Edge

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THE ADOLESCENT BRAIN

Sarah- Jayne Blakemore [6.5.12]

The idea that the brain is somehow fixed in early childhood, which was an idea that was very strongly believed up until fairly recently, is completely wrong. There's no evidence that the brain is somehow set and can't change after early childhood. In fact, it goes through this very large development throughout adolescence and right into the 20s and 30s, and even after that it's plastic forever, the plasticity is a baseline state, no matter how old you are. That has implications for things like intervention programs and educational programs for teenagers.

Introduction

Sarah-Jayne Blakemore is a leading social neuroscientist of adolescent development. She has reawakened research interest into the puberty period by focusing on social cognition and its neural underpinnings. Part of her question is whether adolescence involves egocentrism, as many popular conceptions suggest, since this is testable.

Part of her originality is to remind us of the remarkable changes in brain structure during adolescence, given the traditional focus of developmental psychology is on early childhood. Using a range of techniques, including conducting elegant MRI studies, she illuminates a neglected phase of cognitive development. Given that the sex steroid hormones are produced in higher quantities during this period, her research opens up interesting questions about whether the changes in the brain are driven by the endocrine system, or by changing social experience, or an interaction of these factors.

—Simon Baron-Cohen

SARAH-JAYNE BLAKEMORE is a Royal Society University Research Fellow and Full Professor of Cognitive Neuroscience at the Institute of Cognitive Neuroscience, University College London, UK. Blakemore’s research centers on the development of social cognition and executive function in the typically developing adolescent brain, using a variety of behavioral and neuroimaging methods.

Sarah-Jayne Blakemore's *Edge* Bio

SIMON BARON-COHEN, Psychologist, is Professor of Developmental Psychopathology and Director of the Autism Research Centre at Cambridge University, a Fellow of Trinity College, Cambridge; Author, The Science of Evil; The Essential Difference.

Simon Baron-Cohen's *Edge* Bio

THE ADOLESCENT BRAIN

[SARAH-JAYNE BLAKEMORE:] I'm particularly interested in the development of the adolescent human brain. The reason I became interested in the adolescent brain is twofold. Firstly, we know that most adult mental disorder has its onset at some point during the teenage years, so if you look at disorders like anxiety disorders, depression, addictions, eating disorders, almost all of them will have their onset some time during the teenage years.

Schizophrenia, as you might know, is a very horrific psychiatric condition that's characterized by delusions, like being paranoid and thinking that people are out to get you, and hallucinations like imagining that people are talking to you inside your head, hearing voices. That has its onset at the end of adolescence, normally in the early 20s, on average. So that's one reason why I think it's really important to study the adolescent brain. The hypothesis is that something is going wrong in normal brain development to trigger these psychiatric and psychological disorders.

The second reason why adolescence is an interesting period of life to study is because unlike most other periods of life, the leading causes of death in adolescence are accidents. That's the number one leading cause of death during the period of adolescence, the second is suicide. The accidents are caused, generally, by risk taking. So we know that teenagers take more risks than either children or adults. The question is, why? Why is adolescence associated with this phenomenon like increased risk taking and especially when adolescents are with their peers, so peers become really influential in adolescence. Adolescents are driven towards impressing their peers, trying to seek approval of their peers, and becoming more and more independent from their parents. Social cognition, the social brain seems to change during the period of adolescence, and that's something that particularly interests me.

And finally, self-awareness; awareness of one's self, and consciousness of one's self. We all know, if you remember what it's like being a teenager, that feeling of heightened self-consciousness that seems to happen in early adolescence where you become easily embarrassed by things like your parents, or social situations where you're not seen as cool, and that kind of thing.

That's what we're interested in looking at, the development of these kinds of cognitive processes like self-awareness, social understanding, the understanding of other people, and risk taking and decision making during this period of life.

In our research, what we're really interested in is tracking the development of the brain, both in terms of its structure and its function, and also behavior during the period of adolescence, and comparing that in typically developing adolescents to healthy adults, and also we are moving towards looking at adolescents who develop psychiatric or psychological disorders, in particular adolescents who go on to develop schizophrenia, so that's one of my overarching interests in my ultimate long-term goals, is to look at the brain development patterns in teenagers who later develop schizophrenia.

The kinds of experiments we do are both brain imaging. We use structural MRI and functional MRI, where we bring teenagers into the lab and scan their brains and acquire structural images of their brains, and also look at how their brains function, so record where activity is being produced in their brains during certain tasks. We might give them a task which involves thinking about other people, or thinking about themselves, or taking risks or making decisions, and compare brain activity in the average adolescent brain during those tasks, with the average adult brain.

