

The Neurocognitive Effects of Sleep Disruption in Children and Adolescents

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KEYWORDS

- Behavior • Learning • School performance
- Mood • Sleep disorder

Disrupted sleep in children, whether attributable to poor sleep hygiene, sleep restriction, or an underlying sleep disorder, is associated with a wide range of behavioral, cognitive, and mood impairments. Sleep problems are common in children, with rates between 25% and 40%,¹ and are frequently underrecognized, even though most problems can be effectively treated. In the National Sleep Foundation's Sleep In America Poll,² approximately 70% of parents of young children surveyed reported that their child had at least one sleep problem a few nights per week, yet only a minority (<15%) reported this information to their pediatrician. Adolescence is associated with a natural delay in circadian rhythms, and so it is perhaps not surprising that more than half of adolescents reported feeling sleepy during the day,³ although only 16% believed that they had a sleep problem. Interestingly, even fewer of the parents (7%) in the same poll believed that their adolescent had a sleep problem.

Disruption or fragmentation of sleep often manifests in children as hyperactivity, inattention, poor concentration, poor impulse control, disruptive behavior problems, emotional lability, and poor school performance. Adolescents may be more likely to exhibit poor concentration, depressive symptoms, and excessive daytime sleepiness than hyperactivity, the latter of which is more commonly observed in younger children. Furthermore, the poor sleep habits of young children also affect parents, who have been reported to lose an estimated 200 hours of sleep per year because of their children's sleep disruption.² It is important to note that most of what we know about the neurocognitive effects of sleep disruption in childhood is based largely on data from

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studies measuring associations and correlations rather than proven fact. Ongoing randomized controlled trials in this field will provide us with more robust evidence in the future. This article highlights current understanding of the daytime consequences of sleep disruption in children and adolescents.

CULTURAL

What constitutes normal sleep? Few large-scale epidemiological studies have been conducted to define normal sleep parameters in childhood, and in those studies that have attempted to investigate normal sleep, methodologies differ widely. Childhood and adolescence is a time of rapid growth and maturation; therefore, what is considered normal sleep is a dynamic and complex process. Normal sleep may be defined culturally in terms of what fits with societal or parental expectations, irrespective of the biology of sleep. How abnormal sleep is defined may depend on whether the sleep does not fit within these cultural boundaries, or it may also be defined in terms of associated daytime morbidities. There is wide variation in the biology of sleep, the societal and cultural expectations of normal sleep, the developmental and physical and emotional changes that occur, and the developmental changes in sleep across different stages in child development. Thus, it is operationally difficult to define what constitutes problematic sleep.

POOR SLEEP HYGIENE/INSUFFICIENT SLEEP

We are a 24-hour society. Many young children and adolescents do not obtain enough sleep for a variety of reasons, including family schedules, chaotic living arrangements, television/computer/cell phone use in the bedroom after designated bedtimes, and after-school activities. There are often not enough hours in the day to accomplish what is wanted, and all too often it is sleep that is compromised. Data from the Zurich Longitudinal Studies,⁴ which followed Swiss children from infancy to adolescence, provided percentile curves for sleep duration across the pediatric age range. Total sleep time decreased from approximately 14 hours in infancy, to 11 hours in school-aged children, to 8 hours in adolescence. More recently, the National Sleep Foundation Poll of children in the United States found that the average duration of time school-aged children spend sleeping is approximately 8 to 9 hours,² which is less than the 10 to 11 hours recommended by the American Academy of Sleep Medicine.⁵ Despite this fact, few large-scale studies have systematically investigated the impact of inadequate sleep on children. Clinically, however, there are many observations of the consequences of poor sleep, including inattention, externalizing behaviors, poor emotional control, and daytime sleepiness. **Table 1** summarizes the main daytime effects of sleep disruptions from several sleep disorders.

