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Bi-directional associations of accelerometer-determined sedentary behavior and physical activity with reported time-in-bed: Women's Health Study

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Abstract

Objective—To examine the day-to-day, bidirectional associations of accelerometer-derived sedentary behavior and physical activity (PA) with reported time-in-bed in a large cohort of older women.

Methods—Data are from 10,086 Women's Health Study participants [aged 71.6 (SD): 5.7] years who agreed to wear an accelerometer and complete a diary for seven, consecutive days. Generalized linear (multi-level) models with repeated measures were used to examine the adjusted associations of: (1) reported time-in-bed with next-day accelerometer-determined counts and time spent sedentary and in light and moderate- to vigorous- intensity PA (MVPA) and (2) accelerometer estimates with reported time-in-bed that night, expressed as short (<7 hours), optimal (7-9 hours), and long (>9 hours) sleep.

Results—Across days, short sleep was associated with an average of 5,500 (SE: 1,352) higher accelerometer counts the following day, but was also related to higher average sedentary [46.5

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(SE: 1.5) minutes] and light intensity PA [11.9 (SE: 1.2) minutes] than optimal sleep (all P<0.001). Long sleep was associated with lower accelerometer counts, time spent sedentary and in light intensity PA, and a reduced likelihood of engaging in ≥20 minutes of MVPA (all P<0.001) than optimal sleep. Higher PA during the day (higher accelerometer counts and ≥20 minutes of accumulated MVPA) was associated with a reduced likelihood of reporting short or long sleep that night (all P<0.001).

Conclusions—Findings support the bidirectional associations of accelerometer-determined sedentary behavior and PA with reported time-in-bed in older women. Future studies are needed to confirm findings with sleep actigraphy in older women.

Keywords

accelerometer; epidemiological methods; exercise; sleep; older women

INTRODUCTION

Changes in sleep patterns are thought to be part of the normal aging process.[1] While sleep needs remain relatively constant across the adulthood, older adults have more difficulty initiating and maintaining sleep.[2] Research has also shown that reduced sleep efficiency in older adults is associated with existing chronic diseases[3] and the medications that are used to treat these conditions.[4] There is growing evidence to suggest that both short (<6 hours) and long (>9 hours) sleep duration are associated with adverse health outcomes, including total mortality, cardiovascular disease, type 2 diabetes, obesity, and psychiatric illness.[5,6]

Regular physical activity (PA) has numerous health benefits including a reduced risk of premature death, coronary heart disease (CHD), stroke, hypertension, hyperlipidemia, type 2 diabetes, metabolic syndrome, depression, and maintenance of cognitive function in older adults.[7] Yet, older adult women are one of the least active subgroups in the U.S.[8] A reciprocal association of PA with sleep has also been hypothesized and evaluated.[9-12] Once an association is established, prevention strategies targeting older adult women to improve sleep hygiene may lead to improvements in physical activity levels and vice versa. However, there is a lack of consensus in the literature regarding the day-to-night associations of waking and non-waking behaviors. More specifically, does sleep duration at night impact sedentary behavior and PA the next day and/or does sedentary behavior and PA during the day influence sleep duration that night?

Historically, to examine these associations in population-based research, daily records or accounts of sedentary behavior, PA, and sleep duration were required. However, with recent advancements in technology, examining these associations with accelerometers is now possible. Accelerometers provide direct estimates of waking behaviors, including sedentary behavior and PA. Several strategies have been used to concurrently assess sedentary behavior, PA, and sleep duration using accelerometers to describe 24-hour periods. The first strategy is to use accelerometers that are capable of complete 24-hour monitoring. However, this technology is relatively new and can be challenging given the optimal monitor placement varies by behavior (waist during waking hours; wrist during sleep). The second option is to request participants to wear two monitors during data collection, which increases participant burden and study costs. The third option is to ask participants to wear the monitor only during waking hours and complete a wear time diary where times in and out of bed are recorded. Yet, this option requires participants to record time in and out of bed (rather than simply reporting non-wear time), representing an abbreviated sleep diary for subjective quantification of time-in-bed.

