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Original Article

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COVID-19 instructional approaches (in-person, online, hybrid), school start times, and sleep in over 5,000 U.S. adolescents

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Abstract

Study Objectives: To examine associations among instructional approaches, school start times, and sleep during the COVID-19 pandemic in a large, nationwide sample of U.S. adolescents.

Methods: Cross-sectional, anonymous self-report survey study of a community-dwelling sample of adolescents (grades 6–12), recruited through social media outlets in October/November 2020. Participants reported on instructional approach (in-person, online/synchronous, online/asynchronous) for each weekday (past week), school start times (in-person or online/synchronous days), and bedtimes (BT) and wake times (WT) for each identified school type and weekends/no school days. Sleep opportunity was calculated as BT-to-WT interval. Night-to-night sleep variability was calculated with mean square successive differences.

Results: Respondents included 5,245 racially and geographically diverse students (~50% female). BT and WT were earliest for in-person instruction; followed by online/synchronous days. Sleep opportunity was longer on individual nights students did not have scheduled instruction (>1.5 h longer for online/asynchronous than in-person). More students obtained sufficient sleep with later school start times. However, even with the same start times, more students with online/synchronous instruction obtained sufficient sleep than in-person instruction. Significantly greater night-to-night variability in sleep-wake patterns was observed for students with in-person hybrid schedules versus students with online/synchronous + asynchronous schedules.

Conclusions: These findings provide important insights regarding the association between instructional approach and school start times on the timing, amount, and variability of sleep in U.S. adolescents. Given the public health consequences of short and variable sleep in adolescents, results may be useful for education and health policy decision-making for post-pandemic secondary schools.

Statement of Significance

This study adds to the evidence that later school start times increase sleep opportunity for adolescents by highlighting that hybrid instruction approaches (with both in-person and online instruction) may be detrimental to maintaining consistency in sleep-wake patterns. The study is novel due to the large, diverse sample of adolescents from across the United States, and the comparison of instructional approaches (in-person, online, hybrid) that were used during the COVID-19 pandemic. Future studies should examine the role of morning commute time on adolescent sleep, as well as how adolescent sleep and instruction approaches during the pandemic are associated with mental health, academic outcomes, and health disparities.

Key words: school start times; health policy; education

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Introduction

The COVID-19 pandemic resulted in profound societal changes, including a radical transformation of traditional instructional approaches for many students. Emerging evidence indicates that sleep is an adolescent health domain profoundly impacted by the pandemic [1, 2]. A higher incidence of adolescent insomnia, especially in youth with pre-existing anxiety and depression, has been found in several reports across the globe [3–8]. Yet, several epidemiologic studies examining sleep patterns during COVID lockdowns, when schools closed or switched to remote instruction, reported a beneficial impact on adolescent sleep, including significantly longer sleep duration [9–12]. However, these studies all focused on sleep immediately following the implementation of stay-at-home restrictions, when schools had switched to online instruction, and many were completely asynchronous (with no scheduled classes). Because school schedules are known to impact adolescent sleep-wake schedules, more research is needed regarding adolescent sleep when students returned to school, both in-person and online, more than 6 months after the initial lockdowns.

With COVID-19 restrictions in place, the 2020–2021 school year resulted in different instructional approaches across the United States, including in-person instruction, online with synchronous or asynchronous instruction, and hybrid, combining in-person and online instruction. These approaches vary in schedule requirements (e.g. specific start time, day-to-day variability in scheduled instruction) and other factors that may affect sleep patterns (e.g. no transportation time, less time getting ready for online vs. in-person instruction) [13]. Although previous studies have demonstrated the benefits of later in-person school start times on sleep for adolescents, only one study compared sleep outcomes between traditional in-person learning with home-based learning, showing that homeschool students had a morning wake time similar to the time most in-person students were starting school [13]. However, this study did not consider synchronous versus asynchronous online learning or hybrid education, which combines both in-person and online instruction. The COVID-19 education adaptations offered an unprecedented opportunity to examine the association between a range of instructional formats and sleep in a large sample of youth, with possible implications for post-pandemic education policies.

Thus, the *N*ationwide *E*ducation and *S*leep in *TE*ens *D*uring COVID (NESTED) study was developed to capture the complex associations among instructional approaches, school start times, and sleep outcomes (including timing, opportunity, variability, and behaviors) in a large, racially diverse sample of adolescents across the United States. The NESTED study is one of the first to address the following aims: (1) describe sleep outcomes across instructional approaches for middle and high school students; (2) examine differences in sleep outcomes related to scheduled start times for in-person or online/synchronous days; and (3) compare night-to-night sleep pattern variability for students with different types of hybrid instruction approaches (i.e. in-person + online [synchronous/asynchronous], online synchronous + asynchronous).

Methods

Study design and participants

From October 14 to November 26, 2020, a convenience sample of adolescents was recruited through social media. This minimal risk study was approved by the BRANY SBER Institutional Review Board (#20-053-528) with a waiver of informed parental consent. Adolescents were provided study information, including the voluntary nature of the study, potential risks, and the ability to stop at any point; to continue to the survey, participants had to choose an option indicating assent to participate.

Eligibility criteria included enrollment in grades 6–12 at the time of the survey, U.S. residency, and internet access. The study was promoted on two social media platforms (Facebook and Instagram), targeting students ages 13–18 years through Facebook's marketing platform (which includes Instagram), with a study description and link to a REDCap survey. To obtain a diverse U.S. sample, the study was over-marketed to specific subgroups (e.g. Black males). This approach reached a large number of adolescents across the United States within 6 weeks, capturing a broad range of educational experiences. (Additional details about the promotion strategy are reported in the Supplement.)

