Sleep, learning, and school start times in adolescence

A biological phase delay in the sleep-wake cycle puts adolescent students in conflict with early school start times. Shifting school start times later may help to mitigate the effects.

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Executive Summary

- Around the start of puberty, adolescents begin to experience a phase delay in their sleep-wake cycle, going to bed later and rising later in the morning
- This phase delay puts adolescent students in conflict with early school start times
- Sleep is crucial for learning and memory
- Chronic sleep loss in adolescents affects learning and memory, as well as a wide range of other outcomes relevant to education and development
- Shifting school start times later may help to mitigate the effects of the phase delay

Sleep in adolescence

How many adolescents do you know who joyfully leap out of bed at the first hint of dawn, ready for a new day? Around the start of puberty, most adolescents begin to experience a *phase delay* in their sleep-wake cycle [1-3]. As shown in Figure 1, adolescents tend to go to bed later at night and wake up later in the morning, shifting the cycle later by about two hours [2,4,5]. This phase delay makes teens more like "owls" or "evening types" rather than "larks" or "morning types." This developmental shift has been observed in adolescents worldwide [6-9].

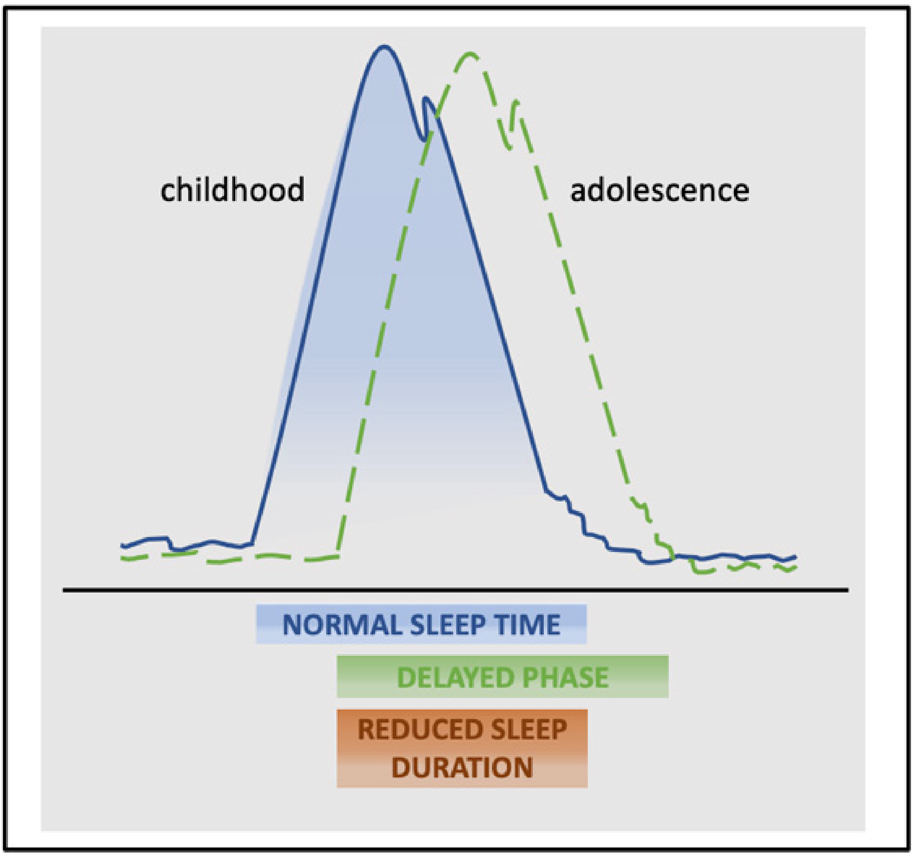

Figure 1. An illustration of the phase delay in the sleep-wake cycle in adolescence, which is related to later release of nocturnal melatonin in the circadian rhythm (as represented by the curves) and slower build-up of sleep pressure. The phase shift results in later bedtimes and reduced sleep duration when adolescents need to rise early in the morning. Based on Figure 4 in ref 3, https://www.frontiersin.org/articles/10.3389/fnmol.2012.00050/full, CC BY-NC