Recent studies examining the bidirectional associations of sedentary behavior and PA with sleep duration reflects these different measurement strategies. Using a single monitor worn on the waist during waking hours and wrist during sleep, Kishida et al. (2016)[13] found that an increase in daily physical activity was related to increases in total sleep time that night; however, there was a null association between MVPA and total sleep time among a sample of 103 midlife women. Higher total sleep time was also significantly related to lower MVPA the next day. Studies by Lambiase[9] and Mitchell[10] used two monitors, worn concurrently, to assess these behaviors. Lambiase et al.[9] examined these associations using data collected from the ActiGraph GT1M accelerometer and Actiwatch-64m in older women [n=143; aged 73.3 (1.7) years] and found that a 10% increase in daily accelerometer counts and accumulated moderate to vigorous intensity PA (MVPA) was associated with a 0.04 and 0.02% reduction in sleep duration that night. While statistically significant, the impact of PA on sleep duration was negligible. Mitchell et al.[10] used two ActiGraph GT3X+ monitors in 353 women, aged 21-75 years, and found no significant associations of sedentary behavior and MVPA with total sleep time that night or total sleep time with sedentary behavior or MVPA the following day. In a study by Baron et al.[14], 11 women (61.3 ± 4.1 years) with insomnia wore an Actiwatch-64 during sleep and completed an exercise log where they reported start time, duration, perceived exertion, and exercise type. Results showed that reported exercise was not significantly associated with sleep time that night. Also, there was no association between total sleep time and reported exercise duration the following day. Given this conflicting research, additional studies are needed to confirm these findings in larger study samples while utilizing clinically meaningful cut-points that reflect the (1) well-established U-shaped distribution[15,16] between sleep and mortality and chronic disease and (2) current physical activity guidelines for general health benefit to determine the impact of both short and long sleep on waking behaviors. Further, no previous studies have examined the bi-directional associations of light intensity physical activity and sleep and only the study by Mitchell and colleagues[10] explored potential day-to-day relations with sedentary behavior.

The primary objective of this study is to examine the bi-directional, day-to-day associations between accelerometer-derived PA, sedentary behavior, and participant recorded time-in-bed in the Women's Health Study (WHS), a large, population-based sample of older women. Similar to the assessment strategy employed by Baron et al.[14], and because sleep actigraphy data were not collected in the WHS, reported accounts of time-in-bed were used in the current study to estimate sleep duration. Subjective report of time-in-bed from sleep diaries has been shown to be comparable to objective sleep duration measurements.[17-20] Also in the current study, the longitudinal structure of the data collected over 7 consecutive days was retained and reported time-in-bed was used as an estimate of sleep duration[18], which were further classified as short [<7 hours (h)·night^{-1}], optimal (7-9 hours·night^{-1}), and long (>9 hours·night^{-1}) sleep to reflect National Sleep Foundation recommendations.[21] Further, due to the well-established benefits of a PA dose reflecting 150 minutes of MVPA per week on health and well-being[22], MVPA was further classified as <20 and ≥20 minutes per day to reflect 2008 Physical Activity Guidelines for Americans.[22] These categorical estimates were used specifically to enhance the interpretation of study findings.

PARTICIPANTS AND METHODS

Design overview and study participants

Participants are from the WHS, a completed randomized trial (1994 to 2004) testing the benefits and risks of low-dose aspirin and vitamin E for primary prevention of cancer and cardiovascular disease (CVD) in 39,876 U.S. women aged ≥ 45 years.[23,24] When the trial ended, women were invited to continue in an observational follow-up study, and 89% of those alive consented. In 2011, an ancillary study was initiated with the primary goal to examine the associations of accelerometer-determined PA and sedentary behavior on health outcomes.

As of January 1 2014, 26,978 women had been invited to participate in the accelerometer ancillary study and 23,934 (88.7%) responded. Of the 23,934, 1,204 (5.0%) were ineligible because they were unable to walk independently outside the home (eligibility criterion). Among the remaining 22,730 women, 16,689 (73.4%) agreed to participate. Participants provided written informed consent and the study was approved by the Brigham and Women's Hospital's institutional review board committee.

