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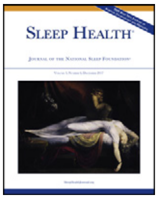

Effects of school start time on students' sleep duration, daytime sleepiness, and attendance: a meta-analysis

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ABSTRACT

Research conducted over the past three decades finds that many children and adolescents do not meet recommended sleep guidelines. Lack of sleep is a predictor of a number of consequences, including issues at school such as sleepiness and tardiness. Considering the severity of this public health issue, it is essential to understand more about the factors that may compromise children's and adolescents' sleep. This meta-analysis examined the effects of school start time (SST) on sleep duration of students by aggregating the results of five longitudinal studies and 15 cross-sectional comparison group studies. Results indicated that later starting school times are associated with longer sleep durations. Additionally, later start times were associated with less daytime sleepiness (7 studies) and tardiness to school (3 studies). However, methodological considerations, such as a need for more longitudinal primary research, lead to a cautious interpretation. Overall, this systematic analysis of SST studies suggests that delaying SST is associated with benefits for students' sleep and, thus, their general well-being.

The amount of sleep needed for optimal functioning varies widely across the lifespan; the National Sleep Foundation recommends newborns sleep for 14 to 17 hours per night, whereas an older adult requires approximately 7 to 8 hours.[1] Although adolescence is a time of transition to adult lifestyle and responsibilities, an adolescent between the ages of 14 and 17 needs more sleep than the average adult: 8 to 10 hours[2]; 12- and 13-year-old children should sleep for 9 to 11 hours per night for optimal functioning.[1] In actuality, studies measuring adolescent nightly sleep estimate that between 66% and 92% of adolescents in the United States do not meet these nightly sleep requirements.[3–5]

The importance of sufficient sleep

Students need to be mentally alert to sufficiently learn during school. Diminished reasoning and verbal skills have been associated with sleep deprivation in middle and high school students.[6] Insufficient sleep interferes with the memorization process, with specific negative effects observed for working memory and the memory consolidation processes, both essential for learning in the classroom.[7–9] Furthermore, lack of sleep has been associated with increased tardiness to class and disciplinary actions.[10*]

The mental alertness gained from sleep is also essential for safe motor vehicle operation. Fine motor skills and reaction times suffer in sleep-deprived adolescent populations.[11] Rates of car crashes have been demonstrably higher in districts in which schools start earlier in the day, along with fewer recorded total minutes of sleep.[12*–14]

Lack of sleep during adolescence may result in symptoms of mental health diagnoses, including depression and anxiety.[15] Inadequate sleep duration may lead to poor health behavior decisions, including overeating; skipping exercise; or misusing drugs such as caffeine, nicotine, or other stimulants.[16,17] Serious physical symptoms such as increased heart rate and blood pressure can result from prolonged sleep deprivation.[18] Sleep disorders may also develop as a result of poor sleep habits, including insomnia, restless leg syndrome, and sleep apnea.[19] Lack of sleep can lead to insulin resistance and changes in hormones which may lead to obesity or diabetes.[20] In summary, sleep is critical for the well-being of children and adolescents.

School start time

During puberty, circadian rhythms, or sleep-wake cycles, shift toward preference for late-morning wake times and late-onset sleep times.[5] Chronotype is an individual's preference for sleep timing[21], and older, more developed adolescents demonstrate a greater

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evening preference chronotype.[22] Both behavioral and intrinsic biological factors appear to be involved in chronotype determination.[22] Early school start time (SST) is believed to directly interfere with the natural sleep-wake cycle and homeostatic sleep regulation process of the typical adolescent.[23] Teens have difficulties falling asleep earlier than 11:00 PM[23] yet still require 8 to 10 hours of sleep. The American Academy of Pediatrics recommends that middle and high schools begin no earlier than 8:30 AM to accommodate the sleep needs of students.[24] Criticisms of shifting SST include logistical and financial concerns, as well as suspicions that students will not use the time to maximize their sleep[12*,25,26]; however, some school districts report increased flexibility and cost-savings for transportation following SST change,[27,28] and studies have demonstrated that increased sleep from SST delay can be attributed to later wake times because bedtimes remain stable.[29*,30*,31*]

The current meta-analytic review

Studies measuring SST and adolescent sleep have been accumulating over approximately 25 years. Few previous systematic reviews have been conducted. One review examined only published longitudinal studies.[17] A review confined to high school student samples[32] had high theoretical validity given the literature on adolescent circadian rhythms; however, one drawback to this approach was the inevitable exclusion of other studies from the SST literature in non–high school samples. A recent extensive systematic review[33] examined a broad array of outcome variables from studies implementing SST delay for students aged 13 to 19, noting positive findings in primary studies examining sleep duration. However, these authors provided arguments for primary study weaknesses, deeming the quality of the current studies on SST too low for any definitive conclusions. Although a large number of studies were included in the review, few studies were included for quantitative synthesis (ie, meta-analysis) because of the authors' evaluation of study design differences among the set of included reports; only 3 studies were meta-analyzed for the outcome of sleep duration.

The primary goal of the current meta-analytic review is to comprehensively, systematically, and quantitatively summarize the evidence from investigations testing whether delayed morning SSTs result in more sleep compared with earlier start times. Three secondary outcome variables were identified in the primary studies: daytime sleepiness, absences from school, and tardiness to school. A priori moderators of interest for the primary outcome variable are outlined below.

