THE WALRUS
FRIDAY, JANUARY 26, 2007

The Teenage Brain

Why adolescents sleep in, take risks, and won't listen to reason

BY NORA UNDERWOOD

Illustration by Josh Cochran

In his speech at the launch of the 1997 I Am Your Child campaign, director and actor Rob Reiner stated that "by the age of ten, your brain is cooked." And until recently, most child experts, including Dr. Spock, would have agreed. They considered the first few years of a child's life to be the most important — and the experiences a child had during those years to play a crucial role in defining the kind of person he or she would ultimately become. That understanding also helped create a whole generation of obsessively child-focused parents, who, with the best of intentions, have tried to cram a lifetime of "educating" into a few short years, subjecting their unwitting fetuses to a diet of Eine kleine Nachtmusik and their pre-verbal toddlers to basic arithmetic and multiple viewings of Baby Einstein dvds. (A wise elementary-school principal once noted, "I very much doubt Einstein was doing any of this when he was young.")

Somewhere along the line, or so many of us believed, the window of opportunity would close. The foundations of the adult-to-be would be laid, and the worst damage would be done. The majority of brain development does, in fact, take place in the early years, when billions of synaptic circuits that will last the child's lifetime are forming. But growth and change don't end there. Important developmental changes, scientists are discovering, are still taking place in a big way through the adolescent years — and into the mid-twenties. Perhaps this helps to explain the growing phenomenon of adult children who linger on under the parental roof;

their growing may not be over, despite their arrival at “adulthood.”

In recent years, researchers have finally been able to get real insight into the workings of the brain thanks to magnetic resonance imaging (mri), using the technology to map blood flow to the areas of the brain that are activated by exposure to various stimuli. By scanning the same group of adolescents over a period of years or by comparing the brain responses of teenagers to those of adults, researchers are putting together a portrait of adolescence that confirms what many parents have always suspected: adolescents might as well be a whole different species. They are, as one neuroscientist puts it, a “work-in-progress.”

Over the past decade, scientists have started to grasp exactly how distinctive the adolescent brain is and how crucial the years between ten and twenty- five are in terms of its development. And their discoveries have implications not only for parents, educators, and the medical community but also for policymakers. “I wouldn’t disagree with Rob Reiner that the first three years are important,” says Jay Giedd, chief of brain imaging in the child-psychiatry branch of the National Institute of Mental Health in Bethesda, Maryland. “I would just say that so are the next three and the next three and the next three, up to twenty-five and perhaps even beyond.”

This news may not come as a surprise to the mother who still lies awake at 3 a.m., waiting for her basement-dwelling, twenty-two-year-old post-grad son to come home. What science suggests is that “adulthood” as we have defined it doesn’t necessarily signal the end of childhood development — or of parental worries.

If the media is to be believed, the stereotypical teen is a selfish, volatile, rude, rebellious hormone-head, capable of little more than taking outrageous risks, ingesting too many harmful substances (legal and otherwise), committing crimes, crashing parties, trashing houses, and generally being a layabout. Of course, this is a gross misrepresentation: many teenagers pass through adolescence smoothly and happily, without becoming parents themselves, dropping out of school, or acquiring a criminal record instead of a degree. Still, there’s a stubborn tendency in the culture to ascribe every negative teen moment to “hormones.” Recent brain research, however, relieves hormones of much of the blame for this period of “storm and stress,” as psychologist G. Stanley Hall, father of adolescent research, called it.

The full extent to which hormones actually influence adolescent behaviour remains unknown. So is what role they play in brain development. Hormones are certainly responsible for the most obvious hallmarks of puberty; at some mysterious point in a child’s

life, a protein called kisspeptin causes the hypothalamus — an area in the brain that orchestrates certain autonomic nervous-system functions — to secrete the gonadotropin-releasing hormone, which sets the pubertal changes in motion. Ultimately, estrogen and testosterone are responsible for the physical transformations — breast and genital development, body-hair growth, deepening of the voice, and so on — but by no means all the behavioural changes of adolescence. Hormones may have nothing to do with the fact that your daughter can't bear your singing voice, for instance; it's a safe bet, however, that a teenager's fixation on sex and social standing is pretty much hormone related.

