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A quasi-experimental study of the impact of school start time changes on adolescent sleep

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ABSTRACT

Objective: To determine whether simultaneous school start time changes (delay for some schools; advance for others) impact adolescents' sleep.
Design: Quasi-experimental study using cross-sectional surveys before and after changes to school start times in September 2015.
Setting: Eight middle (grades 7-8), 3 secondary (grades 7-12), and 8 high (grades 9-12) schools in Fairfax County (Virginia) public schools.
Participants: A total of 2017 (6% of ~34,900) students were surveyed before start time changes, and 1180 (3% of ~35,300) were surveyed after.
Intervention: A 50-minute delay (7:20 to 8:10 AM) in start time for high schools and secondary schools and a 30-minute advance (8:00 to 7:30 AM) for middle schools.
Measurements: Differences before and after start time changes in self-reported sleep duration and daytime sleepiness.
Results: Among respondents, 57.5% were non-Hispanic white, and 10.3% received free or reduced-priced school meals. Before start time changes, high/secondary and middle school students slept a mean (SD) of 7.4 (1.2) and 8.4 (1.0) hours on school nights, respectively, and had a prevalence of daytime sleepiness of 78.4% and 57.2%, respectively. Adjusted for potential confounders, students with a 50-minute delay slept 30.1 minutes longer (95% confidence interval [CI], 24.3-36.0) on school nights and had less daytime sleepiness (−4.8%; 95% CI, −8.5% to −1.1%), whereas students with a 30-minute advance slept 14.8 minutes less (95% CI, −21.6 to −8.0) and had more daytime sleepiness (8.0%; 95% CI, 2.5%-13.5%).
Conclusions: Both advances and delays in school start times are associated with changes in adolescents' school-night sleep duration and daytime sleepiness. Larger changes might occur with later start times.

Introduction

Leading medical and public health organizations, including the American Medical Association,[1] the American Academy of Pediatrics,[2] and the US Department of Health and Human Services,[3] recognize that chronic sleep loss is at epidemic levels among US adolescents and have documented how sleep loss impacts health, the likelihood of engaging in risk-taking behaviors, safety, and academic achievement. Early school start times (SSTs) (ie, before 8:30 AM) have been identified as a major contributor to deficient sleep in teens[2] due to a combination of associated insufficient sleep duration and circadian misalignment that reflects the conflict between school schedules and biologically based pubertal changes in circadian rhythms. Previous research suggests not only that early SSTs for both middle and high school students are associated with diverse and serious adverse sleep, health, safety, and education outcomes but that delaying SSTs may mitigate the impact of negative consequences, such as higher rates of self-reported depression,[4,5] increased car crash rates,[6–9] more school absences and higher dropout rates,[10] lower graduation rates,[11] deficits in attention[12] and vigilance,[13] poorer grades, and lower standardized test scores.[9,14–17]

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Although SSTs have emerged as one of the key potential remediable factors in addressing a growing health crisis, a number of critical knowledge gaps remain.[18] Examining the impact of SSTs requires a comprehensive and detailed approach to assessing sleep outcomes. For example, impacts on sleep duration, sleep timing, and daytime sleepiness are important to assess because they are the primary mechanisms that likely mediate the potential impacts of start time changes on health, safety, and educational outcomes. However, the methodologies used, extent of start time change, populations examined, and scope of sleep parameters assessed vary across studies, leading to some inconsistencies in the findings.[18] For example, only a handful of studies have demonstrated the positive impact of later SSTs using a prospective pre-post quasi-experimental design,[4,5,19] and the generalizability of the findings from these studies may be limited because all involved homogeneous student populations in small independent or public high schools. The only evaluation of SST change in a large, diverse public school district (Minneapolis, MN) lacked baseline data on sleep and other health outcomes and compared students with those in another district with a later start time, potentially confounding effects of SST with other individual, school, or community factors.[10,20] Not all studies have assessed differences in weekday/weekend sleep patterns, which can serve as indicators of both sleep debt and circadian misalignment. Moreover, although most studies have included some measure of daytime sleepiness,[4,5] few have included data regarding napping as a strategy to offset chronic sleep loss. Finally, although many school districts that have delayed high SSTs have used an approach involving a simultaneous advance in either middle or elementary SSTs, no study has assessed the impact on sleep of this multipronged strategy.

This study addresses a critical gap in the literature by prospectively examining key outcomes related to adolescent sleep in one of the largest public school districts in the US before and after SST changes. The purpose of this study was to determine whether 2 simultaneous SST changes—a 50-minute delay in high/secondary schools and a 30-minute advance in middle schools—impacted adolescents' sleep duration, sleep timing and schedule regularity, daytime sleepiness, napping, and satisfaction with sleep. Given these relatively modest changes in start times and a delayed high SST that was still before the recommended time of 8:30 AM or later,[2] we hypothesized that the delay and advance in start times would be associated with, respectively, modest positive and negative changes in sleep duration, timing, and regularity; daytime sleepiness and napping; and satisfaction with sleep.

