DEVELOPMENTAL NEUROSCIENCE

Sleep*more* in Seattle: Later school start times are associated with more sleep and better performance in high school students

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Most teenagers are chronically sleep deprived. One strategy proposed to lengthen adolescent sleep is to delay secondary school start times. This would allow students to wake up later without shifting their bedtime, which is biologically determined by the circadian clock, resulting in a net increase in sleep. So far, there is no objective quantitative data showing that a single intervention such as delaying the school start time significantly increases daily sleep. The Seattle School District delayed the secondary school start time by nearly an hour. We carried out a pre-/post-research study and show that there was an increase in the daily median sleep duration of 34 min, associated with a 4.5% increase in the median grades of the students and an improvement in attendance.

INTRODUCTION

Adolescents typically have a preference to stay active until late in the evening and to wake up late in the morning. This timing of daily activity or "chronotype" is not only a consequence of a change in social life and the use of electronic devices that keep teenagers awake during the evening, but is also a result of changes in both the circadian and homeostatic regulation of sleep (*1*). During puberty, the adolescent circadian system naturally delays the onset of sleep to a later time. One reason for this is an apparent lengthening of the circadian period during the teenage years (*1*), which typically leads to a later onset of the biological night relative to the light-dark cycle (*2*). Furthermore, there is evidence that the adolescent circadian clock is less sensitive to light during the morning when light advances the circadian clock and its timing of sleep (*1*). On the other hand, the homeostatic regulation of sleep, which increases sleep pressure with waking hours, is also modified in older adolescents. This allows them to stay awake longer, relative to younger adolescents, due to a decreased sleep pressure during wake periods (*3*, *4*).

On the basis of these measurable changes in sleep regulation, adolescents find themselves caught between two competing yet equally important forces: their circadian and homeostatic regulation of sleep, which delays sleep onsets, and their social obligations, which impose early sleep offsets resulting in a net decrease in daily sleep. Most adolescents sleep less than the recommended daily sleep at this age (8 to 10 hours) (*5*, *6*), and an intervention that has been proposed to increase sleep is delaying school start times (American Academy of Pediatrics, 2014). Although some studies have used survey data to show that when teens are allowed to go to school later, they report longer sleep times, so far, there is no objectively recorded data indicating that delaying the school start time lengthens daily sleep in adolescent students.

Increasing daily sleep duration in adolescents is not only critical because of the clear adverse physical and mental health outcomes associated with chronic sleep deprivation but also because of the role that normal sleep plays in learning and memory consolidation (*7*). Any action that results in longer daily sleep duration should also result in better academic performance. The link between longer sleep and better school performance has been hard to establish in field studies; whether delayed secondary school start times result in better performance also remains to be determined.

RESULTS

The ideal field experiment to study the potential benefits of later school start time on both sleep and academic performance should include schools that switched from an early start to a late start (or vice versa), in which students of the same grade, taking the same classes, could be studied objectively. The Seattle (WA) School District decided to delay the start time for secondary schools from 07:50 to 08:45 a.m. This change was implemented for the 2016–2017 academic year and allowed us to conduct a pre-/post-study in which we measured sleep-wake cycles using wrist activity devices (Actiwatch Spectrum Plus, Philips Respironics) during the spring of 2016 (pre) and the spring of 2017 (post). The study populations included sophomores of two public high schools in Seattle. In each year, at the same time of the year, an independent sample of students taking the same science class was studied in each school. The study was implemented as a science laboratory practice in which the students could test predictions about their own sleep patterns. Both the Human Subject Division at the University of Washington and the Seattle Public School District Board approved our study. As part of the 2-week recording phase, each student wore an Actiwatch and completed a sleep diary (used to validate the Actiwatch data), the Beck Depression Index II (BDI-II) Questionnaire (*8*), the Epworth Sleepiness Scale Questionnaire, and the Munich (*9*) and Horne-Östberg (*10*) Chronotype Questionnaires.

