Sleep patterns and sleep deprivation recorded by actigraphy in 4th-grade and 5th-grade students

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Highlight

- Approximately two-thirds of 4th- and 5th-grade elementary students sleep less than 9 hours per night.
- Differences in sleep patterns exist between weekdays and weekends.
- Sleep deprivation is more severe in 5th-grade students

Abstract

Objective: This study investigates sleep patterns of 4th- and 5th-grade students using actigraphy.

Methods: The study included 257 students enrolled in a Southwestern US school district who participated in a novel sleep science curriculum during the Spring 2016-17 and Fall 2017-18 semesters and met the study inclusion criteria. As part of this curriculum, participants underwent 5 to 7 days of continuous wrist actigraphy and completed an online sleep diary.

Results: Approximately two-thirds of the 9-11-year-old 4th- and 5th-grade students slept less than the minimum 9 hours per night recommended by both the American Academy of Sleep Medicine/Sleep Research Society and the National Sleep Foundation. The sleep midpoint time on weekends was about 1 hour later than on weekdays. There was a significant effect of age on sleep duration. Compared to 9-year old students, a larger proportion of 10-year old students had a sleep duration less than 8.5 hours. Boys had shorter sleep duration than girls, and a larger percentage of boys obtained less than 9 hours of sleep compared to girls.

Conclusions: Insufficient sleep is a highly prevalent condition among 9-11-year-old 4th- and 5th-grade elementary students. Importantly, there is a difference between sleep patterns on weekdays and weekends which may portend greater problems with sleep in adolescence and young adulthood.

Keywords: Actigraphy; Children; School age; Sleep patterns; Sleep deprivation.

1. Introduction

Sleep plays a critical role in children's physical and mental health development. However, insufficient sleep and irregular sleep-wake behavior are common among children worldwide [1,2]. Insufficient sleep is associated with sleep fragmentation [3–6], later bedtimes [4,5], insomnia symptoms characterized by longer sleep onset latency [5,7], sleep maintenance difficulties [5,6], and early awakenings [4]. Inadequate sleep duration may lead to daytime sleepiness. All of these impair children's learning capacity, safety, social-emotional and behavioral function and school performance [3–7]. The American Academy of Sleep Medicine (AASM) and Sleep Research Society jointly recommend that children between 6 and 12 years of age need 9 to 12 hours of sleep per 24 hours [8]. Similarly, the National Sleep Foundation suggests that school age children (ages 6-13 years) sleep 9-11 hours per night [9]. Based on the 2014 Sleep In America Poll, 55% of children did not get enough sleep in the United States [10]. Therefore, insufficient sleep in school age children is an important public health issue.

Several previous studies employed self- or caregiver-completed questionnaires to investigate children's sleep. They found that a large proportion of students slept less than 9 hours and had difficulty getting up problems in morning [11,12]. Additionally, members of our research group observed insomnia symptoms in 24% of 348 adolescents participating in an observational cohort study [13]. Nonetheless, these studies have been limited because of the potential for inaccurate responses and the likelihood of overestimated sleep duration [14].

Some studies have used laboratory polysomnography or unattended home polysomnography to investigate sleep patterns of children and adolescents [15–18]. Although it is considered the "gold standard" for studying sleep, a "first night effect" can occur with polysomnography resulting in imprecise estimates of sleep duration and quality [19,20]. It also is expensive and generally not logistically feasible to perform multi-night studies [21]. Notably, polysomnography does not reflect the daily sleep and waking patterns of children because it captures data only during the night. In contrast, actigraphy can be a useful method to not only assess patterns of sleep and wake activity, but also capture this data over a number of consecutive days in an ambulatory non-laboratory environment. This can be informative because activity and behavior during wakefulness influence sleep duration and quality, and conversely sleep duration and quality affect daytime function.

In this study, our goal was to document the patterns of sleep and wakefulness of 4th- and 5th-grade elementary school students over a time period that included school and non-school nights using actigraphy. While actigraphy alone may have accuracy problems, actigraphy combined with a sleep diary is becoming a popular and reasonable assessment for sleep in epidemiologic research. Using actigraphy and sleep diary together is considered as a good objective estimate of sleep and wake activity patterns when combined with well-designed scoring rules [22–26]. Therefore, the present study utilizes actigraphy and digital sleep diaries to assess sleep and wake activity patterns and sleep duration of 4th- and 5th-grade students during school semesters.

2. Methods

2.1 Study design and subjects

Participants were 4th- and 5th-grade students from two elementary schools in a local school district in a Southwestern US state who were involved in the Sleep to Enhance Participation in STEM (STEPS) curriculum development project (Z-factor) during two consecutive school years. This project developed a classroom teaching curriculum containing 5 lessons with multiple activities based on principles of sleep science and health with an objective to stimulate students' interest in science, technology, engineering and mathematics (STEM) areas. Its ultimate goal was to increase the numbers of students eventually choosing STEM careers. The schools were part of a suburban school district of approximately 5,000 students with four elementary schools, two middle schools and one high school. Although there were students from all racial groups and ethnicities, most students were non-Hispanic white (Table 1). The adjusted gross income for the zip codes represented by this school district ranged from $122,560 to $145,200. For elementary school students, schools started at 8:00 am from Monday to Friday. The University of Arizona Institutional Review Board and the school district approved this study.

The first school (School 1) conducted the Z-Factor lessons both years, the second school (School 2) only completed the lessons during the second year. There were 3 sections of students who participated initially when they were 4th-graders. Then, they participated a 2nd time when they were 5th-graders. In the Z-factor lessons, students completed a scientific investigation of their own sleep. As part of data collection for this investigation, in their science classes with teacher and university representative guidance, they wore an actigraph (Actiwatch Spectrum Plus, Philips Respironics, Bend, OR, USA) and completed an online sleep diary for one week starting before their 2nd Z-factor lesson. Actigraphs were worn on the non-dominant wrist. The online sleep diaries were integrated into an online web portal, *MySleep* that also contained online instructional material [27]. Appendix Table A.1 describes the questions of sleep diary used for actigraph scoring in this study.