Participants and methods

Using a quasi-experimental design with repeated cross-sectional school surveys, we evaluated the impacts of changes in SST in Fairfax County (Virginia) public schools, the 10th largest US school district.[21] In September 2015, 2 district-wide changes were implemented[22]: (1) a 50-minute delay, from 7:20 to 8:10 AM, in the 24 high schools (grades 9-12, including 22 traditional high schools and 2 alternative high schools) and 3 secondary schools (grades 7-12) and (2) a 30-minute advance, from 8:00 to 7:30 AM, in the 23 middle schools (grades 7-8). Between March and June of 2015, before SST changes went into effect, we conducted an online survey of students and their parents in 8 middle schools, 8 high schools, and all 3 secondary schools. These 19 schools were selected to be representative of the entire district with regard to student race/ethnicity and family income. Between March and June of 2016, after implementation of the SST changes, another online survey of students and their parents was conducted in the same 19 schools. Using self-report data from these cross-sectional surveys, we examined the impact of 2 simultaneous SST changes—a 50-minute delay and a 30-minute advance—on students' sleep and sleep-related outcomes.

Survey design

The questionnaires and survey administration protocols were identical in each cross-sectional assessment. The survey protocols were designed, by school-district request, to protect class time (no in-class administration), minimize disruptions (no direct e-mail or cell phone contact with students by the research team), and obtain parental consent. We attempted to make the surveys available to all students in the sampled 19 schools. Parents (or primary caregivers) at each school received an invitation to participate in the study by way of a district-sponsored e-mail, followed by 3 reminder e-mails. Parents were asked to complete an online survey and to grant electronic consent for their child to complete a survey. Students with parental consent were sent a link via e-mail to a separate online student survey. Upon completion of the survey, students were provided a $5 Amazon gift card.

Of the students enrolled in the 19 schools, we received complete surveys from 2020 before the SST changes (6% of ~34,900) and from 1182 after the SST changes (3% of ~35,300). We excluded from our analysis 2 students aged <12.0 years and 3 students >19.0 years, leaving final samples of 2017 before SST changes and 1180 after SST changes. Compared with the overall population of students in grades 7-12 in the district, those in our survey samples were more often non-Hispanic white (before changes, 60.7% vs 42.1%; after changes, 52.0% vs 41.0%) and less often received free or reduced-price school meals (before changes, 8.1% vs 27.4%; after changes, 14.0% vs 27.6%). Study procedures were approved by the school district's Research Screening Committee and the Institutional Review Boards at the Children's National Medical Center and Temple University.

Measures

Sleep duration, timing, and schedule regularity

Sleep duration was based on student responses to separate questions about usual bedtime on school nights and wake time on school days (school-night sleep duration) and usual bedtime on nights preceding non–school days and wake time on non–school days (weekend sleep duration).[23] Sleep duration was calculated as the difference in hours between these times after excluding 35 cases with implausible school-night bedtimes (<7 PM or >3 AM), wake times (<3 AM or >8:30 AM), or calculated duration (<4 or >12 hours) and 23 cases with implausible weekend bedtimes (<7 PM or >5 AM), wake times (<3 AM or >4 PM), or calculated duration (<4 or >15 hours). Weekend oversleep was calculated as the difference in hours between weekend sleep duration and school-night sleep duration.[23] Weekend delay was calculated as the difference in hours between weekend bedtime and school-night bedtime.[23] All sleep measures had statistically normal distributions and were used in our analysis as continuous variables.

Daytime sleepiness, napping, and sleep satisfaction

Daytime sleepiness was self-reported using a modified version[24] of the 10-item Sleepiness Scale in the Sleep Habits Survey.[23,25,26] Students were asked if they had "struggled to stay awake or fallen asleep" in 10 situations during the last 2 weeks. Response options included "never" (0), "Yes, I struggled to stay awake" (1), and "Yes, I fell asleep" (2), and students also indicated if a situation did not apply to them. A score between 0 and 2 was calculated by summing across the situations and dividing the number of situations that applied to the student, with higher scores indicating greater daytime sleepiness. The Cronbach α of the modified scale was .78. Because scores were skewed toward low sleepiness (28.3% had a score of 0), a binary measure was developed for daytime sleepiness: no daytime sleepiness (sleepiness score $= 0$); daytime sleepiness (sleepiness score > 0).

