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Later Start, Longer Sleep: Implications of Middle School Start Times

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Abstract

BACKGROUND—Although both younger and older adolescents generally get less than the recommended nine hours of sleep per night, research and efforts to delay school start times have generally focused on high schools. This study assesses the relation between school start times and sleep in middle school students while accounting for potentially confounding demographic variables.

METHODS—Seventh and eighth grade students attending eight late starting schools (~8:00a.m., N=630) and three early starting schools (~7:23a.m., N=343) from a diverse suburban school district completed online surveys about their sleep behaviors. Doubly robust inverse probability of treatment weighted regression estimates of the effects of later school start time on student bedtimes, sleep duration, and daytime sleepiness were generated.

RESULTS—Attending a school starting 37 minutes later was associated with an average of 17 additional minutes of sleep per weeknight, despite an average bedtime 15 minutes later. Students attending late starting schools were less sleepy than their counterparts in early starting schools, and more likely to be wide awake.

CONCLUSIONS—Later school start times were significantly associated with improved sleep outcomes for early adolescents, providing support for the movement to delay school start times for middle schools.

Keywords

School Start Times; Sleep; Middle School

In recent years, school systems across the United States have recognized insufficient sleep, one of the top health concerns for adolescents, as a principal risk factor for several negative academic and social outcomes, including decreased attendance and academic achievement

and increased aggression and substance use.¹ Adolescents need an average of nine hours of sleep per night, according to laboratory studies.² Yet, according to the 2015 Youth Risk Behavior Survey, 73 percent of high school students in the United States report getting fewer than eight hours of sleep.³ Although there is no national figure available for middle school students, state-level data suggest this rate to be between 38 to 53 percent.⁴ The high prevalence of middle and high schools that start before 8:30a.m. is a key driver of sleep deficits among adolescents.⁵ As adolescents enter and proceed through puberty, changes in intrinsic circadian rhythms make it increasingly difficult to fall asleep early.^{6,7} When paired with early school start times, teens may be unable to meet their sleep needs, which include both optimal sleep duration as well as optimal sleep timing.⁸ This disconnect has led several groups, including the American Academy of Pediatrics,⁹ the American Medical Association,¹⁰ the Centers for Disease Control and Prevention,⁵ and the U.S. Department of Education¹¹ to recommend later start times for both middle and high schools.

Research and practice, however, have thus far primarily focused on delayed school start times for high school students. School systems that have pursued school start time changes have sometimes pushed middle schools even earlier in order to achieve more optimal timing for high schools given resource and logistical restrictions.^{12,13} Further, the vast majority of research on the effectiveness of later school start times for improving adolescent sleep has focused on older adolescents.^{14,15} Only a handful of studies have explored the potential impact of later school start times for middle school-aged students. A recent review of school start time literature highlighted this gap, calling for more research on the implications of school start times for middle school students, especially as shifts in circadian timing likely occur prior to the transition to high school.¹⁴

For high school students, previous research has generally found a positive association between delayed start times and increased sleep duration, though the magnitudes of such effects vary considerably between studies.^{16–18} One study at a boarding school found a gain of 29 minutes of sleep with a start time delay of 25 minutes.¹⁶ In a comparative analysis of two school districts with just over an hour difference in start times, Boergers and colleagues found an equal gain of one hour in sleep.¹⁷ Another study of two high schools with an hour start time difference found just an eleven minute gain.¹⁸ Two of these studies also looked at daytime sleepiness with mixed findings, one showing a reduction in daytime sleepiness¹⁶ with the other showing no significant difference.¹⁸ Delayed school start times have also been associated with other outcomes, including improved academic achievement^{17,19} and overall well-being,²⁰ as well as decreased motor vehicle accidents²¹ and suicidality.²² Methodological limitations, such as not controlling for background characteristics and absence of comparison groups, make it difficult to attribute such gains solely to differences in school start times; other factors such as differences in the sex, racial, or socioeconomic makeup of the comparative samples between schools or over time, may mediate the observed gains.¹⁴

The few previous studies that focused on middle school students found similar outcomes for younger adolescents and provide critical support for exploring the effects of school start times for this age group. However, these studies similarly do not fully account for other factors that may contribute to findings. Wolfson and colleagues found that seventh and

Parents consented eligible children and completed a short online survey. A separate online survey, which included the measures described below, was sent to consented students via email. Additional data from district administrative records were also obtained for each consented student. This convenience sample represents 9.1 percent of students attending the study schools. This response rate is consistent with observed response rates for similar opt-in, web-based surveys.²⁸

Measures

Table 1 reports descriptive statistics for each measure used in our analyses.

