

The Middle/ High Years

PHOTO BY KEVIN DAVIS

“

It takes courage to grow up and become who you really are.

”

—E. E. Cummings



Demystifying the

*Adolescents can be mature one moment
and frustratingly immature the next.
The nature of brain development helps explain why.*

Laurence Steinberg

In addition to being a transitional time in physical, intellectual, emotional, and social development, adolescence is a time of important changes in the structure and function of the brain.

Scientists are beginning to understand how the psychological changes of adolescence are linked to brain maturation.

Before the development of brain imaging technology, scientists could only speculate about the workings of the adolescent brain. Now, however, with the same scanners that are used to identify tumors and torn ligaments, researchers can see inside the adolescent's brain and watch what happens when teenagers think. We now know that, other than the first three years of life, no period of development is characterized by more dramatic brain changes than adolescence.

What We've Learned from fMRI

It used to be thought that improved intellectual functioning in adolescence would be reflected in larger brain size. However, the brain has reached its adult size by age 10, making it impossible that changes in thinking during adolescence are the result of sheer increases in the brain's size or volume.

Since 2000, there's been an explosion in research on adolescent brain development,

and our understanding of brain maturation has grown at breathtaking speed. Major contributions to our understanding have come from studies using functional magnetic resonance imaging (fMRI). This technique enables researchers to take pictures of individuals' brains and compare anatomy (brain structure) and activity (brain function).

Some aspects of brain development in adolescence are reflected in changes in brain *structure* (for instance, certain parts of the brain are relatively smaller in childhood than in adolescence, whereas other parts are relatively larger). Other aspects of brain development are reflected in changes in brain *function* (for instance, adolescents may use different parts of the brain than children do when performing the same task).

In addition, greater interconnectedness among various regions of the brain allows for better communication between parts associated with different functions. For example, connections between regions of the brain responsible for logical reasoning become better connected with those responsible for experiencing intense emotions; "cross-talk" between these regions enables better impulse control and self-regulation. That's one reason that older teenagers are so much better than younger ones at controlling their emotions.



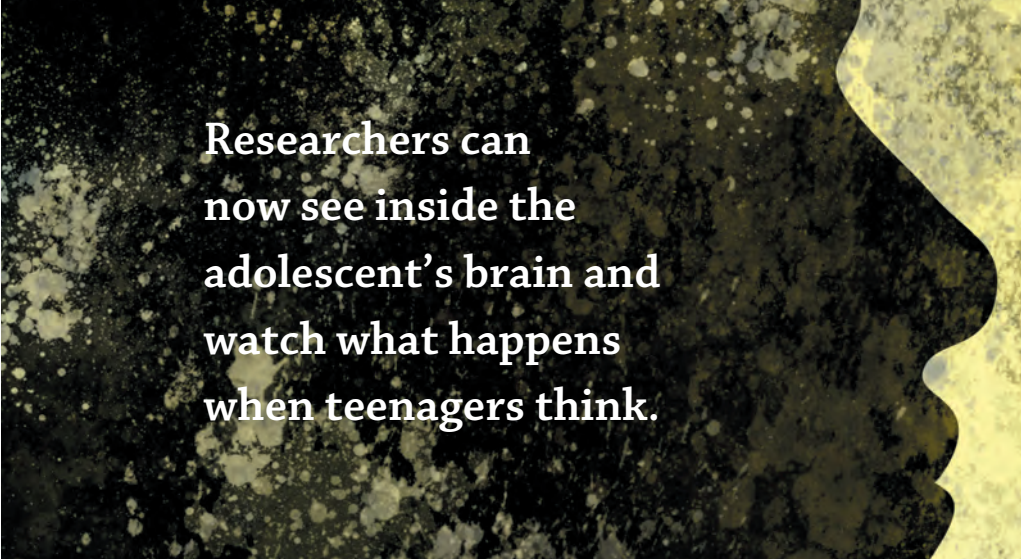
Adolescent Brain



You may have had an MRI exam to diagnose the underlying cause of some sort of pain. Although the technology used in this sort of imaging is the same as that used by neuroscientists who study brain development, the “f” in fMRI refers to the use of the test to examine how the brain *functions*, and not just its anatomy. Researchers use fMRI to examine patterns of brain activity while individuals perform a spe-

whether the ways in which the presence of friends changes brain activity differs between teenagers and adults. We’ve found that the mere presence of peers activates adolescents’ reward centers—but not those of adults. This may make teenagers more inclined to take risks when they’re with their friends because they’re more likely to focus on the rewards of a risky choice than on the potential costs.

opment is the development of connections—synapses—between neurons. By age 2, a single neuron may have 10,000 connections to other neurons. The formation of some synapses is genetically programmed, but others are formed through experience. The rate of synapse formation peaks at about age 1 and slows down in early childhood, but the development of new synapses continues throughout life as we learn new skills, build memories, acquire knowledge, and adapt to changing circumstances.¹



Researchers can now see inside the adolescent’s brain and watch what happens when teenagers think.

cific task (for example, recalling a list of words, viewing photos of one’s friends, or listening to music). Participants in an fMRI study are asked to perform tasks on a computer while they lie inside a brain scanner. With this setup, it’s possible to study both how patterns of brain activity differ during different tasks (for example, when we actively read as opposed to being read to) and whether people of different ages show different patterns of brain activity while performing the same task. Many of the most important brain changes that take place during adolescence are not in the brain’s structure, but in how the brain works.

