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High school start times after 8:30 AM are associated with later wake times and longer time in bed among teens in a national urban cohort study

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ABSTRACT

Objectives: High school start times are a key contributor to insufficient sleep. This study investigated associations of high school start times with bedtime, wake time, and time in bed among urban teenagers.
Design: Daily-diary study nested within the prospective Fragile Families and Child Wellbeing Study.
Setting: Twenty US cities.
Participants: Four hundred thirteen teenagers who completed ≥1 daily diary report on a school day.
Measurements: Participating teens were asked to complete daily diaries for 7 consecutive days. School-day daily diaries (3.8 ± 1.6 entries per person) were used in analyses (N = 1555 school days). High school start time, the main predictor, was categorized as 7:00-7:29 AM (15%), 7:30-7:59 AM (22%), 8:00-8:29 AM (35%), and 8:30 AM or later (28%). Multilevel modeling examined the associations of school start times with bedtime, wake time, and time in bed. Models adjusted for age, sex, race/ethnicity, household income, caregiver's education, and school type.
Results: Teens with the earliest high school start times (7:00-7:29 AM) obtained 46 minutes less time in bed on average compared with teens with high school start times at 8:30 AM or later ($P < .001$). Teens exhibited a dose-response relationship between earlier school start times and shorter time in bed, primarily due to earlier wake times ($P < .05$). Start times after 8:30 AM were associated with increased time in bed, extending morning sleep by 27-57 minutes ($P < .05$) when compared with teens with earlier school start times.
Conclusion: Later school start times are associated with later wake times in our large, diverse sample. Teens starting school at 8:30 AM or later are the only group with an average time in bed permitting 8 hours of sleep, the minimum recommended by expert consensus for health and well-being.

Introduction

The majority of teenagers (teens) in the United States (US) of America have insufficient sleep. Data collected from the Youth Risk Behavior Survey in 2015 showed that 73% of high school students reported less than 8 hours of sleep on school nights.[1] The American Academy of Sleep Medicine Consensus Statement and the National Sleep Foundation's Consensus Statement on sleep both recommend that teens obtain 8-10 hours of sleep per night.[2,3]

Melatonin secretion patterns, a reliable indicator of circadian timing, are delayed in both onset and offset relative to the dark/sleep period during puberty, triggering relatively later bedtimes and desired later wake times in teens.[4,5] These physiological changes in circadian timing are incompatible with the daily life contexts of contemporary US teens. Social pressures, schoolwork, employment, familial schedules, extracurricular activities, and electronic devices are all factors that further delay teens' circadian patterns, interfering with sleep.[6,7] Furthermore, early school start times (SSTs) that require early morning wake times may present a temporal obstacle

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to sufficient nighttime sleep. For most teenagers, the ideal sleep/wake patterns would consist of an 11:00 PM bedtime and an 8:00 AM wake time.[8]

Adequate sleep in teens has been linked with overall academic success and improvements in memory, learning, and attention.[9–11] Sufficient sleep in teens has also been linked with improved mood and health[8] and decreased sports-related injuries,[12] motor vehicle accidents,[13] tardiness and school dropouts,[8] and daytime sleepiness.[8] Given the importance of sufficient sleep during this developmental period, the American Academy of Pediatrics recommends that middle and high schools begin after 8:30 AM.[14]

The purpose of this study was to examine the association of SSTs (ie, 7:00-7:29 AM, 7:30-7:59 AM, 8:00-8:29 AM, and 8:30 AM or later) on sleep timing and time in bed. Teen sleep timing and time in bed were measured by daily logs of bedtime, wake time, and SST (daily diaries) over 1 week. We had 2 specific hypotheses in this study. First, we hypothesized that (1) compared with later SSTs (ie, 8:30 AM or later), earlier SSTs would be associated with earlier wake times. Second, we hypothesized that (2) earlier SSTs would be associated with shorter time in bed than later SSTs, which we investigated using a time in bed variable constructed from the reports of bedtime and wake time. We did not expect to find a relationship between earlier SSTs and earlier bedtimes due to the delayed circadian timing of sleep propensity typically seen during adolescence. Finally, to evaluate current consensus and clinical recommendations,[2,3] we examined categorical start times before and after 8:30 AM for their association with bedtime, wake time, and time in bed, hypothesizing that SSTs after 8:30 AM would be associated with later wake times and longer time in bed.

