Sleep Deprivation and Human Development

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Normal Sleep and Development

Sleep is defined as a behavioral state characterized by a period of reduced motor activity, associated with specific postures such as lying down with eyes closed, decreased interaction with the environment, reduced responsiveness to external stimuli, and easy reversibility.

Sleep patterns and requirements change with age (see Table 8.1). Sleep onset in the first year of life is usually through rapid eye movement (REM) sleep, also referred to as "active sleep" in infants [1]. In the normal adult, sleep is entered through non-REM (NREM), while REM sleep occurs after about 80 min [1]. The characteristic electroencephalogram (EEG) patterns of NREM sleep are not developed until the ages of 2–6 months. The slow wave EEG patterns of NREM stages 3 and 4 begin to emerge as the brain continues to develop in infancy. Slow wave sleep is prominent in young children and is more intense in quality than in adults, as children are "virtually" non-arousable from slow wave sleep during the first sleep cycle. Slow wave sleep declines markedly by mid-adolescence and sleep patterns begin to resemble those of young adults (see Fig. 8.1). By the age of 60, slow wave sleep may be absent altogether, especially in men [1].

Sleep cycles between NREM and REM, which averages 50–60 min in infants and 90 min in adults. In full term infants, REM sleep accounts for approximately 50 % of total sleep time. The proportion of REM sleep declines with age, decreasing to 30–35 % of sleep time by age 2 years down to 25 % by age 10 years, then remaining stable through adulthood until approximately age 65 when the percentage of REM sleep begins to decline further. REM sleep declines markedly in the cases of organic brain disorders [1, 2] and the absolute amount of REM sleep has been shown to correlate with cognitive functioning [1].

The optimal amount of sleep and the capacity to tolerate to sleep deprivation varies between individuals. There is great variability in the amount of sleep required, as there are short sleepers and long sleepers, "morning larks" and "night owls," and those that are more sensitive to sleep restriction and fragmentation than others. Sleep deprivation refers to a reduction in the optimal amount of sleep for an individual at a given age, associated with medical, behavioral, psychiatric, and neurocognitive morbidity. Sleep deprivation affects overall well-being and may exacerbate underlying medical conditions.

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Sleep, Learning, and Memory: An Overview

Memories must be consolidated before they are rendered available for delayed retrieval [3]. Sleep is an integral part of the necessary processes of encoding, consolidating, retrieving, and integrating memories [3]. This may have a greater impact on neuropsychiatric development and functioning, as proper encoding and consolidation of memories may be important for the development of cognitive function and behavioral regulation. Functional magnetic resonance imaging (fMRI) studies have shown decreased hippocampal activity after sleep deprivation [4]. Although early studies focused primarily on the role of REM sleep in learning, studies of adult human subjects have suggested that NREM and REM sleep are both implicated in memory consolidation. Tasks learned during wakefulness are transferred from the cortex and encoded in the hippocampus, a process that is facilitated by cholinergic activity. Cholinergic pathways are active during both wake and REM sleep and are reduced during slow wave sleep. This reduction of cholinergic activity in slow wave sleep is thought to suppress the direction of encoding from the cortex to the hippocampus and to promote memory consolidation by reactivating the hippocampal memory and its transfer to cortical structures [4]. Slow wave sleep is thought to be important in the formation of declarative memory while REM is postulated to be involved primarily in non-declarative memory, although in actuality the pathways are likely far more complex.

Table 8.1 Average sleep requirements by age

Age	Hours of sleep per 24 h
Newborns (0–2 months)	10–19
Infants (2–12 months)	12–13
Toddlers (1–3 years)	11–13
Ages 3–5 years	9–10
Adolescents (12–18 years)	9–9¼
Adults	7.5–8.5

Source: data from Mindell et al. [6]

Consequence of Sleep Deprivation on Human Development: Causes of Sleep Deprivation

Sleep deprivation can be caused by sleep restriction (behavioral, intentional, or medical causes of decreased sleep opportunity) or by sleep fragmentation. The common causes vary with age (see Table 8.2).

