Later School Start Time Is Associated with Improved Sleep and Daytime Functioning in Adolescents

Julie Boergers, PhD,*†‡ Christopher J. Gable, BA,§ Judith A. Owens, MD, MPH§‖

ABSTRACT: ***Objective:*** **Chronic insufficient sleep is a growing concern among adolescents and is associated with a host of adverse health consequences. Early school start times may be an environmental contributor to this problem. The purpose of this study was to examine the impact of a delay in school start time on sleep patterns, sleepiness, mood, and health-related outcomes.** ***Method:*** **Boarding students (n = 197, mean age = 15.6 yr) attending an independent high school completed the School Sleep Habits Survey before and after the school start time was experimentally delayed from 8:00 a.m. to 8:25 a.m.** ***Results:*** **The delay in school start time was associated with a significant (29 min) increase in sleep duration on school nights. The percentage of students receiving 8 or more hours of sleep on a school night increased to more than double, from 18% to 44%. Students in 9th and 10th grade and those with lower baseline sleep amounts were more likely to report improvements in sleep duration after the schedule change. Daytime sleepiness, depressed mood, and caffeine use were all significantly reduced after the delay in school start time. Sleep duration reverted to baseline levels when the original (earlier) school start time was reinstituted.** ***Conclusions:*** **A modest (25 min) delay in school start time was associated with significant improvements in sleep duration, daytime sleepiness, mood, and caffeine use. These findings have important implications for public policy and add to research suggesting the health benefits of modifying school schedules to more closely align with adolescents' circadian rhythms and sleep needs.**

*(J Dev Behav Pediatr 35:*11–17, 2014) **Index terms:** sleep, school start time, adolescence, sleepiness, education.

Chronic insufficient sleep has become a virtual epidemic among adolescents in the United States.[1] A host of adverse health outcomes, including drowsy driving-related crashes,[2] obesity,[3,4] cardiovascular disease,[5] and metabolic dysfunction,[6] have been identified as potential consequences of deficient sleep in adolescents. Adolescents achieving insufficient sleep are vulnerable to impairments in mood, behavioral control,[7] attention, memory, and executive function.[8] Not surprisingly, sleep loss is also associated with negative impacts on academic performance, increased tardiness and absenteeism, and decreased motivation to learn.[9–12]

Factors contributing to chronic sleep deficits are complex and interrelated and include circadian biology and environmental influences, such as homework, jobs, extracurricular activities, and use of technology.[13,14] The pubertal shift in circadian phase preference from "morning" to "evening" type and an attenuation of the homeostatic "sleep drive" during adolescence both contribute to significant difficulty falling asleep at an earlier bedtime.[15] Sleep needs, however, do not decline significantly across the transition to adolescence, and optimal sleep duration remains at 8.5 to 9.5 hours per night.[16,17] Thus, the typical teen has difficulty falling asleep before 11:00 p.m. and should wake up about 8:00 a.m. to obtain enough sleep,[15] although most American high schools start before 8:00 a.m.[18]

The recognition of the high cost of sleep loss in adolescents has led to a quest to identify potentially modifiable factors such as early school start times. Numerous studies comparing middle and high schools with early (before 8:00 a.m.) versus later start times demonstrate adverse consequences, such as shorter sleep duration, increased sleepiness, difficulty concentrating, absenteeism, lower academic performance,[19–22] and motor vehicle crashes.[23]

In response to these findings, a small but growing number of school districts have undertaken initiatives to delay start times and systematically examine the impact on students. In a large study, more than 18,000 high school students were assessed before and after the district's start time changed from 7:15 to 8:40 a.m.[24,25] After the change, bedtimes did not shift to a later time, and as a result, students obtained nearly an hour more of sleep on school nights. In another study of a school district that delayed high school start times by 1 hour

From the Departments of *Psychiatry and Human Behavior and †Pediatrics, Alpert Medical School of Brown University, Providence, RI; ‡Bradley-Hasbro Children's Research Center, Rhode Island Hospital, Providence, RI; §Division of Pulmonary and Sleep Medicine, Children's National Medical Center, Washington, DC; ‖Department of Pediatrics, School of Medicine and Health Sciences, George Washington University, Washington, DC.

Received May 2013; accepted October 2013.

Disclosure: The authors declare no conflict of interest.

Address for reprints: Julie Boergers, PhD, Bradley-Hasbro Children's Research Center, Rhode Island Hospital, Coro West, Suite 204, Providence, RI 02903; e-mail: jboergers@lifespan.org.