Figure 1A presents the wrist activity mean waveforms for students pooled from both schools during each year. During school days, a two-way analysis of variance (ANOVA) yielded an effect of time [$F_{(143,\,25{,}311)} = 224.8$, $P < 0.0001$], no effect of year, and an effect of the interaction [$F_{(143,\,25{,}311)} = 18.43$, $P < 0.0001$]. Similar effects were found for the nonschool days [$F_{(143,\,25{,}025)} = 161.5$, $P < 0.0001$ for time; and $F_{(143,\,25{,}025)} = 2.19$, $P < 0.0001$ for the interaction]. However, multiple comparisons revealed that most of the differences in activity between the 2 years emerged from a different wakeup time during

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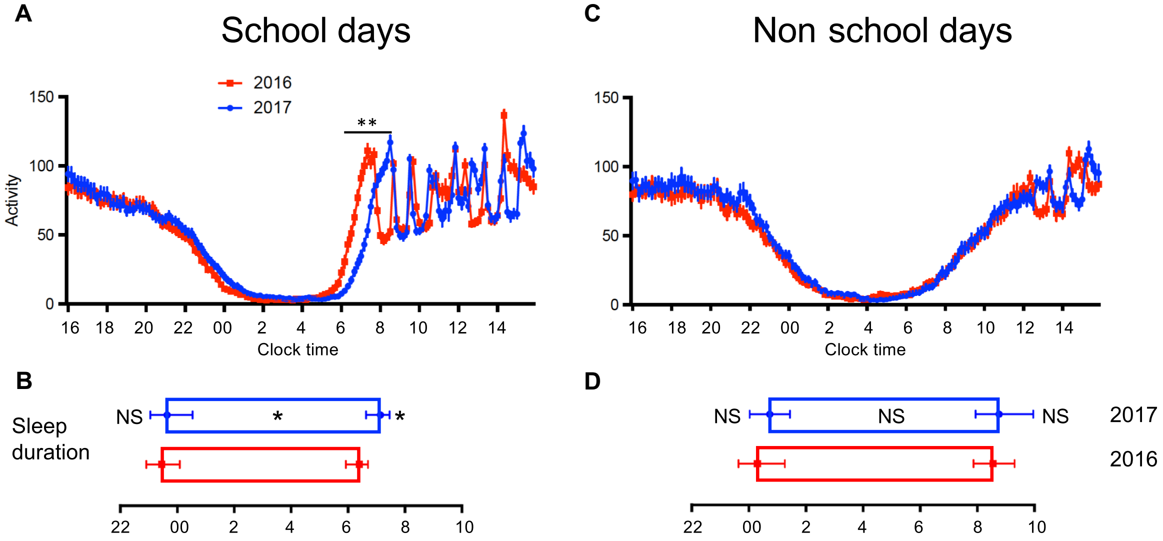

Fig. 1. Delayed school start times result in later sleep offset and longer sleep. Mean student activity waveforms and sleep summaries between years for school (**A** and **B**) and nonschool days (**C** and **D**). For both (A) and (C), there was a significant effect of time, year, and the interaction (see text). **$P < 0.01$, difference between years (Sidak's comparisons). For (B), there is a significant delay in sleep offset ($P = 0.0007$), but not sleep onset ($P = 0.0459$), on weekdays in 2017 as compared to 2016, resulting in a significant increase of sleep duration on school days in 2017 ($P = 0.0007$); $P < 0.017$ threshold for significance for Wilcoxon signed-rank test corrected for multiple comparisons. The same analysis of sleep parameters on nonschool days shows no difference between years (D) [$n = 84$ (2017, school day) and $n = 94$ (2016, school day); $n = 76$ (2017, nonschool day) and $n = 81$ (2016, nonschool day)]. For (B) and (D), values represent median, and bars represent interquartile range. Sleep offset was also tested through generalized linear models (see text). Each student contributed at least five nights for the school-day data and three nights for the nonschool data. NS, not significant.

school days but not during nonschool days. That is, there was a clear difference in the timing of activity between years during school days but not during nonschool days. Notably, the regular peaks observed during the waking hours of school days reveal the break times between classes when students walk from one classroom to another. Analysis of the estimated sleep onset, offset, and sleep duration (see Materials and Methods) confirmed this interpretation. Wilcoxon signed-rank tests corrected for multiple comparisons revealed that students in 2017 had a 44 min later median sleep offset ($P < 0.0001$, effect size = 0.194), and a trend toward a later sleep onset that was not statistically significant. This asymmetric effect led to an overall 34-min increase in the sleep duration median during school days in 2017 ($P = 0.0007$, effect size = 0.353). In contrast to school days, nonschool days did not show any significant differences between years in any of these sleep parameters. The number of naps (counted after inspecting every actogram) students took was very similar between 2016 (152 total naps, 0.6 naps per student) and 2017 (150 total naps, 0.56 naps per student).

