The Impact of Sleep on Learning and Behavior in Adolescents

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Many adolescents are experiencing a reduction in sleep as a consequence of a variety of behavioral factors (e.g., academic workload, social and employment opportunities), even though scientific evidence suggests that the biological need for sleep increases during maturation. Consequently, the ability to effectively interact with peers while learning and processing novel information may be diminished in many sleep-deprived adolescents. Furthermore, sleep deprivation may account for reductions in cognitive efficiency in many children and adolescents with special education needs. In response to recognition of this potential problem by parents, educators, and scientists, some school districts have implemented delayed bus schedules and school start times to allow for increased sleep duration for high school students, in an effort to increase academic performance and decrease behavioral problems. The long-term effects of this change are yet to be determined; however, preliminary studies suggest that the short-term impact on learning and behavior has been beneficial. Thus, many parents, teachers, and scientists are supporting further consideration of this information to formulate policies that may maximize learning and developmental opportunities for children. Although changing school start times may be an effective method to combat sleep deprivation in most adolescents, some adolescents experience sleep deprivation and consequent diminished daytime performance because of common underlying sleep disorders (e.g., asthma or sleep apnea). In such cases, surgical, pharmaceutical, or respiratory therapy, or a combination of the three, interventions are required to restore normal sleep and daytime performance.

According to the National Assessment of Educational Progress (NAEP), reading and mathematics proficiency among 9- and 13-year-olds have not improved significantly since 1973 (U.S. Department of Education, 1996). Furthermore, average scores from Scholastic Achievement Tests (SAT) show that verbal and math proficiency in 17-year-olds has steadily declined since

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1967 (U.S. Department of Education, 1995). Similarly, proficiency in mathematics and science has been shown to be significantly reduced in children educated in the United States as compared to the performance of children trained in other industrialized nations (U.S. Department of Education, 1995).

Although a variety of educational, psychological, and social factors are likely responsible for the lack of improvement in learning proficiency (Wang, Haertel, & Walberg 1993), the mental and physical health of children (or lack thereof) might play a significant role in a child's ability to both concentrate and learn within the classroom environment (Keays & Allison, 1995). In light of this information, the President's Council on Physical Fitness and Sports (PCPFS; U.S. Department of Health and Human Services, 1996) has begun to emphasize the need for proper nutrition and regular exercise because 50% of young children in America between the ages of 12 and 21 do not participate regularly in physical activity. Although improvements in this area might lead to enhancement of classroom performance (Shepard, 1996), little emphasis, until recently, has been placed on a health issue that may alter both physical and mental performance and consequently learning proficiency. Recent findings have shown that students might not be able to learn according to national expectations in part because they are too tired during the day. The National Sleep Foundation conducted a nationwide telephone survey in March 1999 titled Sleep in America, which assessed the effects of sleepiness in children and adolescents within the past year (National Sleep Foundation, 1999). Parents reported that 60% of children under the age of 18 complained of tiredness and sleepiness during the day, and 15% of children admitted to falling asleep in school. Consequently, the symptoms of daytime fatigue often observed in students may not be due to laziness or lack of motivation as traditionally perceived, but rather may be due to insufficient sleep. Thus, scientists and educators have identified the quality and quantity of sleep available to adolescents as a major factor affecting their ability to learn in school. Despite this emerging field many individuals are not familiar with the stages of sleep, the cyclic nature of sleep, and the role that each primary sleep stage might have in human development, behavior, and learning. Thus, these factors will be reviewed prior to examining the causes and side effects of sleeplessness.

SCIENCE OF SLEEP

STAGES OF SLEEP

Sleep is a state in which an individual disengages from and becomes unresponsive to the external environment. Sleep is characterized by a 90-minute cycle that is comprised of non-rapid eye movement (NREM) sleep that is followed by rapid-eye movement (REM) sleep, which is the stage of sleep in which most dreaming occurs. NREM sleep is typically divided into stages 1, 2, 3, and 4. Stages 1 and 2 are lighter stages of sleep, whereas stages 3 and 4 comprise slow wave sleep, which is the deepest stage of sleep. In a given night, the 90-minute NREM–REM cycle is usually repeated five to six times in an individual that experiences restorative sleep (Dahl, 1996; see Figure 1). As one progresses through the night, the amount of slow wave sleep decreases with an increase in the amount of REM sleep that comprises the 90-minute cycle. It has been suggested that the function of NREM sleep is to restore or synthesize neuronal processes that are necessary for optimal daytime mental and physical performance (Dahl, 1996; Dotto, 1996). Additionally, results obtained from previous investigations suggest that REM sleep has a significant role in consolidation of memory and cognitive development required for the completion of goal-directed behaviors (Dahl, 1996; Dotto, 1996).

