School Start Time and Adolescent Sleep Patterns: Results From the US National Comorbidity Survey—Adolescent Supplement

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Objectives. We estimated associations between school start time and adolescent weeknight bedtime, weeknight sleep duration, and weekend compensatory sleep and assessed whether associations differ by age, sex, or urbanicity.

Methods. We used a subsample of a nationally representative, cross-sectional survey of 7308 students aged 13 to 18 years attending 245 schools to estimate associations of school start time, reported by school principals, with weeknight bedtime and sleep duration and weekend compensatory sleep, reported during adolescent face-to-face interviews.

Results. Start time was positively associated with weeknight bedtime. Associations between start time and weeknight sleep duration were nonlinear and were strongest for start times of 8:00 AM and earlier. Associations differed by sex and urbanicity, with the strongest association among boys in major metropolitan counties. Start time was negatively associated with sleep duration among boys in nonurban counties. Start time was not associated with weekend compensatory sleep.

Conclusions. Positive overall associations between school start time and adolescent sleep duration at the national level support recent policy recommendations for delaying school start times. However, the impact of start time delays may differ by sex and urbanicity. (*Am J Public Health.* 2015;105:1351–1357. doi: 10.2105/AJPH.2015.302619)

On the basis of evidence of a "current epidemic of insufficient sleep" in US youths,[1(p642)] the American Academy of Pediatrics recently recommended that most schools in the United States start at 8:30 AM or later.[1] Although the National Sleep Foundation has recommended that adolescents sleep 8.5 to 9.25 hours per night,[2] studies have indicated that children are less likely to meet this recommendation as they age.[3] Insufficient sleep among adolescents has been linked to a number of negative outcomes related to physical health,[4,5] mental health,[6,7] and academic performance.[8] Research has also indicated prospective associations between adolescent sleep and adverse health conditions during adulthood.[9]

There has been a surge of recent interest in school start time as a potentially modifiable, structural influence on adolescent sleep patterns.[10–12] Several studies have documented benefits to sleep patterns after school start time delays, such as increased weeknight sleep duration and reduced compensatory sleep on weekends.[13–16] Studies have also found more desirable sleep patterns among adolescents attending schools with later start times.[16–23] Later start times are thought to improve adolescent sleep by reducing the mismatch between the developmental biological drive toward later bedtimes and wake times and externally imposed school schedules.[10] Later start times may also reduce sleep pattern variability, which tends to increase as adolescents age[24] and has been associated with outcomes such as attention, academic performance, and suicidality.[25–27]

Although studies have demonstrated potential benefits to delaying school start times, the existing evidence regarding the association between school start time and sleep also has limits. As noted by the American Academy of Pediatrics,[1] there is a gap in knowledge regarding factors that might modify the association of school start time with sleep outcomes. Evidence has shown that sleep is developmentally patterned across adolescence[28] and that sleep patterns differ by both age[3,17,29] and sex.[30–32] However, few studies have assessed whether associations between school start time and sleep among adolescents differ by age or by sex, and the evidence has been mixed.[10,15] In addition, there are differences in sleep patterns by urbanicity among adults,[33,34] children,[35] and adolescents,[36,37] with longer sleep durations generally reported among those in rural compared with urban contexts. However, many US studies of school start time have been conducted in metropolitan areas containing urban and suburban schools.[13,22,23,38] Although a few studies have included schools from a greater variety of settings,[16,21] the number of different schools included has generally been too small to allow for meaningful assessment of differences by urbanicity. The 2 US national studies that have reported associations between school start time and adolescent sleep patterns did not investigate differences by urbanicity.[17,20] Many other studies have been conducted among a limited number of schools in a specified region, making it difficult to gauge the generalizability of their findings.[10,13–15,18,21–23,38]

The goal of this study was to describe associations between school start time and adolescent sleep patterns using data from a large school-based sample of adolescents across the United States. The study aims were to (1) estimate the association between school start time and sleep patterns, including weeknight bedtime, weeknight sleep duration, and weekend compensatory sleep, and (2) assess whether the association between school start time and sleep patterns differs by age, gender, or urbanicity. We conducted the study with a subsample of adolescents in the National Comorbidity Survey–Adolescent Supplement, a nationally representative survey of 13- to 17-year-old students in the continental United States. To our knowledge, this is the first study of school start time to use a national school-based sample with geographical and urban–rural variation.

