

THE TEENAGE BRAIN

A Neuroscientist's Survival
Guide to Raising Adolescents
and Young Adults

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An Imprint of HarperCollinsPublishers

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Building a Brain

The human body is amazing, the way it neatly tucks all these complex organs into this finite space and connects them into one smoothly functioning system. Even the average human brain is said by many scientists to be the most complex object in the universe. A baby brain is not just a small adult brain, and brain growth, unlike the growth of most other organs in the body, is not simply a process of getting larger. The brain changes as it grows, going through special stages that take advantage of the childhood years and the protection of the family, then, toward the end of the teen years, the surge toward independence. Childhood and teen brains are “impressionable,” and for good reason, too. Just as baby chicks can imprint on the mother hen, human children and teens can “imprint” on experiences they have, and these can influence what they choose to do as adults.

Such was the case with me. I “imprinted” on neuroscience and medicine pretty early on. My experiences cultivated in me a curiosity that I found irresistible, sustaining me from my high school years

through medical school and graduate research, and to this very day. I grew up the oldest of three children in a comfortable family home in Connecticut, just forty minutes from Manhattan. I happened to live in Greenwich, which even back then was the home of actors, authors, musicians, politicians, bankers, and the independently wealthy. The actress Glenn Close was born there, President George H. W. Bush grew up there, and the great bandleader Tommy Dorsey died there.

My parents were from England; they had immigrated after World War II, and my dad came over after medical school in London to do his urological surgery residency at Columbia. To them, Greenwich seemed a great place to settle within commuting distance of New York City. It was a matter of convenience, and they were pretty oblivious to the celebrity status of the town. Perhaps because of my father, I was open-minded about learning math and science. For me a major “imprinting” moment that propelled me in the direction of medicine was a ninth-grade biology class at Greenwich Academy. The best part to me, memorable in fact, was when we each got a fetal pig to dissect. While many of my classmates slumped in their seats at the proposition of slicing up these small mammals, some rushing to the girls’ washrooms with waves of nausea, a few of us jumped into the task at hand. It was one of those defining moments. The scientists had separated from those destined to be the writers, lawyers, and business-people of the future.

Injected with latex, the pigs’ veins and arteries visibly popped out with their colorful hues of blue and red. I’m a very visual person; I also like thinking in three dimensions. That visual-spatial ability comes in handy with neurology and neuroscience. The brain is a three-dimensional structure with connections between brain areas going in every direction. It helps to be able to mentally map these

connections when one is trying to determine where a stroke or brain injury is located in a patient presenting with a combination of neurological problems—definitely a plus for a neurologist. Actually, that’s how the minds of most neurologists and neuroscientists work. We’re a breed that tends to love to look for patterns in things. I’ve never met a jigsaw puzzle, in fact, that I didn’t like. My attraction to neuroscience in high school and college began at a time before CT scans and MRIs, when a doctor had to imagine where the problem was inside the brain of a patient by picturing the organ three-dimensionally. I’m good at that. I like being a neurological detective, and as far as I’m concerned, neuroscience and neurology turned out to be the perfect profession for me to make use of those visuospatial skills.

If the human brain is very much a puzzle, then the teenage brain is a puzzle awaiting completion. Being able to see where those brain pieces fit is part of my job as a neurologist, and I decided to apply this to a better understanding of the teen brain. That’s also why I’m writing this book: to help you understand not only what the teen brain is but also what it is not, and what it is still in the process of becoming. Among all the organs of the human body, the brain is the most incomplete structure at birth, just about 40 percent the size it will be in adulthood. Size is not the only thing that changes; all the internal wiring changes during development. Brain growth, it turns out, takes a lot of time.

And yet the brain of an adolescent is nothing short of a paradox. It has an overabundance of gray matter (the neurons that form the basic building blocks of the brain) and an undersupply of white matter (the connective wiring that helps information flow efficiently from one part of the brain to the other)—which is why the teenage brain is almost like a brand-new Ferrari: it’s primed and pumped, but

it hasn’t been road tested yet. In other words, it’s all revved up but doesn’t quite know where to go. This paradox has led to a kind of cultural mixed message. We assume when someone looks like an adult that he or she must be one mentally as well. Adolescent boys shave and teenage girls can get pregnant, and yet neurologically neither one has a brain ready for prime time: the adult world.

The brain was essentially built by nature from the ground up: from the cellar to the attic, from back to front. Remarkably, the brain also wires itself starting in the back with the structures that mediate our interaction with the environment and regulate our sensory processes—vision, hearing, balance, touch, and sense of space. These mediating brain structures include the cerebellum, which aids balance and coordination; the thalamus, which is the relay station for sensory signals; and the hypothalamus, a central command center for the maintenance of body functions, including hunger, thirst, sex, and aggression.

I have to admit that the brain is not very exciting to look at. Sitting atop the spinal cord, it is light gray in color (hence the term “gray matter”) and has a consistency somewhere between overcooked pasta and Jell-O. At three pounds, this wet, wrinkled tissue is about the size of two fists held next to each other and weighs no more than a large acorn squash. The “gray matter” houses most of the principal brain cells, called neurons: these are the cells responsible for thought, perception, motion, and control of bodily functions. These cells also need to connect to one another, as well as to the spinal cord, for the brain to control our bodies, behavior, thoughts, and emotions. Neurons send most of their connections to other neurons through the “white matter” in the brain. The commonly used brain imaging tool, magnetic resonance imaging, or MRI, shows the distinction between

gray and white matter beautifully. On the outside surface, the brain has a rippled structure. The valleys or creases are referred to as sulci and the hills are referred to as gyri. Figure 1 shows an image from a brain's MRI scan, like those done on patients. There are two sides to the brain, each called a hemisphere. (When an MRI image shows a cut across the middle in one direction or the other [slice angles A and B], it is easier to see the two sides.) The most superficial layer of the brain is called the cortex and it is made up of the gray matter closest to the surface, with the white matter located beneath it. The gray matter is where most of the brain cells (neurons) are located. The neurons connect directly to those close by, but in order to connect to neurons in other parts of the brain, in the other hemisphere, or in the spinal cord to activate muscles and nerves in our face or body, the neurons send processes down through the white matter. The white matter is called "white" because in real life and also in the MRI scans its color is light, owing to the fact that the neuron processes running through here are coated with a fatty insulator-like substance called myelin, which truly is white in color.

As I said before, sheer size—or even weight, for that matter—doesn't mean everything. A whale brain weighs about twenty-two pounds; an elephant brain about eleven. If intellect were determined by the ratio of brain weight to body weight, we'd be losers. Dwarf monkeys have one gram of brain matter for every twenty-seven grams of body matter, and yet the ratio for humans is one gram of brain weight to forty-four grams of body weight. So we actually have less brain per gram of body weight than some of our primate cousins. It is the complexity of the way neurons are hooked up to one another that matters. Another example of how little the weight of the brain has to do with its functioning, at least in terms of intelligence, is that the

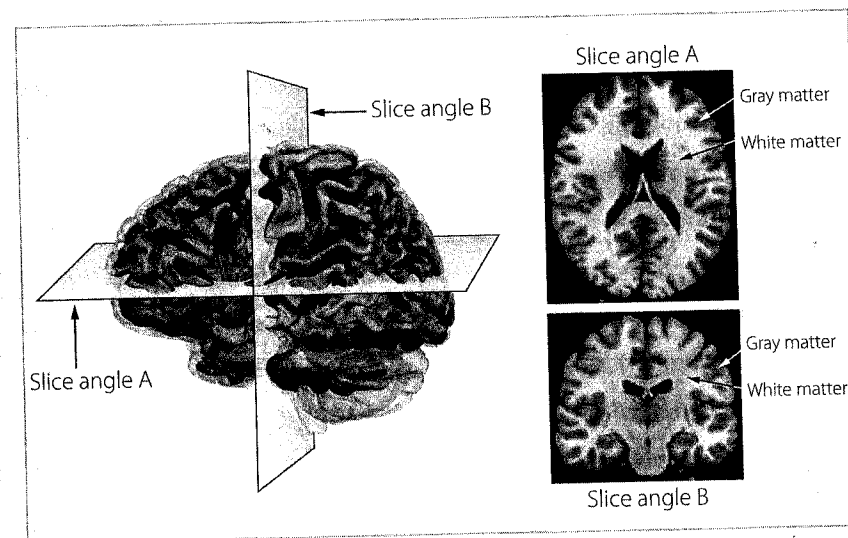


FIGURE 1. The Basics of Brain Structure: A magnetic resonance imaging (MRI) scan of a brain. The horizontal and vertical cross sections (slice angles A and B) show the cortex (gray matter) on the surface and the white matter underneath.

human female brain is physically smaller in size than the male brain but IQ ranges are the same for the two sexes. At only 2.71 pounds, the brain of Albert Einstein, indisputably one of the greatest thinkers of the twentieth century, was slightly underweight. But recent studies also show that Einstein had more connections per gram of brain matter than the average person.

