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Original article

Association of Delaying School Start Time With Sleep–Wake Behaviors Among Adolescents

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A B S T R A C T

Purpose: Few adolescents spend enough time asleep on school nights. This problem could be addressed by delaying high school start times, but does this translate to reduced prevalence of sleep–wake problems like awakening too early or feeling sleepy during the day?
Methods: The START study (n = 2,414) followed a cohort of students from five Minnesota high schools to evaluate impacts of school start time delays. Participants were enrolled in ninth grade (Baseline) when all schools started early (7:30 or 7:45 A.M.). At Follow-Up 1 (10th grade) and Follow-Up 2 (11th grade), two schools had delayed their start times by 50 and 65 minutes while three comparison schools started at 7:30 A.M. Six sleep–wake behaviors were assessed at all three time points via survey. Generalized estimating equation models were used to investigate changes in sleep–wake problems between policy change and comparison schools.
Results: The prevalence of sleep–wake problems at Baseline ranged from 11% for being late to class due to oversleeping to 48% for needing to be told to wake multiple times in the morning. Compared to students from comparison schools, students at policy change schools reported smaller increases in the prevalence of feeling sleepy daily and oversleeping and being late to class between 9th and 11th grade. After implementation of the delayed start, awakening too early was more common among students at policy change schools compared to the comparison schools.
Conclusions: This longitudinal study provides evidence that delaying high school start times reduces daytime sleepiness and school tardiness.

IMPLICATIONS AND CONTRIBUTION

Adolescents commonly experience insufficient sleep and problems like feeling sleepy during the day. Delaying high school start times does more than just extend sleep hours; these policies appear to help adolescents oversleep less often, feel less sleepy during the day, and be more present in school.

Insufficient sleep is a widespread problem among adolescents in the United States. A majority of U.S. 16-year-olds regularly get fewer than 7 hours of sleep per night [1], falling far short of the 8.5–9.25 hours of nightly sleep recommended for adolescents by the National Sleep Foundation [2]. There are potentially broad consequences to truncated sleep among this age group, including increased risk for depressed mood, anxiety, behavior problems, alcohol use, attempted suicide, and prehypertension [3,4]. Additionally, adolescent chronic sleep deprivation may continue into adulthood where it has been associated with consequences such as obesity, diabetes, cardiovascular disease, and increased age-specific mortality [3].

Conflicts of interest: The authors have no conflicts of interest to declare.

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Early high school start times are a key modifiable contributor to insufficient sleep among adolescents [5]. Many U.S. secondary schools begin so early as to be severely asynchronous with adolescent circadian rhythms that naturally shift later at the onset of puberty [6,7]. Despite this well-documented developmental phenomenon [6,8] and recommendations by the American Academy of Pediatrics [5] and many other organizations dedicated to the health and wellbeing of adolescents [9] that high schools start no earlier than 8:30 A.M., only 17% of high schools in the United States started at 8:30 A.M. or later during the 2017–2018 school year [10].

Evidence from natural experiments where high schools have delayed their start times shows that such a shift is both a feasible and effective approach to increasing teens' sleep duration [11,12]. A growing body of research demonstrates that students attending later start schools had longer self-reported sleep duration than students at schools that started 30–90 minutes earlier in either cross-sectional or pre–post comparisons [13–17]. Additionally, our recent report from the START study found that delaying high school start times extended objectively measured school night sleep duration among adolescents in the later starting schools relative to the contemporaneous early-starting comparison schools after 2 years of follow-up [18]. Later high schools start times are also associated with enhanced mental health [14], reduction in car crashes [19,20], better performance in school [20], and improved school attendance [12].

Based on cross-sectional evidence, longer sleep duration is associated with decreased risk of sleep–wake problems like waking early, oversleeping, falling asleep in class, and feeling sleepy among adolescents [21]. Thus, delaying high school start times could plausibly reduce the prevalence of sleep–wake problems, especially if the start time change conferred a substantial quantity of additional sleep time. Compared to students attending earlier starting schools, students who start their school day later experience less daytime sleepiness [12–14,22,23] and are less likely to be late to class due to oversleeping [12–14,22], fall asleep in class [12–14], or need help waking [14]. However, existing evidence on school start times and sleep–wake problems is limited by methodological challenges; most reports to date have been of cross-sectional studies that compare students attending schools with different start times [12,22,23]. The few studies that are longitudinal have pre–post designs without contemporaneous comparisons, comparing students within a school before and after a delayed start policy has been implemented [13,14].

