Review

Neuroscience

The Neurological Impact of Continuous Nicotine Exposure in Adolescents

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Continuous nicotine exposure during adolescence can have profound implications on the development and well-being of individuals in this critical stage of life. As the prevalence of nicotine use among adolescents continues to be a significant public health concern, understanding the impact of this addictive substance on young minds and bodies is crucial. We explored the various dimensions of nicotine exposure in adolescents, from its effects on brain development and cognitive function to the social, emotional, and educational consequences. By looking into the complexities of adolescent nicotine addiction, we can better comprehend the challenges faced by this vulnerable population and develop potential strategies for prevention and intervention.

Keywords: Nicotine; Neurological Mechanisms; Adolescents; Cognitive Dysfunction; Addiction

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NICOTINE use among adolescents is a growing concern in today's society, as more and more young people are turning to tobacco products as a means of coping with stress and fitting in with their peers (Chen et al., 2024; Izenwasser, 2019; Oliver et al., 2023). The trends of nicotine use among adolescents have shifted over the years, with traditional forms of tobacco like cigarettes being replaced by newer and more discreet methods like e-cigarettes and vaping devices (Cheng et al., 2023; Mattingly & Hart, 2024; Murthy, 2016; Oliver et al., 2023; Park-Lee et al., 2022). This shift has led to a resurgence in nicotine use among teens, as these new products are often marketed as being safer and less harmful than traditional cigarettes (Chen et al., 2024; Rayes et al., 2023; Siqueira et al., 2016).

Effects of Nicotine on Adolescent Brain Development

Brain Structure Alteration

The adolescent brain is still in the process of development and is enduring substantial changes during this phase of life. The prefrontal cortex, which is responsible for emotional regulation, impulse control, and decision-making, is one of the last regions of the brain to become entirely mature (Giedd, 2008; Holzer et

al., 2011; Spear, 2013). Nicotine consumption during adolescence can disrupt this process, resulting in changes to the structure of the brain (Counotte et al., 2011; Goriounova & Mansvelder, 2012; Xiang et al., 2023). Numerous studies have demonstrated that nicotine exposure can disrupt the development of neural circuits in the prefrontal cortex, which can have long-term consequences on cognitive functions and behavior (Goriounova & Mansvelder, 2012a; Goriounova & Mansvelder, 2012b; Leslie, 2020; Quam et al., 2024; Yuan et al., 2015; Zhou et al., 2024).

Nicotine use during adolescence can also result in structural alterations to the white matter of the brain (Goriounova & Mansvelder, 2012a; Goriounova & Mansvelder, 2012b). The white matter of the brain is composed of nerve fibers that facilitate communication between various brain regions. Exposure to chronic nicotine has been demonstrated to disrupt the development of white matter in the adolescent brain, which can impact cognitive functions such as decision-making, memory, and attention (Castro et al., 2023; Conti & Baldacchino, 2023; Goriounova & Mansvelder, 2012c; McCarthy et al., 2022; Yuan et al., 2015). The long-term effects of these alterations in white matter structure on brain function may contribute to cognitive impairment in adolescents who use nicotine.

Nicotine can also modify the structure of the adolescent brain by influencing gene expression (England et al., 2015; Gogliettino et al., 2016; Yuan et al., 2015). It has been demonstrated that nicotine exposure leads to changes in the protein levels that modulate neuronal growth and connectivity, as well as the expression of genes that are involved in brain development and function (Doura et al., 2010; Lor et al., 2022; Polesskaya et al., 2006; Ren et al., 2022; Slotkin, 2002; Zhou et al., 2024). Alterations in gene expression can disrupt the typical development of the adolescent brain and contribute to long-term changes in brain structure.

According to research, adolescents who consume nicotine may possess diminished volumes of specific brain regions when contrasted with their non-user counterparts (Chen et al., 2024; Conti & Baldacchino, 2023; England et al., 2015; Goriounova & Mansvelder, 2012a; Quam et al., 2024; Yuan et al., 2015). The prefrontal cortex volume is diminished in adolescents who smoke, which can affect impulse control and decision-making (Churchwell et al., 2010; Conti & Baldacchino, 2023; Counotte et al., 2011; Xie et al., 2020). Nicotine use during adolescence has been linked to a reduction in the volume of the hippocampus, which can impact memory and learning functions, according to additional research (Counotte et al., 2008). Cognitive functions and behavior may be permanently affected by these structural changes in the brain, which may persist into adulthood.

The impact of nicotine on the structure of the brain in adolescents may also be influenced by genetic factors. Accordingly, certain genetic variations can render individuals more susceptible to the effects of nicotine on the brain (Leslie, 2020; Smith et al., 2015). As an illustration, the likelihood of developing addiction and cognitive impairments in response to nicotine use may be elevated by genetic variations that influence dopamine signaling or synaptic plasticity (Benowitz, 2008; Cadoni et al., 2019; Herman et al., 2014; Portugal & Gould, 2008). Comprehending the role of genetics in susceptibility to nicotine-induced brain alterations can assist in the development of personalized prevention and treatment strategies for adolescents who use nicotine.

Conclusively, the use of nicotine during adolescence can result in structural changes in the developing brain that can have an enduring impact on cognitive functions and behavior. In adolescents, the effects of nicotine on brain structure are multifaceted and encompass modifications to gene expression, synaptic plasticity, white matter structure, neurotransmitter systems, and genetic susceptibility (Smith et al., 2015). Effective prevention and intervention strategies are essential for the protection of the developing brain, and it is crucial that parents, educators, healthcare providers, and policymakers are cognizant of the risks associated with adolescent nicotine use. We can assist in the mitigation of the adverse effects of nicotine addiction and the promotion of healthy brain development by addressing the structural changes in the adolescent brain that are a result of nicotine use (**Figure 1**).

Synaptic Plasticity

The use of nicotine during adolescence can significantly impact synaptic plasticity in the brain. Nicotine is a potent addictive compound included in tobacco products that interacts with nicotinic acetylcholine receptors in the brain (Leslie, 2020; Placzek et al., 2009; Smith et al., 2015). These receptors are extensively distributed in the brain and are crucial in modulating synaptic transmission. The consumption of nicotine can induce modifications in synaptic plasticity, affecting the potency and efficacy of synaptic connections inside the brain (Castro et al., 2023; Schwartz & Kellar, 1983; Xiao et al., 2019). Animal studies have revealed that nicotine exposure during adolescence leads to unique effects on synaptic plasticity that differ from the impact observed in adult brains (McDonald et al., 2005; Placzek et al., 2009; Slotkin, 2002).

Studies indicate that nicotine consumption throughout adolescence can disturb the equilibrium of excitatory and inhibitory neurotransmission in the brain (Counotte et al., 2011; Goriounova & Mansvelder, 2012a; Goriounova & Mansvelder, 2012c; Smith et al., 2015). This imbalance may result in alterations in synaptic plasticity, impairing neuronal communication efficacy. These alterations may have enduring impacts on cognitive function and behavior, thereby heightening the likelihood of addiction and other mental health disorders in the future.

Nicotine significantly influences synaptic plasticity by modulating the release of neurotransmitters, particularly dopamine (Tang & Dani, 2009). Dopamine is a neurotransmitter integral to the brain's reward system, significantly influencing motivation, pleasure, and the reinforcement of behaviors (De Biasi & Dani, 2011; Tang & Dani, 2009). Nicotine enhances dopamine release in the brain, resulting in alterations in synaptic plasticity that strengthen the pleasurable effects of nicotine consumption (Addicott et al., 2018; Benowitz, 2008; Ghahremani et al., 2023; Di Matteo et al., 2007; Miyata & Yanagita, 2001).

Prolonged nicotine exposure can result in enduring alterations in synaptic plasticity inside the brain (Feduccia et al., 2012; Mao & McGehee, 2009). Research utilizing animal models has