IMPACT OF CIRCADIAN RHYTHMS ON ADOLESCENT SLEEP PATTERNS

The quality and quantity of the sleep pattern described above is influenced by internal biological mechanisms that are referred to as circadian rhythms

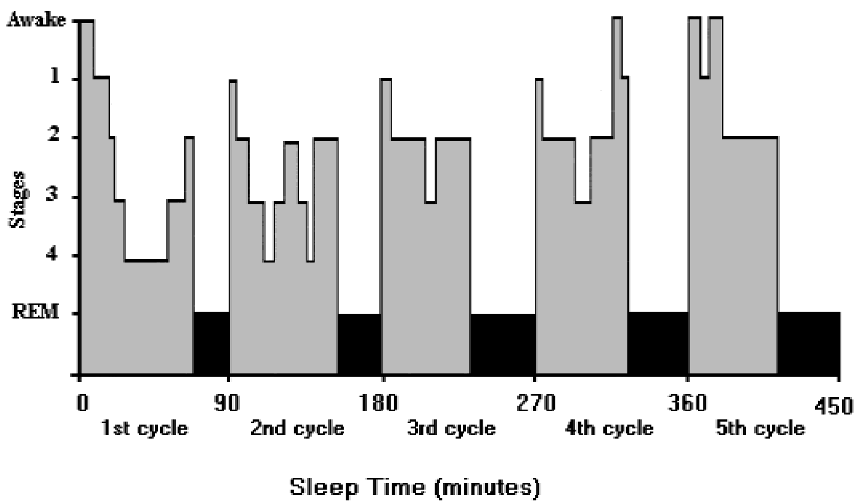

Figure 1. A Plot of the Four Stages of NREM Sleep and REM Sleep Over the Course of an Entire Night (time spent in NREM sleep is lightly shaded; time spent in REM sleep is shown in black)

(Dijk, 1999). Circadian rhythms develop in early childhood and are generated primarily by a specialized structure in the brain (i.e., the suprachiasmatic nuclei of the hypothalamus) (Murphy & Campbell 1996). This structure operates as a biological clock that can influence the sleep–wake cycle independent of stimuli from the environment. Human circadian rhythms oscillate approximately every 25 hours and can be reduced to 24 hours under the influence of changes in light intensity associated with the day–night cycle. Alterations in circadian rhythms might be responsible in part for changes in sleep patterns that occur as children develop during adolescence.

As children mature into adolescents, they tend to go to sleep later and wake up later if given a choice (Acebo Davis, Herman, & Carskadon, 1991). This pattern of sleep is usually most evident on weekends when behavioral constraints on sleep are fewer (see later section for a discussion of the behavioral constraints on sleep). This phenomenon is referred to as the sleep phase delay or delayed phase preference, which is the technical term to describe the tendency to go to sleep later and wake up later the following morning (Carskadon, 1999). According to Mary Carskadon, a leading researcher in the area of sleep and learning in adolescence from Brown University School of Medicine in Rhode Island, the tendency toward a sleep phase delay experienced by adolescents is due to alterations in human circadian rhythms. This suggestion has been supported by a number of studies completed by Carskadon and colleagues. One study that was completed using 275 sixth-grade females found that there was a significant relationship between the level of physical maturity and the time preference associated with sleep onset (Carskadon, Vieira, & Acebo 1993). The more mature females participating in the study preferred a later time for sleep onset. In a subsequent study, the same issue was investigated using measurements of melatonin secretion. Melatonin is a hormone that is secreted in the human body by the pineal gland during sleep and can be measured from saliva samples. The release of melatonin can be used as an indication of the circadian rhythm to determine whether this rhythm is in alignment with the sleep–wake cycle. This study revealed that nighttime peak melatonin secretion was shifted towards a later time in adolescents that are maturer (Carskadon et al., 1998). This finding verified that the later time preference for sleep onset reported by mature adolescents is influenced by a biological change in the circadian rhythm.

Previous research also suggests that the sleep duration requirement for adolescent individuals increases. In other words, if given the choice, adolescents tend to sleep longer. This finding is in direct contrast to the general perception that as children mature they require less sleep. Evidence for the position that adolescents have an increased need for sleep is based partly on the results of a 6-year longitudinal study completed at the Stanford University summer sleep camp. The initial hypothesis prior to completion of the study was that if children between 10 and 12 years of age were allowed to control the amount of sleep obtained between 10 p.m. and 8 a.m., older children would tend to sleep less because the biological need for sleep was reduced. This hypothesis however was not confirmed because, regardless of age, all the children slept approximately 9.25 hours (Carskadon, 1982). Furthermore, use of the Multiple Sleep Latency Test in this study highlighted the increased need for sleep among older children. The Multiple Sleep Latency Test was first used by Richardson et al. (1978) to examine differences in daytime alertness between normal individuals and those suffering from narcolepsy. The test uses six 20-minute daytime naps over an 8-hour period during the morning and afternoon to determine the length of time required for a child to fall asleep during the day. If a child falls asleep within 5 minutes from the onset of the test, then he or she is considered to be excessively sleepy. In contrast, the child that remains awake for the entire 20-minute period is considered extremely alert (Carskadon & Dement, 1982; Carskadon et al., 1986). The older children participating in the longitudinal study consistently fell asleep before the younger children, which was suggestive of a decreased level of alertness (Carskadon, 1982). Collectively, these results suggest that with maturation the need for sleep increases.

Although evidence exists that the biological need for sleep increases as children mature, there is additional evidence to suggest that these biological needs are not met. Wolfson and Carskadon (1996) surveyed 3,120 students between 13 and 19 years of age and discovered that there was a linear decrease in sleep time of up to 40 minutes with increasing age. Similarly, Allen and Mirabile (1989) investigated the self-reported sleep-wake patterns of 61 students from two senior high schools in the United States during the school year. The start time for both schools was between 7:30 and 8:00 a.m., and students from both schools reported a bedtime of approximately 11:00 p.m. during school nights. Consequently, these students obtained 7 hours of total sleep each night, which is approximately 2 hours less than the amount required. Thus, despite the biological need for adolescent children to sleep later and for longer periods, studies have revealed that as children mature, they tend to sleep less and as a result are excessively sleepy.