Methods

Data

Prospective data collection included daily diary data from a subsample of the parent study, the Fragile Families and Child Wellbeing Study (www.fragilefamilies.princeton.edu). The parent study follows a longitudinal birth cohort of children born between 1998 and 2000 in 20 US cities, with an oversampling of nonmarital births. The cohort was designed to create a national urban sample, randomly selecting cities with >200,000 people and then sampling hospitals within those cities and then births within those hospitals.[15] Mothers were initially interviewed in the hospital within 2 days of their child's birth (baseline survey), and follow-up interviews were completed by parents (including fathers if available) and primary caregivers when the focal child was ages 1, 3, 5, 9, and 15. Eligibility for the age 15 wave of the study required participation in the original birth cohort and the age 9 wave of data collection. Separate primary caregiver surveys were used to collect information about the teen's age and sex (baseline survey), teen's household income level, primary caregiver education level, and the type of school the teen attends (age 15 wave, primary caregiver survey). Teen's report of race was collected from the age 15 wave survey.

Of the 3055 eligible teens in the age 15 wave, a randomly selected subset of 1021 teens participated in this nested daily diary study. Participants were asked to complete Web-based electronic daily diaries to report their nightly sleep and SSTs.

The final analytic sample of this nested substudy included 413 high school students who provided at least 1 school day of diary data during nonsummer school months and provided complete daily diary data on school attendance, SST, bedtime, and wake time. The analytic sample was reduced because of teens who (1) provided daily diary entries during summer months (June, July, or August) (315 teens); (2) did not provide at least 1 school day of diary data (175 teens); (3) were homeschooled or did not report type of school (9 teens); (4) were in middle school (58 teens); and (5) did not provide data on SST, or both bedtime and wake time, or 1 or more covariate variables (51 teens). The included and excluded teens within the nested study did not differ by sex, ratio of household income to poverty, primary caregiver education level, or school type. However, compared with teens who were excluded from analyses (608 teens), the teens who were included in the final analytic sample (413 teens) were approximately 1 month older ($M = 15.5$ vs $M = 15.4$, $P < .05$), and a lower proportion were white teens (14% vs 19%, $P < .05$).

Compared with the teens in the parent study who did not participate in the nested study, the teens included in our nested substudy sample did not significantly differ with regard to poverty threshold, primary caregiver education level, and school type. Teens included in our nested substudy sample (N = 413) differed with regard to age, sex, and race from the teens who participated in only the age 15 wave of the larger parent study. Teens in our nested substudy sample were younger ($P < .05$) by about 7.5 months, consisted of more females (54% vs 47%, $P < .05$), and had more Hispanic/Latino teens (31% vs 23%, $P < .001$) than those who did not participate in the nested substudy.

Procedure

Teens were asked to complete an online daily diary each evening, beginning after 7:00 PM, during 7 consecutive days, including school days and nonschool days during both the *academic year* and the *summer*, which we defined as September through May and June through August, respectively. On average, the sample completed this diary at 9:31 PM. Most participants completed the daily diary online through a computer, tablet, or smart phone; 6 did not have access to the Internet and used a paper diary. Each diary entry took an average of 9.3 minutes to complete. Variables of interest collected from each diary entry included the previous night's bedtime, the time the teen woke up in the morning, whether or not the teen went to school, and the SST. Among the total diary entries, we used only school-day entries during nonsummer school months (1555 school-day observations). Sociodemographic variables were obtained from primary caregivers (mostly mothers) during field interviews and also from teens at the age 15 survey.

Measures

Predictor

School start time. Each school day, the daily diary asked teens, "What time did your school day begin?" Responses were coded in the hour:minute AM/PM format. The intraclass correlation of the reported SSTs indicated that there were 47 teens with any variation (1 or more instance where the difference between SST and mode SST is nonzero, mean = 0.99 hour, ±1.24 hours) in SST at the individual level (intraclass correlation = 0.44) presumably due to occasional delays (eg, weather, examinations). The SST variable was coded as a continuous variable. Analyses examined SST as a continuous variable and investigated the associations with bedtime, wake time, and time in bed. Next, for ease of interpretation, SSTs were further broken down into categories to compare teens with SSTs before the recommended 8:30 AM start time with teens with SSTs 8:30 AM or later. To further examine the associations of teens' usual range of SSTs during a week, we used the mode of SSTs across school days and created a categorical indicator of SSTs: 7:00 ≤ x < 7:30 AM was coded as 0, 7:30 ≤ x < 8:00 AM was coded as 1, 8:00 ≤ x < 8:30 AM was coded as 2, and x ≥ 8:30 AM was coded as 3. The mode of the SSTs, the most frequently reported SST for each teen, was used to identify the most probable SST without the influence of school delays.

