



Enhancing Adolescent Brain Health: Addressing Challenges and Exploring Interventions

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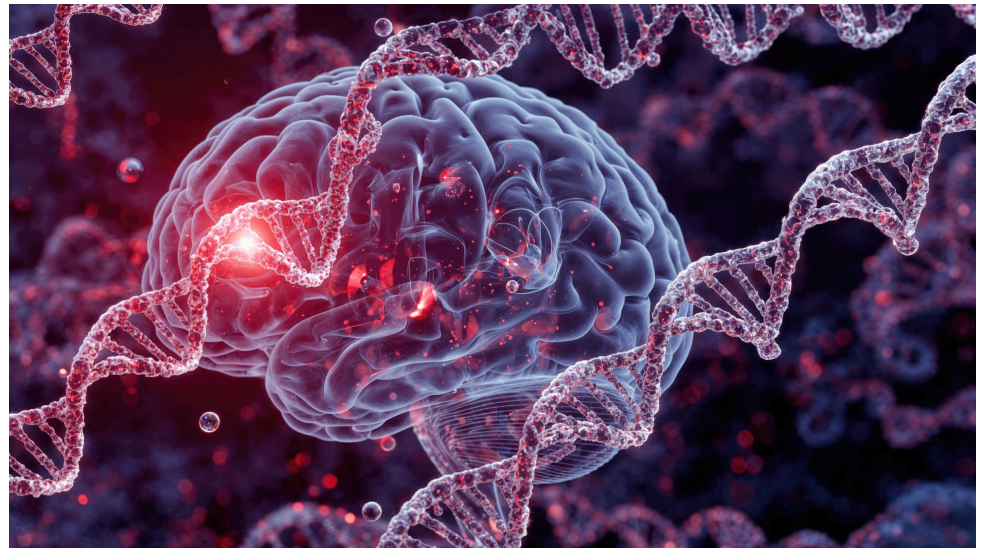
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Abstract

There are complex and multifaceted influences on adolescent brain health, emphasizing the critical need to address both individual and environmental factors that shape cognitive, emotional, and social development during this volatile period. Adolescent brain health is distinct from that of adults and infants, with the prefrontal cortex, responsible for rational decision-making, still maturing until around age 25. As a result, adolescents often rely on the amygdala, the brain's emotional center, for decision-making, leading to behaviors driven more by emotion than rational thought. Socioeconomic status (SES), education quality, parenting styles, and lifestyle choices such as diet, physical activity, and sleep play pivotal roles in adolescent brain development. Additionally, this article underscores the impact of environmental factors, such as pollution and food deserts, on adolescent neurological growth. The lack of access to mental health services, quality education, and nutritious food exacerbates cognitive and emotional challenges. Addressing these issues requires holistic and interdisciplinary interventions that consider the broader social determinants of health and emphasize the importance of nurturing environments, adequate resources, and supportive parenting to promote optimal brain development in adolescents.

1. Introduction

Brain health is the state of the brain functioning across cognitive, sensory, social-emotional, behavioral, and motor domains, enabling a person to think, learn, remember, and carry out everyday activities effectively, thus realizing their full potential throughout life, regardless of the presence or absence of disorders.^{1,2} Determinants like physical health, healthy environments, lifelong learning, social connections, and quality services influence brain development and stress response, promoting overall well-being and societal benefits. However, brain conditions can emerge throughout life, causing disruptions in growth, structure, or function.¹ The developing brain is more vulnerable to changes therefore making sure proper brain development throughout infancy, childhood, and adolescence is critical.¹ Addressing these issues requires a multifaceted approach, person-centered care focusing on prevention, treatment, and involvement of those with lived experience and their support networks.² Cognitive health and mental health are a couple of aspects of overall brain health but especially play critical roles in the growing brain.

It is important to shape the adolescent brain health in particular as adequate brain health is required for a better future since the brain is in its most volatile state at that time. Particularly it is critical to differentiate between adolescence brain health, adult brain health and infant brain health. Adolescents have not yet developed strong judgment skills because the prefrontal cortex, which is responsible for rational thinking, is not fully mature until around age 25.³ Research indicates that the brains of adults and adolescents operate differently; adults utilize the prefrontal cortex for decision-making and considering long-term consequences, while adolescents rely more on the amygdala, the center of emotional responses.³ The neural connections between the emotional and decision-making regions of the brain are still maturing in adolescents and often do so at varying rates.³ As a result, adolescents may act based more on emotion than rational thought during emotionally charged situations, making it difficult for them to articulate their reasoning afterward.³

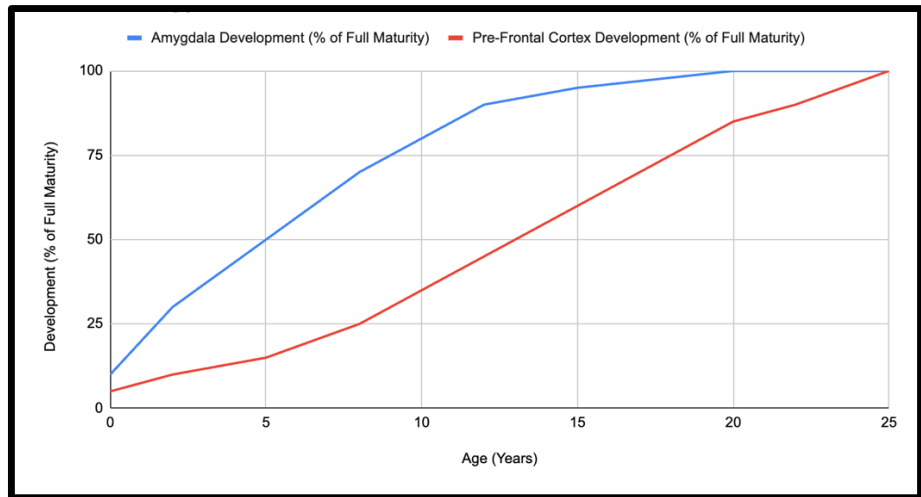


Figure 1: Comparative Brain Development: Amygdala vs. Prefrontal Cortex (% of Full Maturity)

The graph shows the developmental trajectories of the amygdala and prefrontal cortex from childhood to early adulthood. The amygdala is responsible for immediate reactions like fear and aggression and matures early, reaching near full development in early adolescence. The prefrontal cortex is responsible for rational thinking and decision-making continues to mature well into the mid-20s.