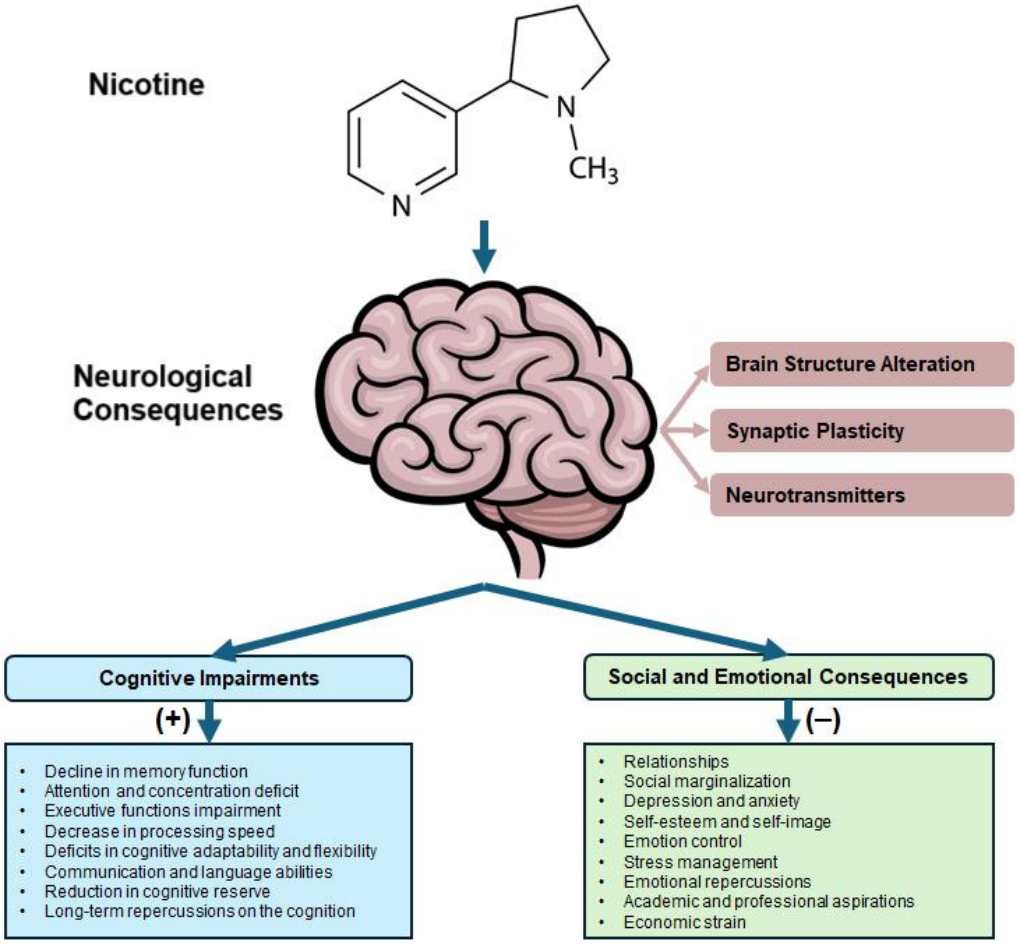

Figure 1. Consequences of Nicotine in Neuronal Regulation.

demonstrated that prolonged nicotine exposure can modify the synaptic connectivity in the prefrontal cortex, a brain region crucial to decision-making, impulse regulation, and cognitive processes (Counotte et al., 2011; Wessels & Winterer, 2008). Alterations in synaptic plasticity can significantly impact behavior, resulting in heightened impulsivity, risk-taking, and cognitive function deficiencies (Kim et al., 2018).

Adolescents are especially susceptible to nicotine's impact on synaptic plasticity since their brains are still developing during this stage (Goriounova & Mansvelder, 2012b; Smith et al., 2015). The teenage brain is experiencing substantial alterations in synaptic connection, neuronal development, and neurotransmitter activity. The use of nicotine during this crucial phase might interfere with developmental processes, resulting in enduring alterations in neuronal plasticity that may elevate the likelihood of addiction and other mental health disorders in the future (Counotte et al., 2012; Dwyer et al., 2009; Ren et al., 2022; Smith et al., 2015; Wessels & Winterer, 2008).

It is essential to recognize that not all adolescents who utilize nicotine will exhibit identical effects on synaptic plasticity. Variations in genetic predisposition, contextual influences, and other prior circumstances can affect the effects of nicotine on synaptic plasticity in the brain (Quam et al., 2024; Yuan et al., 2015). Certain teenagers may exhibit greater resilience to nicotine's effects, whilst others may be more susceptible to enduring alterations in neuronal plasticity that heighten the likelihood of addiction and various mental health disorders (**Figure 1**).

Neurotransmitters

Neurotransmitters are chemical mediators that facilitate the transmission of signals between neurons in the brain. Dopamine, serotonin, and acetylcholine are among the neurotransmitter systems that are implicated in the effects of nicotine (Benowitz, 2008a; Benowitz, 2008b; Benowitz, 2008c). Nicotine alters the activity of these neurotransmitter systems by binding to nicotine receptors on neurons (Narahashi et al., 2000). These alterations can have substantial implications for brain function and behavior in the context of adolescents who use nicotine.

The dopamine system is one of the primary neurotransmitter systems that are influenced by nicotine use in adolescents (Mojica et al., 2013; Slotkin, 2002). Dopamine is a neurotransmitter that is involved in the processing of rewards and motivation. Nicotine induces feelings of reinforcement and pleasure by increasing the production of dopamine in the brain (Di Matteo et

al., 2007; Picciotto & Corrigall, 2002). This can exacerbate the addictive properties of nicotine and make it challenging for adolescents to discontinue its use.

Nicotine also influences the serotonin system in the brain. Serotonin is a neurotransmitter that is involved in the regulation of mood and impulse control. The use of nicotine can disrupt the balance of serotonin in the brain, resulting in changes in mood and behavior (Fletcher et al., 2008; Seth et al., 2002). These changes in serotonin function may lead to an increase in impulsivity and risk-taking behaviors in adolescents who use nicotine (Bang & Commons, 2011).

Additionally, nicotine affects the acetylcholine system in the brain. Acetylcholine is a neurotransmitter that is involved in cognitive functions, including memory and learning (Wu, 2009). Nicotine has the potential to increase cognitive performance by increasing the release of acetylcholine in the brain (Gil & Metherate, 2018; Narahashi et al., 2000; Olszewski et al., 2024; Valentine & Sofuoglu, 2017). Nevertheless, the long-term impairment of cognitive function may result from the desensitization of acetylcholine receptors that can be induced by chronic nicotine use.

Nicotine's influence on neurotransmitters in adolescents is not restricted to the short term. Research has demonstrated that the effects of nicotine exposure during adolescence can be long-lasting on brain function (Trauth et al., 2001). Adolescents who have a history of nicotine use experience modifications in the structure and function of their neurotransmitter systems (Counotte et al., 2011; Doura et al., 2010; Leslie, 2020). These changes have the potential to endure into maturity and contribute to long-term cognitive and behavioral deficits.

It is crucial to evaluate the implications for prevention and intervention initiatives in light of the substantial influence of nicotine on neurotransmitters in adolescents (Leslie, 2020; Olszewski et al., 2024). Strategies for addressing nicotine use among adolescents can be informed by an understanding of the impact of nicotine on neurotransmitter systems in the developing brain (Bang & Commons, 2011; Holliday et al., 2016; Castro et al., 2023; Slotkin, 2002; Slotkin & Seidler, 2006). The detrimental effects of nicotine on the adolescent brain may be mitigated through targeted interventions that regulate neurotransmitter function.

Therefore, the effects of nicotine on the adolescent brain are significantly influenced by neurotransmitters. The brain's function and behavior are altered by nicotine's effects on dopamine, serotonin, and acetylcholine systems. These modifications can have a long-term impact on brain development and contribute to cognitive and behavioral deficits. Targeted interventions can be developed to address nicotine use and promote healthy brain development during this critical period by comprehending the impact of nicotine on neurotransmitters in adolescents (**Figure 1**).

Cognitive Impairments Associated with Nicotine Exposure

A decline in memory function is one of the most well-known cognitive impairments associated with nicotine exposure (Holliday et al., 2016; Xie et al., 2020). Nicotine has been demonstrated to disrupt the normal functioning of the hippocampus, a critical brain region that is involved in memory formation and retrieval (Kenney & Gould, 2008; Scerri et al., 2005). This disruption has the potential to result in challenges with learning, recall, and overall cognitive performance.

Nicotine exposure has been associated with attention and concentration deficits (Ernst et al., 2001; Park, 2000). Nicotine users may experience difficulty in maintaining focus, remaining focused, and filtering out distractions (Jasinska et al., 2013; Valentine & Sofuoglu, 2017). This can have a substantial effect on academic success, work performance, and daily functioning.

Executive functions, including impulse control, problem-solving, and decision-making, have been demonstrated to be influenced by nicotine (Valentine & Sofuoglu, 2017; Wignall & Wit, 2011). The prefrontal cortex, a brain region that is responsible for these higher-order cognitive processes, can be impaired by nicotine exposure (Goriounova & Mansvelder, 2012a; Goriounova & Mansvelder, 2012b). Consequently, individuals who consume nicotine may demonstrate impulsivity, poor discernment, and challenges in task planning and organization.

A decrease in processing speed is another cognitive impairment that is linked to nicotine exposure (Naudé et al., 2014; Wignall & Wit, 2011). Nicotine has the potential to impede the processing of information in the brain, resulting in delays in cognitive tasks and reactions (Ernst et al., 2001; Valentine & Sofuoglu, 2017). This can affect the performance of activities that necessitate rapid decision-making and quick thinking, such as operating machinery or driving.

Deficits in cognitive adaptability and flexibility have been associated with nicotine exposure (Heishman et al., 2010). Some nicotine users may experience challenges in effectively problem-solving, adapting to new circumstances, and transitioning between tasks (Ashare et al., 2013; Evans et al., 2018; Heishman et al., 2010). This can impede their capacity to adapt to changes and obstacles in their environment.