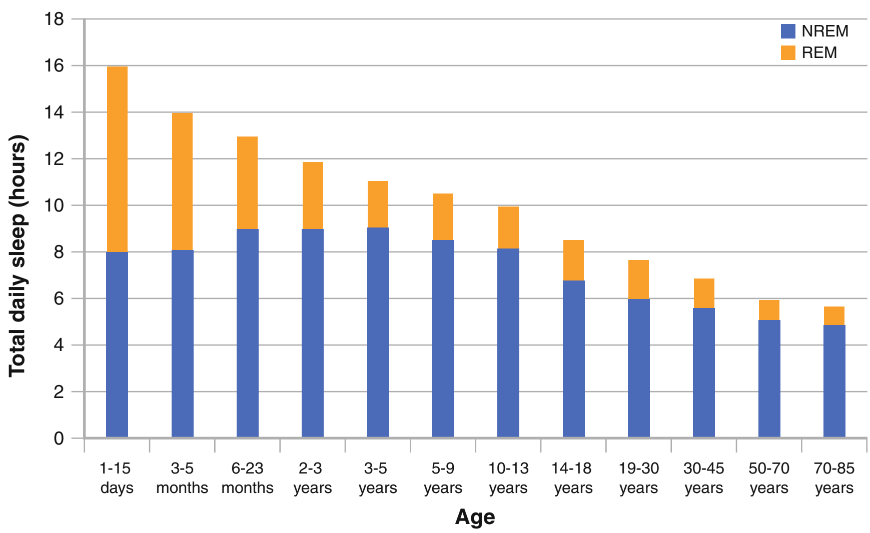

Fig. 8.1 The changes in total daily sleep, REM sleep, and NREM sleep with age. Notice the large amount of REM sleep in the neonate and infant (Based on data from Roffwarg et al. [42])

Table 8.2 Common causes of sleep disturbances

Infancy	Behavioral insomnia of childhood
	Medical problems
	Sleep disordered breathing
Early childhood	Behavioral insomnia of childhood
	Poor sleep hygiene
	Medical problems
	Sleep disordered breathing
	Periodic limb movements of sleep
Adolescence	Circadian rhythm disorders
	Medical and psychiatric disorders
	Psychophysiologic insomnia
	Sleep disordered breathing
	Periodic limb movements of sleep
Adulthood	Sleep disordered breathing
	Periodic limb movements of sleep
	Circadian rhythm disorders
	Medical and psychiatric disorders
	Psychophysiologic insomnia

Neurocognitive Effects of Sleep Deprivation in Infancy

Sleep is the primary activity of the brain during infancy. By the age of 2 years, the average child has spent nearly 14 months asleep and only 10 months awake [5]. Most newborns (aged 0–2 months) require 10–19 h of sleep per 24-h period [6]. Premature babies may have higher sleep requirements. In the first few weeks of life, sleep is polyphasic without clear nocturnal or diurnal patterns, as sleep occurs throughout the day and night. Sleep begins to consolidate around 3 months of age with emerging diurnal patterns of nighttime sleep and daytime wakefulness. Infants (aged 2–12 months) require an average of 9–10 h of sleep at night with naps averaging 3–4 h, resulting in an average of 12–13 h of sleep across the 24-h period.

Extensive research has been done on the implications of inadequate sleep on cognition and behavior in children and adolescents, but there is a paucity of literature on the same in infants. A study by Montgomery-Downs and Gozal [7] found that healthy 8-month-old infants who snored, without any polysomnogram (PSG) evidence of other sleep disorders, scored lower on assessments of cognitive function. Infants were assessed after PSG using the Bayley Scales of Infant Development II (BSID-II), which includes the Mental Development Index (MDI) and the Motor Scale. The MDI assesses sensory/perceptual acuities, discriminations, and response; acquisition of object constancy; memory learning and problem solving; vocalization and beginning of verbal communication. It was found that infants with higher snoring-arousal indices had lower scores on the BSID-II.

Bernier et al. [8] investigated the contribution of sleep disturbances to the development of executive function and impulse control. Sleep regulation was assessed at the ages of 12 and 18 months with a parent sleep diary. Executive functioning was assessed at age 18 and 26 months. Higher total sleep times at 12 months were related to executive function and impulse control at 26 months. Total sleep times at 18 months were related to concurrent working memory and later impulse control. Furthermore, it was found that children who obtained a higher percentage of their total sleep time at night were more advanced in their development of executive functioning. Thus, not only are total sleep times important for neurocognitive development, but the ratio of daytime to nighttime sleep is an important indicator of development and sleep consolidation.