Teens often appear not to think things through or consider the consequences of their actions, differing from adults in behavior, problem-solving, and decision-making due to biological factors.^{3,4} Research shows that the brain continues to mature into early adulthood, with the amygdala, responsible for immediate reactions like fear and aggression, developing early, while the frontal cortex, which governs reasoning, matures later.⁴ During adolescence, increased brain connectivity and the development of myelin enhance communication between nerve cells, essential for coordinated thought and behavior.⁴ Brain imaging reveals that adolescents rely more on the emotional amygdala than the logical frontal cortex when making decisions, a process that drugs and alcohol can disrupt.⁴ Consequently, teens are more prone to impulsive actions, misinterpreting

social cues, accidents, fights, and risky behaviors, and less likely to think before acting, consider consequences, or change inappropriate behaviors.⁴

2. Adolescent Brain Development

Understanding these brain differences can help adults better manage and guide adolescent behavior while recognizing that teens are still capable of making good decisions and understanding right from wrong.⁴ Decision-making skills, impulse control, and understanding social cues are all social skills that develop alongside physical brain growth and life experiences. This is why the experiences, health, and environments adolescents are exposed to can greatly influence their brain development and subsequent behavior. It is critical for the United States to emphasize the importance of fostering good brain health in developing adolescent brains.

Currently, many adolescents in the United States alone are suffering from mental health issues, brain health issues, and poor cognitive function. In 2021, over 42% of students reported feeling persistently sad or hopeless, and nearly 29% experienced poor mental health.⁵ In the same year, over 22% of students seriously considered attempting suicide, and 10% actually made an attempt.⁵ Fifteen percent of high school students reported having used certain illicit or injection drugs (such as cocaine, inhalants, heroin, methamphetamines, hallucinogens, or ecstasy) at some point, and 14% reported misusing prescription opioids.⁶ Academic success is a crucial indicator of youth well-being and adult health outcomes, emphasizing the importance of fostering health within educational environments. Students with mostly Ds and Fs were significantly more likely to engage in risky behaviors, feel hopeless, and miss school due to safety concerns compared to those with mostly As.⁷

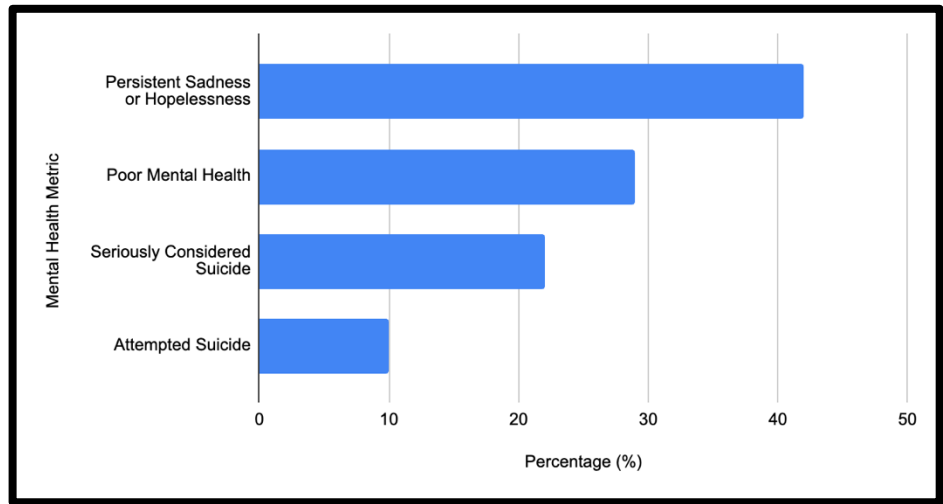


Figure 2: Percentage of Students Reporting Various Mental Health Issues in 2021

The chart shows the percentage of students experiencing persistent sadness or hopelessness, poor mental health, seriously considering suicide, and attempting suicide, highlighting the prevalence of mental health challenges among adolescents.

3. Current Mental Health Crisis

Adolescents today face numerous challenges that impede their development, including poverty, exposure to violence, lack of access to quality education, inadequate healthcare, and unstable home environments.⁸ These factors lead to chronic stress, emotional distress, and engagement in risky behaviors, further disrupting cognitive, emotional, and social growth. The lack of access to mental health services exacerbates these issues, as many adolescents do not receive the necessary support and treatment for depression, anxiety, and trauma.⁸ Additionally, educational environments that fail to provide safety, inclusivity, and adequate resources contribute to poor academic performance and disengagement.^{7,8} The influence of social media and technology also poses challenges, such as cyberbullying and exposure to harmful content, which impact self-esteem and mental health.

There are a limited number of current interventions with limited access to mental health resources and guidance that adolescents have to help with their brain health.⁸ Additionally, because brain health is a broad and interdependent growth process, adverse situations and environments can affect different parts of the brain simultaneously.^{2,8} Solutions to this problem should therefore be able to fix multiple problems for brain growth and development.

4. Determinants of Adolescent Brain Health

Adolescent brain health interventions must address socioeconomic disparities, environmental aspects, and lifestyle choices encompassing a holistic approach to mitigate the risks of disrupted brain health.^{7,8}

4.1 Socioeconomic Factors

Socioeconomic status (SES) affects adolescent brain health due to factors such as education, parental influence, and screen time.

4.1.1 Education

Education is vital to a child's brain development schools are not only a place to learn academics, but also impact children's self-esteem and brain development. According to a trial conducted in 2021, a nurturing school climate with supportive staff leads to student sense of belonging.⁹ Students were more willing to participate in class, allowing them to practice their social capabilities, in turn decreasing depressive symptoms, bullying, and violence.⁹ Therefore, if schools facilitate a safe and welcoming environment, they will aid in the betterment of adolescent brain health by decreasing the chances of depressive symptoms.