(7:30 to 8:30 a.m.), the percentage of students who reported >8 hours of sleep increased from 37% to 50%.[26] A recent study of adolescents at an independent high school that delayed start time by 30 minutes (8:00 to 8:30 a.m.) reported bedtimes actually shifted on average 20 minutes earlier, school night sleep duration increased by 45 minutes, and the percentage of students reporting at least 8 hours of sleep increased from 16% to 55%.[27] In addition to increased sleep, these studies have demonstrated a wide range of other benefits, including lower drop-out rates,[24,25] improvements in standardized reading and math scores,[22] lower rates of depression symptoms,[27] and lower rates of car crashes.[26] Recent research also demonstrates that delaying school start times for middle school students is associated with similar positive outcomes, including more sleep on school nights, decreased daytime sleepiness and tardiness, and better performance on computerized attention tasks.[19,28]

In summary, research suggests that early school start times are associated with numerous adverse health and educational consequences and that delaying school start times results in a range of benefits to students. Economists have also suggested that delaying school start times would have a substantial benefit to cost ratio (9:1).[29] However, the decision to delay school start times typically involves substantial logistical considerations and is often controversial.[18] Therefore, it is important for school districts contemplating a change in start times to have access to outcome data and to details regarding the structure and implementation of start time delays from a variety of school settings.

The aim of this study was to examine the impact of a very modest (25 min) experimental delay in school start time on students' sleep patterns, sleepiness, mood, and health-related outcomes at a competitive independent boarding school. We hypothesized that school start time delay would be associated with an increase in sleep duration and a decrease in daytime sleepiness. Participants would also rate themselves as experiencing fewer depressive symptoms, using less caffeine, and seeking less medical attention for fatigue-related concerns after the implementation of the later school start time. Finally, we hypothesized that sleep duration would revert to baseline levels when the original (earlier) school start time was reinstituted.

METHODS

Sample

The study was conducted at a coeducational residential school serving primarily boarding students (n = 849) in grades 9 through 12 and postgraduate level; the school also serves a smaller number (n = 203) of day students. The demographic characteristics of enrolled students were as follows: 51% were girls, 43% were white, 11% black, 7% Hispanic, 31% Asian, and 8% multiracial or other.

The daily schedule during the fall and spring term was 8:00 a.m. to 6:00 p.m. on Mondays, Tuesdays, Thursdays, and Fridays and 8:00 a.m. to 12:35 p.m. on Wednesdays and Saturdays. An experimental schedule was implemented during the winter term only, 8:25 a.m. to 5:35 p.m. on Mondays, Tuesdays, Thursdays, and Fridays and 8:25 a.m. to 12:35 p.m. on Wednesdays and Saturdays. To accommodate the alternate schedule, class times, break times, and lunch time were all reduced by 5 minutes.

Procedures

Data were collected at the end of the fall term (Time 1: November 2010), winter term (Time 2: March 2011), and spring term (Time 3: May 2011); survey dates were selected so that student workload would be comparable at each time point. Parents or guardians of students were contacted by school officials and investigators via e-mail before the first survey distribution and were informed about the study. Parents were asked to give consent via e-mail for their child's participation. The survey was available for parents to download and review if desired. All students were informed about the study in dormitory or adviser meetings. Students with parental consent to participate received a link to provide assent and complete the survey independently and anonymously using an online secure server (http://www.surveymonkey.com). Students who declined to participate simply closed the browser. Only students who completed this initial survey were eligible to take the follow-up survey. Access to the data was restricted to the investigators and research assistant. These procedures were approved by the Institutional Review Board of the sponsoring organization.

Measures

The School Sleep Habits Survey (SSHS)[30] is an adolescent self-report survey that is widely used in the United States and in other countries. The survey elicits information regarding typical sleep-wake behaviors during the previous week, in addition to daytime functioning, participation in activities, and school health center utilization for fatigue-related health complaints (e.g., requests for rest periods during the school day). We used a version of the SSHS that was slightly modified for previous use in a similar study of sleep and school start times.[27] The SSHS has several subscales. The Sleepiness subscale is a 13-item modified version of the Epworth Sleepiness Scale; a higher score indicates greater propensity to fall asleep under various conditions (Survey 1, α = .55; Survey 2, α = .63). The Morningness/Eveningness subscale is a 10-item scale measuring the circadian propensity; higher scores are indicative of morning (vs evening) chronotype (Survey 1, α = .77; Survey 2, α = .81). The Depressed Mood subscale is a six-item scale with higher scores indicating greater levels of depressed mood (Survey 1, α = .87; Survey 2, α = .88). In addition, a total caffeine score was created by aggregating weekly total use (number of products used × frequency of use) of all caffeinated items (soda, coffee/tea, energy drinks, caffeinated water/juices, and caffeinated foods [e.g., chocolate]).