When assessing sleep objectively using actigraphy, sleep disruption has been associated with deficits in complex neurobehavioral tasks, such as selective attention in otherwise healthy children,⁶ with the strength of the association being higher in younger children. In adolescents, shortened sleep time and irregular sleep schedules (poor sleep hygiene) are associated with impaired school performance, as reflected by lower grades.⁷

Few studies of sleep deprivation have been conducted in children. However, data from adults, including functional neuroimaging studies, provide substantial evidence that sleep deprivation negatively impacts vigilance, cognitive performance, and learning.^{8,9} Acute sleep restriction of 1 night in children is associated with an increase in behaviors such as yawning and daydreaming, as well as inattentive behaviors, although this study did not find an increase in hyperactivity or impulsivity.¹⁰ Partial

	Hyperactivity/ Impulsivity	Inattention	ADHD Symptoms	Aggression/ Conduct Problems	Poor School Performance	Depression/ Anxiety
Poor sleep hygiene	√	√	√	√	√	√
Sleep restriction	√	√	√	√	√	√
Circadian rhythm problems	—	√	√	—	√	√
SDB	√	√	√	√	√	√
RLS/PLM	√	√	√	√	—	√
Narcolepsy	—	√	√	—	√	√
Insomnia	—	√	√	√	√	√

Abbreviations: √, published literature supports association; —, no published data; ADHD, attention-deficit hyperactivity disorder; RLS/PLM, restless legs syndrome/periodic limb movement; SDB, sleep-disordered breathing.

sleep restriction studies in children have shown that even after restricting sleep to 6.5 hours (third graders and above) or 8.0 hours (first and second graders) as compared with the control duration of 10.0 hours per night for 3 weeks, those with restricted sleep were more likely to have academic problems and attention problems.¹¹ Again, no increase in hyperactive behaviors was observed in this teacher-report study. In a longitudinal study of sixth, seventh, and eighth graders, those with shorter sleep durations were more likely to have reduced self-esteem, poor grades, and an increase in depressive symptoms.¹²

DELAYED SLEEP PHASE SYNDROME

Circadian rhythms develop throughout life and are entwined with the light-dark cycle. Optimal sleep occurs when the internal circadian cycle is aligned with the external sleep-wake schedule, and when this alignment becomes destabilized, circadian rhythm sleep disorders can occur. One of the most relevant circadian disorders in childhood and adolescence is delayed sleep phase disorder, where the sleep period is delayed in relation to the required or desired sleep-wake times. As children develop and reach puberty, there is a natural tendency to fall asleep later with greater difficulty waking up early. The circadian cycle undergoes changes during adolescence, and a phase preference for eveningness (owl), as opposed to morningness (lark), has been reported to be associated with pubertal development.¹³ Delayed sleep phase syndrome may be an extreme variant of these developmental shifts. It is no surprise to parents that as children get older they go to bed later and, coupled with early school start times, most adolescents have great difficulty waking on school mornings. Indeed, the National Sleep Foundation Poll reported that 70% of adolescents needed someone to wake them on school mornings.³

Common comorbidities of delayed sleep phase syndrome are attention-deficit hyperactivity disorder (ADHD)-like behaviors and depressive symptoms. Many children who are unable to fall asleep at the required time have daytime sleepiness at school, which may preclude full participation in classroom activities. Giannotti and colleagues¹⁴ have shown that children with delayed sleep phase syndrome frequently

have problems with daytime sleepiness, attention, emotional outbursts, and poor school achievement. In addition, they reported an increased frequency of physical injuries. Several studies have reported an association with ADHD, as well as oppositional problems and conduct disorder (for a review see Cardinali¹⁵). Mood disorders, particularly depression, are frequently associated with circadian rhythm problems. It can be a challenge for the clinician to treat these patients, as the relationships with behavioral or emotional problems are likely bidirectional with the circadian disorder.¹⁶ Many of the adolescents with delayed sleep phase disorder are labeled as having behavioral problems, but if they are allowed to sleep until later in the morning, their symptoms abate.¹⁷

This finding raises the issue of school start times. The biological delay in the circadian system of adolescents coupled with early school start times has been associated with impaired school performance. Most of this work has been conducted in middle school and high school students, and several studies suggest that more time in bed is related to better school grades.⁷ In a group of 800 Israeli preadolescents, investigators compared children who started school before 7:15 AM with those who started at 8:00 AM. They found that those who started earlier were more likely to complain of daytime sleepiness, doze off in class, and have more attention and concentration problems.¹⁸ In a large survey of more than 3000 students, those reporting B grades or better were significantly more likely to go to bed between 10 and 50 minutes earlier and obtain 17 to 33 minutes more sleep than their peers who obtained C grades or below.¹⁹ In a landmark study²⁰ that was the first large-scale longitudinal study of the effects of delayed school start times on the academic performance of children, 18,000 children were followed from 2 years before until 3 years after their schools delayed start times from 7:15 AM to 8:40 AM. Multiple improvements were observed from decreases in tardiness, increases in graduation rates, improved academic performance, and higher morale. These findings underscore the serious impact of early school start times on children's and adolescent's school performance, yet most schools still have start times that are not conducive to good performance (for a review see O'Malley and O'Malley²¹).

