School Start Times and the Sleep–Wake Cycle of Adolescents: A Review and Critical Evaluation of Available Evidence

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The authors have integrated the major findings on the sleep–wake cycle and its performance correlates in adolescents. Basic research shows that lack of synchronicity between early school start times and the circadian rhythm of adolescents (and the sleep debt accumulated as a result) involves several cognitive correlates that may harm the academic performance of adolescent students. The authors therefore examined findings from pilot interventions in which schools delayed their start times; specifically, they examined the effects on students, including potential pitfalls and strategies to consider for effective scheduling change. There is sufficient evidence that adolescent students would benefit from delaying school start times and that this change can be implemented with tolerable consequences if adequately strategized by school districts and communities.

Keywords: circadian rhythm; school starting times; sleep; student performance

As children grow into adolescents, they tend to experience changes in the sleep–wake cycle, causing them to exhibit a natural preference to go to bed later and wake up later in the day (Carskadon, 1999, 2002; Dement & Vaughan, 1999). Although in the past this change in the sleep–wake cycle was attributed to cultural and psychosocial factors (see the review by Millman et al., 2005), most recent research points to a change in specific biological processes during adolescence as a primary determinant of this delayed sleep cycle (Carskadon, 1999, 2002; Fischer et al., 2008), which has been coined *delayed phase preference* (DPP; Mitru, Millrood, & Mateika, 2002).

Previous studies have shown a strong relationship between various features of the sleep–wake cycle, affective states, and cognitive performance (Schmidt, Collette, Cajochen, & Peigneux, 2007). Therefore, it is not surprising that researchers and educators alike are concerned with the study of DPP and how it may influence the academic achievement of adolescents. More specifically, researchers and educators are exploring the possibility of having schools accommodate DPP in adolescents by delaying start times, for the sake of improving academic performance in the student population.

In this article, we review the most current research on the topic of DPP and discuss the impact of schools' setting later start times. More specifically, we focus on the following issues: relevant features of the sleep–wake cycle; how the circadian typology of an individual typically changes over the life span (i.e., DPP in adolescents); the behavioral and cognitive correlates associated with performing different tasks at different times of day and their repercussions in an academic context; case studies; and finally, considerations for implementing a change in start times. However, the present review will not address in detail an economic benefit–cost analysis because 1980 research linking DPP to vital statistics regarding adolescent students has unequivocally demonstrated the hidden and nonhidden, potentially incalculable costs to society (see reviews in Kryger, Roth, & Dement, 2000). We hope the reader will keep these incalculable costs in mind as critical context for our article.

The Sleep–Wake Cycle

Blatter and Cajochen (2007) explain that there are two key phenomena that characterize the sleep–wake cycle in humans: Sleep readily occurs at specific times of the day, and although we are prone to experiencing fluctuation in our level of sleepiness throughout the day, the longer we go without sleep, the more difficult it becomes to resist its onset. These features of the sleep–wake cycle are thought to reflect two opposing yet simultaneous processes: the circadian rhythm and the homeostatic drive for sleep. The circadian rhythm, which oscillates within a period of approximately 24 hours, has been described as "a clock-like process independent of whether the person is asleep or awake that is normally synchronized with external time (i.e., time of day)" (Blatter & Cajochen, 2007, p. 201). The circadian rhythm can also be described as a wake-promoting system, increasing wakefulness at a regulated time of day (Blatter & Cajochen, 2007; Edgar, Dement, & Fuller, 1993). This circadian process acts in direct opposition to the homeostatic drive for sleep, which represents a sleep-promoting process. The homeostatic drive for sleep accumulates during time spent awake and decreases during time spent asleep.

In general, according to this two-process model, an individual will become sleepy when the homeostatic drive for sleep is exerting

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greater influence than the wake-promoting circadian process, and the individual will feel awake when the opposite is true. This model of sleep, involving these two opposing processes, was originally developed to predict and explain human sleep regulation; however, researchers are now using it to help explain task performance, which has been found to be mediated by these processes (Blatter & Cajochen, 2007).