Students were asked to report the number of school days during the past 2 weeks that they took a planned or scheduled nap. A binary measure was determined for napping on school days (no naps vs ≥1 nap reported). Students were also asked how often they felt satisfied with their sleep in the last 2 weeks. Response options included never, once, twice, several times, and every day/night. A binary measure was developed from this question. Those who responded never, once, or twice were considered unsatisfied with sleep.

Potential confounders

Data on 10 potentially confounding variables were obtained from the student survey, parent survey, and school district's electronic administrative records. Students reported their race and Hispanic ethnicity in separate questions, and these data were merged into a 5-category race/ethnicity variable. Students reported whether they had attention-deficit/hyperactivity disorder and completed the 10-item Morningness-Eveningness Scale for Children, which was used to create a chronotype score.[27] Each parent respondent provided information on their own educational level and that of their spouse/partner, and the highest education level of both parents was determined. The parent respondent also reported how many children <19 years and other adults lived in the home. The school district provided data (yes/no) on student qualification for free or reduced-price school meals (household income ≤185% of the federal poverty guideline),[28] school, sex, and birthdate (used to calculate age on the date of the survey).

Data analysis

Our analyses involved 3197 surveys of students (hereafter, “students”). There were 2146 secondary and high school students (1416 before and 730 after the 50-minute SST delay, hereafter called the “high school” group) and 1051 middle school students (601 before and 450 after the 30-minute SST advance, hereafter called the “middle school” group). We determined the unadjusted differences between the samples before and after the SST changes in 11 outcome variables. This included differences in minutes for school-night and weekend sleep durations, bedtimes, and wake times; differences in minutes for weekend oversleep and delay; and differences in the prevalence (%) of daytime sleepiness, napping on school days, and being unsatisfied with sleep. Missing data were imputed for all potential confounders (not outcomes).[29] We used sequential regression imputation[30] to create 20 imputed data sets for each outcome.[31] Each imputation model included all 10 potential confounders, a binary variable for before or after SST change, and the outcome of interest. Separate regression models were determined for each outcome for the high school (SST delay) and middle school (SST advance) groups (22 total models). For adjusted mean differences, we ran linear regression models on the imputed data sets with reported model parameters adjusted for potential confounders and aggregated across data sets.[32] Using logistic regression models and adjusting for confounders, we computed standardized prevalence differences in daytime sleepiness, napping on school days, and being unsatisfied with sleep before and after the SST change.[33]

Supporting analyses

To support our primary analyses, we also conducted 3 additional analyses involving subgroups. First, we compared the overall impacts on sleep duration to a subgroup of 281 students (203 high school and 78 middle school) who responded to both surveys. For these 281 students (longitudinal subsample), we determined age-adjusted differences in school-night sleep duration before and after the SST changes. Secondly, we conducted subgroup analyses within the larger group that had an SST delay. This larger group included a subgroup of 7th- to 8th-grade students in secondary schools as well as a subgroup of 9th- to 12th-grade students in secondary and high schools. Using the same approach as in our main analysis, we determined adjusted differences in school-night sleep duration before and after the SST delay in the 2 subgroups. Lastly, in both high and middle school groups, we examined adjusted differences in school-night sleep duration before and after the SST changes in 2 subgroups—those who did and did not report using light-emitting electronic devices (televisions, computers, and smartphones) in bed before falling asleep.

Results

Among the 3197 students surveyed, 57.5% were non-Hispanic white and 10.3% received free or reduced-priced school meals. The characteristics of students in samples obtained to assess the SST delay and advance are presented in Tables 1 and 2, respectively. On school nights before the SST changes, high school and middle school students slept a mean (95% confidence interval [CI]) of 7.4 (95% CI, 7.3-7.5) and 8.4 (95% CI, 8.3-8.5) hours, respectively, and went to bed at 10:32 PM (95% CI, 10:28-10:36) and 10:00 PM (95% CI, 9:55-10:04), respectively.

Adjusting for potential confounders, students sampled after the 50-minute SST delay slept 30.1 minutes longer on school nights (95% CI, 24.3-36.0; $P < .001$) (Table 3) than those sampled before the SST change. After the SST delay, students went to bed 6.9 minutes later (95% CI, 1.2-12.6; $P = .02$) and woke up 37.7 minutes later (95% CI, 34.9-40.5; $P < .001$). Adjusting for potential confounders, students sampled after the 30-minute SST advance slept 14.8 minutes less on school nights (95% CI, −21.6 to −8.0; $P < .001$) (Table 4). After the SST advance, students went to bed 11.0 minutes earlier (95% CI, −17.2 to −4.7; $P = .001$) and woke up 25.8 minutes earlier (95% CI, −29.3 to −22.3; $P < .001$).