Bedtime, Wake Time, & Sleep Duration.—All sleep measures were derived from the *School Sleep Habits Survey*.²⁹ Students were asked to report their school-night bedtime, weekend bedtime, school-day wake time, and weekend wake time, by selecting the hour, minutes in fifteen minute increments (:00, :15, :30, :45), and a.m./p.m. School-night sleep duration and weekend sleep duration were calculated in hours based on bedtime and wake time. Bedtimes were centered at 10:00p.m., the approximate mean for weekday bedtime for the total sample, for ease of interpretation.

Daytime Sleepiness.—Students were asked whether they struggled to stay awake or had fallen asleep while engaging in 10 activities--such as while in class or during a test--during the previous two weeks on a three-point scale: 0-never, 1-struggled to stay awake, 2-fell asleep. Students also indicated if they had not engaged in a particular activity. Each student's sleepiness score is an average of the total of their ratings for activities they engaged in. For example, if a student indicated they did not drive a car, the average score was derived from nine items rather than 10. For purpose of analysis, scale scores were transformed using log-transformation to address skewness; over 40 percent had scale scores between 0.0 and 0.1. Additionally, a separate dichotomous item, "wide awake," was tested representing a score of 0 versus any endorsement of fatigue on these items.

Demographic Covariates.—Demographic covariates were collected from student and parent surveys as well as school district administrative records. Student participants were asked to self-report sex, race and Hispanic origin, and language spoken at home. Parents additionally provided student birthdate which was used to calculate age on date of survey completion. Because a dummy variable for eighth grade was also included in the analysis, resulting in collinearity, we mean-centered age by grade. These data were matched to administrative records provided by the school district, which were given priority in cases of discrepancy or missing data. Administrative records also provided information about student eligibility for free and reduced priced meals (FARMS), a proxy for family economic disadvantage. Parents provided information regarding their marital status and educational attainment. The latter was used to generate a variable for highest level of parent education.

School Start Time.—School start times were obtained from administrative records. On average, middle schools started 37 minutes later than secondary schools. This difference was treated as a dichotomous variable: earlier vs. later school start time. School start times varied for each sample school, however (7:55–8:05 for middle schools; 7:20–7:25 for secondary

schools). To account for this variation in the model, a variable accounting for the difference from the mean start time in each group was included in the analyses. This variable was never significant.

Data Analysis

We used several different analytic approaches to generate estimates of the average treatment effect of attending a later starting school on our outcomes of interest. Our preferred estimates are those generated by weighted regression analysis, with weights generated from IPTW. These estimates are limited to the region of common support, ensuring that similar students are being compared and limiting the potential for bias, and they allow for an investigation of potential heterogeneity in effects between the late and early starting school populations.³⁰ The weighted regression analysis accounts for potentially confounding observed variables by balancing early starting and later starting samples across the series of demographic variables. That is, the IPTW adjusts for the probability that a student with a given set of characteristics attends a later starting school. It cannot, however, illuminate the extent to which these potential confounders actually relate to our outcomes of interest. To this end, we additionally present results from multiple Ordinary Least Squares (OLS) regression analyses, which provide information on the magnitude and statistical significance of the effects of the covariates. All analyses accounted for clustering by school when generating standard errors.