Circadian Typology of Adolescence: Delayed Phase Preference

Individuals exhibit different preferences regarding the best time of day to be awake and to be asleep; this preference is called the *chronotype* of an individual, the extremes of which are morning preference and evening preference. Previous research has found that the evening preference chronotype, which is most prevalent in adolescents (Yoon, May, & Hasher, 1999), is correlated with pubertal development; this means that adolescents who are older and more mature (in terms of pubertal development) show greater evening preference than do younger, less mature adolescents (Crowley, Acebo, & Carskadon, 2007; Giannotti, Cortesi, Sebastiani, & Ottaviano, 2002).

This DPP in adolescents is not a recent discovery; however, it was previously believed to have been mediated exclusively by behavioral factors such as social and academic pursuits (Crowley et al., 2007). Although behavioral factors appear to play a role in determining chronotype, as evidenced by reports of adolescent social and entertainment activities (e.g., the Sleep in America Poll by the National Sleep Foundation, 2006), there is a growing body of evidence that implicates biological changes at the onset of puberty as being major determinants of DPP (Crowley et al., 2007). At least partially determined by intrinsic biological factors, the lengthening of the circadian oscillation period, a slower accumulation of the homeostatic drive for sleep, and a greater requirement for sleep during adolescence have all been cited as likely contributors to DPP (Carskadon, 1999; Carskadon & Acebo, 2005; Crowley et al., 2007; Taylor, Jenni, Acebo, & Carskadon, 2005; Wright, Gronfier, Duffy, & Czeisler, 2005). These findings indicate that educators and parents may not be able to simply restrict or encourage certain behaviors for the purpose of reducing DPP. Telling adolescents to go to bed earlier will not necessarily attenuate DPP, as certain contributing factors are intrinsic to the development of healthy adolescents.

Cognitive Correlates of the Sleep Cycle and Implications for School Start Times

Multiple studies have shown that various forms of cognitive performance fluctuate according to the time of day (e.g., May, 1999; Petros, Beckwith, & Anderson, 1990; Yoon et al., 1999). The two-process model introduced earlier, composed of the homeostatic drive for sleep (process S) and the circadian wakefulness process (process C), provides a useful paradigm for analyzing the various stages of the sleep–wake cycle and how they relate to various measures of cognitive performance.

In general, the accumulation and intensification of process S, representing the homeostatic drive for sleep (also known as *sleep pressure*), is associated with a decrease in cognitive performance and an increase in perceived sleepiness (Schmidt et al., 2007). However, in spite of the accumulation of sleep pressure during waking hours, cognitive performance can remain stable and even increase throughout the day, depending on the relative magnitude of process C (Cajochen, Blatter, & Wallach, 2004). This established relationship between processes S and C and cognitive performance often holds true; however, research into specific components of cognition has revealed that the relationship between the sleep–wake cycle and cognitive performance is largely task dependent. Variables such as the duration, difficulty, and cognitive domain of a task have been shown to influence the specific effects of the sleep–wake cycle on cognitive performance (Bonnet, 2000; Schmidt et al., 2007).

Although more research needs to be conducted regarding the separate components of cognition and the sleep–wake cycle (because various components of cognition have been shown to differ in their responses to the influence of the sleep–wake cycle), there are some confirmed findings that may be helpful in determining optimal school schedules for adolescents:

1. Synchronicity effects (i.e., when optimal performance is generally achieved at the peak time of day as determined by chronotypology) have been found in performance on measures of attention (Cajochen, Khalsa, Wyatt, Czeisler, & Dijk, 1999; De Gennaro, Ferrara, Curcio, & Bertini, 2001; Kirby & D'Angiulli, 2009; Schmidt et al., 2007) as well as in explicit and working memory (see Schmidt et al., 2007). However, research on *implicit memory*—memory that is acquired and expressed without conscious mediation—has not found the same synchronous relationship between the circadian rhythm and performance (May, Hasher, & Foong, 2005); this finding will be discussed in a later section.
2. Performance on tasks measuring executive functions (which control the content and execution of cognitive processes and protect cognitive activity from distractions) demonstrates significant modulations by time of day. For adolescents, optimal performance on such tasks occurs later in the day (May, 1999; Yoon et al., 1999).
3. Sleep debt (cumulative sleep loss) also has been shown to contribute to an inability to concentrate, memory lapses, difficulty in accomplishing tasks that require planning or following a complex sequence of actions, and a decrease in creative thought (Carskadon, 1999; Dinges & Kribbs, 1991).