We also examined the change in social jet lag, a measure of the difference in sleep timing on school versus nonschool days. We predicted that given the delayed sleep pattern of students on school days in 2017, their sleep during school days would more closely align with their sleep on nonschool days. After controlling for oversleep during nonschool days, because of the accumulated sleep debt during the school days (see Materials and Methods), we observed a significant decrease in social jet lag in students from 2017 (median = 1.25, $n = 76$) as compared to 2016 (median = 1.60, $n = 81$; Wilcoxon signed-rank test, $P = 0.0118$, effect size = 0.616). Social jet lag was also evident when the sleep onset of students was compared between the night from Sunday to Monday and the night from Monday to Tuesday. On both years, Wilcoxon matched-pairs, signed-rank tests revealed that, compared to Monday nights, sleep onset was later ($P = 0.0021$ for 2016 and $P = 0.0003$ for 2017) and sleep duration was shorter ($P = 0.0234$ for 2016 and $P = 0.0142$ for 2017) on Sunday nights; no differences were found for sleep offset. The reduction in social jet lag after the school start time delay further emphasizes the conclusion that later school start times allow students to better align sleep on school days with the circadian timing of their sleep.

A potential outcome of delaying school start times is that a trend for students to go to bed later could lead to exposure to artificial light later in the evening, which could in turn delay the master circadian clock. Figure 2 (A and B) shows the waveforms for exposure to light during different years. Visual inspection of the profiles during school days suggests that, compared to 2016, students in 2017 started their exposure to brighter light intensities later in the morning but did not necessarily end their exposure to bright light later in the evening. Furthermore, in both years, students appear to have a delayed exposure to light on nonschool days compared to school days. Because light intensities students are exposed to vary greatly—indoor light is several orders of magnitude lower intensity than outdoor light—light exposure never showed a normal distribution even after data transformation, precluding us from running a two-way ANOVA. Furthermore, Actiwatch light measurements are typically inaccurate at lower light intensities [see the Supplementary Materials and (*11*, *12*)]. A more meaningful measure of the time course of light exposure is to assess when a student was exposed to a specific light threshold for the first time and the last time each day. We chose a 50-lux threshold as it is just above the threshold for inhibition of melatonin release (*13*). A two-way ANOVA with factors year and day of week (school versus nonschool) of time of first or time of last exposure to 50 lux yielded an effect of year and of day of week but not of interaction (Table 1 and Fig. 2C). Sidak's comparisons

Table 1. Two-way ANOVA results for first and last time of daily exposure to 50-lux light intensity.

	Year		Day of the week		Interaction	
First daily 50-lux light exposure	$F_{(1, 331)} = 18.2$	$P < 0.0001$	$F_{(1, 331)} = 258.1$	$P < 0.0001$	$F_{(1, 331)} = 3.7$	$P = 0.0557$
Last daily 50-lux light exposure	$F_{(1, 331)} = 6.2$	$P = 0.0136$	$F_{(1, 331)} = 111.0$	$P < 0.0001$	$F_{(1, 331)} = 0.01$	$P = 0.92$