To execute the weighted regression analyses, we first used logistic regression to estimate a propensity score for each student, by grade. The propensity score is the probability of a student attending a later starting school, given the student's observed characteristics. Then, we used our estimated propensity scores to generate weights for the late and early starting groups. For purposes of simplicity in discussion and consistency with IPTW methodology, we consider having a later school start time as the "treatment" condition in our construction of weights. In order to explore potential heterogeneity of effects depending on the population of students experiencing early or late starting schools, three different sets of weights and thus three separate weighted regressions were conducted and compared. Specifically:³⁰

$$\text{For } d_i = 1: \quad w_{i, \text{ATE}} = \frac{1}{\hat{p}_i},$$

$$\text{For } d_i = 0: \quad w_{i, \text{ATE}} = \frac{1}{1 - \hat{p}_i},$$

and

$$\text{For } d_i = 1: \quad w_{i, \text{ATT}} = 1,$$

$$\text{For } d_i = 0: \quad w_{i, \text{ATT}} = \frac{\hat{p}_i}{1 - \hat{p}_i},$$

and

$$\text{For } d_i = 1: \quad w_{i, \text{ATC}} = \frac{1 - \hat{p}_i}{\hat{p}_i},$$

$$\text{For } d_i = 0: \quad w_{i, \text{ATC}} = 1.$$

Where, for student i , d_i represents school start time status, that is, whether or not the student attended a school with a late start time; $w_{i, \text{ATE}}$ represents the Average Treatment Effect weight, or the average effect of moving the population from early starting to late starting; $w_{i, \text{ATT}}$ represents the Average Treatment effect on the Treated weight, or the average effect of having a later start time for those who attended later starting schools; $w_{i, \text{ATC}}$ represents the Average Treatment effect on the Controls weight, or the average effect of a later start time for students at the earlier starting schools, had they had a later school start time, and; $\hat{p}_i$ represents the estimated propensity score. We set weights to near-zero values for estimates outside the region of common support, or the range of propensity scores for which propensity scores from the early starting and later starting samples overlap. We then used these weights in our weighted regression analyses. These analyses were doubly robust in that they also included the covariates used to generate the propensity score in the final regression to control for any remaining imbalance after weighting. As a sensitivity check, we re-ran analyses trimming high weights to the 99th percentile and the 95th percentile, and our results held.

Approximately 16 percent of cases contained missing data on one or more variables used in these analyses. To address these missing data and correct the associated standard errors, we used multiple imputation by chained equations using Stata's `mi impute` command.³¹ Consistent with best practices for multiple imputation, we generated 20 imputed datasets prior to employing our analysis procedures described above and used Stata's `mi estimate` procedure to aggregate results. In addition to our dependent, independent, and conditioning variables, we included school ID as an additional variable that likely contributed to the missing mechanism.

RESULTS

We first focus on the results for the main effect of school start time for each of our dependent variables from weighted regression analyses. Means and standard deviations of demographic covariates for the unweighted and weighted samples are presented in Table 2. As reflected in these values, the weighting procedures employed resulted in particularly well-balanced samples. Table 3 presents estimates for each outcome for each estimation approach; weighted regression estimates are presented for the overall averaged effect of later

school start times (ATE), the average effect of later school start times for those attending later starting schools (ATT), and the average effect of later start times for students attending early starting schools (ATC).

There was substantial consistency across the estimated effects of later school start times across all estimation strategies and across early and later starting students (Table 3). The high level of concordance between our weighted regression ATT and ATC estimates suggests that there is limited hidden bias resulting from unobserved differences between the groups of students attending later and early starting schools. Because the vast majority of observations were within the region of common support, our weighted regression and OLS estimates of the ATE were similar. The similarity of our naïve estimates to our more sophisticated estimates suggests that our naïve estimates were only slightly biased because of observed confounding variables. The consistency of measured effects across all estimation strategies gives us confidence in the accuracy of our estimates.

In addition to the main effect models presented below, we also ran OLS models including an interaction between start time and grade. Across all outcomes, these interaction terms were not statistically significant, indicating no detectable difference in the effects of school start time for seventh and eighth grade students.

School-Night Sleep Duration.

