Are we getting enough sleep? Frequent irregular sleep found in an analysis of over 11 million nights of objective in-home sleep data

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Abstract

Objectives: Evidence-based guidelines recommend that adults should sleep 7-9 h/night for optimal health and function. This study used noninvasive, multnight, objective sleep monitoring to determine average sleep duration and sleep duration variability in a large global community sample, and how often participants met the recommended sleep duration range.

Methods: Data were analyzed from registered users of the Withings under-mattress Sleep Analyzer (predominantly located in Europe and North America) who had ≥28 nights of sleep recordings, averaging ≥4 per week. Sleep durations (the average and standard deviation) were assessed across a ∼9-month period. Associations between age groups, sex, and sleep duration were assessed using linear and logistic regressions, and proportions of participants within (7-9 hours) or outside (<7 hours or >9 hours) the recommended sleep duration range were calculated.

Results: The sample consisted of 67,254 adults (52,523 males, 14,731 females; aged mean ± SD 50 ± 12 years). About 30% of adults demonstrated an average sleep duration outside the recommended 7-9 h/night. Even in participants with an average sleep duration within 7-9 hours, about 40% of nights were outside this range. Only 15% of participants slept between 7 and 9 hours for at least 5 nights per week. Female participants had significantly longer sleep durations than male participants, and middle-aged participants had significantly longer sleep durations than younger or older participants.

Conclusions: These findings indicate that a considerable proportion of adults are not regularly sleeping the recommended 7-9 h/night. Even among those who do, irregular sleep is prevalent. These novel data raise several important questions regarding sleep requirements and the need for improved sleep health policy and advocacy.

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Introduction

Sleep is essential for optimal health and function. In epidemiological studies, sleeping < 6 hours on average per night is associated with increased all-cause mortality risk and multiple health conditions including hypertension, obesity, and cardiovascular disease. Similarly, sleeping > 9 hours on average is also associated with increased all-cause mortality risk and a similar array of health conditions, including hypertension, stroke, and diabetes. In experimental studies, reducing sleep duration to < 7 hours adversely affects glucose metabolism and cortisol secretion, and results in neurobehavioral deficits. These adverse effects accumulate over successive nights of partial sleep restriction. Together, these studies suggest a U-shaped relationship between sleep duration and health outcomes, whereby the optimal sleep duration range to avoid both functional deficits and longer-term ill-health is 7-9 hours for adults.

Based on available evidence, expert taskforces established by professional sleep societies developed guidelines on the optimal sleep duration ranges to support health across the human lifespan.
In a joint consensus statement, the American Academy of Sleep Medicine and Sleep Research Society taskforce recommended ≥7 hours for adults aged 18-60 years.2,11-13 The National Sleep Foundation taskforce recommended 7-9 hours of sleep per night for adults, while 6-10 hours “may be appropriate,” and sleep durations of <6 or >10 hours were “not recommended.”14,15 Given these recommendations and the importance of sleep for health, it is necessary to investigate the prevalence of short- and long-duration sleep.

The overwhelming majority of evidence to date regarding typical sleep durations in naturalistic environments is derived from self-report measures. Epidemiological studies suggest about 29%-34% of adults report sleeping below and ~8% above the recommended sleep duration range for adults.16-19 Importantly, these studies only assess self-reported average sleep duration (often via phone interview or single-timepoint surveys) and do not capture how often individuals sleep outside the recommended sleep duration range. In studies that used objectively derived estimates of sleep duration with device-based measures, most assessment periods were limited to 1-2 weeks. This window may be insufficient to capture real-world variations in sleep duration over time.18,19 Sleep irregularity itself, with frequent deviations from the recommended sleep duration range, may also contribute to adverse health outcomes.20 Given the prolific and growing use of consumer sleep trackers in the global community, data from these devices present an opportunity to observe sleep over extended recording periods on a much greater scale than has previously been possible. Such datasets have already been used to evaluate intra-individual changes in sleep during significant historical events (eg, the COVID-19 pandemic and Britain’s exit from the European Union21-23), as well as interindividual differences in sleep and their associations with health markers (eg, heart rate).23-25 The current study presents objective, device-based derived sleep durations collected over approximately 9 months from an under-mattress sensor with almost 68,000 adults from around the world. The aim was to determine average sleep duration and sleep duration variability in a large global community sample, and how often, and how many people within, this sample meet the recommended sleep duration range. This was examined across age groups and sex, given that sleep duration varies by these factors.26-27