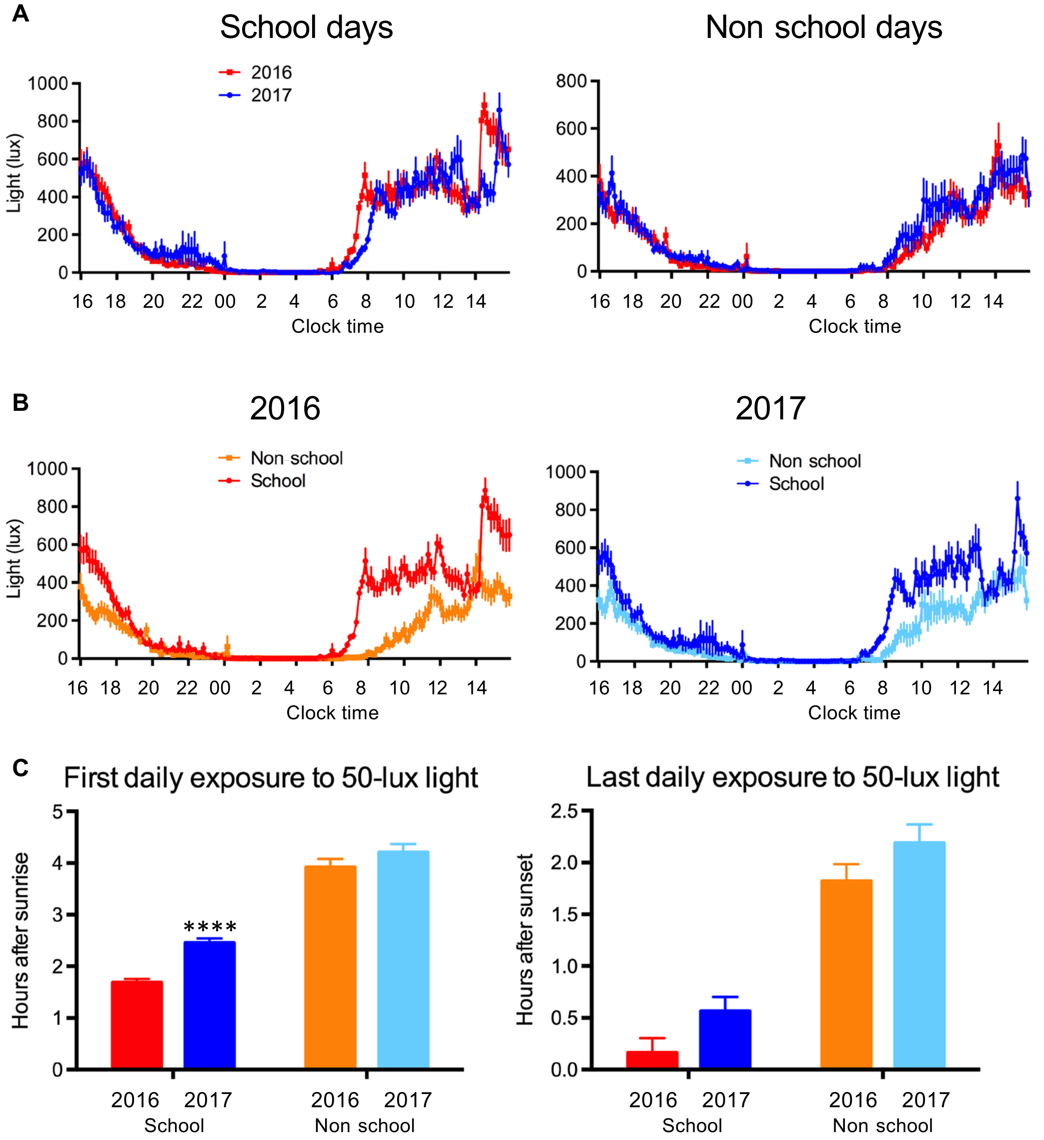

Fig. 2. Delayed school start times result in later exposure to light in the morning but not in the evening. (**A**) Mean student light exposure waveforms between years for school and nonschool days. During school days, students appear to have a delay in morning light exposure but not in evening light exposure. This delay is not evident in the data from nonschool days. (**B**) For both years, exposure to light is delayed in weekends relative to weekdays. (**C**) Because of the non-normal nature of the light data, the times for first and last exposure to 50-lux light on school, and nonschool days were tested for each year using a two-way ANOVA. There was a significant effect of day of week (school or nonschool) and year but not of the interaction (see Table 1); ****$P < 0.0001$, significant difference between years (Sidak's multiple comparisons). No difference was observed on nonschool days nor in the timing of the last daily exposure for school or nonschool days.

for school days demonstrated that while the first daily exposure to 50-lux light intensity occurred later in 2017 than in 2016, there was no difference between years in the last daily exposure to the same light intensity. In both years, comparisons revealed that students' first and last daily exposure to 50-lux light intensity occurred later during nonschool days than during school days (Fig. 2C).

We used generalized linear models with years as the independent predictive variables to determine which dependent variables were significantly different between years. Because of the interdependence among sleep parameters (onset, offset, and duration), we tested one of these sleep variables separately in each model with the remaining parameters (school, sleepiness, depression index, chronotype, and grades). The final, best-fitting model included school, school day sleep offset, academic performance, mood, chronotype, and sleepiness, with sleep offset ($P = 2.8 \times 10^{-5}$; $\text{median}_{2016} = 06{:}24$ a.m., $\text{median}_{2017} = 07{:}08$ a.m.), performance ($P = 0.0261$; $\text{median}_{2016} = 77.5\%$, $\text{median}_{2017} = 82\%$), and sleepiness ($P = 0.0370$; $\text{median}_{2016} = 7.0$, $\text{median}_{2017} = 6.0$), emerging as significant factors between years (Fig. 3). None of the other variables, including school, sex, depression index, and chronotype, emerged as significantly different between years in the final models or any of the other models tested.