Participants included in the ancillary study were mailed an accelerometer and asked to wear it on the hip for 7 days during waking hours. They also completed a wear time diary, indicating which days the monitor was worn, and returned both the accelerometer and diary by mail. Women were then mailed a brief PA questionnaire; inquiring about leisure time PA during the time the monitor was worn. As of May 2014, 14,796 women had returned their accelerometers, which represent those potentially eligible for these analyses.

Data collection

Participant characteristics—WHS participants complete annual questionnaires that ask about socio-demographic characteristics, health behaviors, and medical history. Date of birth, race, and education were obtained from the baseline questionnaire at the start of the WHS trial, while information on weight, height, self-rated health, and smoking for the present analysis were from the 2011 follow-up questionnaire. Data on cancer, CVD, and diabetes were obtained throughout the WHS from self-reports and validated against medical records.

Accelerometer-determined PA and sedentary behavior—Women were mailed a tri-axial accelerometer (ActiGraph GT3X+) and were asked to wear it on the hip, secured by an adjustable elastic belt, for 7 consecutive days during all waking hours. Monitors were initialized to begin data collection one day prior to the estimated delivery date and continued to collect data until data were downloaded. Raw accelerometer data were sampled at 30 Hertz (Hz) and data were reintegrated and expressed as 60-second epochs. ActiGraphs have been extensively validated.[25]

Accelerometer data, using all three axes, were screened for periods of wear[26] and summary estimates were derived using the vertical axis data. Total accelerometer counts ($ct \cdot d^{-1}$) were calculated using summed daily counts detected over wear periods. Time spent per day ($min \cdot d^{-1}$) in different intensity levels were estimated using established count threshold values [sedentary (0-99 $ct \cdot min^{-1}$), light- (100-1951 $ct \cdot min^{-1}$), moderate- (1952-5724 $ct \cdot min^{-1}$), and vigorous- (≥5725 $ct \cdot min^{-1}$) intensity].[27] The MVPA estimate included every minute above the 1952 $ct \cdot min^{-1}$ threshold (accumulated MVPA). For multivariable models, total accelerometer counts were expressed per every 1,000 $ct \cdot d^{-1}$, sedentary time and light intensity PA estimates were expressed per every 10 minutes, and accumulated MVPA as the proportion of participants <20 or ≥20 $min \cdot d^{-1}$ as it represents a daily exercise dose that approximates 2008 PA Guidelines.[22] Participants who wore the accelerometer <4 days of ≥10 hours of wear per day were excluded from further analysis.

Time-in-bed—Participants recorded the time in and out of bed for sleep in the wear time diary, which were used as our estimate of sleep duration ($min \cdot d^{-1}$). For multivariable models, categories of time-in-bed were created and defined as short, optimal, and long sleep (<7, 7-9, and >9 $h \cdot night^{-1}$, respectively) based on National Sleep Foundation recommendations.[21]

Data management and statistical methods

Two analytic datasets were created to capture the day-to-day, bidirectional associations of sedentary behavior and PA with time-in-bed. The first dataset included each day with the preceding night's time-in-bed to examine if time-in-bed at night impacts sedentary behavior and PA the next day (i.e., reported time in bed on night i was aligned with sedentary behavior and PA on day i + 1). The second dataset included each day with time-in-bed that following night to evaluate if sedentary behavior or PA during the day influences time-in-bed that night (i.e., sedentary behavior and PA on day i aligned with time in bed on night i).

Descriptive univariate analyses were conducted on measured parameters and all continuous estimates were assessed for normality using histograms and Kolmogorov-Smirnov tests, for each dataset, separately. Normally distributed variables were reported as means and SDs and non-normal distributed variables as medians with 25th and 75th percentiles. Frequencies and percentages were noted for categorical variables. PA, sedentary behavior, and time-in-bed estimates were also described, stratified by day of the week (e.g., Monday). When results were stratified by day of observation of monitor wear (e.g., Day 1), findings were similar (data not shown).