Before accounting for sample differences, students at early starting schools averaged eight hours and nine minutes of sleep while students at later starting schools averaged eight hours and 23 minutes. After accounting for potentially confounding demographic variables, having a later school start time was significantly associated with longer sleep durations ($b=0.29$, $p<.001$)--a difference of approximately 17 minutes. Given the 37 minute average difference between the early and later school start times, this equates to increases in sleep duration of approximately 46 percent of time invested in the school start time delay. Assuming a linear relationship, for every two minutes delay in school start time, almost one minute is gained in sleep duration.

School-Night Bedtime.

Average bedtime for all participants was 9:54p.m., with an average bedtime of 9:43p.m. for students at the early starting schools and 10:02p.m. for those attending later starting schools. After accounting for demographic variables, school start time was significantly associated with bedtime ($b=0.25$, $p<.001$), indicating that students at early starting schools go to bed 15 minutes earlier than their peers at later starting schools.

Weekend Sleep and Weekend Bedtime.

Average weekend sleep duration was 10 hours and six minutes and weekend bedtime was 11:06p.m. There were no significant associations between school start time and weekend bedtime or sleep duration.

Daytime Sleepiness.

Students at later starting schools were less likely to report daytime sleepiness ($b=-0.34$, $p<.001$) and more likely to report being wide awake, or having no activities for which they struggled to stay awake or fell asleep during the previous two weeks ($b=0.09$, $p<.001$).

Effects of Covariates.

Table 4 presents findings from OLS regressions, which were used to understand the associations of demographic covariates to our dependent outcomes. Significant associations with sleep duration were observed for grade, sex, race, and home language, with eighth grade students receiving approximately 25 fewer minutes, girls receiving approximately 10 fewer minutes, those reporting two or more races receiving 22 fewer minutes than white students, and those speaking a language other than English at home receiving 27 fewer minutes of sleep per school-night, on average. Similarly significant associations for bedtime were observed for grade, race, and home language, but no significant association was observed between sex and bedtime, indicating that their difference in sleep duration is likely driven more by earlier wakeup times rather than later bedtimes. Eighth grade students, black students, and female students were more likely to report daytime sleepiness.

DISCUSSION

This paper took advantage of natural variation in school start times among seventh and eighth grade students in a large suburban school district, using weighted regression techniques in order to investigate the links between school start times and sleep duration, bedtimes, and daytime sleepiness. Exploring such associations is critical to the ongoing local and national policy debates about the impact of school start times for middle school students,^{1,5} as there are only a handful of studies that have previously explored these outcomes for this age group.^{23,25} After accounting for differences in our sample demographics, we found that attending a school starting on average 37 minutes later was associated with getting an average of 17 more minutes of sleep per weeknight, despite going to bed an average of 15 minutes later. This means that students at the later starting schools wake up approximately 32 minutes later. In addition, students attending early starting schools did not make up for lost sleep over the weekend, relative to students attending later starting schools, as there were no significant differences in weekend bedtime or sleep duration in either group. Ultimately, students attending later starting school were less sleepy than their counterparts in early starting schools, and more likely to be wide awake.

We believe our findings to be substantively meaningful and to provide clear evidence of benefits of a later school start time for seventh and eighth graders in our sample. Our findings on sleep duration suggest that students attending later starting schools get an extra hour and 15 minutes of sleep per week, resulting in an extra 51 hours of sleep per school year. Furthermore, on average, moving from an earlier starting school to a later starting school would be associated with a 34 percent decrease in daytime sleepiness and a nine percentage point increase in the probability of being wide awake, or having a zero on the sleepiness scale.

Although some previous research has suggested an equal or even a greater than 100 percent return on sleep for later school start times,^{16,17} our finding of a 46 percent return is consistent with the majority of existing research on both high school and middle school start times.^{18,23,25} The impact of incremental increases in sleep time on academic performance, mood and physical health for middle school students have yet to be determined, but in several studies of high school students, there are at least short term improvement across these domains.^{17,19,22,15}

Much of the loss between the difference in school start times and the difference in sleep duration seems to be due to later bedtimes for the late starting group. This is consistent with adolescents' biological drive towards later bedtimes and extended morning sleep, promoting overall better sleep quality.^{6,7} This is reflected in our finding that students at the later starting schools reported significantly less daytime sleepiness and were more likely to report being wide awake. Later bed times, thus, are both an expected and desired outcome in delaying school start times.