The size of the human brain *does* have a lot to do with the size of the human skull. Basically, the brain has to fit inside the skull. As a neurologist, you have to measure the size of children's heads as they grow up. I have to admit there were occasions when I did this with my own sons—just like noting changes in their height—to make sure they were on track and in the normal range for skull size. When they were older, they thought I was nuts, of course, but when they were babies and toddlers, I just couldn't resist coming at them with a tape

measure I'd take from my sewing kit, then trying to get them to stop squiggling free so I could take just one more measurement. The truth is, skull size doesn't tell us a lot. It's a gross measurement, and the skull can be large or small for a variety of reasons. There are disorders in which the head is too big and disorders in which the head is too small. The most important characteristic of the skull is that it limits the size of the brain. Eight of the twenty-two bones in the human skull are cranial, and their chief job is to protect the brain. At birth, these cranial bones are only loosely held together with connective tissue so that the head can compress a bit as the baby moves through the birth canal. The skull bones are loosely attached and have spaces between them: one of these is the "soft spot" all babies have at birth, which closes during the first year of life as the bones fuse together. Most growth in head size occurs from birth to seven years, with the largest increase in cranial size occurring during the first year of life because of massive early brain development.

So with a fixed skull size, human evolution did its best to jam as much brain matter inside as possible. *Homo erectus*, from whom the modern human species evolved, appeared about two million years ago. Its brain size was only about 800 to 900 cubic centimeters, as opposed to the approximately 1,500 cubic centimeters of today's *Homo sapiens*. With modern human brains nearly double the size of these ancestors', the skull had to grow as well and, in turn, the female pelvis had to widen to accommodate the larger head. Evolution accomplished all of this within just two million years. Perhaps that's why the brain's design, while extraordinarily ingenious, also gives a bit of the impression that it was updated on the fly. How else to explain the cramped conditions? Like too many clothes crammed in too small a closet, the evolution-sculpted brain looks like a ribbon repeat-

edly folded and pressed together. These folds, with their ridges (gyri) and valleys (sulci), as seen in Figure 1, give the human brain an irregular surface appearance, the result of all that tight packing inside the skull. Not surprisingly, humans have the most complex brain folding structure of all species. As you move down the phylogenetic scale to simpler mammals, the folds begin to disappear. Cats and dogs have some, but not nearly as many as humans do, and rats and mice have virtually none. The smoother the surface, the simpler the brain.

While the brain looks fairly symmetrical from the outside, inside there are important side-to-side differences. No one is really sure why, but the right side of your brain controls the left side of your body and vice versa; this means that the right cortex governs the movements of your left eye, left arm, and left leg and the left cortex governs the movements of your right eye, right arm, and right leg. For vision, the input from the left side of the visual field goes through the right thalamus to the right occipital cortex, and information from the right visual field goes to the left. In general, visual and spatial perception is thought to be more on the right side of the brain.

The image of the body, in fact, can actually be "mapped" onto the surface of the brain, and this map has been termed the "homunculus" (Latin for "little man"). In the motor and sensory cortex, the different areas of the body get more or less real estate depending upon their functional importance. The face, lips, tongue, and fingertips get the largest amount of space, as the sensation and control necessary for these areas have to be more accurate than for other areas such as the middle of the back.

An early-twentieth-century Canadian neuroscientist, Wilder Penfield, was the first to describe the cortical map, or homunculus, which he did after doing surgery to remove parts of the brain that

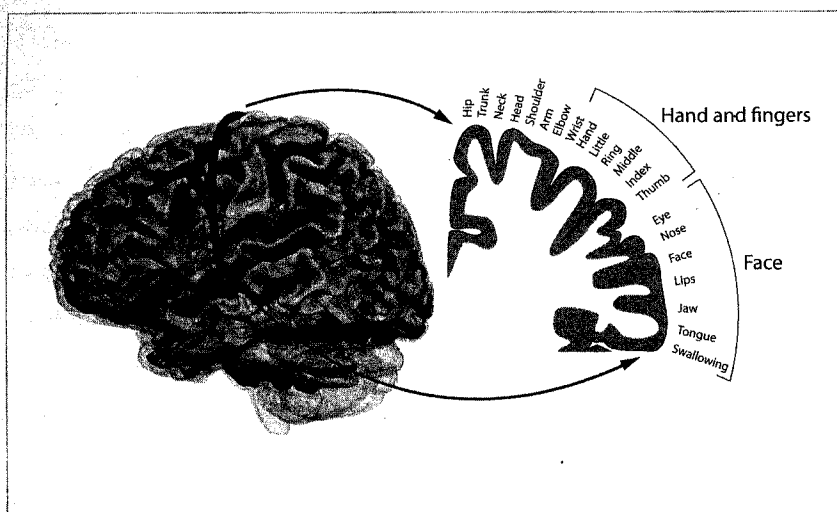


FIGURE 2. The “Homunculus”: A “map” of the brain illustrating the regions that control the different body parts.

caused epileptic seizures. He would stimulate areas of the surface to determine which parts would be safe to remove. Stimulating one area would cause a limb or facial part, for instance, to twitch, and having done this on many patients he was able to create a standard map.

The amount of brain area devoted to a given body part varies depending on how complicated its function is. For instance, the area given to hands and fingers, lips and mouth, is about ten times larger than that for the whole surface of the back. (But then, what do you do with your back anyway—except bend it?) This way all the brain regions for the same part of the body end up in close proximity to one another.

My undergraduate thesis at Smith College in Northampton, Massachusetts, examined several of those areas of the brain given over to individual body parts and whether overstimulation of one of the body’s limbs might result in more brain area devoted to that part.

This was actually an early experiment in brain plasticity, to see if the brain changed in response to outward stimulation. Many impressive studies that have been done since the late 1970s back up the whole concept of imprinting. Some of the most famous work, which inspired me to do my little undergraduate thesis, was done by a pair of Harvard scientists named David Hubel and Torsten Wiesel. The term that started to be used was “plasticity,” meaning that the brain could be changed by experience—it was moldable, like plastic. Hubel and Wiesel showed that if baby kittens were reared with a patch on one eye during the equivalent of their childhood years (they looked sort of like pirate kittens!), for the rest of their lives they were unable to see out of the eye that had been patched. The scientists also saw that the brain area devoted to the patched eye had been partially taken over by the open eye’s connections. They did another set of experiments where the kittens were raised in visual environments with vertical lines and found that their brains would respond only to vertical lines when they were adults. The point is that the types of cues and stimuli that are present during brain development really change the way the brain works later in life. So my experiment in college showed basically the same thing, not for vision, but rather for touch.

I actually had some fun showing off this cool imprinting effect in our everyday lives. Our beloved cat had died at the ripe old age of nineteen, and we all missed her so. Of course, it didn’t take long before Andrew, Will, and I were at the local animal shelter, looking at kittens to bring home. We fell in love with the runt of a litter and brought home the most petite and needy little tabby kitten you could ever imagine. The boys came up with a name: Jill. Jill was always on our laps; she was a very people-friendly cat. I remembered the experiments on brain plasticity and said to Andrew and Will, when we

hold her, let's massage her paws and see if she becomes a more coordinated cat. So anytime we had her in our laps, we would massage her paws with our hands, spreading them out, touching the little "fingers" that cats' paws contain. Sure enough, Jill started to use her paws much more than any other cat we had ever had (and I have had back-to-back cats since the age of eight). She used her paws for things most cats don't. She was very "paw-centric," going around the house batting small objects off tables and taking obvious pleasure in watching them hit the ground. This was a source of consternation as not all the things she knocked off were unbreakable. She also often used her left paw to eat, gingerly reaching into the cat food can with her paw and scooping up food to bring to her mouth. Watching her, we started to notice that she almost always used her left paw to do these things. We had a left-pawed cat! Then suddenly we realized that when we picked her up to massage her paws, she was facing us and because we are all right-handed, we were always stimulating her left paw much more than her right! Home neuronal plasticity demonstration project accomplished. I know if we could have looked into her brain, we'd have seen that she had more brain space given over to her paws, and especially her left paw, than the average cat. This same phenomenon of reallocating brain space based on experience during life happens in people, too. We call this part of life the critical period, when "nurture," that is, the environment, can modify "nature." But more on that later.