Using each dataset, separate generalized linear models with repeated measures (also known as multi-level models) were constructed to examine the adjusted day-to-day associations of PA and sedentary behavior with categories reflecting the previous night time-in-bed (four models) and that night's time-in-bed (four models). This modeling strategy incorporates the day-to-day variability within participants (level 1) as well as the variability between participants (level 2).

All models were adjusted for: age (years), education level (<bachelor's degree, bachelor's degree, and graduate school), body mass index (BMI; <18.5, 18.5 to 24.9, 24.9 to 29.9, and

≥30 kg/m^2) and self-rated health (excellent, very good, good, fair, and poor), which were selected a priori based on established associations with the exposure and/or outcome variables. To examine if time-in-bed categories at night predicted total accelerometer counts, sedentary behavior, and light intensity PA the next day, models with normal link and an autoregressive covariance structure were used. For MVPA categories, a cumulative logit link was used. To determine if total accelerometer counts, sedentary behavior, light intensity PA or MVPA categories during the day predicted time-in-bed categories that night, models with cumulative logit link were also used. For all generalized repeated linear, multi-level models, optimal sleep served as the reference group. All statistical significance tests were two-sided with the type I error level set at $P<0.05$. All analyses were generated with SAS/STAT software, version 9.4 (Cary, NC).

RESULTS

Of the 14,796 women who returned their accelerometer, 245 were excluded due to technical error with the accelerometer; 1,850 women who did not return a diary, 2,197 women who did not return a PA questionnaire, 389 women who did not have ≥4 days of ≥10 hours of wear per day (convention for valid accelerometer data), and 29 had missing time-in-bed data were also excluded resulting in an analytic sample of 10,086 participants. The mean age and BMI was 71.6 [standard deviation (SD): 5.7] years and 26.1 (SD: 4.9) kg/m^2, respectively, and the majority of participants were white (96.7%) (Table 1).

Time-in-bed predicting PA and sedentary behavior the next day

Table 2 presents the median (25th, 75th percentile) daily and weekly summary PA, sedentary behavior, and reported time-in-bed, including times corresponding to reported time in and out of bed, using the first dataset that includes the previous night time-in-bed with PA and sedentary behavior the next day. Across the 7-days of observation, median recorded time in bed (hh:mm), time out of bed (hh:mm), and total time-in-bed (min·d^{-1}) were consistent among study participants. However, total time in bed (min·d^{-1}) appeared slightly longer on weekend days, which was likely due to getting out of bed a reported 10-15 minutes later than recorded on weekdays. Accelerometer data, including monitor wear time (min·d^{-1}) and time spent sedentary and in light- moderate- and vigorous- intensity (min·d^{-1}) were also consistent across observation days.

Generalized linear (multi-level) models with repeated measures for time-in-bed predicting PA and sedentary behavior the next day are shown in Table 3. Across observation days, short sleep was associated with an average of 5,500 [standard error (SE): 1,352] higher accelerometer counts the next day compared to optimal sleep ($P<0.001$), after adjustment for covariates. Further, compared to optimal sleep, short sleep was associated with an average of 46.5 (SE: 1.5) and 11.9 (SE: 1.2) additional min·d^{-1} of time spent sedentary and in light intensity PA the next day, respectively. There was no difference in the odds of ≥20 min·d^{-1} of accumulated MVPA with short sleep compared to optimal sleep. After adjustment for covariates, long sleep was associated with an average of 12,680 (SE: 946) fewer total accelerometer counts, 46.5 (SE: 1.5) and 11.9 (SE: 1.2) additional min·d^{-1} of time spent sedentary and in light intensity PA, respectively, and a reduced odds of engaging in ≥20 min·d^{-1} of accumulated MVPA the following day (OR: 0.73 (95% CI: 0.67, 0.78) compared to optimal sleep (all $P<0.001$).

Sedentary behavior and PA predicting time-in-bed that night

Using the second analytic dataset, the univariable results were similar to those previously reported (data not shown). When compared to optimal sleep, higher total accelerometer counts and time spent sedentary or in light intensity PA was associated with a reduced likelihood of short or long sleep that night (all $P<0.05$), after adjustment for covariates. After adjustment, participants classified in the ≥20 min·d^{-1} of accumulated MVPA category were 16% less likely to report short or long sleep that night when compared to optimal sleepers (Table 4).

