



Original Article

Objective changes in activity levels following sleep extension as measured by wrist actigraphy



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ABSTRACT

Objective/Background: It is widely established that insufficient sleep can lead to adverse health outcomes. Paradoxically, epidemiologic research suggests that individuals who report habitual nightly sleep greater than 9 h also are at risk for adverse health outcomes. Further, studies have shown that long sleepers have decreased activity levels, which may partially explain the relationship between long sleep duration and mortality. The influence of sleep extension (longer time in bed) on levels of daily activity has not yet been established. The current study examined whether a week of sleep extension altered activity levels within the subsequent daily waking active and sleep period in order to determine whether increased time in bed indeed is related to decreased activity levels.

Methods: A total of 26 healthy volunteers wore wrist accelerometer devices (Actiwatch 2.0, Philips) in order to objectively measure sleep and activity for six days during their normal schedules and for six days during a sleep extension (10 h time in bed) intervention.

Results: There were no significant or clinically-relevant differences in 24-h activity or activity during the active or sleep period between baseline and sleep extension conditions. There were no main or interaction effects of day and condition when daily activity counts were compared between baseline and sleep extension conditions for the 24 h period (Day: $F_{(5, 21)} = 1.92$, $p = 0.12$; Condition: $F_{(1,25)} = 2.93$, $p = 0.09$; Day by Condition: $F_{(5,21)} = 0.32$, $p = 0.83$), Active Waking Period (Day: $F_{(5,25)} = 1.53$, $p = 0.18$; Condition: $F_{(1,25)} = 0.26$, $p = 0.61$; Day by Condition: $F_{(5,21)} = 0.55$, $p = 0.74$) or Nightly Sleep (Day: $F_{(5,21)} = 0.86$, $p = 0.51$; Condition: $F_{(1,25)} = 1.78$, $p = 0.19$; Day by Condition: $F_{(5,21)} = 0.79$, $p = 0.56$) periods. In contrast, there was a main effect of condition when examining sleep duration by day between conditions (Day: $F_{(5,21)} = 1.60$, $p = 0.16$; Condition: $F_{(1,25)} = 167.31$, $p < 0.001$; Day by Condition: $F_{(5,21)} = 2.31$, $p = 0.07$), such that sleep duration was longer during the sleep extension condition.

Discussion: Sleep duration increased during six days of a sleep extension protocol but activity levels remained similar to their baseline (normal) sleep schedule. The current findings suggest that extending time in bed alone does not alter waking activity counts in young healthy adults. The link between extended sleep and adverse health outcomes may be attributable to other phenotypic factors, or other biological correlates of extended sleep and poor health.

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1. Introduction

Insufficient sleep is associated with adverse health and performance outcomes, including decreased cognitive performance [1], impaired neuroendocrine and metabolic function [2,3], increased pain sensitivity [4] and impaired immune function [5,6]. A necessary countermeasure to sleep loss is to extend sleep either in anticipation of, or during recovery from, a period of insufficient

sleep. Most work that has focused on sleep extension has been performed in the context of recovery sleep, following an acute period of sleep loss. Studies in healthy adults on prophylactic sleep extension, conceptualized as the volitional lengthening of nighttime sleep duration in the absence of greater-than-normal homeostatic sleep pressure, usually in preparation for an upcoming period of sleep loss, is far less common. The few studies that examine prophylactic sleep extension, (or “sleep banking”) suggests that extending sleep decreases vulnerability to the effects of sleep deprivation [7,8].

Notably, there is an epidemiological link between habitual long sleep duration, low levels of physical activity and overall mortality [9,10]. Furthermore, there is a possibility that prolonged sleep duration promotes sedentary behavior, which could counteract the potential health benefits of sleep banking. While this possibility has not been extensively investigated in a research setting, individuals who would benefit from extending their sleep (such as shift workers, medical care providers or Service members) may view increased time in bed negatively or in connotation with sickness, laziness or a sedentary lifestyle and therefore be reluctant to adapt a potentially-beneficial lifestyle change. These concerns cannot be confirmed or alleviated without investigating the impact of increasing sleep time on activity levels. In order to thoroughly investigate the effects of prophylactic sleep extension on healthy adults, it is therefore important to estimate if and how sleep extension impacts levels of physical activity.

In this study, in order to objectively measure sleep and activity healthy volunteers wore wrist actigraphy devices (Actiwatch 2.0, Philips) during their normal daily schedules. Determination of sleep/wake patterns by actigraphy has been validated against polysomnography and sleep diary [11,12]. A few studies have investigated the utility of these devices to measure waking movement behavior [13,14] and have shown that Actiwatch 2.0s can provide a reasonable estimate of activity. However, the analysis of physical activity levels from wrist-worn actigraphy should still be considered exploratory and in its infancy.