But puberty does have an impact on how they think. For instance, as Giedd points out, boys fairly predictably base their decisions on the question "Will this lead to sex? " Giedd adds: "They may not say it in that way or it may not be that blatant, but if you just sort of go with that model it works pretty well." When girls make decisions, he adds, they are more likely to keep the social group, and their place in it, in mind. But Giedd feels that puberty's influence doesn't extend much outside that realm. "Your ability to do a logic problem or to do geometry or to do other things seems to be more [related to] age itself." Researchers have also found that the onslaught of testosterone in both male and female adolescents at puberty literally swells the amygdala — the brain centre associated with the emotions. Perhaps we can blame the amygdala for the slammed doors and sudden tears that overcome previously sunny children when they hit adolescence.

So hormones are not the only players in the changes that characterize adolescence. And while it is difficult to tease out the varying roles played by chromosomes, hormones, and other factors in teen behaviour, the insights that mri reveals are nothing short of astounding.

Jay Giedd has been using mri since 1991 to understand how the brain develops from childhood through adolescence and into early adulthood. He has scanned the brains of about 1,800 children, teenagers, and young adults every two years and interviewed them about their lives and feelings. As it turns out, Dr. Spock was not entirely wrong: by the time a child reaches the age of six, the brain is 90 to 95 percent of its adult size. But massive changes continue to take place for at least another fifteen years. They involve not just the familiar "grey matter," but a substance known as "white matter," the nerve tissue through which brain cells communicate — literally the medium that delivers the messages. White matter develops continuously from birth onward, with a slight increase during puberty. In contrast, grey matter — the part of the brain responsible for processing information, or the "thinking" part — develops quickly during childhood and slows in adolescence, with the frontal and temporal lobes the last to mature.

And this is the crux: the frontal lobe, or more precisely the prefrontal cortex, is the home of the so-called “executive functions” : planning, organization, judgment, impulse control, and reasoning. The part that should be telling the sixteen-year-old not to dive off the thirty- foot cliff into unknown water. The seat of civilization.

What Giedd has witnessed via mri is a constant push and pull in the grey matter. Certain forces cause a process known as arborization, during which grey matter gets bushier and grows new dendrites. Balancing that is a regressive pull, a competition for survival of sorts, in which some branches of the grey matter thrive while others are sacrificed. Both processes are continuous; as some new pathways grow, others are being pruned back. The quantity of grey matter peaks in girls around the age of eleven and in boys around thirteen, after which the amount of white matter increases. As grey matter decreases, there is also an increase in myelination, a process during which neurons, or nerve fibres, are insulated to enhance their performance.

In the end, though, the amount of grey matter isn’t really the issue. “It’s much more related to quality than quantity,” explains Giedd. “This pruning process is normal and natural and healthy in terms of optimizing the brain for different environments. Our brains are built to be very adaptable during the teen years” — just the time when children start to figure out how to make it in the world. “The brain is incredibly plastic, which allows us to make it at the North Pole or the equator, to use a computer versus hunting with a stick. The teen brain is able to make changes depending on the demands of the environment.” (This might explain a thirteen- year-old’s ability to easily master new technology while parents struggle with the TV remote.)