DISCUSSION

Findings support the bidirectional, day-to-day associations of accelerometer-determined sedentary time and physical activity with reported time-in-bed in older women. After adjustment for covariates, short sleep was associated with additional time spent sedentary and light intensity PA the next day, while long sleep decreased the likelihood of engaging in health promoting levels of accumulated MVPA the following day. Further, after adjustment for covariates, additional PA during the day (i.e., higher accelerometer counts and ≥20 minutes of accumulated MVPA) was associated with a reduced likelihood of reporting short or long sleep that night.

The technological capabilities of contemporary accelerometers and related methodologies provide unique opportunities to clarify the associations of habitual, lifestyle behaviors within the context of the participant's home environment. Examining these associations is particularly intriguing and could influence strategies that promote PA and/or good sleep hygiene to improve health in older women. This study contributes to this burgeoning area of research by prospectively exploring the bidirectional, day-to-day associations between waking and non-waking behaviors using cut-points for reported time-in-bed, our proxy measure of sleep duration, that reflect national recommendations.[21] Further, while the majority of previous research in this area has specifically focused on relations between MVPA and sleep duration, findings from the current study also provides compelling new information about bidirectional associations with time spent sedentary and in light intensity physical activity.

Does sleep duration at night impact sedentary behavior and PA the next day?

Conceptually, within the context of a 24-hour day, less time sleeping would result in additional waking time, the following day, where an individual can choose to either be inactive or active during more discretionary periods. The current study findings support this notion in that, after adjustment, short sleep was associated with higher total accelerometer counts the following day compared to those reporting optimal sleep. However, based on our findings, these additional accelerometer counts were likely spent sedentary or in light intensity PA, such as housework or self-care. While light intensity activity contributes to overall daily energy expenditure and the promotion of energy balance, the health benefits in relation to risk of mortality or development of chronic disease, are still unknown.[7,28] Interestingly, short sleep was not associated with the likelihood of engaging in ≥20 min·d^{-1} of accumulated MVPA the following day. Therefore, while sleeping less at night results in additional waking time the following day, participants did not spend this extra time engaged in health promoting activity.

Conversely, additional time-in-bed (i.e., long sleep) would conceptually result in less waking time, and perhaps less discretionary time the next day; a notion supported by our findings. When compared to optimal sleep, long sleep was associated with fewer accelerometer counts and less time spent sedentary and in light intensity activity the following day. Long sleep was also associated with a reduced likelihood of ≥20 minutes of accumulated MVPA the following day. These findings suggest that there may be a threshold where the proposed restorative features of sleep (e.g., energy conservation, tissue repair and regeneration)[29] does not increase the probability of engaging in health promoting PA the next day. The finding that long sleep at night was associated with less sedentary time is interesting as it contradicts previous hypotheses suggesting that long sleep and/or high sedentary time may be indicators of existing disease[30-32], particularly in older adults. However, it is also quite possible that this observed association may have resulted from examining these bidirectional associations within the context of 24-hour cycles (i.e., more sleep = less waking hours with which to be sedentary).[33]

The findings from the current study contrast those previously reported by Lambiase et al[9] and Mitchell et al.[10] More specifically, both showed no association between sleep duration and MVPA the next day. However, a recent study by Kishida et al.[13] found a similar association such that increased total sleep time was significantly associated with reduced time spent in MVPA the following day. In the current study, we found that short sleep was associated with higher sedentary time the following day; a finding that reflected those reported by Booth et al.[34] However, in this study of 48 men and women (aged 21 to 40 years) at risk for type 2 diabetes, short sleep (<6 hours per night) was also statistically significantly associated with 27% fewer daily activity counts (P=0.04) and significantly less time spent in accumulated MVPA (−43 min·d^{-1}); findings that were not observed in our study. In the paper by Mitchell et al.[10], total sleep duration was not significantly related to sedentary time in their study sample of adult women (mean age: 55.5 ± 10.2 years).