Our analyses also revealed interesting findings related to demographic differences in our various sleep outcomes, highlighting the importance of accounting for demographics in comparative studies of school start times, especially when demographics significantly differ between groups. For instance, female students in our sample slept less, woke earlier, and reported greater daytime sleepiness than male students. Black students reported greater daytime sleepiness than white students, but did not significantly differ on sleep duration or bedtime.

The use of doubly robust weighted regression to improve balanced comparisons between students at early and later starting schools greatly improves upon the existing school start time literature. Unweighted comparisons between the early and later starting samples revealed demographic differences between the groups, particularly in terms of sex and racial composition, despite being pulled from the same school district. Accounting for these differences allowed us to mitigate observed selection bias in this cross-sectional study.^{14,32}

Limitations

There are remaining potential confounders and limitations to acknowledge, however. First, our analyses revolved around start time difference in two types of schools serving seventh and eighth grades. Although this difference is the most logically related to our findings, other structural differences, for instance the influence of older peers in the early starting secondary schools, may have additionally contributed. Following the same schools over time as they change school start times would control for these unmeasured attributes and allow for stronger claims regarding the causal nature of school start times and sleep outcomes. Second, our analyses relied solely on self-reported bedtimes and wake times reported in 15 minute increments. Though consistent with previous evaluations of school start time and adolescent sleep,⁶ self-reported sleep often contains measurement error. Using more objective measurement, such as the use of multiday sleep-wake actigraphy data,³³ will be an important next step in understanding the impact of later school start times.

Conclusions

Despite these limitations, the findings from this study suggest that delayed school start times may significantly benefit middle school students, complementing the growing literature supporting later start times for older students. Seventh and eighth grade students with later school start times have significantly longer sleep durations and less daytime sleepiness than do similar students with earlier school start times. These findings underscore the importance of considering the implications of school start time reform for all students, not just high school students.

IMPLICATIONS FOR SCHOOL HEALTH

Over the last several years, both advocacy for and research about school start times and adolescent sleep have continued to amass. Although advocacy for later school start times has included calls for such changes at the middle school level, to date, research evidence has largely been limited to school start time changes for older adolescents.^{14,15} Paralleling this trend, many school systems have focused limited resources to changing start times for high schools, sometimes to the detriment of middle schools, which have been pushed earlier in some school districts.^{13,12} The present study's findings that middle school students with later school start times not only have longer sleep durations, but also report less daytime sleepiness, demonstrate the importance of also considering delays in school start times for middle school students as a way to improve student sleep and sleep quality.

Thus, as school systems should include the potential impact of school start times on middle school students in any deliberations of school start time policies. After all, middle school is often considered a critical window for the prevention of delinquency, substance use, and other problem behaviors, as well as the promotion of school engagement and academic success.³⁵ Sleep is linked to each of these outcomes.¹⁵ Promoting more healthy sleep durations for early adolescents may provide them with a better foundation for school success.

Further, our finding that for every two minutes of school start time delay just under a minute of sleep is gained also provides important context for school officials and other policy makers implementing school start time changes. Previous evaluations have shown wide variation in the magnitude of this effect, but few have shown a return higher than our findings. It is therefore important to set expectations that delaying school start times by 30 minutes will likely not result in 30 minutes of gained sleep duration. Still, even the 17 minute difference demonstrated in the current study likely has a meaningful, cumulative effect over time.