The phase delay is related to both environmental and biological factors [10]. On the one hand, it is influenced by psychosocial factors that contribute to staying up later, like a desire for independence shown by setting one's own bedtime. Social opportunities, peer pressure, homework, extracurricular activities, employment, and use of electronic devices can also affect bedtimes [6,11-14]. Early school start times, which force adolescents to wake up when their bodies still want to be asleep [15, p. 64], are an environmental factor that affects wake times.

On the other hand, the phase delay is influenced by neurobiology. Daily (circadian) rhythms are driven by two tiny clusters of neurons called the *suprachiasmatic nuclei* (SCN), as shown in Figure 2A. Light signals from the eyes are sent to the SCN and then on to the *pineal gland*, as shown in Figure 2B. The pineal gland produces the sleep-promoting hormone melatonin when light begins to fade. Within the circadian rhythm, the start of melatonin production signals readiness to sleep, and usually precedes bedtime by about an hour [16].

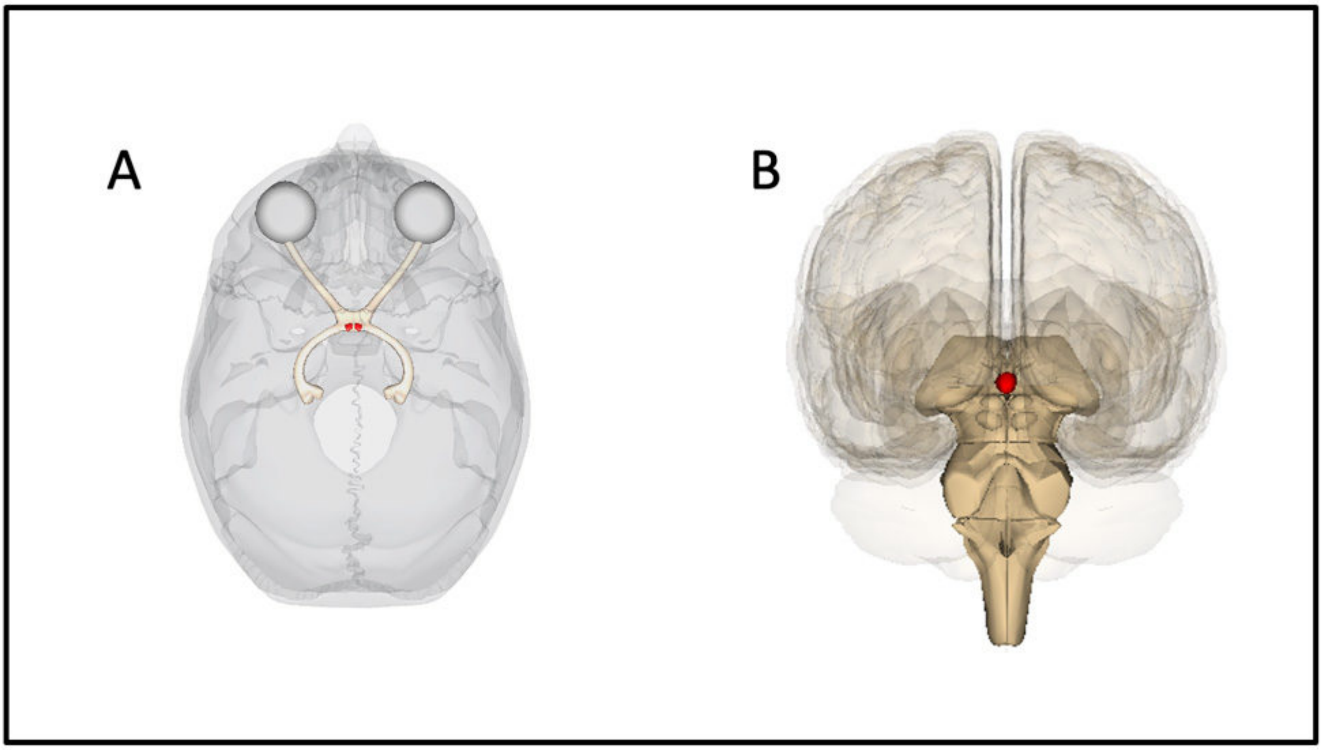

Figure 2. (A) As viewed from above, the tiny suprachiasmatic nuclei (SCN, shaded red) within the hypothalamus are the neural clock that regulates daily (circadian) rhythms. (B) Light signals travel from the eyes to the SCN and then on to the pineal gland (shaded red), which releases the hormone melatonin as light fades. Life Science Databases(LSDB)/Wikimedia Commons, Life Science Databases(LSDB)/Wikimedia Commons, CC BY-SA 2.1 JP

