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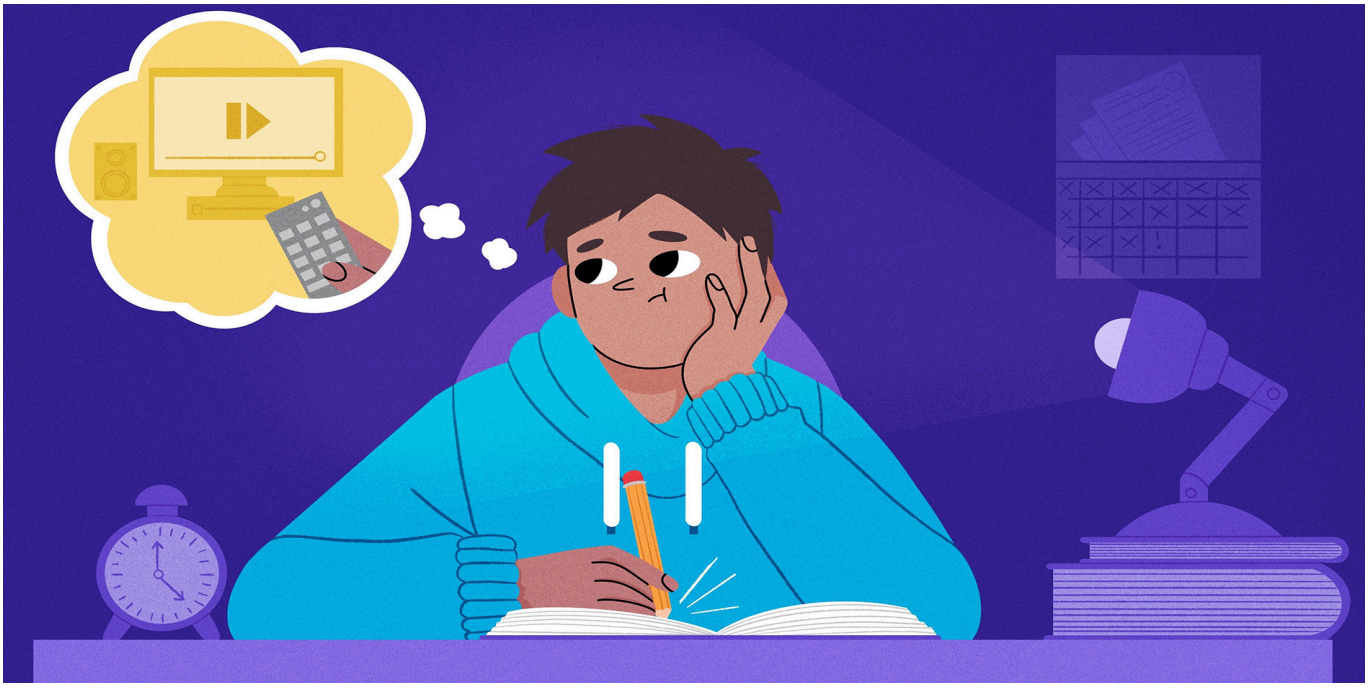

HOW ALCOHOL AFFECTS THE ADOLESCENT MIND

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AGE: 14

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AGE: 15

Have you ever heard about executive functions (EFs)? These are skills that you use every single day! They allow you to achieve your goals, resist your impulses, and make wise decisions. During adolescence, your brain is still developing. In particular, the area of your brain responsible for your EFs is still maturing and becoming more efficient. This means that, as an adolescent, you are still getting better at exercising your EFs. This ongoing brain and skill development is probably one of the reasons why adolescents are more likely to engage in risky behaviors, including drug abuse and binge drinking (BD). BD is a pattern of excessive alcohol use that negatively affects EFs and other aspects of brain structure and function. In this article, we describe three important EFs and explain how development of these skills is related to brain maturation. We discuss how BD may impact EFs and potentially disrupt an adolescent's transition to adult life.