Volunteers then extended their nightly time in bed to 10 h over a six night period. While volunteers slept in the laboratory during the sleep extension period, they were free to leave the laboratory during the day and engage in their normal daily schedules while being continually monitored via actigraphy. The current study aims to investigate whether, and the extent to which, a week of sleep extension alters activity levels across the 24-h day. Moreover, the current study addresses the impact of a week of sleep extension on activity levels during the daily waking active period and sleep period in order to determine whether increased time in bed is related to changes in activity levels.

2. Methods

This study was approved by the Walter Reed Army Institute of Research Human Use Review Committee and was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki.

2.1. Participants

Twenty-eight healthy volunteers were included in this study. Participants were recruited via flyers posted at local colleges, universities, and military installations. The Institutional Review Board at the Walter Reed Army Institute of Research approved the study. Participants provided written informed consent and were compensated monetarily for their participation. Study participants first completed questionnaires to determine eligibility based on physical and psychological health; sleep habits and chronotype

(described in more detail below). In order to reduce inter-subject variability in nighttime sleep, participants who self-reported habitual nightly sleep amounts outside the target range of 6–9 h nighttime, lights-out times earlier than 2100 h on average during weeknights, morning wake-up times later than 0900 on average during weekdays, and habitual napping more than three times a week were excluded. Participants who reported consuming more than 400 mg of caffeine daily, on average, were also excluded. If eligible for our study, participants underwent a physical examination including evaluations of blood and urine samples to determine general health, including pregnancy and drug use. Participants with a history of neurological disorders, chronic pain, heavy alcohol use defined as 14 drinks or more per week, tobacco use and psychiatric disorders were also excluded. Additionally, a score ≥ 41 on either side of the State Trait Anxiety Inventory (STAI) [15] a score ≥ 13 on the Beck Depression Inventory (BDI) [16], and scores < 31 or > 69 on the Horne Ostberg Morningness-Eveningness Questionnaire (MEQ) [17] (indicative of extreme morning or evening preference) rendered the participants ineligible to participate in the study. After the medical examination, participants were scheduled to complete a one night in-laboratory overnight sleep screening, where sleep and breathing were monitored using a portable wearable device (Embletta MPR PG, Natus, Pleasanton, CA) to rule out sleep disorders.

2.2. Experimental design

This study was a part of a larger experiment aimed at testing the impact of sleep extension and subsequent sleep deprivation on different health and performance markers [18,19]. Volunteers wore actigraphs for the entire duration of the study. Following enrollment (Day 1), volunteers were instructed to maintain their normal sleep/wake routines from Day 2 to Day 14 (Baseline). On Days 15 and 16, volunteers reported to the Sleep Research Center (SRC) at 1900 in order to acclimate to the laboratory environment and were provided a scheduled sleep opportunity of 8 h time in bed (TIB) (2300-0700). Night 17 began the Sleep Extension phase of the study. During this period (Night 17 – Day 22), volunteers reported to the SRC at 1900 and were provided a scheduled sleep opportunity of 10 h TIB (2100-0700). Further, during the hours of 1900 until bedtime during the Sleep Extension phase, physical exercise was not allowed. Following scheduled sleep opportunities, volunteers were released from the SRC and were not given any instructions about changing or maintaining their usual daytime schedules.

2.3. Actigraphy and activity monitoring

A wrist actigraph (Actiwatch 2.0 Philips Respironics, Murrysville, PA) was worn on participant's non-dominant wrist. Participants, as part of compliance to study procedures, wore the device on the wrist continuously. Activity data was collected in 30-s epochs and sleep-wake determination was computed by the Actiware 5.59 scoring algorithm. Minor rest intervals (ie, naps) were automatically determined by Actiware 5.59 minor rest interval scoring algorithm. Mean activity counts per minute (AC/min) for Sleep periods (the time period between sleep onset and offset), Active periods (the time period between sleep offset and subsequent sleep onset) and 24 h period (0000–0000) were exported from the Actiware software. Moreover, mean and total activity counts (AC) for each day was exported in hourly bins (0000–2300 h) in order to model changes in activity across the 24 h period. Sleep and activity data from each participants' two week at-home Baseline (Day 2–14) were averaged by day of the week (such that the first Tuesday and second Tuesday were averaged together, etc.). The resulting averages were matched to data from the Sleep

Extension period (Day 17–22) based on day of the week (such that the Tuesday average from Baseline was matched to Tuesday of the Sleep Extension period; the Baseline Wednesday average was matched to Sleep Extension Wednesday, etc.) and hour of day.