In adolescence, melatonin secretion is delayed until 10:00 PM or later, meaning that teens may not be ready to sleep until at least 11:00 PM [6,16,17]. Also, the homeostatic "sleep drive" that accumulates across waking hours is slowed in teens. So, biologically, the adolescent phase shift involves both the later release of nocturnal melatonin and the slower build-up of pressure to fall asleep [1-3,5,6,10,18,19].

As noted above, nighttime media use is an environmental factor affecting the phase shift. But electronic media also often emit blue light [20]. Blue light is especially effective at suppressing melatonin production [21]. Thus, nighttime media use may directly affect the biology underlying the phase shift by further inhibiting melatonin production and reducing homeostatic rise [5,22-25]. So messaging with friends late into the night to stay socially connected might also delay sleep biologically.

Although the optimal amount of sleep varies by individual, there are some guidelines [26], as in Figure 3. Worldwide, the majority of teens do not obtain the recommended 9 hours of sleep per night [12]. For example, one study reported that the average amount of sleep on weekdays was 7.4 hours for North American teens, 8.3 hours for European teens, and 7.6 hours for Asian teens [8]. In a survey of about 3,800 high schoolers in Korea, the students reported an average of 6.4 hours of sleep [27]. A similar survey of over 22,000 12- to 18-year-olds in Hong Kong found that only about 27% reported getting more than 8 hours of sleep on weekdays [28]. And in a survey of almost 2,000 Indian 12- to 18-year-olds, students reported an average of 7.8 hours of sleep [29]. Finally, in a recent CDC survey in the United States [30], 78% of high school students reported that they did not get 8 or more hours of sleep on an average school night (https://www.cdc.gov/healthyyouth/data/yrbs/index.htm).