Measures

Instructional approaches. Adolescents were asked to select one of three instructional approaches for each weekday (Monday–Friday) during the past week: (1) in-person; (2) online/synchronous (live online classes or interactions with teachers); or (3) online/asynchronous (online, but without live classes or scheduled teacher interactions). Students could also identify days they did not attend school. Because responses were provided for each day of the week, students could report up to three types of instructional approaches, along with nonschool days. In the United States, it is not common for students to attend school on weekends, thus we only asked about instruction type on weekdays.

Sleep timing and opportunity. For each instructional approach selected, participants were asked what time they tried to fall asleep the night before (bedtime) and what time they woke up on that school morning to start their day (wake time). All participants were also asked about their bedtimes and wake times on weekends/nonschool days, with the assumption that sleep schedules were similar on nonschool days and weekends. Sleep opportunity was calculated as the number of hours between bedtime and wake time, with separate calculations for each instructional approach and weekends/nonschool days. Sleep opportunity served as a proxy for sleep duration, a common approach used in pediatric sleep survey studies [14], and sufficient sleep was defined as at ≥9 h for middle school (MS) students and ≥8 h for high school (HS) students, using the lower end of recommended sleep duration by the American Academy of Sleep Medicine [15]. Because MS students included adolescents ≥13 years, we also examined MS sleep opportunity as ≥8 h.

Sleep behaviors. To describe the sleep behaviors of the sample, participants completed four items from the Pediatric Sleep Practices Questionnaire [16]. Three items asked about bedtime routine, bedtime consistency, and wake time consistency in the past 7 days, and were used to calculate the *Routines/Consistency* scale. Scores ranged from 0 to 6, with higher scores indicating poorer routines and less consistency. One indicator item was also included asking about technology use prior to falling asleep in the past 7 days. Per scoring guidelines [16], categorical responses were collapsed to "*Never*," "*Almost Never/Sometimes*," and "*Almost Always/Always*." The Pediatric Sleep Practices Questionnaire has been validated in children ages 8–17 years [16].

School start time. If adolescents indicated in-person and/or online/synchronous instruction, they were asked to select the time of their first class (choosing the earliest time if their schedule varied). Response choices were in 30 min intervals from “before 7:00 am” to “12:00 pm or later.” Due to low-frequency responses, the upper category included all responses for 9:30 am or later.

Demographic variables. Participants were asked to self-identify grade, gender (male, female, nonbinary, other/prefer not to respond), race/ethnicity (White, Black, Hispanic/Latino[a], Asian, Native American/American Indian, or Other [providing description]), type of school (public, private, or other), and home address zip code (used to determine region based on U.S. Census tracts). Figure 1 illustrates the geographic distribution of participants. Race/ethnicity responses were grouped into the following categories: White, Black, Hispanic/Latino(a), Asian, and Multiracial/Other.

Data analysis

Statistical analyses were performed using SPSS version 27 (IBM, Armonk, NY) and R version 4.0.3. Due to the large sample size and number of analyses, a significance threshold of $p < 0.001$ was adopted for all tests.

Aim 1: Describe sleep patterns across instructional approaches for middle and high school students. Each student could have reported on sleep for up to three instructional approaches: in-person, online/synchronous, or online/asynchronous instruction, with all students also reporting on sleep for weekend/no school days. Descriptive statistics (means and 95% CI) were used to examine sleep patterns for each of the four schedules. Due to known developmental differences between sleep patterns of MS (grades 6–8) and HS (grades 9–12) students, data are summarized by school level.

Aim 2: Examine differences in sleep patterns related to scheduled start times for in-person or online/synchronous days. For this aim, data from students who reported in-person and/or online/synchronous days were included in analyses, as these two types of instruction had a set school start time. Because of the correlated nature of bedtime, wake time, and sleep opportunity, two separate multivariate ANCOVA models (in-person, online/synchronous), each controlling for school level (MS/HS), were used to compare the three sleep outcomes (bedtime, wake time, sleep opportunity) across school start times. We first examined multivariate effects, using Pillai’s Trace; when significant, separate univariate tests examined each of our outcome variables. To

