For years, the teenage brain was seen by researchers, policymakers, and the public as more of a burden than an asset. Adolescents were risk machines who lacked the decision-making powers of a fully developed prefrontal cortex—and liable to harm themselves and others as a result. That narrative is beginning to change.

There is growing recognition that what was previously seen as immaturity is actually a cognitive, behavioral, and neurological flexibility that allows teens to explore and adapt to their shifting inner and outer worlds.

Developmental cognitive neuroscientists are at the frontier of this new outlook, using updated methodology, larger and more diverse samples, and experimental tasks with real-world
Neuroscience of the Teen Brain

relevance to answer questions about adolescents in the context of society. They’re also supporting developmentally informed policy and practice on everything from mental health care to juvenile justice. “The adolescent brain was long portrayed as broken, immature, or contributing to problematic behaviors,” said Eva Telzer, PhD, an associate professor of psychology and director of the Developmental Social Neuroscience Lab at the University of North Carolina, Chapel Hill. “But in the last 5 years, there’s been a huge shift toward seeing

Previously maligned, teenage brains are now getting more positive attention for their healthy developmental activity.

the developing brain as malleable, flexible, and promoting many positive aspects of development in adolescence.”

Heightened sensitivity to rewards, for example, which is partly driven by increased activity in a part of the brain called the ventral striatum, has been implicated in behaviors such as substance use and unprotected sex among teens. But research now shows that in different settings, that same neural circuitry can also promote positive peer influence and behaviors, Telzer said, such as wearing a seat belt or joining a peaceful protest.

As the field of developmental neuroscience matures, so too do the questions researchers ask. Studies are increasingly considering the influence not just of peers but also of parents. Researchers are also looking closely at how social media use may affect young brains, as concerns mount about teens’ online activity. As a result, research on the teenage brain is finally starting to catch up with studies of other age groups, complete with the level of detail it deserves.

“The shift from childhood
to adulthood is not a linear one. Adolescence is a time of wonderfully dynamic change in the brain," said BJ Casey, PhD, a professor of psychology who directs the Fundamentals of the Adolescent Brain Lab at Yale University. “Too often, we’ve superimposed an adult model onto a developing brain, but now we’re starting to see more nuanced findings.”

EMBRACING NEW APPROACHES

Adolescence—spanning from puberty until the mid-20s—describes the transitional period between childhood and adulthood, according to the National Academies of Sciences, Engineering, and Medicine. During this period, the brain grows and changes in a number of ways.

Gray matter in the cerebral cortex tends to thin, while white matter that connects various regions of the brain generally increases in volume. Functional connections between regions, which researchers measure with brain scans that track oxygen usage in blood, also undergo widespread changes during adolescence.

Beyond that, things get a little more complicated—and recent replication efforts indicate that some findings considered fundamental to the field may not hold up in larger samples. For example, early research suggested that brain volume increases peaked earlier in adolescent girls (Lenroot, R. K., & Giedd, J. N., Brain and Cognition, Vol. 72, No. 1, 2010), but more recent studies of large, international samples have shown it’s not that simple. Instead, boys’ brains tend to change at similar rates regardless of variability in other brain metrics, while changes in girls’ brains can be predicted based on certain measurements, such as the thickness of the cortex (Mills, K. L., et al., NeuroImage, Vol. 242, 2021).

“This kind of finding is emblematic of a bigger shift in the field as to how we’re approaching our science, what techniques we use, and what information we consider valuable,” said Jennifer Pfeifer, PhD, a professor of psychology and director of the University of Oregon’s Developmental Social Neuroscience Lab. “It’s become clear that if we want to understand developmental processes within individuals, we need to use some different tactics.”

More sophisticated methodology is a big part of that shift, she added. Instead of merely comparing brain structure or activity between two age groups (12- and 18-year-olds, for instance), researchers are increasingly relying on a variety of experimental approaches that follow the same youth over time.