There were 335 students who participated in science classes that delivered the Z-factor lessons at least one time. The lessons were universally implemented across the 4th- and 5th-grade classes. Students who were enrolled in special or gifted education participated if they attended the class sessions during the time which the Z-factor lessons were scheduled. Actigraphy data from 307 first time participants were available. However, actigraphy data were included in this analysis only if actigraph included at least 5 nights of data, and weekday and weekend data were available. Because the epoch duration influenced the accuracy of the scoring algorithm, we excluded one student whose Actiwatch was misconfigured as 15-sec epochs. We also excluded six students who did not provide gender, ethnicity, or age information. After the mentioned exclusions, data from 257 students were available for analysis. Table 1 presents the demographic characteristics of all selected students.

2.2 Data processing

The Actiwatch records both activity and light data and was configured to collect data in 30-sec epochs. Actiwatch data were downloaded and analyzed with Philips Respironics Actiware v.6 software. After completion of data collection, files were de-identified and data were manually scored as rest interval start time and rest interval end time using three inputs: sleep diary, light intensity, and activity count. The rest interval start time and end time algorithms are shown in Appendix Figure B.1 and Figure B.2, respectively. The daytime naps were not included for this study as the endpoints were overnight sleep duration and timing. Additionally, in the event that a student had a prolonged awakening in the middle of the night, the rest interval included that interval rather than breaking up the night into small sleep periods. In the Actiware software, based on previous studies [28,29], we set the wake threshold as 40 activity counts, the immobile minutes for sleep onset as 10 minutes, and the immobile minutes for sleep end as 10 minutes. Then, we identified sleep onset latency (Appendix Figure B.1), sleep onset time, and wakeup time through the Actiware auto-scoring algorithm.

2.3 Definitions and computation

For this study, we describe the following characteristics of 13 variables for weekdays and weekends: sleep duration, standard deviation (SD) of sleep duration, sleep duration shorter than 9 hours, sleep duration shorter than 8.5 hours, sleep duration shorter than 8 hours, sleep onset latency, wake after sleep onset (WASO), sleep efficiency, fragmentation, sleep onset time, sleep offset time, sleep midpoint time, and SD of sleep midpoint time. The weekends included the night of Friday to Saturday and the night of Saturday to Sunday. We investigated the 13 variables for all valid days as well as calculation of the sleep regularity index (SRI) [30,31]. We computed sleep duration as the mean of the total time between sleep onset time and sleep offset time over multiple nights. The SD of sleep duration was computed as the standard deviation of the sleep duration across evaluated nights. The sleep onset latency measured the mean duration between rest interval start and sleep onset time over multiple nights. Wake time after sleep onset was computed as the average over multiple nights. Sleep efficiency was calculated as the ratio of total sleep time over rest interval duration in percentage format and then was averaged over multiple nights. Sleep fragmentation was assessed as an index that tabulates the frequency of mobility episodes and short sleep bouts between sleep onset time and sleep offset time. It is calculated as the sum of percent mobile and percent one-minute immobile bouts divided by the number of immobile bouts. Then we averaged the fragmentation index over multiple nights. The auto-scoring algorithm scores an epoch as immobile when the activity count is less than 2. Sleep onset time was the first epoch scored as sleep in clock time format (HH:MM) and averaged over multiple nights. Sleep offset time was defined as the last epoch scored as sleep and was averaged over multiple nights. Sleep midpoint time was computed as the midpoint between sleep onset and sleep offset time and was averaged across overall nights. The SD of sleep midpoint time was computed as the standard deviation of the sleep midpoint time across evaluated nights. The SRI assesses the likelihood that a person is in the same wake or sleep state at any 2 time points 24 hours apart averaged over a designated time interval [30]. It is scaled from 0 to 100 with 100 representing an individual who sleeps and wakes at the same time each day, and progressively lower scores denoting more sleep schedule irregularity. In this study, we used 30-second epochs to calculate the SRI. The SRI was computed using Equation 1 and Equation 2 below, where D is number of days, and E is number of daily epochs. We also rescaled the SRI to range from -100 to 100 to give a more intuitive range [30,31]. In the actigraphic dataset, 3 records missed 1-2 weekdays' data. Because the computation of SRI required continuous time series data, we used average of the weekdays' sleep onset time and average of weekdays' sleep offset time to impute the missing sleep data.

$$SRI = 200 * \left(\frac{\sum_{j=1}^{D-1} \sum_{i=1}^{E} \delta(e_{j,i}, e_{j+1,i})}{\sum_{n=1}^{D-1} E_n} - \frac{1}{2} \right) \quad (1)$$

$$\delta(e_{j,i}, e_{j+1,i}) = \begin{cases} 1 \; for \; e_{j,i} = e_{j+1,i} \\ 0 \; for \; e_{j,i} \neq e_{j+1,i} \end{cases} \quad (2)$$

2.4 Statistical analysis

Paired t-tests were used to compare the difference between weekdays and weekends. McNemar's tests were performed to compare the difference for proportion of sleep duration shorter than 9 hours, 8.5 hours, and 8 hours between weekdays and weekends. Equal variance unpaired t-tests were employed to compare the differences between genders and grades. To show age effect, analysis of variance (ANOVA) was performed in age groups. Tukey HSD tests were performed for post-hoc comparisons. Chi-square tests were performed to compare the difference for proportion of sleep duration shorter than 9 hours, 8.5 hours, and 8 hours in week, genders, grades, and age. Bonferroni corrections were applied to the post-hoc comparisons of multiple χ^2 tests in age groups. All p-values were 2-tailed. Data are presented as mean ± SD or percentages. We considered that $p < 0.05$ indicated statistical significance in our analyses. Analyses were performed using Python SciPy V1.3 and StatsModels V0.9.0.

3. Results

No differences were found with respect to any sleep parameter between the students of the two participating schools. Therefore, we combined both schools' data.

