The Changing Adolescent Brain

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Adolescence is the transition from childhood to adulthood, a period during which an individual acquires the skills necessary to survive on his or her own, away from parents or other caregivers. Adolescence can be a very confusing time – a time of intense flux, emotionally, behaviourally, and physically. Even the healthiest and happiest adolescents exhibit behaviours that would cause concern if exhibited by adults. They experience changes in sleep, diet, mood, weight and attitude and a decreased pleasure from daily activities. These changes are all normal and, in many ways, crucial to healthy adolescent development. And they're not new, as reflected by the words of a character in Shakespeare's play, *The Winter's Tale:*

> I would there were no age between sixteen and three-and-twenty, or that youth would sleep out the rest; for there is nothing in the between but getting wenches with child, wronging the ancientry, stealing, fighting. (Shepherd, Act III, Scene III)

Recent research has shown that changes in brain function underlie many of these behavioural changes. These findings have important implications for understanding both normal and abnormal adolescent behavioural patterns, promoting communication between parents and young people, and helping adolescents make the most of their educational opportunities and developing brains.

The importance of adolescence

Not all animals pass through adolescence. Some are born prepared for independence and begin fending for themselves immediately after hatching from an egg or leaving the womb. On the plus side, such animals do not require an extended period of nurturing. They can find their own food immediately, do not have to compete with siblings for the attention of the mother and, with some luck, can survive without adult help. On the negative side, however, these animals are born with essentially all of the instructions they will ever receive about how to survive in the world. They might be able to learn a new trick or two, but they will not be able to roll with major changes in the environment. If such an animal's brain tells it to eat green bugs and there are no green bugs in its environment, then it's in big trouble!

Humans are born with an incredible ability to adapt to changes in their environment. While our brains have probably not changed in the past thousand years, the repertoire of skills necessary to survive certainly has. The flexibility to adapt comes at a price, however: we are born completely dependent on others. Imagine a five month old, or even a five year old, trying to survive without support! During the first decade of life, we explore our world using the family, or other caregivers, as a home base.

EN BREF Au cours de l'adolescence, l'organisation et le fonctionnement du cerveau se transforment, ce qui produit des changements importants dans le comportement des jeunes alors qu'ils passent de l'enfance à l'âge adulte. En effet, les circuits neuraux qui gèrent notre comportement et nous aident à prendre de bonnes décisions, à contrôler nos impulsions et à réagir de façon appropriée se réorganisent afin de jeter les fondations de ce qui sera notre personnalité adulte. Comme le cerveau de l'adolescent est plus malléable que celui de l'adulte, une grande partie de ce travail de réorganisation est influencée par les interactions avec le monde extérieur.

Eventually, in order for our species to survive another generation, we need to venture away from the family, into the deeper end of the gene pool, and create families of our own. That clearly cannot happen overnight. In fact, the period of biological and behavioural change that we call adolescence generally occupies much of the second decade of life, although social expectations for independence can shorten or lengthen the period of transition.

Changing Adolescent Behaviour

Adolescence is a misunderstood stage of development. Each generation of adolescents views its behaviour as normal, while each generation of adults is perplexed, and even frightened, by it. And yet, there are good developmental reasons for the consistent behavioural patterns that occur during this stage.[1]

Increase in time spent with peers

Most teenagers choose to spend their time sending instant messages to their friends, talking to friends on their cell phones, paging their friends – communicating with friends via courier pigeon, if necessary. In fact, this is adaptive behaviour. In order to jockey for position in the social hierarchy, find mates, acquire the skills necessary to compete with and form alliances with peers, they need to learn social skills and "the rules of the game" – rules that change from generation to generation.

Increase in risk-taking and exploration

This is one of the most important and most poorly understood aspects of normal adolescent development. If adolescents were perfectly content staying at home with their families and had no desire to explore the world, the species would quickly die out. They simply must be driven to explore, seek novelty, and take risks. Acquiring the skills they need requires adolescents to take risks and venture out away from home.[2]

Increase in conflicts with authority

Adolescents must push away from their parents and other authority figures in order to propel themselves into the deeper end of the gene pool. Because the skills required to succeed during adulthood change from generation to generation, it is not necessarily healthy or adaptive for adolescents to take on the characteristics of the adults around them. This would limit the true evolutionary utility of the adolescent period. A natural tendency to be in conflict with adults helps adolescents find their own paths.

Changes in sleep patterns

We do not know why sleep patterns change during adolescence, but teens stay up later, experience less restful sleep, and awaken later (if possible!).[3] Peak levels of melatonin, a hormone thought to promote sleep, are lower in adolescents than in either children or adults. Despite evidence that teenagers actually require more sleep than children or adults, the average number of hours spent sleeping decreases from 8.3 during Grade 8 to 7.3 during Grade 12. Tardiness, absenteeism, lower test scores, problems with mood, traffic accidents, and failure to graduate are all related to poorer sleep during the teen years.