In the brain, white matter is vital for sending and receiving signals in the brain, allowing the body to process information.¹⁰ With regard to education, it allows humans to solve problems and learn.¹⁰ A study published in 2024 proved that educational opportunities are related to accelerated white matter development in the context of socioeconomic status.¹¹ Essentially, SES is a factor in the quality of education students in

public schools receive.¹² Higher academic achievement in higher SES leads to more white matter development because adolescents are more challenged with better resources.¹¹ Hence, the quality of education impacts brain development throughout adolescence.¹¹

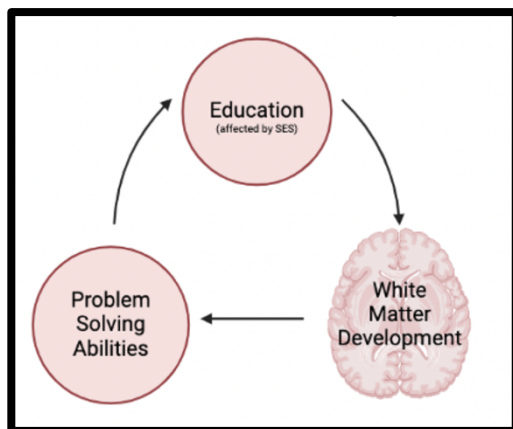


Figure 3: The Connection Between Education and Adolescent Brain Development

Public school education in the United States is affected by the socioeconomic status of that specific region. The quality of education is one of the factors that aids white matter development, which directly impacts problem solving capabilities. Thus, these capabilities are strengthened by education.

In the United States, one of the major sources of funding for schools comes from local property taxes.⁵⁴ In areas with lower SES, it can be difficult for schools to secure funding that would otherwise be easily accessible in areas with higher SES.¹² Therefore, investigating low-cost classroom techniques that promote learning is a method to bridge the gap between low SES education and high SES education. Introducing Project-Based-Learning (PBL) in low SES showed increased growth in social studies and informational reading.¹³ The six parameters of high quality PBL are “intellectual challenge and accomplishment, authenticity, a public product, collaboration, project management, and reflection.”¹³ PBL can be implemented in low SES schools because it does not require extensive funding, many of these parameters can be met with traditional school supplies. For example, teachers can comprise intellectually challenging prompts with an award system and organize students into groups for

collaboration. Allowing students to work in groups with a prompt rather than specific instructions forces them to manage their projects themselves. After the project is accomplished, students can reflect on their results and the overall experience of working in a PBL format. Since we know that childhood education impacts brain development in adolescents, introducing intervention strategies such as PBL can improve their quality of education despite their SES.

Resources such as, but not limited to, food quality, mental health care, and school atmosphere are affected by SES.

In 2023 the NIH published a study conducted on fourteen-year-old males and females via the IMAGEN algorithm.¹⁴ Their goal was to find relationships between SES stress, family support, peer problems, brain composition, and emotional symptoms. It shows that “peer problems” are positively associated with “emotional symptoms” and “SES stress” is negatively associated with “family support” in both genders. In other words, teenagers with better social standing with their peers have fewer emotional problems. Additionally, higher SES indicates more family support compared to lower SES.¹⁴

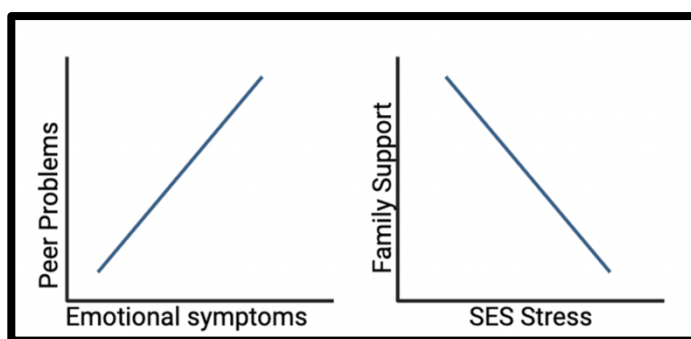


Figure 4: Male and Female Correlations Between Social, Emotional, Family, and SES Parameters

Peer problems and emotional symptoms are positively correlated so it is more likely for an adolescent who undergoes bullying to have more emotional symptoms. SES stress and family support are negatively correlated so it is more likely for adolescents with high family support to feel less SES stress.

4.1.2 Family and Peer Support

Furthermore, in males only, ventromedial prefrontal cortex gray matter volume is negatively correlated with emotional symptoms. In turn, if males do not have a supportive family structure, their gray matter volume decreases.¹⁴ Gray matter helps develop social cognition, judgment, and decision making.¹⁵ This lack of gray matter volume can affect other aspects of their lives, such as impairing their judgment in social conditions, causing a domino effect that then affects their “peer problems” and subsequently their emotional symptoms. In females only, SES stress was found to be negatively associated with entire brain volume.¹⁴ Given this data, low SES is associated with decreased abilities in executive and cognitive functioning, such as neurocognition.¹⁴ Neurocognition, by definition, is the ability to “think and reason”, so a decline in neurocognition will directly affect a person’s capability academically and their everyday decision making.⁵⁹ An intervention strategy would need to cater to SES stress in order to have the domino effect on the other variables. If adolescents did not undergo SES stress, they would be more likely to have family support, which can extend into them having a safe space at home to discuss any peer problems they may be facing at school.

4.1.3 Drug Use

The brain is developing throughout adolescence, making it even more susceptible to drug use than adults with matured brains.¹⁷ Adolescent brain motivation regions peak during the ages thirteen to seventeen, while the regions responsible for self-control are still developing.¹⁷ This makes adolescents more inclined to engage in risky behavior, such as drug use with their peers, because their brains are more impulsive without self-control regulation. Therefore, addiction can occur in this age range, heavily impacting their brain health and future.¹⁷

In 2022, almost one in ten high school students in California used cannabis.⁵⁵ There are about 1.6 million students enrolled in public high schools across California.⁵⁶ By combining these two statistics it can be concluded that approximately 160,000 high school students in California

use cannabis. Tetrahydrocannabinol (THC) is found in cannabis and decreases the brain-derived neurotrophic factor (BDNF) in adolescents who use cannabis.⁵⁷