The reasons that children are experiencing less sleep as they mature are likely behavioral or pathophysiological in nature. There are a number of causes, including the following: parental involvement and social opportunities, academic workload and school starting times, employment opportunities, and sleep-disordered breathing. These causes are reviewed in the following sections.

CAUSES OF SLEEPLESSNESS

PARENTAL INVOLVEMENT AND SOCIAL OPPORTUNITIES

Parental control of sleep and wake time may diminish when a child is 12–13 years of age. This statement is supported in part by work completed by Carskadon (1999), which revealed that until ages 11 and 12 most children reported that they woke spontaneously in the morning and that parents set their bedtime. Conversely, most children in their early teens reported that parents did not set their bedtime and that an alarm clock or parent was required to assist them in waking up. Thus, as students mature, they may have greater freedom to make their own decisions regarding bedtime. These decisions may be greatly influenced by their cultural environment. Peer pressure to engage in late night activities, in addition to unsupervised television viewing, and increased access to the telephone, computerized games, or the Internet, may prevent students from going to bed early (Carskadon, 1999). However, the impact of these factors on sleep quality has not been well explored and requires further investigation.

ACADEMIC WORKLOAD AND SCHOOL STARTING TIMES

Although later bedtimes might occur because of lifestyle choices, this delay may also occur because students stay up later to complete additional homework that often is associated with increased academic expectations that typically occur as children mature. In addition, older adolescents often attend schools that have earlier school starting times when compared with school start times for younger students. This combination of increased academic workload with earlier starting times may impose serious limitations on the amount of sleep adolescents obtain. Kowalski and Allen (1995) studied 119 students in the 12th grade that were enrolled in a late-start school schedule (9:30 a.m.) and 97 11th- and 12th-grade students involved in an early-start school schedule (7:20 a.m.). Students completed a sleep-wake questionnaire in which they addressed their sleep patterns, level of alertness and sleepiness, as well as other relevant social factors. Students' responses showed that total sleep time during the school week was significantly longer for the group that started school at 9:30 a.m. (7.5 hours vs. 6.9 hours). However, during the weekend both groups went to bed and woke up at approximately the same time. This data is supported by comments that were obtained from high school students that participated in focus groups that were conducted at three high schools, which were drawn from a stratified random sample of schools in the Minneapolis Public School system. As reported by Kubow, Wahlstrom, & Bemis (1999), nearly all the students in the focus groups noted that after school start times were shifted from 7:15 a.m. to 8:40 a.m., they were feeling more rested and alert for the first hour of class and that they were generally going to bed at the same time prior to the shift in the school starting time. Thus, they were obtaining 1 additional hour of sleep each night. Additionally, results from a School Sleep Habits Survey, distributed by the Center for Applied Research and Educational Improvement (CAREI) located at the University of Minnesota, which focused primarily on data obtained from 3 of 17 Minnesota school districts that were demographically similar (socioeconomic status, racial and ethnic diversity, school population size), showed that shifting school start times to a later hour in one district resulted in students obtaining an additional full hour of sleep, compared with students attending school with earlier start times in two other districts (Frederickson & Wrobel, 1997). Thus, it appears that some adolescents may lose sleep during weekdays because they are required to meet early school start times that present a non-negotiable influence on sleep quality and quantity.

EMPLOYMENT OPPORTUNITIES

Opportunities to be employed may present themselves as children mature. Many teenagers work to supplement family income, increase independence, improve self-confidence, and develop interpersonal skills. According to the United States Department of Labor and the National Academy of Science, 44% of 16- and 17-year-olds work for 20 hours or more during the school year (U.S. Bureau of the Census, 1997). As a result of working after school, students may stay up late to complete their homework, socialize with friends or family members, watch television, or relax. Surveys completed in the 1980s revealed that working after school was often associated with a later bedtime, shorter total sleep time, school tardiness, fatigue, and sleepiness (Carskadon, 1990). Similarly, additional correlation analysis of data obtained from the School Sleep Habits Survey that was distributed by CAREI to students attending high school in 1 of 17 Minnesota school districts revealed that students who reported more sleepiness (stated that they struggled to stay awake or fell asleep in various situations, such as reading or during a test) tended to report working more hours during the week. (Frederickson & Wrobel, 1997). Therefore, the biological need for an increase in sleep quality as a child matures is opposed by a variety of behavioral factors that may manifest themselves in increased sleepiness and daytime fatigue.

SLEEP-DISORDERED BREATHING

In addition to the behavioral factors responsible for decreased sleep in children, a relatively common pathophysiological problem may also be responsible for reduced sleep quality in some children. Approximately 10%

of children suffer from sleep-disordered breathing, with approximately 3% of the population suffering from obstructive sleep apnea, which is the severest form of this disorder. Obstructive sleep apnea is characterized by repeated obstruction of the upper airway throughout the sleep period. In the most severe cases, obstruction of the airway can occur 50 times per hour. Enlarged adenoids or tonsils often cause the obstructive episodes recorded in children and adolescents (Carskadon et al., 1993). In response to these obstructive episodes, individuals are aroused from sleep. These arousals are often not perceived by the individual during the sleep period and are only recognized if the individual's sleep is monitored visually or by completion of a sleep study in a clinical setting. As a consequence of these repeated arousals, deep sleep is often disturbed and reduced in quantity. The result of fragmented sleep patterns is daytime sleepiness and fatigue (Engleman et al., 2000).