Participants and methods

Participants

In total, 67,254 participants (52,523 males and 14,731 females) aged between 18 and 90 years old who registered to use an under-mattress sleep sensor device (Withings Sleep Analyzer [WSA]) between July 2020 and March 2021 were included in this analysis. Inclusion criteria for the study were availability of ≥28 sleep recordings and an average of ≥4 sleep recordings per week. Participant characteristics such as age, sex, height, and weight were self-reported by participants on the first use of their device. All participants provided consent for their de-identified data to be used for research by agreeing to the WSA terms and conditions. Withings provided the dataset for this work but had no role in study design, data analysis, interpretation, decision to publish, or manuscript preparation. Ethics approval was obtained from the Flinders University Human Research Ethics Committee (project number: 4291).

Materials

The WSA is a sleep monitoring device which consists of a thin inflatable mat approximately 20 cm × 60 cm that is positioned under the user’s mattress at chest height. The device uses ballistography to record pressure changes to estimate body movements, respiratory, heart rates, and time in and out of bed. Using proprietary algorithms, these estimations contribute to the derivation of sleep macrostructure and other sleep metrics beyond the scope of the present study.28 Indeed, the WSA has been used in several recently published research studies to investigate sleep health questions that would not otherwise be possible without the use of noninvasive monitoring technology that allows for multimight assessment of sleep.20,28-30 In addition, a validation study found that, compared to polysomnography, the WSA device over-estimated sleep duration by ~30 minutes.31 This is comparable to other wearable and nonwearable sleep trackers32,33 and was replicated in our in-house validation20 and in another study.34 Sleep duration and irregularity were assessed using the mean sleep duration and the standard deviation (SD) of sleep duration across the recording period.

Statistical analysis

The association between sleep duration (average, SD, and proportion of nights within and outside the recommended 7-9 hours range) and age and genders was investigated using linear and logistic regressions. Age was categorized (18-25, 26-40, 41-50, 51-65, 65+ years, determined by considering the age distribution) as required to visualize the association between sleep duration, age, and sex. Data are presented as means and SD or 95% confidence intervals (CI) for continuous data, and frequencies and percentages for categorical data. A p-value of <.05 was considered statistically significant. All analyses were conducted in R (v 4.2.2) using the ggplot2 modeling package.35

Results

Participant characteristics

Characteristics of the 67,254 participants who met eligibility criteria are summarized in Table 1. There were significantly more males than females, and more younger and middle-aged adults than older adults. The sample was also primarily comprised of slightly overweight people, located in Europe and America. In countries with data from more than 100 participants, there was a ~0.5-hour range in average sleep duration (Fig. 1), with the lowest average duration in Japan and the highest average duration in Mexico and Finland. There were 174 (SD = 72) nights of sleep data on average per participant with an average of 6 sleep recordings per week (SD = 1).

Mean sleep duration

The interaction between age and sex for average sleep duration was significant (p < .001), but the effect size was small (coeff. = -0.002 hours, 95% CIs [-0.002 to 0.0006]). Both main effects of age and sex were also significant (p < .01). When split into age groups, participants in this sample aged 41-50 and 51-65 years both had shorter average sleep durations than participants aged 18-25 and 65 years or older (Fig. 2, bottom panel). Females also had significantly longer average sleep durations (mean difference = 0.37 hours, 95% CIs [0.32-0.43]) than males (Fig. 2, top panel).

Compared to the recommended 7-9 h/night, 31% of adults in this sample showed an average sleep duration outside this range (ie, < 7 or > 9 h/night). Approximately 19% of people aged 18-25 years had an average sleep duration outside the recommended 7-9 h/night range, versus 35% of people aged 51+ years (Fig. 3).