Statistical Analyses

Sleep duration was assessed by a self-report item on the SSHS, which asks students to estimate how long they sleep on a typical school night or weekend night, not including any time they spend in bed awake. Weekend sleep compensation was calculated by subtracting school night from nonschool night sleep duration. Paired *t* tests were used to examine differences in sleep parameters, sleepiness scale scores, and health-related outcomes before and after the change in start time. McNemar's tests were used to compare paired proportions for dichotomized variables (sleepiness-related behaviors). Grade and sex differences at each timepoint were examined via analysis of variance (ANOVA). A logistic regression was conducted to identify the characteristics of students whose total sleep time extended after the start time change. Values ±3 standard deviations from the mean were removed from the regression model. A repeated-measures ANOVA examined differences in sleep duration across 3 timepoints. Skewed variables were logarithmically transformed for analysis, and untransformed means were substituted for logarithmic means in the reported results.

RESULTS

A total of 557 students (432 boarding students and 125 day students) received parental permission and were eligible to participate in the study (52.9% of student population). Of those students whose parents provided consent, 396 (308 boarding students and 88 day students) completed the first survey (71.3% of eligible boarding students and 70.4% of eligible day students). A total of 228 students (197 boarding students, 64% of those who completed the first survey; 31 day students, 35.2% of those who completed the first survey) completed both Time 1 and Time 2 surveys. Day students were excluded from subsequent analyses because of presumed differences in the morning and evening routines and sleeping environments between boarding and day students, which could not be adequately controlled because of sample size. The primary analyses presented in this study were conducted with the 197 boarding students who completed both Time 1 and Time 2 surveys. A smaller number of boarding students (n = 72, 23.3% of those who completed the first survey) also completed a survey at Time 3, and preliminary analyses were also reported for this group.

To examine for retention bias, students who completed only the first survey were compared with students who completed Time 1 and Time 2 surveys. There were no significant differences in sex ($\chi^2 = 3.53$, $p > .05$), grade level ($\chi^2 = 7.02$, $p > .05$), or average baseline school night or nonschool night sleep duration ($t = -1.67$, $p > .05$; $t = 1.08$, $p > .05$), bedtime ($t = -.03$, $p > .05$; $t = .96$, $p > .05$), or wake time ($t = .61$, $p > .05$; $t = -1.30$, $p > .05$) between the students who did and did not complete the second survey.

Student respondents were fairly evenly distributed across grade levels: 9th (26%), 10th (25%), 11th (29%), and 12th (18%); 2% were postgraduate year students. The mean age was 15.6 years, and 59% were girls. The racial/ethnic composition of our sample was 52% white, 7% black, 6% Hispanic, 24% Asian, and 10% multiracial or other. All students reported the goals of attaining at least a college-level degree. On average, students reported believing that they needed 8.8 hours of sleep each night; however, 51.2% of students at Time 1 and 35.5% at Time 2 reported that they rarely or never get enough sleep. Most students (64%) endorsed a more nocturnal circadian preference. Sleep onset latency was reported by most students to be very short (Time 1: $X = 16.2$ min, SD = 13.2 min; Time 2: $X = 16.7$ min, SD = 15.5 min) and did not significantly differ between timepoints.

School Night Sleep Patterns

Table 1 reports mean bedtimes, wake times, and sleep duration for school nights and nonschool nights at Time 1 (8:00 a.m. start time) and Time 2 (8:25 a.m. start time) for the total sample and by grade-level. As expected, wake times were later (24 min) at Time 2 than at Time 1 ($t(189) = 8.94$, $p < .001$). Average school night bedtimes did not significantly change. School night sleep duration increased by 29 minutes after the start time delay ($t(191) = 7.43$, $p < .001$). Figure 1 illustrates average school night sleep duration categorized in hourly increments at Time 1 and Time 2. The sample was also dichotomized into students receiving 8 hours or more hours of sleep on school nights versus <8 hours. The percent of students receiving 8 or more hours of sleep on a school night increased by more than double after the school start time shift, from 18% at Time 1 to 44% at Time 2 ($t(192) = 7.23$, $p < .001$).