2.4. Statistical analysis

Repeated measures analysis of variance tests were used to compare sleep (Bedtime, Wake Time, and Sleep Duration) and activity measures (Average AC/min, an output measure exported from Philips Actiware, and Total AC/period duration in minutes for Sleep, Active and 24 h period, calculated as the total AC collected during a given Sleep, Active or 24 h period divided by the length of that given period in minutes) between conditions and days of the week using SPSS 24 (SPSS, Inc., Chicago, IL). An exploratory Pearson's chi-square analysis further investigated sedentary behavior between conditions by categorizing average AC/min values for Active, Sleep and 24 h as either above or below 100 (AC/min < 100⁸) to create a binary variable. We compared the median and distribution of average and total AC by hour between conditions via non-parametric independent samples Mann Whitney U Test. Independent samples t-test were run to confirm differences in average and total AC by hour.

3. Results

Of the 28 individuals that participated in this study, 17 were males. The average age of the sample was 24.25 years old (SD = 5.26). The racial background of the individuals included in this study was diverse, with only 10 individuals self-identifying themselves as exclusively white or Caucasian. All participants wore the actigraphy devices continuously throughout the Baseline and Extension periods with no discernable periods of removal. Two participants were excluded from the current analyses for having irregular sleep schedules during the Baseline data collection. The analyses between conditions is therefore N = 26.

3.1. Between-condition differences in weekly average sleep and activity

As shown in Table 1, there were no significant differences in Average AC/min (the average of all valid activity counts/minute for a given interval) or Total AC/period (the sum of all valid activity

counts recorded during a given interval) between the baseline and sleep extension conditions with the exception of a trend towards significance for 24 h Average AC/min (see Table 1). Specifically, average activity across 24 h was 207.95 ± 41.91 AC/min during Baseline and 193.07 ± 39.40 AC/min during Sleep Extension. Sleep duration was longer during Sleep Extension (see Table 1). Bedtimes and Wake times, as determined by the Actiware 5.59 scoring algorithm, were earlier during Sleep Extension compared to Baseline (see Table 1). Moreover, there were no main or interaction effects of day or condition when AC were compared by day between Baseline and Sleep Extension conditions for the Sleep period, Active period or 24 h period (all p > 0.20). In contrast, there was a main effect of condition for sleep duration (Day: $F_{(5,21)} = 1.60, p = 0.16$; Condition: $F_{(1,25)} = 167.31, p < 0.001$; Day by Condition: $F_{(5,21)} = 2.31, p = 0.07$). Exploratory chi-square analysis indicated fewer incidence of Average AC/min < 100 for 24 h periods ($\chi^2_{(1)} = 7.15; p = 0.008$) during Sleep Extension. Specifically, there were seven incidences of Average AC/min < 100 for 24 h periods during the Baseline condition compared to no incidences of Average AC/min < 100 for 24 h periods for the Sleep Extension condition. Average AC/min < 100 during the Sleep period and the Active period was indistinguishable between conditions ($\chi^2_{(1)} = 1.00; p = 1.00$).

3.2. Between-condition differences in hourly average and total activity counts

Mean and total AC by hour were highly correlated. Mean hourly AC by condition is shown in Fig. 1. The median hourly mean or total AC were not significantly different between conditions (both p = 0.96). However, the distribution of mean and total AC were different (both p = 0.022). Specifically, there was more activity in Baseline compared to Sleep Extension for hours 0000–0600 (all p < 0.05) and for hours 2000–2300 (all p < 0.05). Activity was greater during Sleep Extension in the early morning (0700–0900; all p < 0.05) and early evening (1700–1800; all p < 0.05).

4. Discussion

Average levels of activity were not statistically different during a six-day sleep extension period compared to habitual sleep conditions (baseline). Participants were less active between the hours of midnight and 0600 during sleep extension, but were more active in the morning and in the early evening, most likely due to the

Table 1
Average weekly differences in sleep and activity between baseline and sleep extension (As determined by Actiware 5.59 scoring algorithm).