Nicotine exposure has a detrimental effect on communication and language abilities (Counotte et al., 2012; Martin & Sayette, 2018; Wignall & Wit, 2011). Nicotine users may encounter challenges in comprehending intricate information, maintaining conversations, and articulating their thoughts verbally. This can result in interpersonal challenges and social difficulties (Counotte et al., 2011; Goriounova & Mansvelder, 2012c).

Additionally, a correlation between nicotine exposure and a reduction in cognitive reserve exists. Cognitive reserve is the brain's capacity to endure cognitive decline and injury associated with aging (Cho et al., 2024; Majdi et al., 2017; Nop et al., 2021; Mitsis et al., 2008; Reitz et al., 2005; Swan & Lessov-Schlaggar, 2007). Nicotine exposure can erode this reserve, rendering individuals more susceptible to cognitive impairments as they age.

Cognitive impairments that are linked to nicotine exposure can have long-term repercussions on the cognitive function and healthy brain of individuals (Jasinska et al., 2013; Nop et al., 2021; Swan & Lessov-Schlaggar, 2007). The risk of developing neurodegenerative diseases, including Alzheimer's disease and Parkinson's disease, has been associated with the chronic use of nicotine (Conti et al., 2018; Koranda & Beeler, 2019; Smith &

Giacobini, 1992; Swan & Lessov-Schlaggar, 2007). The quality of life and independence of individuals can be significantly impacted by these conditions.

Overall, the cognitive impairments that are linked to nicotine exposure are a substantial concern for those who use tobacco products. Memory, attention, executive functions, processing speed, cognitive flexibility, language skills, and cognitive reserve can all be adversely affected by nicotine. These impairments can have significant repercussions on the daily functioning, work performance, and overall cognitive health of individuals. As a result, it is imperative that individuals are cognizant of the cognitive risks associated with nicotine use and seek assistance and resources to cease smoking and enhance their cognitive function.

Social and Emotional Consequences of Nicotine Exposure

The most substantial social consequence of nicotine exposure in adolescents is its effect on relationships. Nicotine dependence may result in discord and strain with family, friends, and romantic partners (Counotte et al., 2011; Iñiguez et al., 2008; Martin & Sayette, 2018). Nicotine addiction can induce physical and psychological repercussions, resulting in mood fluctuations, irritation, and violence, hence straining relationships and fostering social isolation (Andrews & Tingen, 1999; Cosci, 2011; Hughes, 1996; Kotlyar & Hatsukami, 2002).

Besides causing relationship tension, nicotine consumption in adolescents may also result in social marginalization (Da Silva Reis Dos Santos Ferreira & De Freitas Paúl Reis Torgal, 2010; Niño et al., 2015; Slotkin & Seidler, 2006). Smoking is frequently stigmatized in society, leading to discrimination and adverse judgment on adolescent smokers by their peers (Aho et al., 2019; Aloise-Young & Kaeppner, 2005; Alvarado & Breslau, 2005; Sæbø & Lund, 2024). This may result in feelings of shame and loneliness, since adolescents who smoke could feel excluded from their social circles.

Nicotine exposure in adolescents may result in emotional repercussions, including an elevated risk of mental health disorders such as depression and anxiety. Nicotine is a stimulant that can intensify symptoms of anxiety and depression, resulting in a detrimental cycle of substance use and mental health disorders (Foxon et al., 2024; Hudson et al., 2020; Leventhal et al., 2015; Riehm et al., 2019). Adolescents experiencing mental health issues may resort to nicotine as a coping strategy, so exacerbating their addiction and heightening their susceptibility to mood disorders (Chang et al., 2005; Hockenberry et al., 2011; Hudson et al., 2020; McMahon, 1999;).

Nicotine exposure in adolescents can adversely affect self-esteem and self-image. Smoking is frequently linked to specific social norms and stereotypes, leading young smokers to internalize these adverse self-perceptions (Carvajal et al., 2000; Chang et al., 2005; Conti & Baldacchino, 2023; McMahon, 1999; Penny & Robinson, 1986). This may result in emotions of shame, remorse, and diminished self-esteem, as adolescents could perceive themselves as failing to meet societal standards or inflicting harm on themselves and others due to their addiction.

Another emotional consequence of nicotine exposure in adolescents is its effect on their capacity to control emotions and manage stress. Nicotine addiction can impair the brain's inherent reward system, resulting in challenges in emotional regulation and the pursuit of healthy coping strategies (Counotte et al., 2011; Iñiguez et al., 2008; Leslie, 2020). This may foster a cycle of addiction and emotional dysregulation, as adolescents could resort to nicotine to mitigate challenging emotions and relieve stress.

Nicotine exposure in youth can result in enduring emotional repercussions, as addiction may prove challenging to surmount and can extend into adulthood (Holliday et al., 2016). Nicotine addiction is a persistent disorder necessitating continuous treatment and assistance, and adolescents who develop an early addiction may encounter difficulties in cessation and sustaining abstinence over time (Benowitz, 2008; Benowitz, 2010; Jenssen & Boykan, 2019). This may result in emotions of despair, frustration, and self-doubt, as young individuals could perceive themselves as incapable of overcoming their addiction and achieving a healthy, rewarding life.

Nicotine exposure in adolescents can adversely affect their academic and professional aspirations, as addiction may hinder their capacity to concentrate, focus, and excel in educational or occupational settings (Counotte et al., 2011; Holliday et al., 2016; Horn et al., 2022). Nicotine addiction can result in diminished academic performance, increased absenteeism, and challenges in sustaining work, perhaps leading to enduring repercussions on the educational and occupational prospects of young individuals (Goriounova & Mansvelder, 2012a; Gould & Leach, 2013; Tobacco Use and Academic Achievement, 2013). This may further intensify feelings of poor self-esteem and self-worth, since young individuals could perceive themselves as incapable of realizing their full potential due to their addiction.

Nicotine exposure in youth might result in financial repercussions, as addiction can be costly to sustain and may induce economic strain. Adolescents who smoke may allocate a substantial fraction of their income to cigarettes, resulting in restricted funds for essential needs such as nutrition, shelter, and medical care (Ali, 2012; Medicine, 1994; Olumide et al., 2021). This may lead to tension, anxiety, and uncertainty, since young individuals often find it challenging to meet their financial obligations and support themselves and their family.

In short, nicotine exposure in adolescents can lead to substantial social and emotional repercussions affecting their relationships, mental health, self-esteem, coping strategies, academic and career aspirations, financial stability, and overall quality of life. Young individuals must recognize the dangers linked to nicotine exposure and pursue assistance and resources to combat addiction and achieve a healthy, fulfilled life. By tackling the social and emotional ramifications of nicotine exposure in youth, we may strive to establish a healthier, more supportive environment for all young individuals to flourish and achieve their full potential.

Educational Implications of Nicotine Addiction in Adolescents

The most pressing educational consequence of nicotine addiction in adolescents is its impact on academic performance (Hol-

liday et al., 2016). Studies indicate that students who smoke tend to achieve worse grades and test scores than their non-smoking counterparts (Bryant et al., 2000; Heishman et al., 1997; Hu et al., 1998; Warburton et al., 1984). Nicotine in cigarettes can hinder cognitive function, obstructing students' ability to concentrate, retain information, and acquire new knowledge (Goriounova & Mansvelder, 2012b; Heishman et al., 2010). This may result in diminished academic performance and impede a student's capacity to achieve their maximum academic potential.

Besides academic performance, nicotine use in adolescents may result in heightened school absences. Students who smoke are more prone to absenteeism or class skipping due to smoking-related ailments or the necessity to smoke during the day (Alberg, 2003; Alqahtani et al., 2023; Bryant et al., 2000). This may lead to considerably missed teaching and assignments, placing these pupils at a disadvantage relative to their counterparts without a nicotine addiction. Chronic absenteeism may result in disciplinary measures and diminished graduation rates, adversely affecting a student's educational opportunities (Alqahtani et al., 2023; Levy et al., 2011; Perelman et al., 2019).

Nicotine dependence in adolescence may also lead to behavioral problems in the classroom. Students addicted to nicotine may display heightened irritation, hostility, or impaired impulse control, so disrupting the learning environment for themselves and their peers (Slotkin et al., 2014). This may result in confrontations with educators and classmates, disciplinary measures, and maybe suspensions or expulsions from the institution (Çiçek, 2012; Hoch & Olszowy, 1979). These behavioral concerns can adversely affect a student's connections with school personnel and peers, as well as their overall educational experience.

Another educational impact of nicotine addiction in teens is the possibility of enduring health repercussions. Smoking and nicotine consumption can result in numerous health complications, such as respiratory disorders, cardiovascular diseases, and malignancies (Heishman et al., 1997; Iñiguez et al., 2008; Holliday et al., 2016). These health issues can affect a student's capacity to attend school consistently, partake in physical activities, and engage in extracurricular activities. Moreover, the financial strain of smoking-related healthcare expenses can adversely affect a student's academic performance and overall health (Matingwina, 2018).