METHODS

The National Comorbidity Survey—Adolescent Supplement is a cross-sectional survey of a representative sample of adolescents aged 13 to 17 years residing in households in the contiguous United States.[39] It was conducted from 2001 to 2004 and used a complex sampling design with household and school frames, details of which have been published previously.[40] We used data from the school sampling frame. A probability sample of 320 schools was initially sampled from the same counties as household participants in the National Comorbidity Survey—Replication, a nationally representative household survey of adults aged 18 years and older. Schools were selected from a list of all schools in each county with probabilities proportional to the size of the relevant student age group. Among 289 schools initially targeted for participation, 81 agreed. Replacement schools were selected that matched the originally selected schools on geographical location, size, and demographic characteristics.[39] Within each school, a random sample of 40 to 50 students was targeted for interview. A total of 9244 students participated, with an overall student response rate of 74.7%. Written informed consent was obtained from parents (except for adolescents who were emancipated minors) and adolescents.[39]

Measures

Sleep patterns and adolescent characteristics were assessed via adolescent interview. Adolescents were interviewed with the World Health Organization Composite International Diagnostic Interview Version 3.0, a fully structured, lay-administered interview assessing mental and physical health conditions, demographics, individual and family characteristics, and more.[41] Interviews were conducted in adolescents' homes by trained interviewers using computer-assisted personal interview methods.

A separate module on sleep patterns was included in the Composite International Diagnostic Interview. Weeknight bedtime was assessed with the question "What time do you usually go to bed on weeknights?" Sleep duration was assessed with the question "How many hours of sleep do you usually get on week (weekend) nights?" This question was also used to indicate whether each adolescent obtained at least 8.5 hours of sleep on weeknights as recommended by the National Sleep Foundation (referred to as adequate sleep).[2] Weekend compensatory sleep was calculated as the difference between weekend and weeknight sleep duration.

We considered a number of adolescent and school characteristics as potential confounders of the association between school start time and sleep patterns. These characteristics included demographics, family characteristics, employment and extracurricular involvement, and school type and grade level (described later, with details in Table 1). We controlled for potential confounders in the analysis if they were associated with both school start time and the respective sleep outcome.

Demographic characteristics assessed in the interview included age, sex, race, geographical region, and urbanicity. Urbanicity was classified as major metropolitan county (census-defined metropolitan counties with ≥ 1 000 000 population), other urbanized county (metropolitan counties with < 1 000 000 population), and nonurban county (nonmetropolitan counties). Family characteristics included family income-to-poverty ratio, sibship size, parental education, parental marital status, number of parents, and number of working parents. Student employment history was assessed via the question "Do you now/did you ever hold a part-time job during the school year?" Student extracurricular involvement was assessed with 8 questions about current or past involvement in activities such as sports, music, and clubs; responses to these items were summed and divided into tertiles.

School characteristics were obtained from a written questionnaire that was mailed to the principal of each participating school. Principals who did not initially respond were provided the opportunity to complete the questionnaire by telephone or in person. Completed principal questionnaires were obtained for 253 schools. School start time was assessed with the question "At what time does the school day officially begin?" School grade level was assessed by

TABLE 1—Mean School Start Time by Adolescent and School Characteristics: National Comorbidity Survey—Adolescent Supplement, United States, 2001–2004

