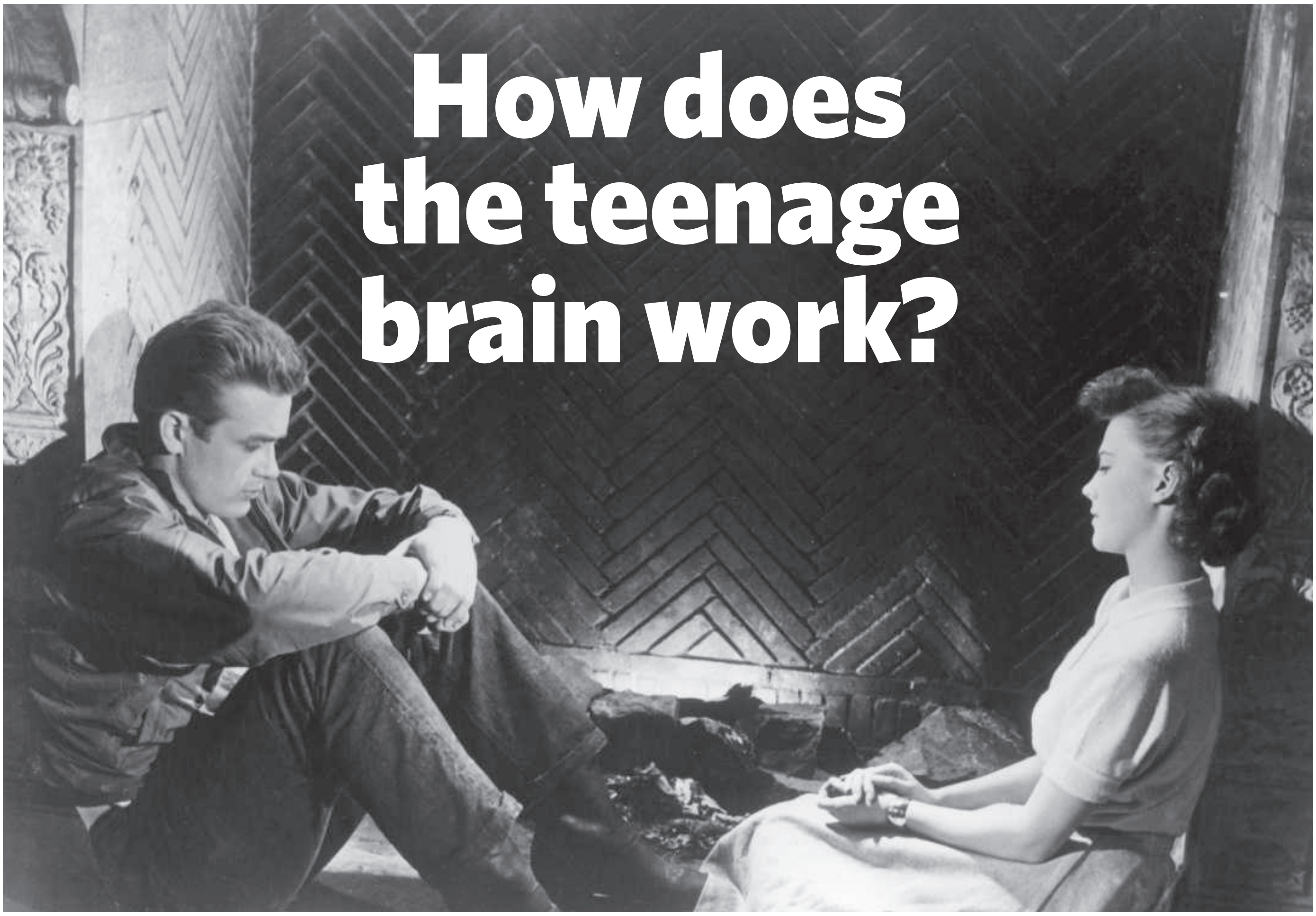


KOBAL COLLECTION

How does the teenage brain work?

Changes in the structure of children's brains may account for some of the risky business of adolescence, **Kendall Powell** finds.

The 14-year-old has a very simple decision to make. When he sees a light out of the corner of his eye he is supposed to ignore it and keep looking straight ahead. It seems extraordinarily easy — even eight-year-olds can do it correctly half of the time — but it requires reigning in a natural impulse to look. And every parent of a teenager knows that reigning in impulses is not their strong suit.

In this simple test, the teenager performs as well as adults do. But a peek inside his head reveals that he puts a lot more work into it. His brain uses a whole host of frontal regions — those involved in planning and executing actions — that adults ignoring something in their peripheral vision just don't need.