Does sedentary behavior and PA during the day influence sleep duration that night?

The findings from the current study support the relations of time spent sedentary and active during the day with sleep that night. More specifically, increases in total accelerometer counts and time spent sedentary or in light intensity PA during the day were statistically significantly associated with a lower odds of being classified with short or long sleep that night. Further, if an individual engaged in ≥20 minutes of accumulated MVPA during the day, there were also less likely to report short or long sleep. Yet, it is difficult to discern whether these findings support or conflict with the results reported by Lambiase et al.[9] and Kishida et al.[13] given that continuous estimates of sleep duration were used in analysis rather than categories reflecting National Sleep Foundation recommendations. Interestingly, Mitchell and colleagues[10] found no significant associations of sedentary behavior or MVPA on total sleep time. Among a small sample of women with insomnia (n=11), Baron et al[14] also found no statistically significant association between reported exercise duration (i.e., time spent in MVPA) and sleep during the corresponding night; however, this may have been the result of a small sample size and limited statistical power. Interestingly, results of the current study suggested a significant association between higher sedentary time and reduced risk of short or long sleep. This finding lends support to the notion that lifestyle risk behaviors co-occur.[35,36] Future studies should further explore if this particular behavioral profile predicts underlying or existing disease.

The strengths of the study included use of a large and well-characterized cohort of older women. Further, accelerometers are capable of detecting movement-based activity across a broad intensity spectrum, which provided the unique opportunity to additionally explore the reciprocal associations of sedentary and light intensity PA with sleep duration. Despite these strengths, there are limitations to consider. First, the analytic sample was predominantly white and participants were originally enrolled in an experimental study, which impacts generalizability. Second, sleep actigraphy measures of sleep duration and quality were not collected in the current study. Instead, times that correspond to time in and out of bed were used to estimate sleep duration. While not objectively-determined, reported time-in-bed has been shown to be an acceptable estimate of total sleep duration.[18] Future studies are needed to confirm these findings with sleep actigraphy. Finally, the WHS did not include self-reported measures of sleep complaints (e.g., problems initiating or maintaining sleep), which may have provided additional context to these findings.

CONCLUSIONS

The National Sleep Foundation recommends that adults accumulate 7-9 hours of sleep per night. An estimated 50-70 million adults report chronic sleep or wakefulness disorders.[2] Exercise is one of the top 10 strategies recommended by the National Sleep Foundation to promote good sleep hygiene; a recommendation that is largely supported by the findings from the present study.[37] In this study, the acute, day-to-day effects were explored. However, PA may play a larger role in reducing the likelihood of chronic sleep deprivation (i.e., sleep debt), which may be more related to mortality and chronic disease. Given that accelerometers are now capable of collecting data over longer periods of observation, future studies should examine the effect of chronic short or long sleep on time spent sedentary and active.

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Table 1

Descriptive Characteristics of Women's Health Study (n=10,086).

	n	Mean (SD); Median (25th, 75th percentile), or n (%)
Participant Characteristics		
Age	10,086	71.6 ± 5.7
Race, %	10,013	
White / Non-Hispanic		96.7
Non-White		3.3
Education, %	9,917	
<Bachelor's Degree (e.g., LPN)		50.2
Bachelor's Degree		26.0
Graduate Degree		23.8
BMI, kg/m^2	9,982	26.1 ± 4.9
BMI, %	9,982	
Underweight (<18.5 kg/m^2)		2.0
Normal (18.5 to 24.9 kg/m^2)		45.0
Overweight (25 to 29.9 kg/m^2)		34.6
Obese (≥30 kg/m^2)		18.4
Self-rated health, %	9,853	
Excellent		26.8
Very good		52.5
Good		18.5
Fair		2.1
Poor		0.1
Cigarette smoker, %	10,024	
Yes		3.2
No		96.8
Self-reported Physical Activity, MET·hr·wk^{-1}	10,086	17.0 (5.6, 32.2)
Self-reported Physical Activity, min·wk^{-1}	10,086	221.0 (79.0, 423.5)
CHD, %	10,086	
Yes		2.9
No		97.1
Cancer, %	10,086	
Yes		11.0
No		89.0
Type 2 Diabetes, %	10,086	
Yes		8.7
No		91.3

