7 School Start Time and Its Impact on Learning and Behavior

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INTRODUCTION

Following the U.S. baby boom in the 1960s, schools not only increased in number but educators also began to experiment with staggered class schedules to accommodate the influx of new students. As other social, economic, and politico–legal pressures converged, school start times, particularly for the older high school students, gradually migrated to earlier hours (1). By 1975 most U.S. high schools started as early as 8:00 a.m. and school systems throughout the Western world, under similar pressures, eventually followed suit (2). Consequently, increasing societal demands promoted by a 24/7 culture over the past three decades have contributed to even earlier school start times for both middle and high school students (3); (Fig. 1).

Based on early sleep research, it initially appeared that after birth the number of sleep hours needed per day would decline steadily during childhood development, and level off at about eight hours needed per night during puberty and through adulthood. Instead, the past twenty-five years of laboratory and field research have shown that the need for sleep in children does not decline from age 10 to 17 years of age, but remains at nine hours or more per night during the explosion of growth and other body changes of puberty. In addition, the work of Wolfson and colleagues (4) has shown that puberty brings on a biological delay in the circadian timing of sleep, making the preferred sleep onset time for most adolescents after 11 p.m. These adolescent biological sleep needs, as well as psychosocial pressures to remain awake later at night, clash with early school start times, leading to the net result that adolescents get significantly less than the optimal 9.2 hours of sleep per night, particularly during school nights (5–7). A 2006 poll conducted by the National Sleep Foundation on 1600 adolescents nationwide found that more than half (56%) of teenagers report getting less sleep than they need to feel rested during the school week (8). The often serious impact of this chronic under-sleeping is now evident in both high school and middle school students.

For all students one of the most salient—and correctable—social factors contributing to student sleep deprivation, is school start times. This chapter will review the developmental sleep needs of adolescents, the accumulated evidence documenting sleep deprivation imposed by earlier school start times, and its detrimental effect on learning and behavior. Finally, this chapter will discuss the positive impact on students' health that delaying school start times has demonstrated in several communities across the U.S.

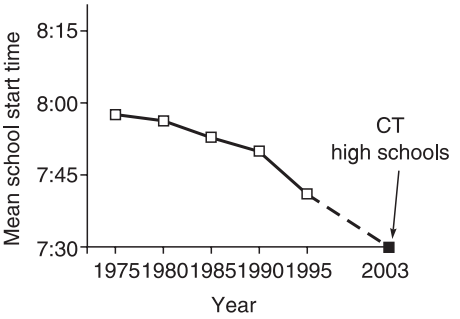

FIGURE 1 Average scheduled start times of high schools in Providence, Rhode Island school districts through 1995 (2), and in Fairfield County, Connecticut through 2003.

DEVELOPMENTAL SLEEP NEEDS IN ADOLESCENTS

The first longitudinal study of sleep need in adolescents took place at the Stanford Sleep Disorders Center "summer sleep camp" conducted by Drs. Mary Carskadon and William Dement, in the late 1970s. Pre-pubertal children aged 10–12 years were evaluated prospectively during consecutive summers over the course of four to six years. Biological age was determined by Tanner stage (assessment of appearance of secondary sex characteristics as indicator of pubertal stage) to insure uniformity of developmental groups. Notably, nocturnal sleep studies were designed to allow a maximum time in bed of up to 10 hours because prior research had established on average a maximum 10-hour sleep requirement for this age group. The chief hypothesis was that as children matured, sleep need would decrease until reaching a nadir of eight hours sleep, the adult requirement. Both diurnal and nocturnal sleep was assessed with polysomnography. In contrast to the expected result, not only did pubertal children require more sleep than predicted, but they demonstrated significant daytime sleepiness despite even 9–10 hours of sleep at night (5), consistent with a higher incidence of sleep deprivation. One manifestation of this was that a greater number of older adolescents than young adolescents had to be awakened as the 10-hour time in-bed limit was reached. Optimal sleep length in adolescents was shown to be 9.2 hours per night (9). No gender differences in sleep patterns were observed in these early studies.

Additional research over the past twenty-five years has reinforced and extended these initial findings. Laboratory studies confirmed the need for 9–10 hours in older adolescents (10). Comparative studies have identified some differences in sleep practices and challenges among adolescents from 11 European countries (11), but the underlying biological sleep need appears to be relatively constant among growing children everywhere.