What determines the fate of a cell is whether it has made a meaningful connection with other cells. This is a real use-it-or-lose-it process. As some scientists have noted, if an adolescent forgoes reading in favour of lying around on the couch playing video games, those unused synapses will be pruned. Nobel Prize-winning scientist Gerald Edelman has called this “neural Darwinism” — the survival of the fittest synapses. So scientists know that different activities — playing sports, speaking a second language, drinking, smoking, and so on — influence how the adolescent’s brain will ultimately be wired, though they aren’t clear what the implications are: Is the pianist going to do better in life than the crossword- puzzle fiend? Will the jock have a leg up, brain-wise, on the geek? “Can you actually see changes in the brain of someone doing music? The answer to that is yes,” says Giedd. “But is that a good thing particularly? Is it just that our brains will become specialized in whatever we spend our time doing or is there a more general benefit?”

A father compliments his thirteenyear- old daughter on her new dress, only to have her swivel around, glare at him, and hiss, “What’s that supposed to mean?” Nervous parents can rarely tell when an adolescent is going to fly off the handle. Why do they often have such hair-trigger responses? Two different mri studies indicate that teenagers do not process emotion the same way adults do. In fact, one study shows that the adolescent brain actually reads emotion through a different area of the brain. Dr. Deborah Yurgelun-Todd, director of neuropsychology and cognitive neuroimaging at McLean Hospital in Belmont, Massachusetts, has scanned both adults and teenagers as they were shown images of faces that are clearly expressing fear. All the adults correctly identified the emotion; many of the teens got it wrong (about half labelled the expression one of “shock,” “sadness,” or “confusion”). Yurgelun-Todd found that during the scan of the adults, both the limbic area of the brain — the area especially connected to emotions — and the prefrontal cortex lit up. When teens were seeing the same pictures, the limbic area was bright but there was almost no activity in the prefrontal cortex. They were having an emotional response essentially unmediated by judgment and reasoning.

In another brain-imaging study, Daniel Pine, a researcher at the National Institute of Mental Health, tried to determine how the brain was able to stay focused on a task while the subject was being exposed to faces that were registering strong emotion. The result: activity in the frontal cortex of the adults was steadier, indicating they were better able to stay on task than teenagers. The emotional faces seemed to activate key areas in the brains of both age groups but only the adults were able to mute that activity so they could stay focused. Teenagers are more at the mercy of their feelings.

There is another fascinating phenomenon that plays havoc with the family of a teen: the adolescent sleep pattern. Suddenly, the kid who always woke you up at sunrise, when you were desperate to sleep, turns thirteen or fourteen and can neither be dragged from bed in the morning nor forced into it at night. Making matters worse, this change invariably occurs as the sleep needs of the middle-aged parents are flipping around the other way. It may seem like just another case of teenage passive aggression, but it’s just biology; the circadian rhythm of the brain has changed and teenagers simply don’t want to — or can’t — go to bed before 12 or 1 a.m.

Why this happens has been the focus of some interest. Researchers at Brown University and Bradley Hospital in Providence, Rhode Island, measured the amount of melatonin, the hormone that helps regulate the sleep-wake cycle, in teenagers’ saliva over the course of the

day. They discovered that the levels of the hormone increased later in the day and decreased later in the morning in teenagers than in adults and children. A separate study indicated that the biological trigger for sleep — called the sleep pressure rate — slowed down during adolescence.

So if teenagers appear to be cycling through the day at a different pace from the rest of the world, it's because they are. In fact, because they are waking up when the world dictates — rather than when their bodies tell them to — teenagers are chronically sleep-deprived, which can have consequences ranging from superficial to severe. For starters, as Carlyle Smith, a psychology professor at Trent University in Peterborough, Ontario, who has studied how the adolescent brain processes information during sleep, notes, "They're just sleepy." They go to school tired, unfocused, and — because nobody likes to eat breakfast when they'd rather be sleeping — typically unfed. And as many teachers can attest, teenagers are also generally less able to absorb information in the morning. But by later in the afternoon, as the rest of the world is struggling not to nod off at their desks, teenagers begin to fire on all cylinders. "[As an adult], your temperature is at its high point shortly after lunch," explains Smith, "and then it starts its way down and drops all night until 3 or 4 a.m., when it starts to go up again. Theirs doesn't reach its height until later in the day." As a result, teenagers are just starting to focus and become more verbally adept as the rest of the world is crashing. By midnight, while the rest of the family is doing its best to fall asleep, teenagers are wide awake and instantmessaging away.

