometers on their non-dominant wrist for 24 hours per day, and to wear the second accelerometer around their waist by means of an elastic belt at the right hip during waking hours. The accelerometers were removed when swimming or bathing and the participants were provided with a 7-day sleep diary so that they could report any times they removed their wrist or hip accelerometers and the time they went to bed each night and woke each morning. Upon completion, the participants mailed back their devices and the stored data were downloaded using ActiLife (Version 6.7, ActiGraph, Pensacola, FL). All downloaded data files were visually screened for wear time compliance at each study site before being sent to UCSD for full, standardized processing.

Accelerometer Data Processing: Sleep

The data downloaded from the wrist accelerometers were used to derive estimates of total sleep time (TST, hours per night), sleep onset latency (SOL, minutes per night), wake after sleep onset (WASO, minutes per night) and sleep efficiency (SE, percentage of time asleep during each sleep period categorized as follows: <85% or ≥85%) (10, 31). The sleep period was defined using self-reported bed and wake times and the Cole-Kripke algorithm was applied to generate all sleep parameters (13). These sleep parameters were used to describe the characteristics of the study sample. In addition, TST and SE were used as primary predictors or primary exposures in the analytical models. In general, wrist accelerometry has high sensitivity (>90%) and moderate specificity (30–40%) for measuring TST in comparison to polysomnography (15).

Accelerometer Data Processing: Physical Activity and Sedentary Behavior

The data downloaded from the hip accelerometers were used to derive estimates of MVPA (minutes per day) and sedentary behavior (SB, hours per day). The hip accelerometers had to be worn for at least 10 hours per day to be included in our analyses. Non-wear time was determined using the algorithm developed by Choi et al. (12). A cutpoint of >1040 counts per minute (cpm) was used to define MVPA and a cutpoint of <100 cpm was used to define SB (14, 27). Sensitivity analyses were performed using a less conservative cutpoint of 760 cpm to define MVPA and a more conservative MVPA cutpoint of 2020 cpm to define MVPA. The sensitivity analyses involving the less conservative cutpoint allowed us to make more direct comparisons with the Lambiase et al. findings (25).

Covariates

We included age, race (white or other), education (high school, some college, college degree or graduate degree), and employment (employed ≥35 hours per week, employed <35 hours week, or not in regular employment [unemployed, seasonal, homemaker, or retired]) as covariates. Differences in sleep and physical activity patterns have been reported across each of these categorical variables (18, 33). We also included BMI (kg/m^2), calculated using self-report height and weights, and self-reported health status (1=poor to 5=excellent) as covariates because obese and less healthy participants are more likely to have shorter TST and lower physical activity levels (19, 36). Finally, daily hip accelerometer wear time was included as covariate to control for variations in accelerometer wear times among participants.

Statistical Analyses

To describe the characteristics of our sample we used means and standard deviations for the continuous variables and frequencies and percentages for the categorical variables. The descriptive data are presented for the entire sample and by tertiles of TST and MVPA. An overview of our study analyses is provided in Table 1. To test whether daytime physical activity was associated with nighttime sleep, sleep on night i was aligned with physical activity on day i; whereas, for the analyses testing if nighttime sleep was associated with physical activity the following day, sleep on night i was aligned with physical activity on day $i+1$. Since we analyzed our data at the daily level, participants with at least 1 day of sleep and physical activity data were included in our analyses. Once the data were appropriately aligned, we used linear mixed models to account for correlation of data within a participant. Logistic mixed models were used, when SE (<85% [referent] vs. ≥85%) was the outcome variable. In the mixed effects analyses random intercepts, maximum likelihood estimation and an unstructured correlation structure were applied. The fixed effects of the model included the time varying predictors MVPA and SB when TST or SE were the outcome variables. When MVPA or SB was the outcome variable, the fixed effects of the model included TST and SE as time varying predictors. For all models the fixed effects included the time-constant covariates: age, race, BMI, education, employment status, marital status, and self-reported health status. We also conducted sensitivity analyses to test if any bi-directional associations between the sleep and physical activity variables differed as a function of age, BMI, and breast cancer survivor status (i.e. predictor-age, predictor-BMI, and predictor-survivor interactions, respectively). Note, breast cancer survivor status was not confirmed among the participants recruited at WUSTL and Harvard; therefore, the related sensitivity analysis assumes that all unconfirmed participants are not breast cancer survivors.