More research is needed to identify the optimal school start time to result in the greatest outcomes for students. It is not necessarily clear whether the association between school start time delay and sleep is linear or whether gains will plateau or accelerate at some point. Even so, if the targeted sleep need for adolescents is nine hours, later school start times may be needed. In the present study, we observed that students at schools starting at around 8a.m. average eight hours and 23 minutes of sleep. The American Academy of Pediatrics policy statement suggests 8:30a.m. as the target timing.⁹ Applying our finding of one minute sleep

gained for every two minutes of delayed start time, an 8:30a.m. start time would still result in less than nine hours of sleep, adding only an additional 15 minutes to result in eight hours and 38 minutes of sleep. Our findings suggest that a start time of 9:15a.m. may be necessary for middle students to meet their sleep need.

Such a delay may not be feasible for many school systems, which face costs and challenges related to shifting student transportation and after school activities, and resistance from school staff, students, and parents. Although some research suggests that such challenges are often speculative and may not actually materialize following the passage of school start time delays,³⁴ no rigorous cost-benefit analysis has been conducted to date, and such costs may significantly vary between school systems. As such, school systems must balance their expectations regarding the effect of school start time changes with their investment.

HUMAN SUBJECTS APPROVAL STATEMENT

Study procedures were approved by the Institutional Review Boards (IRB) of the Children's National Health System, Child Trends, and the participating school district.

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Table 1.
Sample Demographics and Descriptive Statistics Without Weights by School Start Time

Demographics/Covariates	Overall sample (N=973)	Early school start time (N=343)	Late school start time (N=630)
Grade 8	458 (47%)	168 (49%)	290 (46%)
Age			
12	22 (2%)	6 (2%)	16 (2%)
13	466 (48%)	151 (44%)	315 (50%)
14	436 (45%)	165 (48%)	271 (43%)
15	49 (5%)	21 (6%)	28 (4%)
Female	501 (51%)	158 (46%)	343 (54%)
Race and Hispanic Origin			
White	604 (62%)	238 (69%)	366 (58%)
Black	41 (4%)	16 (5%)	25 (4%)
Hispanic	71 (7%)	27 (8%)	44 (7%)
Asian	138 (14%)	31 (9%)	107 (17%)
Two or more races or other	119 (12%)	31 (9%)	88 (14%)
English is home language	915 (94%)	326 (95%)	586 (93%)
Two, married parents at home	837 (86%)	295 (86%)	542 (86%)
Highest level or parent education			
Below Bachelor's	95 (10%)	32 (9%)	63 (10%)
Bachelor's degree	269 (28%)	99 (29%)	170 (27%)
Master's degree	431 (44%)	154 (45%)	277 (44%)
Above Master's	178 (18%)	58 (17%)	120 (19%)
Free and Reduced Priced Meals	53 (5%)	21 (6%)	32 (5%)
Outcomes			
School-night sleep duration (hours)			
Mean (SD)	8.30 (1.06)	8.15 (0.98)	8.39 (1.09)
Range	2.5–12.0	3.50–11.0	2.5–12.0
School-night bedtime			
Mean (SD)	9:54p.m. (1:02)	9:43p.m. (0:57)	10:02p.m. (1:01)

	Overall sample (N=973)	Early school start time (N=343)	Late school start time (N=630)
Range	7:00p.m. – 3:00a.m.	7:00p.m. – 3:00a.m.	7:00p.m. – 2:15a.m.
School-day wake time			
Mean (SD)	6:12a.m. (0:30)	5:51a.m. (0:25)	6:24a.m. (0:31)
Range	3:00a.m. – 7:45a.m.	3:30a.m. – 7:00a.m.	3:00a.m. – 7:45a.m.
Weekend sleep duration (hours)			
Mean (SD)	10.10 (1.47)	10.09 (1.45)	10.11 (1.49)
Range	4.0–17.5	4.0–15.75	4.50–17.50
Sleepiness scale			
Mean (SD)	0.22 (0.28)	0.24 (0.28)	0.22 (0.28)
Range	0–2	0–1.3	0–2
Wide awake (0 on sleepiness scale)			
Mean (SD)	0.40 (.49)	0.34 (0.48)	0.43 (0.50)
Range	0–1	0–1	0–1

NOTE: Descriptive statistics are based on one of 20 multiply imputed datasets.