Table 2 shows the actigraphic characteristics of the study cohort and demonstrates that 66.9% of the students had sleep duration shorter than 9 hours and 35.4% had a sleep duration shorter than 8.5 hours during weekdays. However, during weekends, the percentage of students with shorter than 9 hours sleep duration was significantly lower than the percentage on weekdays (57.6% vs 66.9%, $p < 0.05$). Furthermore, during weekends, 21.0% students had a sleep duration shorter than 8 hours ($p < 0.001$). Figure 1 depicts the distribution of sleep durations on weekdays and weekends and graphically demonstrates there is considerable heterogeneity in weekend sleep duration with a large percentage of students having low values. The sleep midpoint time shifted about 1 hour later (02:56 ± 55 HH:MM (mean ± std) during weekends vs during weekdays, 01:51 ± 29 HH:MM, $p < 0.001$). The weekdays' standard deviation of sleep midpoint was also smaller than weekends' (18.0 ± 12.2 vs 21.2 ± 19.0 minutes, $p < 0.05$). Additionally, the WASO during weekdays is about 2 minutes longer than during weekends (45.0 ± 14.5 vs 42.8 ± 14.5 minutes, $p < 0.01$). However, percentage fragmentation was not different between weekdays and weekends and the SRI showed only a mild amount of deviation from complete regularity. However, all actigraphic records with a SRI < 70 (n = 10) included at least one late sleep night (sleep onset time is after midnight).

Table 3 presents the comparison of sleep patterns between 4th- and 5th-grade. Sleep duration was 528.7 ± 33.8 minutes for 4th-grade students and 519.3 ± 31.7 minutes for 5th-grade ($p < 0.05$). The 4th-grade students had a sleep midpoint time of 12 minutes earlier than the 5th-grade students (02:08 ± 33 vs 02:20 ± 33 HH:MM, $p < 0.01$). Compared to 4th-grade students, a larger proportion of 5th-grade students had sleep duration less than 9 hours (n=102, 63.8% vs n=74, 76.3% p <0.05) and less than 8.5 hours (n=43, 26.9% vs n=38, 39.2% p <0.05).

Table 4 shows the comparison of sleep patterns between boys and girls. The overall sleep duration of boys was 12.1 minutes shorter than that of girls (519.0 ± 33.2 vs 531.1 ± 32.3 minutes, $p < 0.01$). Furthermore, boys in comparison to girls had larger proportion with sleep duration less than all thresholds although not statistically significant at less than 8 hours. The sleep efficiency of boys was slightly lower than that of girls (86.0 ± 3.0 vs 87.2 ± 3.7 %, $p < 0.01$). The sleep fragmentation of boys was 2% higher than that of girls (18.6 ± 4.4 vs 16.6 ± 4.3 %, $p < 0.001$). The sleep offset time of boys was 8 minutes earlier than girls (06:31 ± 33 vs 06:39 ± 32 HH:MM, $p < 0.05$). Sleep regularity was not different between genders.

In our cohort, most of the students were 9 or 10 years old. We excluded two 8-year old students in age-related analyses because the sample size was too small. Table 5 presents sleep duration among age groups stratified by gender. As shown in Figure 2a and Table 5, there was a significant effect of age on sleep duration (531.7 ± 31.8 vs 521.9 ± 34.7 vs 518.4 ± 29.5 minutes, $p < 0.05$). Nine-year old students generally had longer sleep duration. Additionally, 10-year old students had a larger proportion than that of 9-year old students of sleep duration less than 8.5

hours (39.7 vs 19.8%, $p < 0.01$). There was a trend for this effect to be present in both boys and girls. Figure 2b illustrates the differences and distribution in sleep duration between genders stratified by age. Sleep durations of 9-, 10-, and 11-year old girls are generally longer than boys. Age also had significant effect on sleep onset time (Table 5). Nine-year old students had a sleep onset time of 17 minutes earlier than the 10-year old and 20 minutes earlier than the 11-year old students (21:39 ± 44 vs 21:56 ± 37 vs 21:59 ± 44 HH:MM, $p < 0.01$); the effect appeared to be present in both genders, but was statistically significant only for boys. Furthermore, 9-year old students had a sleep midpoint time of 12 minutes earlier than the 10-years old students (02:05 ± 35 vs 02:17 ± 29 HH:MM, $p < 0.05$), but was statistically significant only for boys. Additionally, as shown in Table 5 and Figure 3, there was a significant effect of age on the SRI of girls (85.7 ± 5.8 vs 85.4 ± 5.2 vs 80.8 ± 10.6, $p < 0.05$), but not boys. Both 9- and 10-year old girls had a higher SRI than 11-year old girls ($p < 0.05$).

4. Discussion

This study utilized cross-sectional data collected by students as part of their sleep science curriculum. We found that more than 50% of 9-11-year-old 4th- and 5th-grade school children during both school and weekend nights slept less than the lower limit of 9 hours recommended by both the American Academy of Sleep Medicine/Sleep Research Society and the National Sleep Foundation. Furthermore, on weekends, there was considerable variability in sleep duration with a marked delay in onset. Fifth grade students had slightly less sleep than 4th-grade students; girls had better quality and more sleep than boys; 9-year old students generally had longer sleep duration than older students.

Mean overall sleep duration, as well as stratified by weekdays and weekend days, was less than the lower limit of 9 hours in currently recommended standards. More alarming is the proportion of students sleeping less than 8.5 and 8 hours. Childhood is a critical time for brain growth. In magnetic resonance imaging (MRI) studies, cortical and subcortical gray matter volumes peak at age 8.5 years in females and 10.5 years in males; white matter volumes continue to increase until adulthood [32]. Additionally, a MRI study of children and adolescents aged 5-18 years, suggested the hippocampal regional gray matter volumes were positively correlated with sleep duration [33]. Another recent MRI study of 9^{th}- and 10^{th}-grade students provided evidence that shorter sleep duration on weekdays and later weekend sleep onset time correlated with smaller brain gray matter volumes in frontal, anterior cingulate, and precuneus cortex regions [34]. Experimental data have suggested that sleep deprivation can alter synaptic plasticity leading to dysfunction in cerebral cellular metabolism, neuronal loss, reduced neurogenesis and alterations in protein synthesis [35]. These consequences would be particularly impactful in a developing brain.