So what I have just told you is that brain areas for vision and body parts are compartmentalized in different places, but that they can shrink or grow relative to one another during development based on how much the senses are used. Structurally, the human brain is divided into four lobes: frontal (top front), parietal (top back), temporal

(sides), and occipital (back). The brain sits on the brainstem, which connects to the spinal cord. In the rear of the brain, the cerebellum regulates motor patterning and coordination, and the occipital lobes house the visual cortex. The parietal lobes house association areas as well as the motor and sensory cortices (which include the homunculus in Figure 2). The temporal lobes include areas involved in the regulation of emotions and sexuality. Language is also located here, more specifically in the dominant hemisphere (the left temporal lobe for right-handed people and 85 percent of left-handed people, and the right temporal lobe for that small group of truly strong lefties). The frontal lobes sit most anteriorly and this area is concerned with executive function, judgment, insight, and impulse control. Importantly,

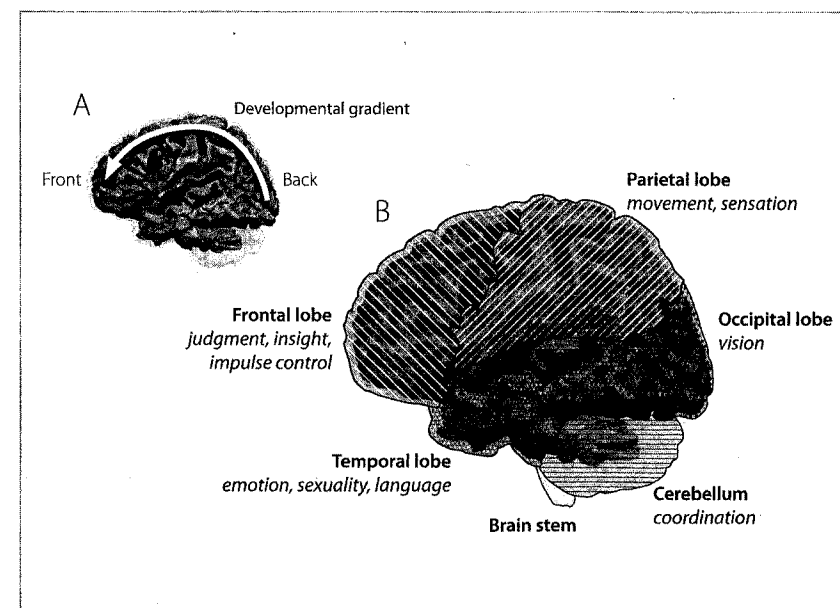


FIGURE 3. The Lobes of the Brain: A. The brain matures from the back to the front. B. The cortex of the brain can be divided into several main areas based on function.

as the brain matures from back to front in the teen years the frontal lobes are the least mature and the least connected compared with the other lobes.

The brain is divided into specialized regions for each of the senses. The area for hearing, or the auditory cortex, is in the temporal lobes; the visual cortex is in the occipital lobes; and the parietal lobes house movement and feeling in the motor and sensory cortices, respectively. Other parts of the brain have nothing to do with the senses, and the best example of this is the frontal lobes, which make up more than 40 percent of the human brain's total volume—more than in any other animal species. The frontal lobes are the seat of our ability to generate insight, judgment, abstraction, and planning. They are the source of self-awareness and our ability to assess dangers and risk, so we use this area of the brain to choose a course of action wisely.

Hence, the frontal lobes are often said to house the “executive” function of the human brain. A chimpanzee's frontal lobes come closest to the human's in terms of size, but still make up only around 17 percent of its total brain volume. A dog's frontal lobes make up just 7 percent of its brain. For other species, different brain structures are more important. Compared with humans, monkeys and chimpanzees have a much larger cerebellum, where control of physical coordination is honed. A dolphin's auditory cortex is more advanced than a human's, with a hearing range at least seven times that of a young adult. A dog has a billion olfactory cells in its brain compared with our measly twelve million. And the shark has special cells in its brain that help it detect electrical fields—not to navigate but to pick up electrical signals given off by the scantest of muscle movements in other fish as they try to hide from this deadly predator.

We humans don't have a lot else going for us other than our wile

and wit. Our competitive edge is our ingenuity, brains over brawn. This edge happens to take the longest time to develop, as the connectivity to and from the frontal lobes is the most complex and is the last to fully mature. This “executive function” thus develops slowly: we certainly are not born with it!

So in what order are these brain regions all connected to one another during childhood and adolescence? This could never have been learned before the advent of modern brain imaging. New forms of brain scans, called magnetic resonance imaging (MRI), not only can give us accurate pictures of the brain inside the skull but also can show us connections between different regions. Even better, a new kind of MRI, called the functional MRI, abbreviated fMRI, can actually show us what brain areas turn one another on. So we can actually see if areas that “fire” together are “wired” together. In the last decade, the National Institutes of Health conducted a major study to examine how brain regions activate one another over the first twenty-one years of life.

What they found was remarkable: the connectivity of the brain slowly moves from the back of the brain to the front. The very last places to “connect” are the frontal lobes (Figure 4). In fact, the teen brain is only about 80 percent of the way to maturity. That 20 percent gap, where the wiring is thinnest, is crucial and goes a long way toward explaining why teenagers behave in such puzzling ways—their mood swings, irritability, impulsiveness, and explosiveness; their inability to focus, to follow through, and to connect with adults; and their temptations to use drugs and alcohol and to engage in other risky behavior. When we think of ourselves as civilized, intelligent adults, we really have the frontal and prefrontal parts of the cortex to thank.

Because teens are not quite firing on all cylinders when it comes to

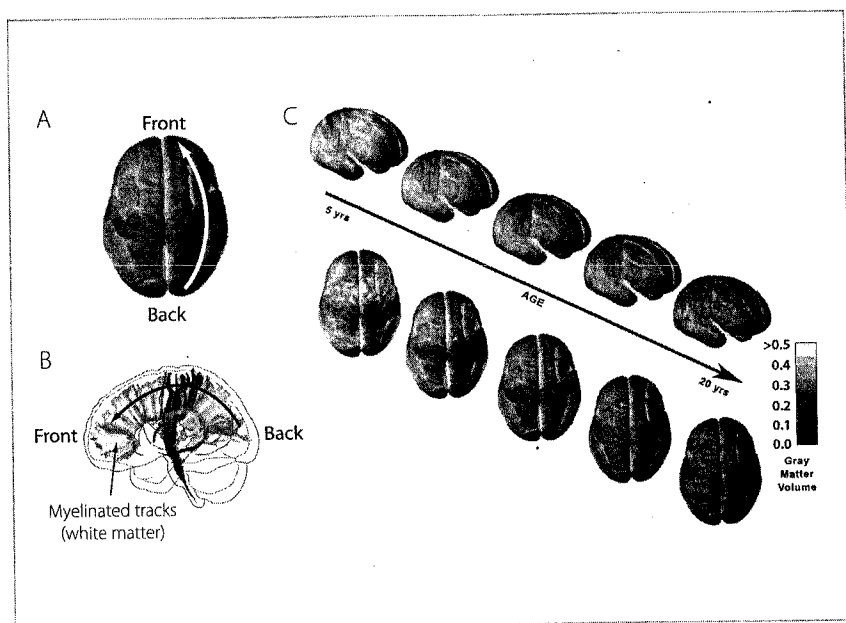


FIGURE 4. Maturing Brain: The Brain “Connects” from Back to Front: A. A functional MRI (fMRI) scan can map connectivity in the brain. Darker areas indicate greater connectivity. B. Myelination of white matter tracks cortex maturation from back to front; this is why the frontal lobes are the last to be connected. C. Serial connectivity scans reveal that frontal lobe connectivity is delayed until age twenty or older.

the frontal lobes, we shouldn't be surprised by the daily stories we hear and read about tragic mistakes and accidents involving adolescents. The process is not really done by the end of the teen years—and as a result the college years are still a vulnerable period. Recently a friend of mine told me about his son's college classmate, Dan, an all-around great kid who'd rarely caused his parents to worry. He was popular, had been a star ice hockey player in high school, and was a finance major in college. Over the summer my friend's son got a phone call from Dan's mother. Dan had drowned the night before, she told him. He'd been out with friends, drinking, and sometime

between three and four in the morning, on their way home, the group—there were eight of them—decided they wanted to cool off, so they stopped at the local tennis club. The club was closed, of course, but the locked gate didn't stop them. All eight scaled the fence and jumped into the pool. It was only after they'd gotten home that someone said, “Where's Dan?” Racing back to the club, they found their friend facedown in the water. The medical examiner listed the cause of death as accidental drowning due to “acute alcohol intoxication.” One of the news reports I read made me shake my head: “Police are asking kids and adults to think twice about potential dangers before taking any risks that could turn deadly.”

“Think twice.”

How many times have we all said this to our teenage sons and daughters? Too many times. Still, as soon as I heard about Dan, I called my boys to tell them the story. You have to remember this, I told them. This is what happens. Drinking and swimming don't go together. Neither does the decision to suddenly scale a fence in the middle of the night, or jump into a pool with seven friends who are also intoxicated.

How parents deal with these tragic stories and talk about them with their own kids is critical. It shouldn't be, “Oh, wow, I'm so glad that wasn't my child.” Or, “My teenager would never have done that.” Because you don't know. Instead, you have to be proactive. You have to stuff their minds with real stories, real consequences, and then you have to do it again—over dinner, after soccer practice, before music lessons, and, yes, even when they complain they've heard it all before. You have to remind them: These things can happen anytime, and there are many different situations that can get them into trouble and that can end badly.

One of the reasons that repetition is so important lies in your teenager's brain development. One of the frontal lobes' executive functions includes something called prospective memory, which is the ability to hold in your mind the intention to perform a certain action at a future time—for instance, remembering to return a phone call when you get home from work. Researchers have found not only that prospective memory is very much associated with the frontal lobes but also that it continues to develop and become more efficient specifically between the ages of six and ten, and then again in the twenties. Between the ages of ten and fourteen, however, studies reveal no significant improvement. It's as if that part of the brain—the ability to remember to do something—is simply not keeping up with the rest of a teenager's growth and development.