There was a main effect of grade on school night sleep duration at Time 1 ($F = 6.55$, $df = 4,189$, $p < .01$), with 12th graders getting less sleep than 9th or 10th graders. This was partially explained by grade differences in bedtimes ($F = 9.93$, $df = 4,191$, $p < .001$): 12th graders reported later bedtimes than 9th and 10th graders, and 11th graders reported later bedtimes than 9th graders. A similar pattern of grade-level differences was observed at Time 2 ($F = 10.67$, $df = 1,189$, $p < .001$), with 11th and 12th graders getting less sleep than 9th and 10th graders. Bedtimes also differed by grade at Time 2 ($F = 13.21$, $df = 1,189$, $p < .001$), with 11th and 12th graders going to bed later than 9th and 10th graders. Wake times did not significantly differ by grade level at either timepoint. There were no sex differences in sleep duration or bedtime. Girls (6:56 a.m.) awoke slightly earlier than boys (7:10 a.m.) on school days at Time 1 ($F = 8.71$, 1,192, $p < .01$) but not at Time 2.

Within-subject changes in sleep duration were calculated from the difference in total sleep duration from Time 1 to Time 2 and ranged from a loss of 125 minutes to a gain of 195 minutes (mean = 28.45 ± 53.06 min) on

Table 1. Mean (Standard Deviation) Bedtimes, Wake Times, and Sleep Durations on School Nights and Nonschool Nights by Grade Level

	Overall (N = 193)				Grade 9 (N = 51)				Grade 10 (N = 49)			
	Time 1		Time 2		Time 1		Time 2		Time 1		Time 2	
School Nights	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Bedtime	11:48 p.m.	1:03	11:44 p.m.	1:06	11:22 p.m.	0:39	11:19 p.m.	0:43	11:30 p.m.*	0:58	11:12 p.m.*	0:52
Wake time	7:02 a.m.**	0:34	7:26 a.m.**	0:36	6:53 a.m.**	0:23	7:26 a.m.**	0:27	6:58 a.m.***	0:36	7:19 a.m.***	0:43
Sleep duration (h:min)	7:01**	1:00	7:30**	1:12	7:17**	0:39	7:56**	0:56	7:18**	0:57	7:56**	0:58
Nonschool nights												
Bedtime	12:45 a.m.	1:08	12:46 a.m.	1:10	12:32 a.m.	1:08	12:43 a.m.	1:00	12:54 a.m.*	1:14	12:28 a.m.*	1:04
Wake time	9:51 a.m.	1:25	9:53 a.m.	1:20	9:38 a.m.	1:26	9:58 a.m.	1:11	9:54 a.m.	1:16	9:43 a.m.	1:13
Sleep duration (h:min)	9:04	1:16	9:06	1:15	9:09	1:22	9:09	1:10	8:56	1:10	9:14	1:06

	Grade 11 (N = 55)				Grade 12 (N = 35)			
	Time 1		Time 2		Time 1		Time 2	
School Nights	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Bedtime	12:01 a.m.	1:03	12:05 a.m.	1:10	12:35 a.m.	1:13	12:31 a.m.	1:09
Wake time	7:05 a.m.*	0:36	7:31 a.m.*	0:37	7:13 a.m.	0:41	7:27 a.m.	0:37
Sleep duration (h:min)	6:56***	1:04	7:14***	1:17	6:26*	1:11	6:45*	1:14
Nonschool nights								
Bedtime	12:35 a.m.	1:05	12:46 a.m.	1:11	1:08 a.m.	1:01	1:10 a.m.	1:23
Wake time	9:57 a.m.	1:27	10:02 a.m.	1:23	9:55 a.m.	1:35	9:49 a.m.	1:38
Sleep duration (h:min)	9:13	1:17	9:15	1:24	8:53	1:16	8:33	1:16

Sleep duration was accessed by self-reported amount of sleep on a typical night not including time in bed awake. Means with the same superscript are significantly different at the following levels: *$p < .05$; **$p < .001$; ***$p < .01$.