Variable	School Start Time, Mean (SE)	*P*
Individual characteristics		
Age, y		.059
13	8:02 (2.57)	
14	8:01 (2.98)	
15	7:56 (2.43)	
16	7:53 (2.97)	
17	7:54 (2.61)	
18	7:56 (4.13)	
Sex		.843
Female	7:57 (2.10)	
Male	7:57 (2.52)	
Race		.941
Hispanic	7:56 (3.37)	
Black	7:55 (4.22)	
Other	7:57 (3.25)	
White	7:57 (2.35)	
Region		.437
Northeast	7:50 (5.08)	
Midwest	7:57 (3.00)	
South	8:01 (4.47)	
West	7:55 (4.79)	
Urbanicity		.022
Major metropolitan	7:54 (2.97)	
Other urbanized	7:58 (4.15)	
Nonurban	8:03 (1.41)	
Income:poverty ratio		.445
< 1.5	7:58 (2.91)	
≤ 3	7:58 (2.34)	
≤ 6	7:57 (2.21)	
> 6	7:56 (2.54)	
Parental marital status		.115
Married or cohabitating	7:57 (2.27)	
Previously married	8:00 (2.61)	
Never married	7:59 (3.94)	
Unknown	7:56 (2.61)	
Parental education		.741
< high school	7:57 (2.68)	
High school graduate	7:58 (2.47)	
Some college	7:58 (2.55)	
College graduate	7:56 (2.45)	
No. of parents		.806
2	7:57 (2.23)	
1 or other	7:57 (2.78)	

Continued

TABLE 1—*Continued*

No. of working parents		.864
0	7:56 (2.58)	
1	7:57 (2.33)	
2	7:57 (2.23)	
Sibship size		.865
1	7:57 (2.57)	
2	7:58 (2.33)	
3	7:57 (2.20)	
≥ 4	7:58 (2.50)	
Extracurricular involvement		.766
Low	7:57 (2.56)	
Moderate	7:57 (2.28)	
High	7:58 (2.27)	
Adolescent employment		.008
None	7:59 (2.28)	
Current or previous	7:55 (2.52)	
School characteristics		
School level		.038
High school	7:54 (2.84)	
Upper school	7:57 (3.37)	
Middle school	8:04 (4.29)	
Lower school	8:11 (4.87)	
Kindergarten–12 school	7:51 (5.74)	
School type		.155
Public	7:56 (2.54)	
Public magnet or charter	7:56 (6.69)	
Private	8:05 (3.46)	

Note. Standard errors are in minutes. *P* values were determined by the Wald test.

asking principals to indicate the number of students enrolled at the school in each grade level from prekindergarten through 12th grade. School type was assessed by asking principals to mark yes or no for 14 school descriptors; it was categorized as public, private, and magnet or charter for analysis.

Analysis

We corrected bedtime responses for AM–PM coding errors and omitted extreme values of bedtime (1.6%) and sleep duration (1.3%) using a cutoff of ±3 standard deviations in the full sample. Complete information on sleep patterns, start time, and confounders were available for 7206 adolescents for analysis of bedtime and 7216 adolescents for sleep duration (each representing 78% of the total sample) and for 7115 adolescents for compensatory sleep (77% of the total sample). These adolescents attended 245 different schools, the majority of which were public and were high schools and middle schools, although other school types were also represented. The bulk of missing data were due to missing start times for students in schools with unreturned principal questionnaires (n = 1767). Although the schools included did not differ significantly from those not included on any of the characteristics presented in Table 1, school type, region, urbanicity, and number of working parents were associated at marginal levels ($P < .1$), which indicated that inclusion in the study was more likely for those in rural areas and less likely for those in the Northeast and those with no working parents. We treated students with complete data as a subpopulation of the total sample for design-based analyses. We conducted the analysis using the SVY commands in Stata version 13 (StataCorp LLP, College Station, TX). Variances were estimated using Taylor series linearization.