Variability in sleep duration

The SD of sleep duration was significantly associated with age (p < .0001), such that the SD of sleep duration reduced with increasing age (Fig. 2, bottom panel). However, these were small effects (coeff. = 0.002 hours, 95% CIs [-0.002 to 0.002]). The association between sex and SD of sleep duration was not significant (p = .46), nor was the interaction between age and sex (p = .57).
Table 1
Baseline characteristics of participants

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>Younger adults (18-25 y)</th>
<th>Adults (26-40 y)</th>
<th>Adults (41-50 y)</th>
<th>Adults (51-65 y)</th>
<th>Older adults (65+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>67,294</td>
<td>18,296</td>
<td>21,096</td>
<td>18,369</td>
<td>19,838</td>
<td>612</td>
</tr>
<tr>
<td>Age</td>
<td>47 (13)</td>
<td>23 (2)</td>
<td>34 (4)</td>
<td>46 (3)</td>
<td>57 (4)</td>
<td>72 (6)</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>27.3 (5.5)</td>
<td>24.9 (5.4)</td>
<td>26.6 (5.7)</td>
<td>27.7 (5.5)</td>
<td>27.8 (5.2)</td>
<td>27.0 (4.9)</td>
</tr>
<tr>
<td>Sex, n (%)</td>
<td>Male</td>
<td>52,523 (78.1%)</td>
<td>16,701 (79.2%)</td>
<td>14,819 (80.7%)</td>
<td>15,223 (76.7%)</td>
<td>4314 (70.5%)</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>14,771 (21.9%)</td>
<td>4395 (20.8%)</td>
<td>3550 (19.3%)</td>
<td>4615 (23.3%)</td>
<td>1808 (29.5%)</td>
</tr>
<tr>
<td>Location by region</td>
<td>Europe</td>
<td>41,571 (61.8%)</td>
<td>11,772 (55.8%)</td>
<td>11,635 (63.4%)</td>
<td>13,400 (67.6%)</td>
<td>3826 (62.5%)</td>
</tr>
<tr>
<td></td>
<td>America</td>
<td>20,001 (28.7%)</td>
<td>7018 (33.3%)</td>
<td>5159 (28.1%)</td>
<td>9159 (26%)</td>
<td>1971 (32.2%)</td>
</tr>
<tr>
<td></td>
<td>Asia</td>
<td>4,197 (6.2%)</td>
<td>1781 (8.4%)</td>
<td>1166 (6.3%)</td>
<td>916 (4.6%)</td>
<td>196 (3.2%)</td>
</tr>
<tr>
<td></td>
<td>Australia</td>
<td>796 (1.2%)</td>
<td>342 (1.6%)</td>
<td>210 (1.1%)</td>
<td>157 (0.8%)</td>
<td>49 (0.8%)</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>689 (1.1%)</td>
<td>183 (0.9%)</td>
<td>199 (1.1%)</td>
<td>206 (1.0%)</td>
<td>80 (1.3%)</td>
</tr>
<tr>
<td>Average number of nights</td>
<td>174 (72)</td>
<td>137 (69)</td>
<td>166 (71)</td>
<td>178 (70)</td>
<td>181 (71)</td>
<td>176 (75)</td>
</tr>
<tr>
<td>Average nights of use per week</td>
<td>6 (1)</td>
<td>5 (1)</td>
<td>6 (1)</td>
<td>6 (1)</td>
<td>6 (1)</td>
<td>6 (1)</td>
</tr>
<tr>
<td>Mean sleep duration, h</td>
<td>7.5 (0.8)</td>
<td>7.7 (0.8)</td>
<td>7.5 (0.8)</td>
<td>7.4 (0.8)</td>
<td>7.4 (0.9)</td>
<td>7.5 (1.1)</td>
</tr>
<tr>
<td>SD sleep duration, h</td>
<td>1.2 (0.6)</td>
<td>1.3 (0.6)</td>
<td>1.2 (0.5)</td>
<td>1.2 (0.6)</td>
<td>1.1 (0.6)</td>
<td>1.1 (0.7)</td>
</tr>
</tbody>
</table>

Continuous variables are reported as mean (SD) and categorical variables as n (%). SD, standard deviation; BMI, body mass index; y, years.

When analyzed as the proportion of nights that participants slept for the recommended sleep duration, only 15% of the sample slept between 7 and 9 hours for at least 70% of nights (equivalent to 5 nights per week). Similarly, only 2% slept between 7 and 9 hours for at least 85% of nights (equivalent to 6 nights per week). When categorized by average sleep duration, 30%-40% of nights fell outside of participants’ sleep duration reference category (Fig. 4). Even among participants with average sleep durations between 7 and 9 hours, 28% of nights were <7% and 13% were >9 hours.