Normal adolescent sleep is an essential physiologic component of healthy development. The huge changes in body development during adolescence are directly linked to the sleep process. Growth hormone is released in conjunction with slow-wave sleep during the night, and the development of secondary sex characteristics also depends upon the secretion of the gonadotrophic hormones during sleep (12). These critical physiological processes are highly conserved, but

can be significantly affected in situations that alter adolescent sleep patterns such as sleep deprivation, illness, or the use of substances or certain medications. In addition, normal sleep appears to serve a vital role in learning new skills, both by fostering memory encoding and consolidation (13), and by facilitating the generation of insight that solves complex problems (14). Getting adequate dream (rapid eye movement [REM]) sleep is essential to perceptual, cognitive, and emotional processing. Selective REM sleep deprivation has been demonstrated to cause symptoms of irritability and moodiness, as well as problems with memory (15). The issue of under-sleeping in adolescents takes on added significance when one considers that waking up too early costs the sleeper mostly REM sleep which predominates during the last two to three hours of a night's sleep.

CIRCADIAN BIOLOGY OF SLEEP IN ADOLESCENCE

Many parents and teachers become frustrated that adolescents seem to create their own problem of not getting enough sleep by choosing a late bedtime, despite their complaints of sleepiness in the morning. However, there are multiple factors that contribute to later bedtimes, and it is increasingly clear that adolescents stay awake later largely for biological, not social, reasons. As with adults, the physiological factor that most powerfully regulates the timing of waking and sleeping in adolescents is the circadian rhythm, a hard-wired "clock" in the suprachiasmatic nucleus (SCN) of the brain (16). The SCN determines whether one is an "evening-type" or a "morning-type" by setting the timing of wakefulness relative to exposure to morning sunlight. In addition to determining the timing of wakefulness, the circadian rhythm system also *drives* alertness increasingly throughout the day, right up until the biological bedtime, when this drive for alertness is withdrawn (Fig. 2). This circadian-dependent wakefulness allows extended periods of waking despite rising levels of sleepiness as the day progresses (17). This underlying physiology is very clear from many lines of research in humans, and other animals with similar circadian biology (18).

In 1993, Carskadon and colleagues (19) demonstrated that more mature self-reported pubertal ratings in sixth-grade girls was associated with a delay in circadian sleep timing as evident in increasingly greater "eveningness" scores. Subsequent studies more precisely demonstrated that advancing Tanner stage of puberty evokes a delay in the secretion of melatonin by about an hour (2). These findings indicate that a change in the biological system regulating circadian timing appears to accompany puberty, which prompts later timing of sleep seen during adolescence. This puberty-linked delay in sleep timing has been confirmed in studies of children in Japan (20), Brazil (21) and Australia (22).

The circadian rhythm also underlies the common problem of "Sunday night insomnia." Sleeping-in on weekend mornings tends to shift the underlying circadian rhythm to even later timing, making it more difficult to reset the circadian clock for early school rise times on Monday morning (2). Thus, teens who regularly sleep in over the weekend will likely experience a harder time waking for school on Monday, and greater performance impairments during the morning as they struggle with alertness, especially early in the week.

The fact that teens' late bedtime is a reflection of their biology rather than a social choice is illustrated by data collected on the sleep habits of young recruits to the U.S. Navy (23). In 2000, the young men (predominantly ages 17–19) at the