Based on these findings, it would seem plausible that setting early school start times for adolescents sufficiently impairs their ability to effectively perform school-related tasks. Early start times are causing adolescents to accumulate sleep debt during the week (Carskadon, 1999; Noland, Price, Dake, & Telljohann, 2009)—some studies have reported that adolescents receive approximately two hours of sleep less than the recommended amount nightly as a result of early start times (Mitru et al., 2002). Furthermore, these start times are causing students to attend class before their circadian wake-promoting process is fully engaged. This combination of factors is likely leading to deficits in academic performance and attendance, as well as to behavioral problems (Carskadon, 1999; Dahl, 1999; Owens, Belon, & Moss, 2010; Wahlstrom, 2010). The results imply that we may be able to optimize adolescent academic achievement and improve not only adolescents' cognitive but also their affective states by delaying school start times so that their circadian rhythms are synchronized with their daily school schedule.

Changing School Start Times: In Practice

Because of the growing evidence suggesting that the evening preference chronotype of adolescents conflicts with early school start times, in the 1997–1998 school year the Minneapolis Public School District changed the start times of seven high schools from 7:15 a.m. to 8:40 a.m. Classes that were formerly dismissed at 1:45 p.m. were rescheduled to end at 3:20 p.m. The Minneapolis School Board asked the Center for Applied Research and Educational Improvement to examine the impact of this change in school start times over the long term (see Wahlstrom, 2002, for details). The findings of this study indicate that the delay in school start times of 1 hour and 25 minutes in the Minneapolis school district resulted in several positive changes in the student population (Center for Applied Research and Educational Improvement, 1998a, 1998b; Wahlstrom, 2002). Perhaps most important is that the students, rather than simply staying up later at night in response to having more time to sleep in the morning, used the extra time in the morning for actual sleep (Center for Applied Research and Educational Improvement, 1998b). Furthermore, the attendance rates for students in Grades 9, 10, and 11 improved from the 1995 school year (early start time) to the 2000 school year, with the greatest increase in attendance noted in Grade 9 students (Wahlstrom, 2002). Parents, teachers, and school administrators also noted significant improvements in student demeanor and a reduction in disciplinary problems (Center for Applied Research and Educational Improvement, 1998a; Wahlstrom, 2002), which is unsurprising considering that the students slept 5 hours more per week when school started later. These results support the conclusion that students are emotionally and cognitively better suited for the later start time.

Those who oppose the change to school start times may cite the failure to find any significant increases in letter grades as a lack of evidence that the change is worthwhile. However, letter grades are not necessarily an accurate and objective measure of policy efficacy; factors such as grade inflation, changes in curriculum, teacher and administrator turnover, changes in the assessment process, and other complicating factors compromise the reliability of letter grades as a valid measure. Wahlstrom (2002) notes that "there are other equally important measures of impact, such as student physical and emotional well being, benefits associated with teaching and learning, and improved family relationships" (pp. 18–19), all of which showed marked improvement after the change in start times.

The Minneapolis study serves as an important example of changing school start times because it is the most thorough longitudinal study to date that demonstrates the lasting effects of changing school start times. It is important to note that other schools that have delayed their school start times have demonstrated similar results, which include an increase in amount of sleep, a positive change in attitudes, and increased alertness (National Sleep Foundation, 2005a, 2005c, 2005e; Owens et al., 2010).

Costs and Other Problematic Issues Associated With Changing Start Times

The monetary costs associated with changing school start times are difficult to generalize, as bus schedules and busing policies (i.e., to whom does the school provide transportation?), the geographical distribution of the student population, the number of schools in the district, and other interdistrict differences all contribute to the costs associated with the changing of school start times. The most commonly cited monetary expense associated with changing school start times is the cost of changing bus schedules; however, for the aforementioned reasons, these costs can vary significantly from district to district. For example, the suburban school district of Edina, Minnesota, and the urban district of Minneapolis, Minnesota, did not find that delaying start times increased transportation costs, as they used the same bus routes as before changing school start times and simply delayed the schedules accordingly (Wahlstrom, 2002).

However, a school district in Fairfax County, Virginia (composed of nearly 200 schools), estimated transportation costs associated with changing school start times at anywhere between $4 million and $40 million (Chandler, 2009). Thus there are systematic differences between districts that can affect the monetary costs. To determine the monetary costs of changing school start times, a district-specific analysis must be conducted.