Furthermore, Dionne et al. [9] examined the association between sleep consolidation in infancy and language development in early childhood. Sleep consolidation was measured by parental reports of day and night sleep durations in twins at the ages of 6, 18, and 30 months. Language skills were assessed at the ages of 18 and 30 months with the MacArthur Communicative Development Inventory and at the age of 60 months with the Peabody Picture Vocabulary Test. It was found that children who exhibited language delays at the age of 60 months had less mature sleep consolidation at 6 and 18 months than children without language delays or with only transient early delays. Genetic and environmental influences were also shown to play a role. The authors concluded that poor sleep consolidation within the first 2 years of life may be a risk factor for impaired development of language skills and that good sleep consolidation may enhance language development.

Neurocognitive Effects of Sleep Deprivation in Childhood

Sleep requirements and patterns continue to change throughout childhood. Toddlers require an average of 9.5–10.5 h of sleep at night with 2–3 h of naptime during the day, for an overall sleep requirement of 11–13 h per 24-h period. Around the age of 18 months, the number of naps decreases from two to one nap per day. By the age of 3 years, only about half of children take a nap. Children aged 3–5 years require an average of 9–10 h of nighttime sleep. About 25 % of 4 year olds and 15 % of 5 year olds take a nap. By the school years, children aged 6–12 years require an average of 9–10 h of sleep over 24 h. A circadian sleep phase preference may begin to emerge during the school years. Children with circadian phase delay may be at high risk for sleep deprivation as sleep onset difficulties associated with phase delay are often compounded by early school start times.

Sleep disturbances in children are common, as 25–40 % of children experience some kind of sleep problem during childhood, ranging from transient issues with insomnia and nighttime wakings to primary sleep disorders such as obstructive sleep apnea [10, 11].

Sleep disruption leads to impairments in neurocognitive and behavioral functioning regardless of the underlying cause (sleep restriction, sleep-related breathing disorders, etc.) [12]. It has been well established that sleep disruption in children can cause ADHD-like symptoms including hyperactivity, poor concentration, inattention, impulsivity, irritability, and poor academic performance. It is estimated that 25–50 % of children and adolescents with a diagnosis of ADHD have reported problems with sleep during clinical visits [13]. Furthermore, comorbid psychiatric conditions including mood disorders, learning disorders, and externalizing behaviors such as conduct disorder and oppositional defiant disorder are common in children and adolescents with ADHD. Such comorbidities have also been implicated in sleep disruption [14].

The relationship between sleep, behavior, mood, and cognition is bidirectional. Mood disorders and behavioral problems often result in sleep disturbance. In turn, sleep deprivation frequently causes problems with mood, cognitive impairment, behavioral disturbances, and inattention.

Reduced sleep duration is shown to be associated with high emotional lability scores [15, 16]. Holly et al. [17] found that reduced sleep duration, measured in absolute minutes by actigraphy, may be a risk factor for childhood conduct problems. Furthermore, their research suggested that an absolute reduction in the number of minutes of sleep is correlated with an increase in conduct problem scores, and that a 60-min reduction in sleep duration may in itself be a risk factor for conduct problems. As stated above, the relationship between sleep and behavior is bidirectional. Thus, it remains unclear to what extent conduct problems cause sleep disruption and vice versa.

Whereas conduct disorders, which fall under the spectrum of externalizing behaviors, are linked with sleep disruption, internalizing behaviors may also develop in association with sleep disorders. The spectrum of internalizing behaviors includes emotional withdrawal, somatization, depression, and anxiety, and these are thought to affect up to 40 % of youth [18]. Again, the interaction between sleep and mood is bidirectional—sleep problems may be a symptom of anxiety and depression, while feelings of anxiety and depression may develop as a consequence of chronic sleep problems. The risk of developing internalizing problems, particularly anxiety, in the setting of chronic sleep issues is increased across all ages, from toddlers to adults [19, 20].

It has been shown that sleep problems can result in long lasting issues with emotional internalizing [18]. Touchette et al. [18] studied a sample of over 1,500 French subjects over the course of 18 years. They found that children with sleep problems were 4.5 times more likely to experience persistently high levels of internalizing symptoms into young adulthood than those without sleep problems, after accounting for important covariates such as sex, age, childhood temperament, externalizing problems, stressful life events, socioeconomic status, and parental depression. These findings were equal in males and females.