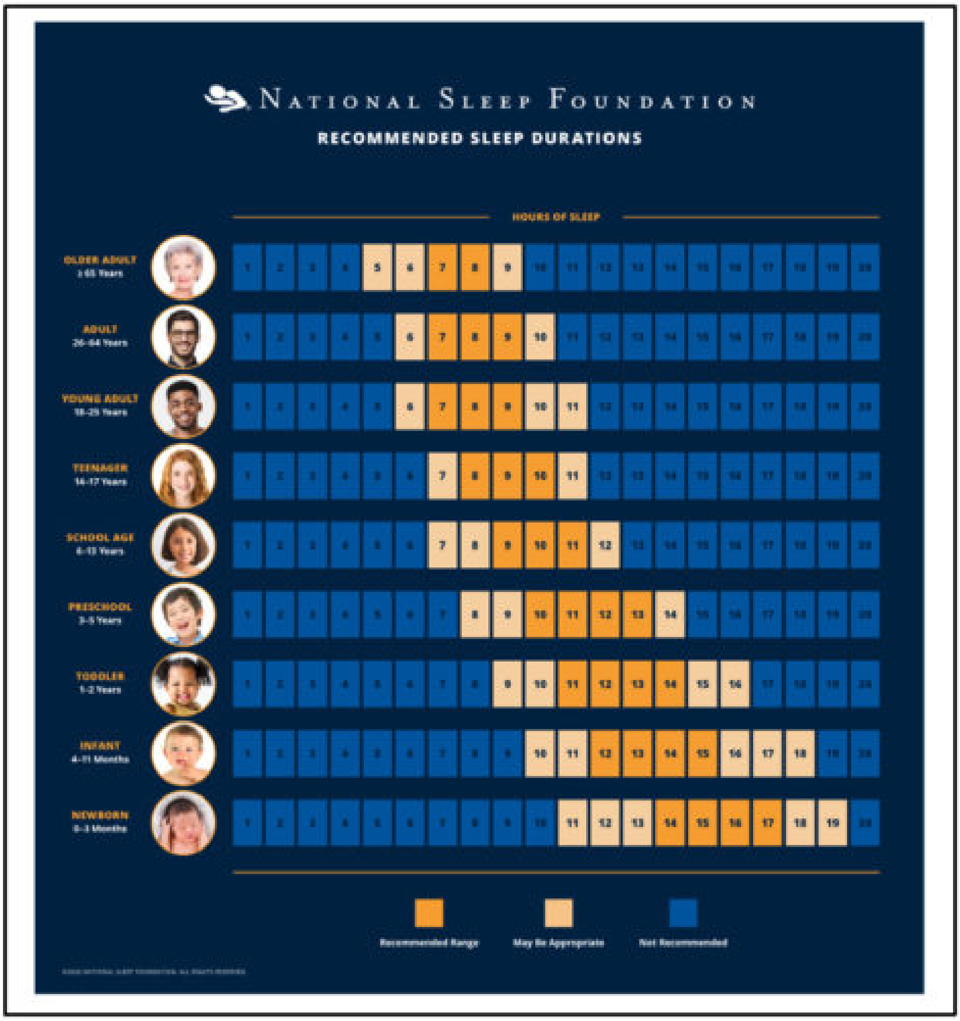

Figure 3. Recommendations for hours of sleep per night by age group from the National Sleep Foundation in the United States. Note that teenagers are recommended to sleep 8 to 10 hours per night. Used with permission from https://www.thensf.org/making-time-for-sleep/.

If adolescents fell asleep at 11:00 PM and slept for the recommended average 9 hours, they would wake at 8:00 AM. Because many schools serving adolescents have start times earlier than an 8:00 AM wake-up allows, this puts school schedules in conflict with biology. This means that many adolescent students are sleep deprived and sleepy while in school [31], which has implications for their learning and memory.

Sleep, learning, and memory

In the brain, newly learned information is a fragile memory trace; sleep helps to strengthen and consolidate these fragile memory traces and transform them into more stable long-term memories [32-34]. Studies with rats and mice have shown that neural circuits that were active during awake learning are active in the same way during sleep [35,36], as if the learned material is "replayed" during sleep in order to be strengthened and remembered. Studies with humans have also shown that brain areas involved in a learning task while awake are reactivated during sleep [37-39].

At a regional level, this process of memory consolidation involves interactions between the *hippocampus* and the *prefrontal* *cortex* [32,34,40], as shown in Figure 4. At a cellular level, memory formation involves strengthening connections between neurons (synapses) [41]. If a learner is deprived of sleep after initial learning, it interferes with memory consolidation and the newly learned material is less likely to be integrated into long-term memory [42]. That is, *newly learned information is less likely to be remembered without adequate sleep*. This is, of course, crucial to education. Although many of the studies on learning, memory, and sleep have been conducted with adults, there is evidence that sleep facilities memory consolidation in children and adolescents in a similar way [43,44]. For example, in one small study with 27 9- to 12-year-olds, the children learned word pairs and were tested on recall later, both before and after sleep; similar to the pattern observed in adults, memory (in this case, for word pairs) was increased after sleep [44].