LPN = Licensed Practical Nurse; BMI = body mass index; CHD = coronary heart disease

Table 2

Descriptive Statistics for Daily and Weekly Summary Estimates Reflecting Reported Time-in-bed Predicting Physical Activity and Sedentary Behavior the Next Day.[a]

Sleep	**Sunday to Monday**	**Monday to Tuesday**	**Tuesday to Wednesday**	**Wednesday to Thursday**	**Thursday to Friday**	**Friday to Saturday**	**Saturday to Sunday**	**Weekly Summary**
	n=8,525	**n=7,240**	**n=8,219**	**n=8,534**	**n=8,059**	**n=7,877**	**n=7,864**	**n=10,086**
	Median (25th, 75th %ile)	**Median (25th, 75th %ile)**	**Median (25th, 75th %ile)**	**Median (25th, 75th %ile)**	**Median (25th, 75th %ile)**	**Median (25th, 75th %ile)**	**Median (25th, 75th %ile)**	**Median (25th, 75th %ile)**
Reported time in bed (at night), hh:mm	22:30 (21:54,23:15)	22:30 (21:55,23:15)	22:30 (21:53,23:15)	22:30 (21:55,23:15)	22:15 (21:55,23:15)	22:35 (22:00,23:21)	22:32 (22:00,23:24)	22:34 (21.58,23:11)
Reported time out of bed (in the morning) hh:mm	7:00 (6:12,7:45)	7:00 (6:06, 7:45)	7:00 (6:05,7:40)	7:00 (6:10, 7:40)	7:00 (6:10, 7:45)	7:15 (6:30,8:00)	7:10 (6:30,8:00)	7:01 (6:24,7:42)
Total Time-in-bed, min·d^{-1}	503 (455, 550)	500 (454, 545)	500 (452, 550)	501 (455, 550)	505 (455, 550)	515 (470, 568)	510 (465, 560)	506 (469, 545)
Physical Activity (next day)	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**	**Weekly Summary**
Accelerometer Wear Time, min·d^{-1}	905 (845, 960)	908 (847, 963)	909 (848, 963)	908 (848, 965)	907 (846, 964)	890 (826, 947)	888 (824, 946)	900 (850, 942)
Total Counts (per 10,000), ct·d^{-1}	19.0 (12.6, 27.4)	18.2 (12.2, 26.4)	18.2 (12.4, 26.6)	18.2 (12.2, 26.3)	18.4 (12.4, 26.8)	18.1 (12.0, 27.0)	15.4 (10.3, 23.1)	18.9 (13.4, 25.6)
Sedentary, min·d^{-1}	587 (505, 663)	594 (512, 671)	593 (512, 672)	593 (511, 673)	591 (506, 671)	577 (492, 654)	606 (521, 685)	590 (526, 651)
Light intensity, min·d^{-1}	291 (228, 362)	288 (225, 358)	291 (227, 357)	288 (223, 359)	291 (227, 362)	287 (222, 360)	259 (198, 327)	288 (237, 343)
Moderate intensity, min·d^{-1}	7 (2, 24)	6 (1, 22)	6 (2, 22)	6 (1, 22)	6 (1, 22)	6 (1, 21)	4 (1, 16)	9 (3, 22)
Vigorous intensity, min·d^{-1}	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
Accumulated MVPA[b], min·d^{-1}	7 (2, 25)	6 (1, 22)	6 (2, 22)	6 (1, 22)	6 (1, 22)	6 (1, 21)	4 (1, 16)	9 (3, 22)

ct·d^{-1} = counts per day; MVPA = Moderate to vigorous intensity physical activity; min·d^{-1} = minutes per day; %ile = percentile

[a]Reported time-in-bed obtained via recorded times corresponding to time in bed at night and out of bed the next morning; sedentary behavior and physical activity data were assessed via accelerometers.