“Many people may not realize that our early insights about adolescent brain development were based on cross-sectional approaches, which can sometimes lead to the wrong conclusions,” said Pfeifer, who also codirects the National Scientific Council on Adolescence.

Now, researchers use other techniques, such as accelerated longitudinal designs, where participants are sampled a handful of times at a range of ages (starting at ages 12 to 15, for instance, and then annually for 3 years), which can paint a more comprehensive picture of neurodevelopment.

Large collaborative consortia, in particular the Adolescent Brain Cognitive Development (ABCD) Study, a decade-long effort that follows a nationally representative sample of nearly 12,000 teens, are also providing richer data that can power more rigorous studies of the developing brain. The ABCD Study shares its brain scans measuring neurological development, clinical tests of mental and physical health, and behavioral data on substance use, academic achievement, and more with researchers around the world; of about 250 papers published using the survey’s data so far, half were from investigators outside the consortium. Fittingly, one of the study’s early insights is that very large samples—with thousands of individual brain scans—are needed to detect reproducible differences between individuals at the whole-brain level (Marek, S., et al., Nature, Vol. 603, 2022).

“On the other hand, there is still a need for innovative, smaller-scale studies,” said Eveline Crone, PhD, a professor of neurocognitive developmental psychology and director of the Society, Youth and Neuroscience Connected (SYNC) Lab at
Erasmus University Rotterdam in the Netherlands. “If we only ran the big consortia, we would miss out on a lot of novelty in terms of our methods and research questions.”

Some questions—for instance, how adolescents’ brains respond, on average, to winning money for themselves, a family member, or a stranger—can be examined effectively in much smaller samples, pointing to the importance of a balance between large and small efforts (Developmental Cognitive Neuroscience, Vol. 51, 2021). (Crone and her colleagues who conducted this research have found that teen brains show activation in the nucleus accumbens, part of the brain’s reward system, when achieving gains for themselves or their parents but not for strangers. Those findings point to the development of ingroup-outgroup distinctions during adolescence.) Like others in the field, Crone employs a mixed-methods approach, combining brain imaging with behavioral measures, youth panels, and large-scale surveys to contextualize development alongside behavior, relationships, and society.

Another major advance is the creation and use of “ecologically valid” experimental tasks, or those that more accurately mimic teens’ experiences outside the lab.

“If we really want to understand how the adolescent brain works, we need to use stimuli—things like social media and video games—that they actually care about,” said Jennifer Silk, PhD, a professor of psychology at the University of Pittsburgh who runs the Families, Emotions, Neuroscience & Development Lab.

Silk and her colleagues have developed one such activity, called the Chatroom Interact Task, which simulates acceptance and rejection from peers. Teenage girls participating in the task are either “chosen” or “rejected” by other girls their age while undergoing an fMRI scan, which maps brain activity by measuring changes in blood flow and oxygen levels. Other tasks monitor teens while they use platforms similar to Instagram and Facebook, including how their brains respond to receiving “likes.”

Researchers are even collecting data that may redefine the meaning of “adolescence,” with an eye on the juvenile justice system. “We’re expanding the age ranges we’re looking at because the field is recognizing that significant neurocognitive changes continue into the 20s,” said Casey. “Those changes have consequences with regard to..."
decision-making," and research in this area may ultimately inform more scientifically aligned approaches to reward, punishment, justice reform, and other areas.

OPTIMIZING MENTAL HEALTH

Teens are famous for their heightened emotional sensitivity, especially in social interactions. Researchers are starting to pin down brain circuitry linked to that sensitivity—and differentiate between cases where it's an asset that helps teens reach emotional maturity versus a risk factor that may predict mental health problems (Casey, B. J., et al., *Neuroscience Letters*, Vol. 693, 2019).