Table 1
Student characteristics in samples before and after 50-minute delay in SST

Characteristic	Before SST delay (n = 1416)	After SST delay (n = 730)	All[a] (n = 2146)
Age, y, mean (SD)	15.6 (1.5)	15.7 (1.5)	15.7 (1.5)
Female sex, n (%)	770 (54.4)	432 (59.2)	1202 (56.0)
Race/ethnicity, n (%)			
Non-Hispanic white	876 (61.9)	375 (51.4)	1251 (58.3)
Non-Hispanic black	98 (6.9)	52 (7.1)	150 (7.0)
Hispanic, any race	141 (10.0)	73 (10.0)	214 (10.0)
Non-Hispanic Asian	156 (11.0)	141 (19.3)	297 (13.8)
Non-Hispanic other race	145 (10.2)	89 (12.2)	234 (10.9)
Highest parental education, n (%)			
Higher than master's	229 (17.0)	113 (19.4)	342 (17.7)
Master's or some graduate school	666 (49.4)	249 (42.6)	915 (47.3)
College graduate	281 (20.8)	127 (21.8)	408 (21.1)
Some college or technical degree	113 (8.4)	58 (9.9)	171 (8.9)
High school diploma or less	60 (4.4)	37 (6.3)	97 (5.0)
Children <19 y in the household, n (%)			
1 Child	363 (26.6)	186 (31.4)	549 (28.1)
2 Children	637 (46.8)	254 (42.8)	891 (45.6)
3 Children	245 (18.0)	103 (17.4)	348 (17.8)
≥4 Children	117 (8.6)	50 (8.4)	167 (8.5)
Single parent household, n (%)	145 (10.6)	56 (9.4)	201 (10.2)
Receives free or reduced-price meals, n (%)	133 (9.4)	132 (18.1)	265 (12.3)
Attention-deficit/hyperactivity disorder, n (%)	151 (10.9)	58 (8.1)	209 (10.0)
Chronotype score, mean (SD)	26.4 (5.1)	26.3 (5.2)	26.4 (5.1)

[a] Participants were missing data on characteristics as follows: parental education (213), children <19 years in the household (191), single-parent household (179), attention-deficit/hyperactivity disorder (48), and chronotype (145). Column percentages for race/ethncity, parental education, and children <19 years in the household may not add to 100.0% because of rounding.

Table 2
Student characteristics in samples before and after 30-minute advance in SST

Characteristic	Before SST advance (n = 601)	After SST advance (n = 450)	All[a] (n = 1051)
Age, y, mean (SD)	13.5 (0.6)	13.5 (0.6)	13.5 (0.6)
Female sex, n (%)	325 (54.1)	249 (55.3)	574 (54.6)
Race/ethnicity, n (%)			
Non-Hispanic white	348 (57.9)	239 (53.1)	587 (55.9)
Non-Hispanic black	23 (3.8)	24 (5.3)	47 (4.5)
Hispanic, any race	45 (7.5)	32 (7.1)	77 (7.3)
Non-Hispanic Asian	103 (17.1)	104 (23.1)	207 (19.7)
Non-Hispanic other race	82 (13.6)	51 (11.3)	133 (12.6)
Highest parental education, n (%)			
Higher than master's	112 (19.7)	71 (18.4)	183 (19.2)
Master's or some graduate school	287 (50.4)	191 (49.5)	478 (50.0)
College graduate	117 (20.6)	93 (24.1)	210 (22.0)
Some college or technical degree	41 (7.2)	26 (6.7)	67 (7.0)
High school diploma or less	12 (2.1)	5 (1.3)	17 (1.8)
Children <19 y in the household, n (%)			
1 Child	108 (18.7)	77 (19.8)	185 (19.1)
2 Children	308 (53.3)	209 (53.9)	517 (53.5)
3 Children	113 (19.5)	78 (20.1)	191 (19.8)
≥4 Children	49 (8.5)	24 (6.2)	73 (7.6)
Single-parent household, n (%)	52 (9.0)	23 (5.9)	75 (7.8)
Receives free or reduced-price meals, n (%)	31 (5.2)	33 (7.3)	64 (6.1)
Attention-deficit/hyperactivity disorder, n (%)	66 (11.1)	35 (8.0)	101 (9.8)
Chronotype score, mean (SD)	27.3 (5.3)	27.2 (5.1)	27.3 (5.2)

[a] Participants were missing data on characteristics as follows: parental education (96), children <19 years in the household (85), single-parent household (84), attention-deficit/hyperactivity disorder (20), and chronotype (55). Column percentages for race/ethncity, parental education, and children <19 years in the household may not add to 100.0% because of rounding.