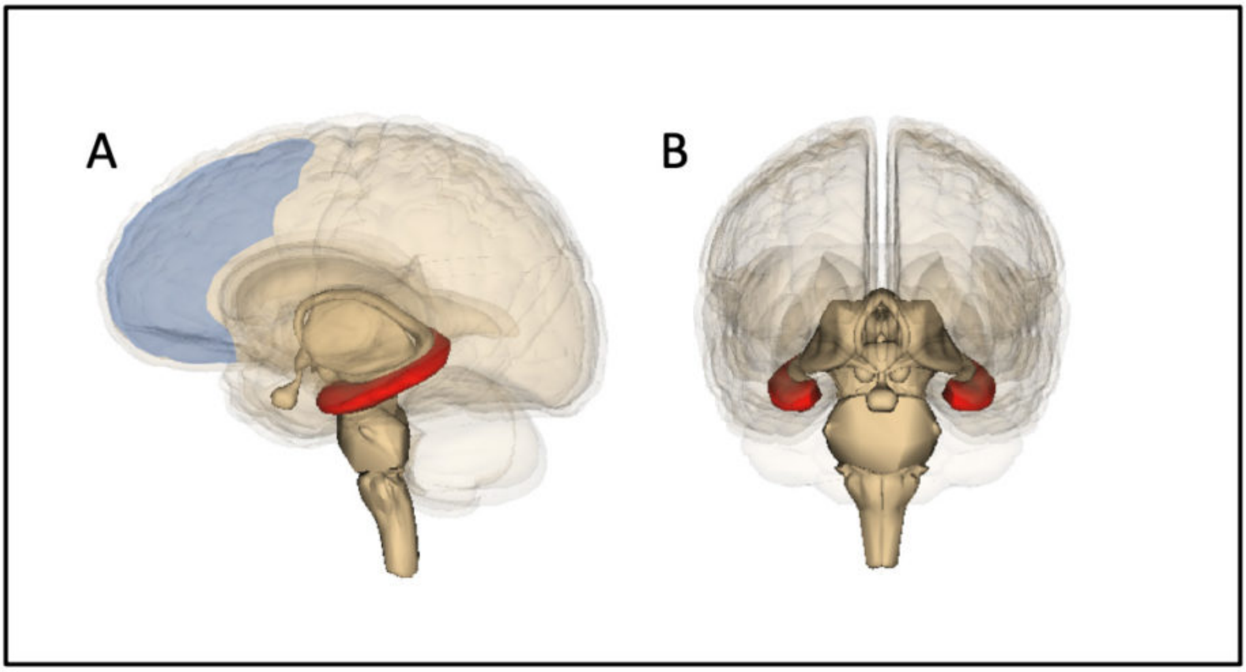

Figure 4. (A) The left hippocampus (shaded red) and the left prefrontal cortex (shaded blue, added) as seen from the side. (B) The left and right hippocampus (shaded red) as seen from the front. Life Science Databases(LSDB)/Wikimedia Commons, CC BY-SA 2.1 JP

Effects of insufficient sleep

Given the fundamental role of sleep in learning and memory, it is not surprising that insufficient sleep in adolescents is associated with negative effects on school performance (for reviews, see [1,31,45-48]). For example, in a study of over 1,000 adolescents in Norway, shorter sleep duration was related to poorer grade-point average (GPA in the lowest quartile); the odds ratio for 6 hours of sleep was 1.21, for 5 hours was 1.54, and for less than 5 hours was 2.53 [49]. Another study of over 380,000 Finnish students aged 14 to 20 found that later bedtimes, especially after 11:30 PM, were associated with poorer school performance [50]. In this study, school performance was measured by 11 items, from difficulty with teamwork to completing reading tasks [50]. And in an economic modelling analysis of data from students aged 10 to 19 in the United States, there was a significant positive association between sleep and test scores [51]. The authors noted that if test scores represent the acquisition of human capital (skills and knowledge correlated with long-term life outcomes), their findings indicate that nonoptimal sleep in adolescence can have lifelong consequences [51, p. 522].