Attendance has been shown to improve and tardiness to decrease with later school start times in other school districts (*14*). We tested whether the later school start in 2017 improved attendance and punctuality by comparing the percent of absents and tardies among all students in the school in first period for each year in each school separately. Whereas Roosevelt High School (RHS) showed no difference between years, students in Franklin High School (FHS) had significantly fewer tardies and absentees in 2017 than in 2016 (Fig. 3, C and D). Notably, FHS has many more economically disadvantaged students (88%) and ethnic minorities (68%) than RHS (31 and 7%, respectively).

DISCUSSION

We show that a delay in the high school start times from 7:50 to 8:45 a.m. had several measurable benefits for students. The change led to a significant lengthening of daily sleep of over half an hour. There is evidence that adolescents in most industrialized societies do not achieve the recommended approximately 9 hours of daily sleep during school days (*5*, *15*), which is consistent with estimates that in the past 100 years, sleep has shortened by about 1 hour in children (*16*). Our study demonstrates a lengthening in the median daily sleep duration from 6 hours and 50 min to 7 hours and 24 min, restoring the historical sleep values present several decades before evenings within brightly lit environments and with access to light-emitting screens were common among teenagers. These results demonstrate that delaying high school start times brings students closer to reaching the recommended sleep amount and reverses the century-long trend in gradual sleep loss.

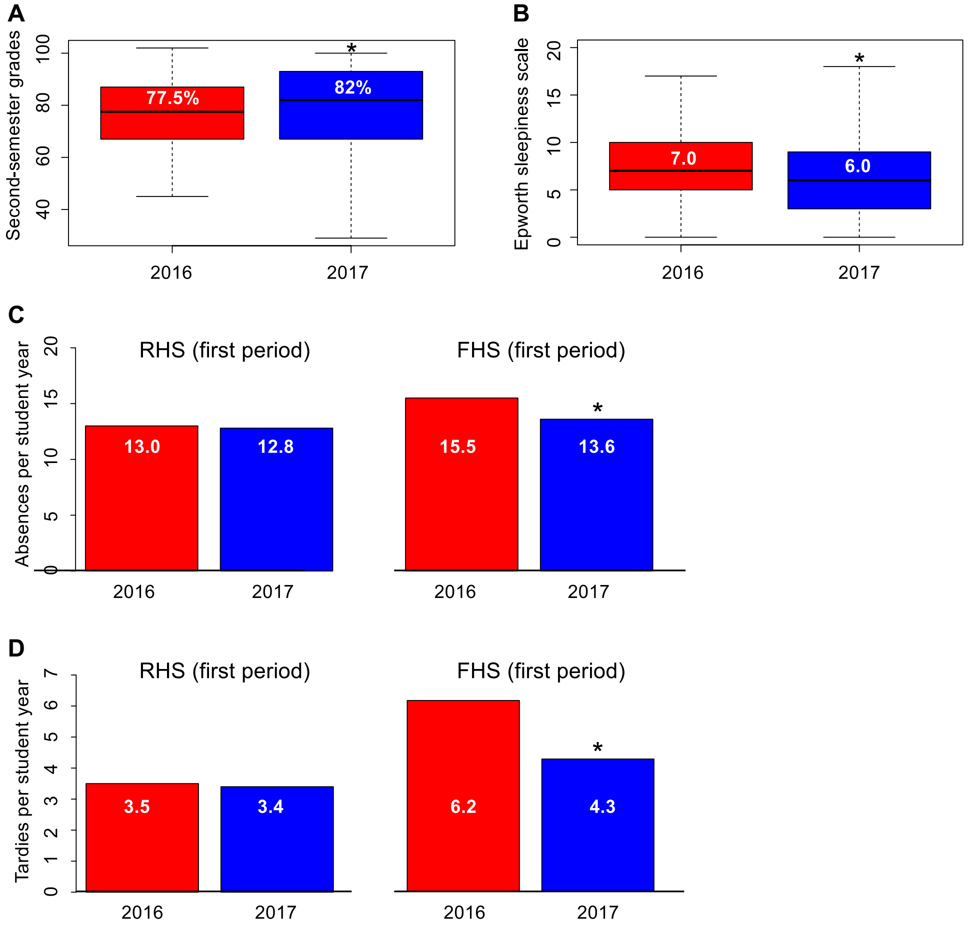

Fig. 3. Delayed school start times are associated with higher grades, reduced sleepiness, and improved attendance and punctuality. (**A** and **B**) Box plots of student performance and daytime sleepiness. Generalized linear models indicated that student performance, as measured by second-semester grades, was significantly higher ($^*P = 0.0261$), whereas daytime sleepiness was significantly lower ($^*P = 0.0370$) in 2017 than 2016. First-period absence (**C**) and tardy (**D**) data were compared between years using a χ^2 test. Students from FHS but not from RHS had a significant reduction in absences and tardies ($^*P < 0.0001$) in 2017 as compared to 2016. Numbers within boxes in (A) and (B) represent medians, and numbers in bars in (C) and (D) represent absolute value.