The parietal lobes, located just behind the frontal lobes, contain association areas and are crucial to being able to switch between tasks, something that also matures late in the adolescent brain. Switching between tasks is nearly a constant need in today's world of information overload, especially when you consider the fact that multitasking—doing two cognitively complex things at the same time—is actually a myth. Chewing gum and doing virtually anything else is not multitasking because chewing gum involves no real cognitive focus. Both talking on a cell phone and driving, however, do involve cognitive focus. Because there are limits to how many things the human brain can focus on at any one time, when someone is engaged in multiple cognitively significant activities, like talking and driving, the brain must constantly switch back and forth between the two tasks. And when it does, neither of those tasks is being accomplished particularly well.

The parietal lobes help the frontal lobes to focus, but there are

limits. The human brain is so good at this juggling that it seems as though we are doing two tasks at the same time, but really we're not. Scientists at the Swedish medical university Karolinska Institutet measured those limits in 2009 when they used fMRI images of people multitasking to model what happens in the brain when we try to do more than one thing at a time. They found that a person's working memory is capable of retaining only between two and seven different images at any one time; this means that focusing on more than one complex task is virtually impossible. Focusing chiefly happens in the parietal lobes, which dampen extraneous activity to allow the brain to concentrate on one thing and then another.

The problem of having immature parietal lobes was illustrated in a segment on *Good Morning America* in May 2008 by the ABC TV correspondent David Kerley and his teenage daughter Devan. Using a course set up by Allstate Insurance, and with her father in the passenger seat, Devan, who had been driving for a year, was instructed about speed, braking, and turning and allowed to take a practice run through the course. Then she was given a series of three “distractions” to handle while navigating the course's twists and turns. First, she was handed a BlackBerry and told to read the text on the screen while driving. She hit several cones. Next, three of her friends were put in the backseat and a lively conversation ensued. Devan hit more cones. Finally, Devan was handed a package of cookies and a bottle of water, and just passing the cookies around and holding the bottle of water caused her to run over several more cones. Multitasking is not only a myth but a dangerous one, especially when it comes to the teenage brain.

“Multitasking” has become a household word. The research in Sweden suggests that there are limits. Teenagers and young adults

pride themselves on their ability to multitask. Have today's teens and young adults imprinted on a multitasking world? Maybe. In studying how young adults these days handle distractions, researchers at the University of Minnesota have shown that the ability to successfully switch attention among multiple tasks is still developing through the teenage years. So it may not come as a surprise to learn that of the nearly six thousand adolescents who die every year in automobile accidents, 87 percent die because of distracted driving.

The question of whether today's teens and young adults have a special skill set for learning while distracted was more formally tested in 2006 by researchers at the University of Missouri. They took twenty-eight undergraduates, including kids in their late teens, and asked them to memorize lists of words and then recall these words at a later time. To test whether distraction affected their ability to memorize, the researchers asked the students to perform a concurrent task—placing a series of letters in order based on their color by pressing the keys on a computer keyboard. This task was given under two conditions: when the students were memorizing the lists of words and when the students were recalling those lists for the researchers. The Missouri scientists discovered that simultaneous tasks affected both encoding (memorizing) and retrieving (recalling). When the keyboard task was given while the students were trying to recall the previously memorized words (which is akin to taking a test or exam), there was a 9 to 26 percent decline in their ability to memorize the words. The decline was even more if the concurrent distracting task occurred while they were memorizing, in which case their performance decreased by a whopping 46 to 59 percent.

These results certainly have implications for the teen bedroom during a homework night! I not-so-fondly remember walking in on

my sons during evening homework time to find them with the television on, headphones attached to iPods, all the while messaging someone on the lower corner of their computer screens and texting someone else on their iPhones. It wasn't a problem, they protested, when I suggested they concentrate on their homework, assuring me their course reviews for the next day's exams were totally unaffected by the thirty-two other things they were doing at the same time. I didn't buy it. So I buttressed my argument with the Missouri data. I put Figure 5 in this book in case you want to use it to make the same point to your teen.

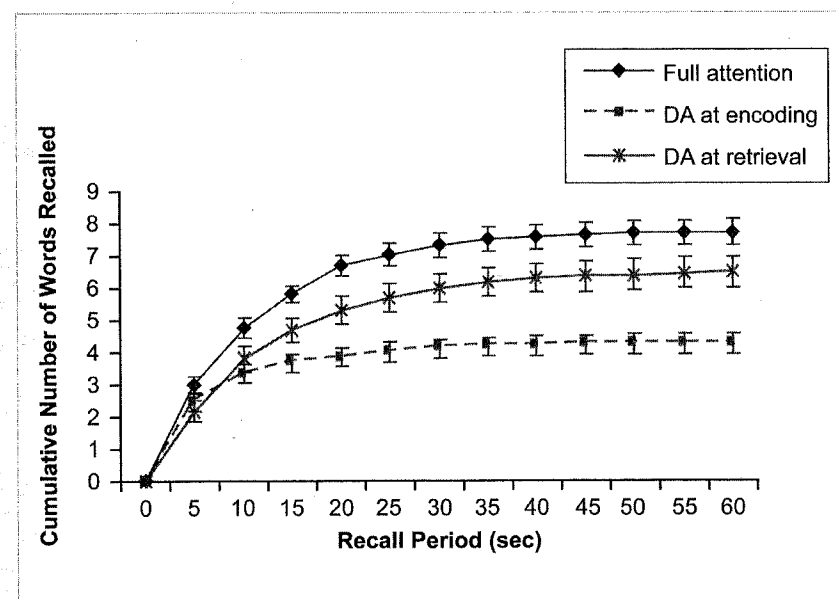


FIGURE 5. Multitasking Is Still Not Perfect in the Teen Brain: College students were tested under three conditions: No Distraction (full attention), Distracted Attention (DA) when memorizing (DA at encoding), and Distracted Attention when recalling (DA at retrieval). Students performed poorly when multitasking during recall, and even worse when they multitasked while memorizing.

Attention is only one way we can assess how the brain is working. There's a lot more under the hood of the brain than just the four lobes, so returning to Figure 3 let's start at the back, where we find the brainstem at the very bottom of the brain, attached to the spinal cord. The brainstem controls many of our most critical biological functions, like breathing, heart rate, blood pressure, and bladder and bowel movements. The brainstem is on "automatic"—you are not even aware of what it does, and you normally don't voluntarily control what it does. The brainstem and spinal cord are connected to the higher parts of the brain through way station areas, like the thalamus, which sits right under the cortex. Information from all the senses flows through the thalamus to the cortex. Right below the cortex are structures called the basal ganglia, which play a big role in making coordinated and patterned movements. The basal ganglia are directly affected by Parkinson's disease and account for the trembling and the appearance of being frozen, or unable to move, which are the hallmark symptoms of Parkinson's patients.

As we move closer to the cortex, we encounter structures that together make up what is called the limbic system. The limbic system gets involved in memories and also emotions. A part of the brain we will talk about a lot in this book is the hippocampus. The hippocampus is a little seahorse-shaped structure underneath the temporal lobe. In fact the name "hippocampus" comes from the Latin word for "horse" because of the shape. The hippocampus is truly the brain's "workhorse" for memory processing—it is used for encoding and retrieving memories.

So what do we know about our memory workhorse? It has the highest density of excitatory synapses in the brain. It is a virtual beehive of activity, and turns on with every experience. As we will ex-

plain later, the hippocampus in the adolescent brain is relatively "supercharged" compared with an adult's.

The connection of the hippocampus to memory was recognized some six decades ago through the unforeseen consequences of one patient's radical brain surgery. This surgery was performed in 1953 on a twenty-seven-year-old Connecticut man who, until his death several years ago, was known only by his initials, H.M. He underwent an experimental operation in an attempt to cure him of frequent and severe epileptic seizures. So incapacitating was H.M.'s epilepsy that he was unable to hold down even a factory job. When the Yale neurosurgeon William Beecher Scoville removed most of H.M.'s medial temporal lobe, which was causing his seizures, the operation appeared to be a success. By cutting away brain tissue in the area of the seizures, Scoville dramatically reduced their frequency and severity. In the process, though, he also removed a large portion of H.M.'s hippocampus. (That the hippocampus is critical for memory formation was unknown at the time; the case of H.M. shed much light on the subject.) What became clear when H.M. awoke was that while his seizures were by and large gone, so, too, was his ability to turn short-term memories into long-term memories. Essentially, H.M. could remember his past—everything before the time of the operation—but for the rest of his life he had no short-term memory and could not remember what happened to him, what he said or did or thought or felt or whom he met, in the decades following the surgery. H.M.'s loss, as often happens in the history of science, was neuroscience's gain. For the first time researchers could point to a specific brain region (the temporal lobe) and brain structure (the hippocampus) as the seat of human memory.

Next door to the hippocampus, in another part of the limbic

system under the temporal lobe, is another key brain structure, the amygdala, which is involved in sexual and emotional behavior. It is very susceptible to hormones, such as sex hormones and adrenaline. It is sort of the seat of anger, and when stimulated in animal experiments, it has been shown to produce rage-like behavior. The limbic system can be thought of as a kind of crossroads of the brain, where emotions and experiences are integrated.