Short sleep duration not only associates with brain development, but also correlates with behavioral problems. Accordingly, we, as well as others, have demonstrated that short sleep durations are related to learning problems and worse neurocognition in children [36–39]. Sleep deprivation is implicated in hyperactive behavior in children [40], worse academic grades [4], and internalizing symptoms [13]. In addition, childhood short sleep duration has been identified as a risk factor for the development of obesity and diabetes [41].

Our findings with respect to overall sleep duration are consistent with data from the National Sleep Foundation reporting that parents estimated their children slept 1 hour less than was needed [10]. Although subjective reports of sleep duration may be erroneous [42], our results are nevertheless consistent with a recent meta-analysis of actigraphy studies performed in children in this age range in which the mean overall sleep duration was 8.85 hours [43]. In a study similar to ours in Quebec school children, Gruber et al. also found differences between weekday and weekend sleep duration [44]. However, in contrast to our findings, they observed only 2.5-7% of children obtained less than 9 hours of sleep, a proportion much smaller than in our cohort [44]. Possible explanations include cultural/language differences (French Canadian vs. US Southwest) and a greater seasonal variation in the lengths of days and nights (latitude of Quebec vs. Arizona).

Insufficient sleep and sleep problems may be of a particular importance among children residing in low socioeconomic environments [45,46]. However, our results emphasize that this concern is a problem even for a relatively affluent suburban school district.

Another important observation from our study was the marked variation in weekend sleep duration which was coupled with a one-hour phase delay. This indicates that many students have misaligned sleep schedules between weekdays and weekends; this has been termed "social jet lag" [47]. Use of electronic devices and social activities are likely culprits. Inasmuch as there was no difference in sleep duration between weekdays and weekends, sleeping to catchup for insufficient sleep on weekdays was not occurring. However, social jet lag by itself has been associated with a variety of negative health consequences including depression [48], obesity [49], elevations in heart rate [50], and worse glycemic control [51]. Indeed, a shift in bedtime (delayed onset) has been found to predict grades and state standardized test scores [52], both of which are metrics for schools to gauge the quality of their programming and impacts students' future academic careers. Our results are consistent with some, but not all studies examining discrepancies between school day and weekend day sleep time in 9-11 year old children [43]. However, these previous studies were performed in Asian or European countries where cultural differences are present or in children with medical conditions. To our knowledge, there are no previous data concerning differences between weekend and weekday sleep in US school children in this age group. Our data indicate that social jet lag is common in 9-11-year-old 4th- and 5th-graders.

Delays in school start times with the goal of extending sleep have improved academic performance and mental health in high school students [53,54]. There are limited data evaluating whether manipulations in school start times or a sleep health education intervention in elementary students will extend their sleep and reduce social jet lag, thus preventing the occurrence of the latter in adolescence and young adulthood. In a recent Canadian study, a community-based education program involving children, family, and school staff increased sleep by 18.2 min per night resulting in an improvement in grades in comparison to a control group [55]. However, further research will be required to replicate these findings and to determine the essential components of such a program.

Despite the differences between weekend and weekday sleep duration in our cohort, consistency of sleep overall, as measured by the SRI, was generally good. This result, however, needs to be interpreted cautiously because weekend sleep, which was generally more heterogeneous, was not incorporated in our calculation of the index. Nevertheless, the regimented nature of a uniform weekday school start time likely contributes to a higher degree of sleep consistency. Our results stand in contrast to the results observed in college students who often exhibit a high amount of irregularity in their sleep [30].

Analyses from this study also found that sleep duration was about 10 minutes less in 5th-grade students than those in 4th-grade. Inasmuch as 5th-graders were generally one year older than 4th-graders, this observation is consistent with the normal age-related evolution of childhood sleep-wake patterns. It replicates previous actigraphic and ambulatory polysomnographic studies [15,43,56,57]. Although not statistically significant, it appears that the reduction in sleep duration is a result of a later sleep onset time in 5th-graders.

In this study we observed several differences between the sleep of girls and that of boys. Sleep duration was approximately 13 min longer for girls than for boys and girls had a slightly higher sleep efficiency. These findings were consistent across all three age strata although there was likely an insufficient sample size to demonstrate statistical significance. Additionally, younger girls had more consistent sleep as measured by the SRI than older girls, a finding that was not observed in boys. Girls begin puberty (Tanner II) around 10-11 years old and boys begin puberty (Tanner II) around 11-12 years old [58]. It is generally accepted that hormonal fluctuations in women impact their sleep quality [59]. Thus, it likely that the differences in sleep between boys and girls that we observed are a consequence of earlier sexual maturation in girls and the innate differences in sex hormones between genders.

We acknowledge that our observed age, grade and gender stratified differences in sleep duration are relatively small. Nevertheless, they are consistent with the findings of Gruber et al. [44] who also assessed sleep duration with actigraphy. Furthermore, relatively small differences in average sleep duration in large studies have been associated with important clinical outcomes. In a study by Kim et al, an average of 30 min greater sleep on weekends was associated with a lower risk of childhood overweight [60], and an 18.2 min increase in sleep in the aforementioned Canadian sleep intervention study resulted in improved grades [55]. More recently, a median increase in sleep duration of 34 min in secondary school students increased attendance and academic performance [53]. It should be further emphasized that although mean differences in these strata were relatively small, there was substantial heterogeneity indicating that a number of the students had sleep that was considerably outside the norm.

This study has several limitations. First, the acquisition of actigraphy and sleep data occurred as part of the students' curriculum and there was limited oversight or monitoring. In most cases, it was not possible to query the individual student concerning anomalies in the recordings since the data had been de-identified. Second, there may be some imprecision of sleep efficiency calculations because of inaccuracy in the estimates of fall asleep time and sleep offset time on the electronic sleep diary. Some students completed the weekend sleep diary on Mondays, which may also have introduced error in the accuracy of reported sleep efficiency. Nevertheless, despite these limitations, this study has important strengths: a large sample size (n=257), multi-night recordings that included weekdays and weekends and a high participation rate among the students.

5. Conclusion

In conclusion, insufficient sleep is a highly prevalent condition among 9-11-year-old 4th- and 5th-grade elementary students. Importantly, there is a difference between sleep patterns on weekdays and weekends which may portend greater problems with sleep in adolescence and young adulthood. It may be important to establish long-term sleep education and time management courses to resolve the sleep insufficiency problem among elementary school students.