"The adolescent brain is acting like an adult brain doing something much more difficult. An adolescent can look so much like an adult, but cognitively, they are not really there yet," says Bea Luna, a neuroscientist at the University of Pittsburgh Medical Center in Pennsylvania. It is her brain scans that have revealed this tendency for teenagers to 'overuse' their frontal brain regions when stopping themselves from looking at the light[1].

Work such as Luna's begins to explain why a teenager can behave maturely on Monday and do something unutterably foolish on Tuesday. Neuroscientists probing the teen brain have found that it undergoes a major remodelling that may be responsible for the teenager's propensity to take risks, seek out new experiences and fail to restrain inappropriate responses. Their work suggests that, even before you add raging hormones and peer-group-driven rebelliousness-without-a-cause to the mixture, teenagers may simply be unable consistently to make decisions the same way adults do. This could well be one of the reasons that, although most people are healthier during their adolescence than at any other time in their lives, adolescents are three or four times more likely to die than children past infancy[2]: they take risks, have accidents and pay the prices.

"An adolescent can look so much like an adult, but cognitively, they are not really there yet." — Bea Luna

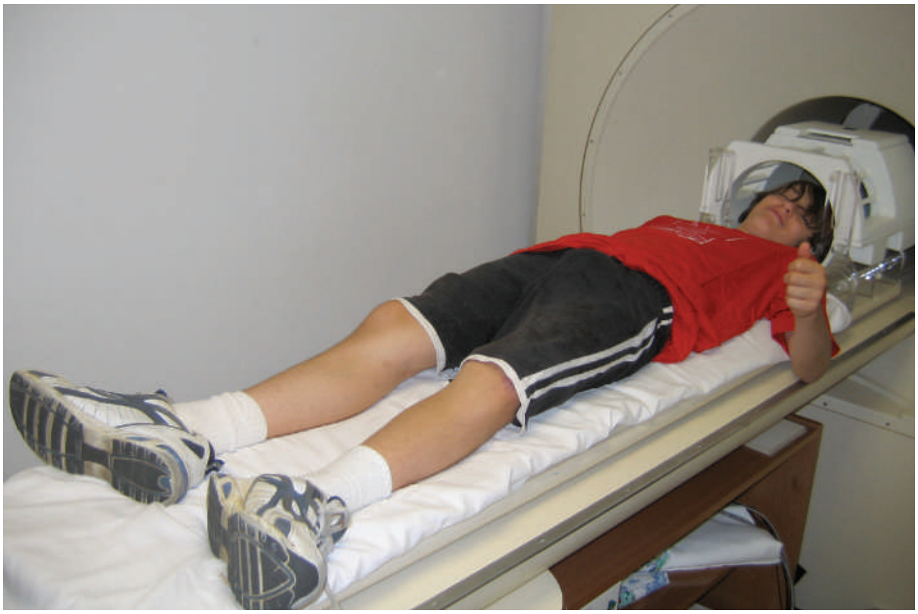
The teenage years turn out to be a complicated time in the brain, with cells fighting it out for survival and the connections between different regions being rewired and upgraded. Some abilities, such as quashing offensive behaviour and empathizing with others, keep maturing well into the twenties. The passage from childhood to adulthood is not straightforward: some researchers now see the teenage remodelling as analogous to the 'developmental window' that allows the brain to be moulded by experience in infancy. There are ways in which teenage brains perform quite differently from either childish or adult ones.

No one is saying that a desire to yak endlessly on the phone, sneak out of the house or throw yourself off the side of a mountain on a snowboard in the gnarliest way possible is purely a function of neural architecture. But the brain changes tracked by neuroscientists offer parents, teachers and any other caring adult insights in how to help teenagers avoid too much danger. And such studies look likely to enrich scientific explanations of teenage vulnerability to depression, addiction, eating disorders and schizophrenia.

By around the age of 12, a child's brain has the size, folding, weight and regional specialization of an adult's. But a decades-long study conducted by the US National Institute of Mental Health (NIMH) in Bethesda, Maryland, has shown that such a brain still has a long way to go to reach adulthood. Begun in 1991, the study has followed 2,000 people who were then aged from 3 to 25, taking brain scans every 2 years. The study uses magnetic resonance imaging (MRI) to measure the water-to-fat content of tissues: in the brain, this distinguishes grey matter, which is mostly water-filled nerve cell bodies, from white matter, which is mostly made up of the nerve connections sheathed in fatty insulation called myelin.

The NIMH research team, led by Jay Giedd, has made a movie of normal brain changes from ages 5 to 20 (ref. 3). It reveals that the grey matter thickens in childhood but then thins in a wave that begins at the back of the brain and reaches the front by early adulthood (see graphic, below). The process completes itself sooner in girls than in boys. This corresponds to a long-held assumption that adolescence sees the prefrontal cortex regions that handle executive functions 'waking up' and to the conventional wisdom that girls mature faster in this respect.