Quantile regression was also used to extend our data analysis beyond the mean of the outcome variables (37). In contrast to linear mixed models, quantile regression test associations at the median and any other percentile of the frequency distribution (2). In the context of MVPA and TST, it is especially important to know if a predictor associates with changes in MVPA or TST for those in the sample with lower MVPA and TST (i.e. below the 50th percentiles). In contrast, it is especially important to know if a predictor associates with changes in SB for those in the sample with higher SB (i.e. >50th percentile). Quantile regression also has the advantage of modeling the outcome as a continuous variable and so does not require categorization which has limitations (1), and this regression method is robust to outliers. Using quantile regression we specifically tested if our predictors were associated with the 5th, 10th, 15th, …, 85th, 90th and 95th percentiles of the outcome variables. The related beta coefficients, 95% confidence intervals and P-values are interpreted in the same way as standard regression methods (i.e. difference in outcome per unit increase in the predictor). The 95% confidence intervals were estimated using 100 cluster bootstrap samples to account for the correlation between daily accelerometry measures (37). All analyses were performed using Stata 14.1 (StataCorp, College Station, TX).

Results

A total of 353 women completed the study protocol and had complete sleep, MVPA, SB, and covariate data (Table 2). Over 92% of the sample (N=326) provided 4 or more consecutive days of data (see Table, Supplemental Digital Content 1, Description of data collection patterns of the 353 participants with valid accelerometry data). On average the participants were 55 years old and had a BMI of 27.6 kg/m^2. The majority of the sample was white (79%) and married (72%), with approximately half in full-time employment (49%). On average, the participants spent 9 hours per day in SB, 1 hour per day in MVPA, and 7 hours per night asleep. Average time spent in SB and MVPA remained relatively constant across the TST tertiles; similarly, TST remained relatively constant across the MVPA tertiles (Table 2).

We first investigated if SB and MVPA were associated with TST at night (Table 3). MVPA was not associated with TST (beta=−0.03; 95% CI: −0.12, 0.06); similarly, we observed no association between SB and TST (beta=0.002; 95% CI: −0.04, 0.04). Time spent engaged in MVPA and SB were not associated with SE at night (OR=0.88; 95% CI: 0.70, 1.10; and OR=1.07; 95% CI: 0.97, 1.18, respectively). There was no statistical evidence that the findings in Table 3 differed by age, BMI or breast cancer survivor status (interaction *P*-values >0.05). Furthermore, the MVPA results did not change when we re-assessed using cutpoints of 760 cpm and 2020 cpm to define MVPA [see Table, Supplemental Digital Content 2, Associations between physical activity (760 cpm and 2020 cpm cutpoints) with nighttime sleep outcomes (N=353); see Table, Supplemental Digital Content 3, Associations between sleep exposures at nighttime and physical activity (760 cpm cutpoint) behavior the following day (N=353)].

We then investigated if TST was associated with MVPA and SB during waking hours the next day (Table 4). We did not observe any associations between TST and MVPA (beta=0.01; 95% CI: −0.01, 0.04) or between TST and SB (beta=−0.02; 95% CI: −0.07, 0.04). Similarly, SE at night was not associated with MVPA (beta=0.06; 95% CI: −0.001, 0.12) or SB on the following day (beta=−0.05; 95% CI: −0.19, 0.09). There was no evidence that the findings in Table 4 differed by age, BMI or breast cancer survivor status (interaction *P*-values >0.05). Again, the MVPA related results did not change when we re-assessed using cutpoints of 760 cpm and 2020 cpm to define MVPA [see Table, Supplemental Digital Content 2, Associations between physical activity (760 cpm and 2020 cpm cutpoints) with nighttime sleep outcomes (N=353); see Table, Supplemental Digital Content 3, Associations between sleep exposures at nighttime and physical activity (760 cpm cutpoint) behavior the following day (N=353)]. Although, SE at night was associated with higher MVPA when using the 2020 cutpoint definition [see Table, Supplemental Digital Content 3, Associations between sleep exposures at nighttime and physical activity (760 cpm cutpoint) behavior the following day (N=353)]

