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The Impact of School Daily Schedule on Adolescent Sleep

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ABSTRACT. *Objectives.* **This study was initiated to examine the impact of starting school on adolescent sleep, to compare weekday and weekend sleep times, and to attempt to normalize the timing of the circadian sleep/wake cycle by administering bright light in the morning. This was a collaborative project involving high school students and their parents, as well as high school and university faculty members, for the purpose of contributing information to the scientific community while educating students about research processes and their own sleep/wake cycles and patterns.**

Methods. **Sixty incoming high school seniors kept sleep/wake diaries beginning in August and continuing through 2 weeks after the start of school in September. Sleep diaries were also kept for 1 month in November and 1 month in February. Early-morning light treatments were given to 19 students in the last 2 weeks of November and the last 2 weeks of February. Neuropsychologic performance was measured with computer-administered tests. Paper-and-pencil tests were used for assessment of mood and vigor. A testing period consisted of 2 consecutive days at the beginning and end of November and at the beginning and end of February. Tests were given 3 times per day, ie, in the morning before school (6:30–8:00 AM), during midday lunch periods (11:30 AM to 1:00 PM), and in the afternoon (3:00–4:30 PM), on each of the test days.**

Results. **Adolescents lost as much as 120 minutes of sleep per night during the week after the start of school, and weekend sleep time was also significantly longer (~30 minutes) than that seen before the start of school (August). No significant differences were found between weekday sleep in the summer and weekend sleep during the school year. Early-morning light treatments did not modify total minutes of sleep per night, mood, or computer-administered vigilance test results. All students performed better in the afternoon than in the morning. Students in early morning classes reported being wearier, being less alert, and having to expend greater effort.**

Conclusions. **The results of this study demonstrated that current high school start times contribute to sleep deprivation among adolescents. Consistent with a delay in circadian sleep phase, students performed better later in the day than in the early morning. However, exposure to bright light in the morning did not change the sleep/wake cycle or improve daytime performance during weekdays. Both short-term and long-term strategies that address the epidemic of sleep deprivation among adolescents will be necessary to improve health and maximize school performance.** ***Pediatrics*** **2005;115:1555–1561;** ***adolescents, sleep, school, schedule, performance.***

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Adolescent sleep has received growing attention in the past 10 years. Parents state that sleep problems are common among their children.[1,2] In a community survey, pediatric doctors reported that sleep problems affect the health and well-being of children and families but they themselves were not confident of their ability to manage those problems. Only 38.3% of pediatricians asked adolescents about sleep habits, and <46% of them felt confident of their ability to screen children for sleep problems.[3]

Circadian rhythms or biological sleep patterns among adolescents are thought to be different from those of preadolescents or adults.[4] Adolescents prefer to go to sleep later at night and wake up later in the day, a pattern not typically seen among preadolescents and older adults.[4,5] The delayed phase of sleep and wake cycles in adolescence is probably a result of several factors, including changes in the intrinsic period of the circadian clock and behavioral and social factors that may promote and perpetuate the delayed bedtime and wakening.[6]

The combination of delayed circadian sleep phase and early start times at high schools in the United States causes adolescents to lose sleep during the school week.[4,7,8] Chronic partial sleep loss has negative effects on neurocognitive performance, mood, and health. A large survey of 12- to 15-year-old subjects showed correlations between sleep problems, rebelliousness, depressive symptoms, and cigarette smoking.[9] Sleep deprivation among adolescents causes an increase in inattentive behavior,[3] and daytime sleepiness may affect mood, behavior, and academic performance and even put adolescents at risk for accidents or injury. However, information on these effects and their relationship to adolescent sleep remains inconclusive.[4,6,10–12] Many authors have suggested that more studies are needed to determine the underlying causes of adolescent sleep patterns and their specific relationship to problems and overall functioning in this age group.[1,2,9,11]

Adolescent sleep scheduling is unstable,[13] and there is a marked difference between weekday and weekend sleep during the school year.[4] Sleep times and wake times occur later and total sleep time is greater on weekends, which suggests that adolescents are attempting to recover sleep during the weekend.[11,14]

Light is a major synchronizing agent for the circadian clock.[15] Exposure to bright light in the early morning advances circadian rhythms, resulting in earlier bedtimes and wake times.[11,16–18] In addition, the possibility that bright light can increase alertness and enhance performance has been studied.[19–22] Therefore, it seemed possible that exposure to bright light in the morning in the classroom might help normalize the phase of circadian rhythms and sleep, as well as improving students' performance.