Although causal relationships cannot be determined in observational and survey studies, less sleep is associated with daytime sleepiness, which is associated with poor attention and working memory, which are associated with poor school performance [e.g., 42,52,53]. Some of these links were confirmed in a small study in which 16 adolescents were limited to 6 hours of sleep for five consecutive nights or allowed 10 hours of sleep for five nights [54]. At the end of each five-night sequence, the adolescents viewed an educational film and took a related quiz in a simulated classroom [54]. The authors reported both more inattentive behavior and lower quiz scores when the adolescents were sleep-deprived [54].

However, chronic sleep loss related to the phase delay in adolescence is not just associated with poorer school performance. Shorter sleep duration affects a stunningly wide range of important developmental outcomes that are relevant to education[1], as summarized in Table 1.

- Physical health and safety
  - Increased obesity risk
  - Metabolic dysfunction (hypercholesterolemia, type 2 diabetes mellitus)
  - Increased cardiovascular morbidity (hypertension, increased risk of stroke)
  - Increased rates of motor vehicle crashes ("drowsy driving")
  - Higher rates of caffeine consumption; increased risk of toxicity/overdose
  - Nonmedical use of stimulant medications; diversion
  - Lower levels of physical activity
- Mental health and behavior
  - Increased risk for anxiety, depression, suicidal ideation
  - Poor impulse control and self-regulation; increased risk-taking behaviors
  - Emotional dysregulation; decreased positive affect
  - Impaired interpretation of social/emotional cues in self and others
  - Decreased motivation
  - Increased vulnerability to stress
- Academics and school performance
  - Cognitive deficits, especially with more complex tasks
  - Impairments in executive function (working memory, organization, time management, sustained effort)
  - Impairments in attention and memory
  - Deficits in abstract thinking, verbal creativity
  - Decreased performance efficiency and output
  - Lower academic achievement
  - Poor school attendance
  - Increased dropout rates

Table 1. The many impacts of inadequate sleep and chronic sleep loss in adolescents ref 1. Reproduced with permission from Journal Pediatrics, Vol. 134, page 643, Copyright © 2014 by the AAP.

If teenagers knew about the extensive and concerning effects of chronic sleep loss, would they change their sleep behaviors? Basic biology cannot be changed, and, unfortunately, most school-based sleep education programs do not seem to be effective. In many [55-58], but not all [59], studies, such programs might increase knowledge about sleep but do not change behavior. In some studies, small changes in behavior related to intervention (such as sleep time increasing by about 10 minutes) were not maintained at follow-up [60,61]. However, combining parental involvement and bright light therapy with a sleep education program increased both sleep knowledge and sleep duration (by about 27 minutes) in a study with year 11 students in South Australia [62]. This research suggests, as educators and policymakers, that we may need to take a closer look at modifiable environmental factors other than sleep itself.

School start times

Early school start times contribute to short sleep duration in adolescents. The resulting chronic sleep loss affects both their education and their health. Based on the scientific evidence regarding sleep in adolescents, in just the United States alone, the American Academy of Pediatrics, National Association of School Nurses, Society of Pediatric Nurses, American Medical Association, and American Academy of Sleep Medicine have all endorsed secondary schools starting no earlier than 8:30 AM [1,63-65].

Start times are an environmental contributor to insufficient sleep in adolescents that can be changed [1]. Through policy decisions, we can reduce or remove the detrimental effects of early school start times. Indeed, school districts worldwide have delayed start times to address chronic sleep deprivation and its effects on adolescents [7,66]. However, only about 18% of public schools serving adolescents in the United States started at 8:30 AM or later in 2011-2012 [67]. California has only recently become the first state to mandate that all public high schools start no earlier than 8:30 AM (and middle schools start no earlier than 8:00 AM) by the 2022-2023 school year [68].