We further analyzed our data using quantile regression models. Time spent engaged in MVPA was not associated with TST at any of the specified percentiles (Figure 1A). SB was not associated with TST at any percentile below the 85th percentile; however, SB during waking hours was associated with higher TST at night at the 85th (beta=0.09; 95% CI:

0.003, 0.12), 90th (beta=0.07; 95% CI: 0.01, 0.14), and 95th TST percentiles (beta=0.10; 95% CI: 0.03, 0.18) (Figure 1B). Nighttime TST and SE were not associated with MVPA, at any of the specified percentiles, on the following day (Figure 1C and Figure 1E), or with SB, at any of the specified percentiles, on the following day on the following day (Figure 1D and Figure 1F). The MVPA related quantile regression results did not change when we re-assessed using cutpoints of 760 cpm and 2020 cpm to define MVPA [see Figure, Supplemental Digital Content 4, Quantile regression associations between physical activity, sedentary behavior, and sleep (N=353)].

Discussion

This is the largest study to date that has used objective measures of sleep and MVPA over a 7-day period to investigate the relationship between sleep and MVPA in free-living adult women. We did not find evidence of reciprocal associations between TST or SE with time spent in MVPA. We took the extra step to analyze our data using quantile regression; importantly, this demonstrated that there were no associations between TST and MVPA specifically among women with below average TST and below average MVPA (i.e. those in the population most in need of increasing TST and increasing MVPA). In addition, we tested for associations between sleep and SB, which has not been previously investigated in a sample of adult women using accelerometry to estimate both sleep and SB. As with MVPA, there was no evidence of reciprocal associations between TST or SE and time spent in SB. However, using quantile regression we did observe that an additional hour of SB was associated with increased TST among those with the highest TST (≥85th percentile); although, these associations translate to no more than a 6 minute per night increase in TST.

Our study design closely reflects that used by Lambiase et al. (25). In that study, using an MVPA cutpoint of 760 cpm (average time spent in MVPA was 1 hour per day), it was observed that more time spent in MVPA associated with shorter TST at night, but greater SE at night was associated with higher MVPA on the following day (25). The average age of the women in our sample was 55 years and 72% were in full or part time employment. In contrast, the sample of women studied by Lambiase et al. had an average age of 73 years and, in the absence of employment data, it is reasonable to assume that less than 72% of this sample was in full or part time employment (25). Work schedules and child-care responsibilities are possible factors that could have a greater influence on sleep-wake cycles in our sample, and this may have made it more difficult to observe associations between nighttime sleep and physical activity patterns. Indeed, McClain et al. used 2005–2006 National Health and Nutrition Examination Survey (NHANES) data to determine if accelerometry estimated MVPA and SB were associated with self-reported TST (28). There were no reciprocal associations observed in women aged 40–59 years; however, among the older women (≥60 years) those sleeping for ≤5 hours per night had lower MVPA levels compared to those sleeping between 6 or 7 hours per night (28). Importantly, in our study we did not find statistical evidence that our results differed as a function of age.

Differences in accelerometry methods may also have contributed to our inability to replicate the findings by Lambiase et al. (25). In both studies the ActiGraph GT3X+ was worn at the hip to estimate MVPA, but we used a cutpoint of 1041 cpm to define MVPA and Lambiase et al. used a cutpoint of 760 cpm (25). We conducted sensitivity analyses using the lower 760 cpm cutpoint to enable a more direct comparison, yet did not observe any reciprocal associations between sleep and MVPA with this lower cutpoint. Furthermore, we used the ActiGraph GT3X+ (worn on the wrist) to estimate sleep, whereas Lambiase et al used the Actiwatch-64m accelerometer to estimate sleep (25). It has been shown that the Actiwatch performs slightly better than the ActiGraph at estimating TST in the lab-setting, when compared against polysomnography (9).