YOUR BRAIN AT SCHOOL

It is Monday morning and your first day of school after the summer break. You see your best friends and run in their direction—you have so much to tell them about your summer holidays at the beach. They laugh about the story you are telling, and you continue to explain how awesome it all was, but suddenly the bell rings and it is time for class! The teacher enters the room, so you stop talking to your friend—you know that it is time to pay attention to what the teacher has to say. She starts by welcoming the students and gives out the first assignment: turn to page 78 and do exercise 3. You try to remember the math rules that you learned last year, and you manage to complete the exercise. After a while, it is time for lunch. You go to the vending machine to get something to eat, and at the same time, you continue telling your friends about your summer adventures, while you also respond to a message from your mother (Figure 1).

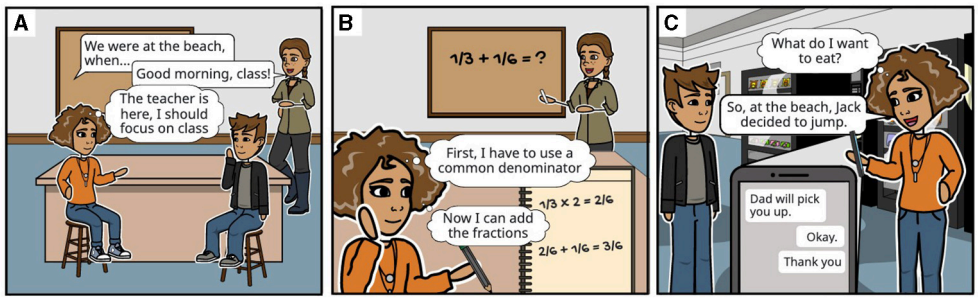

Figure 1

Every day, your brain works in complex ways that allow you to achieve your goals, as in the scene above. To do this, you make use of crucial brain abilities called **executive functions** (EFs). "Executive" is related to the verb "to execute," meaning to put into effect. Thus, EFs are skills we need to achieve a goal, like successfully completing an exercise in class. EFs allow us to go from *wanting* to do something to actually *getting* it done, like planning a vacation, solving a problem, and even having a conversation with a friend. To organize, plan, and complete these tasks we need three main EFs: inhibition, updating, and shifting.

EXECUTIVE FUNCTIONS IN DAILY LIFE

Inhibition refers to the ability to control attention, behavior, thoughts, and emotions, preventing inappropriate responses from occurring. Inhibition keeps you from acting impulsively, so you can do what is most appropriate and necessary (Figure 1A). For example, imagine you are crossing the street on your way to school, but suddenly you see a car that is not slowing down. You must stop walking (inhibit your behavior) so you do not get run over. You can inhibit your thoughts,

Figure 1

You use your executive functions all the time! For example, during a day at school, you might: **(A)** inhibit inappropriate behaviours, like stopping yourself from talking while the teacher is teaching; **(B)** maintain and update information in memory by keeping track of the calculations you are doing while solving a math problem in class; and **(C)** flexibly switch between tasks, like when you are texting while talking to a friend and deciding what to eat.

EXECUTIVE FUNCTIONS

A set of mental processes that allow you to guide and manage your thinking and emotions and help you to act in appropriate, purposeful, and goal-directed ways.

INHIBITION

Inhibition involves being able to suppress or control impulsive thoughts, actions, or feelings and instead do what is more appropriate or needed in a given situation.

too. Imagine a situation in which you must study for an exam, but you cannot stop thinking about the last episode of your favorite TV series. In this case, you must control that thought so you can focus on studying for the exam and get a good grade.

Updating is the ability to bring to mind (and keep in mind) information that is most important for the task at hand (Figure 1B). Imagine someone gave you directions to a certain destination and, after each turn you take, you must update the information in your mind and remember what the next turn is.

Lastly, **shifting** refers to your ability to adapt to a new environment by switching your attention to a new task that has become more important (Figure 1C). Imagine that you are on your way to school, but the road you usually take is closed for construction. In this situation, you must come up with a new way to get to school, while you inform your mother that you are taking a different route *and* keep track of time, so you will not be late for class.

ADOLESCENCE—A WINDOW FOR BRAIN DEVELOPMENT... AND RISKY BEHAVIORS!