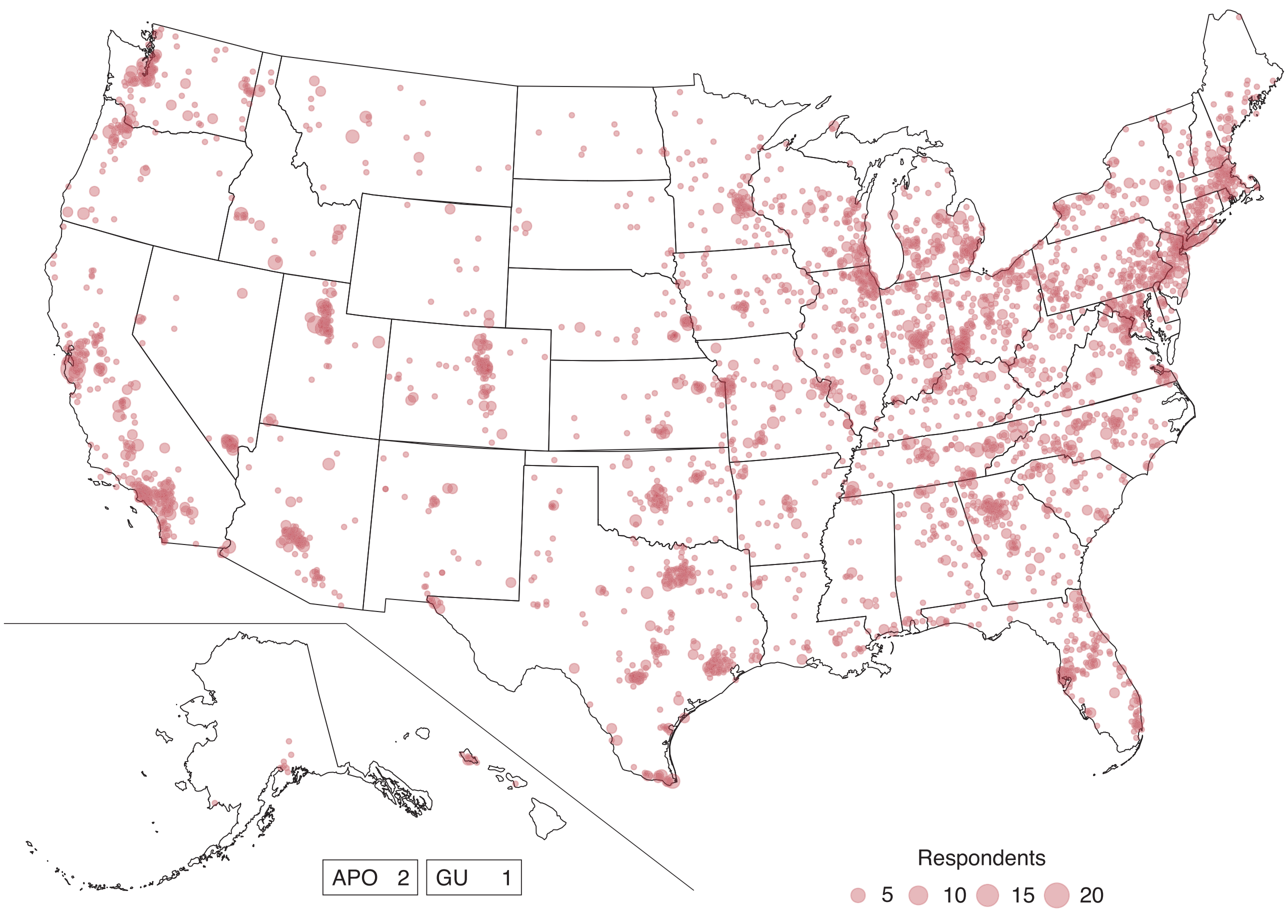

Figure 1. Geographic distribution of survey respondents.

U.S. map depicting the geographic distribution of respondents. Each zip code provided by a participant was reverse geomapped to its latitude and longitude and projected onto the Lambert Azimuthal Equal Area projection using R packages “zipcodeR” and “albersusa.” Non-localizable zip codes (e.g. post office boxes or invalid entries) were excluded from plotting, yielding a total of n = 4,239 data points. Larger red circles indicate greater number of participants in that zip code. APO, US Armed Forces in the Pacific; GU, Guam.

examine whether sleep outcomes varied monotonically across school start times, a planned linear trend analysis to decompose the main effect was conducted. The main effect was decomposed into polynomial components and linear trends were quantified by corresponding psi statistics. Finally, to explore differences among school start times, pair-wise differences with Tukey HSD correction for multiple comparisons were tested. Given different thresholds for sufficient sleep, a stratified analysis was performed to examine whether school start times were associated with the likelihood of receiving sufficient sleep separately for MS and HS students. Associations between school start times and proportion of students with sufficient sleep opportunities were explored using chi-square tests; *p*-values were derived from 2,000 simulations to account for low sample size in some cells. Effect sizes for η^2 were interpreted as follows: 0.01 = small, 0.06 = medium, 0.14 = large, and Cramer's *V* effect sizes were interpreted as follows: 0.1 = small effect size, 0.3 = medium effect size, 0.5 = large effect size [17].

Aim 3: Compare night-to-night sleep pattern variability for students with different types of hybrid instruction approaches (i.e. in-person + online [synchronous/asynchronous], online synchronous + asynchronous). Many students had hybrid schedules that included a combination of in-person, online/synchronous, and online/asynchronous approaches. To examine night-to-night variability in sleep that was associated with instruction approaches, students were grouped into two categories to reflect the restrictiveness of their school schedules (i.e. in-person days were likely more restrictive than online/synchronous due to transportation time) [13]. *Hybrid* schedules included at least one in-person day during the week. *Online/mixed* schedules included at least one online/synchronous day, but no in-person days. Variability in bedtime, wake time, and sleep opportunity was calculated using mean square successive differences (MSSD) [18]. This approach captures both variability and temporal dependence in a time series and is more sensitive to greater night-to-night fluctuations than traditional variance approaches [18, 19]. Differences in sleep outcomes were calculated among adjacent observations for each participant (e.g. Tuesday–Monday, Wednesday–Tuesday), with values squared and added, then divided by the number of observations minus one as seen in the following formula:

$$\mathrm{MSSD} = \frac{\sum_{i=1}^{n-1} (x_{i+1} - x_i)^2}{n-1}.$$

A higher MSSD value indicates greater variability. A multivariate ANCOVA model, controlling for school level, was used to examine differences in MSSD for each of the three sleep outcomes, comparing students with a hybrid schedule to students with an online/mixed schedule

Results

Sample characteristics

Consent and instructional approach responses were provided by 6,577 adolescents. Of these, 5,245 (79.7%) provided complete sleep outcome data and were included in analyses. Details for all adolescents who provided consent and comparisons between the study sample and those who did not provide sleep data or those who did not provide demographic information (5.5%) are found in the Supplement.