We also conducted sensitivity analyses using the higher 2020 cpm cutpoint to define MVPA. This more conservative cutpoint measures “more vigorous” physical activity and interestingly, using this definition, we did observe an association between more efficient nighttime sleep and higher MVPA the following day. This is consistent with the Lambiase et al finding (25), but only translates to an additional 4 minute per day increase in MVPA.

Our findings have important public health implications for adult women. Addressing high SB, physical inactivity, and short TST are important public health goals, but based on our findings targeting daily increases in TST and SE may not necessarily increase MVPA and lower SB in the short-term (and vice versa), on the basis of our specific sample. However, from a clinical standpoint there is growing evidence that aerobic exercise training could be beneficial for adults with a diagnosed sleep disorder (21). Furthermore, aerobic exercise training among adult women has been demonstrated to improve self-reported sleep outcomes, including improved sleep quality, shorter SOL, longer TST, improved apnea-hypopnea index, and a reduction in reported sleep disturbances/problems (20, 22, 23, 30, 34). Importantly, these sleep outcomes were self-reported and sleep was not a primary outcome in any of these exercise trials. In addition, the women enrolled in these studies were all overweight/obese, physically inactive, and postmenopausal at enrollment (20, 22, 23, 30, 34), and in one study the women were diagnosed with insomnia (30). Our observational study sample included normal, overweight and obese women; and women considered physically active and inactive. While our findings do not support daily relationships between evening TST and SE with MVPA and SB (and there was no evidence of age or BMI statistical interactions), this does not detract from the mounting evidence of a relationship between longer-term aerobic exercise training and improved sleep outcomes in adult women with a sleep disorder or who are overweight/obese and physically inactive (20, 22, 23, 30, 34). However, the findings from these aerobic exercise trials need to be replicated in trials where more stringently measured sleep parameters are the primary outcome.

Our study has several strengths and limitations. We used accelerometry to estimate sleep outcomes, MVPA, and SB prospectively over 7 days. However, accelerometer models and data processing models used vary across different studies and this makes direct comparisons challenging. While accelerometry provides an estimate of total SB, this method is not able to measure time spent in specific behaviors and it has been shown that screen-based SB is a more important predictor of self-reported sleep outcomes than accelerometry estimated SB (35). Similarly, accelerometry is limited in its ability to capture certain MVPA contexts such as swimming and weight training. We did not prospectively measure screen time on the days when the accelerometers were worn; future studies should consider doing so to test for reciprocal associations between daily screen time and sleep outcomes. We also did not consider the timing of sleep or the timing of MVPA and SB and follow-up investigation is required to determine if the timing of these behaviors is more important than the total duration (5). There may be other factors as well, such as time spent outdoors, which may moderate the effects. It is also possible that a 7-day period is not sufficient for capturing more long-term effects of MVPA on sleep (and vice versa). Research examining this relationship over a more prolonged period of time may identify differences between acute and long-term effects, and would allow for the investigation of weekend versus weekday differences. We did not prospectively measure tiredness and fatigue during the week of observations; sleep deprivation cannot be measured using accelerometry and future studies should consider investigating reciprocal relationships between sleep deprivation and physical activity patterns. We used a sample of adult women recruited at four sites in the U.S. that included nurses and confirmed breast cancer survivors (20% and 100% of the UCSD and UPenn samples, respectively). Replication of findings in a larger, more representative, sample of women is required; and replication in a more detailed breast cancer survivor sample is required. It would also be of interest to study reciprocal associations between daily sleep and physical activity patterns in other settings; for example, in other chronic disease populations, in children and adolescents, and in those diagnosed with a sleep disorder.