Delay of SST in minutes

Although there is a policy movement toward delaying SST, it is not clearly evident how many minutes a school should shift its starting time to achieve potential benefits for students. Delays as short as 15 minutes have been investigated as well as delays of 60 minutes or more. The number of minutes delayed was included as a potential moderating variable to understand whether longer delays produced greater benefits.

Clock time of the later SST

The clock time of the "later" SST was extracted as a second method for measuring potential differences by starting time. This variable was extracted by converting the starting time into the number of minutes past midnight (for example, 8:00 AM is equal to 480 minutes past midnight).

Before and after 8:30 AM SST

Studies were coded categorically for whether the later starting time was before or after/at 8:30 AM, corresponding to the recommendation from the American Academy of Pediatrics.[24]

Student grade in school

Most primary studies have focused on high school and middle school populations because of the fact that circadian rhythms shift with puberty. However, a small number of studies have tested the effects of an SST delay in elementary school students. Given that shifting high schools to later starting times may involve younger children starting school earlier in the day (for logistical reasons such as bus availability), it is important to explore the potential effects of SST on elementary school students. Studies examining the effects of earlier SSTs on elementary school students, although their focus is different, provide relevant data to the question at hand and were thus included in the review to allow for a comprehensive analysis of the literature on SST. Synthesizing research on this population may aid in understanding the optimal SST for elementary school students and the timing of the circadian rhythm shift. The grade in school was included as a moderator to determine whether potential effects differed based on the grade level of the participants, and a sensitivity analysis was included to determine whether findings were any different with these studies excluded.

Time elapsed between assessments before vs after an SST delay

Longitudinal studies reported the amount of time that elapsed between measurements of sleep before (time 1) vs after (time 2) implementation of an SST delay. This variable was included as a potential moderator to determine whether any potential effects on sleep depended on the length of time following the implementation of the SST delay.

Publication status

A search of the gray literature was conducted in an attempt to mitigate against the effects of any potential publication biases. In addition to peer-reviewed published articles, conference abstracts were retrieved and publication status was coded as a moderator.

Methods

Search strategy and inclusion process

The search strategy to identify relevant articles assessing SST and sleep duration included database searches (PsycINFO, PubMed, Scopus, and ProQuest) and manual searches for citations in recently published reviews of the literature.[17,34] The following search terms were used for database searching: *school start time, students, school, education, sleep, sleep deprivation, sleep restriction, circadian rhythm, adolescent,* and *sleep pattern.* Date restrictions were not applied. The search was conducted in September 2016 and updated in March 2017.

The initial database and backwards searches yielded a total of 163 articles. After applying filters that only included records written in the English language and peer-reviewed journal articles (except in ProQuest, a dissertation database), 88 total articles were collected from the databases and manual backwards searches. These 88 articles were imported into a citation manager (Endnote X7). Duplicates were removed, and 57 articles remained to be screened.

Titles and abstracts were screened for the following inclusion criteria: (1) 2 different morning SSTs (eg, 8:15 AM compared with 7:30 AM) were compared; (2) total sleep duration measured in minutes was reported; and (3) participants were elementary, middle, or high school age students from any country. Using these eligibility requirements, 35 articles were removed. Common reasons for removal at this stage include the following: (1) the report was a review article or commentary style article, (2) sleep duration was not measured or calculable, and (3) the report described another type of intervention study (such as morning UV light or melatonin).

Twenty-two studies remained for further screening with full-text review, and 2 records were removed during this stage of screening. One article was excluded because the experimental group's start times were inconsistent throughout the week,[11] and 1 conference abstract[35] was removed because the study sample was presumed to be the same as that studied in one of the included published articles.[36*] This search strategy yielded a final total of 20 records (Fig. 1).

Data extraction

For the primary outcome variable, sleep duration, the data extraction process prioritized locating reported sleep duration means and standard deviations, as well as total N of each group or time point. When means were not reported, P values associated with statistical tests were extracted, and directionality of the effect was specified as positive or negative. Positive effect sizes indicated that delayed start times were associated with better outcomes (more sleep, less tardiness, less daytime sleepiness, and fewer absences), and negative effect sizes indicated that delayed start times were associated with worse outcomes. When necessary, sleep duration data were converted to total minutes from HH:MM formatting (such as 07:48 converted to 468 minutes) or from total hours reported with a decimal (such as 7.8 hours converted to 468 minutes). Some variations existed with the timing of the recorded sleep data. When available, weeknight or school night sleep duration means were prioritized for extraction over other available means. Some studies did not specify which nights of the week the sleep duration data represented. In those cases, data were still extracted and assumed to pertain to the full week or weeknights, not weekends (adolescents are prone to overcompensating for lost sleep on the weekends[37]). Most studies used self-report sleep and wake times, and fewer used actigraphy, a technology for recording sleep. Because of the lack of variability in sleep length measures, this variable was not considered in the analysis. For longitudinal studies that measured follow-up at 2 time points, data from the first follow-up were extracted.

For moderator variable data, all studies provided the needed information within the record. Publication status was determined during the search process. For longitudinal studies, the time between T1 and T2 was recorded in terms of or converted to months, as this was most commonly reported. The number of minutes of the SST delay was often reported in the abstracts of the articles, as this information is essential for describing the nature of the intervention. Each study at least reported the 2 times being compared (such as 7:00 AM and 7:35 AM), and if necessary, subtraction was performed to code the difference (35 minutes). The sample's grade in school was often extracted from abstracts or titles. Despite some differences across studies in which grade constitutes which level of school (eg, fifth grade as elementary or middle school), this variable was coded based on the authors' terminology.

