How sleep loss and stress affect brain development in adolescents

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Abstract

Adolescence is a crucial period for brain development that if affected, can lead to long-lasting detrimental changes in adulthood. During adolescence, the body enters a transition period from childhood to adulthood where the brain continues to mature. For instance, the prefrontal cortex in particular is not fully developed during adolescence which is evident in decision making skills and cognitive abilities. Additionally, adolescents today experience a significant amount of sleep loss and emotional stress due to school pressures, home life, and social obligations that can tremendously alter brain development and further affect decision making and cognitive abilities. Therefore, understanding the unique pressures of adolescence is crucial for better brain development and overall health. This review will evaluate how sleep loss and stress in particular affect brain development in adolescents. This work will highlight the importance of healthy sleep and stress management habits for adolescents with the aim of fostering positive outcomes in adulthood.

Keywords: Brain Development, Adolescence, Sleep, Stress

Introduction

According to the Center for Disease Control (CDC), more than 77% of adolescents (13-18 years) do not receive the recommended eight hours of sleep a night. Adolescence is a crucial period for brain development as it marks the transition from childhood to adulthood. It includes structural and functional changes in the brain that significantly affect future learning, behavior and mental health. In today's society many adolescents face a significant amount of sleep deprivation and stress which are heavily fueled by academic and athletic pressures, home life and social anxiety (Ma. et al.; Rowson et al.). Stress and sleep deprivation are not just inconveniences for adolescents, but key disruptors of brain health. A mere few minutes of deviation from the recommended sleep amount has been shown to result in reduced brain volume and function in adolescents (Ma et al.). Adequate sleep is hugely important because it plays an essential role in memory consolidation, emotional processing, and the brain's natural repair processes, including clearing away metabolic byproducts that build up during the day. Without sufficient sleep, this restoration is impaired, leaving the brain more vulnerable to stress and long-term dysfunction (Bellesi et al.).

Additionally, chronic stress elevates cortisol levels in the body and brain, which can impair the hippocampus and prefrontal cortex, important regions responsible for learning and decision-making (Harris et al.). Moreover, research reveals that disrupted sleep and stress can interfere with key developmental processes in the adolescent brain. As a result, inadequate sleep combined with chronic stress may impair academic performance, heighten vulnerability to anxiety and depression, and hinder emotional growth (Harris et al.). Given the growing body of

research, it is crucial to investigate how these deeply connected issues of sleep loss and stress impact the developing adolescent brain. This review explores how stress and an insufficient amount of sleep impair cognitive and emotional brain development in adolescents, emphasizing the urgent need for lifestyle changes for them. By understanding the neurological consequences, educators and parents can play a more effective role in fostering resilience during this critical stage of growth.

The Impacts of Sleep Deprivation in Adolescents

Sleep deprivation has been a widespread issue among adolescents, with a large percentage of adolescents consistently failing to get the recommended 8-10 hours of sleep per night. This problem stems from a myriad of factors including busy schedules, athletics, homework, social media/device use, and home pressures. Additionally, adolescence is a time of dramatic physical changes. During puberty, adolescents experience a biological shift in their circadian rhythms. This causes a natural delay in the release of melatonin, which is the hormone responsible for regulating the body's sleep-wake cycle. Research exhibits that this delay can be around one to two hours, which causes adolescents to not become sleepy until around 10:30 or 11:00 PM (Carskadon et al). However, school start times remain as early as 7:30 AM. Late sleep times and early wakeups lead to a cycle of inadequate sleep. As a result, adolescents often experience daytime fatigue, reduced attention, and weakened memory, negatively affecting learning and academic performance (Carskadon et al.).