In particular, the variability between average sleep durations on weekdays versus weekends was explored in subsequent analyses. There was a significant difference, such that participants slept on average 28 minutes (95%CI; 27-29) longer on weekend days than during the week (see Fig. 5). On weekdays, 61% of adults met the recommended 7-9 hours sleep duration during weekdays compared to 72% of adults on the weekend. The difference (mean [95%CI]; 11 [10,12]) was significant (p < .001).

Discussion

This study examined sleep durations over ∼9 months in almost 68,000 adults worldwide. Compared to the recommended 7-9 hours of sleep per night, 31% of adults showed average sleep durations outside the recommended range. Age and sex were significantly associated with average sleep duration, with middle-aged adults sleeping less than other age groups, and males sleeping slightly less than females. There were lower average sleep durations in Japan and higher sleep durations in Mexico and Finland, noting that seasonality differences across the ∼9-month recording duration limit the ability to compare northern and southern hemispheres. In addition, variability in nightly sleep duration decreased with age group but was not different between males and females. Finally, 30%-40% of nights were outside of participants’ average sleep duration reference category, and only 15% of the sample were sleeping the recommended sleep duration for at least 70% of night (equivalent to 5 times a week). Indeed, sleep durations were 30 minutes longer on the weekend compared to weekdays.

These findings from a large sleep tracker consumer dataset contribute to the growing body of evidence regarding suboptimal sleep duration habits in the global community. Prior estimates have suggested that about 30%-35% of US adults do not obtain 7-9 hours of sleep per night,16 which is consistent with the findings from the current study. These prior estimates in the community were largely derived from self-report assessments. While this under-mattress
sleep sensor has not been directly compared to self-report assessments, similar overestimation of about 30-40 minutes with self-report versus polysomnography would suggest that they yield similar overall estimates of sleep duration.\textsuperscript{19,36}

Notably, in this study, even among participants who slept between 7 and 9 hours per night, average sleep duration was outside the recommended sleep duration range on \textasciitilde40% of nights. Given that the under-mattress sleep sensor used in this study overestimates sleep by about 30 minutes on average, even more adults than the rate reported here may be regularly sleeping less than 7 hours. Experimental studies have demonstrated acute impairments from short sleep on health and function.\textsuperscript{10} Thus, it is concerning that such a large proportion of people are not sleeping within the recommended sleep duration range. Recent evidence from another consumer sleep device dataset found that irregular sleep patterns differ across countries, but nonetheless, was a common global phenomenon.\textsuperscript{37} Irregular sleep itself is emerging as an important factor likely contributing to adverse health,\textsuperscript{38-40} including a previously-reported association with hypertension from participants within this dataset.\textsuperscript{20} A recent study has also found irregular sleep to be one of the 3 most influential sleep variables associated with mortality, alongside the AHI and sleep duration.\textsuperscript{41}

Social jetlag is a specific pattern of irregular sleep, often resulting in people sleeping in later on free days (ie, nonworkdays) and

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**Fig. 2.** Top panel shows the distribution of average sleep duration across the recording period split by age group for male (gray) and female (green). Bottom panel shows the average (left) and standard deviation (SD, right) of sleep durations across the recording period split by age group.

**Fig. 3.** Proportions of average sleep durations across the recording period in hourly sleep duration categories across age groups.
subsequently struggling to adjust back to the nonfree day sleep schedule, a pattern which has been associated with increased risks of type 2 diabetes and obesity. The current findings of an average of 30 minutes more sleep on weekends in the current study are consistent with other studies. However, experimental studies are required to establish causality and to elucidate the effect of variable sleep durations (the combination of short and long sleep episodes) on acute functioning. It is possible that “rebound” sleeps may fully or partially mitigate chronic effects of this sleep pattern to some extent, but could also be counterproductive to some extent through circadian dysregulation effects.