We also show that the later school start time is associated with a better alignment of sleep timing with the circadian system (reduced social jet lag), reduced sleepiness, and increased academic performance. Although it is highly likely that increased sleep was the cause for reduced sleepiness, it is much harder to attribute causality for 4.5% higher grades on increased sleep; nevertheless, it is certainly reasonable that students who are better rested and more alert should display better academic performance. Last, the later school starts led to an increase in punctuality and attendance that, remarkably, was only evident in the economically disadvantaged school. Obviously, attending school and arriving on time to school is beneficial for learning, and this result suggests that delaying high school start times could decrease the learning gap between low and high socioeconomic groups. Other studies have shown impacts of later school start times that are consistent with our findings [see reviews in (*14*, *17*)]. However, to our knowledge, ours is the first report to show that an across-the-district change in school start times results in a significant increase in daily sleep measured objectively with actimetry. Carskadon and colleagues (*18*) measured sleep in a group of high school students in one Rhode Island School District that transitioned from a 08:25 a.m. start time in nineth grade to a 7:20 a.m. start time in 10th grade and confirmed a shortening of daily sleep of approximately 20 min, which was also associated with a delay in the circadian phase and increased sleepiness. A recent study showed that a delay of 45 min in start times in one all-girls high school in Singapore resulted in a modest, almost 10 min, lengthening of daily sleep (*19*). This small change in sleep duration, in comparison to our study, could be related to several differences in the study design: (i) the authors performed the study on female students and within a larger range of ages and school grades; (ii) the study was performed longitudinally on the same students before and after the school start change, which not only introduces an age difference but can also be associated with changes in schedule; and (iii) sleep parameters were based on a single week of recordings and on less recorded days per student. The nature of our pre-/post-study prevents us from having a control group. However, in an intervention study with middle school students, in which the starting time was delayed by 1 hour for a week, students gained nearly 1 hour of daily sleep compared to themselves under the normal schedule or to nondelayed controls (*20*). The Seattle school start time delay of 55 min did not result in a gain of 55 min of sleep, suggesting that after a year—as opposed to an acute change lasting for 1 week—students may delay their bedtimes, indicating that there may be other factors that are keeping teens awake in the evenings of school days. Delayed school start times should be paired with advice on sleep hygiene, including preventing the increasingly pervasive use of screens late in the evening that is known to delay sleep onset (*21*). Given the widespread negative effects sleep deprivation has on adolescent physical and mental health, our study points to the value of a measure such as delaying the school start time toward improving teenage sleep and, in turn, health and academic outcomes.

MATERIALS AND METHODS

Data collection

Activity, light, and sleep data were collected using Actiwatch Spectrum Plus wrist activity monitors. Watches were programmed to collect data in 15-s epochs for 2 weeks (14 days), and students were instructed to press a marker button on the watch each time they went to sleep and woke up. Philips Actiware (version 6) software was used to construct actograms and determine sleep intervals. Activity and light data were exported and analyzed separately for mean waveforms using R Studio and Prism. Students also completed a daily retrospective online diary, which included questions about sleep onset, offset, how they were awakened, if they took any naps, if they removed the watch, and a place for text comments. Diary information was used in the data cleanup procedure (described below) to validate the sleep bouts automatically determined by Philips Actiware.

Chronotype, daytime sleepiness, and mood were measured by a one-time completion of the respective surveys located in the same portal as the daily diary. Chronotype was assessed using the Horne-Östberg Chronotype Questionnaire (*10*) and the Munich Chronotype Questionnaire (*9*). Daytime sleepiness was measured using the Epworth Sleepiness Scale. Mood was measured using the BDI-II. Students who scored higher than 20 on the BDI-II were contacted by their teacher and reminded about access to mental health resources.