Table 2
Means and Standard Deviations of Covariates by Weight Status and School Start Time for the Weighted Regression Analysis

Covariate	Unweighted						Weighted												
	Early			Late			ATT			ATC			ATE						
	M	SD		M	SD		Early	M	SD	Early	M	SD	Early	M	SD	Early	M	SD	
Grade 8	0.49	(0.50)		0.46	(0.50)		0.47	(0.50)	0.46	(0.50)	0.49	(0.50)	0.50	(0.50)	0.48	(0.50)	0.47	(0.50)	
Age (mean-centered by grade) ^a	0.02	(0.36)		-0.01	(0.36)		0.00	(0.37)	-0.01	(0.36)	0.02	(0.36)	0.03	(0.36)	0.01	(0.36)	0.00	(0.36)	
Race and Hispanic origin																			
Black	0.05	(0.22)		0.04	(0.20)		0.04	(0.19)	0.04	(0.20)	0.05	(0.22)	0.05	(0.22)	0.04	(0.20)	0.04	(0.20)	
Hispanic	0.08	(0.27)		0.07	(0.26)		0.07	(0.26)	0.07	(0.26)	0.08	(0.27)	0.07	(0.26)	0.07	(0.26)	0.07	(0.26)	
Asian	0.09	(0.29)		0.17	(0.38)		0.16	(0.37)	0.17	(0.38)	0.09	(0.29)	0.09	(0.29)	0.14	(0.34)	0.14	(0.35)	
Two or more races or other	0.09	(0.28)		0.14	(0.35)		0.15	(0.36)	0.14	(0.35)	0.09	(0.28)	0.09	(0.29)	0.13	(0.33)	0.12	(0.33)	
Female	0.46	(0.50)		0.54	(0.50)		0.55	(0.50)	0.54	(0.50)	0.46	(0.50)	0.46	(0.50)	0.52	(0.50)	0.51	(0.50)	
English is home language	0.95	(0.21)		0.93	(0.26)		0.93	(0.25)	0.93	(0.26)	0.96	(0.21)	0.95	(0.21)	0.94	(0.24)	0.94	(0.24)	
Two, married parents	0.86	(0.35)		0.86	(0.35)		0.85	(0.35)	0.86	(0.35)	0.86	(0.35)	0.86	(0.35)	0.86	(0.35)	0.86	(0.35)	
Highest level of parent educ.																			
Bachelor's	0.29	(0.46)		0.27	(0.44)		0.27	(0.44)	0.27	(0.44)	0.29	(0.45)	0.30	(0.46)	0.28	(0.45)	0.28	(0.45)	
Master's	0.45	(0.50)		0.44	(0.50)		0.45	(0.50)	0.44	(0.50)	0.46	(0.50)	0.45	(0.50)	0.45	(0.50)	0.44	(0.50)	
Above Master's	0.17	(0.37)		0.19	(0.40)		0.19	(0.39)	0.19	(0.40)	0.17	(0.37)	0.17	(0.37)	0.18	(0.39)	0.18	(0.39)	
Free and Reduced Priced Meals	0.06	(0.23)		0.05	(0.22)		0.05	(0.21)	0.05	(0.22)	0.05	(0.22)	0.06	(0.23)	0.05	(0.21)	0.05	(0.23)	

^aMean-centered by school type (early or late start).

NOTE: Descriptive statistics are based on one of 20 multiply imputed datasets.

Table 3.
Estimates of the Association Between Later School Start Time and Various Outcomes by Estimation Approach

