Six

Adolescence; or, Dude, Where's My Frontal Cortex?

This chapter is the first of two focusing on development. We've established our rhythm: a behavior has just occurred; what events in the prior seconds, minutes, hours, and so on helped bring it about? The next chapter extends this into the developmental domain—what happened during that individual's childhood and fetal life that contributed to the behavior?

The present chapter breaks this rhythm in focusing on adolescence. Does the biology introduced in the preceding chapters work differently in an adolescent than in an adult, producing different behaviors? Yes.

One fact dominates this chapter. Chapter 5 did in the dogma that adult brains are set in stone. Another dogma was that brains are pretty much wired up early in childhood—after all, by age two, brains are already about 85 percent of adult volume. But the developmental trajectory is much slower than that. This chapter's key fact is that the final brain region to fully mature (in terms of synapse number, myelination, and metabolism) is the frontal cortex, not going fully online until the mid*twenties*.[1]

This has two screamingly important implications. First, no part of the adult brain is more shaped by adolescence than the frontal cortex. Second, nothing about adolescence can be understood outside the context of delayed frontocortical maturation. If by adolescence limbic, autonomic, and endocrine systems are going full blast while the frontal cortex is still working out the assembly instructions, we've just explained why adolescents are so frustrating, great, asinine, impulsive, inspiring, destructive, self-destructive, selfless, selfish, impossible, and world changing. Think about this—adolescence and early adulthood are the times when someone is most likely to kill, be killed, leave home forever, invent an art form, help overthrow a dictator, ethnically cleanse a village, devote themselves to the needy, become addicted, marry outside their group, transform physics, have hideous fashion taste, break their neck recreationally, commit their life to God, mug an old lady, or be convinced that all of history has converged to make this moment the most consequential, the most fraught with peril and promise, the most demanding that they get involved and make a difference. In other words, it’s the time of life of maximal risk taking, novelty seeking, and affiliation with peers. All because of that immature frontal cortex.

THE REALITY OF ADOLESCENCE

Is adolescence real? Is there something qualitatively different distinguishing it from before and after, rather than being part of a smooth progression from childhood to adulthood? Maybe "adolescence" is just a cultural construct—in the West, as better nutrition and health resulted in earlier puberty onset, and the educational and economic forces of modernity pushed for childbearing at later ages, a developmental gap emerged between the two. Voilà! The invention of adolescence.[*][2]

As we'll see, neurobiology suggests that adolescence is for real, that the adolescent brain is not merely a half-cooked adult brain or a child's brain left unrefrigerated for too long. Moreover, most traditional cultures do recognize adolescence as distinct, i.e., it brings some but not all of the rights and responsibilities of adulthood. Nonetheless, what the West invented is the longest period of adolescence.[*]

What does seem a construct of individualistic cultures is adolescence as a period of intergenerational conflict; youth of collectivist cultures seem less prone toward eye rolling at the dorkiness of adults, starting with parents. Moreover, even within individualistic cultures adolescence is not universally a time of acne of the psyche, of Sturm und Drang. Most of us get through it just fine.

THE NUTS AND BOLTS OF FRONTAL CORTICAL MATURATION

The delayed maturation of the frontal cortex suggests an obvious scenario, namely that early in adolescence the frontal cortex has fewer neurons, dendritic branches, and synapses than in adulthood, and that levels increase into the midtwenties. Instead, levels *decrease*.

This occurs because of a truly clever thing evolved by mammalian brains. Remarkably, the fetal brain generates far more neurons than are found in the adult. Why? During late fetal development, there is a dramatic competition in much of the brain, with winning neurons being the ones that migrate to the correct location and maximize synaptic connections to other neurons. And neurons that don't make the grade? They undergo "programmed cell death"—genes are activated that cause them to shrivel and die, their materials then recycled. Neuronal overproduction followed by competitive pruning (which has been termed "neural Darwinism") allowed the evolution of more optimized neural circuitry, a case of less being more.