The present analysis uses data from the START study, which took advantage of a natural experiment in high school start time modification, allowing us to compare changes in sleep patterns among students in schools that changed their start times and students in schools that maintained an early start time throughout the study. We investigated whether the delay in start time was associated with changes in commonly reported sleep–wake problems among adolescents. We hypothesized that fewer students in the policy change schools with delayed start times would report sleep–wake problems after 2 years of follow-up, compared to students in the comparison schools with earlier start times.

Methods

Data

The START study aimed to evaluate the impacts of delaying high school start times. In START, we recruited a cohort of students from five suburban/rural high schools in Minneapolis, Minnesota to participate in a variety of data collection activities. Students were first surveyed in the Spring of 2016 when the students were in ninth grade (Baseline) and then the same students were resurveyed in Spring of 10th grade (Follow-Up 1) and 11th grade (Follow-Up 2). At Baseline, all schools started at either 7:30 or 7:45 A.M. Between Baseline and Follow-Up 1 measurements, two schools, which we refer to as "policy change schools," implemented a 50–65 minutes delay in their start times. The three "comparison schools" maintained a start time of 7:30 A.M. throughout the study period.

Participant recruitment

Parents and guardians of all ninth-grade students at the five high schools were sent letters describing the study, explaining that participation was voluntary, and giving instructions for opting out of the research. Students who had not been opted out were provided with information about the study on the data collection days and were given the opportunity to assent to participate. In the Spring of 2016, 90.3% of the classes of ninth graders participated in the survey at Baseline ($n = 2{,}134$). In the Spring of their 10th grade and 11th grade years students were once again invited to participate, using the same procedures from Baseline. During these subsequent surveys, 280 students who were not present at Baseline were added into the sample, creating a final sample of 2,414 students. In total, 1,473 students (61% of the sample) completed the survey at all 3 time points, while 583 (24%) contributed 2 observations of data, and the remaining 358 students (15%) completed 1 survey.

Measures

Six symptoms of sleep–wake behavior problems were assessed at the Baseline survey and both follow-up surveys. These measures were derived from a 10-item scale of sleep–wake behavior problems developed for high school students as part of the "School Sleep Habits Survey" [24,25]. The parent sleep–wake problem scale has an internal consistency of .75 [26]. Students were asked how often (never, once, twice, several times, every day/night) they had experienced each problem over the last 2 weeks. Sleep–wake behaviors included the following: (1) awakened too early in the morning and could not get back to sleep, (2) needed to be told more than once to get up in the morning, (3) slept later than noon, (4) arrived late to class because you overslept, (5) fallen asleep in a class, and (6) felt tired or sleepy during the day. Consistent with a prior analysis by our team of sleep–wake behaviors at baseline [21], the first five sleep–wake behaviors were then dichotomized as ever experiencing the behavior in the last 2 weeks versus not at all. Because nearly all students reported feeling tired/sleepy during the day at least once over the 2-week period (94.3%), the sixth behavior (feeling tired or sleepy during the day) was dichotomized as everyday versus less frequently.

We measured several individual-level demographic factors that might be associated with both the exposure (whether school delayed its start time) and outcome (sleep–wake problems) for confounding control. At each survey, students were asked to report demographic items including age, sex (male, female), the highest level of education of a parent or guardian (five levels were given on the survey, we dichotomized to finished college vs. high school/some college), and whether they qualified for free and reduced lunch (yes, no, or don't know). We measured race/

ethnicity by asking participants to select multiple responses from seven categories (American Indian or Alaskan Native; Asian; Black, African, or African American; Hispanic or Latino/a; Native Hawaiian or Other Pacific Islander; White or Caucasian; something else). The purpose of including this measure as a covariate in our models was an attempt to at least modestly control for confounding by features related to race/ethnicity (including experience of racism, cultural difference, and aspects of social position that are not captured by parent education). Given that the START population predominantly identified as white, we collapsed these categories into white and nonwhite. The demographic characteristic reported in the earliest available survey for each student was applied to following observations of that student.