The goal of this study was to characterize the impact of sleep loss after the start of school on neurocognitive performance and mood, to examine the relationship of weekday to weekend sleep among adolescents, to determine whether early-morning light treatments given to a portion of the students could improve sleep, mood, and performance, and to educate adolescents regarding the importance of sleep for performance and health. The subjects were all advanced-placement biology students spread throughout 3 sections or classes. They were chosen because the 3 classes were held at different times of day and because these highly motivated students could be subjects of the study and later become involved in scientific research by helping to discuss, process, and analyze the data they generated.

METHODS

Protocol

Northwestern University professors and Evanston Township High School science department faculty members first met when Northwestern University faculty members gave a science seminar (in January 1997) on circadian rhythms at the high school. Interest in a collaborative project was generated, and permission was granted by both schools.

Students who had registered for advanced-placement biology for the autumn of 1997 were contacted in June, before the end of the 1996–1997 school year. An informational meeting was held for incoming students and their parents, which was attended by both Evanston and Northwestern faculty members. At that time, consent forms, addressing the procedure for the project, benefits and risks, and confidentiality, were distributed and discussed. The institutional review board of Northwestern University and the administrators at the high school approved this study. Consent was obtained from both the students and their legal guardians. Students had the option to drop out of the study at any time without it affecting their grade or any other activity. Sleep-diary packets were distributed to each student to begin in August 1997, and the procedure for filling them out was discussed.

Sleep Diaries

Distributed sleep-diary packets included record-keeping sheets, on which students recorded the date, bedtime, wake time, number of awakenings per night, and naps. These diaries were kept for the month of August, the first 2 weeks of September, the last week of October, the first 3 weeks of November (this schedule was moved up 1 week to avoid Thanksgiving vacation), and the entire month of February. Diaries were collected and data were entered into computer databases. Students, some of whom were in the study, performed most of the data entry. Numerous systems for editing and crosschecking the accuracy of the data entered were used to ensure that mistakes were not made.

Light Treatments

Artificial white light (1800 lux at ~66 cm from the source, for 93 minutes) was administered to the early morning class only on weekdays from 8:10 to 9:43 AM, from November 10 through November 22 and again from February 16 through February 27. This group is referred to as the light group. The other 2 classes (9:48–11:25 AM and 1:08–2:41 PM) received red-light treatments (100 lux at ~66 cm from the source, for 93 minutes). This group is referred to as the placebo group; the students thought they also were receiving a significant amount of light. All students were confined to a rectangular area of 17.95 m^2 (4.89 m wide and 3.67 m long) for the duration of the daily treatment period. Seating was not always constant, and some students shifted during the period, but all remained in the rectangle and no student received <1800 lux (light group) or <100 lux (placebo group). Blinds in the room were kept shut so that outside light was not a variable. Students were facing the front of the room, and 7 light panels were positioned around the front of the rectangle from 29 cm outside the line of the rectangle containing the students to 103.5 cm outside the rectangle, with the average distance from the rectangle being 66 cm. During placebo treatments, only 4 red lights were used (every other panel) and an additional small red lamp was positioned at the front of the room. During red-light treatments, filters were constructed that fit over the light panels. These consisted of layers of Parafilm covered by transparent red cellophane. Light readings were checked to ensure that no more than 100 lux of light was received in any part of the rectangle during placebo treatment. All light panels were obtained from Medic-Light (Lake Hopatcong, NJ).