What is the fallout from a world that runs against the adolescent clock? There are four non-rem stages of sleep, and stages three and four, the deepest, which occur during the first third to first half of the night, are particularly useful to adolescents, who still have those frontal lobes to myelinate and lots of overall growing left to do (growth hormone is released during deep sleep). But because teenagers are so often deprived of rem sleep, which occurs during the last part of the night, their memories can suffer; they lose out on the stage of sleep that sees the information they've absorbed throughout the day replayed and consolidated. "Kids should be getting over nine hours of sleep," says Smith. "Most are getting one to two hours less than they should. They're missing quite a chunk of rem sleep and that's important for understanding new things. If you don't get much rem sleep, you're not going to learn as fast as people who do."

In one study, Smith set his subjects, who ranged in age from eighteen to twenty-two, to learning a logic task and then deprived them of the last half of the night of sleep. A week later, after the participants had recovered, the researchers tested them again. All had forgotten between 20 and 30 percent of what they'd learned. Once in a while, this kind of sleep loss is no problem. People can catch up. But when sleep deprivation becomes chronic,

the consequences are compounded. “You’re forgetting 20 percent, but 20 percent every day,” says Smith. “And that goes on for months and months and months. That’s an inefficient system.”

Chronic sleep deprivation also increases the risk of developing depression (though, paradoxically, if someone is already depressed, sleep deprivation tends to help them feel better). This is a particularly serious issue for adolescents, as certain mental-health disorders tend to manifest themselves during these years. “There’s so much confusion over this,” Smith admits, “but one of the worries is if you just keep on with the sleep deprivation, eventually [that person] will become depressed. And we’re seeing a lot more depressed kids around now.”

But it’s not easy to fight nature; perhaps the best parents can do is to encourage a slowdown of activity at a reasonable time in the evening, keep technology out of the bedroom and caffeine out of the fridge, and let their kids catch up on weekends.

Most adults know what they’re up against because they remember their own night-owl days. They may have dabbled in rule-breaking, underage drinking, and general wildness as teenagers and now they shudder at the thought of their own children doing the same or worse. They were lucky, but will their kids inherit their luck? (The bad news for former hellraisers: some research suggests a person’s tendency to take risks is partly genetic.)

In fact, there’s some indication that cultivating unhealthy habits through this whole tumultuous period of development can have serious long-term effects. Those who start smoking during adolescence, for example, will likely have a much harder time quitting later in life than those who take up smoking in their twenties; the addiction, according to researchers at Duke University in Durham, North Carolina, appears to get hard-wired during the teen years.

Evidence from some studies also suggests that alcohol is more likely to damage memory and learning ability in the hippocampus of the evolving adolescent brain. At the same time, adolescent rats — whose brains are rela- tively similar to those of adolescent humans — suffer less from some of alcohol’s other effects, including sedation. That sounds like a good thing, but if it is indeed true for adolescents (and for obvious ethical reasons researchers don’t put adolescents through alcohol- related trials), it means they can drink more, and for longer periods — and therefore run a greater risk of long-term damage. Repeated alcohol use during these years may also lead to lasting memory and learning impairment — not to mention the fact that young binge drinkers are more likely to set themselves up with a

lifetime alcohol- abuse problem.

This is one area where brain-research findings have affected how Giedd, the father of four, behaves as a parent. “In terms of substance abuse and alcohol, I’m a lot less hip now,” he says. “I wouldn’t have the mentality of, ‘Oh it’s better to have them do it at home.’ [Adolescence is] a very vulnerable time in brain development to be exposed to these other substances.” Giedd is surprised by how many parents say that their kids are going to drink and take drugs anyway, so they might as well do it at home, in a safe environment. “Biologically, it’s a time when the cement is setting. If people cannot do these things until the age of nineteen, the odds of them not having trouble as adults go up enormously.”