Student demographics, including sex, race, birthdate, commute time to school, and mode of transportation, were collected via a paper demographic survey handed out in class. Students were also given the opportunity to disclose any sleep disorders and/or scheduled responsibilities (work, child care, etc.) that might affect the data. In addition, students from the 2017 cohort were asked to disclose any school activities that were scheduled for before school as a result of the delayed start times; the number of cases was small and was not considered separately in the statistics. Second semester grades for the students included in the sleep study were provided by the teachers whom we partnered with for this study. These represent absolute (not normalized) grades and could carry an implicit bias from teachers who could have been for or against the school time change. Last, global attendance data for each school were provided by Seattle Public Schools.

Data were collected over the course of 6 weeks during the Spring of 2016–2017 in 2-week rounds. Students from the first period participated in data collection for the first 2 weeks, second period for the following 2 weeks, and third or fourth period for the final 2 weeks. Students in each round were given the same instructions. The data were stripped of all identifying information upon collection. At the end of the semester, the data were returned to the students for an in-class learning exercise on research methods, data interpretation, and the relationship between sleep and their lifestyles.

Participants

The first cohort of students was selected to participate from the first three periods of two sections of 10th grade Biology at RHS and one section from FHS in 2016. The second cohort of students was selected from the same grade, classes, and schools and during the same time of the year but in 2017, when the new school start time had been in effect for 7 months. Each section was taught by a separate instructor but instructors remained the same between years, and course credit was given for participating in the data collection as an in-class learning exercise. While all students were assigned to complete the online diary and surveys, watches were assigned to a subset of each section with the help of the instructors due to resource constraints. This assignment was designed to represent gender and underrepresented minorities in each class (table S1). Informed assent and consent were obtained from the students and their parents, respectively.

Inclusion criteria

Activity, light, and sleep data were segregated by school day nights (Sunday night to Thursday night) and nonschool day nights (Friday night, Saturday night, or the night before one holiday, Memorial Day) for analysis. School and nonschool days were treated separately. If a student was missing one or more nonschool nights (out of four), then the nonschool nights for that student were not included in the analysis. If a student was missing 5 or more school nights (out of 10), then the school nights for that student were not included in the analysis. Students missing both one or more nonschool night and five or more weekday nights were removed entirely from the analysis.

Activity data

Raw activity data for each subject were binned in 10-min intervals and then averaged across either school or nonschool days, giving each subject two averaged 24-hour activity profiles. Individual profiles were then used to construct activity waveforms for school and nonschool days in 2016–2017 (Fig. 1). Waveforms were analyzed using a two-way ANOVA with year and time of day as factors, followed by Sidak's multiple comparisons.

Light data

Light exposure data were analyzed using the "white light" reading supplied by the Actiwatch. Light readings are subject to occlusion by sleeves, and they are also attenuated when the light source is off-axis [50% attenuation at 50° to 60° and near-complete attenuation at 70° to 80° (*11*, *12*)]. It is therefore conceivable that illuminances above 100 lux at normal arm position could result in momentary readings of 0 to 10 lux. Figure S1 shows that this does happen; even during the middle of the day, when an exposure to illuminances lower than 1 lux is extremely unlikely, a large proportion of individual readings are very low. In addition, levels of illuminance <~1 lux resulted in a greatly increased measurement error with these devices (*11*, *12*). Therefore, we excluded readings during which the subject was asleep, the watch was off wrist, or illumination was below 1 lux. Raw data for the same students that met inclusion criteria for activity were binned in 10-min intervals and processed for waveforms (Fig. 2).

The >1 lux criterion does not completely preclude momentary incorrect measurements. However, while Actiwatches can underestimate illuminance levels by more than an order of magnitude, they are not known to do the opposite, i.e., provide artifactually high illuminance values. Therefore, the times of first and last exposure to a given light threshold represent a more meaningful measurement than the mean of the illuminance reading. While this measure does not fully describe the illuminance over the 24-hour period, it provides a direct measurement of how long a subject experienced light levels above a physiologically interesting value. Figure S2 portrays the difference between the probability of the mean of all readings within a 10-min interval being above 50 lux and the probability of a single reading being above the 50 lux. Inside a given 10-min bin of a student day, three possibilities exist: (i) no measurements are >50 lux; (ii) one or more measurements are >50 lux, but the mean is <50 lux; and (iii) the mean measurement is >50 lux. Figure S2 shows that during the early morning and late evening, when a person's watch produces a single reading above 50 lux, it is more likely that the mean of the readings in these 10-min intervals will be below 50 lux than it is for the mean to be above 50 lux. Given that most subjects experience indoor light levels at this time range and the potential for inaccurately low, but not high, measurements discussed above, times of the first and last light measurements above a given threshold are a more accurate depiction than the mean illuminance reading at a given time. The former variable represents a better proxy for the overall window of time during which the subject experiences physiologically relevant levels of artificial light. This analysis could potentially use any threshold; the choice of 50 lux was based on the estimated threshold for the inhibition of melatonin release.