Children that suffer from asthma might also experience sleep disturbances related to this respiratory disorder. Overall, approximately 1.4% of children in the United States suffer from disabling asthma, with a significantly higher prevalence of asthma exhibited in black children (2.4%), children from impoverished families (2.2%), and children living in single-parent households (2.1%) (Benson & Marano, 1997). To examine the link between asthma and sleep disruption, Sadeh and Horowitz (1998) used actigraphy recordings, which measure physical activity levels in nonlaboratory environments. Their results showed that a significant decrease in sleep duration and an increase in sleep fragmentation occurred in asthmatic as compared to nonasthmatic children. Thus, children with obstructive sleep apnea or asthma might be considered at risk for daytime neurobehavioral deficits associated with sleep deprivation as confirmed by increased reports of fatigue and reduced alertness (Bender & Annett, 1999; Diette et al., 2000; Marcus, 2000; Rhodes et al., 1995). Additionally, the increased odds of a reduction in school attendance, academic performance, or both, that was recently reported for children suffering from obstructive sleep apnea (Gozal, 1998) or symptoms of nocturnal asthma (Diette et al., 2000) suggests that teachers who are able to recognize daytime symptoms of sleep disordered breathing (see later discussion on side effects of sleeplessness for a discussion of these symptoms) might play a significant role in identifying children that suffer from this disorder. Treatment of sleep-disordered breathing could ultimately lead to improved academic performance, behavior, or both in some children, although further research in this area is required to provide additional support for this contention.

SIDE EFFECTS OF SLEEPLESSNESS

The side effects that manifest as a consequence of sleep deprivation are independent of whether or not the cause is behavioral or pathophysiological in origin. These side effects, which are reviewed in the following section, include inattention and poor performance in the classroom and emotional and behavioral changes.

INATTENTION AND POOR PERFORMANCE IN THE CLASSROOM

Sleepiness and fatigue is an unavoidable consequence of sleep loss (Carskadon et al., 1998). It often presents itself in later waking times, tardiness, sleeping during class time, and memory loss. Thus, sleepy or fatigued students might be the last ones to take initiatives when participating in group or cooperative learning (Dahl, 1996, 1999). Even if a student does not sleep during class time, they may experience brief mental lapses. Sleep experts often refer to mental lapses as microsleep. A state of emotional arousal or increased effort due to increased motivation can overcome sleepiness and fatigue for a short period of time without observed changes in performance. Thus, teaching techniques employed in the classroom would have to be highly rewarding and stimulating to ensure that sleepy or fatigued students remain engaged and motivated. However, tasks that are complex in nature and require simultaneous abstract thinking, creativity, integration, and planning, might be impervious to compensatory motivational strategies. These are the tasks that might be influenced primarily by sleep deprivation (Dahl, 1996,1999). This suggestion is supported by a recently completed study (Schlesinger et al., 1998), which showed that students with one night of sleep deprivation had no difficulty maintaining their performance on a difficult computer task when the task was performed alone. In addition, one night of sleep deprivation caused no degradation in a postural balance performance test, in which the center of pressure on a platform measuring force was recorded during three increasingly difficult standing positions in which a) the platform was fixed, b) the platform swayed side to side, and c) the platform swayed side to side and a visual scene swayed in a similar manner. However, when the two tasks were performed simultaneously, postural control was impaired. Similarly, preliminary data from Dahl's group (R. E. Dahl, personal communication, April 10, 1999) showed impairments in sleep-deprived adolescents who were performing cognitive and emotional tasks. When the cognitive and emotional tasks were performed separately, no impairment was observed; however, performance of the tasks was diminished when they were performed simultaneously. Given that the degree of alertness can alter completion of complex tasks, it is possible that the impact of classroom instruction on learning performance might be more effective if the first class period began later in the morning. This suggestion is supported by findings that showed that reading scores improved when instruction was provided in the afternoon as compared with the early morning (Carskadon, 1999).

Similarly, Wolfson and Carskadon (1996) observed that students who were struggling or failing at school were getting less sleep than their counterparts who were achieving A's and B's. Additionally, findings from the School Sleep Habits Survey (Frederickson & Wrobel, 1997) of 7,168 students that were drawn from a total student population of 66,394 in 17 Minnesota school districts revealed that students who reported more sleepiness (as indicated by positive responses to struggling to stay awake or falling asleep at various situations such as reading or during a test) also tended to report lower grades.

Collectively, these findings present evidence that academic performance may be enhanced by providing children with learning opportunities during the time period when cognitive function is optimal, rather than attempting the futile task of educating adolescent students early in the morning when they should be sleeping.

EMOTIONAL CHANGES

Sleep also influences the regulation of human emotions. Inadequate sleep may result in increased irritability and less tolerance for situations that create negative emotions, depending on the psychological profile of the individual (Dahl, 1996, 1999). Wolfson and colleagues (1995) found that students who went to bed at later times and slept less tended to display increased aggressive behavior. The conflict that arises between students and parents because of late wake-up times, and between teachers and students because of tardiness or sleepiness in class, can further affect a student's emotional state, leading to hostility and resentment. Sleep-deprived adolescents often lose conscious control over their emotional state, resulting in anger and aggression during stressful or unpleasant situations. Under these circumstances adolescents could become more vulnerable to the use of alcohol, drugs, and risky driving (Dahl, 1996).