Performance and Mood Tests

Vigilance was assessed as part of the Harvard Cognitive Battery. The Harvard Cognitive Battery consists of 4 tests, ie, 3-dimensional rotation, vigilance, Posner, and reasoning. The Posner and vigilance computer-generated tests measure reaction times. Both tests were administered to each student during each test period. In the Posner test, the student hits the space bar as soon as an asterisk appears on the screen. In the vigilance test, the student pushes a specific key on the computer when a 0 appears instead of a number from 1 to 9. The tests were given 3 times per day, ie, in the morning before school (6:30–8:00 AM), during midday lunch periods (11:30 AM to 1:00 PM), and in the afternoon (3:00–4:30 PM), on each of the test days. Here we report only the morning and afternoon results, because no differences among the groups were found. Macintosh computers (Apple, Cupertino, CA) were used, and results were stored with Mac Lab (D. Costin, dcostin@euco.com). Posner data were not used because these bright students quickly learned the test and were able to score 100% after the first trial. Vigilance tests were more difficult for the students and were judged to be a better assessment of performance reaction times. Paper-and-pencil tests[23] were administered to measure symbol copying, visual search tasks, and logical reasoning. Again, students quickly learned these tests and scored 100% on all of them, thus excluding the data as an accurate measure of performance.

The visual analog scale of vigor and mood[24] was used by students to self-evaluate their feelings in different areas (alert, sad, tense, effort, happy, weary, calm, and sleepy), from very little to very much along a 10-cm line. These distances were later measured. Overall mood and vigor were calculated as follows: global affect = [happy + calm + (200 − sad − tense)]/4; global vigor = [alert + (300 − sleepy − effort − weary)]/4.

Statistical Methods

Total sleep time, bedtime (minutes before or after midnight), vigilance, global affect, and global vigor were analyzed. Results are expressed as mean ± SEM. The method of analysis was repeated-measures analysis of variance. SAS Proc Mixed (SAS Institute, Cary, NC) was used with fixed effects for analysis for all subjects who provided data for at least 2 time periods (August and September, for example). All results were confirmed with complete cases only.

For the analysis assessing changes in sleep from summer to the beginning of school, 2 within-subjects factors were used, namely, summer (yes/no) and weekday/weekend. For the analysis across time, group (placebo or light) was included as a between-subjects factor. For the analyses of vigilance, global affect, and global vigor, 2 repeated factors, namely, month (ie, November before treatment, November after treatment, February before treatment, or February after treatment) and time of day (morning or afternoon), and 1 between-subjects factor (light, yes or no) were used. Posthoc *t* tests were used subsequently when warranted by overall significant results.

RESULTS

Study Subjects

Students kept sleep diaries in August, September, November, and February. A total of 60 students enrolled in the study, but the sample size decreased to 37 from August to September (Fig 1). In November and February, the sample size for sleep (Fig 2) was 55