Given these educational ramifications, it is imperative for schools and educators to implement proactive strategies to combat nicotine addiction in adolescents. Preventive programs and educational initiatives can enhance knowledge regarding the hazards of smoking and vaping among kids, parents, and school personnel (Guidelines for School Health Programs to Prevent Tobacco Use and Addiction, 1994; Harvey & Chadi, 2016; Jenssen & Boykan, 2019; The Harmful Consequences of Vaping: A Public Health Threat, 2020). Furthermore, educational institutions can offer resources and support services for students grappling with nicotine addiction, including counseling, cessation programs, and access to healthcare specialists.

Educational institutions can establish rules and initiatives to foster a smoke-free and vape-free atmosphere on campus (Berg et al., 2020; Bower & Enzler, Butler et al., 2011; 2005; Diehl, 1967; Halperin & Rigotti, 2003; Lee et al., 2012; Wang et al., 2019; Wechsler et al., 2001; Seitz et al., 2018). This may involve implementing stringent no-smoking regulations, offering smoking cessation options, and instructing students on the hazards of nicotine addiction. By fostering a friendly and healthy educational atmosphere, educators can mitigate and tackle nicotine addiction among teenagers while enhancing positive academic results (Chen et al., 2024; Dove et al., 2024; Guidelines for School Health Programs to Prevent Tobacco Use and Addiction, 1994).

Collaboration among parents, healthcare providers, and community organizations is crucial in tackling nicotine addiction in teenagers. Educational institutions can collaborate with parents to inform them about the dangers of smoking and vaping, while also offering resources to assist families in supporting their child's cessation of nicotine use (Hardie et al., 2023; Hughes et al., 2015; Jenssen & Boykan, 2019; Stopping the start: our new plan to create a smokefree generation, 2023; The Harmful Consequences of Vaping: A Public Health Threat, 2020). Furthermore, educational institutions can partner with healthcare professionals to recognize and assist students grappling with nicotine dependence, facilitating referrals to treatment programs and counseling services.

Nicotine addiction in adolescents has considerable educational consequences that can affect a student's academic performance, attendance, behavior, and overall well-being. Schools and educators must implement proactive strategies to tackle this issue, encompassing prevention initiatives, policy enforcement, and engagement with parents and healthcare professionals. By collaboratively fostering a supportive and health-oriented atmosphere, schools can aid in the prevention and management of nicotine addiction among students, thereby enhancing their academic performance and future opportunities.

Conclusion

In conclusion, addressing the challenges posed by continuous nicotine exposure in adolescents requires a comprehensive and multi-faceted approach. By recognizing the detrimental effects of nicotine on adolescent development and prioritizing early intervention and support, we can work towards mitigating the long-term health and social consequences of youth nicotine addiction. Continued research, advocacy efforts, and community engagement are essential in creating a healthier and nicotine-free future for our adolescents.■

References

Addicott, M. A., Sweitzer, M. M., & McClernon, F. J. (2018). The Effects of Nicotine and Tobacco Use on Brain Reward Function: Interaction with Nicotine Dependence Severity. Nicotine & Tobacco Research, 21(6), 764-771. DOI: https://doi.org/10.1093/ntr/nty059

Aho, H., Koivisto, A., Paavilainen, E., & Joronen, K. (2019). The relationship between peer relations, self-rated health and smoking behaviour in secondary vocational schools. Nursing Open, 6(3), 754-764. DOI: https://doi.org/10.1002/nop2.260

Alberg, A. J. (2003). Invited Commentary: Attendance and Absence as Markers of Health Status--The Example of Active and Passive Cigarette Smoking. American Journal of Epidemiology, 157(10), 870-873. DOI: https://doi.org/10.1093/aje/kwg038

Ali, M. M. (2012). Social Learning Theory, Cigarette Taxes and Adolescent Smoking Behavior. In De Gruyter eBooks (pp. 633-651). DOI: https://doi.org/10.1515/9783110508628-004

Aloise-Young, P. A., & Kaeppner, C. J. (2005). Sociometric status as a predictor of onset and progression in adolescent cigarette smoking. Nicotine & Tobacco Research, 7(2), 199-206. DOI: https://doi.org/10.1080/14622200500055277

Alqahtani, J. S., Aldhahir, A. M., Alanazi, Z., Alsulami, E. Z., Alsulaimani, M. A., Alqarni, A. A., Alqahtani, A. S., AlAyadi, A. Y., Alnasser, M., AlDraiwiesh, I. A., Alghamdi, S. M., Almarkhan, H. M., Alsulayyim, A. S., AlRabeeah, S. M., & AlAhmari, M. D. (2023). Impact of Smoking Status and Nicotine Dependence on Academic Performance of Health Sciences Students. Substance Abuse and Rehabilitation, Volume 14, 13-24. DOI: https://doi.org/10.2147/sar.s393062

Alvarado, G. F., & Breslau, N. (2005). Smoking and young people's mental health. Current Opinion in Psychiatry, 18(4), 397-400. DOI: https://doi.org/10.1097/01.yco.0000172058.48154.14

Andrews, J., & Tingen, M. S. (1999). Nicotine Addiction: Current Treatment Options. Journal of Addictions Nursing, 11(1), 3-12. DOI: https://doi.org/10.3109/10884609909059849

Ashare, R. L., Falcone, M., & Lerman, C. (2013). Cognitive function during nicotine withdrawal: Implications for nicotine dependence treatment. Neuropharmacology, 76, 581-591. DOI: https://doi.org/10.1016/j.neuropharm.2013.04.034

Bang, S., & Commons, K. (2011). Age-dependent effects of initial exposure to nicotine on serotonin neurons. Neuroscience, 179, 1-8. DOI: https://doi.org/10.1016/j.neuroscience.2011.01.032

Benowitz, N. L. (2008a). Clinical Pharmacology of Nicotine: Implications for Understanding, Preventing, and Treating Tobacco Addiction. Clinical Pharmacology & Therapeutics, 83(4), 531-541. DOI: https://doi.org/10.1038/clpt.2008.3

Benowitz, N. L. (2008b). Neurobiology of Nicotine Addiction: Implications for Smoking Cessation Treatment. The American Journal of Medicine, 121(4), S3-S10. DOI: https://doi.org/10.1016/j.amjmed.2008.01.015

Benowitz, N. L. (2008c). Pharmacology of Nicotine: Addiction, Smoking-Induced Disease, and Therapeutics. The Annual Review of Pharmacology and Toxicology, 49(1), 57-71. DOI: https://doi.org/10.1146/annurev.pharmtox.48.113006.094742

Benowitz, N. L. (2010). Nicotine Addiction. New England Journal of Medicine, 362(24), 2295-2303. DOI: https://doi.org/10.1056/nejmra0809890

Berg, C. J., Yang, Y. T., Pratt-Chapman, M. L., Evans, W. D., Cupertino, A., Horn, K., Bernat, D. H., Abroms, L. C., & Tercyak, K. P. (2020). Campus tobacco control policies and cessation interventions in college students: A commentary calling for research and action to address tobacco-related health disparities. Translational Behavioral Medicine, 11(4), 1030-1036. DOI: https://doi.org/10.1093/tbm/ibaa083

Bower, G. G., & Enzler, D. (2005). Protecting students and faculty from environmental tobacco smoke. Health Education, 105(4), 259-272. DOI: https://doi.org/10.1108/09654280510602480

Bryant, A. L., Schulenberg, J. E., Bachman, J. G., O'Malley, P. M., & Johnston, L. D. (2000). Understanding the links among school misbehavior, academic achievement, and cigarette use: a national panel study of adolescents. Prevention Science, 1(2), 71-87. DOI: https://doi.org/10.1023/a:1010038130788

Butler, K. M., Fallin, A., & Ridner, S. L. (2011). Evidence-Based Smoking Cessation for College Students. Nursing Clinics of North America, 47(1), 21-30. DOI: https://doi.org/10.1016/j.cnur.2011.10.007

Cadoni, C., De Felice, M., Corongiu, S., Dessì, C., Espa, E., Melis, M., & Fenu, S. (2019). Role of genetic background in the effects of adolescent nicotine exposure on mesolimbic dopamine transmission. Addiction Biology, 25(5), e12803. DOI: https://doi.org/10.1111/adb.12803

Carvajal, S. C., Wiatrek, D. E., Evans, R. I., Knee, C., & Nash, S. G. (2000). Psychosocial determinants of the onset and escalation of smoking: cross-sectional and prospective findings in multiethnic middle school samples. Journal of Adolescent Health, 27(4), 255-265. DOI: https://doi.org/10.1016/s1054-139x(00)00124-5

Castro, E. M., Lotfipour, S., & Leslie, F. M. (2023). Nicotine on the developing brain. Pharmacological Research, 190, 106716. DOI: https://doi.org/10.1016/j.phrs.2023.106716

Chang, G., Sherritt, L., & Knight, J. R. (2005). Adolescent cigarette smoking and mental health symptoms. Journal of Adolescent Health, 36(6), 517-522. DOI: https://doi.org/10.1016/j.jadohealth.2004.05.008

Chen, D. T., Grigg, J., & Filippidis, F. T. (2024). European Respiratory Society statement on novel nicotine and tobacco products, their role in tobacco control and "harm reduction." European Respiratory Journal, 63(2), 2301808. DOI: https://doi.org/10.1183/13993003.01808-2023

Cheng, H. G., Lizhnyak, P. N., & Richter, N. (2023). Mutual pathways between peer and own e-cigarette use among youth in the United States: A cross-lagged model. BMC Public Health, 23(1), 1609. DOI: https://doi.org/10.1186/s12889-023-16470-5

Cho, E. R., Brill, I. K., Gram, I. T., Brown, P. E., & Jha, P.