At Temple University, we’re studying how patterns of brain activity vary when individuals perform tasks either alone or with their friends watching them, and

A Primer on Brain Maturation *Synapse Formation*

The human brain contains approximately 100 billion neurons, cells that carry information by transmitting electrical charges within the brain by means of chemicals called neurotransmitters. Neurons do not actually touch; there’s a minuscule gap between them called a synapse. When the electrical charge travels through a neuron, it stimulates the release of neurotransmitters, chemicals that carry the signal across the synapse from one neuron to the next. Anytime we perceive something (for example, feel an itch); move something (scratch the itch); or process information (wonder where the itch came from), this process of electrical transmission is involved.

A key process in early brain devel-

Synaptic Pruning

Initially, the brain produces many more connections among cells than it will use. The number of synapses in the brain of a 1-year-old is about *twice* the number in the adult brain. However, soon after birth, unused and unnecessary synapses start to be eliminated, a process called *synaptic pruning*. As a general rule, we tend to assume that “more is better,” but that’s not the case here. Imagine a meadow between two patches of forest. Hundreds of lightly trodden paths connect one side to the other (the unpruned brain). Over time, people discover that one path is more direct than others. More people begin using this path more often, so it becomes wider and deeper. Because the other paths are not used anymore, the grass grows back and those paths disappear. That’s what synaptic pruning is like.

The elimination of synapses continues through adolescence and is normal and necessary to development and functioning. Just as pruning a rose bush—cutting off weak and misshapen branches—produces a healthier plant with larger flowers, so synaptic pruning enhances the brain’s functioning. It makes the brain more efficient by transforming an unwieldy network of small pathways into a better organized system of superhighways.

In general, the development of synapses is characterized by a period of growth (when more and more synapses

are created) followed by a period of decline (when more and more synapses are pruned). Although synaptic pruning takes place throughout infancy, childhood, and adolescence, different regions of the brain are pruned at different points in development. As a rule, the brain regions in which pruning is taking place at a particular point in development are the regions associated with the greatest changes in cognitive functioning during that stage.

Myelination

Initially, neurons are “nude,” but in the course of development, white fatty tissue called myelin encases the projections of neurons that interconnect them, a process called myelination. Myelin, which acts like plastic insulation around an electrical wire, increases the speed of neural impulses and so improves information transmission. Myelination occurs in waves, beginning in the prenatal period and continuing into adulthood. As with synaptic pruning, examining *where* myelination occurs most dramatically at a particular point in development provides clues about the aspects of cognitive functioning that are changing most at that stage.

What This Means for the Adolescent Brain

More Advanced Reasoning...

During adolescence, the brain is remodeled through synaptic pruning and myelination in particular brain regions. The most important part of the brain to be pruned in adolescence is the *prefrontal cortex*, the region of the brain directly behind your forehead, which is most important for sophisticated thinking abilities, such as planning, thinking ahead, and weighing risks and rewards. There's also continued myelination of the prefrontal cortex and its connections to other parts of the brain throughout adolescence, which leads to many cognitive advances, including improvements in our ability

to regulate our emotions and coordinate our thoughts and feelings. Maturation of the prefrontal cortex is not complete until the mid-20s, a much later point in development than scientists had once thought.

Imaging studies have also shown important changes in the functioning of the prefrontal cortex in adolescence. Patterns of activation within the prefrontal cortex typically become more focused. For instance, in experiments in which participants are presented with a rapid succession of images and asked to push a button when a certain image appears but refrain from pushing it when a different image appears, adolescents are less likely than children to activate prefrontal regions that are not relevant to performing the task well. In addition, individuals become more likely to use multiple parts of the brain simultaneously and coordinate activity among prefrontal regions and other areas of the brain, such as the limbic system, a region that's important for our experience of reward and punishment and for processing emotional and social information, such as reading someone's facial expression or judging what a person thinks of us.

But More Risk Taking

At the same time that the adolescent brain is maturing in ways that enable teenagers to become more capable of reasoned thinking, it's also changing in ways that make them do risky things.