A slightly unbridled and overexuberant immature amygdala is thought to contribute to adolescent explosiveness; this explains in part the hysteria that greets parents when they say no to whatever it is their adolescent thinks is a perfectly reasonable request. Cross that immature amygdala with a teen's loosely connected frontal lobe, and you have a recipe for potential disaster. For example, the sixteen-year-old patient of a colleague of mine was so incensed when his parents said driving was a "privilege" (for which he did not yet qualify), and not a "right," that he stole the car keys and drove away from the house. He didn't get very far, though. He forgot the garage door was closed and plowed right through it. One of my colleagues also told me that, because he himself had three grown daughters, rather than sons, he had few "terrible teen tales" to tell. Then he reconsidered: "Oh, yes, there was the weekend we were away and the 'couple of friends' became a party that got out of hand, including the raid on our wine cellar, a minor fender bender with our stolen liquor in the trunk, and maybe a navel ring (which I never knew about until years later after it disappeared). But all's well that ends well."

3

Under the Microscope

If you pick out any random region of brain and look at it under a microscope, you'll find it jam-packed with cells. In fact, there is almost no space between the billions of cells in the brain. Evolution made sure of that, putting to use every cubic micron wisely. A cell is the body's smallest unitary building block, and each has its own command center, called a nucleus, a large oval body near the center of the cell. There are more than two hundred different types of cells making up every organ, tissue, muscle, etc. A unique cell type in the brain is the neuron. This is a cell we will talk about frequently in this book. Thoughts, feelings, movements, and moods are nothing more than neurons communicating by sending electrical messages to one another.

I remember my first time looking at brain cells under a microscope. In the mid- to late 1970s the only way to study changes in neurons, for instance the changes that occur during learning, was by looking through a microscope at individual cells over a given period of time. Today, we have amazing tools—brain imaging scans and spe-

drunk when he arrived and that she had walked him part of the way home. Not until 5:00 a.m. did she admit the truth, that there had been more than a dozen people at the house, many of them drinking alcohol, all underage, and that she tried to clear them out around 11:30 before her parents returned home. Two girls said they were going to walk Bennett up the street, "but when they went outside with him and he was too drunk," they took him back inside and left him alone while they helped their friend clean up. That was the last time they saw Bennett.

Teen consumption of alcohol was only half the problem. The other half was the poor decision-making on the part of Bennett and his friends at the party, the lying that led to a delay before the police found Bennett, and even his panic at the thought of being caught by the police. All the teenagers involved exhibited a stunning lack of insight.

What scientists tell us is that insight depends on the ability to look outside oneself, and because that skill arises in the frontal and prefrontal lobes, it takes time to develop. The dynamic changes taking place in the brain are part of what make the adolescent years an age of exuberance. But a malleable, still-maturing teenage brain can be a scary proposition. Anything can happen—much of it not good. Teenagers may look like adults, they may even think like adults in many ways, and their ability to learn is staggering, but knowing what teenagers are unable to do—what their cognitive, emotional, and behavioral limitations are—is critically important.

4

Learning

A Job for the Teen Brain

What did I do wrong?"

Often that's the second question I get from parents of teenagers. The first question is usually rhetorical:

"How could my [son/daughter] [fill in the blank]?"

Most of the parents who come up to me after a talk, or e-mail me or stop me at the grocery store, are exhausted or exasperated or both, and all of them could fill in the blank in that question with a whole host of perplexing actions, from "Why would my teenage daughter sneak out of the house in the middle of the night to be with her boyfriend after they just spent the whole weekend together?" to "How could my son raid the liquor cabinet of his friend's parents—and then leave the empty bottles behind to boot?!"

A neighbor of mine with a sixteen-year-old was flummoxed when she caught her son smoking pot in his room when he was supposed to be studying. That was bad enough, she told me, but what astonished her even more was the fact that he had the window wide open (it was the middle of winter, mind you) in order to air out his room—and

the wind was blowing the smoke back *into* the room, under the door and down the stairs, where it wafted toward my horrified friend in the kitchen!

"How could he be that stupid?" she asked me.

Parents quickly blame themselves for a teen's poor behavior, even though they're not exactly sure how or why they're to blame. With biological parents, the guilt may come from passing on flawed DNA; and with biological and nonbiological parents or guardians, the guilt comes from questioning how they raised the child. In either case, you, the parent, are to blame, right? Yes, the two scenarios are different, but no, it's not because of the genes or anything you did or didn't do or because the teenager was somehow struck on the head and woke up as an alien species from the planet Adolescent.

Teenagers are different because of their brains and specifically because of two unusual aspects of their brains at this stage of their development. Their brains are both more powerful and more vulnerable than at virtually any other time in their lives. Even as they are learning things faster, their brains are eliminating gray matter and shedding neurons. How both of these facts can be true is because of something called neural plasticity.

Even as a teenager I used to wonder about the brain. Did it make a difference where a person grew up? How he or she grew up? Was the brain at all like the rest of the body—capable of changing depending on what went into it or what it was exposed to? I enjoyed turning these questions over in my head, and when I got to college they turned up again, only this time I began to have inklings of some of the answers.

During one summer while I was still in high school I volunteered at the Greenwich chapter of the Association for Retarded Citizens

(ARC), now known simply as the Arc, which aids people with intellectual and developmental disabilities. Some of those who regularly attended the Greenwich ARC were born with Down syndrome, and though they had varying abilities, most were self-sufficient. They were able to swim and to participate in the theater program; some even learned to read and write. Because of Greenwich's affluence, not only was the local ARC always well funded, but many of the kids came from very privileged backgrounds as well. To this day I remember being astonished when a limousine dropped off a tot for his day of activities with us. These children were really in an unusually enriched situation, and the effects of this gifted environment showed. Despite their handicaps and rather serious diagnoses, they were active and curious and engaged, and many were approaching milestones for reading and arithmetic close to those expected for normal kids their age. I knew that not only were they getting a great day at the ARC, but when they went home, they were often given physical therapy and tutoring there, too.

While at Smith, I had an opportunity to see what life was like for the mentally and developmentally disabled who did not have the same advantages as the children at the Greenwich ARC. I volunteered several hours a week at the Belchertown State School, a seventy-year-old state institution for the cognitively handicapped, located just a few miles from Smith. Belchertown's residents ranged from children to the very elderly, many of whom had spent most of their lives at the institution. Before it closed in 1992, Belchertown housed as many as 1,500 people, ages one to eighty-eight, living in thirteen dormitories. The hospital was understaffed, even after a local newspaper exposed overcrowding and maltreatment in the 1960s. When I volunteered in 1975, I primarily spent time in the children's

dormitory. It was not a pleasant place. The rooms smelled of disinfectant, toys were few and far between, and many of the kids hadn't been bathed in quite some time. Like the children at Greenwich's ARC, some were more disabled than others, but even those who were more functioning seemed to lag far behind their peers at ARC. They sat in corners and rocked and had difficulty speaking, and their eyes appeared vacant.

This was a time at the height of the nature-versus-nurture debate, and my psychology and biology professors at Smith were keen on discussing how much a person's makeup, from personality to intelligence to likes and dislikes, is dependent on genes (nature) and how much on the influence of environment (nurture). There was clearly little nurturing going on at Belchertown, while at ARC there were always activities, directed therapies, teaching, and, most of all, stimulation.

At some point I realized the children at Belchertown who had the same disabilities and the same hurdles to overcome were far worse off than the kids at ARC in Greenwich, and at least from my limited viewpoint, environment seemed to be the overwhelming determining factor. It was pure and simple: the brains of the ARC children were being stimulated and encouraged, and the brains of the Belchertown children were not.

Like fingerprints, no two brains are identical. Everything we do, think, say, and feel influences the development of our most precious organ, and those developments trigger ever more changes until the thread of action and reaction is too complex to unwind or undo. Our brains, in essence, are self-built. They not only serve the particular needs and functions of the particular individual, but also are shaped—landscaped if you will—by the individual's particular experiences. In neuroscience, we refer to the human brain's unique ability

to mold itself as plasticity. Thinking, planning, learning, acting—all influence the brain's physical structure and functional organization, according to the theory of neuroplasticity.

As far back as Socrates, some believed the brain could be "trained," or changed, much as a gymnast trains his or her body to balance on a high beam. In 1942 the British physiologist and Nobel Prize winner Charles Sherrington wrote that the human brain was like "an enchanted loom, where millions of flashing shuttles weave a dissolving pattern, always a meaningful pattern, though never an abiding one." In essence, the human brain, said Sherrington, was always in a state of flux.

Five years after Sherrington, Donald Hebb, an American neuropsychologist, was struck by a kind of accidental inspiration that led to the first quasi-experimental test of the theory of brain plasticity. When the forty-three-year-old researcher took rat pups home from his lab at Canada's McGill University and gave them to his children as pets, he allowed the rodents to roam freely around the house. Hebb's inspiration was to compare the brains of these free-roaming pet rats with those of rats kept in cages in his lab. After several weeks he put both groups of rats through a kind of intelligence test involving a maze. The pet rats, which had free access to explore the environment of Hebb's home and unfettered interaction with one another as well as with Hebb and his family, performed significantly better on the maze test than the lab rats confined to small cages.