The same occurs in the adolescent frontal cortex. By the start of adolescence, there's a greater volume of gray matter (an indirect measure of the total number of neurons and dendritic branches) and more synapses than in adults; over the next decade, gray-matter thickness declines as less optimal dendritic processes and connections are pruned away.*[3] Within the frontal cortex, the evolutionarily oldest subregions mature first; the spanking-new (cognitive) dorsolateral PFC doesn't even start losing gray-matter volume until late adolescence. The importance of this developmental pattern was shown in a landmark study in which children were neuroimaged and IQ tested repeatedly into adulthood. The longer the period of packing on gray-matter cortical thickness in early adolescence before the pruning started, the higher the adult IQ.

Thus, frontal cortical maturation during adolescence is about a more efficient brain, not more brain. This is shown in easily misinterpreted neuroimaging studies comparing adolescents and adults.[4] A frequent theme is how adults have more executive control over behavior during some tasks than do adolescents and show more frontal cortical activation at the time. Now find a task where, atypically, adolescents manage a level of executive control equal to that of adults. In those situations adolescents show *more* frontal activation than adults—equivalent regulation takes less effort in a well-pruned adult frontal cortex.

That the adolescent frontal cortex is not yet lean and mean is demonstrable in additional ways. For example, adolescents are not at adult levels of competence at detecting irony and, when trying to do so, activate the dmPFC more than do adults. In contrast, adults show more activation in the fusiform face region. In other words, detecting irony isn't much of a frontal task for an adult; one look at the face is enough.[5]

What about white matter in the frontal cortex (that indirect measure of myelination of axons)? Here things differ from the overproduce-then-prune approach to gray matter; instead, axons are myelinated throughout adolescence. As discussed in appendix 1, this allows neurons to communicate in a more rapid, coordinated manner—as adolescence progresses, activity in different parts of the frontal cortex becomes more correlated as the region operates as more of a functional unit.[6]

This is important. When learning neuroscience, it's easy to focus on individual brain regions as functionally distinct (and this tendency worsens if you then spend a career studying just one of them). As a measure of this, there are two high-quality biomedical journals out there, one called *Cortex*, the other *Hippocampus*, each publishing papers about its favorite brain region. At neuroscience meetings attended by tens of thousands, there'll be social functions for all the people studying the same obscure brain region, a place where they can gossip and bond and court. But in reality the brain is about circuits, about the patterns of functional connectivity among regions. The growing myelination of the adolescent brain shows the importance of increased connectivity.

Interestingly, other parts of the adolescent brain seem to help out the underdeveloped frontal cortex, taking on some roles that it's not yet ready for. For example, in adolescents but not adults, the ventral striatum helps regulate emotions; we will return to this.[7]

Something else keeps that tyro frontal cortex off-kilter, namely estrogen and progesterone in females and testosterone in males. As discussed in chapter 4, these hormones alter brain structure and function, including in the frontal cortex, where gonadal hormones change rates of myelination and levels of receptors for various neurotransmitters. Logically, landmarks of adolescent maturation in brain and behavior are less related to chronological age than to the time since puberty onset.[8]

Moreover, puberty is not just about the onslaught of gonadal hormones. It's about *how* they come online.[9] The defining feature of ovarian endocrine function is the cyclicity of hormone release—"It's that time of the month." In adolescent females puberty does not arrive full flower, so to speak, with one's first period. Instead, for the first few years only about half of cycles actually involve ovulation and surges of estrogen and progesterone. Thus, not only are young adolescents experiencing these first ovulatory cycles, but there are also higher-order fluctuations in whether the ovulatory fluctuation occurs. Meanwhile, while adolescent males don't have equivalent hormonal gyrations, it can't help that their frontal cortex keeps getting hypoxic from the priapic blood flow to the crotch.

Thus, as adolescence dawns, frontal cortical efficiency is diluted with extraneous synapses failing to make the grade, sluggish communication thanks to undermyelination, and a jumble of uncoordinated subregions working at cross-purposes; moreover, while the striatum is trying to help, a pinch hitter for the frontal cortex gets you only so far. Finally, the frontal cortex is being pickled in that ebb and flow of gonadal hormones. No wonder they act adolescent.

Frontal Cortical Changes in Cognition in Adolescence

To appreciate what frontal cortical maturation has to do with our best and worst behaviors, it's helpful to first see how such maturation plays out in cognitive realms.