SLEEP-DISORDERED BREATHING

The cognitive and behavioral manifestations of sleep disruption are probably most well studied in children with sleep-disordered breathing (SDB). SDB describes a spectrum of sleep-related breathing problems ranging from snoring to obstructive sleep apnea and is most common in young school-aged children. Although there has been a considerable research effort in this area in the past few decades, the first reports of learning and behavioral problems in children with SDB were published in the late 1800s.²² Behavioral dysregulation is the most commonly encountered comorbidity of SDB, and the vast majority of studies consistently report some association between SDB symptoms, or objective measures of SDB, and hyperactivity, impulsivity, and ADHD-like symptoms.²³⁻²⁶ In a survey of more than 800 families using validated instruments,²³ symptoms of SDB were associated with hyperactive behaviors with a trend toward a dose-response relationship between reported snoring frequency and behavior. Even in children with primary snoring (snoring in the absence of obstructive apneas), behavioral problems have been reported.²⁷ Children with SDB have been reported to have more inattention than other children, although the strength of the associations is not as robust as for hyperactivity. Continuous Performance Tests that can differentiate between types of attention, such as selective or sustained

attention, show that children with SDB, even if only mild, exhibit deficits in attention when compared with control children.²⁸⁻³⁰

SDB and ADHD

The major features of ADHD (eg, inattention, hyperactivity, and impulsivity) are frequent manifestations of childhood SDB, and, thus, the relationship between these two disorders is of great interest. Parental reports of children with ADHD show that these children demonstrate a number of sleep problems, with a frequency five times greater than that of otherwise healthy children.³¹ Children with ADHD are more likely to snore than their peers, with some studies suggesting that snoring is more common in those with the hyperactive/impulsive subtype of ADHD.³² Polysomnographic data are less clear in terms of an association between SDB and ADHD, with many studies failing to find a consistent relationship. However, recent data, including a systematic review,³³ suggest that children with ADHD are indeed more likely to have SDB, albeit rather mild in severity. In a study of school-aged children undergoing polysomnography before removal of enlarged tonsils and adenoids (typically for SDB), formal diagnoses of ADHD were found in almost a third of children,²⁹ yet half of these children did not fulfill criteria for a diagnosis of ADHD a year after adenotonsillectomy. Disturbances of prefrontal cortex functions have been implicated in deficits observed in children with ADHD,³⁴ as the prefrontal cortex is believed to play a critical role in the regulation of arousal, sleep, and attention.³⁵

Conduct Disorder and Aggressive Behaviors

Conduct problems and aggressive behaviors are beginning to receive more attention in the SDB literature. These behaviors pose a particular problem for schools, which often have local, state, and national programs to address this public health issue. Although studies are more limited than those of hyperactivity and inattention, several large survey investigations have found a relationship between parentally reported symptoms of SDB and aggressive behaviors.^{24,26,36} Based on the reports of parents surveyed at a general pediatric clinic, children between 2 and 14 years old at high risk for SDB, as identified by a validated screening tool, were 2 to 3 times more likely to be bullying, constantly fighting, quarrelsome, and cruel in comparison with other children.³⁶ Conduct problems are associated with a myriad of well-studied social and cultural underpinnings, although it is possible that SDB or other reasons for sleep disruption may contribute to some of these behaviors. Children with aggressive behaviors have also been found to have electroencephalogram slowing during wakefulness,³⁷ which may reflect deficient levels of arousal or excessive daytime sleepiness, likely mediated via the prefrontal cortex.³⁸

Cognitive Dysfunction

As well as behavioral manifestations, there are many reports of children with SDB demonstrating cognitive impairments, although the findings of such studies are not as robust as those for behavioral dysregulation. Reduced intelligence, as measured by either full-scale intelligence quotient (IQ) or subscale IQ (eg, verbal IQ), has been reported.^{28,39,40} However, most studies still report IQ scores within normal limits, the differences being perhaps explained by control children frequently scoring higher than would be anticipated. Memory deficits also have been reported,^{41,42} although this finding is not universal even in large samples with variable degrees of SDB severity. Differences in aspects of memory measured across studies (eg, declarative memory, verbal memory, or working memory) may have contributed to these discrepancies.