By the late 1990s researchers had confirmed a range of changes associated with experience and stimulation, including brain size, gray matter volume, neuron size, dendritic branching, and the number of synapses per neuron. The more stimulation and experience, they concluded, the larger the neurons, the bushier the dendrites, the higher the number of synapses, and the thicker the gray matter.

During my senior year at Smith College in 1977–78, I wrote my first professional journal article under the tutelage of Nico Spinelli, a professor in both the psychology department and the computer and information science department at the University of Massachusetts Amherst. He was doing pioneering experiments in the plasticity of the visual cortex. Previous research had looked at the brains of mammals raised in a deprived environment. Spinelli wanted to see if plasticity was still at work in a “normal” environment. So we took kittens raised with their mothers in a standard animal facility and gave them what’s called avoidance training. In these experiments, a “safe” and an “unsafe” stimulus were associated with two different visual stimuli: vertical lines and horizontal lines. As the kittens learned to associate the safe stimulus with either the horizontal or the vertical lines, the number of neurons in those parts of the visual cortex expanded. The results, which were published in the journal *Science*, confirmed “that early learning produces plastic changes in the structure of the developing brain,” or, to put it more simply, young brains are shaped by experience.

Of course, adult brains can be shaped by experience as well. Researchers in neural plasticity have found that even in the last decades of life, adult brains can be remodeled, just not as easily or as constantly as during childhood and adolescence. Whereas kids’ brains will respond and change in response to virtually any stimulation, so-called adult plasticity occurs only in specific behavioral contexts. For instance, cab drivers in London (a notoriously difficult city to navigate) have been found by scientists to have an enlarged hippocampus particularly in the area responsible for spatial memory. Violinists and cellists, who must use their hands fluidly and rapidly, have been shown to have an enhanced motor cortex. And in an unusual experi-

ment conducted several years ago, Patricia McKinley of McGill University was able to show that learning the tango, which involves both complex movement and a fine sense of balance, improved the ability of senior citizens, ages sixty-eight to ninety-one, to switch between two different cognitive tasks. “Plasticity,” then, is just another way of saying “learning.”

In the first few years of childhood there is a critical period of plasticity in which learning comes quickly and easily. Evolution experts believe this is the brain’s way of helping us adapt early to the specific environment in which we are raised. The concept is the same as that of imprinting, whereby a baby duckling develops a keen and powerful preference to follow the mother duck over any other. When I was five years old, I saw this in action, although I obviously didn’t know it at the time. It was Easter, and my baby brother had just been born. Perhaps because of that, friends of my parents gave me my own “baby”—a baby chick, that is, much to my parents’ consternation. I loved that fuzzy little animal and was absolutely fascinated that it would follow me around the house, through the swinging door between the kitchen and the dining room, even out of the house and around the yard. Because I was with the chick almost from its birth, it had determined I was its mother. Years later I would read the children’s book *Are You My Mother?* by P. D. Eastman to my sons. Basically, the book is really all about imprinting. A young hatchling leaves its nest too early while its mother is out foraging for food, and goes on a journey, asking every animal and object it meets—a kitten, a hen, a dog, a cow, a car, even an enormous power shovel—the question of the title. Luckily the power shovel lifts the young bird up and deposits it back in its nest beside its real mother.

Five-year-old me, of course, was the only mother my baby chick

had. Unfortunately, the end of the relationship was sudden and brutal. About a week after Easter, after I'd just gotten home from kindergarten, my baby chick was once again following me all over the house, but this time, as I skipped between the kitchen and the dining room, the little hatchling failed to make it through the swinging door and was squished. I cried for days.

Thirteen years later, as a freshman at Smith, I created my own chick-imprinting experiment for a class in advanced biology. In order to imprint them to sound, I exposed my baby chicks to a specific sound or tone every day over a week. At the end of this training period, the chicks were placed on a kind of runway and were then exposed to two sounds, one of them being the familiar tone I'd played for them for seven straight days. Every one of the chicks toddled toward the familiar tone: they had imprinted to sound. I remember this so well because my mother was visiting me at the time of the experiment and she helped me type the results!

But how does learning actually happen? Young brains and old brains work much the same way, by receiving information from the senses—hearing, seeing, tasting, touching, smelling. Sensory information is transmitted by synapses through a network of neurons and is stored, temporarily, in short-term memory. This short-term memory region is highly volatile and is constantly receiving input from the nearly continuous information our senses encounter every minute of our waking life. After information is processed in the short-term memory region, it is compared with existing memories, and if the information matches, it is discarded as redundant. (Brain space is too limited and too precious to allow duplicates to take up neural real estate.) If, on the other hand, the information is new, then it is farmed

out to one of several locations in the brain that store long-term memories. Although nearly instantaneous, the transmission of sensory information is not perfect. In the same way that the otherwise seamless signal coming from your TV is occasionally interrupted, briefly distorting the picture, so, too, does degradation occur as information races up and down the axons of your brain's neurons. This explains why our memories are never perfect, but have holes or discontinuities, which we occasionally fill in, albeit unconsciously, with false information.

The brain is programmed to pay special attention to the acquisition of novel information, which is what learning really is. The more activity or excitation between a specific set of neurons, the stronger the synapse. Thus, brain growth is a result of activity. In fact, the young brain has more excitatory synapses than inhibitory synapses.

The more a piece of information is repeated or relearned, the stronger the neurons become, and the connection becomes like a well-worn path through the woods. "Frequency" and "recency" are the key words here—the more frequently and the more recently we learn something and then recall it or use it again, the more entrenched the knowledge, whether it's remembering the route between home and work or how to add a contact to your smartphone's directory. In both cases, the mental machinery of learning is dependent on the synapse, that minuscule space where packets of information are passed from one neuron to another by electrical or chemical messengers. For these neural connections to be made, both sides of a synapse need to be "on," that is, in a state of excitation. When an excitatory input exceeds a certain level, the receiving neuron fires and begins the molecular process, called long-term potentiation, by which synapses

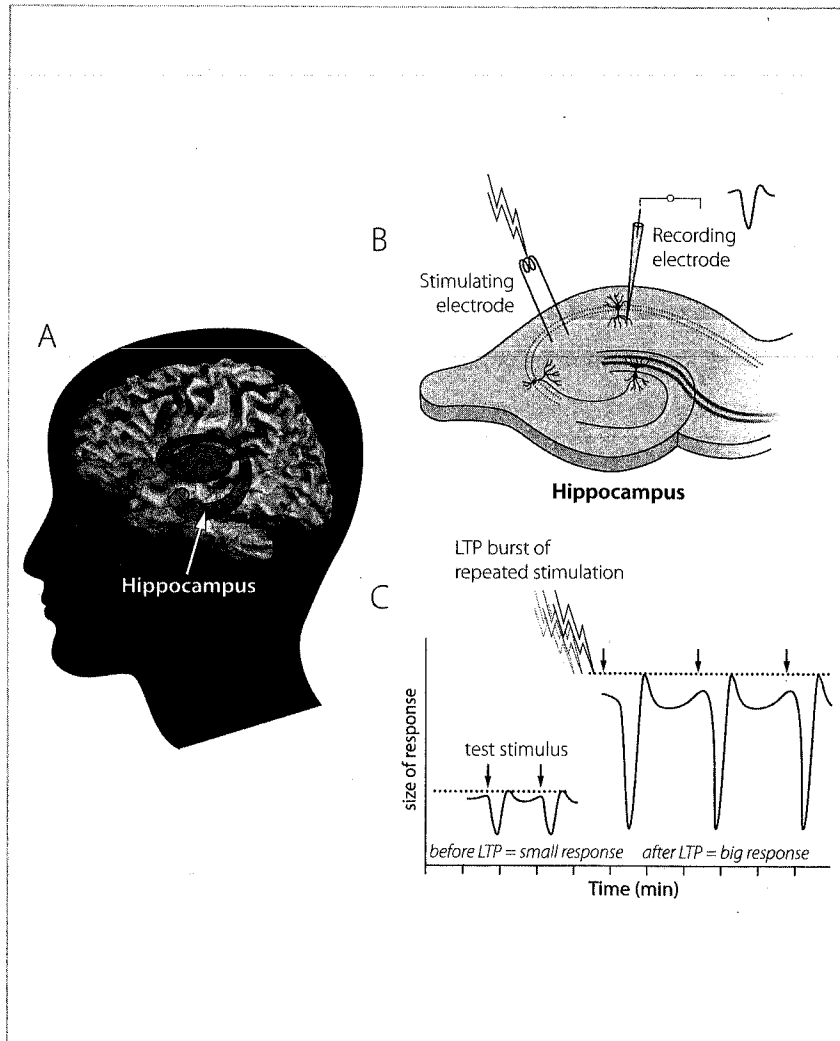


FIGURE 10. Long-Term Potentiation (LTP) Is a Widely Used Model of the “Practice Effect” of Learning and Memory: A. The hippocampus is located inside the temporal lobe. B. Brain cell activity recorded in hippocampal slices from rodents shows changes in cell signals after a burst of stimulation. C. LTP experiments commonly record repeated small responses to stimuli until a burst is given (akin to the “practice effect”), after which point responses from the neuron to the original stimulus become much larger, as if “memorized” or “practiced.”

and neuronal connections are strengthened. The process of long-term potentiation, or LTP, is a complex cascade of events involving molecules, proteins, and enzymes that starts and ends at the synapse.