Do you remember how good your first passionate kiss felt? How much you loved the music that was popular when

you were a teenager? How hard you laughed with your high school friends? Things that feel good feel better during adolescence. Scientists now understand why.

A chemical substance in the brain called dopamine is responsible for the feeling of pleasure. When something enjoyable happens, we experience what some scientists have called a “dopamine squirt,” which leads to the sensation of pleasure. It makes us want whatever elicited the squirt because the feeling of pleasure it produces is so strong. (Some stimuli produce so much pleasure that we get a dopamine squirt just anticipating the experience.)

We now know there's a rapid increase in dopamine activity in early adolescence—in fact, there's more dopamine activity in the brain's reward center in early adolescence than at any other time of life. Because things feel especially pleasurable during early adolescence, young adolescents go out of their way to seek rewarding experiences. At all ages we seek out things that make us feel good, of course. But the drive to do this is much more intense in early adolescence than before or after.

The urge to seek out rewarding and pleasurable experiences is a mixed blessing. On the plus side, it's part of what makes it so much fun to be a teenager. But sometimes this drive is so intense that adolescents can exhibit a sort of reward tunnel vision. They're so driven to seek pleasure that they may not pay attention to the associated risks. To teenagers, driving fast, having unprotected sex, and drinking alcohol



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feel so good that thoughts about a speeding ticket (or worse), an unwanted pregnancy, or being grounded for coming home smelling of beer may not even make it onto their radar screen.

This combination of advanced (but not yet totally mature) reasoning and heightened sensation-seeking explains why otherwise intelligent adolescents often do surprisingly foolish things. More important, the fact that teenagers' ability to control their impulses is immature at the same time that their interest in sensation seeking is stronger than ever makes them vulnerable to making mistakes. Early adolescence is like starting a car without having a skilled driver behind the wheel.

What This Means for Adolescent Behavior

Although scientists agree about the ways in which the structure and function of the brain change during adolescence, the implications of these changes for adolescent development are still the subject of a great deal of ongoing research and considerable speculation. I'm often asked when adolescents begin to think like adults. This is hard to answer on the basis of brain science alone because it depends on which aspects of thinking you're concerned about.

Both Mature and Immature

Psychologists draw a distinction between "cold" cognition (when we think about something that doesn't have much emotional content, like how to solve an algebra problem) and "hot" cognition (when we think about something that can make us feel exuberant or excited, angry or depressed, like whether to go joyriding with friends or throw a punch at someone who insulted a girlfriend). The systems of the brain responsible for cold cognition are mature by the time most individuals are 16. But the systems that control hot cognition aren't—they're still developing well into the 20s. That's why

teenagers who get straight As in algebra can also do really dumb things when out with their buddies.

Teachers sometimes are surprised by the inconsistency in students' behavior, especially during the middle school years. Understanding the nature of brain development in adolescence helps explain why adolescents can vacillate so often between mature and immature behavior. When it comes to more basic abilities, such as those involving memory, attention, and logical reasoning, especially under optimal condi-

Just as pruning a rose bush produces a healthier plant, so synaptic pruning enhances the brain's functioning.

tions, the average 15-year-old is just as mature as the average adult. But research on brain maturation indicates that relatively more sophisticated cognitive abilities, such as thinking ahead, envisioning the consequences of a decision, balancing risks and rewards, or controlling impulses, are still developing at that age.

The Need to Practice Autonomy

It's important to keep in mind that the brain is very malleable, or "plastic," and that its development is affected by experience as well as biology. Both synaptic pruning and myelination are influenced by experience, such that repeated activation of a specific collection of neurons as a result of engaging in a particular behavior will actually strengthen the connections among those neurons, which, in turn, will make them function more efficiently. This is one reason that practicing the same task over and over again makes that task easier to perform each time.

Although research on brain plasticity during adolescence is just in its infancy, many scientists believe that

the maturation of the brain systems responsible for thinking ahead and controlling impulses is influenced by the sorts of experiences young people have, including their experiences in the classroom. Given the well-documented finding that practicing something will strengthen the brain circuits that control that behavior, it's important that, as educators, we provide adolescents with opportunities to practice things like planning, anticipating the consequences of a decision, and regulating their own behavior. Although it can

be frustrating to teachers and parents when young adolescents push for more autonomy, we need to respond by gradually granting them more control. Assignments that require teenagers to think ahead, make a plan, and carry it out may stimulate the maturation of brain systems that enable more mature self-regulation.

Initially, adolescents who haven't been given many opportunities to develop these capabilities may not always succeed. But be patient. Over time, with practice, as synapses are pruned and neural circuits myelinated, adolescents' ability to exercise mature control over their own behavior will improve. ¹

¹ Steinberg, L., Vandell, D., & Bornstein, M. (2011). *Development: Infancy through adolescence*. Belmont, CA: Wadsworth.

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