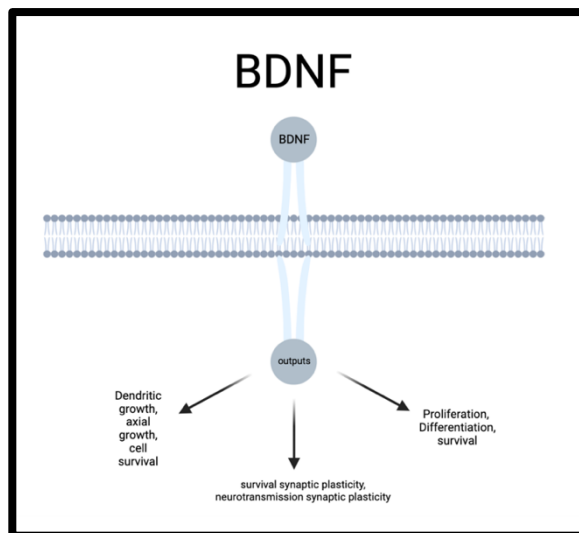


Figure 5: BDNF Pathway Options

The BDNF pathway produces the stated outputs. All of these outputs essentially aid in developing the brain, especially during the adolescent development period. Mitigation of this pathway will disrupt brain development, with consequences that will follow adolescents into adulthood.

The BDNF pathway is vital for “neuronal survival, structural changes, and plasticity.”⁵⁸ It represents an “axonal growth and extension factor, a pro-survival factor and a synaptic modulator in the central nervous system (CNS).”⁵⁸ In other words, the BDNF pathway is crucial for adolescents because their brains are still developing so they need proper formation of neuronal connections. This aids their memory and learning which sets the stage for adolescent brain development into adulthood.⁵⁸ Cannabis usage disrupts this pathway which decreases cognitive ability and educational achievement.⁵⁷

Due to the higher risk of adolescents being susceptible to substance abuse and the opioid epidemic in the United States, a review paper targeting intervention strategies was published in 2022.¹⁸ It compiled a list of five

programs that are useful intervention strategies: Functional Family Therapy (FFT), Positive Family Support (PFS), Lifeskills Training (LST), Positive Action (PA), and Good Behavior Game (GBG).¹⁸ The FFT's target audience are adolescents who were recommended by juvenile justice systems or other well-care professionals.¹⁸ This is a short-term program with a high impact outcome; it has a 100% predictability rating that the benefits will outweigh the costs of the program.¹⁸ LST targets middle school students and places them in a three-year program combating substance abuse and violence.¹⁸ This program has a 63% predictability factor with aims to teach students self-discipline, social, and anti-drug skills.¹⁸ The PA curriculum teaches the same lessons but adapted to appropriate age levels.¹⁸ There are seven units, all of which are built to increase positive behavior and emotions in students with a 94% predictability rating.¹⁸ This is a very realistic intervention strategy because it is scripted for teachers to deliver with little preparation and are short in length.¹⁸ PFS is a program with three levels intended for family intervention with middle schoolers that are at risk for substance abuse.¹⁸ The first level provides guardians with videotaped lessons which provide insight on how to navigate parenting in a healthy manner to mitigate drug use.¹⁸ The second level provides three family therapy sessions with the goal of establishing healthy communication methods.¹⁸ The third level, the most extreme, offers direct professional support on a case-by-case basis.¹⁸ PFS has a 70% predictability score and has been shown to reduce substance abuse.¹⁸ According to the paper, these programs are proven to make a noticeable difference in adolescent substance usage.

4.1.4 Parenting Practices

Children absorb and learn from their environment and the guidance of those around them.¹⁹ Therefore, parental involvement heavily impacts their various schemas of their life.

Studies have shown that adolescents who faced adverse childhood experiences (ACE) are more likely to develop substance use disorder and depression.²⁰ ACEs include ten categories of trauma including physical abuse, sexual abuse, and witnessing domestic violence.²⁰ Hence, many of

these traumatic experiences can be produced by environments parents create for their children.²⁰ For example, abusive parents can subject their children to witnessing domestic violence, violent discipline methods, and sexual assault. An intervention strategy to combat child abuse could be a forced law mandate where school officials are required to check-in on students periodically throughout the school year, regardless of any prior suspicion.

An intervention strategy to combat the adverse effects of parenting is to become educated on which parenting techniques are most effective. As technology is developing, there are increased debates over parents allowing their children screen time. One angle to this debate is seen through a study conducted in 2024, analyzing screen-time and parenting styles.²¹ It showed that parents who do not limit screen time at all result in adolescents having a problematic amount of screen time.²¹ Parents who use screen time as punishment/reward (control behavior) result in children having higher screen time and problematic video game usage.²¹ Parents who monitored the screen time and had general rules resulted in lower screen time and less problematic social media, video game, and mobile phone use.²¹ Based on this data, parents should provide structured rules that are regularly enforced rather than no rules or control behavior. Guardians should also take into account that low screen time paired with physical exercise showed decreased blood pressure, compared to participants with high screen time and low physical activity.²³ Based on this evidence, guardians can devise a strategy that balances physical activity and screen time. Such as giving their adolescents designated activity time throughout the day and designated screen time, which will eliminate using screen time as a reward. Parenting techniques promoting a balance of exercise and screen time can help the overall health of the adolescent as well.²³

Another perspective can be seen through Smart-Ecological Momentary Interventions (EMIs) applicable through Ecological Momentary Assessments (EMA).²² Smart-EMIs provide real-time, context-specific strategies that can give a dopamine reward system, enhancing daily motivation in the form of an app.²² For example, if the Smart-EMI app detects the user is feeling sad or stressed, it could suggest a meditation

exercise or a motivational quote.²² They have been proven to show potential in improving depressive symptoms in patients.²²

4.2 Lifestyle Factors

While socioeconomic and environmental factors may lie outside an adolescent's immediate control, strategic lifestyle choices regarding sleep, physical activity, and diet can have a significant positive influence on individuals' cognitive and mental health.