Statistical analysis

We reported demographic characteristics and Baseline prevalence of the six sleep–wake problems among the full sample and by policy change versus comparison. We also determined the amount of missing data within each variable prior to imputation.

We then investigated whether students attending policy change schools reported patterns of sleep–wake problems over time that differed from students in the comparison schools. We used generalized estimating equation logistic regression models to regress each sleep–wake behavioral outcome on time, condition (policy change vs. comparison), and the interaction of time and condition. Generalized estimating equation models account for correlation between the repeated measures on students using an empirical robust sandwich-type variance estimator and are considered robust to misspecification of the correlation structure of the outcome [27,28]. Within each model, the primary effects of interest are estimated by the condition-by-time interaction terms at Follow-Up 1 and Follow-Up 2 as they represent the difference-in-differences of sleep–wake problems between students in policy change and comparison schools. All models included a fixed effect for school and were adjusted for individual-level demographics (sex, race/ethnicity, parental education, and free/reduced lunch eligibility) that could be confounding any relationships between policy and sleep–wake behaviors as they were potentially drivers of both exposure and outcomes yet not a result of the policy. Using the adjusted regression results, we then calculated average marginal probabilities for each outcome by condition and time.

Some participants who completed the baseline survey were lost to follow-up and did not complete both follow-up surveys. Table A1 shows the characteristics of students who completed all three surveys compared to students who completed the baseline survey but were lost to follow-up. Additionally, we are missing baseline data for students (n = 280) who entered the sample at Follow-Up 1 or Follow-Up 2. Finally, some students who completed the surveys were missing item-level information on demographic characteristics or sleep–wake outcomes. We used multiple imputation by chained equations (20 imputations) using the "mi impute chained" command in Stata to account for censored observations and missing data. All outcome variables were imputed in their raw categorical format using ordinal logistic regression. Dichotomous covariates (sex, race, parental education) were imputed using logistic regression and categorical covariates (free or reduced-price lunch eligibility) were imputed using multinomial logistic regression. School and student ID were included in the imputation model as independent variables. Each imputed demographic characteristic was missing for 1%–7% across all time points. Additionally, each sleep–wake outcome variable was missing approximately 14% at Baseline, 21% at Follow-Up 1, and 23% at Follow-Up 2. Missingness in outcome variables was more common among students at comparison schools than students in the policy change schools (Table A2). Across all time points, most missing responses were due to nonparticipation in the survey rather than selective nonresponse.

Analyses were conducted using Stata Version 16. All study procedures were reviewed and approved by the University of Minnesota Institutional Review Board and the school districts' research review panels.

Results

The sample (n = 2,414) was approximately half male and majority white (Table 1). Regarding socioeconomic status (SES), majority of the sample (73.2%) reported having at least one parent or guardian with a college degree, and approximately 14% of students reported that they qualified for free or reduced-price school lunch. The sample of students at the policy change schools included a greater proportion of participants reporting they have at least one college-educated parent (78.2% vs. 66.2% in comparison schools), indicating they can be viewed as being a somewhat higher SES group.

At Baseline, when all schools started early, sleep–wake problems were common; for instance, being told to wake multiple times in the morning was reported by nearly half (46.7%) of participants (Table 1). Several sleep–wake problems, including awakening too early, sleeping past noon, falling asleep in class, and feeling sleepy daily, were more common in comparison schools than policy change schools (Table 1). However, the prevalence of being told to wake multiple times and oversleeping and being late to class were similar in policy change schools and comparison schools at Baseline.