During adolescence there's steady improvement in working memory, flexible rule use, executive organization, and frontal inhibitory regulation (e.g., task shifting). In general, these improvements are accompanied by increasing activity in frontal regions during tasks, with the extent of the increase predicting accuracy.[10]

Adolescents also improve at mentalization tasks (understanding someone else's perspective). By this I don't mean emotional perspective (stay tuned) but purer cognitive challenges, like understanding what objects look like from someone else's perspective. The improvement in detecting irony reflects improvement in abstract cognitive perspective taking.

Frontal Cortical Changes in Emotional Regulation

Older teenagers experience emotions more intensely than do children or adults, something obvious to anyone who ever spent time as a teenager. For example, they are more reactive to faces expressing strong emotions.*[11] In adults, looking at an “affective facial display” activates the amygdala, followed by activation of the emotion-regulating vmPFC as they habituate to the emotional content. In adolescence, though, the vmPFC response is less; thus the amygdaloid response keeps growing.

Chapter 2 introduced “reappraisal,” in which responses to strong emotional stimuli are regulated by thinking about them differently.[12] Get a bad grade on an exam, and there’s an emotional pull toward “I’m stupid”; reappraisal might lead you instead to focus on your not having studied or having had a cold, to decide that the outcome was situational, rather than a function of your unchangeable constitution.

Reappraisal strategies get better during adolescence, with logical neurobiological underpinnings. Recall how in early adolescence, the ventral striatum, trying to be helpful, takes on some frontal tasks (fairly ineffectively, as it’s working above its pay grade). At that age reappraisal engages the ventral striatum; more activation predicts less amygdaloid activation and better emotional regulation. As the adolescent matures, the prefrontal cortex takes over the task, and emotions get steadier.*[13]

Bringing the striatum into the picture brings up dopamine and reward, thus bringing up the predilection of adolescents for bungee jumping.

ADOLESCENT RISK TAKING

In the foothills of the Sierras are California Caverns, a cave system that leads, after an initial narrow, twisting 30-foot descent down a hole, to an abrupt 180-foot drop (now navigable by rappelling). The Park Service has found skeletons at the bottom dating back centuries, explorers who took one step too far in the gloom. And the skeletons are always those of adolescents.

As shown experimentally, during risky decision making, adolescents activate the prefrontal cortex less than do adults; the less activity, the poorer the risk assessment. This poor assessment takes a particular form, as shown by Sarah-Jayne Blakemore of University College London.[14] Have subjects estimate the likelihood of some event occurring (winning the lottery, dying in a plane crash); then tell them the actual likelihood. Such feedback can constitute good news (i.e., something good is actually more likely than the person estimated, or something bad is less likely). Conversely, the feedback can constitute bad news. Ask subjects to estimate the likelihood of the same events again. Adults incorporate the feedback into the new estimates. Adolescents update their estimates as adults do for good news, but feedback about bad news barely makes a dent. (Researcher: "How likely are you to have a car accident if you're driving while drunk?" Adolescent: "One chance in a gazillion." Researcher: "Actually, the risk is about 50 percent; what do you think your own chances are now?" Adolescent: "Hey, we're talking about me; one chance in a gazillion.") We've just explained why adolescents have two to four times the rate of pathological gambling as do adults.[15]

So adolescents take more risks and stink at risk assessment. But it's not just that teenagers are more willing to take risks. After all, adolescents and adults don't equally desire to do something risky and the adults simply don't do it because of their frontal cortical maturity. There is an age difference in the sensations sought—adolescents are tempted to bungee jump; adults are tempted to cheat on their low-salt diet. Adolescence is characterized not only by more risking but by more novelty seeking as well.[*][16]