The process of LTP begins with the main excitatory neurotransmitter, glutamate, being released at the axon terminal of one neuron across the synapse to the receptor on the dendrite of the receiving neuron. Glutamate is directly involved in building stronger synapses. How does it do this? Glutamate acts as a catalyst and sets off a chain reaction that eventually builds a bigger and stronger synapse, or connection in a brain pathway. When glutamate “unlocks” the receptor, it triggers calcium ions to zip around the synapse. The calcium, in turn, activates many molecules and enzymes and interacts with certain proteins to change their shape and behavior, which in turn can change the structure of synapse and neuron to make them more or less active. Calcium can alter existing proteins very rapidly, within seconds to hours, and it can also activate genes to make new proteins, a process that can take hours to days. The end result is a synapse that is bigger and stronger and that can cause a bigger response in the activated cell. In experiments, this increased response can be measured electrically as a bigger signal. Compared with the response before the “training” and the consequent building of a stronger synapse, the response in the cell after this strengthening, or potentiation, is much larger, and these measurements are the typical ones used in LTP experiments. In fact, if you are learning any of this at all, you are building new synapses as you read. Only minutes after you learn a new thing, your synapses start to grow bigger. In a few hours they are virtually cemented into a stronger form.

John Eccles, who would go on to win a Nobel Prize for his early

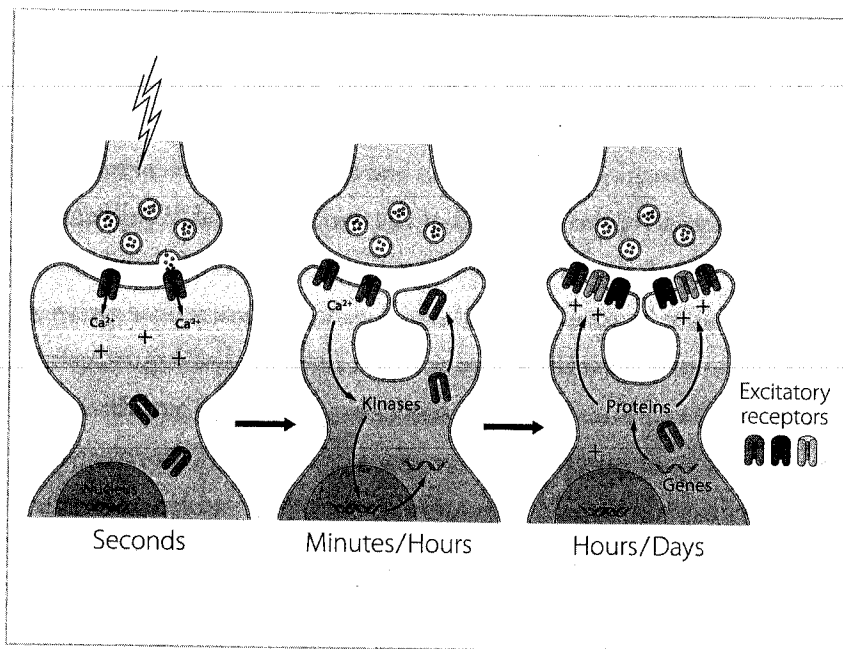


FIGURE 11. New Receptors Are Added to Synapses During Learning and Memory and Long-Term Potentiation (LTP): Axonal signals that originally elicited a small response elicit a larger response in the neuron after LTP, owing to the development of a larger synapse over time.

work in the study of synapses, was perplexed by how much stimulation was needed to produce a synaptic change. "Perhaps the most unsatisfactory feature of the attempt to explain the phenomena of learning," he wrote, "is that long periods of excess use or disuse are required in order to produce detectable synaptic change." What Eccles failed to realize is that the repetitions he observed so frustratingly—those "long periods of excess use"—were the brain at work, learning and acquiring knowledge. After repeated stimulation, a brain cell will respond much more strongly to a stimulus than it initially did. Hence, the brain circuit "learns." And the more ingrained the knowledge, the easier it is to recall and use. As when skiers race through a slalom

course, the quickest route down becomes worn by use. Ruts develop. By the time the last competitors race through the gates, the route is so deeply entrenched in the snow that they can't ski out of it, nor do they need or want to. The deeply imprinted line, in fact, guides them down without their having to search for it.

The process of fine-tuning and turning off neuronal connections that may have been made in childhood but are no longer needed is called pruning, and it accelerates during mid- to late adolescence when unnneeded synapses are removed. Scientists call this pruning phase a kind of "neural Darwinism," in which only the "fittest," that is, the most used neurons, survive. What accounts for gray matter loss so early in a person's development when many cognitive and behavioral functions have yet to fully develop? Researchers have discovered in the past few years a direct correlation between an adolescent's decrease in gray matter and the increase in white matter. Scientists know that gray matter continues to decrease through adulthood, especially after the age of sixty, but they also believe that gray matter loss in adolescence is a distinctly different process. In later life gray matter declines as a function of degenerative processes, that is, cell shrinkage and death, whereas in adolescence gray matter decline is a product of the brain's plasticity. ("Use it or lose it.")

Researchers at UCLA discovered not only that effective pruning increased brain efficiency but also that higher intelligence could be correlated with prolonged, accelerated neuronal growth in childhood followed by vigorous cortical pruning in adolescence. What is less, it turns out, is actually more, and this is why in the midst of all the chaos of the teenage years, adolescents are developing a leaner, more efficient adult mental "machine." Adults have an advantage over children and teens in that their white matter is more extensive, meaning

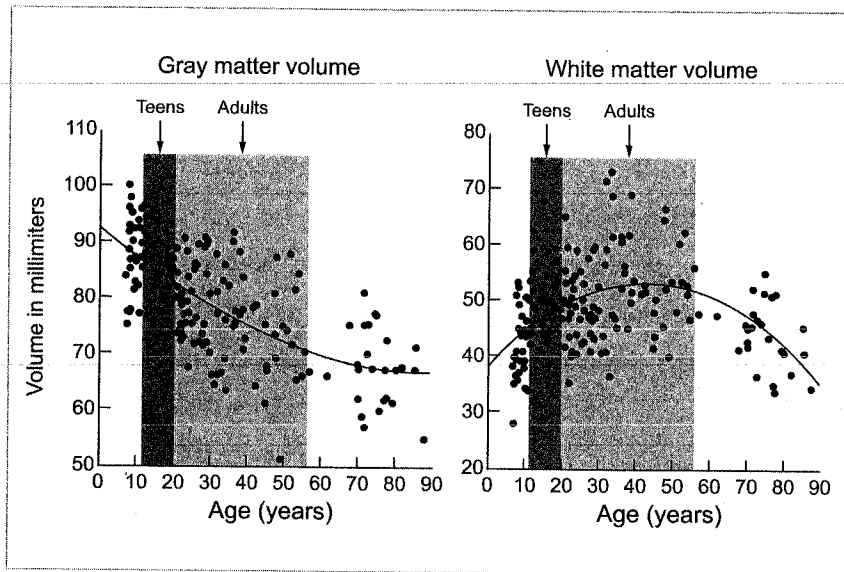


FIGURE 12. Gray Matter and White Matter Develop Differently Throughout Life: Children and teens have more gray matter and synapses than adults, because as we age our brains remove unnecessary connections for greater efficiency. However, in old age white matter also diminishes, contributing to age-related cognitive issues such as memory loss and abnormal conditions such as dementia.

that they have more speedy connections between brain areas, such as the frontal lobes.

The real news in all of this science is that the teen brain is more than capable of learning, and this fact should not be taken for granted! LTP is indeed more robust in teens. Adolescent animals similarly show faster learning curves than adults, and scientists wanted to know whether this was because they had better synaptic plasticity, given all the increase in excitatory synapses, which are required for LTP. Studies were performed on brain slices from rats to look at the LTP in an adolescent rat versus an adult rat. They found that the strength of LTP was “way better” in the adolescents. The

“before” and “after” comparisons following the burst of stimulation showed that synapses in adolescent slices had about one and a half times as much increase and that it lasted a lot longer.