Meta-analytic procedure

Analyses for the 5 meta-analyses, 1 for longitudinal studies (sleep duration) and 4 for cross-sectional comparison group studies (sleep duration, daytime sleepiness, attendance, and tardiness), were conducted using Comprehensive Meta-Analysis software (CMA Version 2[38]). Entering the data for outcome variables and sample N yielded an effect size for each study. When the N for T1 did not match T2, the sample size for T2 was used. The majority ($k = 4$) of longitudinal studies did not use control groups, so the pre-post effect size for the delayed group was calculated. Once all study effect sizes were calculated for each outcome variable (sleep duration, daytime sleepiness, absences, and tardiness), CMA produced an aggregate effect size using weights and the random-effects model. Meta-regression was used to test for continuously coded moderators, and analogue to analysis of variance (ANOVA) was used to test for categorically coded moderators.

Results

Study characteristics

Tables 1 and 2 show the descriptive characteristics of the selected studies. Five longitudinal studies and 15 cross-sectional comparison group studies were included for separate analyses. The sample size for primary studies ranged from 15 to 10,656 ($M = 867$, SD = 2383, median = 340). The length of SST delay ranged from 15 to 130 minutes. Sex, race, ethnicity, and age information was widely unavailable in the primary studies and therefore could not be analyzed as moderators. Little variation existed for country of study, with most studies having been conducted in the United States. Type of school was initially coded as public, private, boarding, or home school; however, there were not enough available data or variation to analyze this variable as a moderator. Secondary outcome variables were not analyzed in the longitudinal studies because there were not enough studies measuring these variables. Ultimately, 5 meta-analyses were conducted to keep separate the longitudinal studies and the cross-sectional ones, and to analyze each outcome variable.

Analysis of longitudinal studies

Each individual study effect size was positive, indicating that later SSTs were associated with more sleep ($P < .05$). As shown in Table 3, the effect sizes (d) for sleep duration ranged from 0.24 to 1.07, with a small-to-medium[39] aggregate weighted effect size of $d = 0.38$, $P < .001$, and with significant heterogeneity, $Q^4 = 9.99$, $P < .05$, $I^2 = 59.97$. Delayed starting time increased sleep duration by approximately 20 minutes, from 424 minutes (7 hours and 4 minutes) to 444 minutes (7 hours and 24 minutes).

Meta-regression found that longer delays in minutes were associated with longer sleep duration, $Q^1 = 7.56$, $P < .01$. The clock time of the delay, $Q^1 = 0.22$, $P = .64$, and the length of time between T1 and T2, $Q^1 = 0.61$, $P = .44$, were not significant moderators. Analogue to ANOVA found that whether the late starting time was before or after 8:30 AM was also not significant, $Q^1 = 0.59$, $P = .44$. The grade in school and publication status moderators lacked the required variation for analysis.

Analysis of cross-sectional comparison group studies

Sleep duration

Each individual effect size was positive, indicating that later SSTs were associated with more sleep ($P < .05$). As seen in Table 4, effect sizes (d) ranged from 0.05 to 0.96, with a small-to-medium aggregate weighted effect size of $d = 0.40$, $P < .001$, and with significant heterogeneity, $Q^{14} = 326.28$, $P < .001$, $I^2 = 95.71$.

Meta-regression showed that longer delays were associated with *less* sleep, $Q^1 = 57.71$, $P < .01$, as was clock time of the delayed start, $Q^1 = 75.33$, $P = .001$. Analogue to ANOVA showed that grade in school, $Q^2 = 0.04$, $P = .98$; whether the delayed start time was before or after 8:30 AM, $Q^1 = 0.58$, $P = .45$; and publication status, $Q^1 = 2.24$, $P = .14$, were not significant moderators. Because elementary school students are often studied separately because of circadian rhythm differences,[40*] a sensitivity analysis that removed studies including