A variety of clinical disorders have provided evidence that a link between the regulation of emotion and sleep exists, whereby the amount and quality of sleep affects daily emotional status and alternatively emotional status affects sleep regulation (Dahl, 1996, 1999). Consequently, it has been reported that 75% of children complain of sleep loss during episodes of depression (Dahl, 1996). The manifestation of depression as a result of sleep abnormalities in adolescence is dependent on the severity of sleep deprivation and the maturation process. In adults the inability to initiate and maintain sleep is often associated with depression and results in a diminished amount of deep sleep. Children that suffer from depression do not experience sleep disruption to the same degree as adults; however, difficulty in initiating sleep is often the first sign of depression in adolescence. As depressed children age, they begin to experience decreases in deep sleep and alterations in the onset of REM sleep. The findings that sleep disruption is not the same in adolescents and adults that are depressed suggests that maintenance of sleep quality is imperative for young people, and as a result sleep is protected from many disturbances that may affect adult sleep patterns. As maturation occurs, these protective mechanisms diminish (Dahl, 1996).

BEHAVIORAL DISORDERS

The impact of sleep deprivation on learning and behavior in children may not be limited to healthy adolescents but indeed may be responsible, wholly or in part, for behavioral problems exhibited by many students diagnosed with attention deficit/hyperactivity disorder (ADHD).

Sleep deprived and ADHD students manifest similar symptoms (Dahl, 1996). These symptoms include the inability to control impulses and drives that lead to inappropriate behavior within a social context and the inability to concentrate for extended periods of time. The relationship between sleep and daytime hyperactivity was initially accounted for by the *Diagnostic and Statistical Manual of Mental Disorders, version III* (*DSM–III*; American Psychiatric Association, 1980), in which excessive movement during sleep was used as one of five possible behavioral characteristics of daytime hyperactivity. However, subsequent editions *DSM–III–R* (American Psychiatric Association, 1987) and *DSM–IV* (American Psychiatric Association, 1994) failed to account for that relationship.

The relationship between behavior and sleep deprivation has received support from recent studies, which showed that the incidence of ADHD in students with sleep disorders (which may result in sleep deprivation) was higher when compared with students without sleep disorders (Dahl, 1999). Similarly, Marcotte and colleagues (1998) found that parents of students classified with learning and behavior disorders reported greater sleep-related problems with their children as compared with parents of students without a learning disorder. Clinical evidence also supports the association between sleep and ADHD. Researchers at the Tel Aviv University Sleep Disorders Laboratory in Israel used actigraphy studies to demonstrate that children suffering from ADHD show a significant reduction in sleep quality (Dagan et al., 1997).

Collectively, the previous findings suggest that the inability of a student to behave or perform intellectually at an expected level might be due in part to inadequate sleep rather than as a result of a fundamental neurological disorder. This suggestion is supported by a study completed by Wiggs and Stores (1999), who examined the effects of the treatment of sleep problems in children with severe learning disabilities and challenging daytime behavior. Their study revealed that improvement of sleep quality via behavior modification, which resulted in increased sleep duration and decreased sleep fragmentation, had a beneficial effect on the daytime behavior of children in the intervention group compared with control subjects. Furthermore, when ADHD students are treated with medications specific to their sleep disorder, their daytime behavior often improves (Dahl, 1996). These findings suggest that treatment of sleep disorders in children with learning and behavior problems may aid in decreasing challenging daytime behavior and improving attention and learning capabilities in the classroom. Inattention, emotional responses, and behavioral problems may be similar in sleep deprived and ADHD students because of the impact that sleep deprivation might have on the function of the prefrontal cortex, which is located in the central nervous system (Dahl, 1996).

IMPACT OF SLEEPLESSNESS ON PREFRONTAL CORTEX FUNCTION

The prefrontal cortex is responsible for the regulatory integration of sleep/arousal and affection/attention and functions to integrate cognition and emotion into goal-directed behaviors (Dahl, 1996; George, Ketter, & Post 1994). The prefrontal cortex accomplishes this task by bridging the gap between internal needs and drives and socially accepted behavior. The prefrontal cortex is responsible for anticipating, preparing, or delaying a behavioral response based on socially acceptable behavior. Unfortunately, sleep deprivation causes dysfunction of the prefrontal cortex, which is similar to various neurophysiological disorders but is reversible with sleep recovery (Horne, 1993). It is this deficiency in prefrontal cortex function that may be responsible for the impact of sleep deprivation on emotions, attention, and intellectual performance of adolescents. Suboptimal performance of the prefrontal cortex may impair frontal functions, such as the regulation of complex tasks, creative thinking, and goal-oriented behaviors. Therefore, silly, erratic, impulsive, aggressive, and even violent behaviors observed in school may be increased as a consequence of sleep deprivation (Dahl, 1996; Horne, 1993).