Inhibition, updating, and shifting are the basis for the ability to plan (e.g., prepare for your next vacation), to reason (e.g., come up with good arguments during a debate) and to solve problems (e.g., find the answer to an equation in math class). The EFs start developing in childhood and they continue improving all the way through adulthood, mainly due to the development of a brain region called the **prefrontal cortex** (PFC), which is located behind the forehead and is in charge of the EFs. It works like the boss of the EFs, since it has a key role in our ability to reason, plan and achieve our goals in coordination with the rest of the brain.

As the PFC develops during childhood and adolescence, the EFs improve. There is just a small problem: this crucial part of the brain matures slowly compared to other regions [1]. For instance, the **limbic system** , also known as the emotional brain, develops earlier than the PFC (Figure 2). The limbic system is involved in your experience of emotions and how you respond to those emotions. It is related to the processing of reward and is responsible for **sensation-seeking** behavior. During adolescence, the reward regions—i.e., structures located deep within the brain that drive behavior towards pleasurable stimuli such as food, sex, and drugs—are more developed than the PFC, meaning that the **reward system** may have more influence over daily decisions than the PFC does [2].

When adults have the desire to do something risky (e.g., jumping from a high cliff into the water, gambling away their savings, or driving a car beyond the speed limit), they can consider the consequences

UPDATING

Updating is a function responsible for bringing and keeping relevant information in your mind while replacing content that is no longer relevant according to the task at hand.

SHIFTING

Shifting is the ability that allows you to quickly switch focus, attention, and strategies when faced with changing tasks or situations, facilitating adaptation to new information or rules.

PREFRONTAL CORTEX

A brain region located behind the forehead that is involved in executive functions as well as the expression of personality and social behavior.

LIMBIC SYSTEM

A set of structures deep inside the brain that is in charge of the survival functions and has a major role in emotional and behavioral responses, motivation, and memory.

SENSATION SEEKING

A tendency to seek out new and intense experiences. It can lead to risk-taking behaviors including drug misuse, with potential short- and long-term negative consequences.

REWARD SYSTEM

A set of brain regions that associates certain behaviors (e.g., eating, drinking, having sex) with sensations of pleasure, so that the likelihood of repeating these behaviors increases.