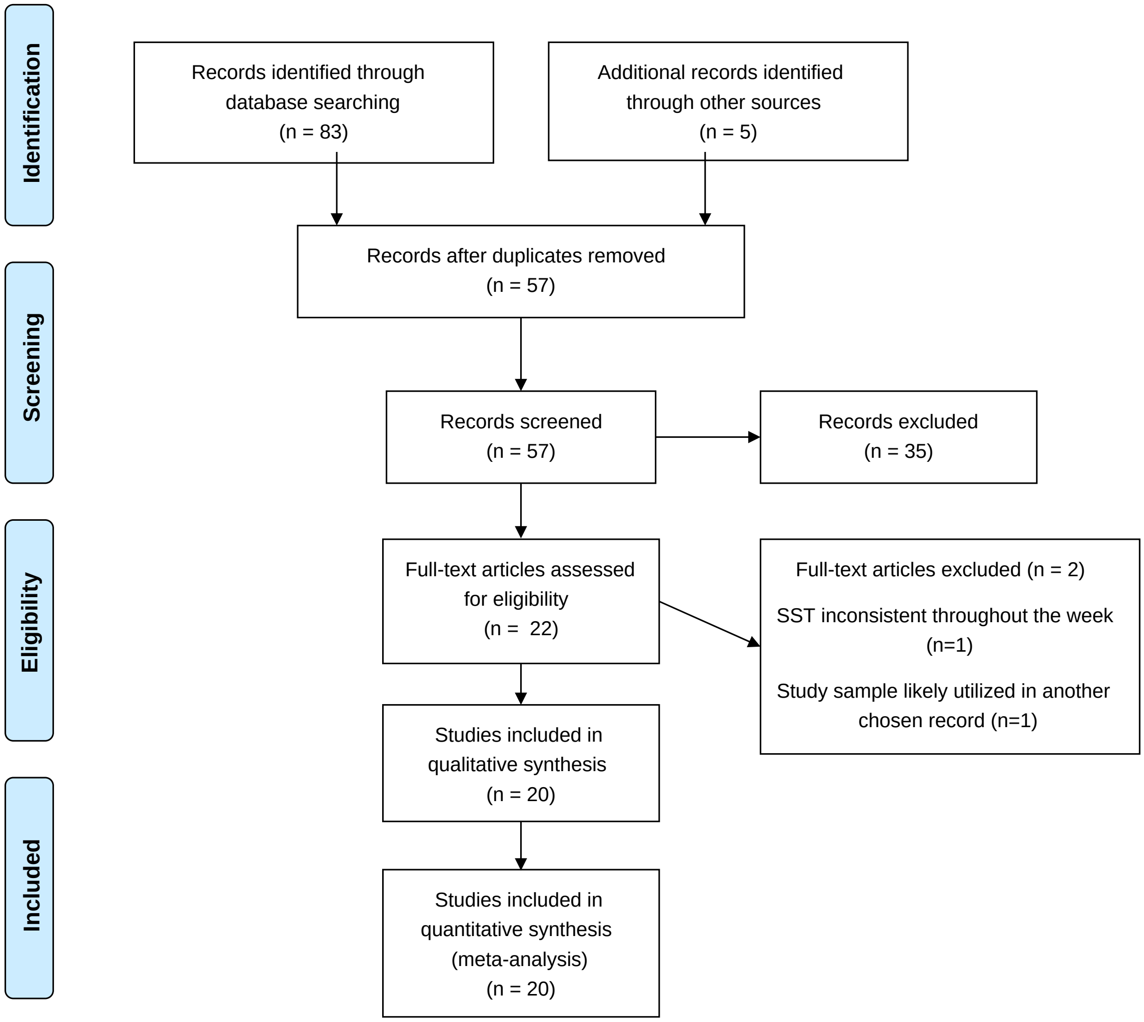


Fig. 1. PRISMA diagram

elementary school students ($k = 3$) was run to determine the soundness of combining all grade levels. The effect size for sleep duration remained the same ($d = 0.40$, 95% confidence interval [CI] 0.24-0.57, $P < .001$), and, thus, studies including elementary school students were retained in further analyses. The combined effect size for the elementary school sample studies was similar and significantly different from zero, $d = 0.39$, 95% CI 0.05-0.72, $P < .05$. Number of months since T1 was not relevant because of the cross-sectional design of these studies.

Daytime sleepiness

Seven studies reported daytime sleepiness with extractable data. Six of these individual effect sizes were positive, indicating that less daytime sleepiness was associated with later SSTs, and significantly different from 0 at $P < .05$. Effect sizes (d) ranged from -0.02 to 0.26, with a quite small aggregate weighted effect size of $d = 0.14$, $P < .01$ (Table 5).

Absences

Three studies reported absences from school with extractable data. Effect sizes (d) ranged from -0.33 to 0.19, with an aggregate weighted effect size of $d = -0.02$ (Table 6). This effect size was not statistically significantly different from 0 ($P = .90$).

Tardiness

Three studies reported tardiness to school with extractable data. Effect sizes (d) ranged from 0.12 to 0.74, with a small aggregate weighted effect size of $d = 0.30$, $P < .05$ (Table 7), indicating that less tardiness was associated with later SSTs.

Table 1
Descriptive information for longitudinal studies (n = 5)

First author (year)	Country	Months since T1*	Publication status	Grade in school	Delay (in min)*	Late STT hh:mm (min)*
Boergers (2014)	United States	4	Published article	High school	25	08:25 (505)
Carskadon (1998)	United States	5	Published article	High school	65	08:25 (505)
Lufi (2011)	Israel	0.25	Published article	Middle school	60	08:30 (510)
Owens (2010)	United States	2	Published article	High school	30	08:30 (510)
Wolfson (1995)	United States	6	Conference abstract	High school	65	08:25 (505)

Asterisk (*) indicates moderator variable used in analyses.