There were no significant differences in the duration and timing (bedtime and wake time) of weekend sleep after the 50-minute SST delay (Table 3). Among students sampled after the 30-minute SST advance, weekend sleep duration was not significantly different, but the timing was significantly earlier (Table 4). After the SST advance, students went to bed 14.8 minutes earlier (95% CI, −23.3 to −6.3; $P = .001$) and woke up 14.3 minutes earlier (95% CI, −24.0 to −4.7; $P = .004$). Adjusting for potential confounders, weekend oversleep was 37.4 minutes shorter among students sampled after the 50-minute SST delay (95% CI, −46.6 to −28.1; $P < .001$) and 16.7 minutes longer among students sampled after the 30-minute SST advance (95% CI, 6.0-27.4; $P = .002$) (Tables 3 and 4). After the 50-minute SST delay, there was also a significantly shorter weekend delay (−7.9 minutes adjusted difference; 95% CI, −14.9 to −0.9; $P = .03$) (Table 3).

The prevalence of daytime sleepiness was significantly lower in students sampled after the 50-minute SST delay (−4.8% adjusted difference; 95% CI, −8.5% to −1.1%; $P = .01$) and significantly higher in students sampled after the 30-minute SST advance (8.0% adjusted difference; 95% CI, 2.5%-13.5%; $P = .005$) (Tables 3 and 4). The adjusted prevalence of napping on school days significantly decreased after the 50-minute SST delay (−8.8% adjusted difference; 95% CI, −12.7% to −4.8%; $P < .001$) but did not significantly change after the 30-minute SST advance (Tables 3 and 4). There was no significant change in being unsatisfied with sleep after the 50-minute SST delay, but the prevalence significantly increased after the 30-minute SST advance (8.2% adjusted difference; 95% CI, 2.5%-13.9%; $P = .005$) (Table 4).

Supporting analyses

Impacts on sleep duration in the longitudinal subsample were comparable to the overall sample. Adjusting for age, high school students in the longitudinal subsample slept 34.3 minutes longer on school nights after the 50-minute SST delay (95% CI, 20.4-48.2; $P < .001$), whereas middle school students slept 18.0 minutes less on school nights after the 30-minute SST advance (95% CI, −51.8 to 15.8; $P = .29$). Among those with the 50-minute SST delay, school-night sleep duration was 27.6 minutes longer for 7th- to 8th-grade students (95% CI, 17.5-37.7; $P < .001$) and 30.2 minutes longer for 9th- to 12th-grade students (95% CI, 23.2-37.1; $P < .001$).

Before the SST changes, high school students who did not use light-emitting devices before bed slept 12.2 minutes longer than those who used these devices (95% CI, 4.4-20.0; $P = .002$); middle school students who did not use light-emitting devices before bed slept 17.8 minutes longer than those who used them (95% CI, 7.9-28.0; $P < .001$). There were no significant changes in light-emitter use after vs before the SST changes in the high or middle school groups (results not shown). Finally, the adjusted impacts of the start time changes on school-night sleep duration were similar in those who did and did not report using light-emitting devices before bed. Sleep duration after the 50-minute SST delay was 31.7 minutes longer for students who used light-emitting devices (95% CI, 24.6-38.8; $P < .001$) and 28.6 minutes longer for students who did not (95% CI, 18.4-38.9; $P < .001$). Sleep duration after the 30-minute SST advance was 17.2 minutes less for students who used light-emitting devices (95% CI, −26.9 to −7.6; $P < .001$) and 11.4 minutes less for students who did not (95% CI, −20.4 to −2.3; $P = .014$).

Table 3
Impact of 50-minute delay in SST on sleep duration, sleep timing, daytime sleepiness, napping, and sleep satisfaction