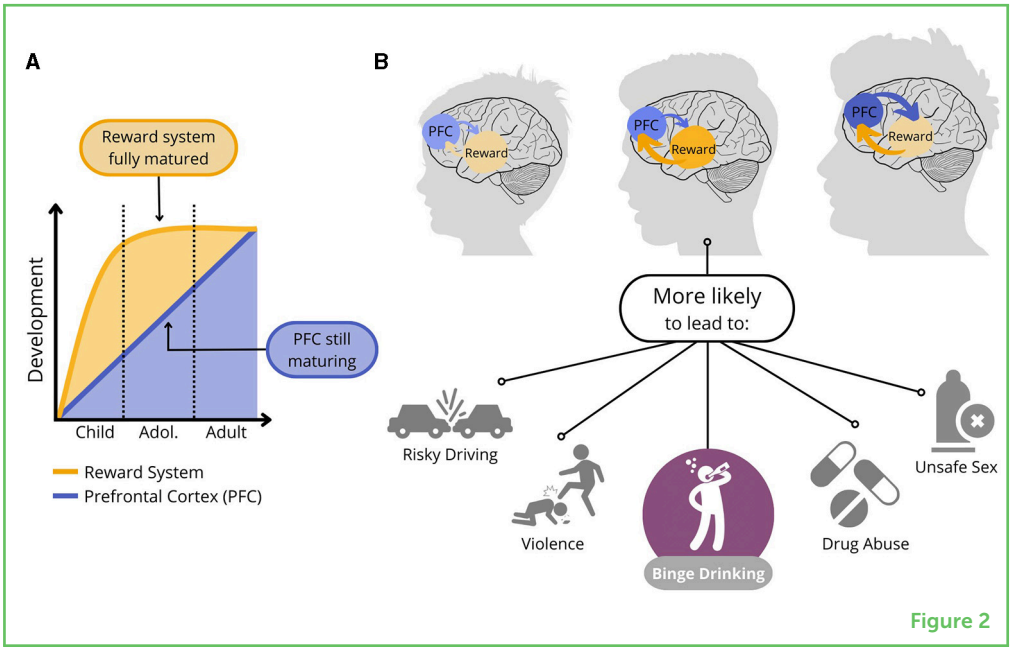

Figure 2

Figure 2

Brain maturation in children, adolescents, and adults. **(A)** The adolescent brain is functionally different from the child and adult brain, as there is an imbalance between the fully mature, overactivated reward system (in orange) and the still-maturing PFC (in blue). **(B)** This imbalance between the strong reward system and weaker PFC may make adolescents more prone to get involved in risky behaviours, including reckless driving, unprotected sexual activity, drug abuse, and binge drinking.

and make a conscious decision about whether to follow their desires. However, adolescents have less control over their impulses and desires due to the imbalance between the (overactivated) reward system and the (still-maturing) PFC. Altogether, this makes teenagers more likely to get involved in risky behaviors, such as getting into fights, having unprotected sexual activity, or abusing drugs or alcohol.

EFFECTS OF BINGE DRINKING IN THE ADOLESCENT BRAIN

Although alcohol use is not allowed until the age of 18–21 in many countries and is totally banned in the majority of North African and Middle Eastern countries, heavy alcohol drinking or **binge drinking** (BD) is one of the most frequent and concerning risky behaviors amongst Western teenagers. BD is when a person drinks an excessive amount of alcohol in a short period of time [3], and it is a regular behavior in about one-third of European and American youths. BD is a major public health concern because it can have many negative consequences on the body and brain, including cognitive deficits (e.g., poor memory skills and reduced ability to control impulses).

Neuroimaging (a technique that allows doctors and scientists to obtain pictures of the brain to study its structure and function), has shown that the brain of young binge drinkers is structurally and functionally different than those of young non-binge drinkers [4]. This is particularly true for the frontal lobe, where the still-maturing PFC is located, and certain regions of the reward system. These brain abnormalities can have several implications for the EFs of young binge drinkers.

BINGE DRINKING

An excessive, episodic alcohol use pattern, particularly prevalent among young people, characterized by the consumption of 4–5 drinks within a short period of time (≤2 h).

NEUROIMAGING

A discipline that examines the structure and function of the brain by means of images or pictures obtained in a safe and reliable way.

Scientific evidence revealed that young people with a pattern of BD perform worse on typical laboratory tasks that measure EFs compared to those who drink small amounts of alcohol or do not drink [5]. For example, in a task to measure inhibition, participants are asked to push a button repeatedly, but to stop as soon as they hear or see a specific "stop" signal, like a beep or a change in color. Studies showed that young binge drinkers commit more errors and stop their responses more slowly, suggesting impairments in inhibition. When switching between tasks, studies report slower performance and lower accuracy in young binge drinkers, which indicates weak shifting ability. Last, when it comes to updating, studies show that binge drinkers do not have major difficulties bringing necessary information to mind, suggesting that this executive function is less impaired by BD.

A VICIOUS CYCLE

Inhibition seems to be the EF most affected by BD. However, in addition to BD decreasing inhibition, reduced inhibitory control may also be the *cause* of this drinking pattern. People with weak inhibition may easily lose control over their drinking, leading to a BD episode. Likewise, the inhibition impairments caused by BD may decrease a person's ability to prevent or stop alcohol misuse [6]. Thus, you can see that there is a vicious cycle between BD and poor inhibition, which may result in a higher risk for developing alcohol abuse as an adult (Figure 3). Longer lasting and heavier drinking patterns have also been linked to changes in brain structures critical for learning, memory, and the proper functioning of EFs. Importantly, however, early evidence suggests that the brain may recover if BD stops [7], which illustrates how important it is to limit the intensity and frequency of BD episodes.