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Conflicts of interest

The authors have no conflict of interest to declare.

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Table-1 Demographic characteristics

	All participants (n = 257)	4^{th}-Grade (n = 160)	5^{th}-Grade (n = 97)
School 1 (%)	70.8	72.5	68.0
Boy (%)	49.0	46.3	53.6
Race/Ethnicity (%)			
Hispanic/Latino	23.7%	21.3%	27.8%
Non-Hispanic	76.3%	78.8%	72.2%
Asian	6.6%	6.3%	7.2%
Black	1.6%	1.3%	2.1%
Pacific Islander	1.2%	0.6%	2.1%
Two or More	7.8%	8.1%	7.2%
White	23.7%	21.3%	27.8%
Age (years)	9.8 ± 0.7	9.4 ± 0.5	10.4 ± 0.5

Table-2 Actigraphic characteristics of students

	Overall (mean ± SD)	**Weekdays (mean ± SD)**	**Weekends (mean ± SD)**	***p*-value***
Sleep duration (minutes)	525.2 ± 33.3	525.4 ± 36.8	524.0 ± 55.3	0.7
SD of sleep duration (minutes)	49.5 ± 23.8	36.4 ± 23.3	50.7 ± 46.1	<0.001
Sleep duration shorter than 9hrs	68.5%	66.9%	57.6%	<0.05
Sleep duration shorter than 8.5hrs	31.5%	35.4%	38.9%	0.448
Sleep duration shorter than 8hrs	8.2%	9.3%	21.0%	<0.001
Sleep onset latency (minutes)	16.0 ± 9.2	16.3 ± 10.0	15.8 ± 17.1	0.649
Wake after sleep onset (minutes)	44.3 ± 13.4	45.0 ± 14.5	42.8 ± 14.5	<0.01
Sleep efficiency (%)	86.6 ± 3.4	86.4 ± 3.8	86.9 ± 4.3	0.088
Fragmentation (%)	17.6 ± 4.4	17.6 ± 4.7	17.5 ± 5.2	0.548
Sleep onset time (HH:MM) ± (minutes)	21:50 ± 41	21:29 ± 39	22:34 ± 65	<0.001
Sleep offset time (HH:MM) ± (minutes)	06:35 ± 33	06:14 ± 29	07:18 ± 58	<0.001
Sleep midpoint time (HH:MM) ± (minutes)	02:13 ± 34	01:51 ± 29	02:56 ± 55	<0.001
SD of sleep midpoint time (minutes)	38.9 ± 19.8	18.0 ± 12.2	21.2 ± 19.0	<0.05
Sleep Regularity Index (SRI)	84.7 ± 6.3	-[1]	-[1]	-

*The *p*-values indicate the statistical significance between weekdays and weekends

[1]The SRI is unavailable for weekdays only because the weekend data included only 2 contiguous days. Hence there was insufficient data 24 hours apart to allow a meaningful calculation.

[2] The rest interval start time and end time algorithms are shown in Appendix Figure B.1 and Figure B.2, respectively.

Table-3 Comparison of actigraphic characteristics between 4th-grade and 5th-grade students

	4th-grade (n = 160) (mean ± SD)	**5th-grade (n = 97) (mean ± SD)**	***p*-value***
Age (years)	9.4 ± 0.5	10.4 ± 0.5	<0.001
Sleep duration (minutes)	528.7 ± 33.8	519.3 ± 31.7	<0.05
SD of sleep duration (minutes)	48.9 ± 23.0	50.4 ± 25.2	0.628
Sleep duration shorter than 9hrs (%)	63.8	76.3	<0.05
Sleep duration shorter than 8.5hrs (%)	26.9	39.2	<0.05
Sleep duration shorter than 8hrs (%)	6.9	10.3	0.330
Sleep onset latency (minutes)	16.0 ± 9.4	16.1 ± 8.8	0.883
Wake after sleep onset (minutes)	44.9 ± 14.0	43.4 ± 12.4	0.370
Sleep efficiency (%)	86.4 ± 3.4	86.8 ± 3.4	0.350
Fragmentation (%)	17.5 ± 4.5	17.7 ± 4.4	0.735
Sleep onset time (HH:MM) ± (minutes)	21:44 ± 42	22:00 ± 38	0.929
Sleep offset time (HH:MM) ± (minutes)	06:33 ± 31	06:39 ± 34	0.148
Sleep midpoint time (HH:MM) ± (minutes)	02:08 ± 33	02:20 ± 33	<0.01
SD of sleep midpoint time (minutes)	38.0 ± 18.6	40.5 ± 21.5	0.300
Sleep Regularity Index	85.0 ± 5.8	84.1 ± 7.0	0.268

**p*-value for t-test comparing 4th-grade and 5th-grade students.

[1] The rest interval start time and end time algorithms are shown in Appendix Figure B.1 and Figure B.2, respectively.

Table-4 Comparison of actigraphic characteristics between boys and girls

	Boys (n=126) (mean ± SD)	**Girls (n=131) (mean ± SD)**	***p*-value***
5^{th}-grade (%)	41.3	34.4	0.253
Age (years)	9.8 ± 0.7	9.7 ± 0.7	0.377
Sleep duration (minutes)	519.0 ± 33.2	531.1 ± 32.3	<0.01
SD of sleep duration (minutes)	50.7 ± 24.0	48.3 ± 23.8	0.402
Sleep duration shorter than 9hrs (%)	77.0	60.3	<0.01
Sleep duration shorter than 8.5hrs (%)	38.9	24.4	<0.05
Sleep duration shorter than 8hrs (%)	10.3	6.1	0.218
Sleep onset latency (minutes)	16.6 ± 9.2	15.4 ± 9.2	0.311
Wake after sleep onset (minutes)	45.9 ± 13.3	42.8 ± 13.3	0.059
Sleep efficiency (%)	86.0 ± 3.0	87.2 ± 3.7	<0.01
Fragmentation (%)	18.6 ± 4.4	16.6 ± 4.3	<0.001
Sleep onset time (HH:MM) ± (minutes)	21:52 ± 41	21:48 ± 42	0.986
Sleep offset time (HH:MM) ± (minutes)	06:31 ± 33	06:39 ± 32	<0.05
Sleep midpoint time (HH:MM) ± (minutes)	02:12 ± 34	02:14 ± 33	0.633
SD of sleep midpoint time (minutes)	38.0 ± 18.0	39.8 ± 21.3	0.464
Sleep Regularity Index	84.4 ± 6.1	84.9 ± 6.4	0.489

**p*-value for t-test comparisons between boys and girls.

[1] The rest interval start time and end time algorithms are shown in Appendix Figure B.1 and Figure B.2, respectively.