Figure 1 depicts the change in the prevalence of each sleep wake behavior among students between Baseline (9th grade) and Follow-Up 2 (11th grade). The prevalence of feeling sleepy daily increased for students in the comparison schools but remained approximately the same for students in the policy change schools (Figure 1F). Results of the difference-in-differences models show that, on average, students in the policy change schools had a 5 percentage point decrease (95% confidence interval [CI]: 0–9 percentage points lower) in the prevalence of feeling sleepy daily at Follow-Up 1 and a 6 percentage point decrease (95% CI: 1–12 percentage points lower) at Follow-Up 2 relative to the comparison schools after 2 years of delayed start times (Table 2). A similar pattern was seen for the prevalence of oversleeping and being late to class (Figure 1D); students in the policy change schools had a mean decrease in prevalence of oversleeping and being late to class of 7 percentage points (95% CI: 3–11 percentage points lower) from Baseline to Follow-Up 1 and a decrease of 5 percentage points (95% CI: 1–9 percentage points lower) from Baseline to Follow-Up 2 (Table 2). Students in policy change schools had a mean increase in prevalence of awakening too early of 7 percentage points (95% CI: 1–12 percentage points higher) from Baseline to Follow-Up 1 and an increase of 7 percentage points (95% CI: 2–13 percentage points higher) from Baseline to Follow-Up 2, relative to comparison schools (Table 2, Figure 1A). No clear differences between students at policy change and comparison schools were seen in

Table 1
Descriptive statistics of sample at Baseline

	Study group, n (%)			*p*-value
	Full sample (n = 2,414)	Comparison (n = 1,000)	Policy change (n = 1,414)	
Demographic characteristics				
Sex				.719
Female	1,165 (48.3%)	473 (47.3%)	692 (48.9%)	
Male	1,234 (51.1%)	521 (52.1%)	713 (50.4%)	
Missing	15 (.6%)	6 (.6%)	9 (.6%)	
Race				<.001
Nonwhite	307 (12.7%)	66 (6.6%)	241 (17.0%)	
White	2,048 (84.8%)	911 (91.1%)	1,137 (80.4%)	
Missing	59 (2.4%)	23 (2.3%)	36 (2.6%)	
Parental education				<.001
Neither parent completed college	483 (20.0%)	255 (25.5%)	288 (16.1%)	
≥1 parent completed college	1,767 (73.2%)	662 (66.2%)	1,105 (78.2%)	
Missing	164 (6.8%)	83 (8.3%)	81 (5.7%)	
Free or reduced lunch eligible				.002
No	1,610 (66.7%)	639 (63.9%)	971 (68.7%)	
Yes	335 (13.9%)	134 (13.4%)	201 (14.2%)	
Don't know	441 (18.3%)	209 (20.9%)	232 (16.4%)	
Missing	28 (1.2%)	18 (1.8%)	10 (.7%)	
Sleep–wake problems at Baseline				
Awakened too early				<.001
At least once	912 (37.8%)	420 (42.0%)	492 (34.8%)	
Never	1,182 (49.0%)	429 (42.0%)	753 (53.3%)	
Missing	320 (13.3%)	151 (15.1%)	169 (12.0%)	
Told to wake multiple times				.100
At least once	1,150 (47.6%)	463 (46.3%)	687 (48.6%)	
Never	937 (38.8%)	384 (38.4%)	553 (39.1%)	
Missing	327 (13.6%)	153 (15.3%)	174 (12.3%)	
Slept past noon				<.001
At least once	779 (32.3%)	361 (36.1%)	418 (29.6%)	
Never	1,294 (53.6%)	484 (48.4%)	810 (57.3%)	
Missing	341 (14.1%)	155 (15.5%)	186 (13.2%)	
Overslept and late to class				.003
At least once	275 (11.4%)	127 (12.7%)	148 (10.5%)	
Never	1,794 (74.3%)	707 (70.7%)	1,087 (76.9%)	
Missing	345 (14.3%)	166 (16.6%)	179 (12.7%)	
Fallen asleep in class				<.001
At least once	630 (26.1%)	313 (31.3%)	317 (22.4%)	
Never	1,437 (59.5%)	524 (52.4%)	913 (64.6%)	
Missing	347 (14.4%)	163 (16.3%)	184 (13.0%)	
Felt sleepy during day				<.001
Every day	536 (22.2%)	251 (25.1%)	285 (20.2%)	
Less frequently	1,546 (64.0%)	588 (58.8%)	958 (67.8%)	
Missing	332 (13.8%)	161 (16.1%)	171 (12.1%)	

the rates of reporting the remaining sleep–wake problems over time (Figure 1B, C, and E). As both sets of models yielded similar results, only adjusted models are displayed in Figure 1 and Table 2. However, the corresponding results from unadjusted models can be found in Table A3.