Outcomes

Bedtime was determined from daily diary reports in the hour: minute AM/PM format. The diary asked "What time did you go to bed and try to fall asleep?" Clock times were then converted to decimal hour (eg, 22.5 indicates 10:30 PM).

Wake time was determined from daily diary reports in the hour: minute AM/PM format. The diary asked "What time did you wake up to start your day?" Clock times were converted to decimal hour for wake time.

Time in bed on school nights was calculated from the daily diary reported bedtimes and wake times and was coded in minutes/night.

Independent measures

Covariates. We considered various potential confounder or adjustment variables, including sociodemographic background characteristics that are important predictors of sleep.[16,17] Those characteristics included teen's *age* in years, *biological sex* (1 = male, vs reference = female), *race* (non-Hispanic White [reference], non-Hispanic Black, Hispanic/Latino, multiracial, and other), and *household poverty* indicator based on ratio of income to poverty threshold (1 = <49%, 2 = 50%-99%, 3 = 100%-199%, 4 = 200%-299%, reference = >300%). The household poverty indicator was constructed from household income values gathered from the primary caregiver interview at year 15 compared with the national poverty threshold incomes established by the US Census Bureau (http://www.census.gov/cps/data/povthresholds.html), which vary by household composition and year. In addition, we controlled for *primary caregiver's education* (defined as completion of 1 = some high school or less, 2 = high school or equivalent, 3 = some college or technical program, or reference = college or graduate program) and *school type* (1 = private or religious/parochial school, vs reference = public school). We also controlled for *daily-level SSTs* (centered at the person-level mode) to consider the associations of occasional variation in SSTs within a teen on sleep variables; however, 89% of teens had no change in SST reported in their daily diary.

Statistical analysis

We used multilevel modeling (Proc Mixed) in SAS 9.4 to take into account the clustered data structure. Repeated school-day observations were clustered within 413 teens. Teens provided multiple school-day reports, resulting in 1555-1560 total school-day observations (observations differed slightly because of missing reports of bedtime or wake time).

Evaluating 1 or more school days for each teen allowed us to test how SSTs are linked to teens' sleep on a daily basis. This can provide a more accurate picture of the association of day-to-day SSTs and teens' sleep than a single recall of typical sleep timing in the past month or year. The use of multilevel modeling also allowed us to consider potential daily changes in time in bed and sleep timing due to occasional variation in SSTs at the within-teen level.

To test our first hypothesis, we examined the independent association of SSTs with teens' bedtimes (model 1) and with teens' wake times (model 2) after controlling for covariates (ie, age, sex, race, household poverty, primary caregiver education, and school type). To test our second hypothesis, we examined the associations of SSTs with the teens' amount of time in bed (model 3) after controlling for the same covariates as model 1 and model 2.

Results

Descriptive results

Table 1 shows descriptive statistics and correlations among all variables used in this study. The average teen age was 15.5 years (SD = 0.6, range = 14.6-17.6 years). About half were boys (46%), and the majority were ethnoracial minorities (see Table 1 for full descriptive results). The household income for 29% of the sample was below the poverty threshold, and approximately 35% of primary caregivers completed high school or less education. The sample was predominantly (89%) comprised of public school students vs private, parochial, or religious school students (11%). After excluding non-school days and incomplete diary entries, the mean ± SD number of diary day entries was 3.8 ± 1.6 school days. Of teens who completed the daily diary on 1 or more school days, 12% logged 1 school day, 8% logged 2 school days, 18% logged 3 school days, 24% logged 4 school days, 26% logged 5 school days, 9% logged 6 school days, and 2% logged 7-10 school days. Figure 1 depicts the distribution of teens in the sample across SSTs: 7:00-7:29 AM, 15%; 7:30-7:59 AM, 22%; 8:00-8:29 AM, 35%; and 8:30 AM or later, 28%. The distribution of observations (school days included in multilevel modeling) from teens in each category was as follows: 7:00-7:29 AM, 237 school days, 15%; 7:30-7:59 AM, 340 school days, 22%; 8:00-8:29 AM, 542 school days, 35%; and 8:30 AM or later, 436 school days, 28%. The unadjusted mean bedtime was 11:11 PM (SD = 1.1 hours, range 8:00 PM to 2:20 AM). The unadjusted mean wake time was 6:51 AM (SD = 1.5 hours, range 1:01 AM to 10:39 AM). The unadjusted mean time in bed was 7.7 hours (SD = 1.8 hours, range = 0.1 to 12.5 hours).