	Baseline (M ± SD)	Sleep Extension (M ± SD)	Statistics (F-value, P-value)
Bedtime (hh:mm)	00:28 ± 1:56	21:17 ± 0:27	$F_{(1,25)} = 118.13, p < 0.001^{**}$
Wake-time (hh:mm)	8:09 ± 2:03	6:41 ± 0:36	$F_{(1,25)} = 21.74, p < 0.001^{**}$
Sleep Duration (minutes)	452.14 ± 86.97	562.78 ± 45.42	$F_{(1,25)} = 167.31, p < 0.001^{**}$
Sleep Period [Interval]			
Average AC/Min	12.68 ± 5.07	12.36 ± 5.07	$F_{(1,25)} = 1.78, p = 0.19$
Total AC/Sleep Period	12.01 ± 5.32	12.56 ± 6.63	$F_{(1,25)} = 0.46, p = 0.50$
Active Period [Interval]			
Average AC/Min	311.87 ± 60.41	320.02 ± 62.50	$F_{(1,25)} = 0.26, p = 0.61$
Total AC/Active Period	306.34 ± 128.94	323.54 ± 89.62	$F_{(1,25)} = 2.09, p = 0.15$
24 h Period [Interval]			
Average AC/Min	207.95 ± 41.91	193.07 ± 39.40	$F_{(1,25)} = 2.93, p = 0.09^{\dagger}$
Total AC/24 h Period	200.74 ± 69.55	193.06 ± 48.19	$F_{(1,25)} = 1.32, p = 0.25$

Average AC/Min = average activity counts per minute (the average of all activity counts counts/minute for a given interval). Total AC/Interval = the sum of activity counts recorded during a given interval divided the interval duration in minutes. Intervals were calculated in minutes as follow: Sleep period (the time period between sleep onset and offset), Active periods (the time period between sleep offset and subsequent sleep onset) and 24 h period (0000–0000). † represents trend for significance at p < 0.10; * represents significance at p ≤ 0.05; ** represents significance at p ≤ 0.001.

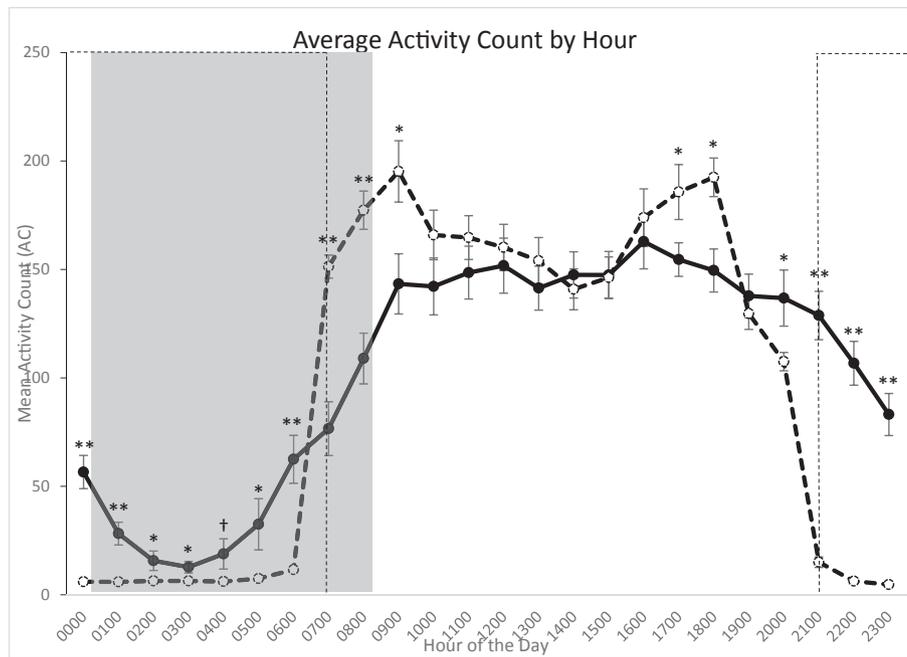


Fig. 1. Hourly differences in mean activity counts between baseline and sleep extension conditions. Hourly mean AC for Baseline (solid line) and Sleep Extension (dashed line) conditions. Time in bed is indicated for Baseline by gray box (■) and for Sleep Extension by vertical dashed line (|). † represents trend for significance at $p < 0.10$; * represents significance at $p \leq 0.05$; ** represents significance at $p \leq 0.001$.

difference in bedtime ($00:22 \pm 1:56$ at Baseline vs. $21:17 \pm 0:27$ during Sleep Extension) and wake-time ($8:13 \pm 2:12$ at Baseline vs. $6:41 \pm 0:36$ during Sleep Extension). Of note, nightly sleep duration was increased during sleep extension although 24-h activity did not significantly change. There was a trend for greater average activity per minute across the 24-h period during the baseline week compared to the sleep extension week, although the difference in average activity counts was minimal and likely not clinically relevant. Conversely, participants were less likely to have an average activity count below the NHANES cutoff for sedentary behavior during sleep extension compared to baseline. Future studies would benefit by focusing on comparing activity levels between healthy habitual long and short sleepers.