Discussion

Sleep–wake problems, including oversleeping and feeling sleepy daily, become more common as students progress through high school. However, this increase in certain sleep wake problems may be mitigated if schools start later. We found that students in the policy change schools reported less oversleeping and less feeling sleepy after a change to a later starting time, relative to students in schools that maintained an early start throughout the observation period. According to our difference-in-differences analysis, students in the policy change schools had a 6 percentage point decrease in prevalence of feeling sleepy daily and a 5 percentage point decrease in prevalence of oversleeping and being late to class relative to the comparison schools after 2 years of delayed start times. Although these percentages may seem small, when applied across a school district with thousands of high school students, they correspond to a large number of adolescents that have less sleep–wake problems if schools do not start so early.

Sleep problems are common among adolescents [1,17,29] and are associated with a variety of negative and/or undesirable outcomes [30–32]. Early high school start times are a predictor of adolescent sleep problems [11,13,17,22,23], and evidence suggests that policies that delay high school start times are effective in increasing sleep duration [18]. Delaying school start times could reduce problems like daytime sleepiness by improving sleep duration but could have unintended consequences for other circadian features. Understanding the complete impact of delayed start policies on all aspects of adolescent sleep is essential for developing strategies to maximize adolescent health and wellbeing.

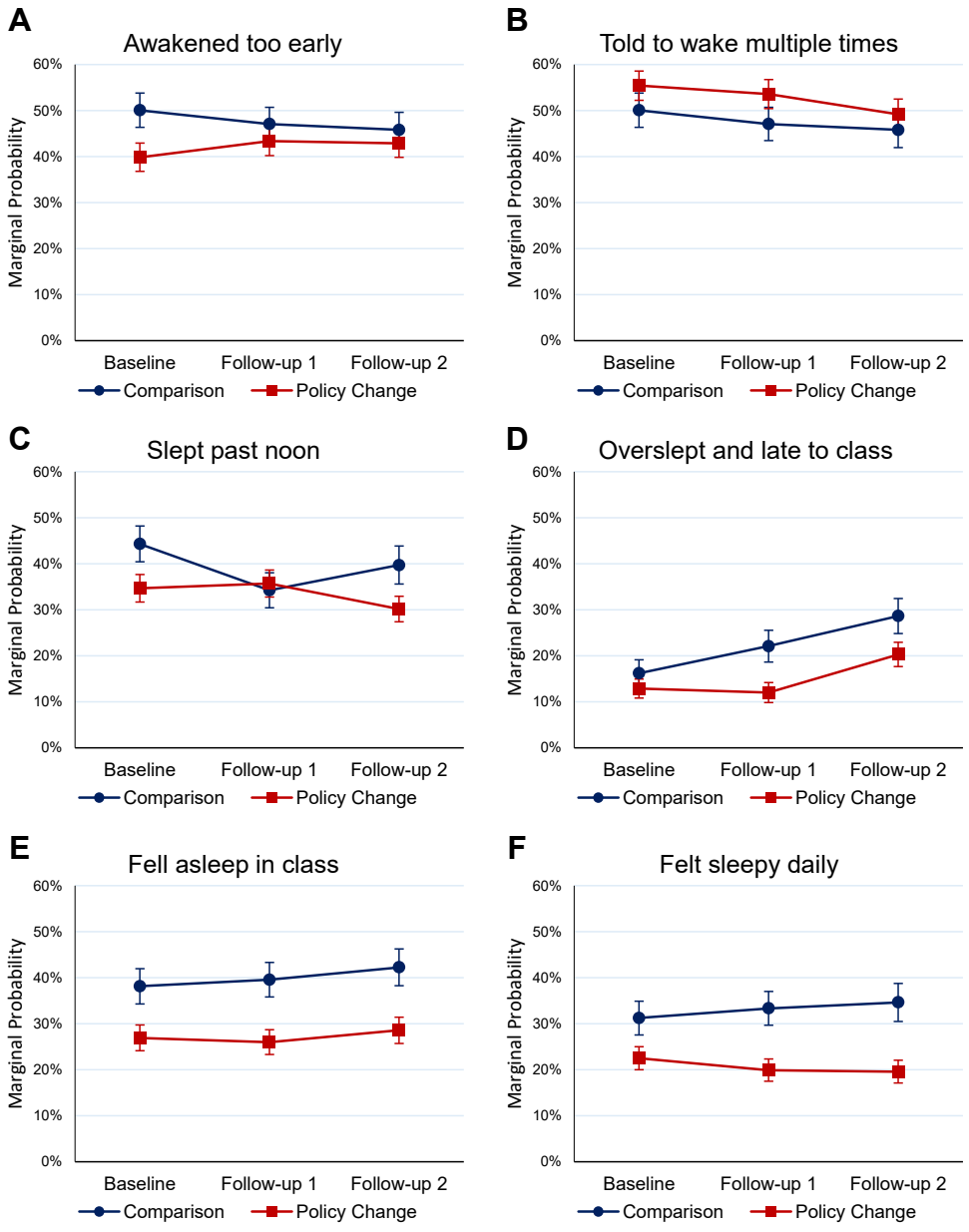

Figure 1. The predicted probabilities of a different sleep-wake problem: (A) awakened too early, (B) told to wake multiple times, (C) slept past noon, (D) overslept and late to class, (E) fell asleep in class, and (F) felt sleepy daily. The probabilities are shown at baseline, follow-up 1, and follow-up 2 by condition (policy change vs comparison). Predicted probabilities are derived from GEE models that include a fixed effect for school and are adjusted for sex, race, parental education, and free lunch eligibility. GEE = generalized estimating equation.