Table 1 provides demographic information of the full sample of survey completers, as well as separated by the students' individual combined instructional approaches across the week. Significant differences between combined instructional approaches were found for race/ethnicity, region, school type, and social vulnerability index. Significant differences were also found for sleep behaviors, with students who had 5 days of in-person instruction reporting less frequent technology use prior to bedtime and more sleep consistency. These effects, while significant, were small.

The NESTED sample is consistent with most key demographic variables in the *School Enrollment in the United States: 2018* report from the U.S. Census Bureau [20]. Specifically, the NESTED Study (NS) sample was similar to the U.S. Census Bureau (US) in sex (Female—NS: 49.9%, US: 48.6%), school type (Public—NS: 93.7%, US: 89.6%), and region (Northeast—NS: 15.1%, US: 16.0%; Midwest—NS: 26.0%, US: 20.9%; South—NS: 34.7%, US: 38.8%; West—NS: 24.3%, US: 24.2%). Despite over-recruiting Black youth, the NESTED Study sample included more White participants (NS: 64.9%, US: 50.5%) and fewer Black participants (NS: 4.4%, US: 14.4%) than the U.S. Census data. The race/ethnicity of the remainder of the sample was similar between NESTED and the U.S. Census (Asian—NS: 3.9%, US: 4.9%; Hispanic—NS: 17.3%, US: 25.2%; Mixed/Other—NS: 9.6%, US: 5.1%), highlighting the diversity of participants.

Aim 1: Instruction approach and sleep outcomes

Sleep characteristics (bedtime, wake time, sleep opportunity, percent of students obtaining sufficient sleep) for each daily instructional approach by school level are summarized in Table 2. Because in-person instruction had both a fixed start time and requirement for travel time (not measured), it is considered the most restricted scheduled approach compared to online/synchronous, which also has a fixed start time but without travel time; online/asynchronous is considered the least scheduled instructional approach.

Bedtime. Reported bedtimes were later for less-scheduled instructional approaches. On average, earliest bedtimes occurred on in-person days, followed by online/synchronous (MS: 33 min later; HS: 28 min later). Compared to online/synchronous days, a smaller delay in bedtime was observed for online/asynchronous days (MS: 13 min; HS: 12 min). Finally, comparing online/asynchronous to weekends/no school days, the reported bedtime delays were larger for both levels (MS: 60 min, HS: 49 min). Compared to in-person days, average weekend/no school day bedtimes were 1.8 h later for MS students and 1.4 h later for HS students.

Wake times. Weekday wake times were significantly later with less-scheduled instructional approaches. In-person wake times were the earliest, followed by online/synchronous days (70-minutes later for both MS and HS students), online/asynchronous days (MS: 1.1 h, HS: 1.4 h later compared to online/synchronous), and weekend/no school day wake times (~50 min later compared to online/asynchronous for both MS and HS students). Overall, the average difference in wake time between in-person and weekend/no school days was >3 h for both MS and HS students.

Table 1. Demographic characteristics of full sample and by combined instructional approaches across the week*

	Full sample (n = 5,245)	In-person 5 days/week (n = 1,163)	Online/synchronous 5 days/week (n = 1,265)	Asynchronous/no school 5 days/week (n = 631)	Hybrid (in-person ≥1 day/week) (n = 1,370)	Online/mixed (synchronous ≥ 1 day/week) (n = 816)	Test statistic
Level							
% Middle	12.8	15.0	13.1	11.3	11.5	12.1	$X^2(4) = 9.05$
% High	87.2	85.0	86.9	88.7	88.5	87.9	$p = 0.06$
Gender							
% Female	49.9	48.6	48.8	50.8	49.7	53.1	$X^2(12) = 22.61$
% Male	41.2	44.2	41.0	40.0	42.1	37.0	$p = 0.03$
% Non-binary	4.7	4.0	5.9	3.5	4.5	5.3	
% Other/prefer not to answer	4.1	3.5	4.3	5.7	3.7	4.7	
Race/ethnicity							
% White	64.9	72.6	49.2	65.7	75.4	60.3	$X^2(16) = 295.21$
% Black	4.4	2.9	6.1	5.0	2.4	6.4	$p < 0.001$
% Hispanic	17.3	13.6	26.5	18.8	11.4	16.7	
% Asian	3.9	1.3	7.5	1.0	2.9	5.5	
% Multiracial/other	9.6	9.6	10.7	9.4	8.0	11.1	
Region							
% Northeast	15.1	7.3	16.9	10.2	23.9	11.6	$X^2(12) = 431.83$
% Midwest	26.0	35.8	18.1	21.9	30.2	20.6	$p < 0.001$
% South	34.7	45.6	29.8	43.8	27.0	33.5	
% West	24.3	11.3	35.1	24.2	18.9	34.2	
School type							
% Public	93.7	90.8	96.1	90.4	94.3	95.8	$X^2(8) = 153.43$
% Private	4.8	8.9	3.1	3.7	4.9	2.6	$p < 0.001$
% Other†	1.5	0.4	0.8	5.9	0.8	1.6	
Social vulnerability index							
% Low	30.0	34.8	32.1	19.7	27.4	32.2	$X^2(12) = 95.57$
% Low-moderate	26.5	26.0	27.6	26.0	25.7	27.3	$p < 0.001$
% Moderate-high	19.7	16.6	22.2	21.2	20.6	17.5	
% Highest	23.8	22.7	18.1	33.1	26.3	22.9	
Technology use prior to bedtime							
% Never	1.5	2.0	1.7	2.1	1.0	0.8	$X^2(8) = 15.77$
% Almost never/sometimes	16.0	18.8	14.9	14.7	15.4	15.6	$p = 0.05$
% Almost always/always	82.6	79.2	83.4	83.2	83.6	83.6	
Sleep consistency (M [95% CI])	4.26 (4.22, 4.31)	3.97 (3.87, 4.07)	4.23 (4.14, 4.32)	4.59 (4.46, 4.72)	4.33 (4.25, 4.42)	4.35 (4.24, 4.46)	$F(4,4495) = 15.99$ $p < 0.001$