The underlying mechanisms of sleep problems leading to internalizing remain unclear. Several physiologic mechanisms have been postulated, including alterations in monoaminergic and glutaminergic pathways, changes in the hypothalamic–pituitary–adrenal axis from chronic stress caused by sleep problems, and decreased daytime vigilance resulting in emotional dysregulation. Environmental factors may include parental behaviors and childhood temperament. Further investigation is needed into these mechanisms and into whether treating sleep disorders early in life can reduce the likelihood of later development of internalizing disorders [18].

Neurocognitive Effects of Sleep Deprivation in Adolescence

Adolescents (age 12–18 years) require on average 9–9¼ h of sleep per night, ranging from 10 h for 12 year olds down to 8.5 h for 18 year olds [21]. Most teenagers, however, report only 7 h of sleep at night [22] and thus are chronically sleep deprived. Sleep times on non-school nights average 9 h, so even attempts to catch up on missed sleep during the school week are inadequate [6]. Average bedtimes become progressively later, ranging from 9:30 p.m. for 6th graders to 11:00 p.m. for 12th graders on school nights and 10:30 p.m. for 6th graders and 12:45 a.m. for 12th graders on non-school nights (see Fig. 8.2) [6]. These patterns are similar across cultures and countries, including those in North America, Europe, Asia, and South America [23]. Many parents are unaware of their teens' sleeping requirements and habits [23] which may exacerbate the problem. A 2006 poll by the National Sleep Foundation [24] found that 90 % of caregivers believed their adolescent was getting enough sleep at least a few nights a week on school nights, whereas the same poll found that only 20 % of adolescents received the optimal 9 h of sleep per night. Given the significant physical, cognitive, and psychological development that occur during adolescence, teenagers may be particularly vulnerable to the effects of sleep deprivation [23].

Adolescents undergo a significant change in their circadian phase, usually delayed phase, around the onset of puberty. Along with changes in hormone secretion, there is a shift in the

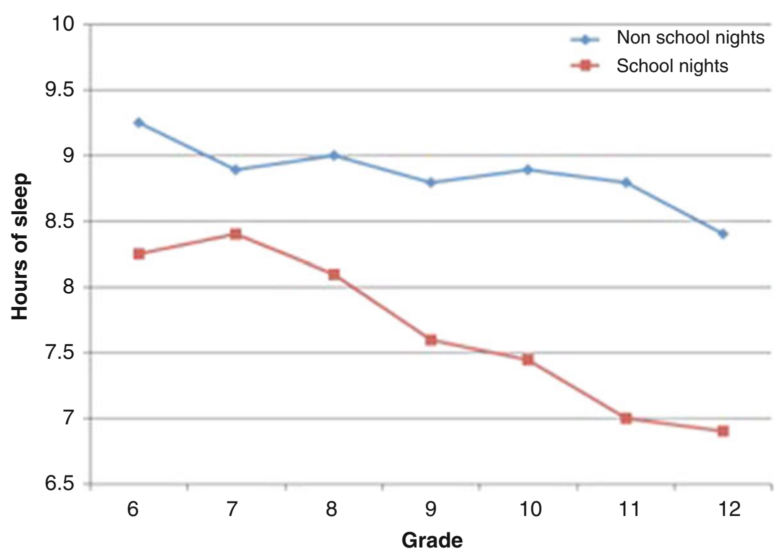

Fig. 8.2 Sleep duration in children (Reprinted with permission from the National Sleep Foundation [24])

secretion of melatonin that results in a 2-h phase delay relative to middle childhood [25]; this hormonal and circadian shift is correlated with Tanner stage rather than chronological age [6]. The circadian phase delay manifests as later sleep onset and later wake times, which tends to conflict with the early start times of most high schools. As a result, many adolescents are at school during their "biological night" [26]. The fundamental biological sleep requirements are not met because of social constraints, resulting in chronic sleep deprivation.

Delayed sleep phase syndrome (DSPS) is common amongst adolescents but may also affect younger children. It is estimated that 7–16 % of adolescents are affected by DSPS [6]. As there is a mismatch between environmental light and dark cues and sleep onset, adolescents often complain of sleep onset insomnia when attempting to initiate sleep sooner than their preferred bedtime. However, when bedtimes are delayed to their preferred time, sleep onset is usually quick, sleep maintenance is good, and the quality of sleep is normal. Children with DSPS experience significant difficulties waking up at required times for school and weekend extracurricular activities and have decreased levels of alertness in the morning. On weekends and vacations, they often extend their sleep times until the late morning or early afternoon hours. Hence these children are in a state of constant jet lag between weekdays and weekends. There also may be problems with daytime sleepiness because of chronic sleep deprivation; adolescents may complain of feeling sleepy or dozing off in the afternoons and they may take long afternoon naps after school to make up for chronic sleep loss.