Table 1
Sample characteristics by SSTs

	Whole sample	SSTs 7:00-7:29 AM	7:30-7:59 AM	8:00-8:29 AM	8:30 AM or later
n=	413	62	90	145	116
Mean age (y)	15.5	15.2	15.4	15.4	15.7
Sex					
Male	46.0%	37.1%	37.8%	44.1%	55.2%
Female	54.0%	62.9%	62.2%	55.9%	44.8%
Race					
White	14.3%	19.4%	30.0%	10.3%	4.3%
African American	45.3%	58.1%	46.7%	37.9%	46.6%
Hispanic/Latino	31.0%	11.3%	10.0%	40.7%	45.7%
Multiracial	6.3%	8.1%	11.1%	5.5%	2.6%
Other	3.1%	3.2%	2.2%	5.5%	0.9%
Income to poverty threshold %					
<49%	11.1%	9.7%	15.6%	9.7%	10.3%
50%-99%	17.4%	22.6%	15.6%	17.9%	15.5%
100%-199%	25.4%	22.6%	20.0%	26.2%	30.2%
200%-299%	15.7%	12.9%	10.0%	16.6%	20.7%
>300%	30.3%	32.3%	38.9%	29.7%	23.3%
Caregiver's education					
Less than high school	18.6%	11.3%	11.1%	23.5%	22.4%
High school or equivalent	16.7%	17.7%	17.8%	12.4%	20.7%
Some college or technical	46.2%	46.8%	48.9%	43.5%	47.4%
College or more	18.4%	24.2%	22.2%	20.7%	9.5%
Type of school					
Public school	89.3%	98.4%	84.4%	88.3%	89.7%
Private/religious school	10.7%	1.6%	15.6%	11.7%	10.3%

The association between SSTs and sleep timing

Table 2 shows the model-adjusted, estimated bedtime per SST category, and Table 3 shows results of multilevel modeling that tested the associations of SSTs with teens' bedtimes (model 1) after adjusting for covariates. Teens who had the earliest SSTs, between 7:00 and 7:29 AM, went to bed significantly earlier (10:30 PM, $P < .05$) than teens in the reference group of SSTs after 8:30 AM (10:50 PM). The 2 middle categories of SST, 7:30-7:59 AM and 8:00-8:29 AM, were not significantly different from the reference group (10:47 PM and 10:43 PM, respectively), as presented in Figure 2. The difference in bedtime between the earliest SST and the latest (after

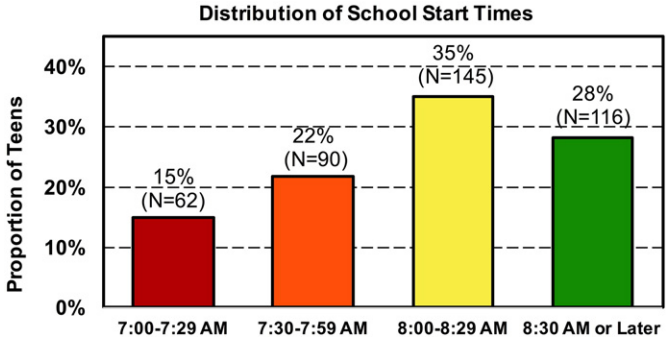

Fig. 1. Distribution of sample teens' high SSTs.

8:30) averaged 20 minutes per school night. The associations between bedtime and a continuous SST variable were also significant ($B = 0.194$, SE = 0.0839, $P < .05$), where SSTs 1 hour later were associated with a bedtime 11.6 minutes later (0.194 hour * 60 min/h).