But experimenting, taking risks, and searching for good times are, it would seem, all part of the adolescent picture. As difficult as it is for parents to grasp, adolescents don’t always make poor choices just to get their goats, or because they’re suddenly gripped by temporary insanity. This sort of behaviour appears to be a predictable part of the identity-formation process, which begins in the early years but dramatically accelerates during adolescence. That’s when children begin playing different roles, trying on different hats, figuring out if they’re gay, straight, or bisexual, whether they’re a geek, a jock, or cool. At the same time, their frontal lobes aren’t fully developed, which means that the appetite for experimentation doesn’t necessarily go along with the capacity to make sound judgments or to see into the not-so-distant future. In other words, by their very nature, teenagers are not especially focused on, or equipped to assess, the consequences of their actions.

A 2004 mri study suggested that adolescent brains are less active than those of adults in regions that motivate reward-based behaviour. James Bjork, a neuroscientist at the National Institute on Alcohol Abuse and Alcoholism, and his colleagues conducted a brain scan on twelve adolescents between the ages of twelve and seventeen and a dozen adults aged twenty-two to twenty- eight. During the scan, the participants responded to targets on a screen by pressing a button; the object was to win (or avoid losing) varying amounts of money. The researchers found that areas of the brain associated with seeking gain lit up in both age groups. But in the adolescents, there was less activity. Adults, says Bjork, may have developed circuitry that enables them to motivate themselves to earn relatively modest rewards — the satisfaction felt after volunteering at church, say, or walking through a ravine. Adolescents, on the other hand, “may need activities that either have a very high thrill payoff or reduced effort requirement or a combination of the two.” Examples, he adds, would be “sitting on the couch playing violent video games or sitting on the couch and pounding alcohol.”

Even if, in quiet conversation, teenagers understand the risks of certain actions — drinking and driving, sex without protection, jumping off cliffs — when the moment of truth actually arrives, reason can be shot to hell. In the heat of the moment, the limbic area of the brain lights up like a pinball machine while the prefrontal cortex, the good angel that tamps down intense feeling and helps us navigate through emotional situations, is essentially asleep. In addition, experts have found that teenagers have a higher level of dopamine, a neurotransmitter connected to pleasure, movement, and sexual desire, which may increase the need for extra stimulation through risk-taking.

Some teenagers slide through adolescence unscathed. But there's no doubt that adolescents in the throes of hormone surges and brain development are extremely vulnerable — to making poor choices, to mental-health problems, to death and injury. A quick look at the statistics paints a troubling picture. According to Statistics Canada, adolescents between fourteen and nineteen are more likely to commit property crimes and violent offences than any other age group; 25 percent of teenagers reported binge drinking at least once a month in 2000-2001, a rate second only to the twenty- to thirty-four-year-olds. During that same period, the pregnancy rate for girls between fifteen and nineteen was thirty-six out of 1,000. Most discouraging is the suicide rate for teenagers: currently about eighteen for every 100,000, with the highest rate occurring among teenaged boys (although girls are hospitalized for attempted suicide at a far greater rate than boys).

In fact, the three leading causes of death for teenagers in North America are accidents, suicide, and homicide. Unsurprisingly, the majority of accidents involve motor vehicles; in 2004, in the United States, about 20 percent of accidents that resulted in fatalities were due to a driver who had a high blood-alcohol level. According to the Insurance Institute for Highway Safety, injuries suffered by teenagers in car crashes have become a pressing public-health problem. Sixty-two percent of teenage passenger deaths in 2004 occurred when another teenager was driving. And teenage drivers are more likely to be at fault in crashes.

All of which is not going to make parents sleep any better — if indeed they can get to sleep in the first place.