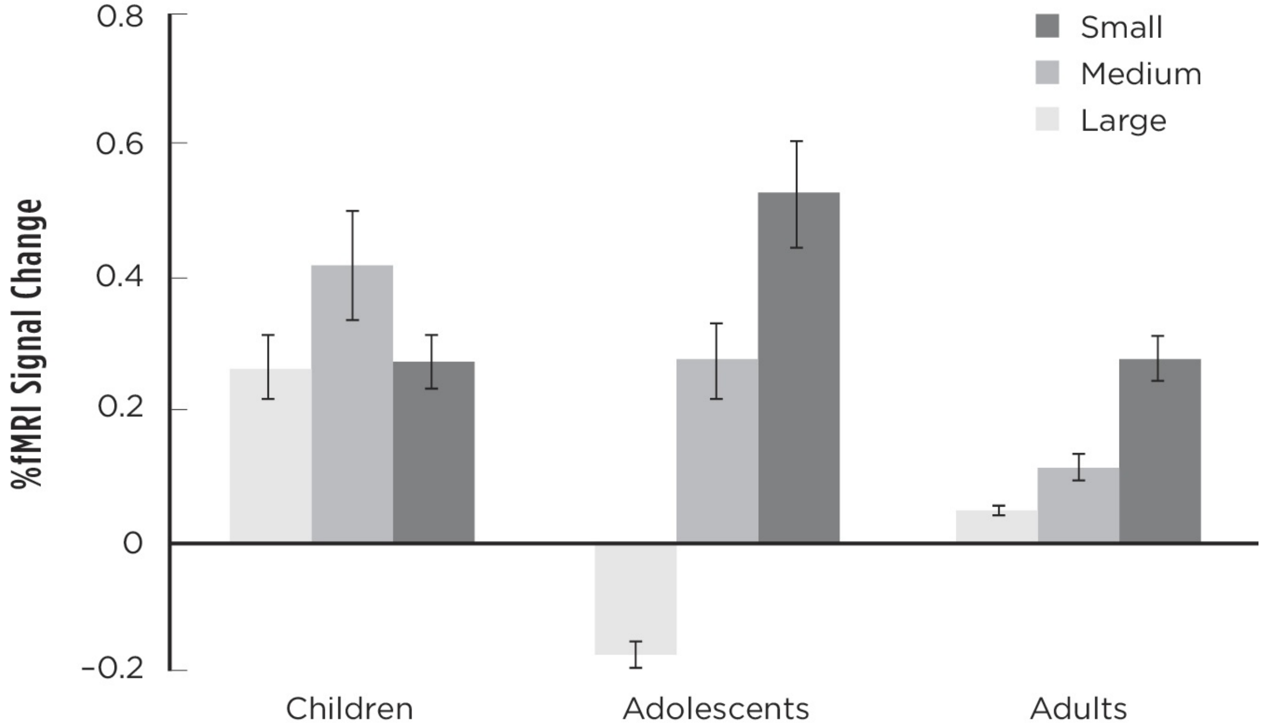
Novelty craving permeates adolescence; it is when we usually develop our stable tastes in music, food, and fashion, with openness to novelty declining thereafter.[17] And it's not just a human phenomenon. Across the rodent life span, it's adolescents who are most willing to eat a new food. Adolescent novelty seeking is particularly strong in other primates. Among many social mammals, adolescents of one sex leave their natal group, emigrating into another population, a classic means to avoid inbreeding. Among impalas there are groups of related females and offspring with one breeding male; the other males knock around disconsolately in "bachelor herds," each scheming to usurp the breeding male. When a young male hits puberty, he is driven from the group by the breeding male (and to avoid some Oedipus nonsense, this is unlikely to be his father, who reigned many breeding males ago).

But not among primates. Take baboons. Suppose two troops encounter each other at some natural boundary—say, a stream. The males threaten each other for a while, eventually get bored, and resume whatever they were doing. Except there's an adolescent, standing at the stream's edge, riveted. New baboons, a whole bunch of 'em! He runs five steps toward them, runs back four, nervous, agitated. He gingerly crosses and sits on the other bank, scampering back should any new baboon glance at him.

So begins the slow process of transferring, spending more time each day with the new troop until he breaks the umbilical cord and spends the night. He wasn't pushed out. Instead, if he has to spend one more day with the same monotonous baboons he's known his whole life, he'll scream. Among adolescent chimps it's females who can't get off the farm fast enough. We primates aren't driven out at adolescence. Instead we desperately crave novelty.*

Thus, adolescence is about risk taking and novelty seeking. Where does the dopamine reward system fit in?

Recall from chapter 2 how the ventral tegmentum is the source of the mesolimbic dopamine projection to the nucleus accumbens, and of the mesocortical dopamine projection to the frontal cortex. During adolescence, dopamine projection density and signaling steadily increase in both pathways (although novelty seeking itself peaks at midadolescence, probably reflecting the emerging frontal regulation after that).[18]



Changes in the amount of dopaminergic activity in the "reward center" of the brain following different magnitudes of reward. For the adolescents, the highs are higher, the lows lower.