Table 2 shows the estimated wake time per SST category, and Table 3 shows results of multilevel modeling that tested the associations of SSTs with teens' wake times (model 2) after adjusting for covariates. The results showed a dose-response relationship, with later SSTs strongly associated with later wake times ($P < .001$). For teens with SSTs of 7:00-7:29 AM, 7:30-7:59 AM, 8:00-8:29 AM, and 8:30 AM or later, wake times were 6:08 AM, 6:21 AM, 6:38 AM, and 7:05 AM, respectively. A post hoc test revealed that differences were also significant between the 7:00-7:29 AM group and 8:00-8:29 AM group and also between the 7:30-7:59 AM group and the 8:00-8:29 AM group ($P < .001$ and $P < .01$, respectively). These results are displayed in Figure 2. Analyses of SST as a continuous variable with respect to wake time were also significant ($B = 0.580$, SE = 0.0620, $P < .001$); for every SST 1 hour later, the associated wake time is 34.8 minutes later (0.580 * 60 min/h).

The association between SSTs and time in bed

Table 2 presents calculated average time in bed per SST category, and Table 3 presents results of multilevel modeling that tested the associations of SSTs with teens' time in bed (model 3) after adjusting for differences due to covariates. Compared with teens who had later SSTs (ie, 8:30 AM or after), those who had earlier SSTs consistently reported significantly ($P < .05$) shorter time in bed by 25-46 minutes. These results, shown in Figure 3, also indicated a dose-response relationship between SSTs and time in bed, with later SSTs extending time in bed. In particular, teens who had very early SSTs (ie, 7:00-7:29 AM) had 46 minutes less sleep duration per school night than teens who had late school times (ie, 8:30 AM or later). The 2 middle groups, 7:30-7:59 AM and 8:00-8:29 AM, reported significantly ($P < .05$) shorter total time in bed by 38 and 24 minutes, respectively, when compared with the teens who start school at 8:30 AM or later, after adjusting for covariates (age, sex, race, household income, caregiver's education, and school type). We found a consistent result when analyzing SST as a continuous variable, indicating an association of 24.9 minutes ($P < .001$) longer time in bed for each SST 1 hour later. Potential moderating roles of sociodemographic characteristics (race and poverty level) were tested for all outcomes, but none had statistically significant ($P < .05$) associations with bedtime, wake time, or time in bed.

Discussion

This study examined the associations between SSTs and teens' bedtime, wake time, and time in bed using repeated daily diary reports across multiple school days. We found that SSTs after 8:30 AM were associated with increased time in bed by 25-46 minutes, primarily due to later wake times relative to the wake times of earlier SST groups. The students going to school after 8:30 AM were the only ones who obtained, on average, the time in bed corresponding to the minimum recommended sleep duration for teens established by both the American Academy of Sleep Medicine and the National Sleep Foundation.[2,3] Those going to school the earliest went to bed slightly earlier than the other groups yet, potentially because of an earlier SST, achieved the shortest time in bed. Importantly, there was a strong dose-response relationship between earlier SSTs and shorter time in bed. In analyses of SST as a continuous variable, each hour later SST corresponded to a later bedtime of 11.6 minutes, later wake time of 34.8 minutes, and longer time in bed of 24.9 minutes. These results are consistent with research published from the National Comorbidity Study, which showed increases in sleep duration for later SSTs in a nationally representative sample of 7308

Table 2
Model-adjusted estimated means of bedtime, wake time, and time in bed by SST categories from the nested sleep substudy of the Fragile Families and Child Wellbeing Study

	SSTs							
	7:00-7:29 AM		7:30 AM-7:59 AM		8:00 AM-8:29 AM		8:30 AM or later	
	Estimated mean (SD)		Estimated mean (SD)		Estimated mean (SD)		Estimated mean (SD)	
Bedtime (clock time)	10:30 PM	(10.45)	10:47 PM	(9.44)	10:43 PM	(7.78)	10:50 PM	(13.65)
Wake time (clock time)	6:08 AM	(7.93)	6:21 AM	(7.14)	6:38 AM	(5.90)	7:05 AM	(10.32)
Time in bed (h:min)	7:24	(13.40)	7:31	(12.17)	7:45	(9.98)	8:09	(17.37)

Standard deviations are in minutes. N = 413; 1560, 1557, and 1555 school-day observations clustered within 413 teens were used for the multilevel models for bedtime, wake time, and time in bed, respectively (differences were due to missing responses in the variables). The models adjusted for age, sex, race, household income, primary caregiver's education, and school type. Estimates reflect the interpretation of the Betas and intercepts available in Table 3.