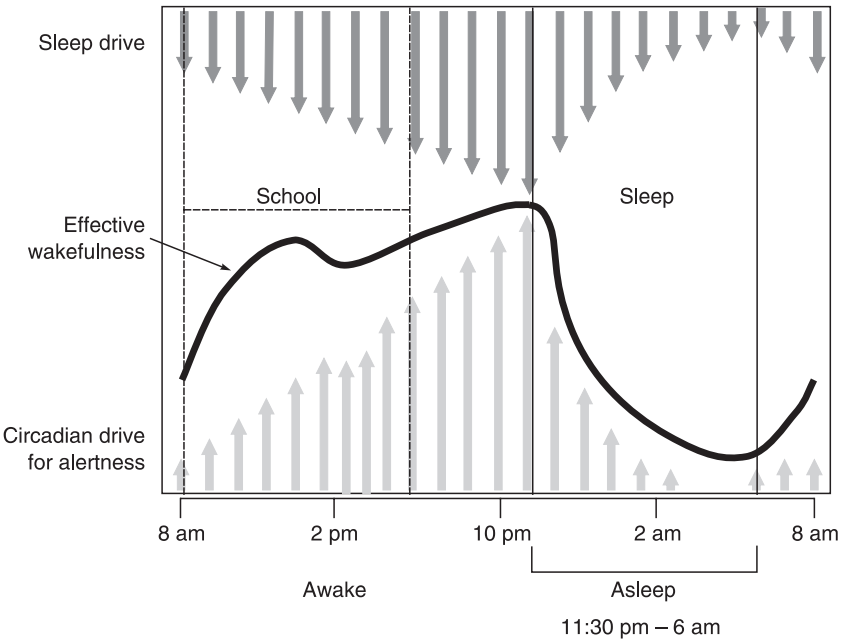

FIGURE 2 Physiology of sleep and wake in an adolescent. Sleep Drive (downward arrows) is the physiologic pressure to return to sleep that begins to build upon waking from sleep. This drive is satisfied by normal sleep, and reduced to near zero at the end of a full night's sleep. If less than a full night's sleep occurs, residual sleep drive (a.k.a., sleep debt) remains upon waking, and is carried forward along with the additional sleepiness that builds normally during wakefulness. The effect of the sleep drive is opposed by the increasing Circadian Drive for Alertness (upward arrows), which increases in intensity as the day progresses, with a short mid-afternoon lessening (the "siesta"). The onset timing of the Circadian Drive is cued by the brain's circadian rhythm pacemaker, the suprachiasmatic nucleus (SCN), a hard-wired pacemaker that determines whether one is an "evening-type" or 'morning-type'. Note that the Alerting Drive is maximally effective in the evening up until the biologic bedtime when the support for alertness is rapidly withdrawn, allowing night time sleep to occur. The cumulative effect of both these opposing drives manifests as one's Effective Wakefulness. In this example, biologic bedtime allows sleep onset by 11:30 p.m. and Sleep Drive is not fully satisfied (residual sleepiness remaining) by the early rise time of 6:00 a.m. Note also that the Effective Wakefulness in this teen is low at school start time of 8:00 a.m., rising rapidly to more effective levels by 10–11 a.m.. Adapted from Ref. (24).

Navy's academically and physically demanding training camp were scheduled to sleep from 10:00 p.m. to 4:00 a.m., allowing only six hours of sleep. To address visible signs of sleepiness among the men, in 2001 Navy officials added another hour of "rack time": from 9:00 p.m. to 4:00 a.m.. Though the young recruits were forced to retire at 9:00 p.m., they were not able to fall asleep despite lying quietly in their dark bunks because they simply felt "awake." Like other teens, these young men could not override their circadian-dependent sleep schedule even if commanded to do so. However, the following year, when sleep hours were shifted to 10:00 p.m. to 6:00 a.m., not only were the recruits able to fall asleep more easily but

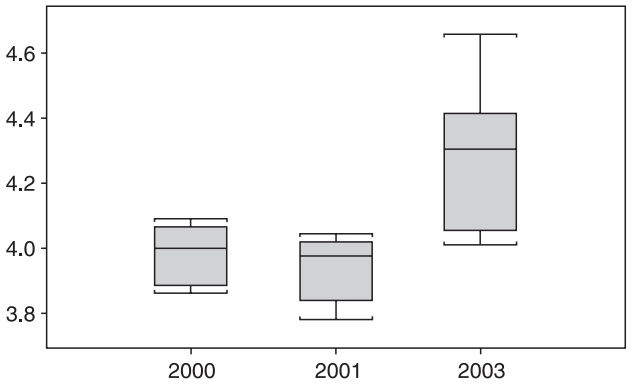

FIGURE 3 Grade averages for standardized test (ASVAB) scores of students at U.S. Naval training academy during years with schedule allowing six hours of night time sleep 3.97 (2000) and 3.94 (2001); and after scheduled night time sleep was increased to eight hours per night 4.28 (2003). (Attrites removed; p-value = 0.0004). Figure adapted from Ref. (25).

the added hours of sleep made a dramatic impact on their daytime performance. The average standardized test scores increased significantly when recruits were scheduled to allow eight hours of sleep at conducive times (Fig. 3). In addition, the number of "sick calls" decreased by 70%, and the rate of attrition decreased by half when the recruits were allowed more time for sleep.

The circadian biology of sleep would predict that among individual children, those who are predisposed to be "night owls" would be even more likely to suffer the consequences of sleepiness in a school system that imposes start times before 9 a.m. A recent, comprehensive survey of 6331 14–18-year-old students in Italy examined the role of individual circadian preferences on sleep symptoms and school performance utilizing the validated "Morningness/Eveningness Questionnaire" (26). As expected, students with the trait of "eveningness" were significantly more likely to report later bedtime and wake-up time, especially on weekends. As a result, this group also reported more irregular sleep–wake schedules, and subjectively poorer sleep than their "morning-type" counterparts. Moreover, evening types napped more frequently during school days, complained of daytime sleepiness, and had more behavioral and psychiatric comorbidities. This chronotype also reported greater use of caffeine-containing beverages and substances to promote sleep. No significant sex differences were reported in the eveningness scores of the students studied, consistent with the gender-neutral biology of circadian rhythm systems. This data confirmed earlier results from studies showing that students with an evening-type circadian preference had more difficulty adjusting to earlier start times and got less total sleep than their morning-type peers (27–29). These studies demonstrate the significant impact that underlying circadian rhythm biology can have on adolescent students, especially those whose individual biology is even less suited to early school start times.