*Combined instructional approaches represent the fact that students may have had more than one instruction approach across the school week. Each student is represented only once in the combined approaches.

†Other school types included homeschool not associated with COVID-19 (n = 67) and boarding school (n = 4).

Table 2. Sleep characteristics by school level for the night prior to each type of instructional approach and weekend nights*

	In-person (n = 2,533)	Online/synchronous (n = 2,822)	Online/asynchronous (n = 2010)	No school/weekend (n = 5,245)
Bedtime (military time)				
Middle school	22:31	23:04	23:19	00:19
(mean, 95% CI)	(22:22–22:39)	(22:56–23:12)	(23:09–23:29)	(00:10–00:28)
High school	22:57	23:25	23:37	00:26
(mean, 95% CI)	(22:54–23:00)	(23:22–23:27)	(23:34–23:40)	(00:23–00:29)
Wake time (military time)				
Middle school	6:19	7:29	8:37	9:29
(mean, 95% CI)	(6:14–6:23)	(7:22–7:35)	(8:23–8:51)	(9:21–9:37)
High school	6:20	7:29	8:51	9:39
(mean, 95% CI)	(6:18–6:22)	(7:27–7:32)	(8:46–8:56)	(9:36–9:42)
Sleep opportunity (h)				
Middle school	7.80	8.42	9.30	9.16
(mean, 95% CI)	(7.66–7.94)	(8.27–8.56)	(9.08–9.52)	(9.04–9.29)
High school	7.38	8.08	9.23	9.21
(mean, 95% CI)	(7.32–7.43)	(8.03–8.13)	(9.15–9.31)	(9.16–9.26)
Sufficient sleep opportunity				
Middle school (>9 h)	20.4%	38.7%	62.3%	62.8%
Middle school (>8 h)	55.6%	65.4%	84.6%	81.9%
High school (>8 h)	37.2%	56.9%	81.1%	83.3%

*Students may have more than one instructional approach during the week, reporting sleep patterns for each type of instructional approach. Thus students may be represented more than across individual night instructional approaches.

Sleep opportunity. Sleep opportunity was longer for days with less-scheduled instructional approaches. The shortest sleep opportunity was reported for in-person days, followed by online/synchronous days (~40 min longer for both MS and HS students); online/asynchronous days had a longer sleep opportunity than online/synchronous (MS: 53 min, HS: 69 min); and weekend/no school day sleep opportunity was similar to online/asynchronous days. Compared to in-person days, the average weekend/no school day sleep opportunity was 1.4 h longer for MS students and 1.8 h longer for HS.

Sufficient sleep opportunity. For in-person instructional days, 20.4% of MS (≥9 h) and 37.2% of HS (≥8 h) students reported a sufficient sleep opportunity. For online/synchronous days, 38.7% of MS and 56.9% of HS students reported a sufficient sleep opportunity. For both online/asynchronous and weekend/no school days over 62% of MS students and more than 81% of HS students reported a sufficient sleep opportunity.

Aim 2: Comparing sleep outcomes by school start times

Sleep patterns by school start times are illustrated in Figure 2. For this aim, we examined how the sleep outcomes (bedtime, wake time, sleep opportunity) differed across school start times. Only students with either in-person or online/synchronous instruction days were included, as these two approaches had a set school start time. The multivariate model for in-person instruction days was significant, $F(10,5052) = 85.66$, $p < 0.001$, η^2=.15, as was the multivariate model for online/synchronous instruction days, $F(10,5630) = 104.31$, $p < 0.001$, η^2=.16. Both models had large effect sizes.

Bedtime. Controlling for level (MS vs. HS), main effects of school start time were significant for bedtime on nights before both in-person, $F(5,2256) = 8.72$, $p < 0.001$, and online/synchronous instruction days, $F(5,2815) = 9.33$, $p < 0.001$. Effect sizes were small (η^2's=0.02). Planned trend contrasts revealed that for both in-person and online/synchronous days, as school start times were later students reported later bedtimes (in-person: $\Psi = 5.00$, $t(2256) = 6.50$, $p < 0.001$; online: $\Psi = 3.25$, $t(2815) = 6.19$, $p < 0.001$).

Wake time. Controlling for level, main effects of school start time were significant for wake time on both in-person, $F(5,2256) = 205.40$; $p < 0.001$, and online/synchronous instruction days, $F(5,2815) = 248.02$, $p < 0.001$ (large effect sizes, in-person: $\eta^2 = 0.29$; online: $\eta^2 = 0.31$). For both in-person and online/synchronous days, as school start times were later, students reported later wake times (in-person: $\Psi = 12.67$, $t(2256) = 30.26$, $p < 0.001$; online: $\Psi = 14.11$, $t(2815) = 34.32$, $p < 0.001$).