(2024). Smoking Cessation and Short- and Longer-Term Mortality. NEJM Evidence, 3(3), EVIDoa2300272. DOI: https://doi.org/10.1056/evidoa2300272
Churchwell, J. C., Lopez-Larson, M., & Yurgelun-Todd, D. A. (2010). Altered Frontal Cortical Volume and Decision Making in Adolescent Cannabis Users. Frontiers in Psychology, 1, 225. DOI: https://doi.org/10.3389/fpsyg.2010.00225
Çiçek, V. (2012). Common Unacceptable Types of Behaviors Referred Directly with no Interventions in US Kindergarten Thru 12th Grade Public School System. Procedia - Social and Behavioral Sciences, 47, 1249-1262. DOI: https://doi.org/10.1016/j.sbspro.2012.06.808
Conti, A. A., & Baldacchino, A. M. (2023). Early-onset smoking theory of compulsivity development: a neurocognitive model for the development of compulsive tobacco smoking. Frontiers in Psychiatry, 14, 1209277. DOI: https://doi.org/10.3389/fpsyt.2023.1209277
Conti, A., McLean, L., Tolomeo, S., Steele, J., & Baldacchino, A. (2018). Chronic tobacco smoking and neuropsychological impairments: A systematic review and meta-analysis. Neuroscience & Biobehavioral Reviews, 96, 143-154. DOI: https://doi.org/10.1016/j.neubiorev.2018.11.017
Cosci, F. (2011). Nicotine dependence and psychological distress: Outcomes and clinical implications in smoking cessation. Psychology Research and Behavior Management, 4, 119-128. DOI: https://doi.org/10.2147/prbm.s14243
Counotte, D. S., Goriounova, N. A., Li, K. W., Loos, M., Van Der Schors, R. C., Schetters, D., Schoffelmeer, A. N. M., Smit, A. B., Mansvelder, H. D., Pattij, T., & Spijker, S. (2011). Lasting synaptic changes underlie attention deficits caused by nicotine exposure during adolescence. Nature Neuroscience, 14(4), 417-419. DOI: https://doi.org/10.1038/nn.2770
Counotte, D. S., Smit, A. B., Pattij, T., & Spijker, S. (2011). Development of the motivational system during adolescence, and its sensitivity to disruption by nicotine. Developmental Cognitive Neuroscience, 1(4), 430-443. DOI: https://doi.org/10.1016/j.dcn.2011.05.010
Counotte, D. S., Smit, A. B., & Spijker, S. (2012). The Yin and Yang of Nicotine: Harmful during Development, Beneficial in Adult Patient Populations. Frontiers in Pharmacology, 3, 180. DOI: https://doi.org/10.3389/fphar.2012.00180
Counotte, D. S., Spijker, S., Van De Burgwal, L. H., Hogenboom, F., Schoffelmeer, A. N. M., De Vries, T. J., Smit, A. B., & Pattij, T. (2008). Long-Lasting Cognitive Deficits Resulting from Adolescent Nicotine Exposure in Rats. Neuropsychopharmacology, 34(2), 299-306. DOI: https://doi.org/10.1038/npp.2008.96
Da Silva Reis Dos Santos Ferreira, M. M., & De Freitas Paúl Reis Torgal, M. C. L. (2010). Tobacco and Alcohol Consumption among Adolescents. Revista Latino-Americana De Enfermagem, 18(2), 255-261. DOI: https://doi.org/10.1590/s0104-11692010000200017
De Biasi, M., & Dani, J. A. (2011). Reward, Addiction, Withdrawal to Nicotine. Annual Review of Neuroscience, 34(1), 105-130. DOI: https://doi.org/10.1146/annurev-neuro-061010-113734
Di Matteo, V., Pierucci, M., Di Giovanni, G., Benigno, A., & Esposito, E. (2007). The Neurobiological Bases for the Pharmacotherapy of Nicotine Addiction. Current Pharmaceutical Design, 13(12), 1269-1284. DOI: https://doi.org/10.2174/138161207780618920
Diehl, H. (1967). College and University Policies on Cigarette Smoking. Journal of Health Physical Education Recreation, 38(7), 27-62. DOI: https://doi.org/10.1080/00221473.1967.10610450
Doura, M. B., Luu, T. V., Lee, N. H., & Perry, D. C. (2010). Persistent gene expression changes in ventral tegmental area of adolescent but not adult rats in response to chronic nicotine. Neuroscience, 170(2), 503-513. DOI: https://doi.org/10.1016/j.neuroscience.2010.06.071
Dove, M. S., Tong, E. K., & Gee, K. A. (2024). Co-use of Tobacco Products and Cannabis is Associated with Absenteeism and Lower Grades in California High School students. The Journal of Pediatrics, 268, 113935. DOI: https://doi.org/10.1016/j.jpeds.2024.113935
Dwyer, J. B., McQuown, S. C., & Leslie, F. M. (2009). The dynamic effects of nicotine on the developing brain. Pharmacology & Therapeutics, 122(2), 125-139. DOI: https://doi.org/10.1016/j.pharmthera.2009.02.003
England, L. J., Bunnell, R. E., Pechacek, T. F., Tong, V. T., & McAfee, T. A. (2015). Nicotine and the Developing Human. American Journal of Preventive Medicine, 49(2), 286-293. DOI: https://doi.org/10.1016/j.amepre.2015.01.015
Ernst, M., Matochik, J. A., Heishman, S. J., Van Horn, J. D., Jons, P. H., Henningfield, J. E., & London, E. D. (2001). Effect of nicotine on brain activation during performance of a working memory task. Proceedings of the National Academy of Sciences, 98(8), 4728-4733. DOI: https://doi.org/10.1073/pnas.061369098
Evans, D. E., To, C. N., & Ashare, R. L. (2018). The Role of Cognitive Control in the Self-Regulation and Reinforcement of Smoking Behavior. Nicotine & Tobacco Research, 21(6), 747-754. DOI: https://doi.org/10.1093/ntr/nty029
Feduccia, A. A., Chatterjee, S., & Bartlett, S. E. (2012). Neuronal nicotinic acetylcholine receptors: Neuroplastic changes underlying alcohol and nicotine addictions. Frontiers in Molecular Neuroscience, 5, 83. DOI: https://doi.org/10.3389/fnmol.2012.00083
Fletcher, P., Le, A., & Higgins, G. (2008). Serotonin receptors as potential targets for modulation of nicotine use and dependence. Progress in Brain Research, 361-383. DOI: https://doi.org/10.1016/s0079-6123(08)00918-7
Foxon, F., Selya, A., Gitchell, J., & Shiffman, S. (2024). Increased e-cigarette use prevalence is associated with decreased smoking prevalence among US adults. Harm Reduction Journal, 21(1), 136. DOI: https://doi.org/10.1186/s12954-024-01056-0
Ghahremani, D. G., Pochon, J. F., Diaz, M. P., Tyndale, R. F., Dean, A. C., & London, E. D. (2023). Nicotine dependence and insula subregions: functional connectivity and cue-induced activation. Neuropsychopharmacology, 48(6), 936-945. DOI: https://doi.org/10.1038/s41386-023-01528-0
Giedd, J. N. (2008). The Teen Brain: Insights from Neu-