Research by Silk, Telzer, Casey, and others has identified several areas of the brain that underlie emotional responses in teens, including the subgenual cingulate cortex, anterior insula, and amygdala. For example, teens who had more activity in those regions during the rejection phase of Silk's Chatroom Interact Task, compared with the acceptance phase, were more likely to experience depression and suicidality down the line (Casey, B. J., et al., *Journal of Clinical Child & Adolescent Psychology*, online first publication, 2022; *Child Psychiatry & Human Development*, Vol. 51, 2020). "There seems to be some sensitivity to rejection in this brain network that's related to the development of internalizing disorders," Silk said.

Because mental health problems increase sharply during adolescence—afflicting an estimated 1 in 4 teens—there's an urgent need to determine who is at risk and what treatments may be most effective (Silva, S. A., et al., *PLOS ONE*, Vol. 15, No. 4, 2020).

In animal models, stressful experiences during adolescence appear to alter the development of emotion-focused regions such as the amygdala and hippocampus, as well as the prefrontal cortex (Eiland, L., & Romeo, R. D., *Neuroscience*, Vol. 249, 2013). Early findings from the ABCD Study have found different patterns of activation in the amygdala, anterior cingulate cortex, and other reward-associated brain regions among preteens with disruptive behavior disorders, as well as brain differences that may underlie attention-deficit/hyperactivity disorder (ADHD) (Hawes, S. W., et al., *The American Journal of Psychiatry*, Vol. 178, No. 4, 2021; Bernanke, J., et al., *The Lancet Psychiatry*, Vol. 9, No. 3, 2022).

Rather than searching for a drug or mechanism that can address the entirety of depression, anxiety, or ADHD, researchers are increasingly studying specific symptoms—anhedonia or inattention, for instance—as well as subtypes of various disorders and seeking solutions for each.

"We are now looking at specific behaviors for which we can identify a neural circuit, mechanisms, and sometimes even genes," said Pradeep Bhide, PhD, a professor of developmental neuroscience and director of the Center for Brain Repair at the Florida State University College of Medicine. "That is a newer, better, and likely more successful approach to treating complex human psychiatric and developmental disorders."

For example, adolescents tend to benefit less from fear extinction efforts than adults (Pattwell, S. S., et al., *PNAS*, Vol. 109, No. 40, 2012). According to Casey, this suggests that they may respond poorly to exposure therapy, a key component of cognitive behavioral therapy (CBT) for anxiety, which recruits the prefrontal cortex to reprogram fear memories. It may therefore be possible to optimize CBT to...
work better for adolescents by using strategies that bypass the prefrontal cortex, instead working to alter memories using other circuitry, including emotion- and memory-focused regions such as the hippocampus and amygdala (Scientific Reports, Vol. 5, No. 8863, 2015; Nature Communications, Vol. 7, No. 11475, 2016). This process is often referred to as "memory reconsolidation" or "reconsolidation update."

"Thus, there appear to be developmental windows in which we can optimize treatments in specific ways," Casey said.

PARENTS AND PEERS
When it comes to teens’ relationships, both the scientific community and the lay public have long embraced the assumption that adolescence triggers a shift away from parents and toward peers, particularly when it comes to risk-taking.

New findings are challenging that assumption, which was pervasive but difficult to test directly, Pfeifer said (Nelson, E. E., et al., Psychological Medicine, Vol. 35, No. 2, 2005). Early data from Project NeuroTeen, Telzer’s 5-year longitudinal study of how parent and peer relationships influence adolescent decision-making and development, show that teens shift their behavior to align with the risky choices of parents more than the risky choices of peers. This shift is supported by increased activation in regions of the brain related to reward, including the ventral striatum and ventromedial prefrontal cortex (Journal of Research on Adolescence, Vol. 31, No. 1, 2021).

Silk, Amanda Morris, PhD, of Oklahoma State University, and their colleagues have started to document the synchrony between teens and their parents in real time, using a new simultaneous scanning technique to measure how one brain responds to another during an interaction. They have found that adolescent brain activity tends to mirror parent brain activity, especially in emotion-processing regions such as the amygdala and anterior insula (Child Development, Vol. 92, No. 6, 2021).