Table 2
Descriptive information for cross-sectional comparison group studies (n = 15)

First author (year)	Country	Publication status*	Grade in school*	Delay (in min)*	Late SST hh:mm (min)*
Appleman (2015)	United States	Published article	Elementary	35	08:25 (505)
Chan (2017)	China	Published article	Middle school	15	08:00 (480)
Danner (2008)	United States	Published article	High school	60	08:45 (525)
Dexter (2003)	United States	Published article	High school	45	08:35 (515)
Epstein (1998)	Israel	Published article	Elementary	50	08:00 (480)
Escribano (2014)	Spain	Published article	High school	30	08:30 (510)
Htwe (2008)	United States	Conference abstract	High school	40	08:15 (495)
Kowalski (1995)	United States	Conference abstract	High school	130	09:30 (570)
Li (2013)	China	Published article	Elementary	30	08:30 (510)
Meltzer (2016)	United States	Published article	Middle school	63	08:30 (510)
Perkinson-Gloor (2013)	Switzerland	Published article	High school	20	–
Short (2013)	U.S. & Australia	Published article	High school	47	08:32 (512)
Thacher (2016)	United States	Published article	High school	45	08:30 (510)
Wahlstrom (2002)	United States	Published article	High school	85	08:40 (520)
Wolfson (2007)	United States	Published article	Middle school	82	08:37 (517)

Asterisk (*) indicates moderator variable used in analyses.

Publication bias

Rosenthal's fail-safe N[41] was used to compute the number of potentially missing studies needed to nullify the significance of the reported effects. Using CMA, the fail-safe N calculated for the longitudinal studies was $N_{fs} = 57$. For sleep duration in the cross-sectional comparison group studies, $N_{fs} = 1536$; $N_{fs} = 62$ for the daytime sleepiness outcome; $N_{fs} = 26$ for the tardiness outcome. Based on this test, it is reasonable to assume that these results are not likely to be influenced by publication bias. Funnel plots were used as an additional metric for investigating potential publication bias for the main outcome variable, and the asymmetric pattern of plotted results suggested a need for further investigation. Egger test of the intercept[42] was used to predict the standardized effect, and the results were significant, indicating potential publication bias (in cross-sectional comparison group studies, $B0 = 5.48$, 95% CI 2.78-8.17, $P = .001$; in longitudinal studies, $B0 = 2.79$, 95% CI 1.87-3.71, $P = .001$). Duval and Tweedie's Trim and Fill method[43] determined where missing studies from the funnel plot were likely to fall, then added them to the analysis, and recomputed the combined effect. Using a random-effects model, for the analysis of cross-sectional comparison group studies, zero studies were trimmed, and the adjusted effect size estimate remained the same, $d = 0.40$, 95% CI 0.25-0.57. For longitudinal studies, 2 studies were trimmed, and the adjusted effect size estimate after trimming became $d = 0.29$, 95% CI 0.09-0.49. Because these adjusted effects remain small to medium,[39] the current results seem robust to publication bias.

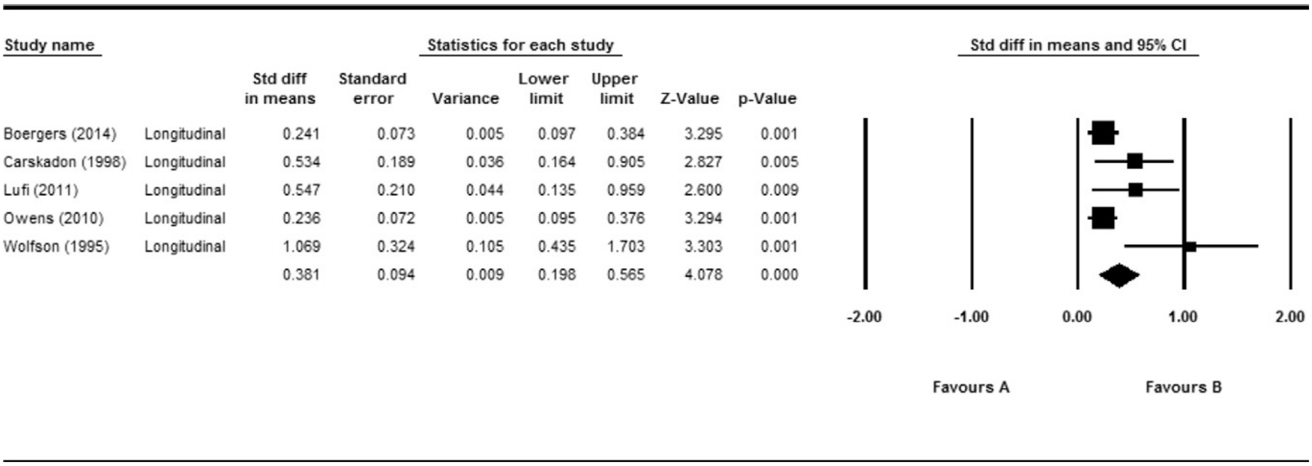
Discussion

Sleep duration

For both longitudinal and cross-sectional comparison group studies, later start times were associated with more minutes of sleep. These separate results must be interpreted slightly differently from one another.

For longitudinal studies, the study effects were within-subjects, and participants were followed from T1 to T2. This design is a strength of the primary studies because the sleep durations are experimentally linked to the SST change and individual differences are accounted for. The outcome of the meta-analysis of these 5 studies indicates that when these students' SSTs were delayed, their sleep durations were higher than when their SSTs were not. Furthermore, the moderator analysis that examined the length of follow-up produced statistically insignificant results, which may be interpreted to mean that the effects of an SST delay persist despite the time that has