The time of first and last exposure to a given light intensity threshold was calculated separately for each student day. We report the mean value of first and last exposure to a 50-lux threshold intensity separately for school days and nonschool days for each school year (Fig. 2C). Data were analyzed by two-way ANOVA with day of week (school or nonschool) and year as factors, followed by Sidak's multiple comparisons. Light data were processed using Python v2.7.9, using the following libraries: pandas v0.22, numpy v1.14.0, and matplotlib 2.1.0.

Sleep data cleanup

For this study, we gathered three potential sources for sleep onset and offset data. The first was the watch, which extrapolated sleep intervals from the raw data using Philips Actiware software. The second were the self-report online diaries that the students were assigned to fill out every day. The third were the time stamps students could add to their recordings by pressing a button on their watch. To validate the sleep intervals, as determined by the watch software, we followed the following protocol:

1) We inspected every single actogram day by day to detect false software calls for sleep onsets or offsets. These represent obvious mistakes that can be easily detected upon inspection (fig. S3).

2) We then looked for discrepancies between the diary, or event recorder, and software calls for sleep onsets or offsets that were larger than 1 hour.

3) For all the nights in which the discrepancy was larger than 1 hour, we inspected once again the actograms on those nights to determine whether the 1 hour error was due to a software error or a student error, entering the wrong time in the diary or with the event marker.

After inspection of the actograms in step 3, we determined that 19% of the discrepancies had already been detected in step 1. Of the remaining discrepancies, 77% were caused by student error in the diary or event marker and 19% by a watch error, and on 4%, we were unable to determine the cause. This means that the error of taking the actimeter calls for sleep onset and offset after step 1 is ≤5% and four times lower than the student-generated error, which was 19.5%.

Cleaned sleep data were broken up by onset, offset, duration, and efficiency for school and nonschool days. Sleep data were then exported and analyzed using Python and R Studio. Normality was tested by (i) visual inspection of distribution histograms, (ii) quantile/quantile plots, and (iii) through the Shapiro-Wilk test. None of the variables had normal distribution, and data on Fig. 1 were presented as medians ± quartiles. Differences in sleep onset, offset, and duration for both school and nonschool days were tested using Wilcoxon signed-rank tests with a Bonferroni correction for multiple comparisons. For each student, social jet lag was calculated as the difference between mean mid-sleep on the nonschool days (after subtracting oversleep) minus mean mid-sleep on the school days (*22*). For the

Wilcoxon signed-rank tests, effect sizes were calculated by dividing the *U* statistic by the product of the *N*s (*23*).

Academic performance and attendance

Academic performance was assessed using second-semester grades from the science class that provided our pool of participants. School, academic performance, mood, chronotype, and sleepiness values were scaled and tested via generalized linear models using a binomial family with year as the dependent variable, testing the hypothesis that years differed on the basis the other variables. Models included a single sleep variable (onset, offset, duration, and efficiency) at a time to avoid multicollinearity. Multiple models were tested, and the model with the lowest Akaike information criterion value was selected as the model of best fit. The final model included school, academic performance, mood, chronotype, sleepiness, and weekday offset. Ethnicity was not tested as a variable per se, but the two schools differ widely in their ethnic backgrounds (table S1). There were no sex differences between years or schools. There is no consensus on how to calculate the effect size for each variable that emerges as significant with generalized linear models; instead, we present the medians for each year, as the data were not normally distributed.

Attendance data were provided by the school district and contained the average number of tardies and absences per student by period for both schools in the study for 2016–2017. Predicted absentee and tardy data for 2017 were calculated on the basis of the rates from 2016, adjusted for changes in enrollment, and assessed using a χ^2 test. This analysis was only performed for the "first period," namely, the first scheduled hour of class in the morning.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/4/12/eaau6200/DC1

Table S1. Demographics of students in each of the high schools included in the study.

Fig. S1. Probability of a light measurement (among all individuals recorded) being below a threshold (X in legend) throughout the day.

Fig. S2. Probability distribution of light measurements across all watch data from Seattle high school students in 2016 and 2017.

Fig. S3. Representative actogram of a student in which the Actiwatch algorithm for sleep offset detection missed a sleep offset (white arrow).

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