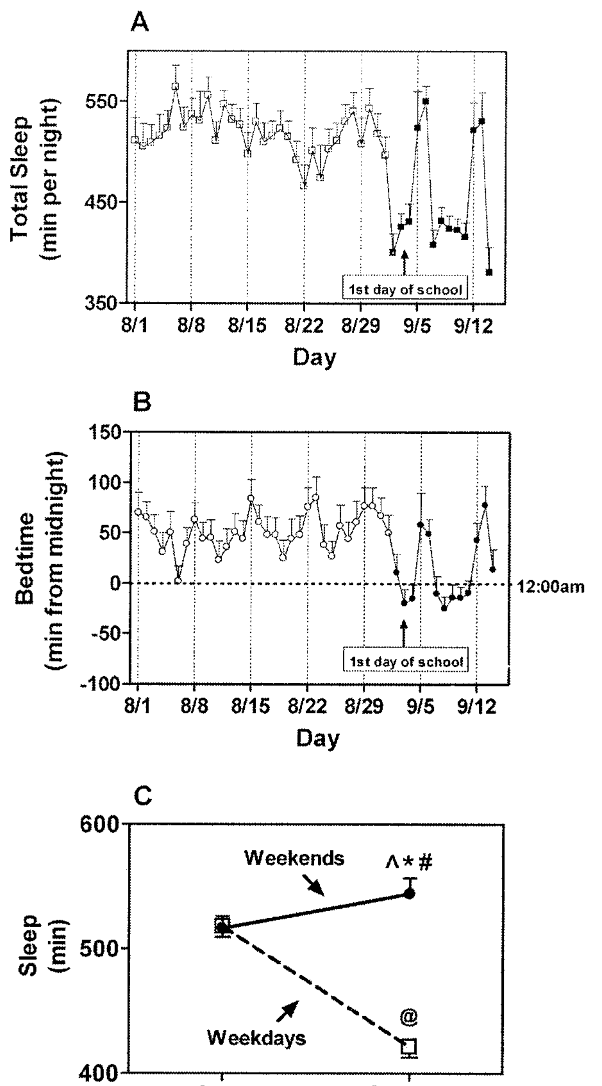

Fig 1. Sleep patterns among high school students before and after the beginning of the school year. A shows changes in sleep per night after school began. The ordinate represents total sleep per night for adolescents from August 1 to September 15, with the first day of school being September 3. The vertical lines denote Fridays (N = 37). B shows changes in sleep onset after school began. The ordinate represents bedtime, expressed as the difference in time between the actual bedtime and midnight, for adolescents after school began. The vertical lines denote Fridays (N = 37). C shows effects of school start on total sleep during weekends and weekdays. The ordinate represents total minutes of adolescent sleep during weekends (N = 36) and weekdays (N = 37) from August 1 to September 15. $\hat{P}$ = .116, compared with weekdays in August. *P < .005, compared with weekdays in September. #P < .038, compared with weekends in August. @P < .0001, compared with weekdays in August.

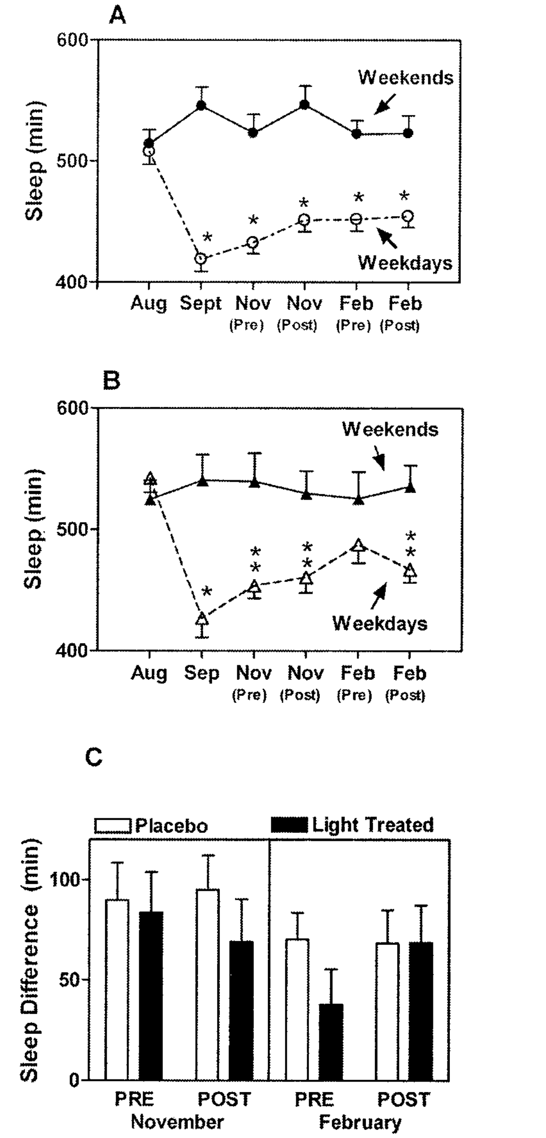

Fig 2. Effects of morning light treatments on total sleep during weekdays and weekends among high school students. A shows the placebo-treated group. The ordinate represents mean sleep per night on weekends and weekdays before (Pre) and after (Post) placebo treatment. Students (N = 37) in this group received red-light treatments on weekdays for 2 weeks in November and February. *P < .0001, compared with weekends. B shows the light-treated group. The ordinate represents mean sleep per night on weekends and weekdays before (Pre) and after (Post) light treatments. Students (N = 18) in this group received artificial white-light treatments on weekdays for 2 weeks in November and February. *P < .0001, **P < .005, compared with weekends. C shows differences in sleep time (weekend versus weekday) before and after placebo or light treatments in November and February. The ordinate represents the difference in sleep for weekends versus weekdays before (PRE) and after (POST) placebo or light treatments in November (N = 37 for placebo, N = 18 for light) and February (N = 37 for placebo, N = 18 for light).