Attention and working memory have a close relationship with executive functioning, which is involved in the ability to plan, develop, and carry out problem solving and is critical for normal psychological development. Impairments in executive functioning have been commonly reported in adults with SDB⁴³ and more recently in children,^{25,40} including preschoolers.⁴⁴ Executive functioning is a complex domain to measure because it is difficult to isolate from other cognitive abilities. Furthermore, deficits in executive functioning may alter recruitment of other cognitive abilities, which may negatively impact behavior. The prefrontal cortex has been implicated in executive dysfunction observed in SDB (see Beebe and Gozal⁴⁵). Children who perform poorly at school are more likely to have SDB, and a seminal study showed that a six- to nine-fold increase in sleep-associated gas exchange abnormalities was evident in first-grade children who were performing at the bottom 10th percentile of their class.⁴⁶ Even reports of frequent snoring (in the absence of hypoxemia) have been associated with twice the risk of poor performance in mathematics and spelling, a relationship that appears to have a dose-response effect.⁴⁷

The impact of SDB on behavior and cognition may be age dependent. Younger children may be more vulnerable to cognitive deficits, and most studies reporting an association were conducted in preschool or early school-aged children. Even snoring infants perform worse on the Mental Development Index of the Bayley Scales of Infant Development than nonsnoring infants.⁴⁸ Older children tend to show weaker associations,^{25,41} possibly suggesting a window of vulnerability in the developing brain. (The reader is referred to Beebe⁴⁹ for an excellent review on the impact of pediatric SDB on behavior and cognition.)

When discussing neurobehavioral manifestations of sleep disturbance, most research, and therefore most of the focus, is on SDB. However, neurobehavioral deficits have also been observed in children with other sleep disorders,⁵⁰ several of which will be discussed in the following sections.

RESTLESS LEGS SYNDROME/PERIODIC LIMB MOVEMENTS

Hyperactivity is most commonly associated with SDB. Nonetheless, restless legs syndrome (RLS) and periodic limb movements (PLM) during sleep in children are also strongly associated with hyperactivity.^{51,52} Children and adolescents with PLMs have a high frequency of ADHD,^{53,54} and conversely children with ADHD are more likely to have PLMs during sleep.⁵⁵ One possibility is that RLS and PLMs may fragment sleep and lead to daytime sleepiness and symptoms similar to ADHD. Strong independent interrelationships between children with RLS/PLMs and symptoms of ADHD have been found,⁵⁶ and such relationships may even be stronger than those between SDB and ADHD.⁵⁷ There is also evidence to suggest that children with RLS may be at increased risk for depression and anxiety.⁵⁸

Both RLS and PLMs respond to dopaminergic therapy. Interestingly, Walters and colleagues⁵² found that dopaminergic therapy was associated with improved behavior, with three of seven children with ADHD no longer qualifying for a diagnosis of ADHD. Iron is also essential for the metabolism of dopamine, and both PLMs and ADHD have been associated with reduced levels of ferritin.^{59,60} Supplementation with iron has been shown to successfully treat PLMs in children,⁵⁹ and although there is a case report of improved behavior in a child with ADHD when treated with iron supplementation,⁶¹ there are no studies that have investigated the role of iron in ADHD. As the mechanisms that link PLMs and behavioral problems have not been fully delineated, explanations for the behavioral improvement could include restoration of consolidated sleep or a common dopaminergic deficit shared by PLMs and ADHD.

NARCOLEPSY

Narcolepsy is rare in preschoolers and uncommon in young children. Affected school-aged children have been reported to have impaired concentration, poor school performance, executive dysfunction, and emotional instability. There are reports of children with narcolepsy being described as lazy and more likely to have negative peer interactions, which can feed the cycle of negative behavior and schooling problems. Depressive symptoms, as well as inattention and ADHD-like behaviors, have been reported in children with narcolepsy, although most information regarding daytime manifestations is obtained from clinical reports. One study of 42 children with narcolepsy and a group of “sleepy children” as controls⁶² found a range of psychosocial problems, including depression. Both narcoleptic children and sleepy controls had higher rates of depression, increased behavioral problems, and impaired quality of life than would be expected from a healthy control group. These findings suggest that the daytime sleepiness associated with narcolepsy may be driving the daytime psychiatric impairments. In adolescents and adults with narcolepsy, there are frequent histories consistent with behavioral problems as children, including many being labeled with ADHD-like behaviors.