We modeled bedtime, sleep duration in minutes, and compensatory sleep in minutes using linear regression. Exploratory analyses revealed nonlinearity in the association between start time and sleep duration. After comparison of model fit between a number of different start time parameterizations using Akaike's information criterion, we included start time as a piecewise linear function in models predicting sleep duration, with 1 knot (a point at which the slope of the regression line is allowed to change) at the mean start time among all schools. In models predicting bedtime and compensatory sleep, we found no evidence that a piecewise function improved model fit over a single continuous variable. Adjusted models controlled for age and sex as well as potential confounders that were associated with both start time and each sleep outcome: school level, urbanicity, and, for bedtime and sleep duration only, student employment. We tested for 2-way interactions between start time, age, and sex, as well as for interactions between start time and urbanicity, using the Wald test. We used logistic regression to model the odds of obtaining adequate sleep on weeknights using the same model as for sleep duration.

RESULTS

The mean school start time was 8:01 AM (range = 7:05 AM–9:22 AM). Table 1 shows mean school start times according to the various demographic factors and family characteristics that were considered as potential confounders. Start time was associated with school grade level, urbanicity, and student employment. We found a trend-level inverse association between start time and age ($P = .059$).

Weeknight Bedtime

The mean bedtime was 10:32 PM (10:33 PM for boys and 10:31 PM for girls). We found a statistically significant interaction between age and sex ($F_{5,38} = 2.65$; $P = .038$). Bedtime was associated with school start time after adjustment, with adolescents with later start times going to bed later. For ease of interpretation, we report estimates in terms of half-hour increases in start time. Adjusting for age, sex, their interaction, school level, urbanicity, and student employment, each half-hour increase in start time was associated with a 10.48-minute later bedtime (95% confidence interval [CI] = 6.48, 14.47; not shown). We found no evidence for interaction of start time with age, sex, or urbanicity.

Weeknight Sleep Duration and Odds of Obtaining Adequate Sleep

The mean weeknight sleep duration was 7.71 hours (7.60 for girls and 7.81 for boys). Table 2 presents associations between school start time, in half-hours, and weeknight sleep duration, in minutes. Because of nonlinearity evident in the association between start time and sleep duration, the slope of the regression line was allowed to differ before and after the mean start time of 8:01 AM, and both estimates are presented. Unadjusted and adjusted models yielded similar inferences. Adjusting for age, sex, school level, urbanicity, and student employment, each half-hour increase in start time before 8:01 AM was associated with 11.36 more minutes of weeknight sleep (95% CI = 3.52, 19.21) in the overall sample. From 8:01 AM onward, start time and sleep duration were not significantly associated (adjusted b = 1.55; 95% CI = −5.96, 9.06).

TABLE 2—Change in Weeknight Sleep Duration and Odds of Getting Adequate Sleep on Weeknights for Each Half-Hour Increase in School Start Time, Overall and by Gender: National Comorbidity Survey–Adolescent Supplement, United States, 2001–2004

	Sleep Duration				Adequate Sleep			
Model and Start Time	b (95% CI)	*P*	Adjusted b (95% CI)	*P*	OR (95% CI)	*P*	AOR (95% CI)	*P*
Overall		< .001		.008		.005		.012
Before 8:01 AM	14.15 (7.01, 21.29)		11.36 (3.52, 19.21)		1.53 (1.16, 2.01)		1.52 (1.16, 1.98)	
8:01 AM and later	6.04 (-3.91, 16.00)		1.55 (-5.96, 9.06)		1.03 (0.80, 1.32)		0.91 (0.74, 1.11)	
Girls		.223		.812		.224		.234
Before 8:01 AM	7.48 (-1.86, 16.81)		2.91 (-6.12, 11.94)		1.39 (0.96, 2.02)		1.34 (0.95, 1.89)	
8:01 AM and later	3.16 (-10.98, 17.29)		-0.31 (-10.58, 9.96)		0.99 (0.71, 1.39)		0.91 (0.71, 1.18)	
Boys		< .001		< .001		.007		.024
Before 8:01 AM	21.43 (13.64, 29.22)		19.77 (10.69, 28.84)		1.69 (1.18, 2.44)		1.69 (1.16, 2.46)	
8:01 AM and later	7.50 (-3.00, 18.00)		2.95 (-6.81, 12.70)		1.03 (0.74, 1.44)		0.91 (0.64, 1.28)	

Note. AOR = adjusted odds ratio; CI = confidence interval; OR = odds ratio. Adjusted estimates control for age, sex, school level, urbanicity, and student employment. Adequate sleep defined as 8.5 hours or more. *P* values were determined by the Wald test of start time as a whole.