Table 3
Results of a multilevel model examining the association between SSTs and teens' bedtimes, wake times, and time in bed

	Bedtime (h)	Wake time (h)	Time in bed (h)
Fixed effects	*B* (SE)	*B* (SE)	*B* (SE)
Intercept	22.84 (0.23)***	7.08 (0.17)***	8.16 (0.29)***
SSTs			
7:00-7:29 AM	−0.34 (0.17)*	−0.95 (0.13)***	−0.76 (0.22)***
7:30-7:59 AM	−0.05 (0.16)	−0.73 (0.12)***	−0.64 (0.20)**
8:00-8:29 AM	−0.12 (0.13)	−0.44 (0.10)***	−0.41 (0.17)*
8:30 AM or later (ref)	–	–	–
Age (y)	0.28 (0.10)**	0.02 (0.07)	−0.22 (0.12)
Sex			
Male	−0.23 (0.10)*	0.03 (0.08)	0.30 (0.13)*
Female (ref)	–	–	–
Race			
Multiracial	0.06 (0.24)	0.01 (0.18)	0.26 (0.31)
African American	0.11 (0.16)	−0.05 (0.12)	−0.04 (0.21)
Hispanic/Latino	0.16 (0.18)	0.08 (0.14)	0.06 (0.23)
Other	0.72 (0.31)*	0.07 (0.23)	−0.42 (0.39)
White (ref)	–	–	–
Daily Variation in SSTs	0.09 (0.04)*	0.18 (0.04)***	0.17 (0.08)*
Income to poverty threshold %			
<49%	−0.27 (0.19)	−0.05 (0.15)	0.15 (0.25)
50%-99%	−0.23 (0.16)	−0.11 (0.12)	0.40 (0.21)
100%-199%	−0.13 (0.15)	−0.05 (0.11)	0.15 (0.19)
200%-299%	−0.10 (0.16)	−0.12 (0.12)	0.19 (0.20)
≥300% (ref)	–	–	–
Caregiver's education			
Less than high school	−0.10 (0.20)	−0.04 (0.15)	−0.07 (0.26)
High school or equivalent	−0.07 (0.19)	0.10 (0.14)	−0.16 (0.24)
Some college or tech	0.21 (0.16)	0.01 (0.12)	−0.37 (0.20)
College or graduate school (ref)	–	–	–
School type			
Attends public school	0.23 (0.16)	0.07 (0.12)	−0.29 (0.21)
Private school (ref)	–	–	–

N = 413; 1560, 1557, and 1555 school days' observations clustered within 413 teens were used for the multilevel models for bed time, wake time, and time in bed, respectively (differences were due to missing responses in the variables). The corresponding units are decimal hours (eg, 22.5 indicates 10:30 PM). The models adjusted for age, sex, race, household income, primary caregiver's education, and school type.

* $P < .05$.

** $P < .01$.

*** $P < .001$.

teens across 245 schools.[18] By measuring daily bedtime, wake time, and time in bed on school nights, this study contributes to our understanding of how teens with SSTs before and after the recommended 8:30 AM start time exhibit different sleep behaviors across the school week.

Previous studies have reported SST as the strongest predictor of teens' wake times on school days.[19,20] Our study results were consistent with this literature and showed that SST was strongly associated with teens' wake times on school days. This finding was independent of sociodemographic characteristics found to be important for sleep behaviors.[16,17] Teens with the earliest SSTs went to bed 20 minutes earlier than teens with SSTs after 8:30 AM. Moreover, with earlier SSTs, wake times were progressively earlier. These linear changes in wake times help to explain the 24- to 46-minute difference in time in bed between teens with early SSTs and those with later SSTs (after 8:30 AM).

Teens with SSTs earlier than 8:30 AM obtained, on average, less than the 8 hours of minimum recommended time in bed (Fig. 3).[2,3] This result supports the recommendation by American Academy of Pediatrics that all high schools begin no earlier than 8:30 AM. Teens with SSTs earlier than 8:30 AM may accrue "sleep debt" during school days due to the misalignment between SSTs and their circadian drives.[4,5] These teens may need to pay their "sleep debt" on nonschool days. Studies found that, on nonschool days, teens' wake times are consistently and significantly later than those on school days.[7,21,22] Additionally, nonschool night sleep durations are often longer to compensate for "sleep debt" accumulated during the school week,[23–25] and this gap widens as teens age.[25] This social jet lag may further misalign teens' circadian clocks from expected early wake timing on school days,[21] interfering with having consistent sleep routines.