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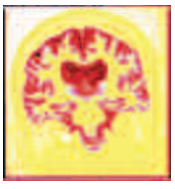
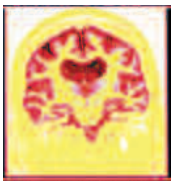




Decreased satisfaction with daily life

One of the hallmarks of adolescence is boredom. Teens commonly complain that there is nothing to do. The extent of this mild anhedonia varies from adolescent to adolescent, but most experience it. How could this be healthy? When combined with an increased interest in novelty seeking and risk taking, decreased satisfaction with daily life helps compel the individual to venture out, interact with peers, and acquire the tools necessary to survive as an adult.

Puberty (sexual maturation)

Puberty refers to a constellation of hormonal and physical changes that prepare the male and female bodies for procreation and physical confrontation. Puberty and adolescence overlap but are not the same thing. In western countries in the 21st century, adolescence typically begins around the time of the onset of puberty but can end well after puberty, particularly among those who go on to post-secondary education.

Brain development during adolescence

The tumultuous behavioural changes exhibited by adolescents arise from a complex set of external and internal forces. The increased focus on social interactions leads them to alter their behaviour to compete for positions in the hierarchy, while changes in brain function and hormonal levels facilitate their abandonment of childhood behaviours.

The brain is an amazingly complex, still poorly understood, organ. It is made up of two broad categories of cells, neurons and glia. Neurons are responsible for processing incoming information, making decisions about how to respond to the information, and controlling the behaviours that follow. Neurons look like bushes or trees, with the branches receiving chemical signals from, and the roots sending chemical signals to, other neurons. Hundreds of billions of neurons bathe one another in chemical messages that influence moment-to-moment changes in brain function, behaviour, and experience. The current chemical milieu of the brain governs how one feels at each moment – how attentive one is, whether one is deeply satisfied with life, whether one is anxious or calm, etc. In contrast, glial cells play a supportive role, contributing to the blood-brain barrier that limits the passage of chemicals into the brain, helping to facilitate communication between neurons, and forming biological scaffolding that helps hold the brain together.

During adolescence, brain organization and function enter a unique period of flux. The dramatic behaviour changes of this period of transition from childhood to adulthood are accompanied by dramatic changes in brain function that give rise to these behaviours. The circuits that coordinate our behaviours, help us make good decisions and control our impulses, react appropriately in different situations, govern our eating and sleeping habits,

etc., are remodeled during the teen years, laying the groundwork for our adult selves. Much of this remodeling is influenced by an individual's interactions with the outside world; the adolescent brain is more highly moldable by experience than the adult brain. The fact that people are willing to completely disrupt their lives to return to their high school reunions sixty years after they graduate is, I think, a pretty clear indication of just how important the adolescent years are for shaping who we are and how our brains function.

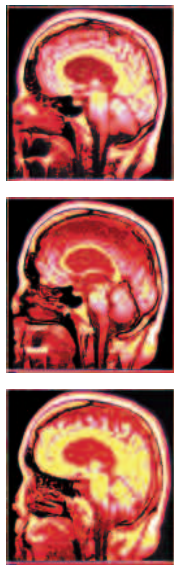
Shaping the brain through experience

Overproduction of neuronal tissue (e.g., brain cells and the synapses, or connections, between them) is a central theme in early brain development, from the womb to late childhood. The infant brain has many more neurons than the adult brain; by some estimates, we lose roughly half of the neurons we are born with before we reach adulthood. The selection process that determines whether an individual neuron lives or dies depends in part on transmission of neurotrophic factors – chemicals that inform a neuron to stay alive – from one cell to another. This process helps ensure that cells making meaningful contacts with other cells survive, while those not effectively communicating die. Circuits that are exercised or used repeatedly will grow to become complex and healthy, while circuits that are underutilized whither on the vine. This process allows a child's brain to be sculpted by his or her interactions with the outside world – the ability that helps set us apart from many other animals and allows us to roll with changes in our environment.

Experience shapes and molds the brain in other ways as well. Just as trees can grow or lose branches without dying, so too can neurons. The tips of the branches represent the points of communication, or synapses, between neurons. These are the locations at which one cell releases its chemical messengers onto another cell, and the second cell receives the signal. A substantial number of synapses are eliminated, or pruned, in the cortex during adolescence, and this process is presumably influenced, at least in part, by interactions with the outside world.