Sleep deprivation not only causes fatigue throughout the day, but can also lead to developmental problems. A study conducted by Bellesi et al. in 2017 explored how different sleep conditions affect two types of brain cells involved in cell maintenance and immune response: astrocytes and microglia (Figure 1). Astrocytes are abundant cells in the central nervous system that support metabolism, maintain homeostasis, regulate the blood–brain barrier, remove excess neurotransmitters, and contribute to synapse formation. Microglia are specialized immune cells in the brain that detect damage, remove waste and defend against infections. The researchers investigated whether normal sleep (6-8h), spontaneous wake, acute sleep deprivation, and chronic sleep restriction (5d) would alter glial cell activity. Using electron microscopy, they found that chronically sleep restricted mice showed excessive active astrocyte activity, leading to breakdown of healthy synapses. At the same time, the microglia became hyperactive, showing signs of inflammation. These changes did not happen with normal sleep, wakefulness or short term sleep deprivation, but only after prolonged sleep loss (Bellesi et al.). Taken together, the findings suggest that sleep deprivation may trigger excessive synaptic pruning and inflammatory responses, leading to the loss of critical neural connections and long term impairments in brain function. For adolescents, this underscores how insufficient sleep may jeopardize healthy brain development, especially during a crucial changing period.

Another study conducted by Ma et al. in 2025 highlights the physical consequences of sleep deprivation to the adolescent brain. The study investigated the relationship between sleep duration and cognitive performance in adolescents in a large sample of adolescents between 12 and 18 years old. Participants were divided into groups based on average sleep time, ranging from just over 7 hours to closer to 7.5 hours per night. Adolescents who slept longer not only performed better on cognitive tests but also showed greater brain volume. Larger brain volume (Figure 1) reflects more neurons and synapses, supporting efficient communication within the brain and signaling healthy growth and maturation. In contrast, those with the shortest sleep had the smallest brain volume and performed more poorly on cognitive tasks. Researchers also measured resting heart rate among participants, finding that adolescents with longer sleep had lower resting heart rates - a sign of more efficient cardiovascular functioning (Ma et al.). These findings provide strong evidence that longer and consistent sleep in adolescents is associated with better cognitive performance and physical functioning.

Stress and its Impacts in Adolescents

In addition to sleep loss, adolescents are increasingly being exposed to chronic stressors that can disrupt their emotional well-being and interfere with healthy brain development. Once triggered, these external stressors can have profound developmental consequences in adolescents. Pechtel and Pizzagalli demonstrate that early life stress (ELS) is associated with significant deficits across cognitive domains (memory, executive functioning, and reward processing) as well as affective domains (emotion regulation and social processing). These developmental problems are concentrated in high functioning brain systems such as the amygdala and hippocampus that further develop during adolescence. The amygdala, a small almond-shaped structure deep within the brain, processes emotions such as fear and anxiety. This region is especially sensitive to ELS. Because the amygdala is integral to both rapid emotional reactivity and the formation of emotional memories, heightened stress during its development can lead to long-lasting changes in emotional regulation, increased anxiety, and exaggerated fear responses (Pechtel and Pizzagalli). Since adolescence is a critical window for the maturation of these high level brain systems, disruptions during this stage can derail healthy emotional and cognitive development, leaving lasting imprints on mental and emotional health.

A similar study conducted by Rowson et al., which investigated how chronic stress during adolescence can lead to long-lasting changes in the hippocampus, which is a key brain region involved in memory and learning. The researchers examined gene expression profiles in adult rodents exposed to prolonged stress during adolescence. They found significant alterations in the hippocampal transcriptome (RNA), meaning that stress changed which genes were active, which differed between males and females, showing a gender dependent effect. In females, there was a more pronounced reduction in DNA methylation, a chemical modification that typically suppresses gene activity, suggesting that stress disrupts gene regulation. These female rodents also showed changes in genes that control synaptic function (how neurons connect and

communicate), which could affect how neurons communicate and respond to future stress. In contrast, male stress displayed changes in genes that help with acute stress response genes. This might exhibit how male brains handle and recover from stress in different ways than females due to biology. These results demonstrate that stress affects male and female brains differently at the molecular level (Rowson et al.). Since adolescence is a crucial period of brain maturation, these gender dependent molecular changes could have lasting effects on emotional health and cognitive function. This emphasizes how important considering gender focused research and treatment of adolescent stress and its consequences is.