Sleep opportunity. Controlling for level, main effects of school start time were significant for sleep opportunity for in-person, $F(5,2256) = 22.98$; $p < 0.001$ and online/synchronous instruction days, $F(2815) = 82.01$, $p < 0.001$ with small-medium effect sizes (in-person: $\eta^2 = 0.04$; online: $\eta^2 = 0.13$). With later start times, students in-person and online/synchronous instruction reported a significantly longer sleep opportunity (in-person: $\Psi = 7.67$, $t(2815) = 9.61$, $p < 0.001$; online/synchronous: $\Psi = 10.86$, $t(2815) = 19.83$, $p < 0.001$).

Sufficient sleep opportunity. The percentage of students with a sufficient sleep opportunity the night before in-person or online/synchronous instruction is illustrated in Figure 3. Data are stratified for middle and HS students based on developmental shifts in the threshold for sufficient sleep. Thus, for MS, two cutoffs are presented: 8 and 9 h, while for HS only 8 h is used. For MS, later school start times were not associated with a sufficient sleep opportunity on nights before in-person instruction for either the 8 h (X^2 =4.38,

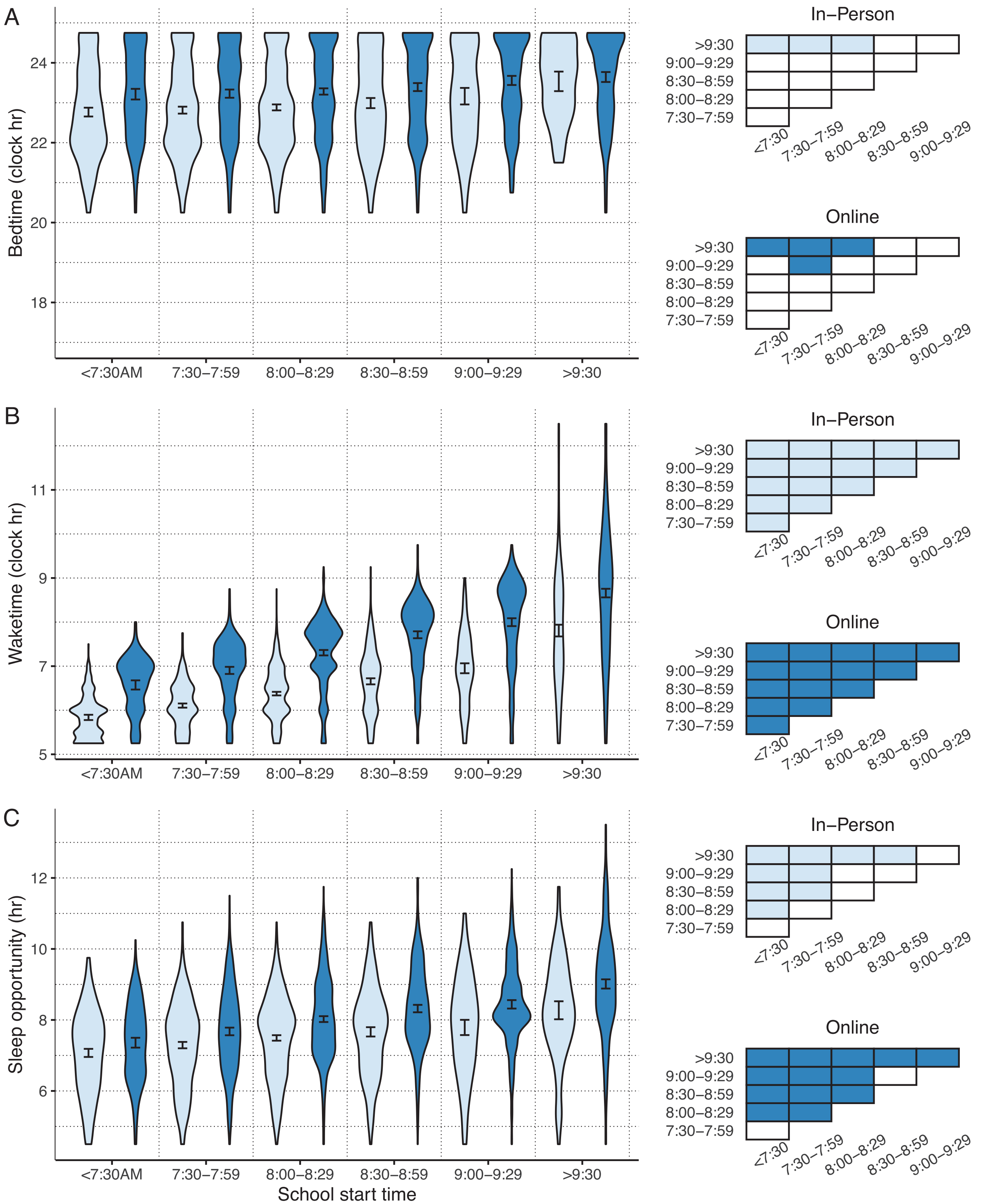

Figure 2. Sleep patterns for in-person and online instruction by school start time.