Table-5 Comparison of actigraphic characteristics between age groups stratified by gender

	9-year-old (n=91) (Boy (n) = 44) (mean ± SD)	**10-year-old (n=126) (Boy (n) = 61) (mean ± SD)**	**11-year-old (n=38) (Boy (n) = 21) (mean ± SD)**	***p*-value**
Sleep duration (minutes)				
Girl	537.9 ± 32.1	527.7 ± 34.4	521.7 ± 19.9	0.122
Boy	525.1± 30.5	515.6 ± 34.2	515.7 ± 35.8	0.317
Overall	531.7 ± 31.8	521.9 ± 34.7	518.4 ± 29.5	<0.05
SD of sleep duration (minutes)				
Girl	45.9 ± 21.4	46.8 ± 20.5	60.9 ± 37.3	0.065
Boy	51.2 ± 24.4	51.5 ± 25.3	47.6 ± 18.3	0.807
Overall	48.5 ± 22.9	49.1 ± 23.1	53.6 ± 28.7	0.520
Sleep duration shorter than 9hrs (%)				
Girl	57.5	60.0	76.5	0.370
Boy	75.0	78.7	76.2	0.902
Overall	65.9	69.1	76.3	0.509
Sleep duration shorter than 8.5hrs (%)				
Girl	12.8	32.3	29.4	0.055
Boy	27.3	47.5	38.1	0.109
Overall	19.8	39.7	34.2	<0.01[a]
Sleep duration shorter than 8hrs (%)				
Girl	0.0	10.8	5.9	0.066
Boy	6.8	9.8	19.1	0.312
Overall	3.3	10.3	13.2	0.087
Sleep onset latency (minutes)				
Girl	16.2 ± 9.8	14.7 ± 9.1	16.4 ± 8.3	0.650
Boy	15.1 ± 8.0	17.2 ± 10.1	18.2± 8.6	0.351
Overall	15.7 ± 8.9	15.9 ± 9.7	17.4 ± 8.4	0.602
Wake after sleep onset (minutes)				
Girl	45.4 ± 16.2	41.4 ± 11.4	40.9± 11.4	0.239
Boy	47.0 ± 14.3	45.3 ± 13.0	45.6 ± 12.6	0.802
Overall	46.2 ± 15.3	43.3 ± 12.3	43.5 ± 12.2	0.262
Sleep efficiency (%)				
Girl	86.8 ± 3.9	87.4 ± 3.5	87.0 ± 3.7	0.716
Boy	86.0 ± 2.9	86.0± 2.9	85.8 ± 3.6	0.961
Overall	86.4 ± 3.4	86.7 ± 3.3	86.3 ± 3.6	0.742
Fragmentation (%)				
Girl	16.5 ± 4.6	16.6 ± 4.3	16.6 ± 3.9	0.992
Boy	18.9 ± 4.8	17.9 ± 3.7	20.3 ± 5.0	0.094
Overall	17.7 ± 4.8	17.3 ± 4.0	18.6 ± 4.9	0.244
Sleep onset time (HH:MM) ± (minutes)				
Girl	21:40 ± 43	21:50 ± 38	22:05 ± 45	0.094
Boy	21:38 ± 44	22:02 ± 35	21:54 ± 43	<0.05[a]
Overall	21:39 ± 44	21:56 ± 37	21:59 ± 44	<0.01[a,b]
Sleep offset time (HH:MM) ± (minutes)				
Girl	06:38 ± 29	06:38 ± 29	06:47 ± 47	0.554
Boy	06:23 ± 36	06:38 ± 32	06:29 ± 27	0.099
Overall	06:31 ± 33	06:38 ± 30	06:37 ± 39	0.291

Sleep midpoint time (HH:MM) ± (minutes)				
Girl	02:09 ± 33	02:14 ± 29	02:26 ± 45	0.198
Boy	02:01 ± 37	02:20 ± 29	02:11 ± 32	<0.05[a]
Overall	02:05 ± 35	02:17 ± 29	02:18 ± 39	<0.05[a]
SD of sleep midpoint time (minutes)				
Girl	36.7 ± 20.3	38.8 ± 18.6	52.0 ± 30.6	<0.05[b]
Boy	37.0 ± 16.9	40.6 ± 19.8	32.3 ± 13.7	0.176
Overall	36.9 ± 18.6	39.7 ± 19.2	41.1 ± 24.6	0.442
Sleep Regularity Index				
Girl	85.7± 5.8	85.4 ± 5.2	80.8 ± 10.6	<0.05[b,c]
Boy	85.3 ± 5.6	83.4 ± 6.7	85.3 ± 5.1	0.229
Overall	85.5 ± 5.7	84.4 ± 6.0	83.3 ± 8.2	0.170

* Bonferroni corrections were applied to the post-hoc comparisons of multiple Chi-square tests with $p < 0.017$

[a] Statistical significance between 9-year-old and 10-year-old

[b] Statistical significance between 9-year-old and 11-year-old

[c] Statistical significance between 10-year-old and 11-year-old

[1] The rest interval start time and end time algorithms are shown in Appendix Figure B.1 and Figure B.2, respectively.