[b]Accumulated MVPA were computed as every minute ≥1952 counts per minute threshold.

Table 3

Multilevel, Generalized Linear Models with Repeated Measures for Reported Time-in-bed Predicting Physical Activity and Sedentary Behavior the Next Day.[a,b,c]

	Physical Activity and Sedentary Behavior												
	Total accelerometer counts, per 1,000 ct·d^{-1}			**Sedentary, per 10 min·d^{-1}**			**Light Intensity, per 10 min·d^{-1}**			**MVPA, % < 20 or ≥20 min·d^{-1}**			
	Estimate	**Standard Error**	***p* value**	**Estimate**	**Standard Error**	***p* value**	**Estimate**	**Standard Error**	***p* value**	**Estimate**	**Standard Error**		***p* value**
Intercept	655.1	9.5	<0.001	30.1	0.96	<0.001	58.1	0.81	<0.001	5.1	0.24		<0.001
Time-in-bed													
	Estimate	Standard Error	*p* value	Estimate	Standard Error	*p* value	Estimate	Standard Error	*p* value	Odds Ratio	95% CI		*p* value
<7 h·d^{-1}	5.5	1.4	<0.001	4.7	0.15	<0.001	1.2	0.12	<0.001	0.94	0.86	1.03	0.16
>9 h·d^{-1}	−12.7	0.95	<0.001	−3.4	0.11	<0.001	−1.6	0.08	<0.001	0.73	0.67	0.78	<0.001

CI = confidence interval; ct·d^{-1} = counts per day; h·d^{-1}= hours per day; min·d^{-1} = minutes per day; MVPA = Moderate to vigorous intensity physical activity

[a]Reported time-in-bed obtained via recorded times corresponding to time in bed at night and out of bed the next morning; sedentary behavior and physical activity data were assessed via accelerometers.

[b]Reference category is 7-9 hours of sleep per night.

[c]Models adjusted for: age (years), education (<Bachelor’s Degree, Bachelor’s Degree, and Graduate School), body mass index (BMI) categories (underweight, overweight, obese), self-rated health status (poor, fair, good, very good).

Table 4

Multi-level, Generalized Repeated Linear Regression Models for Physical Activity and Sedentary Behavior Predicting Reported Time-in-bed that Night.[a,b,c]

		Time-in-bed					
		<7 h·d^{-1}			>9 h·d^{-1}		
Physical Activity and Sedentary Behavior		**Estimate**	**Standard Error**	***p* value**	**Estimate**	**Standard Error**	***p* value**
Total accelerometer counts, per 1,000 ct·d^{-1}	*Intercept*	−1.34	0.18	<0.001	0.37	0.18	0.04
		−0.001	0.0001	<0.001	−0.001	0.0001	<0.001
Sedentary, per 10 min·d^{-1}	*Intercept*	−1.66	0.17	<0.001	0.05	0.17	0.79
		−0.001	0.001	<0.001	−0.001	0.001	<0.001
Light intensity, per 10 min·d^{-1}	*Intercept*	−1.50	0.18	<0.001	0.20	0.18	0.26
		−0.006	0.001	<0.001	−0.006	0.001	<0.001
MVPA, % < 20 or ≥20 min·d^{-1}	*Intercept*	−1.61	0.17	<0.001	0.09	0.17	0.58
		Odds Ratio	95% CI	*p* value	Odds Ratio	95% CI	*p* value
		0.84	0.79, 0.88	<0.001	0.84	0.79, 0.88	<0.001

CI: confidence interval; ct·d^{-1} = counts per day; h·d^{-1}= hours per day; min·d^{-1} = minutes per day; MVPA = Moderate to vigorous intensity physical activity

[a]Reported time-in-bed obtained via recorded times corresponding to time in bed at night and out of bed the next morning; sedentary behavior and physical activity data were assessed via accelerometers.

[b]Reference category is 7-9 hours of sleep per night.

[c]Models adjusted for: age (years), education (<Bachelor's Degree, Bachelor's Degree, and Graduate School), body mass index (BMI) categories (underweight, overweight, obese), self-rated health status (poor, fair, good, very good).