But, Giedd says, "the real message is that what is important is the journey, not the destination". His studies and others show that measuring the shape or size of a certain region in an adult can mislead: what really counts is the developmental trajectory that gets you there. Earlier this year, the team showed that a more pronounced wave of grey-matter thinning corresponds to higher intelligence[4].



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Functional MRI scanning requires this teenager to adopt a favourite position.

Use it or lose it

Giedd and many other neuroscientists think the grey-matter thinning seen during adolescence is probably due to 'synaptic pruning' — the process of eliminating overabundant, unnecessary nerve cell connections. If synaptic pruning is accelerated during adolescence, says Giedd, it follows that this is a time of 'use it or lose it' in the brain. The more environmental input there is to guide that pruning, he says, the better. On the same basis he argues that less guidance could result in a brain less able to react to complex situations, as could uncontrolled pruning: preliminary studies show that childhood schizophrenics have an exaggerated loss of grey matter during adolescence[5].

Giedd takes this to imply that teens should be exposed to rich environments full of sports, travel, music and foreign languages. In the past decade, most efforts to provide brains with extra stimulation focused on the first five or six years of life. This new work, says Giedd, should argue for an equally critical period of brain plasticity in adolescence.

However, Elizabeth Sowell, a neuroscientist at the University of California, Los Angeles, cautions against making direct connections between brain changes and specific teen behaviours. "Jay likes to say 'use it or lose it' and that we should put kids in enriched environments. That makes perfect intuitive sense, but we just don't have the data to say that."

Tomáš Paus, director of the Brain and Body Centre at the University of Nottingham, UK, adds a further note of caution, warning that researchers should be careful not to simplify the brain–behaviour relationship into a one-way street. Behaviour almost certainly influences final brain structure, too; indeed, this is what Giedd's current research is looking at. But Paus agrees the research has shown that the "brain continues to mature way beyond the first 3 to 5 years of life". Referring to a popular pre-school 'enrichment' programme in the United States, he says: "We sorely need a Head Start programme at the beginning of adolescence. Things are not carved in stone by that age. Our field's observations show that you can induce long-lasting changes that are entered into the brain."

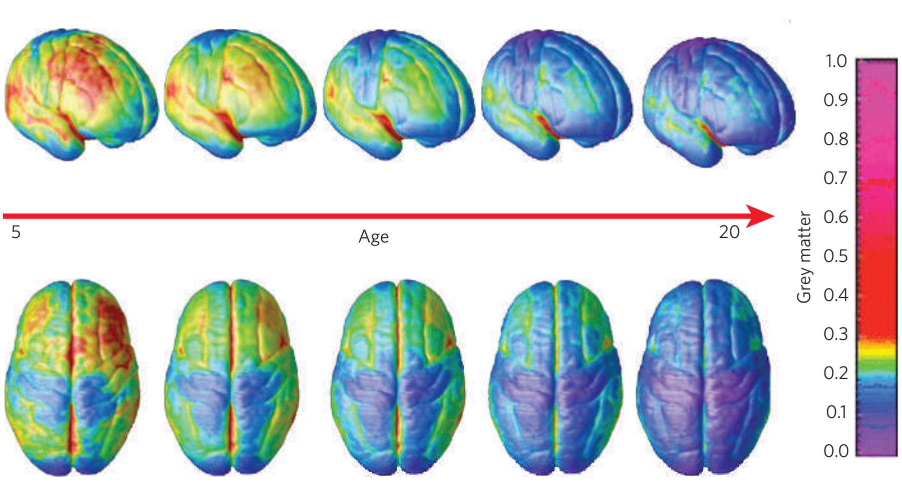
As grey matter thins, white matter is being gained, as layers of insulating myelin are added to the axon connections between nerve cells. George Bartzokis, a neuroscientist at the University of California, Los Angeles, has found that such 'myelination' follows an inverted 'U' shape over our lifetimes, peaking at around age 50 (ref. 6). The teen years are on the early stages of the steep upward curve of myelination.

Bartzokis see this as facilitating connections between different parts of the brain: if you want to retrieve pertinent information quickly to make a decision, he argues, you don't want a supercomputer "but rather a fast Internet". Information held in different centres of the brain has to be 'online' or retrievable, and retrieving lots of it quickly requires increased processing speed and bandwidth. Myelination provides this by increasing the speed of signals travelling along axons and decreasing the time to the next nerve impulse.

"Two years from now, my daughter will be 16, and my car insurance bill will double," notes Bartzokis, even though she probably knows the rules better and has quicker reflexes than he does. "But she will still have a much higher risk of getting into an accident because she can't instantly bring knowledge to bear in a situation like I do." What we call wisdom, Bartzokis says, requires maximum myelination.

J. GIEDD

Brain wave: how adolescents lose grey matter.