Table 2 also presents associations between school start time and the odds of getting adequate sleep on weeknights. Twenty-six percent of adolescents met this recommendation (23% of girls and 29% of boys). Inferences were again similar in unadjusted and adjusted models. In the combined sample, before 8:01 AM, each half-hour increase in start time was associated with 1.52 (95% CI = 1.16, 1.98) times the odds of obtaining adequate sleep on weeknights, adjusted for age, sex, school level, urbanicity, and student employment. From 8:01 AM onward, start time was not significantly associated with getting adequate sleep on weeknights (adjusted odds ratio [AOR] = 0.91; 95% CI = 0.74, 1.11).

Interaction by Sex

We observed significant interactions between start time and sex ($F_{2,41} = 7.63$; $P = .002$) and between age and sex ($F_{5,38} = 3.34$; $P = .013$) in the model for sleep duration. We therefore present separate models for male and female subpopulations (Table 2). Associations between start time and sleep duration were stronger for boys than for girls. For boys, each half-hour increase in start time before 8:01 AM was associated with 19.77 additional minutes of sleep (95% CI = 10.69, 28.84), after adjustment for age, school level, urbanicity, and student employment. From 8:01 AM onward, start time and sleep duration were unassociated among boys (adjusted b = 2.95; 95% CI = –6.81, 12.70). Start time was not associated with sleep duration for girls, either before or after 8:01 AM (Table 2).

Similarly, before 8:01 AM, each half-hour increase in start time for boys resulted in 1.69 (95% CI = 1.16, 2.46) times the odds of getting adequate sleep after adjustment. From 8:01 AM onward, start time was not associated with getting adequate sleep among boys (AOR = 0.91; 95% CI = 0.64, 1.28). Among girls, start time was not associated with getting adequate sleep either before or after 8:01 AM (Table 2).

TABLE 3—Change in Weeknight Sleep Duration and Odds Ratios of Getting Adequate Sleep on Weeknights for Each Half-Hour Increase in School Start Time Among Boys, by Urbanicity Level: National Comorbidity Survey–Adolescent Supplement, United States, 2001–2004

	Sleep Duration		Adequate Sleep	
Urbanicity and Start Time	Adjusted b (95% CI)	*P*	AOR (95% CI)	*P*
Major metropolitan county		< .001		.037
Before 8:01 AM	33.76 (20.43, 47.09)		2.18 (1.22, 3.89)	
8:01 AM and later	-3.26 (-15.83, 9.31)		0.71 (0.44, 1.14)	
Other urbanized county		< .001		.105
Before 8:01 AM	11.86 (-1.85, 25.56)		1.48 (0.77, 2.85)	
8:01 AM and later	9.50 (-7.91, 26.92)		1.21 (0.71, 2.04)	
Nonurban county		.024		.149
Before 8:01 AM	-20.25 (-35.26, -5.23)		0.75 (0.49, 1.13)	
8:01 AM and later	11.26 (-2.07, 24.59)		0.89 (0.59, 1.35)	

Note. AOR = adjusted odds ratio; CI = confidence interval. Adjusted estimates control for age, school level, and student employment. *P* values were determined by the Wald test of start time as a whole.

Interaction by Urbanicity

We found evidence for an interaction between school start time and urbanicity for boys only ($F_{4,39} = 10.33$; $P < .001$; Table 3). For boys in major metropolitan counties, before 8:01 AM, each half-hour increase in start time was associated with 33.76 (95% CI = 20.43, 47.09) more minutes of sleep on weeknights, whereas from 8:01 AM onward we found no association (adjusted b = –3.26; 95% CI = –15.83, 9.31). For boys in other urbanized counties, start time was not significantly associated with sleep duration either before or after 8:01 AM (Table 3).