The current findings suggest that in adults, sleep extension is not related to reduced activity levels despite an increased time spent lying down in bed. Further, it is possible that during sleep extension, individuals may sacrifice sedentary activities, such as watching movies or being in front of their computer, in order to obtain more sleep. This interpretation is supported by a recent at-home sleep extension paradigm in adolescents found that increasing sleep duration reduced sedentary time, with no change in daily schedule or levels of moderate-to-vigorous physical activity (MVPA) [20].

In our study, we defined sedentary behavior as < 100 activity counts/minute using the NHANES cutoff [8] during the Active and 24 h periods, and compared these between sleep extension and baseline habitual sleep period. Using an exploratory chi-square analysis, our results showed that participants were less likely to have an average activity count below the NHANES cutoff (< 100 AC/min) during 24 h periods during sleep extension compared to baseline. These findings may provide evidence that extending sleep may have a positive effect on sedentary behavior. It should also be noted that the devices used in this study are designed to measure sleep/wake patterns, not energy expenditure or MVPA. Using a device specifically designed to measure energy expenditure or MVPA may provide a more accurate depiction of physical activity levels [21]. Finally, there was a trend for 24 h Average AC/min to be

greater at home compared to sleep extension, although the magnitude of the difference was very small and unlikely to be clinically relevant.

Participants in this study departed the laboratory every morning during the sleep extension period and maintained their normal daily routines. Relatedly, midday activity levels (1000–1600) appear to be least affected by sleep extension while time spent in the laboratory (1900–0700) or the shift between their normal schedules to a laboratory-imposed schedule (0700–0900; 1700–1900) is most affected. It could therefore be that the hourly differences in activity were not a result of increased sleep duration, but rather due to the change in schedule, particularly with regards to bedtime and wake-time. In lieu of a controlled environment, future work should replicate this study with an “at-home” intervention in adults, perhaps using a similar approach to the one used by Van Dyk and colleagues in adolescents [20].

Chronotype was not accounted for in the current analyses, but it is possible that sleep extension, which includes a shift in habitual bed and wake times, may be more or less impactful depending on a person's natural propensity to sleep or be active at a particular time of the day. Moreover, participants did not complete a sleep or daily activity diary as part of this study. Diary reports would add additional context to the interpretation of the actigraphy data, and would help account for potentially diverse sleep and activity patterns, such as may be confounded by demographics (eg, age or employment status) or could have been disrupted by returning to the laboratory in the evenings (where exercise was not allowed). In the absence of diary confirmation, nap determination relied solely on automatic scoring of actigraphy data. It is therefore possible that the periods that were quantified as naps could have been periods of low physical activity during the Baseline period. However, sleep duration was still longer during the extension period compared to at home, and physical activity levels were not significantly different. Therefore, while the lack of self-report of napping limits the interpretation of at home data to determine activity levels, our findings still indicate that sleep is longer and activity levels are not significantly lower during the Extension period. Moreover,

comparing average AC by hour between conditions (without differentiating between Sleep or Active periods) also support this interpretation. An additional limitation is that the conditions (Baseline vs Sleep Extension) were not randomized since the goal of the at-home arm of the study was to document habitual sleep patterns prior to the introduction of any interventions. Although, due to this lack of randomization, we cannot rule out any potential order effects. Future sleep extension studies would also benefit by examining the influence of inter-individual differences, such as age, chronotype or habitual long sleep duration on the impact of the intervention. Finally, additional work should examine more distal outcomes beyond activity levels, to assess whether sleep extension leads in fact to improved health outcomes.

In conclusion, six days of sleep extension of 10 h of time in bed increased sleep duration but was not related to a decrease in overall activity. The potential sleep health benefits of increasing time spent in bed are then not likely to be counteracted by an increase in sedentary behavior, which itself is an independent health risk. These findings are supported by a recent study investigating the impact of sleep extension on physical activity in adolescents, in which sleep extension decreased sedentary behaviors without greatly impacting MVPA [20]. While further analyses on the impact of sleep extension on activity are required, the current study represents a step forward towards understanding the relationship between sleep, health and behavior.

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Conflict of interest

None of the authors have any relevant conflicts of interest to report.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: <https://doi.org/10.1016/j.sleep.2019.04.003>.

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