4.2.1 Sleep and Circadian Rhythm

Individuals run on a circadian rhythm, a 24-hour biological clock that homeostatically regulates daily functioning, particularly the balance between sleep and wakefulness, based on the surrounding environment. Dysregulation of the circadian cycle has been associated with psychiatric disorders, such as depression and anxiety, as both a symptom and a causal factor in young people.^{1,2} In particular, natural circadian shifts that occur during puberty can result in irregular sleep onset, placing adolescents at an increased risk of depression.³ On a biochemical level, chronic sleep disruption has been shown to alter the secretion of melatonin, an important neuroendocrine that regulates circadian rhythm, as well as decrease levels of serotonin, a neurotransmitter affecting mood; both kinds of chemical disruption have been observed in the brains of depressed subjects.^{4,5} These brain changes also influence the gut microbiota, which communicates with the nervous system via the production of neuroendocrines.⁶ Disturbance of the circadian rhythm is a physiological stressor for the gut⁷ which can then induce neurochemical changes that precede stress-like behavior relevant to depression and anxiety.⁸

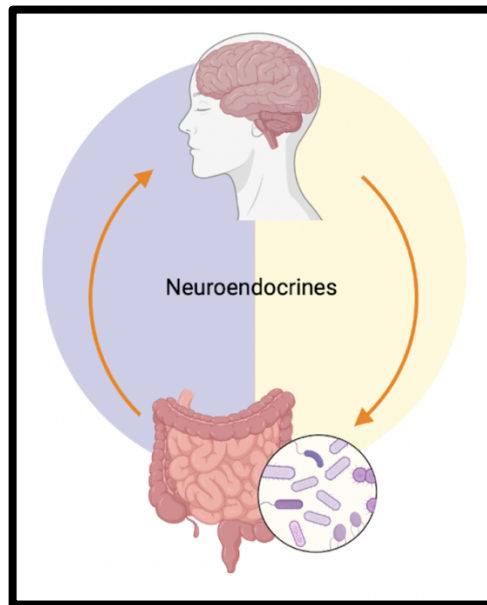


Figure 6: Circadian Regulation of the Gut-Brain Axis

The body's gut-brain axis relies on a delicate balance between neuroendocrine signaling from gut microbiota and the central nervous system, a relationship that is sensitive to the daily circadian rhythm.

4.2.2 Physical Activity

Given the relationship between circadian disruption and psychiatric symptoms, a variety of recent pharmaceutical interventions have been introduced as possible solutions. For instance, agomelatine, a known antidepressant, works as a dual circadian rhythm stabilizer, reducing oxidative stress and inflammatory response while improving depression-like behavior.⁹ Antidepressant drugs alter sleep wave activity, especially slow-wave activity, which is greatest at the initiation of the sleep cycle. However, antidepressants have many reported side effects, such as nausea and indigestion. Thus, further pharmacological research is necessary to improve the efficacy of antidepressant or anti-anxiety therapies.⁹

While adequate sleep is an important contributor to positive mental health, equally important is a conscious effort to maintain healthy physical activity when one is awake.¹⁰ Exercise regulates the activation of various brain

regions related to cognitive performance and mood, including the hypothalamus and striatum, which can be involved in stress and pain perception.¹⁰ Brain connectivity in these regions can be drastically altered in patients with poor mental health and consequently affect their mood.¹⁰ Due to the fact that exercise changes this connectivity, it is crucial for individuals to have a good balance between exercise, sedentary behavior, and adequate sleep to ensure good mental health.¹⁰ However, in an internet-dependent age, excessive screen time among adolescents - especially due to social media platforms - eats into the recommended time for exercise and sleep, which can put these individuals at risk.

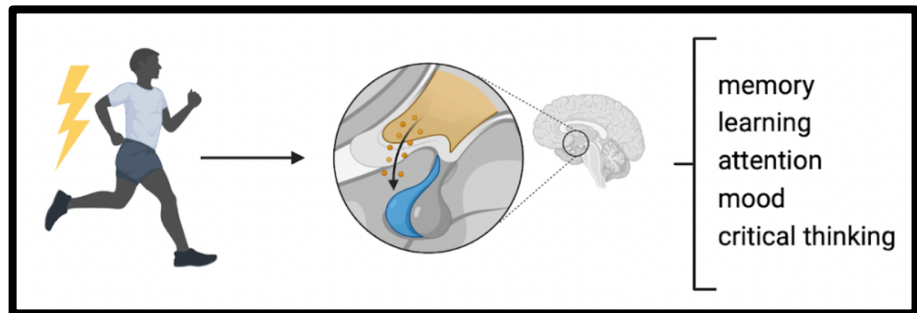


Figure 7: Hypothalamic Neural Modulation by Exercise and its Impact on Behavior

Exercise regulates neural activity in brain regions such as the hypothalamus, ultimately controlling cognitive and emotional behaviors.

With the promise of psychological benefits from healthy exercise, lifestyle choices that prioritize exercise are crucial for reducing the risk of stress-related disorders. Yoga and mindfulness programs, through both school-based settings and individual routines, have been shown to decrease depressive and anxiety symptoms in early adolescents, according to a 2022 study.¹¹ With the relative stress of adjustment in a post-COVID world, yoga can uniquely boost immunity and cardiorespiratory health while decreasing pandemic-induced stress and depression.¹² In addition to yoga, running has been shown to enhance cognitive performance in young adults, with greater benefits among those who enjoy running and those who run outdoors.¹³

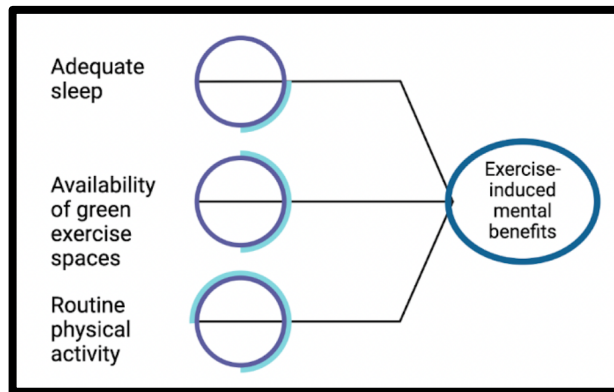


Figure 8: Exercise as a Modulator of Cognitive and Mental Health

Proper physical exercise can provide cognitive and mental health-related benefits.