Previously reported findings from the START study had reported that all six sleep–wake problems were more common among students who reported the shortest duration of sleep on school nights (<6 hours) at Baseline [21]. Additionally, longitudinal analyses of the START study found that delaying high school start times increased school night sleep duration [18]. Thus, we hypothesized that delaying school start times could also reduce sleep–wake problems. Our findings, that the delayed start policy change appeared to reduce the proportions of students who reported oversleeping and being late to class and/or feeling sleepy daily, are consistent with findings from studies with cross-sectional [12,22,23] and pre–post designs [13,14] that high school students who start school later experience less daytime sleepiness [12–14,22,23] and are less likely to be late to class due to oversleeping [12–14,22].

Although previous studies have shown that students with later school start time are less likely to fall asleep in class [12–14] or need help waking [14], we did not see improvements in these sleep–wake outcomes for students in policy change schools after the delayed start policy change was implemented. This difference in findings may reflect differences in study designs as previous analyses were from cross-sectional and pre–post studies. Additionally, we found that delayed start policy change may have increased the proportion of students reporting

Table 2
Adjusted difference-in-differences analysis of changes in sleep–wake problems among high school students in policy change and comparison schools

	Probability of each sleep–wake problem,[a] % (95% CI)							
	Policy change schools			Comparison schools			Difference-in-differences analysis, % (95% CI)	
	Baseline	Follow-Up 1	Follow-Up 2	Baseline	Follow-Up 1	Follow-Up 2	Baseline to Follow-Up 1	Baseline to Follow-Up 2
Awakened too early	40 (37–43)	43 (40–46)	43 (40–46)	50 (46–54)	47 (43–51)	46 (42–50)	7 (1–12)	7 (2–13)
Told to wake multiple times	55 (52–59)	54 (50–57)	49 (46–52)	56 (51–60)	55 (51–59)	53 (49–57)	−2 (−7 to 3)	−3 (−9 to 2)
Slept past noon	35 (32–38)	36 (33–39)	30 (27–33)	44 (40–48)	34 (30–38)	40 (36–44)	11 (6 to 16)	0 (−5 to 5)
Overslept and late to class	13 (11–15)	12 (10–14)	20 (18–23)	16 (13–19)	22 (19–26)	29 (25–32)	−7 (−11 to −3)	−5 (−9 to −1)
Fell asleep in class	27 (24–30)	26 (23–29)	29 (26–31)	38 (34–42)	40 (36–43)	42 (38–46)	−2 (−7 to 2)	−2 (−8 to 3)
Felt sleepy daily	22 (20–25)	20 (17–22)	20 (17–22)	31 (28–35)	33 (30–37)	35 (30–39)	−5 (−9 to 0)	−6 (−12 to −1)