Visit [bit.ly/2o3TBI8](bit.ly/2o3TBI8) for a larger version of this graph.

It's unclear how much dopamine is released in anticipation of reward. Some studies show more anticipatory activation of reward pathways in adolescents than in adults, while others show the opposite, with the least dopaminergic responsiveness in adolescents who are most risk taking.[19]

Age differences in absolute levels of dopamine are less interesting than differences in patterns of release. In a great study, children, adolescents, and adults in brain scanners did some task where correct responses produced monetary rewards of varying sizes (see figure above).[20] During this, prefrontal activation in both children and adolescents was diffuse and unfocused. However, activation in the nucleus accumbens in adolescents was distinctive. In children, a correct answer produced roughly the same increase in activity regardless of size of reward. In adults, small, medium, and large rewards caused small, medium, and large increases in accumbens activity. And adolescents? After a medium reward things looked the same as in kids and adults. A large reward produced a humongous increase, much bigger than in adults. And the small reward? Accumbens activity *declined*. In other words, adolescents experience bigger-than-expected rewards more positively than do adults and smaller-than-expected rewards as aversive. A gyrating top, nearly skittering out of control.

This suggests that in adolescents strong rewards produce exaggerated dopaminergic signaling, and nice sensible rewards for prudent actions feel lousy. The immature frontal cortex hasn't a prayer to counteract a dopamine system like this. But there is something puzzling.

Amid their crazy, unrestrained dopamine neurons, adolescents have reasoning skills that, in many domains of perceiving risk, match those of adults. Yet despite that, logic and reasoning are often jettisoned, and adolescents act adolescent. Work by Laurence Steinberg of Temple University has identified a key juncture where adolescents are particularly likely to leap before looking: when around peers.

PEERS, SOCIAL ACCEPTANCE, AND SOCIAL EXCLUSION

Adolescent vulnerability to peer pressure from friends, especially peers they want to accept them as friends, is storied. It can also be demonstrated experimentally. In one Steinberg study adolescents and adults took risks at the same rate in a video driving game. Adding two peers to egg them on had no effect on adults but tripled risk taking in adolescents. Moreover, in neuroimaging studies, peers egging subjects on (by intercom) lessens vmPFC activity and enhances ventral striatal activity in adolescents but not adults.[21]

Why do adolescents' peers have such social power? For starters, adolescents are more social and more complexly social than children or adults. For example, a 2013 study showed that teens average more than four hundred Facebook friends, far more than do adults.[22] Moreover, teen sociality is particularly about affect, and responsiveness to emotional signaling—recall the greater limbic and lesser frontal cortical response to emotional faces in adolescents. And teens don't rack up four hundred Facebook friends for data for their sociology doctorates. Instead there is the frantic need to belong.

This produces teen vulnerability to peer pressure and emotional contagion. Moreover, such pressure is typically "deviance training," increasing the odds of violence, substance abuse, crime, unsafe sex, and poor health habits (few teen gangs pressure kids to join them in tooth flossing followed by random acts of kindness). For example, in college dorms the excessive drinker is more likely to influence the teetotaling roommate than the reverse. The incidence of eating disorders in adolescents spreads among peers with a pattern resembling viral contagion. The same occurs with depression among female adolescents, reflecting their tendency to "co-ruminate" on problems, reinforcing one another's negative affect.

Neuroimaging studies show the dramatic sensitivity of adolescents to peers. Ask adults to think about what they imagine others think of them, then about what they think of themselves. Two different, partially overlapping networks of frontal and limbic structures activate for the two tasks. But with adolescents the two profiles are the same. "What do you think about yourself?" is neurally answered with "Whatever everyone else thinks about me."[23]