	Before SST delay (n = 1416)	After SST delay (n = 730)	Unadjusted difference (95% CI)	Adjusted difference[a] (95% CI)
School-night sleep duration, mean (SD)	7 h 25 min (70 min)	7 h 49 min (71 min)	24.7 (18.2-31.3) min	30.1 (24.3-36.0) min*
School-night bedtime, mean (SD)	10:32 PM (75 min)	10:45 PM (76 min)	12.5 (5.6-19.4) min	6.9 (1.2-12.6) min†
School-night wake time, mean (SD)	5:54 AM (30 min)	6:32 AM (35 min)	37.7 (34.8-40.6) min	37.7 (34.9-40.5) min*
Weekend sleep duration, mean (SD)	9 h 54 min (89 min)	9 h 50 min (87 min)	−3.8 (−12.0 to 4.4) min	−5.2 (−13.5 to 3.0) min
Weekend bedtime, mean (SD)	11:39 PM (86 min)	11:39 PM (82 min)	0.05 (−7.85 to 7.76) min	−2.1 (−9.1 to 4.8) min
Weekend wake time, mean (SD)	9:33 AM (91 min)	9:30 AM (92 min)	−3.3 (−11.7 to 5.1) min	−6.9 (−14.3 to 0.4) min
Weekend oversleep, mean (SD)	2 h 31 min (104 min)	2 h 0 min (102 min)	−30.7 (−40.4 to −21.0) min	−37.4 (−46.6 to −28.1) min*
Weekend delay, mean (SD)	1 h 6 min (78 min)	55 min (71 min)	−10.7 (−17.7 to −3.7) min	−7.9 (−14.9 to −0.9) min†
Daytime sleepiness, n (%)	1032 (78.4)	503 (74.7)	−3.7 (−7.6 to 0.3)	−4.8 (−8.5 to −1.1)†
Napping on school days, n (%)	394 (30.5)	160 (24.1)	−6.4 (−10.5 to −2.3)	−8.8 (−12.7 to −4.8)*
Unsatisfied with sleep, n (%)	768 (58.6)	367 (56.0)	−2.7 (−7.3 to 2.0)	−4.1 (−8.3 to 0.2)

[a] Difference adjusted for 10 potential confounders: age, sex, race/ethnicity, highest parental education, children <19y in the household, single parent household, free or reduced-price meals, attention-deficit hyperactivity disorder, chronotype, and school. Participants were missing data on outcomes as follows (before SST delay; after SST delay): school-night sleep duration (111; 54), school-night bedtime (78; 40), school-night wake time (84;45), weekend sleep duration (94; 52), weekend bedtime (76; 49), weekend wake time (78; 47), weekend oversleep (153; 69), weekend delay (106; 57), daytime sleepiness (100; 57), napping on school days (124; 66), unsatisfied with sleep (106; 74).
* $P < .001$.
† $P < .05$.

Table 4
Impact of 30-minute advance in SST on sleep duration, sleep timing, daytime sleepiness, napping, and sleep satisfaction

	Before SST advance (n = 601)	After SST advance (n = 450)	Unadjusted difference (95% CI)	Adjusted difference[a] (95% CI)
School-night sleep duration, mean (SD)	8 h 25 min (61 min)	8 h 9 min (54 min)	−15.6 (−23.0 to −8.2) min	−14.8 (−21.6 to −8.0) min*
School-night bedtime, mean (SD)	10:00 PM (60 min)	9:51 PM (52 min)	−9.2 (−16.2 to −2.1) min	−11.0 (−17.2 to −4.7) min†
School-night wake time, mean (SD)	6:23 AM (30 min)	5:58 AM (25 min)	−25.2 (−28.7 to −21.6) min	−25.8 (−29.3 to −22.3) min*
Weekend sleep duration, mean (SD)	10 h 8 min (82 min)	10 h 11 min (81 min)	2.9 (−7.3 to 13.2) min	2.0 (−8.1 to 12.2) min
Weekend bedtime, mean (SD)	11:03 PM (80 min)	10:51 PM (70 min)	−12.4 (−21.9 to −2.8) min	−14.8 (−23.3 to −6.3) min†
Weekend wake time, mean (SD)	9:14 AM (89 min)	9:03 AM (89 min)	−11.7 (−22.8 to −0.6) min	−14.3 (−24.0 to −4.7) min†
Weekend oversleep, mean (SD)	1 h 43 min (91 min)	2 h 1 min (86 min)	17.8 (6.4-29.3) min	16.7 (6.0-27.4) min†
Weekend delay, mean (SD)	1 h 4 min (61 min)	1 h 0 min (58 min)	−4.4 (−11.9 to 3.2) min	−4.5 (−11.9 to 2.9) min
Daytime sleepiness, n (%)	330 (57.2)	271 (65.6)	8.4 (2.3-14.5)	8.0 (2.5-13.5)†
Napping on school days, n (%)	66 (11.6)	65 (15.8)	4.2 (−0.2 to 8.6)	3.1 (−1.2 to 7.4)
Unsatisfied with sleep, n (%)	233 (41.0)	205 (50.1)	9.1 (2.8-15.4)	8.2 (2.5-13.9)†

[a] Difference adjusted for 10 potential confounders: age, sex, race/ethnicity, highest parental education, children <19 years in the household, single-parent household, free or reduced-price meals, attention-deficit/hyperactivity disorder, chronotype, and school. Participants were missing data on outcomes as follows (before SST delay; after SST delay): school-night sleep duration (27; 35), school-night bedtime (16; 24), school-night wake time (17; 32), weekend sleep duration (23; 30), weekend bedtime (18; 23), weekend wake time (12; 28), weekend oversleep (41; 44), weekend delay (28; 27), daytime sleepiness (24; 37), napping on school days (32; 39), and unsatisfied with sleep (33; 41).
* $P < .001$.
† $P < .01$.