school nights. A logistic regression was conducted to identify the characteristics of students whose sleep time increased (n = 131) versus those whose sleep time stayed the same or decreased (n = 61) after the change in school start time. Grade, sex, a dichotomized question regarding chronotype preference, school night total sleep time ≥8 or <8 hours at Time 1, and weekend sleep compensation at Time 1 were selected as predictor variables. The overall model was significant ($\chi^2 = 24.18$, $p < .01$). Students who received <8 hours of sleep at Time 1 were 4 times as likely to have increased sleep duration after the delay in school start time ($\beta = 1.45$, Wald $\chi^2 = 9.16$, $p = .01$, odds ratio [OR] = 4.23, 95% confidence interval [CI] = 1.67–10.92). Being a student in the 9th ($\beta = 1.04$, Wald $\chi^2 = 3.98$, $p < .05$, OR = 2.84, 95% CI = 1.02–7.91) or 10th ($\beta = 1.59$, Wald $\chi^2 = 7.57$, $p < .01$, OR = 4.89, 95% CI = 1.58–15.17) grade increased the odds that student sleep duration would increase after the time change. Sex, chronotype, and weekend sleep compensation were not significant predictors of improved school night sleep duration.

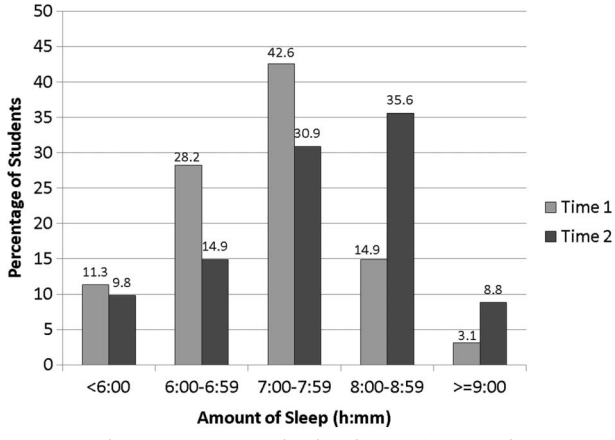

Figure 1. Sleep amounts on school nights at Time 1 and Time 2.

Nonschool Night Sleep Patterns

Comparisons of school night and nonschool night bedtimes, wake times, and sleep duration revealed a shift in participants' sleep schedules, with bedtimes approximately an hour later and wake times about 2.5 to 2.75 hours later on nonschool nights, resulting in a 1.5- to 2-hour extension of sleep duration on nonschool nights. There were no significant differences between Time 1 and Time 2 in student bedtimes, wake times, or sleep duration on nonschool nights. Female students were found to have nonschool night bedtimes, on average, 23 minutes earlier than male students at Time 1 (F = 5.36, $df = 1,192$, $p < .05$). Female students also reported earlier nonschool night wake times than male students at both time points (Time 1: 27 min, F = 4.70, $df = 1,192$, $p < .05$; Time 2: 26 min, F = 5.02, $df = 1,191$, $p < .05$); there were no nonschool night sex differences in sleep duration.

Daytime Sleepiness

Sleepiness scale scores decreased from Time 1 (19.26) to Time 2 (13.86; $t(138) = 11.89$, $p < .001$). Differences in a number of daytime sleepiness-related variables before and after the schedule change are summarized in Table 2. McNemar's tests revealed that, after the school start time was delayed, students were less likely to report napping on school days, sleepiness or falling asleep in class, or tardiness to class. The percentage of students who felt at least somewhat bothered by being too tired to do their schoolwork decreased, although there was no significant change in tiredness during sports or social activities.

Health-Related Outcomes

At both time points, students who reported getting <8 hours of sleep on school nights reported more depressed mood (Time 1: 11.09 vs 10.00, $t(191) = 1.95$, $p < .05$; Time 2: 10.97 vs 8.98, $t(185) = 4.63$, $p < .001$) and weekly caffeine consumption (Time 1: 7.81 vs 3.94, $t(192) = 2.08$, $p < .05$; Time 2: 7.52 vs 4.24, $t(188) = 2.93$, $p < .01$) than students who achieved at least 8 hours of sleep. Achieving <8 hours of sleep was also associated with more fatigue-related school health clinic visits at Time 1 (1.27 vs 1.06, $t(179) = 2.02$, $p < .05$) but not at Time 2 (1.27 vs 1.12, $t(172) = 1.78$, $p < .10$).

After the change in school start time, scores on the Depression Scale decreased (10.98 vs 10.12, $t(185) = 3.73$, $p < .001$), and total weekly caffeine use declined (7.62 vs 5.89, $t(195) = 2.22$, $p < .05$). Self-reported visits to the school clinic for fatigue-related issues did not significantly change.