Figure 1

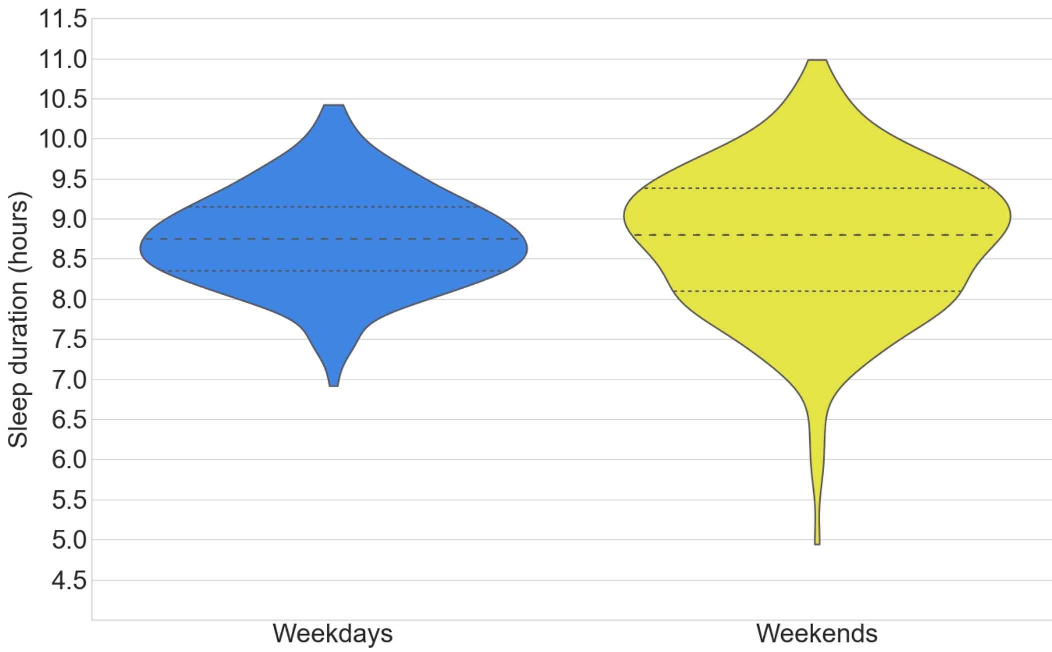
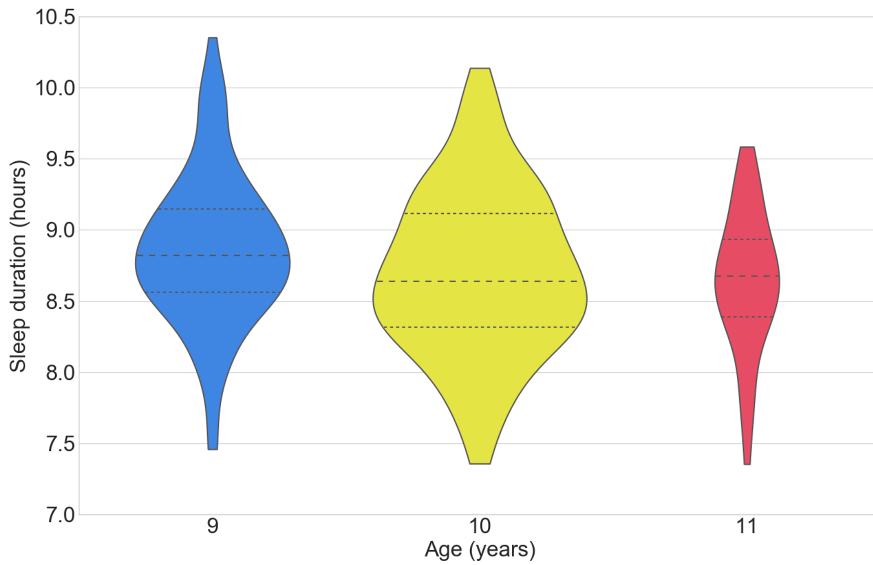
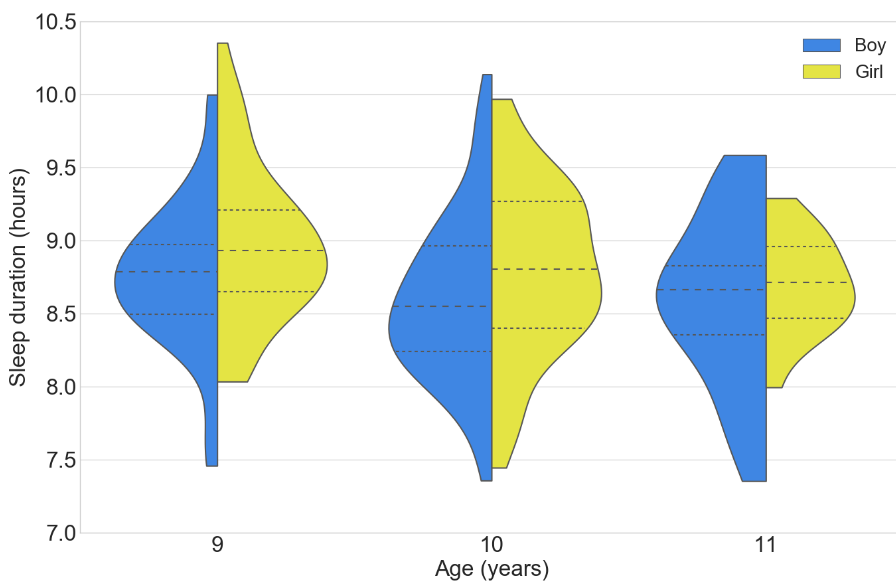


Figure 1. Sleep duration between weekdays and weekends. The black lines in the box correspond to the 25 percentiles, 50 percentiles (median value), and 75 percentiles. The shape shows the distributions of sleep duration.

Figure 2



(a)



(b)

Figure 2. Sleep duration between age and genders. (a) Sleep duration between age groups. (b) Sleep duration among age and gender stratified groups. The black lines in the box correspond to the 25 percentiles, 50 percentiles (median value), and 75 percentiles. The shape shows the distributions of sleep duration.