The frantic adolescent need to belong is shown beautifully in studies of the neurobiology of social exclusion. Naomi Eisenberger of UCLA developed the fiendishly clever "Cyberball" paradigm to make people feel snubbed.[24] The subject lies in a brain scanner, believing she is playing an online game with two other people (naturally, they don't exist—it's a computer program). Each player occupies a spot on the screen, forming a triangle. The players toss a virtual ball among themselves; the subject is picking whom to throw to and believes the other two are doing the same. The ball is tossed for a while; then, unbeknownst to the subject, the experiment begins—the other two players stop throwing the ball to her. She's being excluded by those creeps. In adults there is activation of the periaqueductal gray, anterior cingulate, amygdala, and insular cortex. Perfect—these regions are central to pain perception, anger, and disgust.* And then, after a delay, the ventrolateral PFC activates; the more activation, the more the cingulate and insula are silenced and the less subjects report being upset afterward. What's this delayed vlPFC activation about? "Why am I getting upset? This is just a stupid game of catch." The frontal cortex comes to the rescue with perspective, rationalization, and emotion regulation.

Now do the study with teenagers. Some show the adult neuroimaging profiles; these are ones who rate themselves as least sensitive to rejection and who spend the most time with friends. But for most teenagers, when social exclusion occurs, the vlPFC barely activates; the other changes are bigger than in adults, and the subjects report feeling lousier—adolescents lack sufficient frontal forcefulness to effectively hand-wave about why it doesn't matter. Rejection *hurts* adolescents more, producing that stronger need to fit in.[25]

One neuroimaging study examined a neural building block of conformity.[26] Watch a hand moving, and neurons in premotor regions that contribute to moving your own hand become a bit active—your brain is on the edge of imitating the movement. In the study, ten-year-olds watched film clips of hand movements or facial expressions; those most vulnerable to peer influence (assessed on a scale developed by Steinberg)* had the most premotor activation—but only for emotional facial expressions. In other words, kids who are more sensitive to peer pressure are more prepared to imitate someone else's emotionality. (Given the age of the subjects, the authors framed their findings as potentially predictive of later teen behavior.)*

This atomistic level of explaining conformity might predict something about which teens are likely to join in a riot. But it doesn’t tell much about who chooses not to invite someone to a party because the cool kids think she’s a loser.

Another study showed neurobiological correlates of more abstract peer conformity. Recall how the adolescent ventral striatum helps the frontal cortex reappraise social exclusion. In this study, young adolescents most resistant to peer influence had the strongest such ventral striatal responses. And where might a stronger ventral striatum come from? You know the answer by now: you’ll see in the remaining chapters.

EMPATHY, SYMPATHY, AND MORAL REASONING

By adolescence, people are typically pretty good at perspective taking, seeing the world as someone else would. That's usually when you'll first hear the likes of "Well, I still disagree, but I can see how he feels that way, given his experience."

Nonetheless, adolescents are not yet adults. Unlike adults, they are still better at first- than third-person perspective taking ("How would *you* feel in her situation?" versus "How does *she* feel in her situation?").[27] Adolescent moral judgments, while growing in sophistication, are still not at adult levels. Adolescents have left behind children's egalitarian tendency to split resources evenly. Instead, adolescents mostly make meritocratic decisions (with a smattering of utilitarian and libertarian viewpoints thrown in); meritocratic thinking is more sophisticated than egalitarian, since the latter is solely about outcomes, while the former incorporates thinking about causes. Nonetheless, adolescents' meritocratic thinking is less complex than adults'—for example, adolescents are as adept as adults at understanding how individual circumstances impact behavior, but not at understanding systemic circumstances.

As adolescents mature, they increasingly distinguish between intentional and accidental harm, viewing the former as worse.[28] When contemplating the latter, there is now less activation of three brain regions related to pain processing, namely the amygdala, the insula, and the premotor areas (the last reflecting the tendency to cringe when hearing about pain being inflicted). Meanwhile, there is increasing dlPFC and vmPFC activation when contemplating intentional harm. In other words, it is a frontal task to appreciate the painfulness of someone's being harmed intentionally.