Left: Violin plots indicating the distribution of reported bedtimes (panel **A**), wake times (**B**), and sleep opportunity (**C**) stratified by school start time for nights before in-person (light blue) or online/synchronous (darker blue) instruction. Each plot reflects the data used for the appropriate multivariate ANCOVA (stratified by instructional approach) and not pair-wise comparisons of in-person and online/synchronous instruction. Error bars show 95% confidence intervals around the estimated marginal mean for each stratum, adjusted for school-level.

Right: Post-hoc tests comparing means across school start times for bedtime, wake time, and sleep opportunity within the in-person (light blue) and online/synchronous (darker blue) instruction contexts. Grids represent all possible pair-wise comparisons. Shaded cells indicate a statistically significant difference following family-wise Tukey HSD adjustment. Significance was set at $p < 0.001$ in keeping with the reported analyses.

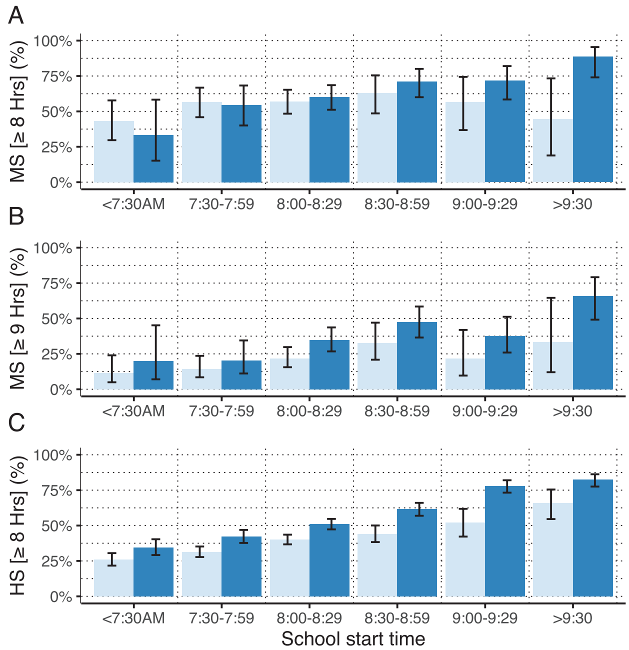

Figure 3. Sufficient sleep for middle and high school students by school start time.

As described in the results section, each bar indicates the proportion of students who receive sufficient sleep opportunity for nights before either in-person (light blue) or online/synchronous (darker blue) instruction. Data are stratified for middle school (panels **A** and **B**) and high school (panel **C**) students. Due to developmental differences within the middle school strata, we report two thresholds for sufficient sleep: 8 h (panel **A**) and 9 h (panel **B**). Error bars represent asymmetrical binomial 95% confidence intervals (Wilson) around the observed percentages.

p = 0.50, Cramer's V = 0.11 [small effect]) or the 9 h (X^2 = 9.36, p = 0.089, Cramer's V = 0.17 [small effect]) threshold. However, a significant association between later school start times and sufficient sleep for MS students was observed on nights before online/synchronous instruction (8 h: X^2 = 20.84, $p < 0.001$, Cramer's V = 0.25 [small effect]; 9 h: X^2 = 22.36, $p < 0.001$, Cramer's V = 0.26 [small effect]). For HS students, significant associations between later school start times and sufficient sleep emerged for nights before in-person (X^2 = 73.34, $p < 0.001$, Cramer's V = 0.18 [small effect]) and online/synchronous (X^2 = 247.02, $p < 0.001$, Cramer's V = 0.32 [medium effect]) instruction.

Aim 3: Comparing sleep variability between hybrid and online/mixed schedules

Weekday bedtime variability did not differ between students with a hybrid versus an online/mixed schedule, $F(1,2183)$ = 2.16, p = 0.14. However, a significant difference in variability was found for weekday wake time, $F(1,2183)$ = 85.62, $p < 0.0001$, η^2 = 0.04 [small effect], with hybrid students reporting greater wake time variability than online/mixed students (hybrid = 1.50 h [95% CI: 1.42, 1.54]; online/mixed = 0.99 h [95% CI: 0.92, 1.08]). Differences between hybrid and online/mixed students were also found for weekday sleep opportunity, $F(1,2183)$ = 53.03, $p < 0.0001$, η^2 = 0.02 (small effect), with hybrid students reporting greater variability in sleep opportunity (hybrid = 1.21 h [95% CI: 1.15, 1.26]; online/mixed = 0.86 h [95% CI: 0.78, 0.93]).

Finally, as combined instruction groups differed in race/ethnicity and regional composition, as well as in school type and social vulnerability (see Table 1), we completed exploratory analyses adding these factors as covariates to our core analytic models (Aim 2 and Aim 3). No demographic factors emerged as significant predictors of the three sleep outcomes (i.e. all p's > 0.001).