From a developmental perspective the ability to regulate internal needs and drives as they are expressed by emotional behavior according to an acceptable social context is a gradual process that is accomplished through maturation. The pre-frontal cortex continues to develop throughout childhood and adolescence with important neurobiological changes occurring during puberty (Dahl, 1996). Puberty therefore is an important period during which sleep and behavioral regulation are coupled with cognitive processes. Given this understanding, it is important that countermeasures are employed in an effort to ensure that students obtain the required amount of sleep. Two of the most recent countermeasures that have been used to reduce or eliminate sleep deprivation caused by societal constraints and sleep disordered breathing are outlined in the following section.

ADDRESSING THE PROBLEM

ALTERING SCHOOL START TIMES

In response to current scientific findings and public opinion, many school districts have arranged a task force to address the problem of teenage sleep deprivation. The Minneapolis Public Schools were the first major metropolitan school district to recognize the role of sleep as a key feature in academic success. In 1997–1998 the Minneapolis school district changed the start time for 7 high schools, 7 middle schools, and 71 elementary schools, which affected approximately 50,000 students (Kubow et al., 1999; Wahlstrom, Wrobel, & Kubow,. 1998). Instruction at elementary schools started at either 7:40, 8:40, or 9:40 a.m.; middle schools moved their start time from 7:40 to 9:40 a.m.; and high schools changed their start time from 7:15 to 8:40 a.m. In addition, high school students were given the option to leave school earlier by taking an alternative "zero hour" class that started at 7:40 a.m. (Kubow et al., 1999).

Simultaneously, CAREI initiated a study in which they examined the impact of school starting times on learning and behavior in children and other factors that would influence the community as a whole. The data specifically relevant to this review on the role of sleep in adolescent learning and behavior was initially collected from focus groups that were conducted separately with teachers, students, and support/administrative staff members at three high schools and five middle schools (Kubow et al., 1999; Wahlstrom, 1999; Wahlstrom et al., 1998). The results from these focus groups were condensed in an executive summary, which examined the impact of the change in Minneapolis Public Schools Start Time (Wahlstrom et al., 1998). Additionally, results from the School Sleep Habits Survey for students and a one-page written survey for high school teachers (which was developed based on results from the previously described focus group data) and results from a case study of the Edina school district in the Minneapolis St. Paul district, which was published in "Final Report Summary of the School Start Time Study" (Wahlstrom & Freeman, 1997), was used to provide both the students' and the teachers' perceptions of the impact that school start times had on a variety of factors. The executive summary focused on data collected at the secondary school level primarily because of fiscal and time constraints; however, related data was also collected at the elementary level. Nonetheless, given the data locus and the primary focus of this review (adolescent learning and behavior), only the data from the middle and secondary schools that address directly the impact changing school start times on learning and behavior from both teachers' and students' perspectives will be summarized. For the reader who is interested in the more widespread impact of changing school start times on the community, (e.g., busing schedules, safety, participation in after school activities, impact on personal lives) the authors would refer the reader to both the CAREI executive summary and an excellent summary by Kubow and colleagues (1999).

ALTERING SCHOOL START TIMES—STUDENTS' PERCEPTION

The data from the School Sleep Habits Survey, which was reported in the executive summary of the "Minneapolis Public School Start Time Study" was obtained from a stratified random sample of 471 Minneapolis high school students and 48 student council members representing three Minneapolis high schools (Wahlstrom et al., 1998). Additionally, data was obtained from 599 Minneapolis middle school students and a sample of high school and middle school students from a comparable urban school district that did not implement a change in school starting times. According to the student survey, the Minneapolis high school students received an additional 45 minutes of sleep per day as compared with students from the urban school district (Wahlstrom et al., 1998). The average score obtained from a measurement of depression (which was a subpart of the survey) and the average number of sick days recorded over a 2-week period were significantly lower for the Minneapolis high school students when compared with the students from the urban school district. In addition, the Minneapolis high school students reported greater alertness during class time, examinations, or computer activities with a decrease in tardiness due to oversleeping compared with the students from the urban school district (Wahlstrom et al., 1998). These results support focus group comments obtained earlier from eight students in an interview designed to determine their responses to later school start times (Wahlstrom & Freeman, 1997). These students attended Edina High School located in the Edina school district, which was 1 of the 17 Minnesota school districts that participated in the School Sleep Habits Survey. One student shared, "I have only fallen asleep once in school this whole year, and last year I fell asleep about three times a week." Another student said, "I feel I pay better attention because my sleep schedule is closer to my normal sleep pattern" (Wahlstrom & Freeman, 1997). Only the student council members reported similar scores compared with the urban school district students. This latter finding was attributed to the demands of school-related extracurricular activities because there was no significant difference in the amount of sleep time between Minneapolis high school students in general and student council members (Wahlstrom et al., 1998). High school students in Minneapolis reportedly achieved higher grades than the students in the urban school district, and the extra hour of sleep could account for this difference. However, this difference may have occurred because Minneapolis has more grade inflation compared to the urban school district. This suggestion is supported by the finding that students attending school in the urban school district spent more time on homework during the week and on weekends compared to the students attending the Minneapolis high schools (Wahlstrom et al., 1998).