In addition to these molecular and gene regulatory changes in the brain, chronic stress can also affect the body's stress hormone system. A review by Harris et al from 2017 examined the long term effects of stress experienced during childhood, adolescence and early adulthood on cortisol (the “stress hormone”) levels later in life. They delve into the glucocorticoid hypothesis which suggests that exposure to stress may lead to elevated and sustained cortisol levels (Figure 1) which could affect their long-term health and well-being. This is significant because high cortisol over extended periods can disrupt normal brain development, which can impair the hippocampus and amygdala. Sustained elevation of cortisol levels can also lead to increased risks of anxiety, depression, cognitive decline and a weakened immune system. In adolescents, this initial stress could lead to these consequences that could last for years, potentially affecting their mental well-being throughout adult life.

Adolescents today face a multitude of stressors that can significantly impact their current and future mental and physical health (Figure 1). There are constant pressures of academic and athletic competition and achievement, changing social dynamics and family expectations, which create a challenging, high stress environment for many adolescents. Social media further exacerbates these pressures, as adolescents frequently compare themselves to curated portrayals of others' lives, which can foster feelings of inadequacy and diminished self-worth. These everyday stressors present in adolescents' lives directly affects the developmental system of their brains and could lead to lasting consequences for their physical and mental well-being.

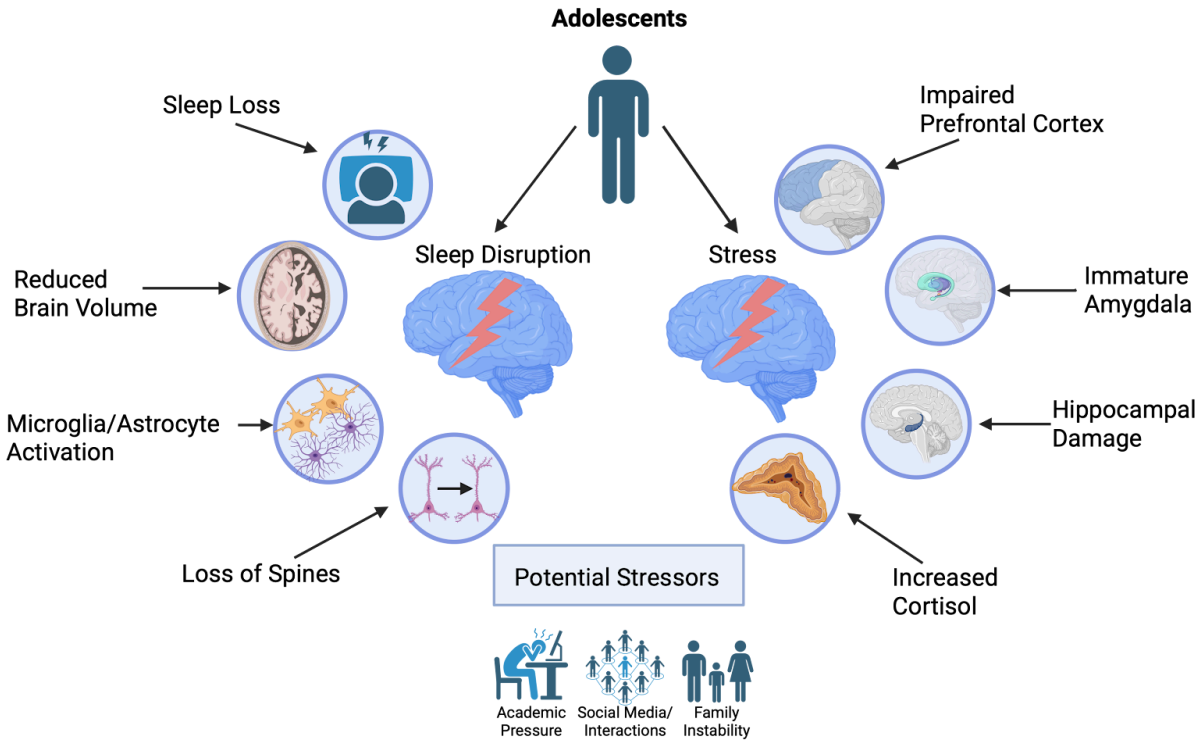

Figure 1. Effect of sleep disruption and stress on the adolescent brain. Circles represent specific behaviors, brain areas and cell types disrupted by sleep loss and stress.