In brief, there are two features of the circadian rhythm especially important to understand regarding sleep in teenagers: (1) the drowsy signal that cues bedtime is dependent on the dampening of circadian-dependent alertness; and (2) the physiology

of puberty causes a shift in the circadian rhythm which delays the timing of this biological bedtime by about an hour. These two biological factors underlie the main difficulties faced by adolescents attending school before 9:00 a.m.: the general problem that one cannot easily fall asleep before their biological bedtime, and the additional problem that puberty creates a tendency for even later bedtimes.

ADOLESCENT SLEEP BEHAVIOR

As children move through puberty, common behavioral changes affecting sleep patterns have been observed. A recent large study compared the sleep habits of children in the U.S. and China, in grades 1–4 with the Children's Sleep Habits Questionnaire (CHSQ). U.S. children reported sleeping an age-appropriate amount of 10.15 hours per night, with average bedtime of 8:46 p.m. and rise time of 7:00 a.m. (30). Interestingly, children of the same age in China reported an hour less of sleep per night (9.25 hours), due to half-hour later bedtime and half-hour earlier rise time, and had higher rates of sleepiness symptoms such as "hard time getting out of bed," though on the whole were rather well-rested. The authors note that children in China routinely take 30 minutes to one-hour naps at lunch time which were not assessed as part of this study, but attributed the decreased night time sleep observed to cultural pressures (smaller living spaces, co-sleeping with parents) and earlier elementary school start time. This study also demonstrated that for both children in the U.S. and China, total sleep time decreased progressively as children matured due to later bedtimes.

Research surveys of adolescent sleep behavior have consistently shown that teens generally obtain significantly less sleep than younger children despite their continued need for 9–10 hours of sleep at night (5,6,31,32). Wolfson and Carskadon (6) reported after measuring total sleep time in over 3000 Rhode Island high school students ages 13–19, that the mean total sleep time on school nights for all the children was well below the 9.2 hours per night needed: sleep per night was only 7 hours 42 minutes among 13-year-olds, and decreased to 7 hours 4 minutes among the oldest children. The sleep loss was due to increasingly later bedtimes in older teens with rise times remaining constant (reflecting school start times). Surprisingly, 45% of 10th to 12th graders went to bed after midnight on school nights and 90% reported going to bed later than midnight on weekends. Weekend sleep time was greater, but average weekend total sleep decreased from 9 hours 20 minutes in the youngest children to 8 hours 38 minutes in the oldest teens. Notably, few differences were found between male and female high school students' sleep/wake patterns. Surprisingly, the sleep timing of the teens studied was consistent across a broad range of socioeconomic backgrounds among the participating schools, suggesting that their bedtime reflected factor(s) common to the group as a whole, such as their underlying biology.

On the other hand, surveys consistently demonstrate that teens are often busy with activities in the evenings. Recent studies have begun to clarify when, and to what extent these activities are responsible for postponing bedtime beyond an adolescent's biologically-driven sleep timing. Teens spend increasing amounts of time with out-of-school activities as they get older and face mounting academic pressure as well. Many students also choose to take on part-time jobs after school. Carskadon (33) demonstrated that 11th and 12th grade students who work 20 hours or more per week at part-time jobs report more problems getting adequate sleep,

and problems being alert in school. Further, Wolfson (34) found that for every 10 hours per week of part-time work, a student lost an average of 14 minutes of sleep per night. These studies show that students who cut short their sleep due to work hours were significantly more likely to report drowsiness while driving, school tardiness, and substance abuse. A growing number of high school students enter the workforce during the school year, and the increasing pressures of consumerism make it likely that this trend will only continue.

In addition to scheduled hours for study, extracurricular events, and work, teens are increasingly surrounded by electronic devices and other activities that can interfere with getting to bed "on time." Though young children depend upon their caretakers to provide an appropriate environment, regular bedtimes, and other habits that promote good sleep, teens must begin to employ these habits for themselves. A few research studies have examined the impact of adolescents' sleep hygiene practices on their night sleep. In Canada, a survey of over 3000 high school students found that bedtime habits such as staying up late or drinking caffeinated beverages before bed were significantly associated with sleep debt and excessive daytime sleepiness (35). As sleepiness scores (Epworth Sleepiness Scale scores of > 10) increased in these teens, there was an increase in the proportion of students who felt their grades had dropped because of sleepiness, were late for school, were often extremely sleepy at school, and were involved in fewer extracurricular activities.