DSPS can cause significant problems with daytime sleepiness, school performance, behavior, and mood. It has been shown in multiple studies that inadequate sleep is associated with lower academic achievement in middle school through college [22]. Excessive daytime sleepiness also puts adolescents at risk for drowsy driving-related accidents, reduced physical activity which can contribute to obesity and metabolic issues, and the use of stimulants such as caffeine and prescription medications [27].

DSPS has been associated with mood disorders. Thorpy et al. [28] found that more than half of adolescent patients with DSPS had symptoms of depression, measured objectively by the Beck Depression Inventory, Minnesota Multiphasic Personality Inventory (MMPI), or formal psychological evaluation. Furthermore, Lee et al. [29] have suggested that DSPS is partially comorbid with seasonal affective disorder (SAD), as there may be a shared circadian physiology causing delayed sleep phase.

Sleep problems in adolescents, whether related to DSPS, sleep restriction, or other sleep disturbances, can be a risk factor for impulsivity and other behavioral problems. A study by Moore et al. [30] showed that sleep problems in adolescents are associated with increased measures of negative affectivity and poorer effortful control, corresponding with increased impulsivity. A meta-analysis by Pigeon et al. [31] found an increased relative risk for suicidality, including suicidal ideation, suicide attempts, and completed suicide in adolescents with sleep problems. Furthermore, Fitzgerald et al. [32] found that extremes in total sleep time, whether short or long sleep times, are associated with suicidal ideation and behavior after controlling for age, sex, levels of sadness, and substance abuse. They postulated that extremes in sleep times may contribute to suicidality by influencing mood instability and impulsivity.

As the appreciation and understanding of the impact of sleep restriction in adolescents is increasing, advocates have proposed later school start times. Owens et al. [27] examined the effects of a 30-min delay in school start times on 9–12th graders' sleep, behavior, and mood. Adolescents' average sleep duration increased by 45 min and the proportion of students reporting at least 8 h of sleep increased from 16 % to nearly 55 %. This had a positive impact on motivation, class attendance, daytime alertness, fatigue, mood, and satisfaction with sleep.

Neurocognitive Effects of Sleep Deprivation in Adulthood

The average healthy adult requires between 7.5 and 8.5 h sleep per night in the absence of sleep debt. However, many adults do not get enough sleep. Data from the National Health Interview

Survey [33] conducted from 2005 to 2007 showed that nearly 30 % of the US adults reported getting 6 or less hours of sleep per day. A survey of 1,000 adults [34] found that adults who slept less than 6 h on work nights were significantly more likely to be obese than adults who slept at least 8 h (41 % vs. 28 %). Ongoing sleep issues in adulthood may have detrimental effects on overall health, exacerbating underlying medical issues such cardiovascular and metabolic disorders, psychiatric disorders such as depression and anxiety, and causing impairment in overall well-being and neurocognitive functioning.

Acute and chronic sleep deprivation result in important and serious deficits in cognition and performance on everyday tasks such as driving. It is estimated by the National Department of Transportation [35] that drowsy driving is responsible for 1,550 fatalities and 40,000 nonfatal injuries annually in the United States. A 2008 poll by the National Sleep Foundation [34] found that 32 % of adults working full-time had driven drowsy at least once a month in the past year, and this number was as high as 48 % in shift workers.

Although we live in a society in which chronic partial sleep restriction is rampant and becoming an increasingly important public health issue, the vast majority of studies have looked at the effects of total sleep deprivation rather than chronic sleep restriction. There are several studies, however, examining the effects of chronic partial sleep restriction. All forms of sleep deprivation, including total sleep deprivation, partial sleep deprivation, and chronic partial sleep restriction, are associated with negative affectivity including irritability, depression, anxiety, confusion, sleepiness, and fatigue [36]. Cognitive performance, including executive function and working memory, are negatively affected by total sleep deprivation. Studies have shown that chronic sleep restriction over several days is associated with a degree of impairment in cognitive performance similar to that seen in acute severe total sleep deprivation [36]. There is significant interindividual variability, however, as some individuals seem to be more sensitive to the effects of sleep loss than others. The underlying neurobiological mechanisms of this variability remain unclear, although it has been postulated that differences between individuals may be based on genes that regulate sleep homeostasis and circadian rhythms [37]. Interestingly, as most individuals become increasingly cognitively impaired as a result of sleep loss, they tend to underestimate the degree of impairment and report only moderate levels of sleepiness [38].