Discussion

The results of this examination of the impact on sleep of a simultaneous delay (high/secondary schools) and advance (middle schools) in SSTs, although relatively modest, are strikingly consistent in directionality, with the expected respective improvements and decrements in sleep associated with different start time changes. For example, within the high school group, school-night bedtime after the SST delay was about 7 minutes later, and wake times were 38 minutes later on average, resulting in a net gain of approximately 30 minutes in sleep duration. The finding that bedtimes did not shift substantially later is in keeping with other studies which have demonstrated largely unchanged [5,10,12,20] or *earlier*[4] bedtimes following delays in start times. The 30-minute earlier start time in the middle school group was associated with a modest shift in school-night bedtimes (10:00 to 9:51 PM), a 26-minute earlier wake time, and a decrease in sleep duration of 15 minutes. Thus, a clear picture emerges of net school night sleep gains (approximately 2.5 h/wk) and losses (approximately 1.25 h/wk) for the 2 student groups.

The finding that a 50-minute delay in high SSTs did not translate directly to a 50-minute increase in sleep duration deserves some attention, particularly because several previous studies have reported a close to 1:1 associated change in sleep amounts.[1–3] A recent review[18] of SST studies showed that start time delays of >60 minutes, compared with delays of <60 minutes, had a greater impact on increasing sleep duration (53 vs 19 minutes, respectively), which was largely due to later wake times when start times delays were longer. The 30-minute gain in sleep duration with our 50-minute start time delay was greater than in most studies with start time delays of <60 minutes. Furthermore, it should be noted that even under highly controlled experimental conditions in which sleep duration is manipulated through restriction or extension of time in bed, adolescent sleep duration still falls short of the target total sleep times, suggesting that other factors influencing sleep duration may come into play.[34,35] Finally, one study suggested that, after start time changes, bedtimes may gradually shift later.[19] Therefore, it is possible that the bedtimes and sleep duration we observed might have been different had we conducted the survey relatively closer to or further away from the start time change in the fall.

Our findings underscore the need to accompany *operational* changes targeted toward improving sleep in adolescents, such as start time delay, with educational efforts focused on the importance of sleep and healthy sleep habits, with an emphasis on personal and family responsibility. The fact that, in contrast to high school students, the impact of a 30-minute SST advance in middle school students was somewhat mitigated by a slightly earlier bedtime suggests that parental involvement could have played a role in these younger students' sleep practices and underscores a potential role for concomitant sleep health education to optimize the impact of schedule change. Many school districts have also used the opportunity afforded by SST discussions to open a dialogue regarding other factors—such as overscheduling and homework burden—that may also contribute to insufficient sleep opportunity.

Recent studies in children and adolescents have demonstrated an association between prolonged sleep onset, shorter sleep duration, and exposure to artificial light near bedtime, particularly light emitted from electronic screens.[36,37] In secondary analyses, we examined whether the self-reported use of light-emitting electronic devices (televisions, computers, and smartphones) in bed before falling asleep modified the impact of the SST changes. Before SST changes, adolescents who reported such use had shorter school-night sleep duration. However, SST changes did not impact the use of the devices. Furthermore, the impact of the SST change on sleep duration was similar between those who did and did not use such devices in bed before falling asleep. These findings are consistent with the potential adverse impacts on sleep of using light-emitting electronic devices near bedtime but suggest that this practice does not appear to alter the potential beneficial impacts on sleep of a delay in SST.

It should also be noted that our findings reflect the typical adolescent pattern of significantly shorter sleep duration on school nights vs weekend nights in middle and high school groups. After the SST changes, both middle and high school students slept 2 hours longer on weekend nights than on school nights. This phenomenon of *weekend oversleep*, defined as the difference between sleep duration on weekdays vs weekends, can be viewed as a marker of chronic sleep debt accumulated during the week, with the adolescent attempting to "catch up" on weekends. Weekend oversleep has been shown to be associated with a number of adverse health consequences in adolescents, such as depressed mood and suicidality, behavioral dysregulation, and increased risk of substance use, presumably related to variability in sleep patterns and consequent disruption of circadian rhythms.[38] In this study, we saw a decline of 37 minutes in weekend oversleep in high school students and a 17-minute increase in middle school students associated with concomitant changes in start times. The former is in keeping with a summary of previous studies which showed an average decline of 28 minutes following SST delays of ≤60 minutes.[18]