Academic and Extracurricular Activities

Self-reported number of hours engaged in athletics, extracurricular activities, and homework did not significantly differ after the schedule change was implemented. The schedule change also did not have an impact on self-reported grades; 93% at Time 1 and 91% at Time 2 reported receiving mostly Bs or better in their classes.

Sleep Duration After Return to Typical School Schedule

A preliminary repeated-measures analysis of variance (ANOVA) examined sleep duration among the subset of students (n = 71) who completed surveys at Time 3, when the school schedule reverted to the original (earlier) start time. Among the students who completed all 3 surveys, weekday sleep duration increased by 33 minutes after the school start time delay was implemented and subsequently decreased by 33 minutes to baseline levels after the start time reverted to the earlier schedule (Time 1: 6:58 ± 1:02; Time 2: 7:31 ± 1:01; Time 3: 6:58 ± 1:15; $F(2,62) = 19.83$, $p < .001$).

DISCUSSION

The results of this study of students attending a college-preparatory independent boarding school replicate and extend previous research documenting benefits of a modest delay in school start time on adolescents' sleep and health-related outcomes. In this study, an experimental 25-minute delay in school start time was associated with a significant (29 min) increase in self-reported sleep duration. As in previous studies, school night bedtimes did not shift later after the school start time change was instituted, and increased sleep duration was largely driven by a later school day wake time. Moreover, a significant reduction in a number of indicators of daytime sleepiness (including falling asleep in class, tardiness, and napping) was observed in conjunction with the delay in start time.

The percent of students receiving 8 or more hours of sleep on a school night increased dramatically after the school start time shift, from 18% at Time 1 to 44% at Time 2. However, it is noteworthy and concerning that, even after the delay in start time, very few students (8.8%) reported getting the recommended[16,17] 9 or more hours of sleep. In particular, students in the upper grades (11th to 12th) received significantly less sleep than students in the lower grades; there was over an hour difference in the sleep duration of 9th graders compared with 12th graders. Furthermore, the start time change did not have an impact on bedtimes or wake times or decrease sleep duration on nonschool days, implying that students continued to feel the need to "compensate" for insufficient sleep during the week. Thus, although this modest policy change yielded important and clinically meaningful improvements in sleep duration, it was not enough to overcome the chronic sleep debt experienced by this group of adolescents.

These results add to a large body of research documenting the association between inadequate sleep duration and negative health consequences among

Table 2. Percentages of Students Reporting Daytime Sleepiness-Related Behaviors at Time 1 and Time 2

	Time 1 (%)	Time 2 (%)	McNemar's χ^2 Value	p
Napped at least sometimes on school days	44	33	8.82	0.0030
Arrived late to class at least once in past 2 weeks	25	16	5.69	0.0171
Struggled to stay awake and/or fell asleep in class	72	55	15.28	<0.0001
Too tired to do schoolwork somewhat or much of the time	76	61	12.26	0.0005
Too tired to play sports somewhat or much of the time	45	44	0.08	0.7794
Too tired to socialize somewhat or much of the time	45	38	3.13	0.0769

adolescents. Insufficient sleep duration was associated with higher levels of depressed mood, sleepiness, and caffeine consumption, both before and after the schedule change, but importantly, there were significant improvements in all of these parameters after the start time delay. Policy measures that could improve adolescent sleep duration have important public health implications, in light of increasing evidence for a bidirectional relationship between mood dysregulation (including suicidal ideation) and sleep patterns in adolescents.[31,32] Similarly, caffeine is increasingly being used among adolescents to counteract the effects of sleep deprivation[33] and is a public health concern given its potential to negatively impact sleep,[34] cause dependence,[33] and increase the risk for later substance abuse.[35]

A unique aspect of this study was the ability to link individual responses before and after the change in school schedule. Perhaps, not surprisingly, examination of within-subject changes in sleep duration revealed that students in 9th and 10th grades and those achieving inadequate sleep (<8 hours) at the start of the study were most likely to benefit from the delay in school start time. Older students may have additional academic and extracurricular demands and social pressures, which constrain the extension of their sleep, and may also be more affected by developmental changes in circadian rhythms than younger students.

Communities considering a change in school start times have often raised concerns that a later schedule will provide less time for homework or participation in sports and extracurricular activities. In this sample, however, students reported no change in the number of hours they spent engaged in athletics, extracurricular activities, and homework after the schedule change was implemented. More importantly, after the schedule change, significantly fewer students felt too tired to do their homework.