An even more detailed evaluation of sleep hygiene in teens has been contributed by LeBourgeois and colleagues in their comparative study of 12–17-year-old students from Hattiesburg, Mississippi and Rome, Italy (36). This study utilized adolescent-specific sleep assessment tools (the Adolescent Sleep Hygiene Scale, ASHS; and the Adolescent Sleep–Wake Scale, ASWS) to identify specific sleep habits and their effects on measures of sleep quality. Teens answered questions about their sleep behaviors in the past month, and rated the frequency of any problems with their sleep quality, where good sleep quality was defined as: one goes to bed easily at bedtime, transitions effortlessly from wakefulness to sleep, maintains undisturbed sleep, re-initiates sleep after nocturnal arousal, and transitions easily from sleep to wakefulness in the morning. Interestingly, the Italian adolescents reported significantly higher sleep quality and better sleep hygiene practices than the Americans. U.S. students were more likely to report problems with sleep due to physiological factors (e.g., being very active before bedtime, going to bed hungry), and cognitive factors (e.g., going to bed after playing video games). Notably, U.S. students had substantially higher rates of medical illnesses and use of medications than the Italian students, though it was not clear how much this contributed to their poorer sleep measures. Though the two populations had significant racial differences (Italian 99% Caucasian vs. U.S. 78% black students), the authors found that this did not appear to account for the variance in sleep quality. Rather, sleep measures corresponded most closely to individual reports of sleep hygiene practices. However, the authors add that better sleep hygiene observed in Italian teens may have been influenced by the cultural tendency for comparatively more parental supervision in the older students. Indeed, self-report data on bedtimes in U.S. children demonstrate that the percentage of students who report a "parent" is the reason for the time they went to bed on school nights decreased from 50% among 10–11-year-olds, to less than 5% among 14–18 year olds (37).

Adolescents often sleep later on weekend mornings to "catch up" on sleep, but also tend to choose even later bedtimes as well. This well-known behavioral pattern creates a weekday/weekend discrepancy in sleep timing that makes Sunday night bedtimes even more difficult. Petta et al. (38) demonstrated more than 20 years ago that children averaged 30–60 minutes more sleep on weekends as 10–14-year-olds and this difference increases to over two hours of "catch-up sleep" by age 18. This pattern of rising sleep debt during the week followed by weekend catch-up still leaves most teens sleep-deprived by an estimated 10 hours sleep per week.

A recent study of teens in Busan, Korea demonstrates a more extreme example of behaviorally-induced sleep deprivation (39). Using the School Sleep Habits Survey among children from grades five to 12 means school night sleep time was found to be eight hours or more for 5th and 6th graders but dropped to an appalling 4.86 hours a night for 12th graders! The authors found that school night sleep time was "dramatically shortened" when students entered high school in 10th grade (mean school night sleep time 6.02 hours). Though the high school's earlier school start time contributed to the problem, the intense competition for college entrance exams coupled with other cultural factors appeared to be the main impetus for older students' sleep restriction. Mean bedtime hours for these Korean adolescents was 12:54 a.m. in 11th and 12th grade, and many students reported self-imposed added study time, along with part-time jobs as contributing factors. Though weekend sleeping-in was apparent, it was not nearly enough to make up for the serious under-sleeping found in these students.

Adolescents are developmentally challenged with learning to make good choices for themselves, (and hopefully to embrace parental guidelines, much as they may desire to rebel against them), and in the realm of sleep habits there are many choices that can interfere with a teen's sleep. Several recent studies have shown that adolescents have a general lack of knowledge about sleep and healthy sleep habits in the U.S. and abroad (40,41). However, an intervention-education program to teach healthy sleep habits to middle-school students has been shown to significantly improve their sleep patterns and increase total nighttime sleep (42,43). Arming teens with this self-knowledge is an essential component in addressing their sleep problems.

EARLY SCHOOL START TIMES AND ADOLESCENT SLEEP PROBLEMS

The idea that being better rested is more conducive to better learning is certainly a compelling, some would say "common sense" idea that many people can relate to directly from their personal experiences. That adolescents across the world are found to be increasingly sleepy in school is also virtually undisputed. However, the hypothesis that adolescent sleepiness is at least partially due to schools starting too early is less widely embraced, in part because accepting its premise has far-reaching implications for educators and communities that have evolved around earlier school start times. The relationship between school starting time and the sleep and wellness of adolescents has been examined in detail (37,44,45), and it is clear that teens' biology is simply not suited to optimal learning and health when school schedules are too early. Though what "too early" means is still not precisely proven; available data so far point to 8:30 a.m. being the earliest time for effective learning in older adolescents.