Research consistently shows that adolescent students sleep longer on weeknights when schools shift to later start times [7,65,69-87]. Much of this research has been conducted in the United States. For example, in one study, delaying school start time by 30 minutes (from 8:00 to 8:30 AM) was associated with an increase of 45 minutes of sleep on school nights [72]. This study included about 200 grade 9 through 12 students at an independent high school in the United States who self-reported on their sleep [72]. The percentage of students getting less than 7 hours of sleep decreased by almost 80% and the percentage of students getting at least 8 hours of sleep increased from about 16% to about 55% [72]. In a similar study, sleep duration reverted back to baseline levels when the earlier school start time was reinstated [82]. Another study used a more direct measure of sleep (actigraphy, a wristwatch that records movement) with 383 15-year-olds in the United States [88]. In this study, students in schools that started at 8:30 AM or later slept about 34 minutes longer than students in schools that started before 7:30 AM, and about 23 minutes longer than students in schools that started between 7:30 and 7:59 AM [88]. In another study using actigraphy, 455 students in five American public high schools were followed as two of the schools delayed their start times (by 50 and 65 minutes) while the other three kept a 7:30 AM start time [77]. In comparison to students in schools with an unchanged 7:30 AM start, students who attended the delayed-start schools gained about 40 minutes of school-night sleep [77]. This effect was sustained over two years [77]. With a control group, this study design allows for the conclusion that delaying start times *caused* students to get more sleep [77]. So delaying school start times accomplishes the goal of increasing the amount of sleep that adolescents get on school nights. In addition, students report being less sleepy during the day when start times are shifted later [7,65,70-72,74,78,81,83,84].

Delayed start times have also been associated with better student achievement, as measured by grades or test scores, in many [15,52,75,76,80,86,89,90], but not all [69,91-93], studies. For example, one study analyzed grade 6 through 8 (middle school) data from a single county in North Carolina [89,94]. Delaying start time by one hour (from 7:30 to 8:30 AM) was associated with an increase in standardized test scores of about 2 percentile points in math and 1.5 percentile points in reading [89,94]. These effects were largest for the lowest-scoring students (more than twice as large for the students in the bottom third of the score distribution than the top third) [89,94]. Another study looked at the effects of delaying start time to 10:00 AM at a state-funded high school in England [90]. This delay was related to a 12% increase in students making good academic progress, as measured by performance on national exams [90]. Performance in the first class of the day may be particularly affected, through less tardiness [15,95,96]. In an economic analysis of start time data, Jacob and Rockoff [97] estimated a 1:9 cost-benefit ratio for later school start times in middle and high schools. They also estimated an average increase in student achievement of about 0.175 standard deviations for shifting start times one hour later in grades 6 through 12 [97]. This converted to about $17,500 in increased earning potential per student [97].

A review of 17 studies across six countries (Brazil, Canada, Croatia, Israel, New Zealand, and the United States) concluded that later school start times appear to increase sleep duration and are positively associated with academic outcomes [66]. However, the authors noted that higher quality studies and more evidence are needed to determine the causal effects of later school start times with confidence [66]. The use of self-report, convenience samples (including small sample sizes in terms of both students and schools), and inconsistent outcome measures and the lack of control groups in many early studies weaken the conclusions that can be drawn [66,74,78]. More recent studies have addressed some of these issues [e.g., 77]. However, implementing large, randomized controlled trials that would allow for clear causal conclusions regarding the effects of delayed start times may be unfeasible [98].

This is in part because shifting to later start times can be administratively and logistically challenging for schools and districts. Educating students and parents about adolescent sleep needs, learning about the research on school start times, sharing the positive experiences of communities that have made the transition, and considering the limited extent of adverse effects may be key to gaining stakeholder support [99]. It is also important to directly address concerns about sports, other afterschool activities, employment, and transportation, which are often perceived as barriers to delaying start times [100]. Guidance for this process is available [e.g.,] [101].

Based on data from the United States, macroeconomic models suggest that shifting school start times to 8:30 AM is a cost-effective population-level strategy [102]. This strategy not only has significant positive impact on public health but also shows significant economic gains relatively soon after implementation [102]. Overall, delaying school start times allows adolescent students to sleep longer and come to school more ready to learn and remember, better preparing them to become contributing members of society.

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