(placebo, N = 37; light, N = 18) and that for vigilance (Fig 3) was 56 (placebo, N = 37; light, N = 19). The sample size for the visual analog scale (affect and vigor) (Fig 4) in November was 42 (placebo, N = 26; light, N = 16) and that in February was 48 (placebo, N = 30; light, N = 18). All students were juniors or seniors enrolled in advanced-placement biology, an elective course.

Changes in Sleep After School Began

During the summer, student-recorded sleep diaries started August 1 and continued through September 15, after school began ($N = 37$). The mean sleep per night on weekdays in August was 8.7 hours, and this decreased to 7.0 hours of sleep per night on weekdays in September (Fig 1A). The loss of sleep after school began was highly significant ($P < .0001$) (Fig 1C). There was no significant difference between total sleep per night on weekdays in August and total sleep per night on weekends in August ($P = .51$). After school started, students went to bed earlier during the week in September, making differences in total minutes of sleep between weekday and weekend bedtimes in September highly significant ($P < .001$) (Fig 1B). Average bedtimes on weekends were 1 to 1.5 hours after midnight. There was no significant difference between total minutes of sleep on weekdays in August and weekends in September ($P = .12$) (Fig 1C). However, total sleep on weekends in September was ~30 minutes longer than that on weekends in August ($P < .0001$). Figure 1C shows the total difference in sleep lost on weekdays versus weekends as students went from summer months into the school year.

Sleep Cycles During School Were Not Phase-Shifted by Early-Morning Light Treatments

The mean sleep per night across the testing period for the placebo group (red-light treatments) and the light-treated group (white light) is shown in Fig 2A and B. Differences in minutes of sleep between weekdays and weekends remained significant for both groups ($P < .0001$ for placebo and light groups). No significant differences were found in comparing the sleep patterns for the 2 groups ($P = .25$). Students slept more on weekdays in February than in November ($P < .02$), but there were idiosyncratic school schedules in February (late-start days). Students' total amount of sleep increased steadily from September through the end of February ($P < .001$ for the linear trend), but whether this was attributable to student adaptation to the school schedule, decreasing light because of day length (seasonal effects), school vacation days, or some combination of these various effects is unclear. Changes in total minutes of sleep attributable to light treatments in November and February were not found to be significant for weekdays or weekends ($P = .90$) (Fig 2A).

Early-Morning Light Treatments During School Showed No Direct Effects on Performance, Global Affect (Mood), or Global Vigor

In the set of graphs dealing with performance (vigilance computer tests), Fig 3A and B are nearly identical, showing that no changes in performance on morning or afternoon vigilance tests were observed for students who received early-morning light treatments. When placebo and light groups were combined and rated on vigilance performance (Fig 3C), all students performed better in the afternoon than in the morning ($P < .001$). Similarly, no significant difference in global vigor (Fig 4A and B) or global mood (Fig 4C and D) was seen for the light-treated group, compared with the placebo group. Students in the light-treated group reported feeling less vigorous than the placebo group throughout the study ($P < .0003$). All students felt less vigorous in the morning than in the afternoon ($P < .0001$).