However, social costs and nonmonetary issues associated with a change in school start times must also be considered before an informed decision regarding changing start times can be made. Researchers, educators, parents, and the general media have cited some complications that may result from changing school start times that should be considered before implementation:

1. Rearranging the transportation schedules has in some cases resulted in high school students being picked up after other student populations (i.e., middle school and elementary school students; Kubow, Wahlstrom, & Bemis, 1999); as a result, these high school students often arrived at school late (Black, 2000), negating the effect of late start times in reducing tardiness (Kubow et al., 1999).
2. Rush-hour congestion may become worse if school buses are on the road later in the day in the morning and afternoon, effectively lengthening the bus ride for many students and potentially creating traffic problems for the rest of the community (W.A.K.E., n.d.).
3. In many families, older siblings babysit younger family members after school, but by keeping high school students in school later in the day, families can no longer depend on their high school–aged children to care for younger siblings. This may force parents to seek other childcare services, which may not be available or affordable (Wrobel, 1999).
4. Teachers', administrators', and other employees' schedules may be inconveniently disrupted (W.A.K.E., n.d.).
5. Extracurricular and athletic activities may be negatively affected. Some schools have had to shorten extracurricular activities as a result of the later school hours. Furthermore, because of interschool differences in class schedules, students from schools with later start times have sometimes sought early dismissal from class (W.A.K.E., n.d.). In an

effort to reduce the negative impact on extracurricular and athletic activities, some schools have rescheduled them to take place in the morning, effectively nullifying the reason for delaying start times in the first place.

6. Student participation in other non-school-related activities may suffer. With delayed school times, students may find it difficult to participate in out-of-school activities such as music lessons, martial arts, dance, gymnastics, and so on (W.A.K.E., n.d.).
7. Students who have part-time jobs may also be adversely affected. Employers may be reluctant to hire students who cannot start work earlier in the day, and later school hours may limit the time when some students can earn much-needed income (Wrobel, 1999).

It is important to point out that of the above complications, numbers 2, 4, 5, and 6 are based on speculation from the Fairfax County School District's deliberations. Although all of these concerns are valid and legitimate, there is evidence that some of those voiced by districts in deliberations can be minimized. As will be shown in the next section, school boards that have introduced later start times have generally been able to mitigate these potential problems through prudent and informed decision-making.

Implementing Change

School boards that have successfully implemented later start times for the benefit of their adolescent students accounted for most of the aforementioned concerns before the inception of any schedule change. We have divided the concerns into the following three categories for the purpose of examining how these successful changes were implemented: transportation issues, non–student body scheduling issues, and extracurricular issues.

Transportation

As previously mentioned, the transportation issues that school districts may encounter will vary according to the features of each district. Thus it is difficult to predict the transportation issues that any one district will encounter without a specific investigation into the features of that district. In instituting a change in school start times, some U.S. districts have had to change elementary and middle school hours of operation as well, in an effort to minimize costs (National Sleep Foundation, 2005a, 2005d). The transportation directors in the Minneapolis study emphasized the importance of staggering the start times of high schools, middle schools, and elementary schools to maximize the efficiency of funds allocated to transportation (Center for Applied Research and Educational Improvement, 1998a). This complete restructuring of transportation scheduling and school hours within a district has the potential to cause significant disturbances to the community as a whole.

Some U.S. school boards have been able to change their school start times without an increase in transportation costs simply by delaying the bus schedule (Wahlstrom, 2002) or switching elementary schedules with high school schedules (National Sleep Foundation, 2005e). One school board saved $750,000 annually by removing transportation altogether for high school students, who instead used the public bus system (National Sleep Foundation, 2005b). And busing is not an issue in some school districts, as many high school students already use public transportation. Because the factors that affect transportation vary from region to region, some school boards have appointed a transportation subcommittee to evaluate the options (e.g., National Sleep Foundation, 2005a), a practice that has proved successful. An analysis of the public transportation system and school schedules in each district is necessary if planners are to understand the consequences that may result from changing school start times, especially for students who are transported by family members or who carpool.