“I think a lot of parents believe that it’s too late, that by adolescence, peers have all the power,” Silk said. “But this research is showing that parents shouldn’t give up, that they still do have the power to help their adolescents learn how to process and regulate their emotions.”

Pfeifer’s lab also recently explored the claim that changes in the brain during adolescence make teens more sensitive to social information related to acceptance by peers, but their findings did not clearly support that idea. Instead, they found that activity in regions such as the ventromedial prefrontal cortex—a brain area related to evaluation of the self—tended to peak during mid-adolescence, especially for information related to status (Cosme, D., et al., Developmental Cognitive Neuroscience, Vol. 54, 2022).

These findings may suggest that “identity is an important source of value to adolescents, and this could be leveraged to promote healthy decision-making,” she said (Child Development Perspectives, Vol. 12, No. 3, 2018).

Peer interactions are still important, of course, and they’re increasingly happening online. Parents, researchers, and policymakers have plenty of unanswered questions about how social media use may affect the developing brain. For example, do certain neural profiles among teens predict riskier online behavior, such as the tendency to compare one’s appearance and social status to others?

Silk and Cecile Ladouceur, PhD, of the University of Pittsburgh, have launched new research to bring more nuance to that conversation. They are collecting information about social media use from teens’ phones, along with fMRI data on their neurological responses to acceptance and rejection, for instance during the Chatroom Interaction Task. Telzer has also launched a new effort, with Mitch Prinstein, PhD, APA’s chief science officer, to study whether brain development in regions responsible for reward, emotion, and cognitive control relates to how frequently teens check their social media apps.

“Undoubtedly there’s a link between teens’ social experiences online and the way their brains respond to the environment, but it’s something we’re slowly working to unpack,” Telzer said.

CHALLENGING ASSUMPTIONS ABOUT TEENS
The malleability of the adolescent brain may make it vulnerable at times, but teen brains are also highly capable of prosocial growth under the right circumstances, Pfeifer said. Teens’ biological need for social

FURTHER READING

Why young brains are especially vulnerable to social media
Abra, Z. APA, 2022

A deep dive into adolescent development
Weir, K. Monitor on Psychology, June 2019

Justice for teens

Teens aren’t just risk machines—there’s a method to their madness
Flannery, J., et al. The Conversation, Feb 6, 2018
connection, combined with their heightened sensitivity to rewards, likely underlies teen-led activism, for instance on climate change, racial justice, and gun control.

Research by Crone and others shows that the ventral striatum is linked to prosocial behavior, responding to rewards not just for oneself but also for others (Nature Communications, Vol. 12, No. 313, 2021). Among teens serving time in youth detention centers, both the ability to spontaneously take the perspective of others and activity in the temporoparietal junction—an associated region of the brain—differed significantly from a control group. The temporoparietal junction is more malleable by environmental influence than other social brain regions, according to studies by Crone among twin populations. This suggests that interventions in perspective-taking, which target this area, may be helpful for justice-involved teens (Social Cognitive and Affective Neuroscience, Vol. 9, No. 12, 2014).

Based on ongoing research by Casey and others about the trajectory of development in regions related to cognitive control, including the prefrontal cortex, APA has launched a task force to review new findings that may inform extending Roper v. Simmons, a Supreme Court decision that abolished the use of the death penalty for those under 18, to cover individuals into their early 20s.

Looking forward, researchers in the field emphasize the importance of continuing to challenge assumptions about adolescence—around risk-taking, emotionality, and more—to ensure that the science remains robust and can ultimately support interventions for healthy development.

"We're not going to change adolescents' brains, nor should we want to," Telzer said. "What we can do is optimize what we know to create social contexts and environments that provide the most enriching experiences for them."