4.2.3 Nutrition

Perhaps more important than exploring a diversity of exercises, however, is the availability of outdoor space for green exercise. Young adults show the greatest improvements in self-esteem and mood through green exercise than any other age group.¹⁴ However, depending on whether the individual lives in a suburban or metropolitan area, green spaces for exercise can be limited. Thus, in addition to individual intervention strategies for exercise-related mental health, public policies, whether school-wide or city-wide, that consider the necessity of creating public exercise spaces can also have a great impact on the maintenance of positive mental health among young populations.

As with poor sleep habits, certain dietary lifestyles can also impact mental health via biochemical interactions in the gut-brain axis. Dietary stressors, such as alcohol and fat, can increase disturbances in the gut microbiome that are initially caused by circadian disruptions, eventually exacerbating psychiatric symptoms.¹⁵ For instance, circadian-related neural circuits are extremely sensitive to acrylamide, a neurotoxin that is commonly consumed in carbohydrate-rich snacks, even at low concentrations.¹⁶ Adolescents who frequently consume unhealthy snacks and drinks, particularly college

students, are thus at an increased risk of experiencing related psychiatric symptoms.

Additionally, young adults who practice vegetarianism or veganism can be at a higher risk for depression and anxiety-related symptoms.¹⁷ Although there are many positive associations between health and vegetarianism, the nutritional deficiencies that these adolescents suffer from may be linked to their higher probability of experiencing self-harm, stress, perfectionism, or an imbalanced mood, as many studies have shown. Specifically, vegans and vegetarians consume little to no eicosapentaenoic acid (EPA) or docosahexaenoic acid (DHA), which are crucial for brain development at an early age. EPA supplements have been shown to significantly improve depressive symptoms among young people, suggesting a link between improper EPA or DHA levels, as vegans and vegetarians experience, and resulting mental health risks.¹⁸ Vegans and vegetarians also experience Vitamin B12 deficiency, which has potential consequences for depression and nerve damage.¹⁹ While the causal relationship between these diets and their resulting mental health symptoms must undergo further research, their significant correlation makes it evident that dietary intervention strategies are an important consideration for adolescent mental health.

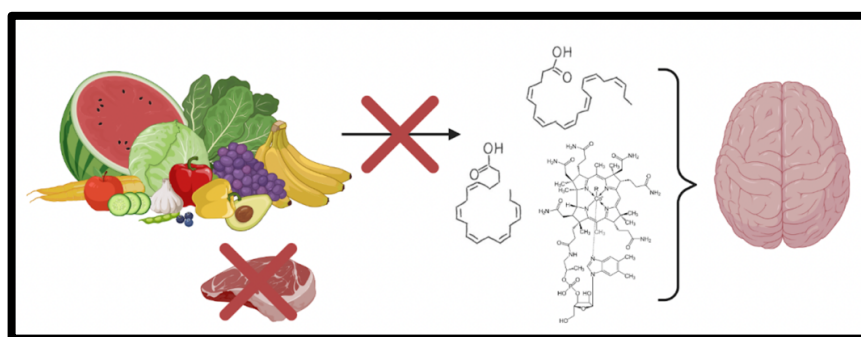


Figure 9: Essential Nutrients for Cognitive Development and Mental Health: Risks of Deficiency in Plant-Based Diets

Healthy EPA, DHA, and Vitamin B12 levels are important for cognitive development and reduction of depressive-like symptoms. Individuals with vegetarian or vegan diets are deficient in all three, along with other key nutritional deficiencies.

When considering the implementation of dietary interventions, it is crucial to consider various diets and diet-related health challenges that exist across cultures. For example, studies involving the MedDiet (Mediterranean-style diet) supplemented with fish oil have been reported to improve both diet quality and mental health scores in depressed adults.²⁰ Additionally, a New Zealand study assessing the dietary habits of South Asian migrants has shown that the adoption of a “Western diet” - low in fruits and vegetables while high in meat and dairy - has serious health consequences that could be addressed with food-based health promotion initiatives that encourage a more balanced diet in these at-risk populations.²¹ Overall, nutritious, high-fiber diets can promote healthy bacterial diversity, as can protein-rich food sources. Being conscious of daily food intake, including deliberately eating a diversity of food groups, is an important step toward maintaining and improving mental health, something which is not stressed nearly enough among young people.

Although diet plays a pivotal role in adolescent development, access to nutritional food sources is not always easy for all individuals. With the rise of pollution, cultural differences, and the growth of food deserts, access to nutritional diets is difficult for many adolescents, stifling their neurological growth.⁴³

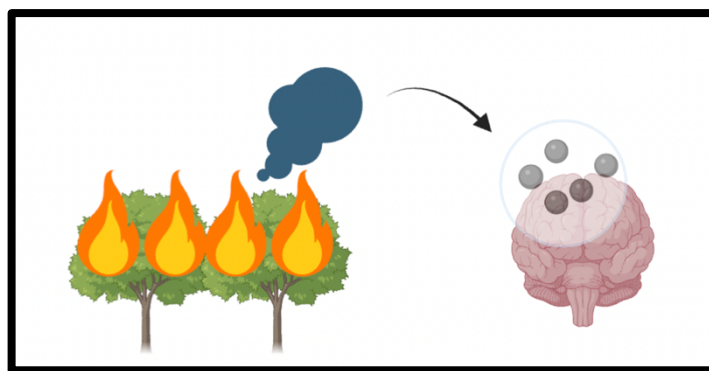


Figure 10: Impact of Biomass Burning Exposure on Adolescent Brain Development

Neurotoxic pollutants from biomass burning impair frontal and temporal lobe development, with adolescents particularly vulnerable due to ongoing synaptic pruning and myelination.

4.3 Environmental Factors

4.3.1 Pollution and Toxins

When considering the implementation of dietary interventions, it is crucial to consider various diets and diet-related health challenges that exist across cultures. For example, studies involving the MedDiet (Mediterranean-style diet) supplemented with fish oil have been reported to improve both diet quality and mental health scores in depressed adults.²⁰ Additionally, a New Zealand study assessing the dietary habits of South Asian migrants has shown that the adoption of a “Western diet” - low in fruits and vegetables while high in meat and dairy - has serious health consequences that could be addressed with food-based health promotion initiatives that encourage a more balanced diet in these at-risk populations.²¹ Overall, nutritious, high-fiber diets can promote healthy bacterial diversity, as can protein-rich food sources. Being conscious of daily food intake, including deliberately eating a diversity of food groups, is an important step toward maintaining and improving mental health, something which is not stressed nearly enough among young people.