As adolescents mature, they also increasingly distinguish between harm to people and harm to objects (with the former viewed as worse); harm to people increasingly activates the amygdala, while the opposite occurs for harm to objects. Interestingly, as adolescents age, there is *less* differentiation between recommended punishment for intentional and unintentional damage to objects. In other words, the salient point about the damage becomes that, accidental or otherwise, the damn thing needs to be fixed—even if there is less crying over spilled milk, there is no less cleaning required.*

What about one of the greatest things about adolescents, with respect to this book's concerns—their frenzied, agitated, incandescent ability to feel someone else's pain, to feel everyone's pain, to try to make everything right? A later chapter distinguishes between sympathy and empathy—between feeling *for* someone in pain and feeling *as* that someone. Adolescents are specialists at the latter, where the intensity of feeling *as* the other can border on *being* the other.

This intensity is no surprise, being at the intersection of many facets of adolescence. There are the abundant emotions and limbic gyrations. The highs are higher, the lows lower, empathic pain scalds, and the glow of doing the right thing makes it seem plausible that we are here for a purpose. Another contributing factor is the openness to novelty. An open mind is a prerequisite for an open heart, and the adolescent hunger for new experiences makes possible walking miles in lots of other people's shoes. And there is the egoism of adolescence. During my late adolescence I hung out with Quakers, and they'd occasionally use the aphorism "All God has is thee." This is the God of limited means, not just needing the help of humans to right a wrong, but needing you, you only, to do so. The appeal to egoism is tailor-made for adolescents. Throw in inexhaustible adolescent energy plus a feeling of omnipotence, and it seems possible to make the world whole, so why not?

In chapter 13 we consider how neither the most burning emotional capacity for empathy nor the most highfalutin moral reasoning makes someone likely to actually do the brave, difficult thing. This raises a subtle limitation of adolescent empathy.

As will be seen, one instance where empathic responses don't necessarily lead to acts is when we think enough to rationalize ("It's overblown as a problem" or "Someone else will fix it"). But feeling too much has problems as well. Feeling someone else's pain is painful, and people who do so most strongly, with the most pronounced arousal and anxiety, are actually *less* likely to act prosocially. Instead the personal distress induces a self-focus that prompts avoidance—"This is too awful; I can't stay here any longer." As empathic pain increases, your own pain becomes your primary concern.

In contrast, the more individuals can regulate their adverse empathic emotions, the more likely they are to act prosocially. Related to that, if a distressing, empathy-evoking circumstance increases your heart rate, you're less likely to act prosocially than if it decreases it. Thus, one predictor of who actually acts is the ability to gain some detachment, to ride, rather than be submerged, by the wave of empathy.

Where do adolescents fit in, with their hearts on their sleeves, fully charged limbic systems, and frontal cortices straining to catch up? It's obvious. A tendency toward empathic hyperarousal that can disrupt acting effectively.[29]

This adolescent empathy frenzy can seem a bit much for adults. But when I see my best students in that state, I have the same thought—it used to be so much easier to be like that. My adult frontal cortex may enable whatever detached good I do. The trouble, of course, is how that same detachment makes it easy to decide that something is not my problem.

ADOLESCENT VIOLENCE

Obviously, the adolescent years are not just about organizing bake sales to fight global warming. Late adolescence and early adulthood are when violence peaks, whether premeditated or impulsive murder, Victorian fisticuffs or handguns, solitary or organized (in or out of a uniform), focused on a stranger or on an intimate partner. And then rates plummet. As has been said, the greatest crime-fighting tool is a thirtieth birthday.

On a certain level the biology underlying the teenaged mugger is similar to that of the teen who joins the Ecology Club and donates his allowance to help save the mountain gorillas. It's the usual—heightened emotional intensity, craving for peer approval, novelty seeking, and, oh, that frontal cortex. But that's where similarities end.

What underlies the adolescent peak in violence? Neuroimaging shows nothing particularly distinct about it versus adult violence.[30] Adolescent and adult psychopaths both have less sensitivity of the PFC and the dopamine system to negative feedback, less pain sensitivity, and less amygdaloid/frontal cortical coupling during tasks of moral reasoning or empathy.

Moreover, the adolescent peak of violence isn't caused by the surge in testosterone; harking back to chapter 4, testosterone no more causes violence in adolescents than it does in adult males. Moreover, testosterone levels peak during early adolescence, but violence peaks later.

The next chapter considers some of the roots of adolescent violence. For now, the important point is that an average adolescent doesn't have the self-regulation or judgment of an average adult. This can prompt us to view teenage offenders as having less responsibility than adults for criminal acts. An alternative view is that even amid poorer judgment and self-regulation, there is still enough to merit equivalent sentencing. The former view has held in two landmark Supreme Court decisions.