It has been proposed that sleep and physical activity patterns are linked in a reciprocal manner. However, our 7-days of accelerometry data among free-living adult women do not support this hypothesis. Time spent engaged in MVPA and SB did not influence TST and SE at night. Similarly, TST and SE at night did not influence time spent engaged in MVPA or SB on the following day. Therefore, based on our findings among a sample of adult women, daily increases in physical activity will not necessarily lead to sleep improvements in the short-term (and vice versa).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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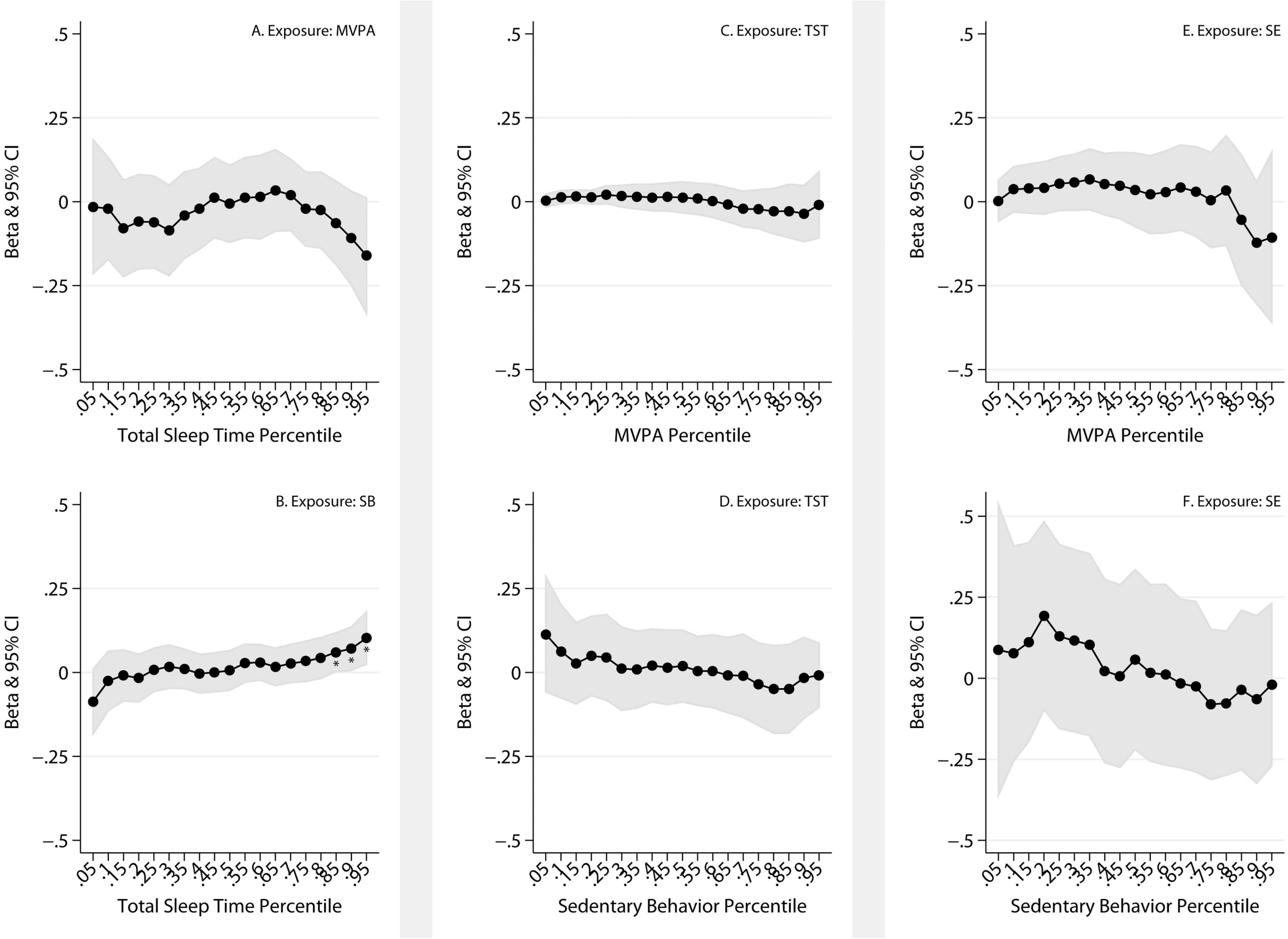

Figure 1.