Pollution, more specifically from biomass burning and particulate matter (PM2.5) has been shown to tremendously affect adolescent mental health and neurological development.⁴³ Biomass burning has been shown to alter cortical development in early adolescents and a study by Sun et. al. depicted that exposure to a plethora of pollutants from biomass burning during critical periods of development can lead to significant alterations in one's temporal, parietal, occipital, and frontal lobe regions.⁴³ This not only impacts further cognitive development but can lead to permanent changes in the brain structure of adolescents with irreparable consequences. Hence, it is pivotal to manage environmental and pollution factors to minimize their impact on adolescents, as the consequences can be detrimental.

Furthermore, the correlation between stress in early life and exposure to harmful toxins can significantly impact changes in both gray and white matter regions in the brain.^{43,44} These can influence brain structure, thereby limiting proper emotional or neurological development, in turn impacting

how adolescents grow and learn to control and regulate their emotions.⁴⁴ Interventions focused on removing air pollution, especially limiting children's early exposure to pollution, are crucial because there will be fewer disruptions in their normal growth pattern and thus reduce the risk of further complications.

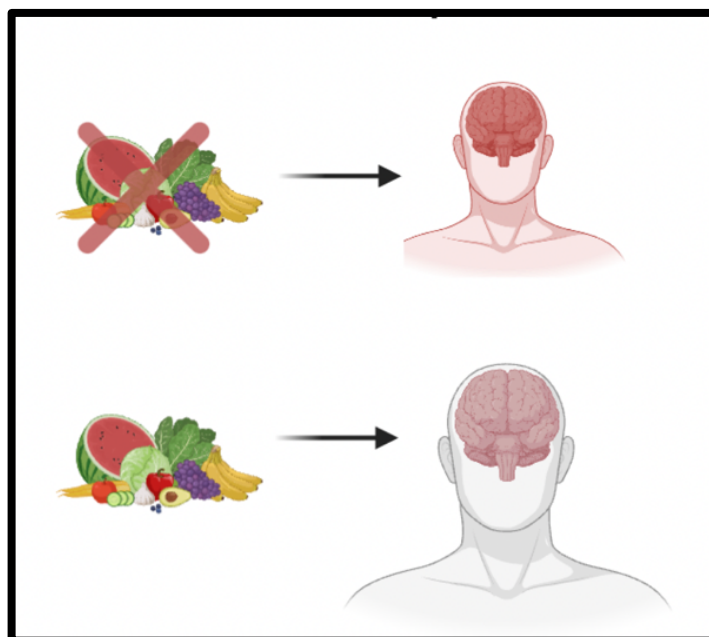


Figure 11: Impact of Malnutrition on Physical and Neural Development

Lack of proper nutrition not only stifles physical growth, such as the body and brain, but also neurological growth and can increase the chances of neural deformities.

4.3.2 Food Deserts

Food deserts are regions that are classified as having limited access to affordable and nutritious food and have been depicted to significantly impact mental health, particularly among adolescents. A longitudinal study by McLaughlin et al. analyzed the association between food insecurities and depression symptoms in early childhood to adolescence.⁴⁵ With the help of an equation model, the researchers found a strong link between heightened anxiety levels and depressive symptoms in these adolescents due to their

food situation.⁴⁵ With less access to proper diets, children are unable to receive the proper nutrients needed for their bodies to grow, especially at pivotal stages such as their teenage years.⁴⁵ This not only stifles them physically but can have emotional effects too.⁴⁵ Access to food packages is filled with unnecessary chemicals that can throw off hormonal balances in children, leading to irregular growth in puberty due to changes in their hormonal cycles.⁴⁵

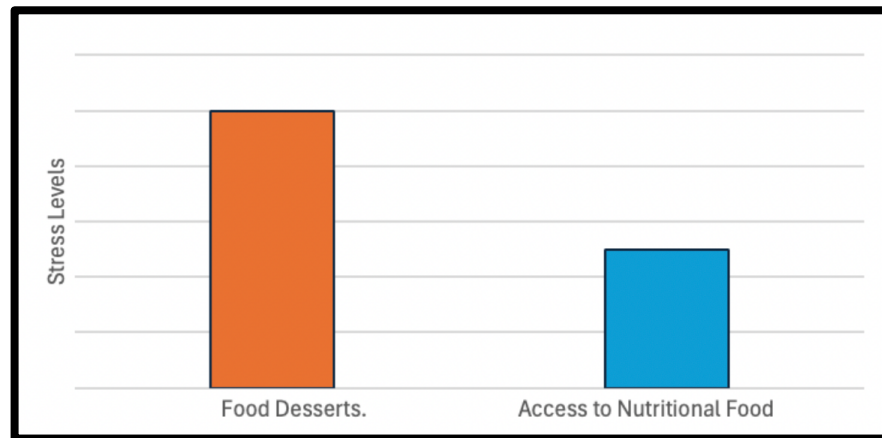


Figure 12: Relationship Between Food Desserts and Stress Levels in Adolescents

Adolescents residing in food deserts exhibit elevated stress responses, with a trend toward increased cortisol levels among those experiencing limited or inconsistent access to nutritious food.