In the first, 2005's *Roper v. Simmons*, the Court ruled 5–4 that executing someone for crimes committed before age eighteen is unconstitutional, violating the Eighth Amendment ban on cruel and unusual punishment. Then in 2012's *Miller v. Alabama*, in another 5–4 split, the Court banned mandatory life sentences without the chance of parole for juvenile offenders, on similar grounds.[31]

The Court's reasoning was straight out of this chapter. Writing for the majority in *Roper v. Simmons*, Justice Anthony Kennedy said:

> First, [as everyone knows, a] lack of maturity and an underdeveloped sense of responsibility are found in youth more often than in adults and are more understandable among the young. These qualities often result in impetuous and ill-considered actions and decisions.[32]

I fully agree with these rulings. But, to show my hand early, I think this is just window dressing. As will be covered in the screed that constitutes chapter 16, I think the science encapsulated in this book should transform every nook and cranny of the criminal justice system.

A FINAL THOUGHT: WHY CAN'T THE FRONTAL CORTEX JUST ACT ITS AGE?

As promised, this chapter's dominant fact has been the delayed maturation of the frontal cortex. Why should the delay occur? Is it because the frontal cortex is the brain's most complicated construction project?

Probably not. The frontal cortex uses the same neurotransmitter systems as the rest of the brain and uses the same basic neurons. Neuronal density and complexity of interconnections are similar to the rest of the (fancy) cortex. It isn't markedly harder to build frontal cortex than any other cortical region.

Thus, it is not likely that if the brain "could" grow a frontal cortex as fast as the rest of the cortex, it "would." Instead I think there was evolutionary selection for delayed frontal cortex maturation.

If the frontal cortex matured as fast as the rest of the brain, there'd be none of the adolescent turbulence, none of the antsy, itchy exploration and creativity, none of the long line of pimply adolescent geniuses who dropped out of school and worked away in their garages to invent fire, cave painting, and the wheel.

Maybe. But this just-so story must accommodate behavior evolving to pass on copies of the genes of individuals, not for the good of the species (stay tuned for chapter 10). And for every individual who scored big time reproductively thanks to adolescent inventiveness, there've been far more who instead broke their necks from adolescent imprudence. I don't think delayed frontal cortical maturation evolved so that adolescents could act over the top.

Instead, I think it is delayed so that the brain gets it right. Well, duh; the brain needs to "get it right" with all its parts. But in a distinctive way in the frontal cortex. The point of the previous chapter was the brain's plasticity—new synapses form, new neurons are born, circuits rewire, brain regions expand or contract—we learn, change, adapt. This is nowhere more important than in the frontal cortex.

An oft-repeated fact about adolescents is how "emotional intelligence" and "social intelligence" predict adult success and happiness better than do IQ or SAT scores.[33] It's all about social memory, emotional perspective taking, impulse control, empathy, ability to work with others, self-regulation. There is a parallel in other primates, with their big, slowly maturing frontal cortices. For example, what makes for a “successful” male baboon in his dominance hierarchy? *Attaining* high rank is about muscle, sharp canines, well-timed aggression. But once high status is achieved, *maintaining* it is all about social smarts—knowing which coalitions to form, how to intimidate a rival, having sufficient impulse control to ignore most provocations and to keep displacement aggression to a reasonable level. Similarly, as noted in chapter 2, among male rhesus monkeys a large prefrontal cortex goes hand in hand with social dominance.

Adult life is filled with consequential forks in the road where the right thing is definitely harder. Navigating these successfully is the portfolio of the frontal cortex, and developing the ability to do this right in each context requires profound shaping by experience.

This may be the answer. As we will see in chapter 8, the brain is heavily influenced by genes. But from birth through young adulthood, the part of the human brain that most defines us is less a product of the genes with which you started life than of what life has thrown at you. Because it is the last to mature, by definition the frontal cortex is the brain region least constrained by genes and most sculpted by experience. This must be so, to be the supremely complex social species that we are. Ironically, it seems that the genetic program of human brain development has evolved to, as much as possible, free the frontal cortex from genes.