Table 3
Random effects model effect size calculations for longitudinal studies

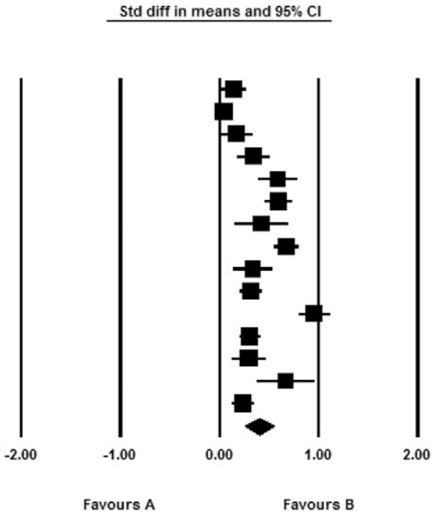


Study name		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Boergers (2014)	Longitudinal	0.241	0.073	0.005	0.097	0.384	3.295	0.001
Carskadon (1998)	Longitudinal	0.534	0.189	0.036	0.164	0.905	2.827	0.005
Lufi (2011)	Longitudinal	0.547	0.210	0.044	0.135	0.959	2.600	0.009
Owens (2010)	Longitudinal	0.236	0.072	0.005	0.095	0.376	3.294	0.001
Wolfson (1995)	Longitudinal	1.069	0.324	0.105	0.435	1.703	3.303	0.001
		0.381	0.094	0.009	0.198	0.565	4.078	0.000

In this table, "A" represents earlier starting schools, and "B" represents later starting schools.

Table 4
Random effects model effect size calculations for cross-sectional comparison group studies: sleep duration

Study name	Study type	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Appleman (2015)	Cross-sectional	0.139	0.066	0.004	0.010	0.268	2.117	0.034
Danner (2008)	Cross-sectional	0.046	0.014	0.000	0.019	0.073	3.291	0.001
Dexter (2003)	Cross-sectional	0.170	0.083	0.007	0.007	0.332	2.041	0.041
Epstein (1998)	Cross-sectional	0.345	0.086	0.007	0.177	0.513	4.019	0.000
Escribano (2014)	Cross-sectional	0.588	0.105	0.011	0.383	0.793	5.629	0.000
Htwe (2008)	Cross-sectional	0.597	0.071	0.005	0.458	0.736	8.417	0.000
Kowalski (1995)	Cross-sectional	0.421	0.138	0.019	0.150	0.692	3.047	0.002
Li (2013)	Cross-sectional	0.672	0.063	0.004	0.549	0.794	10.724	0.000
Meltzer (2016)	Cross-sectional	0.336	0.102	0.010	0.136	0.535	3.293	0.001
Perkinson-Gloor (2013)	Cross-sectional	0.317	0.058	0.003	0.203	0.431	5.466	0.000
Short (2013)	Cross-sectional	0.955	0.081	0.007	0.797	1.114	11.785	0.000
Thacher (2016)	Cross-sectional	0.305	0.056	0.003	0.196	0.414	5.491	0.000
Wahlstrom (2002)	Cross-sectional	0.297	0.090	0.008	0.120	0.473	3.292	0.001
Wolfson (2007)	Cross-sectional	0.664	0.147	0.022	0.375	0.953	4.511	0.000
Chan (2017)	Cross-sectional	0.237	0.059	0.003	0.122	0.352	4.044	0.000
		0.400	0.075	0.006	0.253	0.548	5.324	0.000



In this table, “A” represents earlier starting schools, and “B” represents later starting schools.

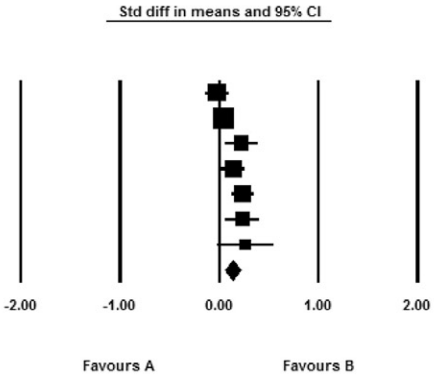
passed since implementing it. In other words, students assessed at later follow-ups did not seem to have adjusted to the later SST and to have simply stayed up later as a result of the delay. Although the design of the primary studies is a strength, the small number of existing studies (only 5) and the paucity of longitudinal studies incorporating a control group (just 1) are clear limitations.

The meta-analysis of cross-sectional comparison group studies must be interpreted more cautiously. The aggregate effect size for this analysis was also significant and in the positive direction. This indicates that students given a delayed SST sleep significantly longer than students who are not. Although one strength of this meta-analysis is the number of included studies,[15] the design of these studies introduces heterogeneity, most of which does not appear to be explained by the moderator variables. A likely reason for this is the nature of the design of the primary studies. Whereas some studies included students from the same school (eg, Danner and Phillips[12*]), several studies compared samples of students from 2 different schools or 2 different school districts. In these cases, important differences between the comparison groups may arise, such as socioeconomic status, which data could not be obtained for. This potential confound is a limitation of the meta-analysis and the literature as a whole, and makes generalizing the results more difficult.