MAKE HEALTHY CHOICES

To conclude, BD has concerning negative consequences in young people. As you have seen, this pattern may lead to weakened EFs, which, in turn, may cause poorer performance in school, violent behaviors, unsafe sex, drug use, and continued or increasing alcohol use. BD during the adolescent period is particularly worrying, given that excessive drinking might disrupt the maturational processes of brain regions that are still developing, such as the PFC. If you ever find yourself tempted or pressured to drink to the point you feel drunk, think about how alcohol can affect both your daily functioning and the healthy development of your brain. Remember to make mindful choices to take care of your brain!

Figure 3

Excessive alcohol use may lead to a "vicious cycle," in which the effects of BD on inhibition encourage continued and increased alcohol intake, which in turn leads to a further decrease in inhibition.

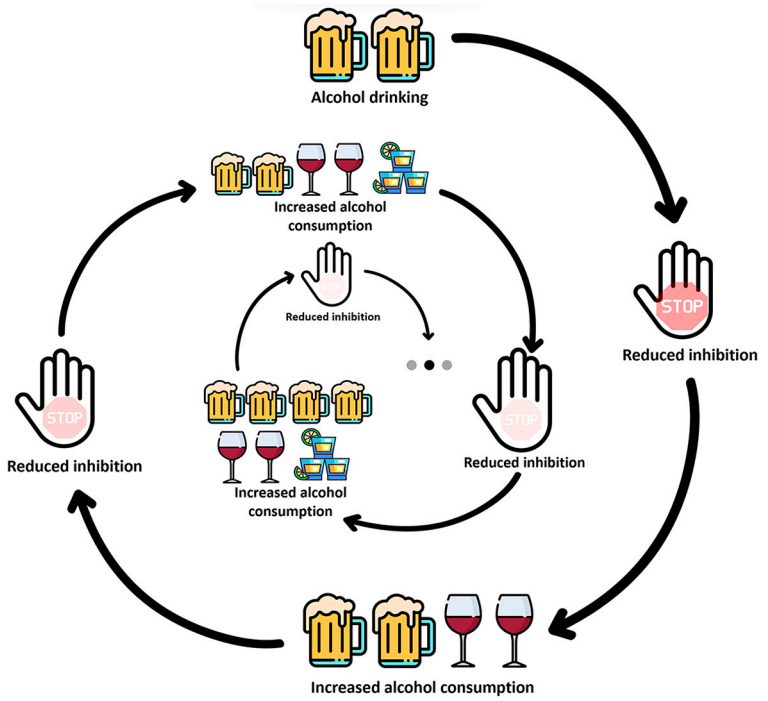

Figure 3

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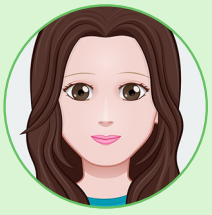
YOUNG REVIEWERS



LETICIA, AGE: 14
I am 14 years old and live in England. I love sciences, reading mystery novels, and playing the piano. I am very passionate about medicine and consider it a potential career. I lived for many years in South America and enjoyed living surrounded by giant volcanoes and discovering exotic animals that helped me develop a passion for the sciences. I am fascinated by the world around me, the human body, and the evolution of species.

SAMUEL, SANTIAGO, AGE: 15
Hello I am Santiago and I am Samuel. We started high school. We like to play soccer. Santi likes history and chemistry. Sammy likes Algebra and English. We enjoy reading Frontiers for Young Minds as it brings science to our life in a way that we can easily understand and use in our lives.

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I am a third-year psychology student at the University of Minho (Portugal). For over a year, I have also been a research collaborator at the Psychological Neuroscience Lab of the same university. I have a particular interest in crisis and emergency intervention, and would like to work and do research in the same field. Outside of my studies, I volunteer with Red Cross Portugal as an Emergency Medical Technician.

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I am a third-year psychology student at the University of Minho (Portugal). For over a year, I have also been a research collaborator at the Psychological Neuroscience Lab of the same university. I also work in a retail company. I want to do a master's degree on Work and Organizations Psychology, and I intend to work on that area in the future, specifically in the field of work satisfaction and wellbeing. I have a particular interest in personality and social psychology.

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