It is tempting to conclude that adolescent brain development must simply be an extension of childhood brain development, that the same changes that occur during childhood simply continue during the adolescent period. In fact, recent scientific evidence indicates that many of the changes taking place during adolescence are novel and do not simply represent the trailing remnants of childhood plasticity.

Some of the most intriguing changes observed thus far during adolescence occur in the frontal lobes (directly behind the forehead), brain regions that play critical roles in memory, voluntary motor behaviour, impulse control, decision-making, planning, and other higher order cognitive functions. Frontal lobe gray matter volumes, which represent dense concentrations of neuronal tissue, increase throughout childhood and reach their peak at roughly the age of 12, at which point they decline throughout the second decade of life. In other words, despite the fact that neurons are dying at a rapid rate during childhood, those that survive are growing and branching out so quickly that there is a net gain in the amount of gray matter in the frontal lobes by the beginning of the second decade of life. During adolescence, a weeding out process begins. Frontal lobe circuits that are exercised are strengthened while other connections are weeded out – leading to a reduction in gray matter volumes in the frontal lobes throughout the adolescent period.



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It can be helpful to think of gray matter in the frontal lobes of a newborn as a lump of clay. The lump of clay continues to grow during childhood and is then sculpted and shaped during adolescence into the structure that will exist during adulthood. Unfortunately, the malleability of the clay continues to decrease as we age, and it becomes increasingly difficult to make changes. While it is certainly possible to teach an old dog new tricks, it is much easier to learn new tricks when we are young. Children and adolescents can move to foreign countries and learn to speak the local language without a noticeable accent, but if this move occurs after the second decade of life, the person will probably always speak with a pronounced accent.

As the amount of frontal lobe gray matter increases during childhood, there is a parallel increase in overall metabolism in the frontal lobes; running the frontal lobes of a child requires quite a bit of energy. During early adolescence, the amount of energy required by the frontal lobes begins to decrease and reaches adult levels by the age of 16-18.[4] These declines in energy use do not reflect a diminution of frontal lobe function; indeed, quite the opposite appears to be the case. During adolescence, the frontal lobes begin to take on an increasingly important role in guiding behaviour and controlling activity in other parts of the brain. This process is commonly referred to as frontalisation. At the same time that frontal lobe gray matter volumes and metabolism decrease, frontal lobe activity during the performance of certain tasks becomes more focused and efficient.[5] Thus, it appears that adolescent brain development, at least in the frontal lobes, represents a unique stage of change during which the frontal lobes become more refined and efficient, using less energy but playing a more important role in guiding behaviour. Prior to this process of frontalisation, adolescents tend to perform more poorly than adults on tasks requiring impulse control and decision-making.

The process of frontalisation continues long after the onset of adolescence. Thus, there is a long lag between the time when adolescents first begin to feel compelled to take risks and seek novelty and the time when the frontal lobes, which govern decision making and impulse control, come online completely. The timing of these events might help explain why adolescents often have difficulty controlling impulses and making good decisions, and seem to act without considering the potential consequences of their actions. The increased drive to take risks and seek novelty occurs long before the frontal lobes are fully developed. Because the frontal lobes are involved in controlling impulses and making good decisions, adolescents often fail to fully consider the consequences of their actions until it's too late. They are all gas and no brakes!

Research suggests that changes also occur elsewhere in the adolescent brain. The volume of gray matter in the parietal lobes, which are involved in processing sensory information and evaluating spatial relationships, peak at around age 11 and decrease throughout adolescence; the occipital lobes, which are dedicated to processing visual information, increase throughout adolescence and into the early 20s; the

temporal lobes, which are critically involved in memory formation, as well as visual and auditory processing, do not reach their maximum until the age of 16-17.[6] A wide variety of changes also occur in deeper brain regions, including the corpus collosum, a thick bundle of axons that allows the two sides of the brain to communicate with one another, and which increases in size during adolescence.[7] Changes in the amounts and types of various chemical messengers, and in the receptors that receive and interpret these messages, occur throughout the brain.[8] We are still trying to determine how these changes in brain function correlate with changes in behaviour during adolescence, but they probably contribute to the boredom, restlessness, and mild anhedonia that most adolescents experience.

Conclusion

Adolescence is a tumultuous time for everyone involved. Somehow, the individual must make the transition from dependence to independence. Evolution seems to have equipped us with a variety of innate biological wedges that naturally help drive adolescents away from the nest. Adolescents push away from parents and others who represent authority, including teachers. They are built this way. They are also built to take risks and seek out novel experiences, which helps them build confidence and acquire the skills needed to make a living in the world. Without these wedges, children from happy homes would simply continue to bathe in the shallow end of the gene pool and the species would not survive. The maturation process of the brain during the second decade of life helps ensure that it does. ■

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Notes

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