This is a kind of question that many labs around the world are now starting to ask. But the interesting thing is that this is a very, very recent field, and if you look in the literature, 15 years ago you would have found virtually nothing. Nothing was known about how the human, living human adolescent brain develops. We've now learned a great deal in the last ten years, due to advances in imaging technology, so we now have the ability to scan the living human brain and to track its development, both in terms of structure and function across the life span, and that has taught us really a great deal. It's really revolutionized what we understand, what we know about how the living human brain develops.

One of the main findings from this kind of research is from a very large pediatric neuroimaging project at the National Institute of Mental Health in Bethesda, in the USA, where they have scanned children, adolescents and adults, many thousands of individuals. As they get older they bring them back into the lab for a scan every couple of years, and they now have approximately over 8,000 scans from two thousand individuals, and they put all this data together to form this kind of semi-longitudinal dataset, which has shed a great deal of light on how the brain develops structurally during this period of life.

One of the things they found, and they found many different findings from this dataset, is that the human cortex undergoes much more protracted development both in terms of gray matter and white matter volumes than was ever previously thought. We know, firstly, from this dataset, that in many different cortical regions, gray matter, which is mostly found in the cortex, the surface of the brain, and contains cell bodies and synapses, the connections between cells, gray matter increases during childhood, peaks at some point during mid to late childhood or early adolescence in most cortical areas, and then declines really dramatically during the period of adolescence right into the 20s or even the 30s. We don't quite know what this corresponds to because MRI doesn't have the resolution to tell us about what's going on at a cellular level, or a synaptic level, but we know from postmortem human brain tissue studies that a large amount of synaptic pruning, so that is the little connections between brain cells, they're called synapses, and in development they firstly increase in number and then decrease again, and that decrease in synapses is caused by synaptic pruning, where excess synapses are just eliminated, synapses that aren't being used are pruned away or eliminated. That we know from postmortem human brain tissue studies. It continues during the period of adolescence, right into the 30s.

We think that the decrease in gray matter volume during the period of adolescence, that we've gleaned from these living human brain MRI studies, corresponds to synaptic pruning going on during the period of adolescence. At the same time, there's an increase in white matter across the brain, and this is thought to be due to the fibers of cells, so these are axons along which electrical impulses pass from cell to cell in the brain, become coated in a white substance called myelin during development. We know that again from animal studies, from cellular studies, and this appears in MRI scans as an increase in white matter.

Now, the functional consequence of that is that myelin acts as an insulator and it speeds up the transmission of signals from cell to cell, and so we think that the implication of that in terms of its function is to speed up signaling between brain regions, and that continues to happen throughout the first, at least the first three, even four decades of life.

Those are the structural studies that have revolutionized what we know about the development of the living human brain. Many labs around the world, including mine, look at how the brain functions in adolescence, compared with adults, in a variety of tasks. I'll just give you an example. One of the areas of cognition that we're particularly interested in is social cognition: the social brain, how we understand other people and how we interact with other people. We know from many human functional MRI, or FMRI studies, that the social brain is a network of brain regions that is consistently activated whenever adults think about other people. There are about three different regions in the brain, one in medial prefrontal cortex, and two other regions in the temporal lobe: the posterior-superior temporal sulcus, and the anterior temporal cortex. It doesn't really matter about the names, but the point is that that network of brain regions in adults is consistently active whenever you think about other people or think about interacting with other people, or think about their mental states or their emotions.

Adolescents use the same network, the social brain network, to a very similar extent, but what seems to happen is that activity shifts from the anterior region, the medial prefrontal cortex region, to the posterior, the anterior temporal cortex or the superior temple sulcus region, as they go through adolescence. In other words, when they're thinking about other people, adolescents seem to be using this prefrontal cortex, right at the front region, more than adults do, and adults seem to be using the temporal regions more than adolescents do.

The question is why? Why should adolescents who complete the task in the same time and as accurately as adults, why should they be using the prefrontal region of their brain more, and the temporal region of their brain less? That's something that we're looking at now. One possibility is that they're using different cognitive strategies to do these tasks. They're doing the tasks, even though they're doing them as well, they're doing them in a different way. That's one of the hypotheses that we're currently looking at.