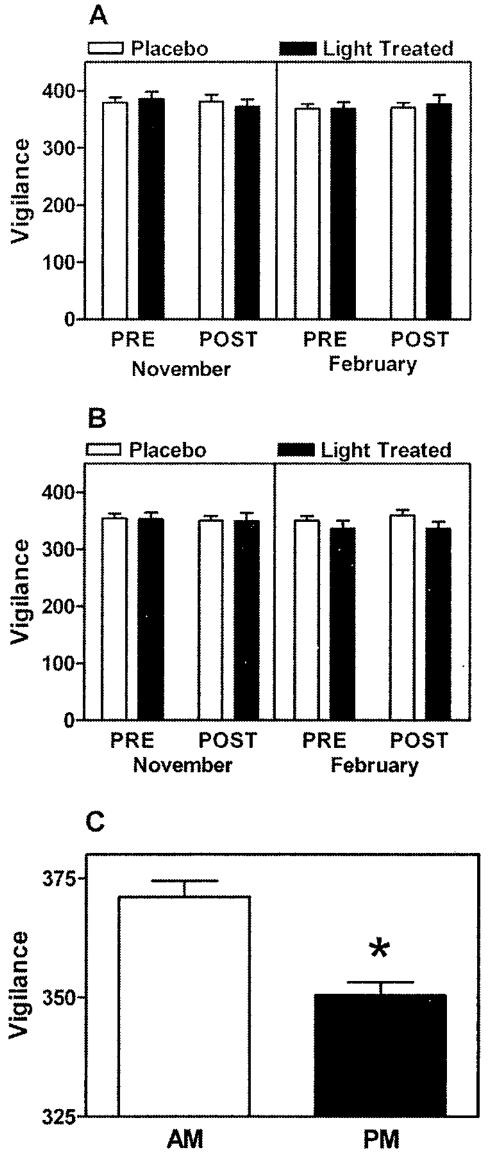

Fig 3. Morning and afternoon performance, determined with computer vigilance tests, among high school students before and after light treatments. A shows the morning test results. The ordinate represents morning performance (vigilance) expressed as reaction time (seconds) before (PRE) and after (POST) light treatments on weekdays for 2 weeks in November and February ($N = 37$ for placebo, $N = 19$ for light). B shows the afternoon test results. The ordinate represents afternoon performance (vigilance) expressed as reaction time (seconds) before (PRE) and after (POST) light treatments on weekdays for 2 weeks in November and February ($N = 37$ for placebo, $N = 19$ for light). C shows the performance results. The ordinate represents performance (vigilance) expressed as reaction time (seconds) in the morning (AM) or afternoon (PM) for all treatments combined on weekdays for 2 weeks in November and February. *$P < .001$, compared with morning.