In the cross-sectional comparison group studies, the grade level of the students was not a significant moderator, indicating that later start times resulted in more sleep for all included grade levels. The grade levels reported across these studies ranged from fourth to sixth (for data reported in Appleman et al.[40*] 2 separate SST changes were investigated, and this review excludes third graders who experienced a larger shift than the remaining sample) with 3 countries represented (Table 2). Children in grades 4 through 6 may be older,

Table 5
Random effects model effect size calculations for cross-sectional comparison group studies: daytime sleepiness

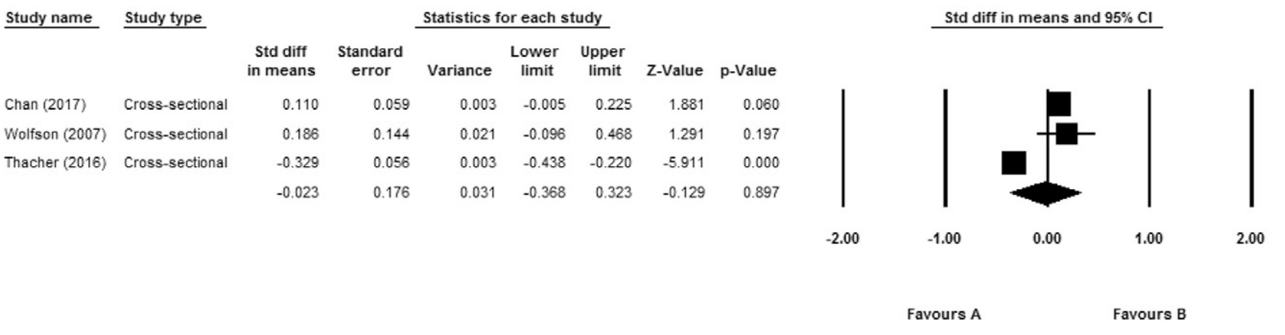
Study name	Study type	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Chan (2017)	Cross-sectional	−0.023	0.058	0.003	−0.137	0.092	−0.388	0.698
Danner (2008)	Cross-sectional	0.046	0.014	0.000	0.019	0.073	3.291	0.001
Epstein (1998)	Cross-sectional	0.227	0.085	0.007	0.059	0.394	2.653	0.008
Li (2013)	Cross-sectional	0.142	0.061	0.004	0.022	0.262	2.327	0.020
Perkinson-Gloor (2013)	Cross-sectional	0.232	0.058	0.003	0.118	0.346	4.000	0.000
Wahlstrom (2002)	Cross-sectional	0.232	0.090	0.008	0.056	0.408	2.577	0.010
Wolfson (2007)	Cross-sectional	0.262	0.144	0.021	−0.020	0.544	1.818	0.069
		0.137	0.043	0.002	0.052	0.221	3.174	0.002



In this table, “A” represents earlier starting schools, and “B” represents later starting schools.

Table 6

Random effects model effect size calculations for cross-sectional comparison group studies: absences



Study name	Study type	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Chan (2017)	Cross-sectional	0.110	0.059	0.003	-0.005	0.225	1.881	0.060
Wolfson (2007)	Cross-sectional	0.186	0.144	0.021	-0.096	0.468	1.291	0.197
Thacher (2016)	Cross-sectional	-0.329	0.056	0.003	-0.438	-0.220	-5.911	0.000
		-0.023	0.176	0.031	-0.368	0.323	-0.129	0.897

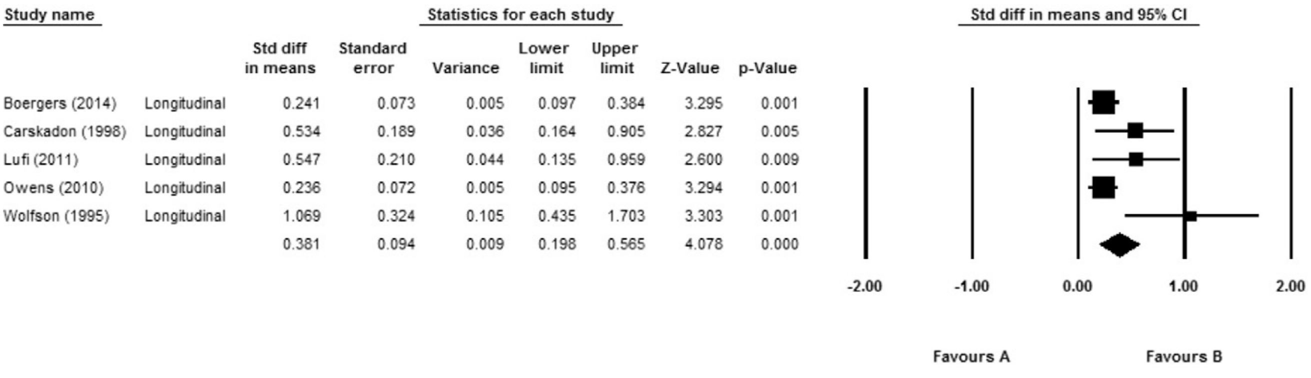
In this table, "A" represents earlier starting schools, and "B" represents later starting schools.

more maturely developed elementary school students, depending on the country of study, which may explain this effect resembling that of higher grades. For example, in Epstein et al,[44*] the participants are fifth graders described as ages 10 to 12 (mean ages are widely unreported in primary studies and thus were not analyzed). Additionally, a sensitivity analysis was conducted to assess the magnitude of the effect with and without these studies included. This analysis resulted in a similar effect size when the elementary school sample studies were excluded, with the effect size of these combined studies also similar in magnitude. For longitudinal studies, there was not enough variation in grade level to examine this variable. These findings, although limited because of the inclusion of only 3 elementary school sample studies, indicate that SST interventions may be effective across several grade levels, despite more studies on SST focusing on high school students. Although SST studies conducted on elementary school students had a different focus, their data could be meaningfully used in the current review. Further research should be conducted on the effects of SST for elementary school students and to investigate potential factors involved in the effects reported here, such as pubertal development (noted as a limitation in Li et al[45*]) and behavioral factors such as screen time.