Figure 3

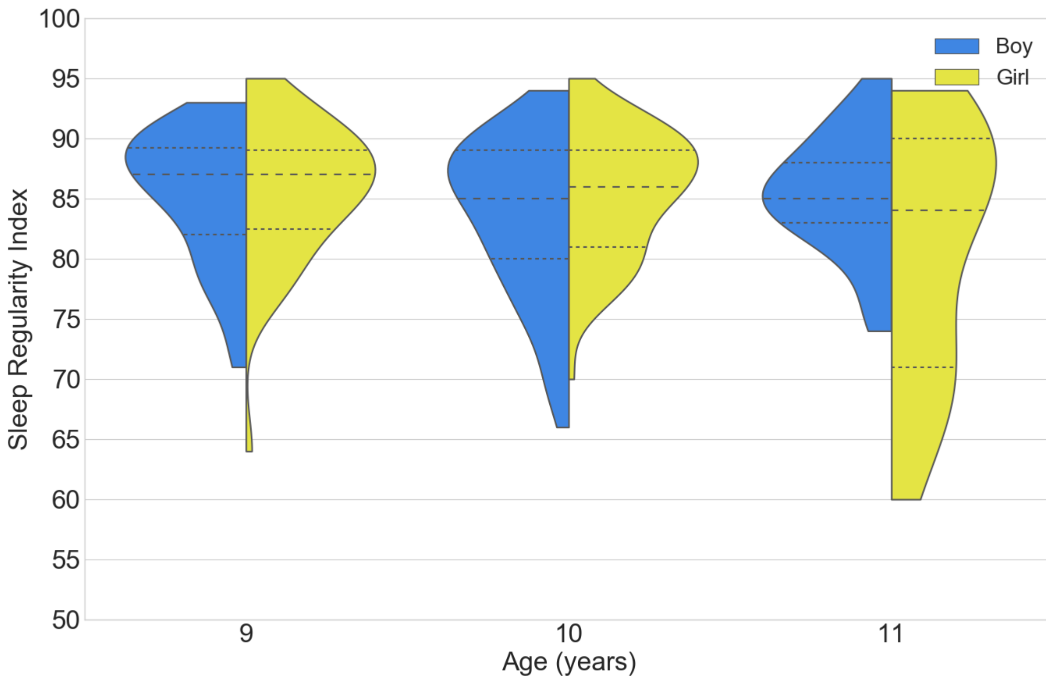


Figure 3. Sleep Regularity Index between age and genders. The black lines in the box correspond to the 25 percentiles, 50 percentiles (median value), and 75 percentiles. The shape shows the distributions of sleep regularity index.

Appendices

Appendix A. Sleep diary

Table A.1. Sleep diary

I attempted to fall asleep at: _______________ Info: Attempted to fall asleep means you were in bed with the intent to go to sleep---this may mean turning lights off, saying goodnight to someone, or closing your eyes.
I woke up this morning at: ________________

*The questions are designed based on the guideline of Carney et al. [61] and modified based on teachers' comments and the authors' experience.

Appendix B. Determination of Rest Interval Start Time

Figure B.1 Algorithm used for setting rest interval start time

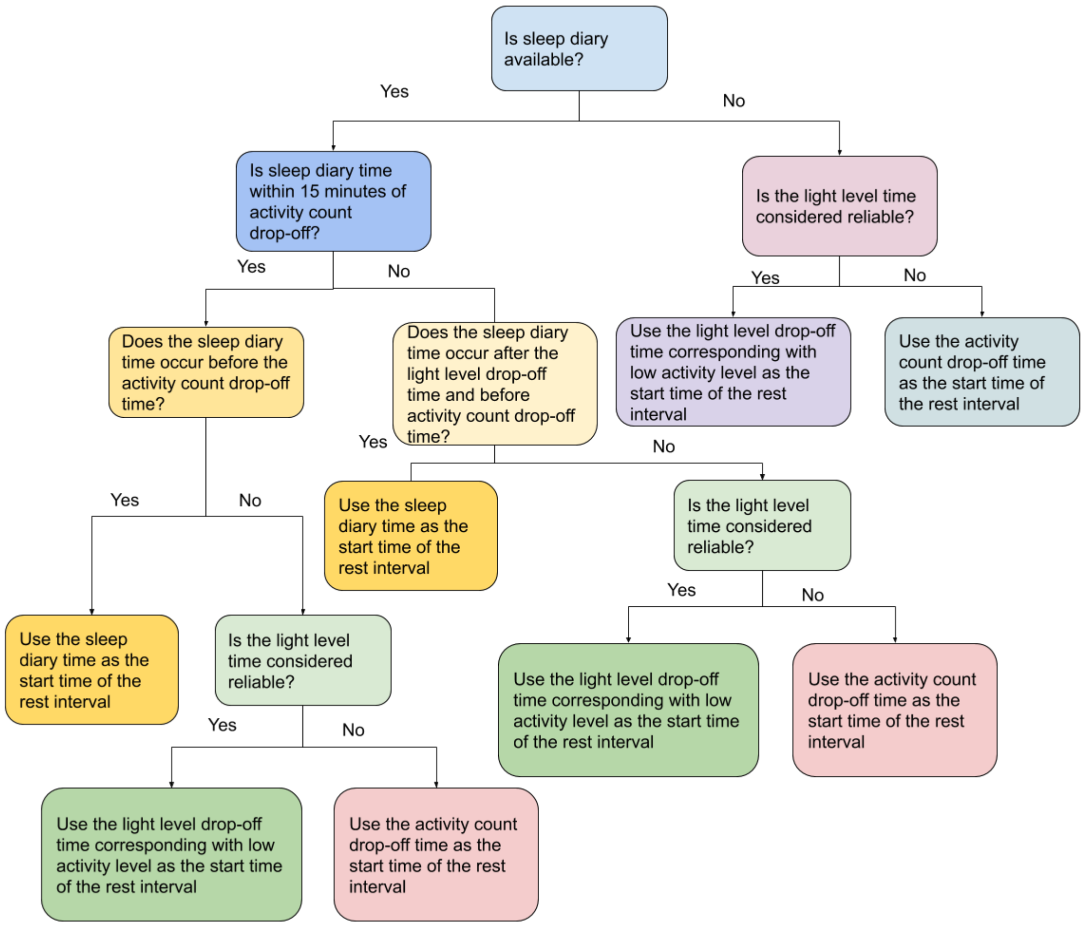


Figure B.2 Algorithm used for setting rest interval end time