A common rebuttal to propositions for later SSTs is the suggestion that teens instead just go to sleep earlier. This study found that teens with the earliest SSTs were going to bed earlier than their peers, possibly due to a higher propensity for sleep from an early wake time that morning and the anticipation of an early wake time the following morning. Despite going to bed significantly earlier than their peers, these earlier bed times did not compensate for the time in bed lost in the morning, presumably due to early SSTs. If we assume that teens in the earliest SST group need to wake up, on average, at 6:08 AM to make it to school on time, they would have to go to bed before 10:08 PM to spend at least 8 hours in bed. This does not account for sleep onset latency, the amount of time it takes to fall asleep, and is still considerably earlier than the mean bedtime of 10:30 PM for this group.

In studies of delayed SSTs, teens not only slept longer[13] but also exhibited decreased risk of motor vehicle accidents[13] and better performance on tests of attention.[26] Even delays of half an hour, from 8:00 AM to 8:30 AM, in accordance with the American Academy of Pediatrics recommendation[14] were related to significant increases in sleep duration, an average extension of 45 minutes, with associated improvements in sleep satisfaction, motivation, alertness, mood, and health and decreased daytime sleepiness.[8,27] Longitudinal studies have further revealed an effect of delayed SSTs on decreased dropout rates and tardiness, along with improved test scores and grades.[8,28] Our findings add to this literature by demonstrating the inverse relationship between early SSTs and high school students' time in bed. The use of a national urban sample from 20 US cities located around the country allowed us to examine the associations of 4 different categories of SSTs (7:00-7:29 AM, 7:30-7:59 AM, 8:00-8:29 AM, and 8:30 AM or later) with teen sleep, with previous literature suggesting that students in urban counties may see greater associations between later SSTs and sleep.[18] The teens in the study are part of a birth cohort that oversampled for nonmarital births, increasing the likelihood of a single-parent family structure during development, which may be related to higher variability in bedtimes than 2-parent households.[29] The use of daily diary, completed by 68% of the sample for about 4 school days, also increases our confidence in interpreting the associations between SSTs and teen sleep by providing repeated measurements.

The current study advances the literature by examining the associations of SSTs with sleep timing and time in bed in 3 important ways. First, taking advantage of a daily diary design, this study uses repeated reports of sleep schedule and SSTs over a school week to assess whether later SSTs are associated with sleep timing and time in bed. These repeated measures allow for a more robust and valid estimate of sleep measures[30,31] and include night-to-night variations.[32] Second, much of the literature examined SSTs across a single or a handful of school districts.[33,34] The current study examines SSTs in students living in 20 large US cities, a nationwide sample particularly valuable for studying the associations of SSTs in diverse ranges (ie, 7:00-7:29 AM., 7:30-7:59 AM, 8:00-8:29 AM, 8:30 AM or later). Lastly, this study includes a greater proportion of "at-risk" teens, as the study participants are part of a cohort of children of predominantly minority mothers from low socioeconomic backgrounds. Socioeconomic disparities in sleep are well documented in the literature.[16,17,35,36]

There are limitations in this study. Although we used a daily diary design that assessed sleep over multiple school days and the results show large and statistically significant associations, causality cannot be inferred. Longitudinal experimental studies implementing a delayed SST intervention are better structured to test the causal