roimaging. Journal of Adolescent Health, 42(4), 335-343. DOI: https://doi.org/10.1016/j.jadohealth.2008.01.007
Gil, S. M., & Metherate, R. (2018). Enhanced Sensory-Cognitive Processing by Activation of Nicotinic Acetylcholine Receptors. Nicotine & Tobacco Research, 21(3), 377-382. DOI: https://doi.org/10.1093/ntr/nty134
Gogliettino, A. R., Potenza, M. N., & Yip, S. W. (2016). White matter development and tobacco smoking in young adults: A systematic review with recommendations for future research. Drug and Alcohol Dependence, 162, 26-33. DOI: https://doi.org/10.1016/j.drugalcdep.2016.02.015
Goriounova, N. A., & Mansvelder, H. D. (2012a). Nicotine exposure during adolescence alters the rules for prefrontal cortical synaptic plasticity during adulthood. Frontiers in Synaptic Neuroscience, 4, 3. DOI: https://doi.org/10.3389/fnsyn.2012.00003
Goriounova, N. A., & Mansvelder, H. D. (2012b). Nicotine Exposure during Adolescence Leads to Short- and Long-Term Changes in Spike Timing-Dependent Plasticity in Rat Prefrontal Cortex. Journal of Neuroscience, 32(31), 10484-10493. DOI: https://doi.org/10.1523/jneurosci.5502-11.2012
Goriounova, N. A., & Mansvelder, H. D. (2012c). Short- and Long-Term Consequences of Nicotine Exposure during Adolescence for Prefrontal Cortex Neuronal Network Function. Cold Spring Harbor Perspectives in Medicine, 2(12), a012120. DOI: https://doi.org/10.1101/cshperspect.a012120
Gould, T. J., & Leach, P. T. (2013). Cellular, molecular, and genetic substrates underlying the impact of nicotine on learning. Neurobiology of Learning and Memory, 107, 108-132. DOI: https://doi.org/10.1016/j.nlm.2013.08.004
Guidelines for School Health Programs to Prevent Tobacco Use and Addiction. (1994). Journal of School Health, 64(9), 353-360. DOI: https://doi.org/10.1111/j.1746-1561.1994.tb06204.x
Halperin, A. C., & Rigotti, N. A. (2003). US Public Universities' Compliance With Recommended Tobacco-Control Policies. Journal of American College Health, 51(5), 181-188. DOI: https://doi.org/10.1080/07448480309596349
Hardie, L., McCool, J., & Freeman, B. (2023). E-Cigarette Retailers' Use of Instagram in New Zealand: A Content Analysis. International Journal of Environmental Research and Public Health, 20(3), 1897. DOI: https://doi.org/10.3390/ijerph20031897
Harvey, J., & Chadi, N. (2016). Preventing smoking in children and adolescents: Recommendations for practice and policy. Paediatrics & Child Health, 21(4), 209-214. DOI: https://doi.org/10.1093/pch/21.4.209
Heishman, S. J., Kleykamp, B. A., & Singleton, E. G. (2010). Meta-analysis of the acute effects of nicotine and smoking on human performance. Psychopharmacology, 210(4), 453-469. DOI: https://doi.org/10.1007/s00213-010-1848-1
Heishman, S. J., Kozlowski, L. T., & Henningfield, J. E. (1997). Nicotine Addiction: Implications for Public Health Policy. Journal of Social Issues, 53(1), 13-33. DOI: https://doi.org/10.1111/j.1540-4560.1997.tb02429.x
Herman, A. I., DeVito, E. E., Jensen, K. P., & Sofuoglu, M. (2014). Pharmacogenetics of nicotine addiction: role of dopamine. Pharmacogenomics, 15(2), 221-234. DOI: https://doi.org/10.2217/pgs.13.246
Hoch, L. L., & Olszowy, J. (1979). Handling Drug Use in Schools. NASSP Bulletin, 63(426), 71-75. DOI: https://doi.org/10.1177/019263657906342611
Hockenberry, J., Timmons, N., & Weg, N. V. (2011). Adolescent mental health as a risk factor for adolescent smoking onset. Adolescent Health Medicine and Therapeutics, 2, 27-35. DOI: https://doi.org/10.2147/ahmt.s11573
Holliday, E. D., Nucero, P., Kutlu, M. G., Oliver, C., Connelly, K. L., Gould, T. J., & Unterwald, E. M. (2016). Long-term effects of chronic nicotine on emotional and cognitive behaviors and hippocampus cell morphology in mice: comparisons of adult and adolescent nicotine exposure. European Journal of Neuroscience, 44(10), 2818-2828. DOI: https://doi.org/10.1111/ejn.13398
Holzer, L., Halfon, O., & Thoua, V. (2011). La maturation cérébrale à l'adolescence. Archives De Pédiatrie, 18(5), 579-588. DOI: https://doi.org/10.1016/j.arcped.2011.01.032
Horn, K., Schoenberg, N., Rose, S., Romm, K., & Berg, C. (2022). Tobacco use among Appalachian adolescents: An urgent need for virtual scale out of effective interventions. Tobacco Prevention & Cessation, 8(November), 1-10. DOI: https://doi.org/10.18332/tpc/155331
Hu, T. W., Lin, Z., & Keeler, T. E. (1998). Teenage smoking, attempts to quit, and school performance. American Journal of Public Health, 88(6), 940-943. DOI: https://doi.org/10.2105/ajph.88.6.940
Hudson, R., Green, M., Wright, D. J., Renard, J., Jobson, C. E., Jung, T., Rushlow, W., & Laviolette, S. R. (2020). Adolescent nicotine induces depressive and anxiogenic effects through ERK 1-2 and Akt-GSK-3 pathways and neuronal dysregulation in the nucleus accumbens. Addiction Biology, 26(2), e12891. DOI: https://doi.org/10.1111/adb.12891
Hughes, J. R. (1996). An Overview of Nicotine Use Disorders for Alcohol/Drug Abuse Clinicians. American Journal on Addictions, 5(3), 262-274. DOI: https://doi.org/10.1111/j.1521-0391.1996.tb00310.x
Hughes, K., Bellis, M. A., Hardcastle, K. A., McHale, P., Bennett, A., Ireland, R., & Pike, K. (2015). Associations between e-cigarette access and smoking and drinking behaviours in teenagers. BMC Public Health, 15(1), 244. DOI: https://doi.org/10.1186/s12889-015-1618-4
Iñiguez, S. D., Warren, B. L., Parise, E. M., Alcantara, L. F., Schuh, B., Maffeo, M. L., Manojlovic, Z., & Bolaños-Guzmán, C. A. (2008). Nicotine Exposure during Adolescence Induces a Depression-Like State in Adulthood. Neuropsychopharmacology, 34(6), 1609-1624. DOI: https://doi.org/10.1038/npp.2008.220
Izenwasser, S. (2019). Nicotine Effects in Adolescents. In Elsevier eBooks (pp. 17-23). DOI: https://doi.org/10.1016/b978-0-12-813035-3.00003-4
Jasinska, A. J., Zorick, T., Brody, A. L., & Stein, E. A. (2013). Dual role of nicotine in addiction and cognition: A review of neuroimaging studies in humans. Neuropharmacology, 84, 111-122. DOI: https://doi.org/10.1016/j.neuropharm.2013.02.015
Jenssen, B., & Boykan, R. (2019). Electronic Cigarettes and Youth in the United States: A Call to Action (at