Estimation approach	School-night sleep duration		School-night bedtime		Weekend sleep duration		Weekend bedtime		Sleepiness (ln scale)		Wide awake					
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE				
Ordinary Least Squares regression																
Simple (Naïve estimate of ATE)	0.25	*	(0.07)	0.29	*	(0.04)	0.04	(0.07)	0.04	(0.10)	-0.27	*	(0.09)	0.08	*	(0.02)
Multiple regression (ATE)	0.28	*	(0.08)	0.26	*	(0.05)	0.01	(0.06)	0.03	(0.06)	-0.30	*	(0.09)	0.09	*	(0.02)
Inverse Probability Weighted Least Squares ^a																
ATE	0.29	*	(0.08)	0.25	*	(0.05)	0.02	(0.06)	0.02	(0.05)	-0.34	*	(0.08)	0.09	*	(0.02)
ATT	0.29	*	(0.08)	0.26	*	(0.05)	0.02	(0.05)	0.01	(0.06)	-0.36	*	(0.07)	0.10	*	(0.02)
ATC	0.29	*	(0.08)	0.24	*	(0.05)	0.01	(0.07)	0.03	(0.06)	-0.30	*	(0.10)	0.09	*	(0.03)

* p<.001

^a Estimates are doubly robust and weights were set to a negligible value for observations outside the area of common support

Table 4
Ordinary Least Squares Estimates of the Effect of a Later School Start Time on Sleep Duration, Bedtime, and Sleepiness

	School-night sleep duration		School-night bedtime		Weekend sleep duration		Weekend bedtime		Sleepiness (ln scale)		Wide awake	
	b	SE	b	SE	b	SE	b	SE	b	SE	b	SE
Treatment												
Later school start time (middle school)	0.28 *	(0.08)	0.26 *	(0.05)	0.01	(0.06)	0.03	(0.06)	-0.30 *	(0.09)	0.09	(0.02)
Covariates												
Grade 8	-0.41 *	(0.07)	0.37 *	(0.06)	-0.10	(0.12)	0.36 *	(0.07)	0.22 *	(0.09)	-0.03	(0.02)
Age (mean-centered by grade)	-0.32 *	(0.08)	0.27 *	(0.09)	0.06	(0.09)	0.30 *	(0.07)	0.41 *	(0.11)	-0.11	(0.03)
Race and Hispanic origin												
Black	-0.14	(0.23)	0.13	(0.23)	-0.52	(0.38)	0.76	(0.40)	0.66 *	(0.25)	-0.18	(0.07)
Hispanic	-0.13	(0.12)	0.10	(0.13)	0.09	(0.25)	0.19	(0.30)	0.28	(0.26)	-0.09	(0.07)
Asian	-0.18	(0.09)	0.30 *	(0.11)	0.14	(0.14)	0.20	(0.15)	-0.02	(0.17)	0.00	(0.05)
Two or more races or other	-0.36 *	(0.12)	0.32 *	(0.11)	0.02	(0.22)	0.44 *	(0.12)	0.08	(0.17)	-0.04	(0.05)
Female	-0.16 *	(0.04)	0.08	(0.05)	0.30	(0.10)	0.02	(0.10)	0.61 *	(0.11)	-0.15	(0.03)
English is home language	0.45 *	(0.13)	-0.49 *	(0.17)	0.37	(0.22)	-0.24	(0.19)	0.10	(0.32)	-0.08	(0.08)
Two, married parents at home	0.02	(0.08)	-0.04	(0.08)	0.09	(0.19)	-0.29	(0.15)	-0.14	(0.21)	0.04	(0.06)
Highest level of parent education												
Bachelor's degree	0.19	(0.13)	-0.19	(0.13)	0.33	(0.22)	-0.42	(0.20)	-0.44	(0.22)	0.07	(0.06)
Master's degree	0.23	(0.12)	-0.21	(0.13)	0.42	(0.22)	-0.63 *	(0.14)	-0.55	(0.25)	0.10	(0.06)
Above Master's	0.20	(0.11)	-0.19	(0.12)	0.31	(0.23)	-0.65 *	(0.20)	-0.18	(0.29)	0.02	(0.08)
Free and Reduced Priced Meals	0.04	(0.21)	0.13	(0.18)	0.32	(0.29)	-0.06	(0.24)	-0.18	(0.24)	0.04	(0.07)
Constant	7.84 *	(0.20)	0.11	(0.24)	9.21 *	(0.38)	1.77 *	(0.24)	-2.41 *	(0.43)	0.43	(0.12)

NOTE: All models include a variable accounting for slight variations in school start time by school type. This variable was never significant.

* p<.05