The first study to directly examine the effects of school start times on adolescents' sleep habits was a longitudinal field study conducted in a group of Rhode

Island students in the early 1990s (6). Students were studied prospectively in the spring of 9th grade, the following summer and the fall of their 10th grade, with a subgroup monitored again in the spring of 10th grade. During ninth grade they attended middle school that began at 8:25 a.m.; the following year in 10th grade they attended high school which began at 7:20 a.m. Students were assessed both in the home environment and in the laboratory for sleep amounts, sleep timing, and daytime alertness. This pivotal study demonstrated that both ninth and tenth graders went to sleep at similar times, but the tenth graders had significantly less sleep on school nights due to earlier rise times. The tenth graders showed significantly greater daytime sleepiness: mean sleep latency on four naps across the day of a Multiple Sleep Latency Test (MSLT) of 8.5 minutes compared with 11.4 minutes for 9th graders. The sleepiness was especially marked in the older students on the first test of the morning at 08:30 hours: sleep onset was 5.1 minutes—a pathological level of sleepiness similar to that seen in sleep disorders such as narcolepsy. Further, at least one REM sleep episode was observed in 48% of the tenth graders, consistent with underlying REM sleep deprivation from truncated sleep on school nights. Essentially, this was the first study to demonstrate that adolescents who transition to an hour earlier school start time experience a corresponding biological consequence: clinically significant sleepiness.

The problem of early start time-related sleepiness in high school students is evident in other Westernized countries as well. The "school duty schedule" was found to be the major determinant of sleepiness and earlier waking times for a group of Polish students age 10–14 who were under-sleeping during the school week, with delayed waking times on weekends (46). A large, longitudinal survey of Icelandic children (47) that examined individual sleep habits over a 5–10 year period found that significant daytime sleepiness and naps increased in adolescence, as progressively earlier wake-up times for school occurred. Similarly, a large survey study of 3235 high school students in Canada found 70% reported sleeping fewer than 8.5 hours per night, and the majority of students reported feeling "really sleepy" between 8:00 and 10:00 a.m., consistent with the expected timing of their underlying circadian clock, and the effects of sleep deprivation. As might be expected, even pre-adolescent fifth grade students reported significant sleep deprivation when an extremely early school start time of 7:00 a.m. was imposed in Israel (48).

We found that self-reported sleep amounts in adolescents has continued to worsen as high school start times have gotten even earlier since the last survey in our region by Carskadon and colleagues in 1998 (49) (Fig. 1). Other chapters in this text offer a detailed discussion of the psychological and behavioral effects of sleep deprivation in adolescents, but is important to review here some of the data illustrating the consequences of sleep deprivation in the context of early high school start times. There is ample evidence that excessive sleepiness due to chronic undersleeping impairs cognitive functioning (50). As sleepiness rises, critical higher cortical processes are essentially turned off as the brain prepares for sleep. Sleepiness in children as well as adults makes it harder to sustain attention and stay on task, interferes with memory, decreases creativity, the ability to multitask and make effective choices, and increases impulsivity and irritability (44,51–53). Further, installing new memories—i.e., learning—clearly benefits from, if not depends upon, intervals of normal sleep (13). Given this, it should be no surprise that adolescents who are found to be sleep-deprived also report more attentional difficulties,

poorer academic performance, and less interest or involvement in extracurricular activities (29). Wolfson and Carskadon's study of over 3000 high school students (3) found that students who were struggling or failing academically (i.e., they reported obtaining more Cs, Ds, Fs) also reported being more sleepy, having later bedtimes and more irregular sleep/wake schedules than students with better grades (As and Bs). Students who report being sleep-deprived due to later bedtimes are much more likely to fall asleep in school, particularly in the morning classes, compared with their peers enrolled in schools with later start times (50). More total sleep, earlier and consistent weekday bedtimes, and later weekday rise times are consistently found to correlate with better grades in school (7,32,48,55).