Sleep disruption, whether secondary to medical conditions or environmental disturbances, is also an important contributor to neurocognitive and behavioral problems but is the least studied form of sleep loss [38]. Studies of sleep disruption have shown impaired performance on the psychomotor vigilance test (PVT), reduced speed of cognitive processing, and impairments in working memory [39]. This can have an important impact on functioning in the workplace. Up to 40 % of adults report becoming impatient with others at work at least a few days a month [34] while nearly 30 % report problems with concentration. About 20 % of workers have reported issues with reduced productivity at least a few days a month [34].

Primary sleep disorders that contribute to sleep disruption and fragmentation, such as obstructive sleep apnea, restless legs syndrome, and periodic limb movement disorder, may also contribute to sleep deprivation and problems with neurocognitive impairment.

Electronic Media and Sleep Hygiene

Electronic media are ubiquitous and have become an important contributor to poor sleep habits and sleep deprivation across all ages. In a survey by the National Sleep Foundation, 95 % of respondents reported using some form of electronic device within the hour before bedtime, including televisions, video games, computers, and cell phones. Exposure to artificial light affects the production of melatonin and enhances alertness, which may cause difficulties with sleep onset and alterations in the circadian system [40]. Furthermore, engaging with interactive devices such as cell phones, computers, and video games is thought to be more disruptive to sleep than using passive media such as televisions [40]. About 40 % of Americans use their cell phones when trying to go to sleep [41], with a higher prevalence of use amongst adolescents and young adults (72 % of 13–18 year olds and 67 % of 19–29 year olds). Texting at bedtime is common in adolescents and young adults and has been shown to result in subjectively less restful sleep, waking up unrefreshed, scoring "sleepy" on the Epworth Sleepiness Scale, and a higher likelihood of drowsy driving [41]. Cell phones can be a further sleep disturbance during the night if not turned off or set to silent when going to bed. Up to 60 % of adults and over 70 % of teens and young adults use their computers or laptops in their bedrooms during the hour before bedtime; this has similar results to cell phone use on subjective sleep quality and levels of daytime alertness.

Informing patients about good sleep hygiene is important in minimizing sleep deprivation. Avoiding light exposure and use of electronic media before bedtime, having a relaxing presleep ritual, keeping the bedroom cool and comfortable, and avoiding strenuous exercise, caffeine, alcohol, and large meals before bedtime are conducive to good quality sleep. Adequate sleep duration and good quality sleep are important for overall health, well-being, and development.

Summary

Sleep deprivation can be caused by sleep restriction or sleep fragmentation, with similar effects on overall neurocognitive development regardless of the cause.

Sleep is vital for neurocognitive development and sleep deprivation can have detrimental effects on cognition and functioning across the lifespan. Infants who are sleep deprived show deficits in language development, executive function, and impulse control in early childhood. Sleep disorders in childhood are common and often manifest in ADHD-like symptoms, including poor school performance, inattention, hyperactivity, and behavioral issues. Children with sleep disorders may develop problems with emotional internalizing, such as anxiety and depression, in young adulthood. As children enter adolescence, there is a shift in circadian biology resulting in a phase delay which is often worsened by the use of electronic media. This, compounded with early school start times, social demands such extracurricular activities, and lack of parental understanding of adolescents' sleep needs, leads to chronic sleep restriction and deprivation. Sleep deprivation puts adolescents at risk for poor school performance, drowsy driving, impulsivity, mood dysregulation, and suicidality. Later school start times have been shown to have a positive impact on adolescent cognition, mood, and behavior. As we live in a 24-h society, many adults are chronically sleep deprived. More studies need to be done on chronic partial sleep restriction. However, chronic sleep restriction is associated with poor psychomotor vigilance, cognitive impairment, and mood disorders. Good sleep hygiene and early recognition of sleep problems are important for overall health, development, and functioning. A detailed sleep evaluation should be a part of the well-child visit and the annual health check-up for adults. Screening for subtle sleep disorders should be routine and attention toward good sleep hygiene is recommended to help minimize the adverse effects of sleep deprivation.

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