For boys in nonurban counties, before 8:01 AM, each half-hour increase in start time was associated with 20.25 fewer minutes of sleep on weeknights (95% CI = –35.26, –5.23), whereas from 8:01 AM onward, start time and sleep duration were not associated (adjusted b = 11.26; 95% CI = –2.07, 24.59).

Interaction was also present in the model predicting adequate weeknight sleep among boys. For boys in major metropolitan counties, each half-hour increase in start time before 8:01 AM was associated with 2.18 (95% CI = 1.22, 3.89) times the odds of obtaining adequate sleep on weeknights, whereas increases in start time from 8:01 AM onward were not (AOR = 0.71; 95% CI = 0.44, 1.14). For boys in other urbanized counties and boys in nonurban counties, start time was not associated with adequate weeknight sleep either before or after 8:01 AM (Table 3).

Compensatory Sleep

The mean duration of compensatory sleep on weekends was 73.94 minutes (83.15 min for girls and 64.94 min for boys). Each half-hour increase in start time was associated with 8.34 fewer minutes of compensatory sleep in unadjusted models (95% CI = –16.05, –0.64). However, after adjustment for age, sex, school level, and urbanicity, start time and compensatory sleep were not significantly associated (adjusted b = –5.65; 95% CI = –13.01, 1.71). We found no evidence of interaction with age, sex, or urbanicity.

DISCUSSION

In the largest study to date of adolescents from across the United States, we found associations between school start time and sleep patterns. After adjusting for potential confounders, adolescents in schools with later start times generally went to bed later on weeknights than those with earlier start times but tended to obtain more sleep. They were also more likely to meet or exceed current recommendations for sleep duration among adolescents.[2] We found no significant difference in the amount of weekend compensatory sleep obtained between adolescents with earlier and later start times in adjusted models, indicating that lost sleep on weeknights is not necessarily compensated for on weekends. Together, these findings imply the potential for accumulated sleep debt among adolescents with early start times.

Our results for the overall sample are generally consistent with those of previous reports using national data. Among 1187 students aged 12 to 19 years, Adam et al.[17] found that for each hour increase in school start time, weeknight sleep duration increased by 0.57 hours, which corresponds to a 17.1-minute increase in sleep duration for each half-hour increase in start time, slightly greater than our estimate of about 11 minutes before 8:01 AM. Knutson and Lauderdale[20] found that among 15- to 17-year-old students, each hour increase in school start time was associated with a 25-minute later wake time on school days (associations with sleep duration were not investigated), which corresponds to a 12.5-minute increase in wake time for each half-hour increase in start time, similar to our results for sleep duration before 8:01 AM. Slight differences between these studies and ours may be attributable to methodological differences in sleep measures or statistical modeling. Nevertheless, these findings converge in demonstrating the potential for greater weeknight sleep duration associated with later school start times.

We found that school start time is more strongly associated with sleep duration for adolescent boys than girls, a result that has not been reported previously. In a small laboratory study including 2 weeks of actigraphy before and after the transition from 9th to 10th grade (involving a change in school start time from 8:25 AM to 7:20 AM), Carskadon et al.[10] found that although sleep onset time did not change, the change in sleep offset (wakeup) time after the transition was greater for girls than for boys. Although the sex difference we found differed in direction, our results corroborate the presence of sex differences in this association. They are also broadly consistent with a number of sleep-related sex differences that have previously been reported among adolescents.[3,7,28–30,32] For example, Sivertsen et al.[7] found that among Norwegian adolescents aged 16 to 18 years, associations between insomnia and depression were stronger among boys than girls. Studies have also demonstrated sex differences in the association between sleep duration and body mass index among adolescents.[42,43] A small number of studies have also demonstrated sex differences in predictors of sleep patterns among adults.[44,45] However, there is a paucity of research regarding sex differences in predictors of sleep among adolescents. When possible, future studies should investigate the potential for such sex differences in the association between school start time and sleep patterns.