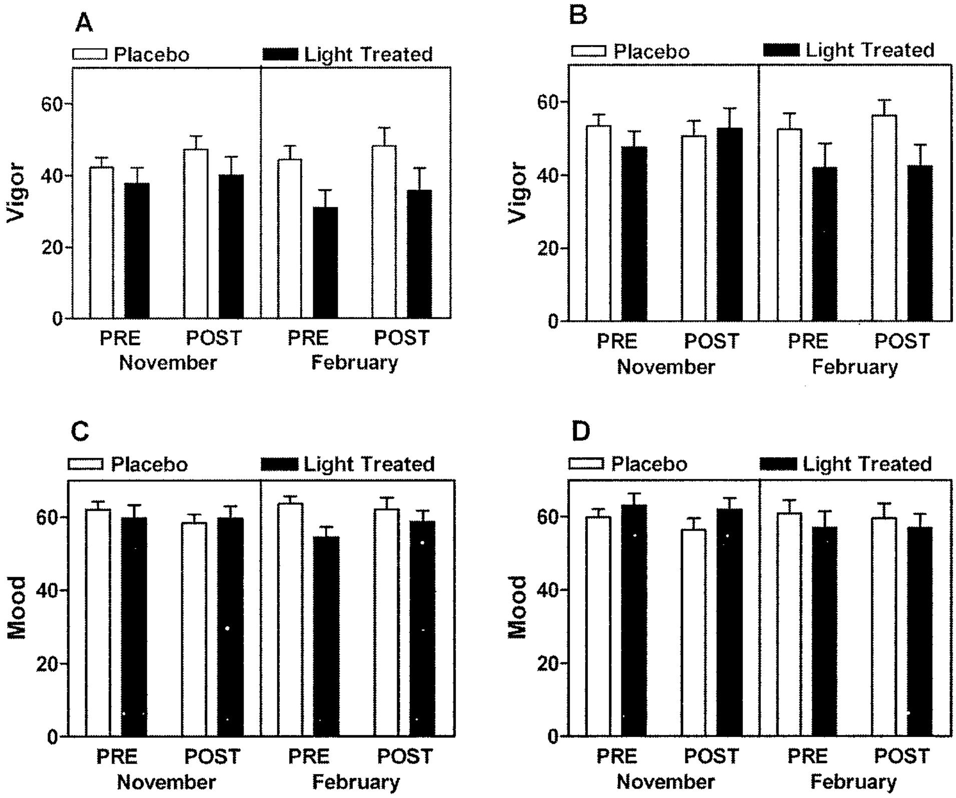

Fig 4. Morning and afternoon global vigor and affect (mood) among high school students before and after light treatments. In A and B, the ordinate represents the students' self-ratings of morning (A) or afternoon (B) vigor before (PRE) and after (POST) light treatments on weekdays for 2 weeks in November ($N = 26$ for placebo, $N = 16$ for light) and February ($N = 30$ for placebo, $N = 18$ for light). In C and D, the ordinate represents the students' self-ratings of morning (C) or afternoon (D) global affect (mood) before (PRE) and after (POST) light treatments on weekdays for 2 weeks in November ($N = 30$ for placebo, $N = 18$ for light) and February ($N = 26$ for placebo, $N = 16$ for light).

DISCUSSION

The results from this study add to the growing body of information being generated to help characterize adolescent sleep patterns and cycles and their effects. The studies by Carskadon and colleagues[4,7,8] reported that students lose sleep after the start of school. In the current study, all students lost up to 2 hours per night but only on weekdays. On weekends, sleep patterns shifted and total minutes of sleep increased, with the difference in the 2 patterns being highly significant ($P < .0001$). Whether the increased amount of adolescent sleep on weekends is an attempt at sleep recovery is not clear.[11,14] This may be true, but the difference between weekend sleep after school started in September and weekday sleep in August was not significant, which suggests that weekend sleep and weekend wake times may represent a return to an intrinsic circadian rhythm that is lost during the week because of the imposed school schedules.

No clear distinction in sleep cycles was seen between students treated with bright light and those treated with dim red light (placebo). There were also no significant differences in global mood, vigor, or performance as a result of early-morning light treatments. It is difficult to know whether light did phase-shift the clock, because both groups needed to get up early. Earlier bedtimes might have been difficult to achieve because of academic (homework) and social influences. It may be necessary to use different light protocols to adjust bioregulatory systems to reduce competing environmental signals. There was also no significant difference in global mood, vigor, or performance as a result of light treatments, although some of these students thought they were expending greater effort. Students in the placebo group seemed convinced that the lights were affecting them in some way, although they were not clear about exactly what the effect was. Recent work suggested that there might be no direct relationship between light treatments and improved performance on vigilance tests.[25] The possibility also exists that students' subjective perception of the effects light had on them altered their performance and mood in ways that were difficult to assess.[25–27] Our data confirmed earlier work by Kraemer et al.[10] All students in the present study exhibited the same pattern of poor morning performance, compared with afternoon performance ($P < .001$), and all students felt less vigorous in the morning ($P < .0001$) than in the afternoon. The data support these statements, and high school teachers across the country can attest to these data anecdotally, through their experience with students throughout the teaching day.

Data were analyzed to determine whether students' total sleep, mood, and performance improved because of adaptation to the school schedule over time. No clear pattern was seen, although students slept more on weekdays in November than in February ($P < .016$) and total sleep increased overall from September through February ($P < .001$). Disruptions in the school schedule during these time periods (eg, special late-start days and school holidays) prevented us from forming conclusions about this data; however, the amount of light received by an individual is known to entrain circadian rhythms.[15] Furthermore, the amount of light received daily (governed by seasonal changes in day length), hormonal secretions, and additional sleep time during vacation periods are all variables that need to be considered during the continuing investigation into the factors regulating adolescent biological cycles.