Quantile regression associations between physical activity, sedentary behavior, and sleep (N=353). Panel A: Change in total sleep time (h/d) per additional unit increase in MVPA (h/d). Panel B: Change in total sleep time (h/d) per additional unit increase in sedentary behavior (h/d). Panel C: Change in MVPA (h/d) per unit increase in total sleep time (h/d) Panel D: Change in sedentary behavior (h/d) per unit increase in total sleep time (h/d). Panel E: Change in MVPA (h/d) for those with sleep efficiency ≥85%, relative to those with sleep efficiency <85%. Panel F: Change in sedentary behavior (h/d) for those with sleep efficiency ≥85%, relative to those with sleep efficiency <85%. All models included the covariates: age, race, education level, employment status, BMI, marital status, self-report heath status and hip accelerometer wear time

Table 1

Overview of the study analyses

Exposure Outcome	**Mixed Model**	**Quantile Regression**
MVPA → TST	Table 3 (linear)	Figure 1A
MVPA → SE	Table 3 (logistic)	
SB → TST	Table 3 (linear)	Figure 1B
SB → SE	Table 3 (logistic)	
TST → MVPA	Table 4 (linear)	Figure 1C
TST → SB	Table 4 (linear)	Figure 1D
SE → MVPA	Table 4 (linear)	Figure 1E
SE → SB	Table 4 (linear)	Figure 1F

Abbreviations: MVPA, moderate-to-vigorous physical activity; SB, sedentary behavior; SE, sleep efficiency; TST, total sleep time

Table 2

Descriptive characteristics of the analytical sample (N=353 women)

		TST Tertiles			MVPA Tertiles		
	All Participants	1st Tertile	2nd Tertile	3rd Tertile	1st Tertile	2nd Tertile	3rd Tertile
Age, years	55.5 (10.2)	55.4 (9.1)	54.0 (11.0)	57.1 (10.2)	58.4 (9.6)	55.7 (10.7)	52.4 (9.5)
BMI, kg/m^2	27.6 (6.1)	28.8 (6.8)	27.5 (6.1)	26.5 (5.2)	28.5 (6.2)	27.0 (5.5)	27.4 (6.6)
Hip ACC Wear, h/d	14.4 (1.4)	14.9 (1.5)	14.5 (1.2)	13.8 (1.1)	14.1 (1.5)	14.2 (1.2)	14.8 (1.2)
SB, h/d	8.9 (1.5)	9.1 (1.6)	9.0 (1.5)	8.5 (1.3)	9.5 (1.4)	8.8 (1.3)	8.4 (1.5)
MVPA, h/d	1.1 (0.6)	1.1 (0.6)	1.0 (0.5)	1.1 (0.6)	0.5 (0.2)	1.0 (0.1)	1.7 (0.5)
TST, h/d	6.8 (1.0)	5.8 (0.6)	6.9 (0.2)	7.8 (0.5)	6.8 (1.1)	7.0 (0.8)	6.7 (0.9)
SOL, min/d	7.8 (8.2)	9.4 (9.0)	7.3 (6.1)	6.8 (8.9)	8.5 (8.9)	7.1 (6.3)	7.8 (9.1)
WASO, min/d	61.6 (34.3)	69.2 (40.3)	58.1 (30.2)	57.4 (30.3)	63.9 (35.5)	62.4 (32.7)	58.4 (34.6)
SE, % per night	85.7 (7.2)	82.0 (9.0)	86.8 (5.3)	88.4 (5.1)	85.0 (8.1)	86.0 (6.7)	86.2 (6.8)
White, N (%)	279 (79.0)	80 (68.4)	97 (81.5)	102 (87.2)	90 (76.9)	92 (78.0)	97 (82.2)
Non-white, N (%)	74 (21.0)	37 (31.6)	22 (18.5)	15 (12.8)	27 (23.1)	26 (22.0)	21 (17.8)
Employed ≥35 h/wk, N (%)	174 (49.3)	73 (62.4)	54 (45.4)	46 (39.3)	57 (48.7)	55 (46.6)	61 (51.7)
Employed <35 h/wk, N (%)	83 (23.5)	26 (22.2)	33 (27.7)	24 (20.5)	23 (19.7)	26 (22.0)	34 (28.8)
Not employed[a], N (%)	96 (27.2)	18 (15.4)	32 (26.9)	47 (40.2)	37 (31.6)	37 (31.4)	23 (19.5)
Graduate Degree, N (%)	126 (35.7)	39 (33.3)	38 (31.9)	48 (41.0)	39 (33.3)	46 (39.0)	40 (33.9)
College Degree, N (%)	122 (34.6)	40 (34.2)	44 (37.0)	39 (33.3)	36 (30.8)	37 (31.4)	50 (42.4)
Some College, N (%)	72 (20.4)	22 (18.8)	27 (22.7)	23 (19.7)	32 (27.4)	27 (22.9)	13 (11.0)
High School, N (%)	33 (9.4)	16 (13.7)	10 (8.4)	7 (6.0)	10 (8.6)	8 (6.8)	15 (12.7)
Currently Married, N (%)	253 (71.7)	77 (65.8)	92 (77.3)	84 (71.8)	78 (66.7)	85 (72.0)	90 (76.3)
Not Currently Married[b], N (%)	100 (28.3)	40 (34.2)	27 (22.7)	33 (28.2)	39 (33.3)	33 (28.0)	28 (23.7)