In addition to the impact of sleep deprivation on school performance, adolescents who obtain less than six hours of sleep per night report significantly more feelings of depression, anxiety and high-risk behavior (56). The emotional lability and social stresses that all adolescents experience are further aggravated as a result of sleep deprivation. The detrimental effects of sleep deprivation on judgment and insight are especially concerning when one considers the high incidence of alcohol and substance use among adolescents. Indeed, substance use is greater among teenagers with sleep difficulties (57,58). For example, Giannotti and colleagues (26) found that the more sleep-deprived "evening-type" Italian high school students experienced significantly greater problems with attention, poor school achievement, more injuries and were emotionally upset more than the morning-type students. These students also reported greater consumption of caffeine-containing beverages and substances to promote sleep. Sleep deprivation, and poor sleep quality also increase the likelihood of interpersonal problems and psychiatric illness (58,59). While many students are able to function well in school with shorter amounts of sleep, they may pay a price in other ways such as emotional instability, argumentativeness, and disturbed social interactions. One unintended consequence of the earlier school schedule is the amount of unstructured time some teens are faced with after school in the afternoons. This "self-care" time lends itself to greater risk taking, and has been correlated with increased substance use and depressed mood (60). Indeed, juvenile crimes are four times more likely to occur in the hours after school than at other times during the day or night (44).

Perhaps the most dramatic and potentially devastating consequence of sleep-deprivation in teens is car accidents. Students who drive themselves to school early in the morning are at even greater risk of a fall-asleep at the wheel car accident because of the combined effects of their greater cumulative sleep-deprivation, and the challenge of operating a vehicle before their circadian-dependent alertness is fully engaged. These factors, compounded by their lack of driving experience, are cited as the reason that the peak age of sleep-related car crashes is 20 years, and the peak time of accidents is between 7:00 and 8:00 a.m. (61). In sum, early school start times clearly contribute to sleep-deprivation in growing teens, making them even more vulnerable to all the challenges of adolescence, and increases the likelihood of accidents, psychological problems, and impaired learning in school.

BENEFIT OF DELAYED SCHOOL START TIMES ON ADOLESCENT SLEEP AND BEHAVIOR

There are so many negative consequences associated with sleep deprivation in adolescents that school leaders in many areas are beginning to consider the practical

measures that would improve total sleep time for their students to promote their health and learning. Though research has not yet identified an ideal school schedule, the wealth of evidence reviewed in this chapter and elsewhere strongly suggests that students have a better opportunity to be rested and ready to learn by delaying school start time to 8:30 a.m. or later.

Initial data documenting statistical improvements in academic performance, mood and attendance after a delayed start time in the Edina, Minnesota school district prompted the first large-scale longitudinal study of the effects of delayed school start time in Minneapolis-St. Paul, Minnesota (44,45). The School Start Time Study was a comprehensive investigation of the impact of a district-wide delay in high school start time for the 1996–1997 school year. Outcomes were collected from over 18,000 students beginning two years prior until three years after high schools changed their start time from 7:15 a.m. to 8:40 a.m. This was a landmark study not only because it documented the impact of such a potentially important determinant of students' educational experience, but also because the study included elements that reflected the changes to the community as a whole. This study demonstrated multiple benefits to the students as a result of the delayed schedule: increased daily attendance and reduced tardiness, increased rates of continuous attendance and graduation, and overall improvement in student academic performance. Surveys of teachers demonstrated a qualitative leap in the school morale as a result of the later schedule, with comments like "there is an alertness in the students coming into school that I haven't seen in many, many years." Administrators reported the school seemed "calmer" and were impressed with the attendance changes. Parents cited some of the challenges, like "eats dinner later because of sports, no time for a job," but also "less stressful mornings," "breakfast never missed," and "the later start time is very beneficial, both relative to grades and to energy level." Many parents also commented "fix the middle schools too!" The vast majority of the students approved of the change in start time.

In addition to evaluating the students in the Minneapolis-St. Paul districts, the School Start Time Study also surveyed secondary schools in neighboring districts with school start times between 7:20 a.m. and 8:40 a.m. This study demonstrated that for all six grade levels (7–12), there was a significant increase in the reported academic grades with progressively later start times. Academic performance was poorest across the board at schools starting before 7:30 a.m., and the most rapid increase in performance was seen between 7:30 a.m. and 8:00 a.m. for 7th and 8th grade students. Whereas 11th and 12th grade students showed only modest improvement academically as start times were compared between 7:20 a.m. and 8:00 a.m., but rapidly accelerated academic grades when start times were 8:15 a.m. and later. These data are consistent with the known underlying circadian phase biology of adolescents, though the author is careful to point out this does not prove a causal relationship between start times and grades.