the Local, National and Global Levels). Children, 6(2), 30. DOI: https://doi.org/10.3390/children6020030
Kenney, J. W., & Gould, T. J. (2008). Modulation of Hippocampus-Dependent Learning and Synaptic Plasticity by Nicotine. Molecular Neurobiology, 38(1), 101-121. DOI: https://doi.org/10.1007/s12035-008-8037-9
Kim, B., Yoon, S., Nakajima, R., Lee, H. J., Lim, H. J., Lee, Y., Choi, J., Yoon, B., Augustine, G. J., & Baik, J. (2018). Dopamine D2 receptor-mediated circuit from the central amygdala to the bed nucleus of the stria terminalis regulates impulsive behavior. Proceedings of the National Academy of Sciences, 115(45), E10730-E10739. DOI: https://doi.org/10.1073/pnas.1811664115
Koranda, J. L., & Beeler, J. A. (2019). Nicotine in Aberrant Learning and Corticostriatal Plasticity. In Elsevier eBooks (pp. 181-189). DOI: https://doi.org/10.1016/b978-0-12-813035-3.00023-x
Kotlyar, M., & Hatsukami, D. K. (2002). Managing Nicotine Addiction. Journal of Dental Education, 66(9), 1061-1073. DOI: https://doi.org/10.1002/j.0022-0337.2002.66.9.tb03575.x
Lee, J. G. L., Goldstein, A. O., Klein, E. G., Ranney, L. M., & Carver, A. M. (2012). Assessment of College and University Campus Tobacco-Free Policies in North Carolina. Journal of American College Health, 60(7), 512-519. DOI: https://doi.org/10.1080/07448481.2012.690464
Leslie, F. M. (2020). Unique, long-term effects of nicotine on adolescent brain. Pharmacology Biochemistry and Behavior, 197, 173010. DOI: https://doi.org/10.1016/j.pbb.2020.173010
Leventhal, A. M., Strong, D. R., Sussman, S., Kirkpatrick, M. G., Unger, J. B., Barrington-Trimis, J. L., & Audrain-McGovern, J. (2015). Psychiatric comorbidity in adolescent electronic and conventional cigarette use. Journal of Psychiatric Research, 73, 71-78. DOI: https://doi.org/10.1016/j.jpsychires.2015.11.008
Levy, D. E., Winickoff, J. P., & Rigotti, N. A. (2011). School Absenteeism Among Children Living with Smokers. PEDIATRICS, 128(4), 650-656. DOI: https://doi.org/10.1542/peds.2011-1067
Lor, C. S., Haugg, A., Zhang, M., Schneider, L., Herdener, M., Quednow, B. B., Golestani, N., & Scharnowski, F. (2022). Thalamic volume and functional connectivity are associated with nicotine dependence severity and craving. Addiction Biology, 28(1), e13261. DOI: https://doi.org/10.1111/adb.13261
Majdi, A., Kamari, F., Vafaee, M. S., & Sadigh-Eteghad, S. (2017). Revisiting nicotine's role in the ageing brain and cognitive impairment. Reviews in the Neurosciences, 28(7), 767-781. DOI: https://doi.org/10.1515/revneuro-2017-0008
Mao, D., & McGehee, D. S. (2009). Nicotine and Behavioral Sensitization. Journal of Molecular Neuroscience, 40(1-2), 154-163. DOI: https://doi.org/10.1007/s12031-009-9230-7
Martin, L. M., & Sayette, M. A. (2018). A review of the effects of nicotine on social functioning. Experimental and Clinical Psychopharmacology, 26(5), 425-439. DOI: https://doi.org/10.1037/pha0000208
Matingwina, T. (2018). Health, Academic Achievement and School-Based Interventions. In InTech eBooks. DOI: https://doi.org/10.5772/intechopen.76431
Mattingly, D. T., & Hart, J. L. (2024). Trends in Current Electronic Cigarette Use Among Youths by Age, Sex, and Race and Ethnicity. JAMA Network Open, 7(2), e2354872. DOI: https://doi.org/10.1001/jamanetworkopen.2023.54872
McCarthy, D. M., Zhang, L., Wilkes, B. J., Vaillancourt, D. E., Biederman, J., & Bhide, P. G. (2022). Nicotine and the developing brain: Insights from preclinical models. Pharmacology Biochemistry and Behavior, 214, 173355. DOI: https://doi.org/10.1016/j.pbb.2022.173355
McDonald, C. G., Dailey, V. K., Bergstrom, H. C., Wheeler, T. L., Eppolito, A. K., Smith, L. N., & Smith, R. F. (2005). Periadolescent nicotine administration produces enduring changes in dendritic morphology of medium spiny neurons from nucleus accumbens. Neuroscience Letters, 385(2), 163-167. DOI: https://doi.org/10.1016/j.neulet.2005.05.041
McMahon, R. (1999). Child and adolescent psychopathology as risk factors for subsequent tobacco use. Nicotine & Tobacco Research, 1(1), 45-50. DOI: https://doi.org/10.1080/14622299050011801
Medicine, I. O. (1994). Growing Up Tobacco Free. In National Academies Press eBooks. DOI: https://doi.org/10.17226/4757
Mitsis, E. M., Cosgrove, K. P., Staley, J. K., Bois, F., Frohlich, E. B., Tamagnan, G. D., Estok, K. M., Seibyl, J. P., & Van Dyck, C. H. (2008). Age-related decline in nicotinic receptor availability with [123I]5-IA-85380 SPECT. Neurobiology of Aging, 30(9), 1490-1497. DOI: https://doi.org/10.1016/j.neurobiolaging.2007.12.008
Miyata, H., & Yanagita, T. (2001). Neurobiological mechanisms of nicotine craving. Alcohol, 24(2), 87-93. DOI: https://doi.org/10.1016/s0741-8329(01)00144-6
Mojica, C. Y., Dao, J. M., Yuan, M., Loughlin, S. E., & Leslie, F. M. (2013). Nicotine modulation of adolescent dopamine receptor signaling and hypothalamic peptide response. Neuropharmacology, 77, 285-293. DOI: https://doi.org/10.1016/j.neuropharm.2013.10.012
Murthy, V. H. (2016). E-Cigarette Use Among Youth and Young Adults. JAMA Pediatrics, 171(3), 209. DOI: https://doi.org/10.1001/jamapediatrics.2016.4662
Narahashi, T., Fenster, C. P., Quick, M. W., Lester, R. A., Marszalec, W., Aistrup, G. L., Sattelle, D. B., Martin, B. R., & Levin, E. D. (2000). Symposium Overview: Mechanism of Action of Nicotine on Neuronal Acetylcholine Receptors, from Molecule to Behavior. Toxicological Sciences, 57(2), 193-202. DOI: https://doi.org/10.1093/toxsci/57.2.193
Naudé, J., Dongelmans, M., & Faure, P. (2014). Nicotinic alteration of decision-making. Neuropharmacology, 96, 244-254. DOI: https://doi.org/10.1016/j.neuropharm.2014.11.021
Niño, M. D., Cai, T., & Ignatow, G. (2015). Social isolation, drunkenness, and cigarette use among adolescents. Addictive Behaviors, 53, 94-100. DOI: https://doi.org/10.1016/j.addbeh.2015.10.005
Nop, O., Miller, A. S., Culver, H., Makarewicz, J., & Dumas, J. A. (2021). Nicotine and Cognition in Cognitively Normal Older Adults. Frontiers in Aging Neurosci-

ence, 13, 640674. DOI: https://doi.org/10.3389/fnagi.2021.640674
Oliver, B. E., Jones, S. E., Hops, E. D., Ashley, C. L., Miech, R., & Mpofu, J. J. (2023). Electronic Vapor Product Use Among High School Students — Youth Risk Behavior Survey, United States, 2021. MMWR Supplements, 72(1), 93-99. DOI: https://doi.org/10.15585/mmwr.su7201a11
Olszewski, N. A., Tetteh-Quarshie, S., & Henderson, B. J. (2024). Neuronal excitability in the medial habenula and ventral tegmental area is differentially modulated by nicotine dosage and menthol in a sex-specific manner. eNeuro, 11(2), ENEURO.0380-23.2024. DOI: https://doi.org/10.1523/eneuro.0380-23.2024
Olumide, A. O., Shmueli, A., Adebayo, E. S., & Omotade, O. O. (2021). Economic costs of cigarette smoking among adolescents in Nigeria. Journal of Public Health, 30(7), 1701-1712. DOI: https://doi.org/10.1007/s10389-021-01644-5
Park, S. (2000). Nicotine Impairs Spatial Working Memory while Leaving Spatial Attention Intact. Neuropsychopharmacology, 22(2), 200-209. DOI: https://doi.org/10.1016/s0893-133x(99)00098-6
Park-Lee, E., Ren, C., Cooper, M., Cornelius, M., Jamal, A., & Cullen, K. A. (2022). Tobacco Product Use Among Middle and High School Students — United States, 2022. MMWR Morbidity and Mortality Weekly Report, 71(45), 1429-1435. DOI: https://doi.org/10.15585/mmwr.mm7145a1
Penny, G. N., & Robinson, J. O. (1986). Psychological resources and cigarette smoking in adolescents. British Journal of Psychology, 77(3), 351-357. DOI: https://doi.org/10.1111/j.2044-8295.1986.tb02202.x
Perelman, J., Leão, T., & Kunst, A. E. (2019). Smoking and school absenteeism among 15- to 16-year-old adolescents: a cross-section analysis on 36 European countries. European Journal of Public Health, 29(4), 778-784. DOI: https://doi.org/10.1093/eurpub/ckz110
Picciotto, M. R., & Corrigall, W. A. (2002). Neuronal Systems Underlying Behaviors Related to Nicotine Addiction: Neural Circuits and Molecular Genetics. Journal of Neuroscience, 22(9), 3338-3341. DOI: https://doi.org/10.1523/jneurosci.22-09-03338.2002
Placzek, A. N., Zhang, T. A., & Dani, J. A. (2009). Nicotinic mechanisms influencing synaptic plasticity in the hippocampus. Acta Pharmacologica Sinica, 30(6), 752-760. DOI: https://doi.org/10.1038/aps.2009.39
Polesskaya, O. O., Fryxell, K. J., Merchant, A. D., Locklear, L. L., Ker, K., McDonald, C. G., Eppolito, A. K., Smith, L. N., Wheeler, T. L., & Smith, R. F. (2006). Nicotine causes age-dependent changes in gene expression in the adolescent female rat brain. Neurotoxicology and Teratology, 29(1), 126-140. DOI: https://doi.org/10.1016/j.ntt.2006.11.005
Portugal, G. S., & Gould, T. J. (2008). Genetic variability in nicotinic acetylcholine receptors and nicotine addiction: Converging evidence from human and animal research. Behavioural Brain Research, 193(1), 1-16. DOI: https://doi.org/10.1016/j.bbr.2008.05.006
Quam, A., Biernacki, K., Ross, T. J., Salmeron, B. J., & Janes, A. C. (2024). Childhood Trauma, Emotional Awareness, and Neural Correlates of Long-Term Nicotine Smoking. JAMA Network Open, 7(1), e2351132. DOI: https://doi.org/10.1001/jamanetworkopen.2023.51132
Rayes, B. T., Alalwan, A., AbuDujain, N. M., Darraj, A., Alammar, M. A., & Jradi, H. (2023). Prevalence, Trends, and Harm Perception Associated with E-Cigarettes and Vaping among Adolescents in Saudi Arabia. Archives of Clinical and Biomedical Research, 7(2), 147-156. DOI: https://doi.org/10.26502/acbr.50170327
Reitz, C., Luchsinger, J., Tang, M., & Mayeux, R. (2005). Effect of smoking and time on cognitive function in the elderly without dementia. Neurology, 65(6), 870-875. DOI: https://doi.org/10.1212/01.wnl.0000176057.22827.b7
Ren, M., Lotfipour, S., & Leslie, F. (2022). Unique effects of nicotine across the lifespan. Pharmacology Biochemistry and Behavior, 214, 173343. DOI: https://doi.org/10.1016/j.pbb.2022.173343
Riehm, K. E., Young, A. S., Feder, K. A., Krawczyk, N., Tormohlen, K. N., Pacek, L. R., Mojtabai, R., & Crum, R. M. (2019). Mental Health Problems and Initiation of E-cigarette and Combustible Cigarette Use. Pediatrics, 144(1), e20182935. DOI: https://doi.org/10.1542/peds.2018-2935
Sæbø, G., & Lund, M. (2024). Is the perceived public stigma of smokers associated with value opposites? An exploratory cross-sectional analysis of Norwegian data 2011-2013. Frontiers in Sociology, 8, 1051189. DOI: https://doi.org/10.3389/fsoc.2023.1051189
Scerri, C., Stewart, C. A., Breen, K. C., & Balfour, D. J. K. (2005). The effects of chronic nicotine on spatial learning and bromodeoxyuridine incorporation into the dentate gyrus of the rat. Psychopharmacology, 184(3-4), 540-546. DOI: https://doi.org/10.1007/s00213-005-0086-4
Schwartz, R. D., & Kellar, K. J. (1983). Nicotinic Cholinergic Receptor Binding Sites in the Brain: Regulation in Vivo. Science, 220(4593), 214-216. DOI: https://doi.org/10.1126/science.6828889
Seitz, C. M., Kabir, Z., Greiner, B. A., Davoren, M. P., & McIntyre, S. C. (2018). Enforcement of Smoke/Tobacco-free Policies at Public Universities in the US. Tobacco Regulatory Science, 4(4), 22-31. DOI: https://doi.org/10.18001/trs.4.4.3
Seth, P., Cheeta, S., Tucci, S., & File, S. E. (2002). Nicotinic-serotonergic interactions in brain and behaviour. Pharmacology Biochemistry and Behavior, 71(4), 795-805. DOI: https://doi.org/10.1016/s0091-3057(01)00715-8
Siqueira, L. M., Ryan, S. A., Gonzalez, P. K., Patrick, S. W., Quigley, J., & Walker, L. R. (2016). Nicotine and Tobacco as Substances of Abuse in Children and Adolescents. Pediatrics, 139(1), e20163436. DOI: https://doi.org/10.1542/peds.2016-3436
Slotkin, T. (2002). Nicotine and the adolescent brain Insights from an animal model. Neurotoxicology and Teratology, 24(3), 369-384. DOI: https://doi.org/10.1016/s0892-0362(02)00199-x
Slotkin, T. A., Card, J., & Seidler, F. J. (2014). Nicotine administration in adolescence reprograms the subsequent response to nicotine treatment and withdrawal in adulthood: Sex-selective effects on cerebrocortical serotonergic function. Brain Research Bulletin, 102, 1-8. DOI: https://doi.org/10.1016/j.brainresbull.2014.01.004
Slotkin, T. A., & Seidler, F. J. (2006). A unique role for