A discrepancy arose when examining delay (in minutes) as a moderator. For the longitudinal studies, the result was significant and the direction was positive, which indicates that the longer the delay implemented by the researchers, the more sleep their sample obtained (as demonstrated by the higher effect sizes). For cross-sectional comparison group studies, the direction of this significant moderator was negative, which means that short delays (such as 20 as opposed to 120 minutes) were associated with more minutes of sleep in these studies. The clock starting time of the school with the later SST was also analyzed to provide more information; this moderator was not significant for the longitudinal studies, and it was significant in the negative direction for cross-sectional comparison group studies, indicating that *earlier* starting groups were more likely to get more sleep. One potential explanation for these discrepancies may be the heterogeneity within the cross-sectional studies and other characteristics of the studies that might be confounded with the length and clock time of the delay. The negatively patterned findings may indicate that the timing of the delay itself is not a significant factor in the results of individual studies of delaying SST's effect on increasing sleep; however, further study is needed. Particularly, longitudinal studies with a comparison group which measure students'

Table 7

Random effects model effect size calculations for cross-sectional comparison group studies: tardiness



Study name		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Boergers (2014)	Longitudinal	0.241	0.073	0.005	0.097	0.384	3.295	0.001
Carskadon (1998)	Longitudinal	0.534	0.189	0.036	0.164	0.905	2.827	0.005
Lufi (2011)	Longitudinal	0.547	0.210	0.044	0.135	0.959	2.600	0.009
Owens (2010)	Longitudinal	0.236	0.072	0.005	0.095	0.376	3.294	0.001
Wolfson (1995)	Longitudinal	1.069	0.324	0.105	0.435	1.703	3.303	0.001
		0.381	0.094	0.009	0.198	0.565	4.078	0.000

In this table, "A" represents earlier starting schools, and "B" represents later starting schools.

sleep patterns over an extended period following an SST delay would be helpful for determining if SST changes produce lasting effects.

Secondary outcome variables

In the cross-sectional comparison group studies, sufficient data were reported to calculate effect sizes for important outcomes that can result from lack of sleep such as daytime sleepiness, absences from school, and tardiness to school. A significant but small effect size emerged from the daytime sleepiness data. This indicates that in samples with later start times, students reported being less sleepy during the day compared with earlier starting samples. Minimized sleepiness during the day is important for attention and learning at school.[8,9] A medium-sized and significant effect was found for the tardiness variable, indicating that later starting schools may result in fewer tardy marks for attendance. Reducing tardiness to school is important for maximizing learning time in the classroom and minimizing disciplinary marks for lateness. Finally, data on absences from school did not result in significant findings, indicating that the time of day that school starts may not impact students' attendance for the full day of school. These results demonstrate that later SSTs may have a positive impact on consequences related to students' learning and daily lives.

Strengths and limitations

Across the 20 studies included in this review, several relevant outcome variables were measured, including behavioral problems, mental and physical health, academic performance, attention, and caffeine consumption. However, daytime sleepiness and attendance (absence and tardiness) were the only secondary outcome variables with sufficient available data to calculate meaningful effect sizes, which is a limiting factor for the applicability of this review. Other variables were not included as moderators because of lack of variability across studies, including country, sleep length measure, and participant sex and age.

One particular strength of this review is the comprehensive search process. Gray literature was searched, and although zero dissertations met the inclusion criteria, 3 conference abstracts were included. This approach limited the influence of publication bias.

Conclusions

This meta-analysis is one way to improve overall understanding of the effects of SST. However, there is a need for more prospective research in this area. Like most large-scale interventions, there are logistical considerations for implementing a change in SST (for studies or permanently), such as bus scheduling and timing afterschool activities. However, even small changes in start time can produce benefits to students that seem to outweigh the costs; for instance, the 25-minute delay experimentally induced by Boergers et al[31*] resulted in a 29-minute increase in school night sleep duration, as well as improvements in depressed mood, daytime sleepiness, and caffeine consumption.

The benefits of achieving adequate sleep are well established, as are the data demonstrating that most adolescents do not attain sufficient sleep during the school week. When delays in SST lead to more sleep, students are better positioned to be mentally and physically healthy.[18] Minimizing daytime sleepiness is essential for proper functioning and attention levels during the school day. Finally, reduced tardiness is also beneficial to students' learning; this effect presumably results in more time spent in the classroom.

The results of this meta-analysis suggest that delaying SST is associated with students sleeping longer; each of 20 studies produced a positive and significant effect for SST promoting longer sleep duration. Meta-analytic techniques indicated moderate effect sizes in support of SST delay. Evidence supporting SST delay is more abundant for middle and high school populations, and the evidence for elementary school students is limited and heterogenous across factors such as country of study. Given the methodological weaknesses of primary studies,[33] such as a lack of randomized control trial design, and notable limitations such as study heterogeneity, this review cautiously supports implementation of delays in SST for middle and high school students for increased sleep duration, decreased daytime sleepiness, and reduced tardiness, with a need for additional primary longitudinal studies.

Disclosure

The authors have nothing to disclose.

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[*] indicates article was used in the meta-analysis.

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