Interventions for Chronic Stress and Sleep Deprivation

Despite these concerning effects, research identifies several interventions that can mitigate these risks. One of the most studied solutions to decrease sleep deprivation is delaying school start times. A study conducted by Dubi Lufi, Orna Tzischnky and Stav Hardar investigated the effects of delaying school start times by one hour. Two groups, the control and the experimental groups, were monitored. The researchers found that this mere one hour difference caused students in the experimental group to sleep, on average, fifty five more minutes than the students in the control group. This increase in sleep led to improved attention and overall alertness, which was exhibited through different types of tests. These improvements are consistent with the role of the prefrontal cortex, which supports decision-making and attentional control (Lufi et al.). In other words, even a modest increase in sleep was associated with stronger cognitive functioning, underscoring how vulnerable the adolescent brain is to small differences in sleep.

In addition to changes in school schedules that allow for better sleep, stress reduction programs within schools show promising results. A randomized study led by Jeanette Johnston tested

classroom-based mindfulness training in adolescents ages fourteen to sixteen years old. The researchers enrolled 285 students across thirteen health education classes, which were randomly assigned to one of three conditions: mindfulness intervention, wellness education, or usual health class. The researchers conducted an eight week long study with limited home practice for students. The researchers found that students who received mindfulness intervention showed a significant reduction in anxiety compared to those in usual health class. They also found that 52% of students used the mindfulness app provided at home at least once during the duration of the experiment (Johnstone et al.). This is significant as it shows that mindfulness helps buffer adolescents and their brains against the neurological, long-term harm caused by stress. Therefore, this helps support the suggestion that more mindfulness focused activities or classes should be implemented into school schedules.

Another important and prevalent factor influencing adolescent sleep and brain health is social media use. A study conducted by Pirdehghan et al. examined the relationship between social media use and its effect on sleep quality and depression among adolescents. The researchers found that adolescents who used social media more had results of poorer sleep quality and greater levels of depressive symptoms. Nighttime users of social media, specifically, experienced more disruptions in their sleep, including difficulty falling asleep and shorter sleep duration (Pirdehghan et al.). These findings reveal a positive correlation between social media use and both sleep deprivation and mental health vulnerability. This opens up the discussion of possible solutions to combating the negative effects of social media including a no phones in school policy, screentime limits enforced by parents and even the development of more positive, less fabricated apps that are still considered social media. Implementing these strategies could help to support better sleep, reduce anxiety and depression and protect the developing brains of adolescents.

Conclusion

Adolescence is a critical stage of brain development where sleep and stress exert significant influence on both brain structure and function. Adolescent brains are particularly vulnerable because they are still maturing, especially in regions essential for decision making, memory and emotional regulation such as the prefrontal cortex, amygdala and hippocampus. Evidence consistently shows that sleep deprivation disrupts essential processes for the brain such as synaptic pruning, memory consolidation and emotional regulation which are all functions that adolescents rely on to learn, navigate social relationships and develop independence (Bellesi et al.). Similarly, high stress from academic and athletic pressures, social media comparisons, peer conflicts and more can negatively affect the amygdala and hippocampus, altering emotional health and cognitive function (Pechtel and Pizzagalli). Together, these factors increase the risk for cognitive deficits, anxiety and long term mental health issues in adulthood due to sleep loss and high stress. However, research also highlights promising solutions including later school

start times, mindfulness intervention and social media restrictions that can help restore balance and protect brain health in adolescents (Johnstone et al.; Lufi et al.; Pirdehghan et al.). Many of these studies have limitations though, such as small sample sizes and reliance on self-reported data, which makes it difficult to determine accurate results. However, by prioritizing healthier sleep schedules and more stress management strategies, schools, parents and communities can help support adolescents transition into healthy and cognitively strong adults.

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