A limitation of this study is that it was based on self-report data, rather than on objectively measured sleep variables. However, sleep duration reported on the School Sleep Habits Survey (SSHS) was found to be highly correlated with sleep diary and actigraphy data in a previous study.[36] Although we collected data regarding the frequency of planned napping, we do not have information about the duration of naps. Because this was an anonymous survey, we were also not able to link actual changes in grades with changes in sleep (only self-reported grades). The overall response rate was modest, although analyses for possible retention bias suggested that the 2 groups were fairly comparable.

Our sample is clearly unique, in that the study was conducted at a highly competitive independent boarding school, which limits generalizability to other settings. However, a distinct advantage of studying boarding students is that there was much less variability in other variables that could affect sleep and sleep-related variables (including morning and evening routines, sleeping environments, and after school demands such as employment) than would be found at a typical American high school. It is striking that, even in a relatively homogenous, high-achieving group of students, a modest delay in school start time can confer significant and meaningful benefits in sleep duration and health outcomes.

Of course, when a school-wide change is initiated, it is impossible to include a control group of students who did not experience the change in school start time, and therefore it is possible that there are other variables that could explain the association between school start time delay and observed benefits for students. This limitation was minimized in this study by implementing an ABA design; that is, during the third term of the academic year, the school schedule returned to the earlier start time, and the students' sleep patterns were surveyed again. Although the response to the Time 3 survey was modest (because of the end of the year demands on students' time), it was noteworthy that students' sleep duration improved when the school start time was delayed and that sleep duration subsequently decreased to baseline levels when the original school schedule resumed. This suggests that the later school start time was responsible for the improvements observed at Time 2.

In summary, although the decision to implement a later start time for middle and high school students is seldom without controversy, this study adds to a growing body of evidence suggesting compelling health benefits with even a very modest delay in school start time to align more closely with adolescents' circadian rhythms. Furthermore, our results suggested that high school students in earlier grades and those with lower baseline sleep amounts were more likely to benefit from the delay in school start time. The findings indicate the importance of systemic countermeasures to mitigate against chronic sleep loss in adolescents.

REFERENCES

1. Eaton DK, McKnight-Eily LR, Lowry R, et al. Prevalence of insufficient, borderline, and optimal hours of sleep among high school students—United States, 2007. *J Adolesc Health*. 2010;46:399–401.
2. Dahl RE. Biological, developmental, and neurobehavioral factors relevant to adolescent driving risks. *Am J Prev Med.* 2008;35(3 suppl):S278–S284.
3. Hasler G, Buysse DJ, Klaghofer R, et al. The association between short sleep duration and obesity in young adults: a 13-year prospective study. *Sleep*. 2004;27:661–666.
4. Cappuccio FP, Taggart FM, Kandala NB, et al. Meta-analysis of short sleep duration and obesity in children and adults. *Sleep*. 2008;31:619–626.
5. Gangwisch JE, Malaspina D, Babiss LA, et al. Short sleep duration as a risk factor for hypercholesterolemia: analyses of the National Longitudinal Study of Adolescent Health. *Sleep*. 2010;33:956–961.
6. Verhulst SL, Schrauwen N, Haentjens D, et al. Sleep duration and metabolic dysregulation in overweight children and adolescents. *Arch Dis Child.* 2008;93:89–90.
7. Pasch KE, Laska MN, Lytle LA, et al. Adolescent sleep, risk behaviors, and depressive symptoms: are they linked? *Am J Health Behav.* 2010;34:237–248.
8. Carskadon MA. Sleep's effects on cognition and learning in adolescence. *Prog Brain Res.* 2011;190:137–143.