Non–Student Body Daily Scheduling

Schedule disruptions for families, teachers, school administrators, and school staff that can result from changed school start times, including disruptions related to students' extracurricular activities and outside jobs, are of considerable concern. Schools that have successfully implemented a start time change have demonstrated that it is also important to ensure that the public is well informed about and included in the decision-making process (e.g., National Sleep Foundation, 2005a, 2005d, 2005e). School boards that have failed to consult community members before announcing a planned change to start times have met with staunch opposition (National Sleep Foundation, 2005c). The importance of allowing everyone who will be affected by a change in school start times to participate in the decision-making process is paramount if the initiative is to be accepted by the community (Wahlstrom, 2002). The findings of the Minneapolis study show that an overwhelming majority of teachers, administrators, and parents were in favor of the change in start times following its implementation (Center for Applied Research and Educational Improvement, 1998a). However, the findings also suggest that students with later start times tend to work less throughout the week, on both schoolwork and paid jobs, than students with early start times, although possibly for reasons other than the differences in start times (Center for Applied Research and Educational Improvement, 1998b).

Extracurricular Activities

Many who oppose changing school start times cite the disruption of extracurricular activities as a prohibiting factor. Some school boards have successfully implemented a start time change without disrupting extracurricular activities—and, ironically, without having to schedule after-school activities before school—simply by scheduling events later. In fact, results from the Minneapolis study show that later start times did not significantly affect student participation in after-school activities (Center for Applied Research and Educational Improvement, 1998b). The only problem was that some children were pulled out of class early for away-from-school sporting events (e.g., Center for Applied Research and Educational Improvement, 1998a; National Sleep Foundation, 2005e).

Perhaps the most important consideration is that the schools that have successfully delayed school start times with minimal complications had adequate time to prepare, which they spent engaged in research, policy analysis, and a healthy discourse with the public. However, it should be noted that, in any school district where the start times are changed, it is likely that those directly and indirectly involved in the school system will need to make some degree of sacrifice for the benefit of the students.

Potential Alternative or Enhancement to Changing Start Times

As previously discussed, the influence of the circadian rhythm on time-of-day modulations in performance of memory tasks varies according to the task (Schmidt et al., 2007). More specifically, it was found that implicit memory task performance was best at the nonpeak time of day according to the circadian oscillation (May et al., 2005). These findings suggest that a restructuring of class schedules so that adolescents are practicing fluency-based skills—such as reading aloud or rehearsing music—in the morning may be more beneficial than trying to have them assimilate new knowledge early in the day. Such arrangements may mitigate some performance deficiencies that result from the misalignment between the typical adolescent circadian rhythm and early classes. However, this kind of restructuring would not have any foreseeable effect on the sleep deprivation that students experience as a result of early school start times; therefore, the cognitive and behavioral problems associated specifically with sleep debt would not likely improve as a result of this change. Restructuring of classes or activities to take into account the time-of-day differences in implicit memory performance may be most effective if used in combination with delaying of school start times; however, more research with regard to the implicit memory performance of adolescents throughout the day needs to be conducted before any claims to this effect can be validated.

Conclusion

There is a sufficient body of evidence showing that adolescents experience changes in social context and physiology at the onset of puberty that cause them to develop an evening preference chronotype, predisposing them to go to sleep later at night and wake up later in the morning than children and adults (Crowley et al., 2007); this evening preference chronotype is not congruent with early school start times. The asynchrony between school start times and adolescent circadian rhythms can lead to an accumulation of sleep debt (Carskadon, 1999, 2002), is associated with cognitive impairments, and appears to adversely affect behavior, subjective levels of sleepiness, subjective levels of depression, and school-related variables such as attendance and tardiness (Dahl, 1999; Dinges & Kribbs, 1991; Wahlstrom, 2002). In accordance with this body of research, some schools have delayed school start times, with promising results. Adolescents who attend schools with later start times have been found to sleep more per night, resulting in a more positive temperament, fewer behavioral problems, and an increase in correlates of good academic performance (e.g., attendance, continuous enrollment; Center for Applied Research and Educational Improvement, 1998a; Owens et al., 2010; Wahlstrom, 2002).

Instituting a delay in school start times may be accompanied by complications related to transportation costs in some school districts, although this is a much lesser issue for high schools that already require students to use alternative transportation methods (e.g., public transportation, car pools). In addition, changes in start times are associated with disruptions of extracurricular activities and other social and leisure activities in many school districts. However, with sufficient strategizing and preparation, the inconvenient consequences of changing school start times can be attenuated. There is evidence that with adequate planning and preparation, school boards have been able to delay school start times at acceptable monetary cost (given the enormous potential payoff) and tolerable disruption of community functioning.

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