ALTERING SCHOOL START TIMES—TEACHERS' PERCEPTION

Teachers' perceptions on the impact of changing school start times in the Minneapolis school district, both before and after school start times were implemented, have been previously summarized in CAREI's final report summary (Wahlstrom & Freeman, 1997) and the executive summary (Wahlstrom et al. 1998). The results in the final report summary were obtained from 2,964 high school teachers from 17 school districts in the Minneapolis-St. Paul area and from focus group data (consisting of eight teachers) obtained from a case study completed at a high school located in the Edina school district. In the summary the data obtained from the large sample of teachers was designed to examine the array of factors that would be inherent in the consideration of changing high school starting times in the Minneapolis-St. Paul area. In contrast, the data from the focus group was designed to obtain impressions and observations regarding the impact on student learning, changes in teaching behavior, and other pertinent issues during the first term in which the later school start time was implemented. The results presented in the executive summary were obtained from a one-page questionnaire that was designed to examine the impact subsequent to changing the school start times. The questionnaire was mailed to 500 high school teachers in the Minneapolis School District of which 335 were returned for a response rate of 67%.

Prior to changing the school start times the majority of high school teachers (86%) believed that the optimal school start time was at or before 8:30 a.m. (Wahlstrom & Freeman, 1997). Subsequent to the change in the school start time 57% of teachers surveyed believed that the new school schedule improved alertness and sleepiness during the first two class periods, whereas 27% of the respondents disagreed, and 16% were neutral. The teachers that participated in the case study of the Edina school district commented that they no longer had "people with their heads down on the desk" and that the students seemed "more engaged in what they're doing" and "more focused" (Wahlstrom & Freeman, 1997).

Although the majority of teachers agreed that a later school start time led to more alert and focused students, no clear conclusion was reached in regards to student behavior. One teacher that participated in the Edina case study called all the parents of the 160 students in her classes and asked if they saw a difference in the behavior and attitudes of their children. Parents responding to this informal survey overwhelmingly answered "yes". However, this was not borne out in the data presented in the executive summary—only 33% of the teachers agreed that there was an improvement in students' behavior, whereas an equal number of teachers (32% of the respondents disagreed, and 35% were neutral) reported that no change in behavior was observed (Wahlstrom et al., 1998). Thus, the impact of altering school start time on student behavior requires further investigation.

Student participation in athletics in conjunction with the later school starting times was perceived to be a significant problem by teachers as it related to learning and classroom performance. One teacher in the Edina focus group stated, "What we're losing at the moment is some of the students involved in these athletics and sports that leave early from their 6th hour to get to the activities" (Wahlstrom & Freeman, 1997). Similarly, a teacher responding to the survey outlined in the CAREI executive summary (Wahlstrom et al., 1998) stated, "Now, I lose one-half of my sixth hour International Baccalaureate class in the fall to sports' start times." The impact of athletics on instructional endeavors was also a concern of teachers who were team coaches. One coach stated, "As a teacher and coach, I was extremely troubled that I had to excuse my student athletes from class 13 times this spring for track meets . . . many of us were very distressed about this situation because it goes against everything we stand for as educators" (Wahlstrom et al., 1998). Clearly, the impact of later school start times on student athletes is a critical issue that remains to be resolved for those schools that plan to implement later school start times.

The most dramatic start time transition that was experienced by middle schools in the Minneapolis school system was from 7:40 a.m. to 9:40 a.m. (Kubow et al., 1999). Most teachers believed that students at this level were alert and performed adequately in the early morning so that valuable instructional time was lost when school start times were shifted to later in the morning. Although a few teachers in the focus group data collected from five middle schools suggested that students were more alert and discipline problems were easier to handle, the majority of teachers reported that it was difficult to keep students motivated at the end of the school day because the students were more fatigued and impatient (Kubow et al., 1999). Teachers also felt fatigued at the end of the day, and the effort they exerted to accomplish the daily teaching objectives were perceived to be greater after the change in school start time (Kubow et al., 1999). Because classes were conducted until late in the afternoon, there was an overlap between after-school activities and late teaching periods. Consequently, teachers noted that many students missed all or part of their last period, disrupting learning for others in the process, to participate in desired after-school activities. Many teachers left the school immediately following dismissal of the students because of the later school starting time. This resulted in less time for parent-teacher communication, which impacted negatively on parent-teacher relationships (Kubow et al., 1999). Although the transition to a later start did not seem to impact positively on those middle school teachers that participated in the focus groups, Kubow et al. (1999) reported that one of the middle school students who completed a survey of his peers for a class project reported that the majority of students favored the later school start time because they were less tired and learning was easier. Thus, although teachers' perception at the middle school level were generally not in support of a later school start time, the students seemed to be more in favor of the change, although further research would be required to support the student's findings.

TREATMENT OF SLEEP DISORDERS

As previously mentioned, delayed sleep onset and early school start times are not responsible for excessive daytime sleepiness and the consequent decrement in performance in children with pathophysiological sleep deprivation. To improve faulty sleep architecture that causes sleep deprivation in such cases, the physiological disorder must be addressed. In children with an obstructive sleep disorder secondary to enlarged tonsils or adenoids, adenotonsillectomy has resulted in significant reduction or complete disappearance of sleep apnea in 90% of the cases postsurgically (Nuyens et al., 1999). Additionally, nasal continuous positive airway pressure (nCPAP), a method of respiratory therapy that provides a steady flow of air into the nose and upper airway that assists in opening the airway mechanically, provides an effective treatment of obstructive sleep disease in children that have facial or upper airway abnormalities (McNamara & Sullivan, 1999). Asthmatic children that suffer from respiratory-related sleep deprivation typically require pharmaceutical intervention to control the symptoms of their disease to allow for improved sleep hygiene (Sadeh & Horowitz, 1998). Each of the treatments outlined here has been shown to improve daytime performance in children (McNamara & Sullivan, 2000; Sadeh & Horowitz, 1998). More specifically, daytime napping was reduced or eliminated and the level of energy increased following treatment. In addition to increases in energy level parents subjectively reported that daytime behavior had also improved (McNamara & Sullivan, 2000).