Similarly, weekend bedtimes were later than school-night bedtimes by about 1 hour in both groups before and after the change, with weekend wake times being 3 to 3.5 hours later in the high school group and 2.5 to 3 hours later in the middle schoolers. This parameter of *weekend sleep delay* (which has been alternatively defined as the difference between weekday and weekend bedtimes *or* wake times) can be considered a marker of variability in sleep patterns and ultimately of circadian disruption (ie, adolescents reverting, when able, to their natural later sleep onset and offset times). In this study, weekend bedtimes for high school students did not change after the SST change, and wake times were about 7 minutes earlier after the change. For middle school students, both average weekend bedtimes and wake times shifted earlier by about 15 minutes with minimal change in weekend sleep duration. The small pre-post differences in weekend bedtimes/wake times in both groups suggest that the changes in start times may not have been sufficient to significantly mitigate (or exacerbate) circadian disruption.

The percentage of students reporting significant daytime sleepiness and daytime napping modestly declined (by 4.8% and 8.8%, respectively) in the high school group and increased (by 8.0% and 3.1%, respectively) in the middle school group after the SST change. This contrasts somewhat with more robust improvements in high school students' self-reported daytime sleepiness found in some previous studies. However, it may be that only relatively greater increases (ie, >60 minutes) in start time delay and/or delays which coincide with the recommended 8:30 AM or later (and, thus, reduce circadian misalignment) are associated with more significant decreases in daytime sleepiness. The latter point is supported by several studies conducted in small independent (largely boarding) high schools that found declines in self-reported sleepiness as high as 20%-25% associated with a delay in start time of just 25 to 30 minutes that also moved the start time to around 8:30 AM[4,5].

Only one previous study has reported differences in satisfaction with sleep; in that study (also in a small independent high school), the percentage of students that reported being unsatisfied with their sleep decreased significantly following a 30-minute delay in SST.[4] However, it should again be noted that the independent school study shifted start times from 8 AM to or within 5 minutes of the recommended start time of 8:30 AM. These findings reinforce the principle that *the time to which SST is delayed* may be equally or more important than the absolute pre-post time difference in regard to maximizing sleep-related variables because both adolescent sleep duration and circadian alignment need to be optimized.

To our knowledge, no previous study has examined the impact of simultaneously moving high SSTs later and middle SSTs earlier in the same public school district. However, for pragmatic, logistical, and financial reasons, these types of concurrent changes in bell times for different grade levels are common compromise scenarios across the country in districts that have implemented SST changes. Thus, an assessment of the "real world" impact of SST changes, especially in such a very large school district, is highly valuable in terms of both documenting specific outcomes from a research perspective and guiding future policy decisions at the district, regional, state, and national levels.

Our study had limitations. The response rates were low in the surveys before and after start time changes. Although the response rates were lower after the start time change (3% vs 6%) and also varied across schools (1% vs 12%), the overall characteristics of students in the samples obtained before and after the start time change were similar (Tables 1 and 2). This fact enhanced the internal validity of the study because it reduced the possibility that the differing characteristics between the samples exposed and not exposed to a given start time, rather than the start time itself, was the cause of the findings we report (Tables 3 and 4). However, those who responded to the surveys were not representative of the students in the entire school district, potentially limiting the external validity of our findings. Although we studied a representative subset of schools in the district, the low response rate was likely due to the school district's restriction on administering the survey during class time, which was the method used to obtain data in other SST studies.

In addition, our findings were based on self-reported measures of sleep, and future studies should include objective sleep measures, such as actigraphy. Students were also not masked to the intervention, which could have resulted in response bias. Furthermore, this was not a randomized controlled trial of SST changes. Although such a design would meet the "gold standard" regarding quality of evidence,[18] our design was akin to a member cross-sectional cluster randomized trial in that we sampled students within schools, but students were not intentionally tracked over time. A student measured at baseline may or may not have been sampled at follow-up. However, among the 281 students who responded to both surveys and were followed longitudinally, our findings were similar to those in the overall sample. This suggests that our findings were not explained by differences in characteristics between students sampled before and after start time changes. Furthermore, given random sampling, the data are representative of students in schools, and the impact on statistical power is nil.[39]

Conclusions

Our study adds to the growing literature supporting a beneficial impact on students of later SSTs, particularly in regard to sleep. Future studies on SST should aim to assess sleep directly with actigraphy; examine a broad range of health, social, and academic outcomes; and be large enough to determine whether impacts differ across sociodemographic subgroups. Important questions remain about how to maximize the benefits of changing SSTs. Given the potential influence of family and peers on sleep,[40] future studies could determine whether there is a greater impact from SST changes when they are combined with interventions to educate students and parents about sleep health. These interventions could provide information about the potential benefits of adequate sleep, modifiable factors in the home environment that can affect sleep, and specific strategies to improve sleep quality and duration.[41,42]

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