Discussion

NESTED surveyed a large racially diverse sample of adolescents drawn from every state in the United States (and two territorial jurisdictions) more than 6 months after the initial COVID-19 lockdowns. Although other studies have considered the impact of the initial lockdowns on adolescent sleep, to our knowledge this is the first study that considered the association of sleep with a range of secondary education instruction approaches. Both middle and high school students reported earlier bedtimes and wake times when their morning schedules were more constrained by a scheduled start time (compared to online/asynchronous days). Examining these trends for in-person or online/synchronous instruction days, the scheduled start of the school day had a major impact on reported sleep: the earlier the start, the earlier the bedtime and wake time, and shorter the sleep opportunity. However, unlike previous studies that have examined sleep and school start times for in-person instruction, this study highlights that bell times are not the only factor that contributes to reduced sleep opportunity. Notably, even when students had the same start times, in-person instruction was associated with shorter sleep opportunity compared to online/synchronous instruction. This novel finding suggests that factors such as morning commute time to school or time to get ready for school further reduce sleep opportunity for in-person students. Future studies should include time spent on commuting and morning routines. Later start times were also associated with sufficient sleep opportunity for both middle and high school students. Notably, for middle school students, a start time of 8:30–9:00 (in-person or online/synchronous instruction) resulted in the greatest proportion of students with a sufficient sleep opportunity of 9 h; yet, this start time applied to only 33% of in-person students and 47% of online/synchronous middle school students. For high school students, only when the online/synchronous school day started at 8:00–8:29 am or later, did the percentage of students with a sufficient sleep opportunity exceed 50%. For in-person days, the 50% threshold was not seen until the school start time was 9:00 am. The benefit of later start times was more notable for high school than middle school students, adding to current evidence illustrating that late school start times make a demonstrable impact on sleep for high school students in the United States [21–27].

Hybrid instruction (with at least one in-person day) had a significant impact on night-to-night sleep variability. In addition, greater variability was observed in students with hybrid schedules compared to students with only online instruction (both synchronous and asynchronous). This finding is presumably due to the earlier start times for in-person instruction, resulting in greater wake time variability across the week. Studies have shown that greater night-to-night variability in sleep patterns is associated with negative daytime outcomes for adolescents, including mood, behavior, and social interactions [28]. Although it has been suggested that in-person hybrid instruction may provide students more days to “catch up” on their sleep [29], NESTED study results show that variable sleep schedules are associated with night-to-night shifts in sleep-wake patterns and social jetlag. These findings should be considered when discussing whether or not to continue in-person hybrid instruction.

In summary, we found that overall sleep patterns for middle school and high school students during the COVID-19 pandemic were significantly affected by the instructional approach and the resulting school start time schedule they experienced. These findings showed that early school start times were associated with a reduced opportunity for sufficient sleep regardless of instructional approach, although the impact is greater for in-person instruction. Similar to previous studies, NESTED study findings suggest that in-person school start times earlier than 9:00 am result in an insufficient sleep opportunity for more than half of students.

Given the context of this study and the large, diverse, nationwide sample, study findings lend significant weight to the growing initiative to start school later for middle school and high school students [23, 25–27, 30, 31]. Yet, many students in this study experienced hybrid instruction, with varying amounts of constrained start times across a single week. The hybrid and online/mixed schedules were associated with more variable day-to-day sleep timing. Differences in sleep timing between school- and weekend-nights, can result in “social jetlag,” which has the potential for serious downstream health effects for adolescents [32]. In this study, however, social jetlag was also seen night-to-night for students with a hybrid instruction approach across the same week. Notably, the greatest differences in sleep opportunity were between in-person (with constrained school start times) and online/asynchronous nights (with no scheduled school start time). Thus, combining in-person and online/asynchronous instruction within the same week cannot be recommended.

We note that a number of other measures not analyzed for this report were collected through the survey, including ratings of mood, satisfaction with school, factors related to social disparities, etc. The current analyses for this paper were limited to a broad description of overall sleep patterns as they related to a range of instructional approaches and school start times. Our additional questions for students may provide a more fine-grained perspective of sleep patterns; for example, a participant’s reported morningness/eveningness may provide an opportunity to examine circadian preferences as a contributory factor to the association between sleep and school start times [33]. Such considerations may be particularly meaningful in understanding differences between high school and middle school students, where developmental changes likely occur. Given reported associations of sleep patterns with mental health and academic performance [34–36], sleep patterns influenced by changes to instructional approaches during the pandemic may likewise affect these markers of wellbeing and performance among adolescents and provide further considerations for post-pandemic education policies. Thus, future reports of this study will examine how sleep and school start times during the pandemic are associated with these domains (e.g. mental health, academic, and disparity factors).

This study has a number of limitations, stemming from having a finite, temporal window of 6 weeks in which to acquire reports. The large sample involved cross-sectional data collection that captured a snapshot during the pandemic and relied on self-report of sleep for each instructional context. The use of sleep opportunity as our outcome measure had limitations as this variable did not account for sleep onset latency or wake after sleep onset. Further, although commonly used as a proxy for sleep duration, sleep opportunity represents the selected window in which adolescents choose to sleep, with bedtimes and wake times often limited by obligations (e.g. school start times) or voluntary choice (e.g. screen time). Thus, it does not represent either sleep need or how much sleep an adolescent would obtain with a greater sleep opportunity. Although the school closures and re-openings were in flux across the United States during the autumn of 2020, we did not capture whether individual survey respondent’s sleep was uniquely affected by any abrupt shifts in school schedules that may have occurred. In addition, we did not collect data on pre-COVID start times, thus it was not possible to examine within-person changes in sleep opportunity before and during COVID. Finally, although our study included a diverse sample of adolescents, we did not achieve a nationally representative sample. Thus, the generalizability of study findings to underrepresented youth may be limited. With these limitations in mind, we nevertheless conclude that our survey provides important insights into the roles of instructional approach and school start times in the timing, amount, and variability of sleep in U.S. secondary school students.

The data provided by the NESTED study may assist educational leaders who are considering options for instructional approaches and bell schedules post-pandemic. The findings may provide guidance for how best to plan for school instruction formats and schedules that address the health and developmental sleep needs of their students.

Supplementary Material

Supplementary material is available at *SLEEP* online.

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