While it is widely accepted that people need 7-9 hours per night for optimal daytime function and long-term health, it is also acknowledged that individuals have variable sleep requirements and habits. Though rare, some individuals anecdotally report obtaining < 7 or > 9 h/night and self-report normal wake function. Such a wide range in the recommended sleep duration is also emblematic of probable variability between individuals in sleep need. Additionally, sleep need likely varies within individuals both acutely and over the lifespan, due to cumulative effects and variability in stressors on the functions of sleep (eg, acute health status, illness or injury recovery, physiological and cognitive stress, and physical and mental activity). Given this, it should be acknowledged that participants in this sample and other study samples may have been misclassified as not obtaining sufficient sleep. Consideration of sleep need and methods to evaluate it at the individual level will be required to determine whether any particular individual is acutely or chronically getting enough sleep. This said, an accepted sleep duration range to assess sleep sufficiency at the population level still provides valuable insights into the sleep health of the global community.

Using an under-mattress sleep sensor for nightly sleep monitoring is a major strength of this study. Given the practical limitations of nightly sleep monitoring using polysomnography, prior studies have relied on self-report assessments inevitably prone to subjective biases (eg, questionnaires), or sleep trackers with similar or inferior accuracy to estimate sleep as the device used in this study. Still, prior studies have been limited to sleep monitoring over short periods (typically 1-2 weeks). Given substantial night-to-night variability in sleep parameters, multinight, long-term under-mattress device measurements have previously enabled more accurate estimation of obstructive sleep apnea severity and associated health outcomes than single-night polysomnography. Similarly, objective multitnight assessments of sleep duration provide for more reliable estimates of sleep duration over longer time periods than have previously been possible. This allows for novel understanding into naturally-occurring sleep rather than more intrusive single-night assessments in the unfamiliar sleep laboratory.

Despite an extensive number of sleep recordings across thousands of individuals in over 20 countries, there are some limitations to the current study. Firstly, the sample was disproportionately comprised of males, although there were still relatively large numbers of females across each age category for these analyses (N ≥ 363). Secondly, the presence of sleep disorders, comorbid conditions, and potential sleep treatments (medications, CPAP, etc.) within this sample is unknown. Thirdly, socio-economic status, work status (shift workers, nonshift workers, unemployed, etc.), and other factors known to influence sleep duration were also unknown in this dataset. Fourthly, while the underbed sensor has been designed to measure sleep in only 1 bedpartner or one half of a larger bed, it is possible that data from a co-sleeper or even a pet may also be
detected should they get sufficiently close to the sensor. This may confound the estimates in some cases but is unlikely to be a common occurrence when appropriately positioned in a user’s bed. Fifthly, the COVID-19 pandemic has been shown to have influenced sleep duration globally to some extent, &47 and the impact of the pandemic on the findings of this study is unclear. Lastly, comparisons across countries are limited given seasonal differences likely impacting the average sleep duration estimates collected over the ~9 month recording period. For this reason, caution is warranted when making comparisons between countries, particularly across the northern and southern hemispheres. However, in this respect, these data are a real-world sample of how much sleep adults were getting during this time.

Conclusions

Based on our findings, policy and advocacy efforts at the population level are needed to support individuals to more frequently sleep within the recommended sleep duration range for their age, especially during the week. Clearly, this may remain challenging for many people to achieve. Given the importance of sleep for health, efforts worth considering could include community awareness campaigns, as well as changes within organizations and society more broadly, to encourage individuals to make their sleep a priority. Increased access to sleep health services to assist individuals to resolve chronic sleep difficulties is also warranted. Longitudinal monitoring using noninvasive sleep sensors combined with assessments of sociodemographic, health, and lifestyle factors will help determine the value and effectiveness of future efforts to improve sleep health on a global scale.

Author contributions

HS, GN, BL, AS, and DJE developed the study concepts and aims. BL and GN performed data extraction. GN performed data analysis. All authors provided important insight on data interpretation and drafting of the manuscript. All authors approve of the final version of the manuscript.

Declaration of conflicts of interest

Outside the submitted work, DJE has had research grants from Bayer, Takeda, Invicta Medical, Apnimed and has served on Scientific Advisory Boards for Apnimed, Invicta, Mosanna and as a consultant for Bayer. PE serves as a consultant for Withings. Withings provided sleep analyzers for the validation trial. None of the other authors have any relevant conflicts to declare.

Funding

This was an unfunded, investigator-initiated study led by the Adelaide Institute for Sleep Health sleep research team.

Acknowledgments

DJE is supported by a National Health and Medical Research Council of Australia Leadership Fellowship (1196261).

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