Additionally, with the lack of proper food, there is a rise in anxiety in households struggling to make ends meet. Individuals in such areas may need access to proper transportation to make the long drives to obtain the proper nutritional value that they need and are stuck in a cycle of resorting to the same unhealthy food to which they are used to.⁴⁶ On the other hand, higher SES is associated with lower BMI, greater total and prefrontal cortical volume, and increased executive function capabilities.¹⁶ This can be attributed to higher SES individuals having access to better quality of food, healthcare, accessibility and time for exercise.¹⁶

Remedies for food deserts start with education. One of the biggest issues in modern education systems in areas near food deserts is the need for more awareness about their circumstances.⁴⁷ Their teachers and adult figures are not informing them about making healthier choices, so they live in a world which they do not know better than their current diet.⁴⁷ If schools start implementing ways to help children understand the importance of a healthy diet and partner with organizations and campaigns that aid in that process it will be crucial for deterring food deserts.⁴⁸ Plus, with the newly acquired knowledge, students themselves can make a change in their community by rallying with their mayor and trying to make governmental changes.⁴⁸

4.4 Immigrant Families

A group specifically more prone to succumbing to the lack of education is typically immigrant households.⁴⁹ Immigrant households and parents who did not attend college have complex parenting landscapes, which include these four types of parenting: authoritative, authoritarian, permissive, and uninvolved.⁴⁹ For most immigrant families, the parenting styles are heavily dependent on their cultural, socioeconomic, and education levels.⁴⁹

Authoritative parenting stems from high repressiveness to high demands, and usually leads to better success in children and lower anxiety.^{49,50} It has a lot of involvement in the open communication aspect which can be challenging for many immigrant parents due to possible language barriers or the recent drastic cultural differences from their children.^{49,50}

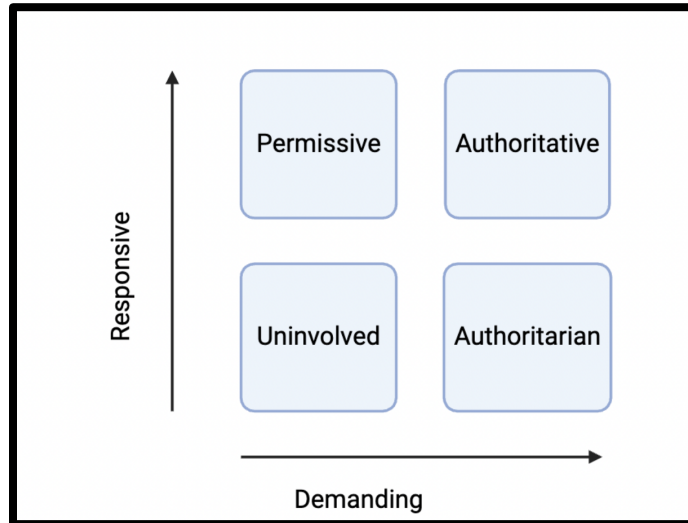


Figure 13: Differentiation of Parenting Styles Based on Behavioral Demands and Emotional Responsiveness

The four types of parenting styles (permissive, authoritative, uninvolved, and authoritarian) are characterized by the severity of how demanding and responsive they are. Authoritative is the most responsive and demanding, and uninvolved is the least demanding and responsive.

Authoritarian parenting on the other hand is characterized by high demand but low responsiveness and is seen a lot more in immigrant families with a strict discipline and respect for authority culture that immigrant families tend to display. This can lead to greater levels of stress and anxiety as children try to meet the overwhelming expectations set by their parents and have minimal emotional support to meet those expectations.⁵¹ Another instance that can lead to high anxiety would be permissive parenting, which has high responsiveness but low demands, and this may occur in a situation where the parents are having a hard time adapting to the new country that they tend to not care as much about the children, and they are neglected.^{50,51} This parenting style can create problems in the discipline of children and can lead to gaps in their identity because they are so displaced from their initial identity and are confused about their culture.^{50,51} Finally, there is uninvolved parenting, which is characterized by low responsiveness and low demands, and this may occur in low-income families that already have

enough pressures in their lives and do not care too much for their children, which deprives them of both discipline and emotional support to thrive.^{50,51}

Additionally, a phenomenon called the newcomer syndrome, common among many immigrant populations, can further these signs of anxiety and mental health disorders. This is due to the pressure to blend one's old culture with the new American culture, and the clash of these two cultures can lead to increased anxiety.⁵² The American Academy of Pediatrics has demonstrated that children of immigrant backgrounds exhibit higher levels of mental health problems than their nonimmigrant peers due to these cultural and identity differences.^{52,53} Furthermore, the lack of stable generational income for many immigrant families can place them at an unfavorable economic standpoint, which in turn can lead to nutritional issues such as the food desert scenario.⁵² By understanding the diverse parenting approaches and the socioeconomic pressures faced by each individual, interventions can be tailored to improve mental health in all individuals. There are previous studies that show dynamic neurobiological and behavioral mechanisms to make personalized mental health treatments.⁵³ With the use of artificial intelligence and personalized approaches, there can be individual mental health treatments so individuals will never feel like their issues have been grouped under the same category as another and can have their own unique plan.⁵³

5. Conclusion

Interventions for adolescent brain health must take a holistic approach, addressing socioeconomic disparities, environmental factors, and lifestyle choices to mitigate the risks of disrupted brain development. Adolescent brain health is influenced by a complex interplay of socioeconomic status (SES), education, nature versus nurture dynamics, and parental or guardian influences.

Socioeconomic disparities impact access to healthcare, nutrition, and education, shaping cognitive development and overall brain health. Quality education enhances cognitive skills and fosters critical thinking crucial for mental well-being. Parental influences, including resources and behaviors like drug use, play a pivotal role in shaping emotional resilience and decision-

making. Environmental factors such as pollutants and access to green spaces affect brain health, with stressors potentially contributing to cognitive impairments. Physical ambiance, including pollution and food access, directly influences diet quality and brain function. Cultural norms shape beliefs and behaviors, impacting mental well-being. Emphasizing healthy lifestyles promotes optimal brain development through balanced nutrition, adequate sleep, and stress management. Teaching self-care practices equips adolescents with resilience and stress management skills. Physical activities like yoga enhance cognitive function and emotional regulation. Addressing these factors comprehensively supports adolescent brain health, fostering resilience and improving mental health outcomes.

This review seeks to make a significant contribution to the field by providing a comprehensive synthesis of potential benefits and treatment options, encompassing longitudinal research, cross-sectional studies, and clinical trials. By highlighting the advantages of combining treatment options rather than focusing on singular solutions for specific issues, we seek to influence researchers toward more integrated approaches that can enhance effectiveness and address multifaceted aspects of adolescent health and development. This approach encourages a broader exploration of therapeutic strategies that can better support long-term brain health and well-being in adolescents. This combination solution will help researchers create effective combinations of treatments to target multiple problems at the same time. Future research holds promise for researching various combination therapies to identify the most efficient solutions addressing the problems mentioned.

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