Although sleep deprivation resulting from societal, behavioral, and pathophysiological influences has been addressed in conjunction with interventions that promote proper sleep hygiene, other important recommendations for the general maintenance of proper sleep hygiene must be considered.

RECOMMENDATIONS

If sleep disruption is pathophysiological in origin and more specifically as a consequence of a respiratory ailment (e.g., obstructive sleep apnea or asthma), educators and parents must be aware of the obvious signs that indicate the presence of this disorder. These signs include snoring, pauses in breathing while the child is sleeping, spontaneous and frequent awakenings during the night, and evidence of daytime sleepiness (sleeping in inappropriate situations) despite spending more time sleeping than peers of a similar age. If these signs are present, the most effective and appropriate treatment should be selected in consultation with a physician specializing in sleep disorders.

Conversely, difficulty waking in the morning, reduced ability to focus (particularly if it is present early in the school day), irritability late in the day, falling asleep spontaneously during quiet times in the day, and sleeping for extra long periods on the weekends are signs of sleep deprivation that an otherwise healthy adolescent might display. As a first step in preventing or reversing the impact of sleep deprivation on learning and behavior, adolescents should assess their sleep patterns. This assessment could be organized by a teacher as part of a school project or completed at home if the opportunity is not available in a school setting. Completing a sleep diary for 7 to 14 consecutive days could complete this assessment most accurately. The diary could provide information regarding poor sleep habits prior to intervention and the effectiveness of efforts to change sleep patterns subsequent to an intervention. If information collected from the sleep diary suggests poor sleep patterns, adolescents in consultation with their teacher or parent(s) should assess how much time is spent in extracurricular and employment activities and how participation in these activities might affect their quality of sleep. If necessary, adjustment in the schedule of extracurricular activities might be required to allow for enough sleep. In addition, a home environment that promotes healthy sleep is a necessity to ensure that adolescents are receiving an adequate amount of sleep. Promoting healthy sleep includes establishing a regular, relaxing routine to unwind from the day to signal the body that it is time to prepare to sleep; avoiding computer games, books, or television programs that are violent, frightening, or controversial 1 hour prior to going to bed; avoiding ingestion of caffeine in the afternoon and evening; and avoiding naps and horseplay with younger siblings prior to bedtime.

Although providing a home environment to promote healthy sleep is the first step to eliminating sleep deprivation in adolescents, increased public awareness of the impact of sleep on learning and behavior is important. For this to occur legislation to ensure that high school start times do not begin before 9:00 a.m. may help in reducing sleep deprivation leading to improved academic performance and behavior as outlined previously. Nevertheless, attempts to obtain this legislation by the introduction of a bill by Zoe Lofgren (D-CA) to Congress entitled The Z's to A's Act, which supports later school start times, has not been passed by Congress at the present time (Knight-Rider, Washington Bureau, 1999). Additionally, beyond changing school schedules the National Sleep Foundation's Sleep and Teens task force (2000) recommended that child labor laws be altered or enforced to ensure that the number of hours and the time of day that adolescents are permitted to work are restricted to ensure that these factors are not responsible for sleep deprivation in adolescents.

Most important, education in proper sleep hygiene is essential to promote increased awareness of the need to obtain the required quality and quantity of sleep for optimal academic performance. Exciting discoveries in the field of sleep are occurring rapidly, and these discoveries can be shared with children from grammar, middle, and high school. Just as nutrition is included in health curriculums, students could learn about the body's need for sleep requirements, how circadian rhythms are responsible in part for the sleep–wake cycle, and the role that sleep plays in memory and learning. Additionally, the impact of many sleep disorders on other health-related issues could be addressed. For example, snoring, which afflicts many individuals, might lead to the development of other health problems, such as hypertension and stroke (Mateika et al., 1992; Mateika, Kavey, & Mitru, 1999; Mateika & Mitru, 2001). Thus, education is important to ensure that children begin to understand that sleepiness and fatigue is not a weakness that can be overcome by will power but rather may lead to inappropriate emotional responses and reductions in intellectual performance. With this understanding in mind, educators and parents must encourage children to obtain the required amount of sleep to maximize their potential both in and out of the classroom. A number of possibilities exist to inform educators and parents about this important matter. Courses in sleep medicine, which cater to a wide audience, have been developed recently at a number of academic institutions and thus would be an ideal course for educators interested in this subject matter. The impact of sleep on learning and behavior in children could be a featured topic of discussion at a parent-teacher association meeting. Additionally, educational pamphlets written in laymen's terms and distributed by the American Academy of Sleep Medicine (www.aasmnet.org) could be obtained and distributed to educators and parents to highlight this important issue. Lastly, numerous Web pages (e.g., http://bisleep.medsch.ucla.edu) are dedicated in part to discussing the biological need for sleep in children. If educators and parents are informed of these sites, further investigation may ultimately lead to a greater appreciation and understanding of the role that sleep has in a child's daily life as it relates to behavior and mental performance.

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