So what this means is that memories are easier to make and last longer when acquired in teen years compared with adult years. This is a fact that should not be ignored! This is the time to identify strengths and invest in emerging talents. It's also the time when you can get the best results from remediation, special help, for learning and emotional issues. We've all long thought that the IQ with which you were “branded” in grade school after taking one of those aptitude tests was the final word on your intellectual destiny. Not true. There is solid data to show that your IQ can change during your teen years, more

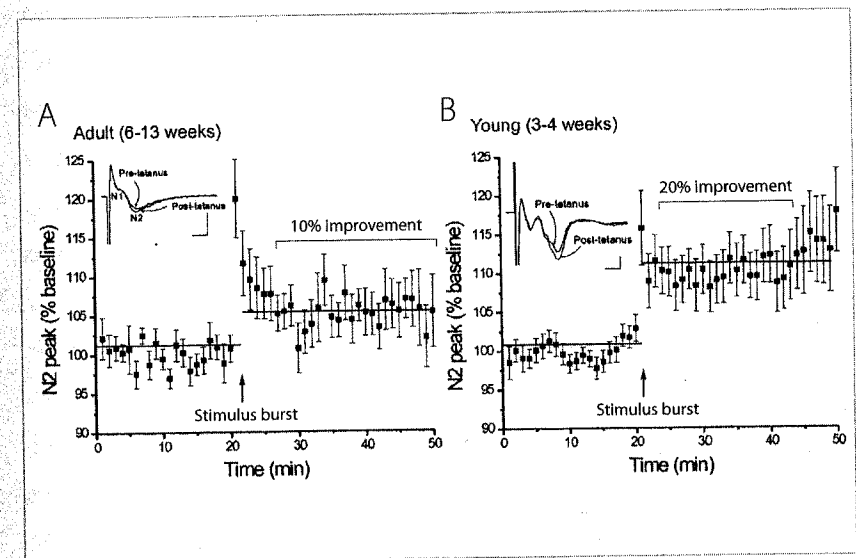


FIGURE 13. Adolescents' Synaptic Plasticity Is “Way Better” Than Adults': To test if teens have better learning abilities than adults because they have better LTP, researchers compared adolescent hippocampal brain slices with those from adults. The signal after the burst stimulation in the adolescent (B) was much higher, and lasted longer, than in the adult (A).

than anyone had ever expected. Between thirteen and seventeen years of age, one-third of people stay the same, one-third of people decrease their IQ, and a remarkable one-third of people actually significantly raise their IQ. The changes in increased IQ were also associated with changes in brain scans. When verbal IQ increased, so did gray matter in the center of the brain, responsible for articulating speech. When nonverbal IQ increased, so did gray matter in the area of the brain related to hand movements. The frustrating part of this study is that the researchers did not track what these people did during those formative years. We'd love to know the secret of how to make your IQ go up during your teen years. At least we are already learning the kinds of things that can make it go down, but we will come back to this later.

Researchers at the University of Colorado's Institute for Behavioral Genetics recently discovered that compared with children with lower IQs, children with high IQs may have an extended learning period during which they are able to maintain a rapid pace of new knowledge acquisition. This extended learning period does not necessarily lead to higher IQ but could have potential long-term benefits. This kind of information needs to get out there: teens need to become aware that this is one of the golden ages for their brains!

That, of course, doesn't really help you in dealing with the here and now of your dizzyingly confusing teenagers. It's important to remember that even though their brains are learning at peak efficiency, much else is inefficient, including attention, self-discipline, task completion, and emotions. So the mantra "one thing at a time" is useful to repeat to yourself. Try not to overwhelm your teenagers with instructions. Remember, although they look as though they can multitask, in truth they're not very good at it. Even just encouraging them

to stop and think about what they need to do and when they need to do it will help increase blood flow to the areas of the brain involved in multitasking and slowly strengthen them. This goes for giving instructions and directions, too. Write them down for your teens in addition to giving them orally, and limit the instructions to one or two points, not three, four, or five. You can also help your teenagers better manage time and organize tasks by giving them calendars and suggesting they write down their daily schedules. By doing so on a regular basis, they train their own brains. ✓ mind

Perhaps most important of all, set limits—with everything. This is what their overexuberant brains can't do for themselves. So be clear about the amount of time you will allow your teenager to socialize "virtually," either on the Internet or through texting. Best-case scenario: limit the digital socializing to just one to two hours a day. And if your teenager fails to comply, take away the phone or the iPod, or limit computer use to homework. Also, insist on knowing the user names and passwords for all their accounts.

None of this means your kids are going to immediately go along with the program. In fact, it's virtually a certainty that there will at least be occasional slip-ups, perhaps a lot of them. That's why it's up to you to keep tabs, to check on teenagers as they do their homework and spend time on the computer. The more on top of it you are, the fewer the temptations for your adolescents, and the fewer the temptations, the more their brains will learn how to do *without* the constant distractions.

In dealing with those unexpected emotional outbursts from your teenage sons and daughters, something as simple as counting to ten before responding can help you stay calm. Being angry, or treating the meltdown like a childish tantrum, is not advisable. Adolescents

believe they're adults, and though we know better, the more you treat them that way, the greater the chance they'll actually try to act that way, too. Because I'm a doctor and a scientist, I could sit my kids down and tell them, Look, you don't believe me when I say that you're being irrational or impulsive or overly sensitive, but let me tell you why it's your brain's "fault." By the time you finish reading this book, you'll be able to do the same thing. And trust me, it works. I've seen it not only with my own sons but also in talking to teenagers after I've given presentations in high schools. They're actually fascinated by the neuroscience and that there's a logic, or rationale, behind what otherwise seem like inexplicable upheavals in their lives. You do run the risk, however, that these "brain explanations" become a kind of adolescent ammunition.

"My brain made me do it." Your teenage son might be tempted to say when he decides to drive off with Dad's car and not tell anyone until he comes home after midnight.

"Well, no," you have to say, "your brain is sometimes an explanation; it's never an excuse."

Your teenagers are knowledgeable and self-aware enough to know that they are not automatons, and this means they have the capacity to modify and the responsibility for modifying their own behavior. This is what you must remind them—and then remind them again and again and again. The brain science isn't an excuse for crazy, stupid, illegal, or immoral behavior. It's an explanation and a framework, about which they should be encouraged to read more. In the same way that I called my sons after I heard the news of Dan's drowning, when you read or hear about something similar, call your teenagers, or sit down with them, and remind them why these things happen. You can't expect them to automatically grasp innuendo and

more subtle connections, so the better thing to do is err on the side of overkill and point out the obvious, explicitly. I did this so many times with my kids that they named me Captain Obvious!

There is a logical reason why plasticity is front-loaded in childhood and adolescence: survival depends on knowledge of one's environment, so the young brain must be flexible and moldable depending on the type of environment in which the person is growing up. The growth of synapses makes teens sensation-seeking learning machines, but the fact that their brain signals can also easily slide off the tracks makes those growth spurts somewhat dangerous. Evolutionarily, being open to new ideas, having new things to learn, leads to useful experiences that are necessary for survival.

For adults, it's our myelin that in part allows certain brain signals to speed their way to the frontal lobe, where we respond by putting the brakes on that impulse to skydive or drive at 120 miles an hour. So pruning happens just as myelin growth increases, giving adolescents a short window to experience the world and figure out what will make them happier, healthier, and, one can only hope, wiser. This delicate balance is why some teen behaviors can appear so confounding, like the teenage boy a colleague told me about who was stopped on a side street for driving at 113 miles an hour and given a speeding ticket. The boy was furious—not that he thought he shouldn't have been ticketed, since he did admit he was driving way over the speed limit, but because the violation was for "reckless driving," when in fact, he told his father, he'd thought about it and planned it all out well in advance. He knew exactly what he was going to do and where to do it, and even picked a straight road with little traffic and good weather to do it in. On the other hand, he then went out and drove 113 miles an hour!

There's an additional, evolution-based reason for this apparent conflict of self-interest. Scientists at University College London recently asked fifty-nine young people, ages nine to twenty-six, to guess the odds that certain bad things might happen to them. The forty unfortunate events ranged from getting lice to getting seriously injured in an auto accident. After the subjects made their guesses, they were told the real odds of those bad things happening. Then they were asked to project the odds again. The majority of the subjects were good at remembering the actual risk if it wasn't as bad as their original guess. But the adolescents were worse at recalling the risk when the risk was *worse* than their original guess. As it turns out, there are more areas of the brain that process positive information, whereas negative information is centered in the prefrontal cortex. In other words, adolescents have less ability to process negative information than adults do, and so they are less inclined *not* to do something risky, and less likely to learn from the ensuing mistake or misadventure, than adults are.

Once someone is out of adolescence, synaptic plasticity, and learning, require more effort. In the same way that a young adult eventually settles down into a life and a routine, so, too, does the brain. The middle-aged man who played electric guitar in a rock band in high school would have trouble picking up the instrument again at age forty-five. Twenty-five years ago, those guitar-playing neurons were in constant use, but by the time he reaches adulthood they've been dormant for so long they were essentially left behind, just like that electric guitar in the attic. Adults also have less glutamate and dopamine and fewer receptors available; therefore they are less cognitively flexible.

But don't tell my dad that. He's now in his early nineties and still

active, and his favorite gadget is his iPad, which he never puts down. He's always e-mailing me, sending me virtual clippings from medical articles he's read, attaching them to an e-mail that just reads, "I thought you'd like to see this." My father's brain is engaged all the time, and the Internet has helped him stay stimulated and on top of current issues and events. If my dad had been born just twenty years earlier than he was, I'm not sure what he'd be doing now or what he'd be able to do. My mother, who is also in her nineties, prefers to play solitaire on the iPad. She says it's easier than shuffling cards. Having grown up in England, she worked in British Intelligence during World War II, and her brain remains sharp. The good news about brain plasticity is that it may peak in childhood and adolescence but it never entirely stops—at least not until we do. The more you learn, the easier it is to learn the next thing.