[a] Not employed includes: seasonal labor, out of work/looking for work, homemaker and retired.

[b] Not currently married includes: never married, single and divorced.

Abbreviations: ACC, accelerometer; BMI, body mass index; cpm, counts per minute; MVPA, moderate-to-vigorous physical activity; SB, sedentary behavior; SE, sleep efficiency; SOL, sleep onset latency; TST, total sleep time; WASO, wake after sleep onset.

Table 3

Associations between physical activity and sedentary behavior with nighttime sleep outcomes (N=353)

	Outcome: TST (h/d)			**Outcome: SE (<85% [ref] vs. ≥85%)**		
Exposures	**Beta**	**95% CI**	***P*-value**	**OR**	**95% CI**	***P*-value**
MVPA (h/d)	−0.03	−0.12, 0.06	0.489	0.88	0.70, 1.10	0.259
SB (h/d)	0.002	−0.04, 0.04	0.925	1.07	0.97, 1.18	0.158

Beta coefficients represent the change in outcomes per unit increase in exposure. Odd ratio (OR)>1.0 indicates that the exposure is associated with an increased likelihood of having sleep efficiency≥85%. All models adjusted for age, race, education level, employment status, BMI, marital status, self-report heath status and hip accelerometer wear time.

Abbreviations: MVPA, moderate-to-vigorous physical activity; SB, sedentary behavior; TST, total sleep time.

Table 4

Associations between sleep exposures at nighttime and physical activity and sedentary behavior the following day (N=353)

	Outcome MVPA (h/d)			Outcome SB (h/d)		
Exposures	**Beta**	**95% CI**	***P*-value**	**Beta**	**95% CI**	***P*-value**
TST (h/d)	0.01	−0.01, 0.04	0.266	−0.02	−0.07, 0.04	0.555
SE (<85% [ref] vs. ≥85%)	0.06	−0.001, 0.12	0.053	−0.05	−0.19, 0.09	0.526

Beta coefficients represent the change in outcomes per unit increase in exposure. All models adjusted for age, race, education level, employment status, BMI, marital status, self-report heath status and hip accelerometer wear time.

Abbreviations: MVPA, moderate-to-vigorous physical activity; SB, sedentary behavior; SE, sleep efficiency.