There were several limitations to this study. First, working with volunteer high school students in the high school itself made it difficult to control variables. Second, the sample size decreased to almost one half of the original number because students who missed 1 of 3 scheduled tests on a single test day were eliminated. Third, some students dropped out after the study began. Finally, finding consistent school schedules that could be maintained over time was challenging. Holidays, special late-start days, and all-school testing days made controlling time and test periods problematic.

Another limitation of this study was the homogeneity of the students. Although the high school itself is diverse, all of the students in advanced-placement biology classes fit the profile of being motivated and engaged. This assisted us in obtaining high-quality sleep journal records, but this also brings into question how applicable the data are for all adolescents. Other data addressed very different segments of the adolescent population,[28] and it is hoped that the mosaic of data can be used to construct a clear picture over time.

In retrospect, an important limitation was the failure to obtain performance data in August to use as a baseline. To determine the correlation between sleep deprivation and performance and mood, these data need to be collected when adolescents are in presumably normal sleep cycles, at optimal functioning. Inherent differences in the 3 classes were also not recorded. Figure 2A and B show that, although no significant changes occurred because of light treatments, there might have been significant differences in the starting groups. A background investigation into these variables was not undertaken before the study began.

Finally, although the rewards of a collaborative project between high school and university communities are plentiful, there are also communication difficulties related to time, location, and the very different environments in the respective settings. Projects of this sort are gratifying, but it may be advisable to delineate strengths and weaknesses carefully and to assign specific responsibilities to the various stakeholders at the outset.

CONCLUSIONS

This study supports the growing evidence that young people have special needs during adolescent development that are related directly to their intrinsic sleep cycles. School schedules are forcing them to lose sleep and to perform academically when they are at their worst. Solutions to these problems exist but are dependent on continuing research and education.

Light administration might still be the most straightforward intervention to affect adolescent sleep cycles. Therefore, it might be worthwhile to attempt different light protocols. An alternative approach, for example, might involve administration of light treatments in August before school starts and again in September, before sleep patterns attributable to the school schedules become established. In addition, smaller student study groups might be monitored throughout the course of their high school careers. This would enable us to generate data for the same student population over time, as the students grow and develop. It might even be possible to establish a research program to which students would commit for 4 years of high school. With such a program, students could earn credit in science, learn research protocols, and contribute to longer studies on topics such as adolescent sleep.

Another long-term solution involves changing school start times. This process is layered, because it must occur at the state level for coordination of school sports and activities. In addition, state legislators and the public must be convinced of the validity of the findings in this area. A second long-term solution, of necessity, is the continuation of research. As the scientific community unravels the mysteries of human functioning, each piece of information is another part of the puzzle that will begin to reveal the picture of adolescent physiology.

There are many solutions that could be initiated easily now. Education is key. All groups dealing with adolescents (including pediatric doctors, parents, and teachers) and the adolescents themselves need to be more aware of the teenagers' lifestyle patterns, school schedules, and normal sleep cycles and the potential health problems associated with lack of sleep.[3] Education alone may offset sleep loss as young people learn the importance of maintaining regular sleep schedules. Better dissemination of information on adolescent circadian cycles can help doctors, psychologists, and social workers look for associations between certain adolescent behaviors and sleep deprivation effects in this group.[3] Knowledge of the unusual weekday/weekend sleep phenomenon among adolescents could promote better family relationships if parents understood that sleeping late on weekends is part of their children's inborn cycle and not lazy or antisocial behavior.

Another short-term solution that can be implemented is to change the time we give standardized tests to 10:00 AM. Almost all standardized tests in high schools begin at 8 AM. Because this is when adolescents show their poorest performance levels, a change is clearly needed and would be relatively easy to negotiate.

Finally, this project forged a collaboration between high school and university students and faculty members in which everyone learned and benefited from the experience. The high school students were subjects of research and scientists engaged in research. They were able to learn about the process of collecting and analyzing data and to discover more about the fascinating topic of themselves.

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