[a] Marginal probabilities derived from generalized estimating equation models with a binomial distribution and a logit link. Correlation between repeated measures on the same students is accounted for using a robust variance estimator. All models include a fixed effect for school. Models adjusted for sex, race, parental education, and free lunch eligibility.

awakening too early and being unable to fall back asleep, a problem that inherently becomes more possible when alarm clocks are not set for such an early hour. For example, when students have to be at school by 7:30 A.M., they may consider waking before 6:30 too early. When they do not have to be at school until 8:20 A.M., their definition of awakening "too early" may shift to 7:20 A.M. Delayed school start times may give students the opportunity to wake later, but they may still awaken early based on external factors like early morning light exposure and household noise from parents and younger siblings who continue to rise early for work and school. However, additional research may be needed to more fully understand the impact of delaying school start times on the problem of waking too early.

This study was subject to several possible limitations. START was a natural experiment, meaning that schools were not randomized to policy change or the comparison condition, so confounding by individual-level or school-level factors remains a possibility. Our individual-level controls like parental education and free or reduced-price lunch eligibility are proxy measures of individual socioeconomic status, and these factors may be measured with error. Thus, there could be residual confounding by individual socioeconomic status. Additionally, because the study was limited to five high schools, we were unable to control for school-level predictors, like community-wide economic conditions, that may have differed between policy change and comparison schools and influenced study results. For example, implementation of an especially strong health education program during the study period could be associated with both district-level decisions to delay start times and student sleep habits and, thus, explain the exposure–outcome relationships we observed. However, we think this is unlikely because no such relevant district-level changes have been identified during the study period. Additionally, due to our limited number of schools, we observed some differences in the prevalence of sleep–wake problems at Baseline. Students in policy change schools were less likely to report some sleep–wake problems, potentially because these students had slightly higher SES than students in the comparison schools. However, as long as the parallel trends assumption holds, the use of a difference-in-differences analysis mitigates these concerns by examining how the change in sleep–wake problems among policy change schools compares to the change in sleep–wake problems among comparison schools. Finally, the START sample was predominantly white and confined to a limited geographic area, which some might argue limits the generalizability of study findings. However, prior adolescent sleep research has shown that school start time appears to be correlated with teen sleep characteristics in various settings, across international borders, and for individual students from varied demographic contexts [13,14,20,33–36].

Using a natural experiment to evaluate the impact of a delayed start policy change on sleep–wake behaviors offers a stronger design to test questions about how policy might impact sleep. Many existing studies have used cross-sectional designs to compare students at high schools with different start times at a single point in time [12,22]. Prior longitudinal studies on school start times and sleep–wake behaviors have relied on pre–post designs that survey the same students prior to and after implementing the policy change [13,17], limiting the ability to distinguish policy effects from changes induced by other factors. Conversely, our START study followed the same students before and after some schools delayed their start times and included students from contemporaneous comparison schools that continued to start early throughout the study period. Other strengths of the START study included a longer follow-up time than prior studies, high participation rates, and a high retention proportion. Thus, this study had a stronger design for causal inference and allowed us to evaluate the longer term impacts of a delayed start policy change than previous studies.

Proper sleep is essential for healthy youth development, but few U.S. adolescents get the recommended 8.5–9.25 hours of sleep [2]. In addition to insufficient sleep, adolescents commonly experience other sleep problems including insomnia and daytime sleepiness. Early high school start times, which are incongruent with adolescent chronobiology, appear to contribute to these sleep problems. This study adds to a growing body of evidence that delaying high school start times does more than just extend sleep hours; these policies appear to help adolescents oversleep less often and feel less sleepy during the day, potentially increasing their ability to actively participate in school.

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Supplementary Data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jadohealth.2021.04.030.

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