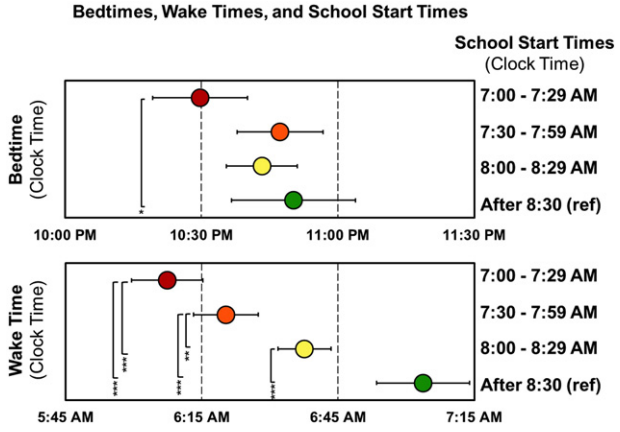

Fig. 2. Differences in bedtime and wake time between SSTs. N = 413; 1560, 1557, and 1555 school-day observations clustered within 413 teens were used for the multilevel models for bedtime, wake time, and time in bed, respectively (differences were due to missing responses in the variables). Vertical bars begin and end at the groups that are significantly different; thus, the absence of a bar reflects no statistical significance. Post hoc test of bed timing revealed significance only in the relationship between the earliest SST and the latest SST (7:00-7:29 AM compared with 8:30 AM or later). Post hoc tests of wake timing revealed that the differences in wake times between SSTs 7:00-7:29 AM and 8:00-8:29 AM and between 7:30-7:59 AM and 8:00-8:29 AM were significant ($P < .001$ and $P < .01$, respectively). There was no significant difference between 7:00-7:29 AM and 7:30-7:59 AM. The models adjusted for age, sex, race, household income, primary caregiver's education, and school type. $^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$.

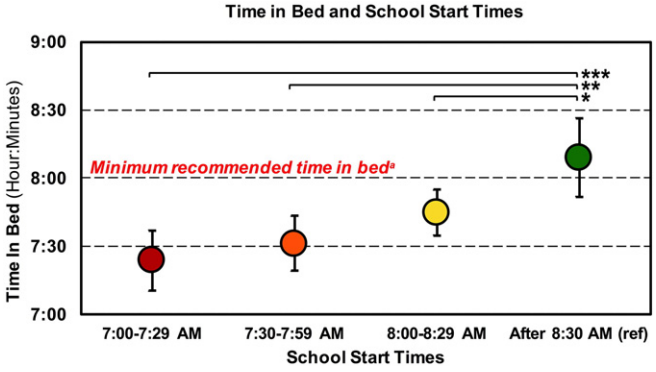

Fig. 3. Associations of high SSTs and teens' time in bed. N = 413; 1560, 1557, and 1555 school-day observations clustered within 413 teens were used for the multilevel models for bedtime, wake time, and time in bed, respectively (differences were due to missing responses in the variables). Post hoc tests revealed that all categories of school times before 8:30 AM (7:00-7:29 AM, 7:30-7:59 AM, and 8:00-8:29 AM) spent less time in bed than the reference group, 8:30 AM or later. The models adjusted for age, sex, race, household income, primary caregiver's education, and school type. [a]The American Academy of Sleep Medicine and the National Science Foundation recommend a minimum of 8 hours of sleep per night for teens.[2,3] $^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$.

effects of SSTs on teen's sleep postintervention. The use of self-reported data has the potential for common reporter bias on SST and sleep.[37] Future analyses might test the associations of SSTs with actigraphically assessed sleep measures. There is also the possibility that the days the teens completed the daily diary may not be reflective of a typical school week.[32] Participants were instructed to complete the daily diary each evening to report events from that day; however, this presents the possibility of recall bias in reporting the previous night's bedtime and the wake time from earlier that morning.

Finally, this sample was purposefully enriched with teens from low socioeconomic backgrounds and may not be generalizable to all teens in the US, but this sample is likely to capture those most vulnerable. Other variables not considered could also influence teen sleep, such as familial structure, household density, and other characteristics of the sleep environment. Furthermore, the 3055 participants who participated in the age 15 follow-up, compared with 4898 participants originally in the prebirth cohort, may reflect a selection bias, including participants who are more likely to continually agree to participate in the study. The subset of teens comprising our final sample differed slightly by age, sex, and race when compared with teens in the parent Fragile Families and Child Wellbeing Study and differed slightly by age and race when compared with teens in the nested study who were excluded. The magnitude of these differences was modest. Future studies that include both low and high socioeconomic samples could test the moderating effects of sociodemographic and household characteristics in the link between SSTs and teens' sleep.

Conclusion

We observed that teens who had early high SSTs (7:00-7:29 AM, 7:30-7:59 AM, and 8:00-8:29 AM) reported earlier wake times and thus shorter time in bed compared with teens with SSTs at 8:30 AM or later. The time in bed for teens with SSTs before 8:30 AM was less than the recommended minimum of 8 hours per night. Further research on the topic of SSTs should be conducted at international, national, and local levels to better inform the public health implications of SSTs.

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