striatal serotonergic systems in the withdrawal from adolescent nicotine administration. Neurotoxicology and Teratology, 29(1), 10-16. DOI: https://doi.org/10.1016/j.ntt.2006.06.001
Smith, C. J., & Giacobini, E. (1992). Nicotine, Parkinson's and Alzheimer's Disease. Reviews in the Neurosciences, 3(1), 25-44. DOI: https://doi.org/10.1515/revneuro.1992.3.1.25
Smith, R. F., McDonald, C. G., Bergstrom, H. C., Ehlinger, D. G., & Brielmaier, J. M. (2015). Adolescent nicotine induces persisting changes in development of neural connectivity. Neuroscience & Biobehavioral Reviews, 55, 432-443. DOI: https://doi.org/10.1016/j.neubiorev.2015.05.019
Spear, L. P. (2013). Adolescent Neurodevelopment. Journal of Adolescent Health, 52(2), S7-S13. DOI: https://doi.org/10.1016/j.jadohealth.2012.05.006
Stopping the start: Our new plan to create a smokefree generation. (2023, November 8). GOV.UK. https://www.gov.uk/government/publications/stopping-the-start-our-new-plan-to-create-a-smokefree-generation/stopping-the-start-our-new-plan-to-create-a-smokefree-generation
Swan, G. E., & Lessov-Schlaggar, C. N. (2007). The Effects of Tobacco Smoke and Nicotine on Cognition and the Brain. Neuropsychology Review, 17(3), 259-273. DOI: https://doi.org/10.1007/s11065-007-9035-9
Tang, J., & Dani, J. A. (2009). Dopamine Enables In Vivo Synaptic Plasticity Associated with the Addictive Drug Nicotine. Neuron, 63(5), 673-682. DOI: https://doi.org/10.1016/j.neuron.2009.07.025
The Harmful Consequences of Vaping: A Public Health Threat. (2020). Journal of Addictions Nursing, 31(2), E3-E4. DOI: https://doi.org/10.1097/jan.0000000000000342
Tobacco Use and Academic Achievement. (2013). [Dataset]. In PsycEXTRA Dataset. DOI: https://doi.org/10.1037/e567522009-001
Trauth, J. A., Seidler, F. J., Ali, S. F., & Slotkin, T. A. (2001). Adolescent nicotine exposure produces immediate and long-term changes in CNS noradrenergic and dopaminergic function. Brain Research, 892(2), 269-280. DOI: https://doi.org/10.1016/s0006-8993(00)03227-3
Valentine, G., & Sofuoglu, M. (2017). Cognitive Effects of Nicotine: Recent Progress. Current Neuropharmacology, 16(4), 403-414. DOI: https://doi.org/10.2174/1570159x15666171103152136
Wang, T. W., Gentzke, A. S., Creamer, M. R., Cullen, K. A., Holder-Hayes, E., Sawdey, M. D., Anic, G. M., Portnoy, D. B., Hu, S., Homa, D. M., Jamal, A., & Neff, L. J. (2019). Tobacco Product Use and Associated Factors Among Middle and High School Students — United States, 2019. MMWR Surveillance Summaries, 68(12), 1-22. DOI: https://doi.org/10.15585/mmwr.ss6812a1
Warburton, D. M., Wesnes, K., & Revell, A. (1984). Smoking and academic performance. Current Psychological Research & Reviews, 3(3), 25-31. DOI: https://doi.org/10.1007/bf02686521
Wechsler, H., Kelley, K., Seibring, M., Kuo, M., & Rigotti, N. A. (2001). College Smoking Policies and Smoking Cessation Programs: Results of a Survey of College Health Center Directors. Journal of American College Health, 49(5), 205-212. DOI: https://doi.org/10.1080/07448480109596305
Wessels, C., & Winterer, G. (2008). Neuronale Entwicklung: Nikotinabhängige morphologische und funktionelle Veränderungen des Zentralnervensystems. e-Neuroforum, 14(2), 199-204. DOI: https://doi.org/10.1515/nf-2008-0204
Wignall, N. D., & De Wit, H. (2011). Effects of nicotine on attention and inhibitory control in healthy nonsmokers. Experimental and Clinical Psychopharmacology, 19(3), 183-191. DOI: https://doi.org/10.1037/a0023292
Wu, J. (2009). Understanding of nicotinic acetylcholine receptors. Acta Pharmacologica Sinica, 30(6), 653-655. DOI: https://doi.org/10.1038/aps.2009.89
Xiang, S., Jia, T., Xie, C., Cheng, W., Chaarani, B., Banaschewski, T., Barker, G. J., Bokde, A. L. W., Büchel, C., Desrivières, S., Flor, H., Grigis, A., Gowland, P. A., Brühl, R., Martinot, J., Martinot, M. P., Nees, F., Orfanos, D. P., Poustka, L., . . . Feng, J. (2023). Association between vmPFC gray matter volume and smoking initiation in adolescents. Nature Communications, 14(1), 4684. DOI: https://doi.org/10.1038/s41467-023-40079-2
Xiao, C., Zhou, C., Jiang, J., & Yin, C. (2019). Neural circuits and nicotinic acetylcholine receptors mediate the cholinergic regulation of midbrain dopaminergic neurons and nicotine dependence. Acta Pharmacologica Sinica, 41(1), 1-9. DOI: https://doi.org/10.1038/s41401-019-0299-4
Xie, C., Xie, Z., & Li, D. (2020). Association of electronic cigarette use with self-reported difficulty concentrating, remembering, or making decisions in US youth. Tobacco Induced Diseases, 18, 1-9. DOI: https://doi.org/10.18332/tid/130925
Yuan, M., Cross, S. J., Loughlin, S. E., & Leslie, F. M. (2015). Nicotine and the adolescent brain. The Journal of Physiology, 593(16), 3397-3412. DOI: https://doi.org/10.1113/jp270492
Zhou, M., Qiu, W., Ohashi, N., Sun, L., Wronski, M., Kouyama-Suzuki, E., Shirai, Y., Yanagawa, T., Mori, T., & Tabuchi, K. (2024). Deep-Learning-Based Analysis Reveals a Social Behavior Deficit in Mice Exposed Prenatally to Nicotine. Cells, 13(3), 275. DOI: https://doi.org/10.3390/cells13030275

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