9. Fredriksen K, Rhodes J, Reddy R, et al. Sleepless in Chicago: tracking the effects of adolescent sleep loss during the middle school years. *Child Dev.* 2004;75:84–95.
10. Curcio G, Ferrara M, De Gennaro L. Sleep loss, learning capacity and academic performance. *Sleep Med Rev.* 2006;10:323–337.
11. Wolfson AR, Carskadon MA. Understanding adolescents' sleep patterns and school performance: a critical appraisal. *Sleep Med Rev.* 2003;7:491–506.
12. Perkinson-Gloor N, Lemola S, Grob A. Sleep duration, positive attitude toward life, and academic achievement: the role of daytime tiredness, behavioral persistence, and school start times. *J Adolesc.* 2013;36:311–318.
13. Cain N, Gradisar M. Electronic media use and sleep in school-aged children and adolescents: a review. *Sleep Med.* 2010;11:735–742.
14. Knutson KL, Lauderdale DS. Sociodemographic and behavioral predictors of bed time and wake time among US adolescents aged 15 to 17 years. *J Pediatr.* 2009;154:426–430.
15. Carskadon MA, Acebo C, Jenni OG. Regulation of adolescent sleep: implications for behavior. *Ann N Y Acad Sci.* 2004;1021: 276–291.
16. Carskadon MA, Harvey K, Duke P, et al. Pubertal changes in daytime sleepiness. *Sleep*. 1980;2:453–460.
17. National Sleep Foundation. *Sleep in America Poll*. Washington, DC: National Sleep Foundation; 2006.
18. Wolfson AR, Carskadon MA. A survey of factors influencing high school start times. *NASSP Bull.* 2005;89:47–66.
19. Wolfson AR, Spaulding NL, Dandrow C, et al. Middle school start times: the importance of a good night's sleep for young adolescents. *Behav Sleep Med.* 2007;5:194–209.
20. Dexter D, Bijwadia J, Schilling D, et al. Sleep, sleepiness and school start times: a preliminary study. *WMJ*. 2003;102:44–46.
21. Carrell SE, Maghakian T, West JE. A's from ZZZZ's? The causal effect of school start time on the academic achievement of adolescents. *Am Econ J.* 2011;3:62–81.
22. Edwards F. Early to rise? The effect of daily start times on academic performance. *Econ Educ Rev.* 2012;31:970–983.
23. Vorona RD, Szklo-Coxe M, Wu A, et al. Dissimilar teen crash rates in two neighboring southeastern Virginia cities with different high school start times. *J Clin Sleep Med.* 2011;7:145–151.
24. Wahlstrom K. Accommodating the sleep patterns of adolescents within current educational structures: an uncharted path. In: Carskadon MA, ed. *Adolescent Sleep Patterns: Biological, Sociological, and Psychological Influences*. Cambridge, England: Cambridge University Press; 2002.
25. Wahlstrom K. Changing times: findings from the first longitudinal study of later high school start times. *NASSP Bull.* 2002;86:3–21.
26. Danner F, Phillips B. Adolescent sleep, school start times, and teen motor vehicle crashes. *J Clin Sleep Med.* 2008;4:533–535.
27. Owens JA, Belon K, Moss P. Impact of delaying school start time on adolescent sleep, mood, and behavior. *Arch Pediatr Adolesc Med.* 2010;164:608–614.
28. Lufi D, Tzischinsky O, Hadar S. Delaying school starting time by one hour: some effects on attention levels in adolescents. *J Clin Sleep Med.* 2011;7:137–143.
29. Jacob BA, Rockoff JE. Organizing schools to improve student achievement: start times, grade configurations, and teacher assignments. Washington, DC: The Hamilton Project at the Brookings Institute; September 2011. Available at: http://www.brookings.edu/research/papers/2011/09/organization-jacob-rockoff. Accessed May 26, 2013.
30. Wolfson AR, Carskadon MA. Sleep schedules and daytime functioning in adolescents. *Child Dev.* 1998;69:875–887.
31. Fitzgerald CT, Messias E, Buysse DJ. Teen sleep and suicidality: results from the youth risk behavior surveys of 2007 and 2009. *J Clin Sleep Med.* 2011;7:351–356.
32. Lee YJ, Cho S-J, Cho IH, et al. Insufficient sleep and suicidality in adolescents. *Sleep*. 2012;35:455–460.
33. Bryant Ludden A, Wolfson AR. Understanding adolescent caffeine use: connecting use patterns with expectancies, reasons, and sleep. *Health Educ Behav.* 2010;37:330–342.
34. Orbeta RL, Overpeck MD, Ramcharran D, et al. High caffeine intake in adolescents: associations with difficulty sleeping and feeling tired in the morning. *J Adolesc Health*. 2006;38: 451–453.
35. Miller KE. Energy drinks, race, and problem behaviors among college students. *J Adolesc Health*. 2008;43:490–497.
36. Wolfson AR, Carskadon MA, Acebo C, et al. Evidence for the validity of a sleep habits survey for adolescents. *Sleep*. 2003;26: 213–216.