In 1999, the Fayette County Kentucky school district delayed their high school start time by one hour to 8:30 a.m. Dr. Fred Danner compared accident rate data for the 17- and 18-year-old age groups before and after the school start time delay. He found that following the school start time delay, teen crash rates in that district dropped by 15.6% while crash rates throughout the rest of the state *increased* by 8.9% during the same time period. He is quick to point out that other factors besides additional sleep time may have accounted for the dramatic difference in accidents in this age group (e.g., increased school bus ridership and fewer teens driving to

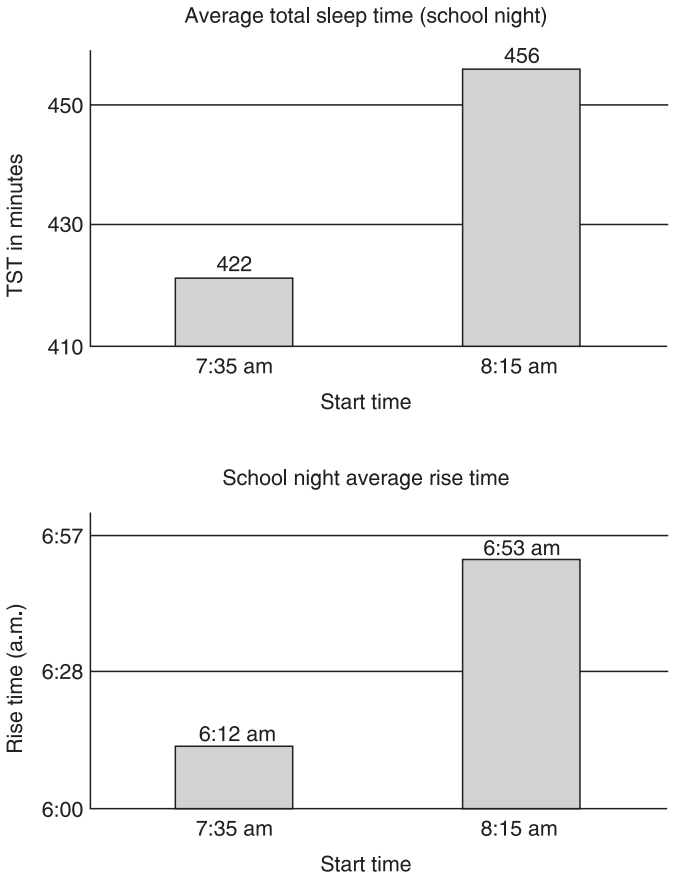

FIGURE 4 Sleep changes in high school students after a 40-minute delay in school start time. Students attending Wilton High School (Wilton, CT) were surveyed with the Condensed Sleep Habits Questionnaire in 2001 and 2002 (N = 297) when school start time was 7:35 a.m. (mean ± S.D., 422 ± 60 minutes), and again in 2004 (N = 977) after the school start time was delayed 40 minutes (mean ± S.D., 456 ± 55 minutes; $p>0.0005$) Average total school night sleep time (top graph) increased by 34 minutes after the schedule change allowed students to delay their school day rise times (bottom graph) by an average of 41 minutes later (before mean ± S.D., 6:12 a.m. ± 24 min; after mean ± S.D., 6:53 a.m. ± 28 minutes).

school). However such a sizable reduction in accident rate in this highly vulnerable population is remarkable, and that it follows the delayed high school start time is consistent with the expected outcome of less sleep deprivation among teen drivers.

Recently, our laboratory performed a study of high school students in Wilton, Connecticut before and after their high school chose to delay its start time by 40 minutes to 8:15 a.m. (Fig. 4). Our goal was to evaluate whether teens actually took advantage of this schedule adjustment to get more sleep, or whether they simply used the extra time for more late-night activities, as some feared would happen. We found that student bedtimes were essentially unchanged compared

with before the schedule change, but later rise times were reported such that they obtained nearly all of this time as additional sleep. Rather than extending their waketime activities at night, students got to "sleep in" before school. As a result, students benefited from a significant increase in their overall weekly sleep amounts after the school start time was delayed. Student self-report measures of daytime sleepiness dropped significantly after the schedule change but at least one third of students reported still having "problem sleepiness" some of the time. Because of the overwhelmingly positive response among students, teachers and parents to the schedule change, other communities surrounding this high school are considering similar schedule changes to promote healthy sleep for their students.

As the magnitude of the problem is often unrecognized, and school schedule adjustments at least initially are met with resistance for practical reasons, studies like ours will help provide necessary data that these changes are effective. Indeed, it is likely that a longer delay in start time than was adopted in Wilton could have an even greater benefit for students, given the number of teens who reported continuing to experience significant sleepiness. However, it is reassuring that the new schedule did result in increased sleep and the impact was so widely apparent. It is almost assumed that insufficient sleep is the normal right of passage for high school and college students, but is this problem of insufficient sleep the beginning of problems with sleep in adults? Could insomnia, anxiety and depression, psychosomatic disorders and the widespread use of stimulants in adults have their genesis in the poor sleep patterns that develop in adolescence? The answers to these questions await further research.

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