G. PALMER/CORBIS

Listen to reason? He might not be able to.

approach 'troubled' kids. "I don't think we can fight the biology of wanting to take risks and try on different identities. Those are good things," says Giedd. "But how do you have outlets that don't give teens STDs, car accidents, drug abuse or jail? As a society, we can give kids creative, positive outlets that do not lead to irreversible mistakes." Attempts to push kids towards safe sex or pharmaceutical temperance shouldn't be expected to succeed if they simply explain consequences. "Adolescents have some fundamental qualities to them that are not voluntary and not easily modified by rational, information-based interventions," says Laurence Steinberg, a developmental psychologist at Temple University in Philadelphia.

Abigail Baird, director of the laboratory for adolescent science at Vassar University, in Poughkeepsie, New York, and her graduate student Craig Bennett mapped white matter in the brains of first-year undergraduates and then looked again six months later to see if anything had changed. They found subtle but significant additions: five brain regions gained white matter, including frontal areas that prepare for action and form strategies, and other areas that integrate sensory input, emotions, body state and context[7]. A control group of postdocs showed no such changes. "It's the stuff that allows you to put yourself in another's shoes or have empathy in the broad sense," explains Baird.

But she adds a strong note of caution about her work — it only shows a correlation between brain development and the ability to empathize. "We can't prove that the changes we saw do anything to cause certain behaviours. It's important to remember that this is a little bit of a 'Just So' story."

Brain at work

If the adolescent brain differences were only a matter of getting the correct grey-matter-to-white-matter balance, the story might end here. But the plot thickens with the work of Luna's group, which uses functional MRI (fMRI) to measure activity in different regions of the brain by tracking blood flow. Connecting her work on the 'overuse' of the teenager's frontal lobes to Giedd's ideas, Luna associates the onset of adulthood with an integration of the frontal regions with other areas of the brain — a move from local-area networks to wide-area networks, in computer terms. Myelination is probably part of the process, but not all of it: if it were, peak brain efficiency would not be seen until late middle age.

Other functional studies link changes in the brain to teenagers' increased appetite for fast cars and other dangerous thrills. B. J. Casey's group at Weill Medical College of Cornell University in New York has measured brain activity in subjects who perform a simple task and then get small, medium or large rewards for performing correctly. In adolescents given a medium or large reward, a centre in the brain called the nucleus accumbens reacted more strongly than in children or adults[8]. That looks like an exaggeratedly positive reaction. When given the small reward, the teenage accumbens response decreased below that of children and adults — as if the small reward represented no reward at all in the teen's view.

"It's important to remember that this is a little bit of a 'Just So' story." — Abigail Baird

Like Luna, Casey sees a more diffuse pattern of activity in the teenage frontal regions than in those of adults. A reward centre on overdrive coupled with planning regions not yet fully functional could make an adolescent an entirely different creature to an adult when it comes to seeking pleasure.

"If it were just that the prefrontal cortex was lagging behind, then children would be as risk-taking as teens, and we don't see that," says Casey. She goes on to speculate that the lag between the frontal regions and the reward centre is an evolutionary feature, not a bug. "You need to engage in high-risk behaviour to leave your village and find a mate," and risk-taking soars at just the same time as hormones drive adolescents to seek out sexual partners. Linda Spear, a behavioural neuroscientist at the State University of New York at Binghamton, says that in rodents, primates and even some birds, adolescence is a time of risky business, seeking out same-age peers and fighting with parents[9], which "all help get the adolescent away from the home territory".

The growing evidence that increased risk-taking is wired into the adolescent brain is beginning to shift the way psychologists approach 'troubled' kids.

Can't wait

And for some kids 'just saying no' will be even harder than for others. Casey, in collaboration with Inge-Marie Eigsti at the University of Connecticut in Storrs, has measured the ability of 4-year-olds to defer gratification by offering them extra cookies if they could leave a first one uneaten for a set period of time. When tested 10 years later, the kids who resisted temptation as pre-schoolers were better at restraining themselves as teenagers[10]. When children are predisposed to listen to their pleasure centres "and then the same system becomes elevated during adolescence", says Casey, "it's a double whammy. Those are the kids we are trying to identify."

Children who show early problems with focusing attention, Casey thinks, may need stronger parental guidance later. But in general she and her colleagues shy away from making specific recommendations on the legal responsibilities, parenting or education of teenagers.

Instead, they tend to emphasize the newfound appreciation for adolescent behaviour their work offers. The next time your quiet reverie in a café is interrupted by a gaggle of teenagers getting their after-school caffeine and sugar fix, as this writer's has just been, take a moment to remember the teenage boy in the MRI scanner, his earnest brain working overtime just to restrain a simple flick of the eyes. Hard work is going on inside those heads. ■

Kendall Powell is a freelance science writer based in Broomfield, Colorado.

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