Teenage speeding, irresponsibility, and status-seeking are not the only explanations for the statistics (though teenagers have been shown to take greater risks behind the wheel when their friends are with them). In fact, they also appear to be at a disadvantage because they have not refined the ability to multitask — driving while drinking a beverage, listening to music, talking on a cellphone, or even chatting with a passenger. One sensible response to this, according to many scientists and policy-makers, is graduated licensing, which is already in place everywhere in Canada except Nunavut. In 1996, many American states started to

introduce some aspects of graduated licensing, and according to a 2003 report in the Journal of Safety Research, they have seen a decrease in crash rates.

So if adolescents are a work-in-progress in terms of judgment, should they be held accountable for their crimes in the same way adults are? Recent adolescent brain-development research was used in arguments against the juvenile death penalty in the United States. If adolescents aren't yet fully capable of controlling their emotional responses or understanding the consequences of their actions, groups like the International Justice Project said, then they should not be punishable by death. In March 2005, when the US Supreme Court finally abolished the juvenile death penalty, there were seventythree people on death rows across the United States for crimes they had committed before the age of eighteen. Many brain researchers believe that science should be part of the debate. But, Giedd adds, "it becomes a very slippery slope: the same data that might support abolishing the juvenile death penalty could be used to take away teenagers' ability to make their own reproductive-rights decisions."

Despite these new findings, has brain science told us anything we don't already know? Bjork's answer: "As Jay Giedd says, a lot of what we're finding out in brain research is the neuroanatomical, neurometabolic correlate of what grandma always told you." Indeed, brain mapping has provided proof of a neurological and biological basis for what sometimes ails the stillforming adult (and the adults who love and live with them).

Of great urgency for Giedd and others now is why certain disorders — anxiety and eating disorders, substance abuse, schizophrenia — develop during adolescence, but not autism, adhd, Alzheimer's, and others. "Many of the things that plague adults really do hap- pen during the teen years," says Giedd, "so identifying them early, treating them early, when the brain is more plastic, would seem to make more sense in terms of really having a lifelong impact." Parents are wise not to assume that misery and anxiety are just part of the teenage rite of passage; it may be that serious unhappiness in adolescence is an early-warning sign of adult disorders.

Another task for scientists is to determine which things in a teenager's environment and experience will, for better or worse, influence brain development. "So many things have already been put forward — music, education in general, learning a second language, bacteria, viruses, video games, diet, sleep, exercise," says Giedd, "and all of them are probably true to some extent."

But what the general culture has to offer to teenagers is only one part of the equation. The brain has always been built for learning by example and experience — which experiences lead

to pain, which lead to good outcomes. And for Giedd, that facility is what will give adolescents the best chance to grow up well — the ability to learn from the people around them. “It’s the little things, the day-to-day things that we say in the car or when we’re solving problems, how we handle relationships, emotions, our work ethic,” he says. “They will believe much more what we do than what we tell them.”

In fact, if there is anything parents can take away from all the scientific research into adolescent brain development, it’s that their influence, patience, understanding, and guidance are very necessary — even when the teenager or young adult shrinks away from affection, grunts, slams doors, blasts music, rolls eyes, breaks house rules, and seems incapable of following simple instructions. Developing brains often can’t handle organizational problems; they have more trouble making social, political, and moral judgments; they have to be reminded of potential consequences and carefully directed toward risks that aren’t quite so, well, risky. Developing adults need appropriate amounts of independence, freedom, and responsibility.

“I would say with a clear conscience that the teen brain is different than the adult brain,” says Giedd. “Just as I would feel comfortable saying men are taller than women.” We ignore those differences at our peril, he adds. Teenagers may drive the family car, move away from home, go to college, and spend their early twenties wrestling with life decisions, all of which are a normal part of growing up. But as Giedd says, just because adolescents have left childhood behind, “parents shouldn’t say, ‘My work is done.’”

- Published November 2006

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