TREATMENT OF SLEEP PROBLEMS

Although it is beyond the scope of this article to discuss treatment options, it is noteworthy to mention that treatment of sleep disruptions, whether caused by insufficient sleep, poor sleep hygiene, SDB, RLS, or circadian problems, can improve daytime functioning. For example, the most well-studied disorder in terms of its impact on neurobehavioral function is SDB. Multiple studies have shown that treatment of childhood SDB by adenotonsillectomy improves both behavior and cognition.^{29,30,46,63} In one study of children undergoing adenotonsillectomy,²⁹ 22 of 78 children had a formal diagnosis of ADHD before surgery, yet 50% of these children no longer qualified for a diagnosis 1 year after surgery. In children with poor school performance who underwent surgery for SDB, school grades were significantly improved the year following surgery in comparison with those who also had SDB but whose parents elected not to seek treatment.⁴⁶ Quality of life is also improved when children with SDB are treated with adenotonsillectomy.⁶⁴

Treatments of other sleep disorders have been less well studied in terms of behavioral outcomes than has SDB. However, there are case reports and anecdotal evidence of improved behaviors, such as ADHD symptoms, aggression, defiance, and moodiness, when children receive treatment for RLS/PLMs.⁶⁵ Similarly, improved behavior, mood, and less stressful family dynamics have all been reported following treatment for circadian rhythm disorders. As already described, readjusting school start times to better align with biological sleep-wake rhythms is associated with improvement in school performance, social interactions, behavior, and emotional outbursts. In parallel with treatment of specific sleep problems, addressing problematic sleep hygiene by both parent and child education is also vitally important. Improvement in sleep hygiene and ensuring children and adolescents receive sufficient time for sleep decreases daytime sleepiness and is associated with improved daytime functioning both academically and socially.

IS THERE A COMMON THREAD?

The behavioral problems observed in multiple sleep disorders described in the preceding sections are remarkably similar: hyperactivity, inattention, conduct

problems, depression, and cognitive/schooling problems. The vast majority of sleep disorders previously described, including SDB, result in fragmented sleep and daytime sleepiness. Thus, it is possible that the common feature of daytime sleepiness could play a role in the daytime morbidities. Children who are sleepy, whether as a result of ADHD, SDB, RLS, narcolepsy, or poor sleep hygiene, may have strong drives to stay awake, and as such develop hyperactive, stimulus-seeking behavior. Insufficient or inadequate sleep may, through induction of sleepiness, impair executive functioning, regulation of impulsivity, and control of emotions.³⁵ Improvement in sleep, whether by treatment of specific sleep disorders or by better sleep hygiene, is associated with less daytime sleepiness and subsequent reductions in problematic behavior. It is tempting to blame sleepiness as the common factor responsible for the resultant daytime deficits observed in a wide range of sleep disorders. However, as Beebe points out in his review,⁴⁹ while daytime sleepiness and neurobehavioral deficits may share a common cause, such as sleep disruption, one should be careful not to solely attribute impaired daytime function to sleepiness until there is clear evidence of physiological mechanisms by which these occur in childhood.

SUMMARY

Sleep disruption in childhood and adolescence is common and associated with multiple behavioral and cognitive impairments. It is important to note that many of the sleep problems discussed here may not occur in isolation. Similarly, there are bidirectional relationships with some sleep problems and psychiatric disorders, and it can sometimes be challenging to disentangle these often complex relationships. Childhood sleep problems are a significant source of stress for the whole family, as parental sleep is also affected, leading to a reduction in the level of effective parenting. Yet many parents are unaware of the major impact of sleep disruption on their child's learning and behavior. Given the impact of sleep disruptions on learning and behavior, sleep education about the broad meaning of "normal" sleep, the impact of sleep disruption on daytime functioning, and how good sleep hygiene and treatment for specific disorders can significantly improve well-being is warranted.

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