This is also the first study to our knowledge to report that the association between start time and weeknight sleep differs according to urbanicity. Later start times were most strongly related to gains in sleep duration for boys in major metropolitan counties. These findings imply that a single start time recommendation may not be appropriate in all contexts, and they highlight the need to consider other contextual, family, and individual factors that may modify associations between school start time and sleep. One potentially important factor that may differ between urban and rural contexts is mode of transportation to school. Time spent traveling to school has been identified as an important determinant of sleep duration among adolescents.[17] At the same time, busing plays a major role in determining school schedules.[46,47] Although we were unable to evaluate the relevance of transportation to school in this study, our findings clearly highlight the existing knowledge gap regarding contexts and conditions under which delays to school start time lead to improvements in adolescent sleep.[1]

The large number of schools and subsequent variation in start times in this study allowed us to investigate the apparent nonlinearity in the association between start time and sleep duration. Our findings indicated a plateau effect, in that the apparent benefit to sleep duration associated with later start time does not continue beyond 8:01 AM. However, the specific time of 8:01 AM was based on statistical fit in a model of average sleep duration in this sample and should not be interpreted as a definitive optimal start time. Actual optimal school start times may vary according to individual or school characteristics. For example, 1 previous multisite study suggested delaying school start time past 8:30 AM.[16] Nonetheless, our findings imply that relatively modest delays in start time may be sufficient to maximize any associated benefit to sleep duration among adolescents.

The decision to delay a school's start time involves numerous considerations, including transportation, athletics, community programs, student employment, and afterschool programs,[46] that are not addressed here. Such decisions can therefore be controversial and require a lengthy decision process.[16] Our findings imply that there may be an additional layer of complication to this issue—that the association between start time and sleep may not be the same for all students or in all contexts. Although we focused specifically on associations with sleep, research has indicated other benefits associated with later start times,[1] including mood, school attendance rates, academic achievement, and motor vehicle crash rates.[14–16,48] Additional research is needed to identify the conditions under which later school start times are most beneficial.

Strengths and Limitations

An important strength of this study is the use of a subsample of data from a large, nationally representative survey of adolescents attending a large number of schools of varying types and levels. As mentioned earlier, this allowed us to investigate associations of sleep patterns with a wide range of start times. However, this study is limited by the use of a cross-sectional survey, which prevents us from inferring causal effects of school start time on sleep. Sleep patterns in this study were measured via adolescent interview rather than objective measures of sleep, which may have resulted in measurement error. We assume that any measurement error of sleep patterns in this study is nondifferential and independent of school start time. Although we have included greater control for confounding than have previous studies, the potential for unmeasured or residual confounding is still present. Furthermore, our measure of urbanicity was at the county level rather than the school district level, making our classification of urbanicity relatively crude. Our results do not take into account any temporal changes in other predictors of sleep, such as personal technology use, since the National Comorbidity Survey—Adolescent Supplement was conducted; our estimates, therefore, do not reflect any impact that these factors may have on the association between school start time and sleep. Finally, a portion of adolescents in our study had missing data, largely because of unreturned principal questionnaires, which precludes us from generalizing our findings to all US adolescents.

Conclusions

Using data from a large survey of adolescents across the United States, we found shorter weekday sleep duration among adolescents with earlier school start times. This association differed according to adolescent and contextual characteristics and was strongest among boys in major metropolitan counties. Although sleep patterns are influenced by a variety of factors, many of which are rooted in families and individuals, school start time may be a modifiable, structural influence on adolescent sleep. However, more research is needed to identify the contexts in which later start times will be most beneficial. Such future research should lead to improvements in adolescent sleep and subsequent physical health, mental health, and educational outcomes. ■

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Contributors

D. Paksarian conducted the analyses and wrote the article. K. E. Rudolph and J.-P. He assisted with analyses, interpretation, and writing. K. R. Merikangas conceptualized and supervised the study and assisted with interpretation and writing.

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Human Participant Protection

This research was approved by the institutional review boards of Harvard Medical School and the University of Michigan. Written informed assent was obtained from adolescents and written informed consent was obtained from adolescents' parents.

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