The final strand of our research looks at how behavior changes during the period of adolescence. If you look back in history over the last 30 or 40 years, if you look at developmental psychology studies of social cognition, what you mostly read is social cognition tasks given to very young children (normally children below the age of five or six). Some of these tasks might be theory of mind tasks. Theory of mind is defined as the attribution of mental states, like the classic example is understanding that someone else can have a belief that is different from your own, or different from reality, and those kinds of tasks.

One of the classic versions of this false belief task is the Sally Anne task. This is a task designed for young children. Normally you have two dolls, Sally and Anne. Sally hides something in a box and then goes out of the room, and when she's out of the room, Anne takes her toy from the box and puts it in a completely different place, a basket. The question is, when Sally comes back into the room, where will she look for her toy? The answer, of course, is she'll look for her toy exactly where she left it, which was in the box, because she doesn't know that Anne has hidden it somewhere else. Of course, as an adult you know that instantly, but actually until the age of about four, very intelligent, typically developing children tend to get that wrong. They tend not to be able to understand, in this kind of explicit task, that Sally could possibly have a belief that's different from reality, that's different from their own belief.

We were interested in given the fact that we know that social brain regions continue to develop, both in terms of structure and function during adolescence, we were interested in how social cognitive behavior changes in adolescence. It would be weird to think that these parts of the brain can change so dramatically and significantly, and have no consequence on behavior. We were interested in looking at behavior during the period of adolescence, however, when we first started out this project there were really no tasks that we could use because almost all theory of mind tasks reached ceiling performance in early childhood. By age five all children get these tasks right almost 100 percent of the time. So we had to find a task that didn't result in 100 percent accuracy.

We used a task that involved taking someone else's perspective in an ongoing kind of communication context. It's very different from a false belief task, but it's more like the way you might use theory of mind in everyday life, constantly having to work out what the other person that you're talking to is intending, what they intend you to understand, and using their perspective in order to guide your ongoing behavior and actions. When we used a task like this, which we know results in many errors, even in adults, what we found was that the ability to take into account someone else's perspective in order to guide ongoing decisions and behavior continues to develop well into late adolescence, so much, much later than what the previous theory of mind, classic theory of mind tasks had indicated.

That's an example, a relatively early example of the kind of results that we found and we are currently expanding our research into areas like risk taking and peer influence and decision making. Eventually, what we want to do is look at things like, we've started a project to look at things like the genetic influence on brain development during adolescence, how your genes influence how your brain develops during this period of life, and also to look at adolescents who have early-onset schizophrenia, teenagers who start to develop schizophrenia-like symptoms, like hearing voices inside their heads or feeling excessively paranoid.

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I did a degree in experimental psychology at Oxford and this degree in Oxford is very biological. There's a lot of neuroscience in it. I quickly became interested in the neuroscience aspect, in particular I became interested schizophrenia. And so for my PhD I decided to study schizophrenia, and I did a PhD in neuroscience at UCL supervised by Chris Frith, who's very well known for his work on schizophrenia, and Daniel Wolpert, who looks at mathematical models of prediction in the brain. I did a PhD on schizophrenia, particularly looking at how people distinguish between self and other, how they make the distinction between when they are causing an action versus when someone else is causing an action. I went on to do a post-doc in France with Jean Decety also looking at schizophrenia and the perception of causality and contingency.

My interest was always in schizophrenia and that's why I became interested in looking at the development of adolescence. It was when I was in France that I started to think about why it is that people with schizophrenia tend to develop in the early 20s. This is a developmental disorder that has its onset relatively late in life, in the early 20s, normally. I became interested in the idea that maybe something in normal brain development goes awry in people who develop schizophrenia. But at that time, ten years ago, looking at the literature, there was very little known about even how the typically developing human brain develops during the period of adolescence, let alone how the brain develops in people who then develop schizophrenia. So that's when I changed track a bit and started to focus my own research on the development of the typically developing adolescent brain.
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Now that's becoming a huge area in itself. Many people are asking questions about this area because, I think, it's just a kind of lucky time in history that we are now able to scan the living human brain at all ages, and many people do that across the age, across the lifespan. Although if you look at the literature, actually, most developmental studies start at about age six, and I think this is because you have to lie completely still inside the MRI scanner to acquire a high quality resolution, a high quality image of the brain, and under age six it's really difficult to get kids to lie still enough in the scanner.

I think a lot of labs are focusing on the teenage years because this seems to be a time that is sort of nonlinear in development. It's not just that teenagers represent a kind of continuation of childhood. There's something special about the period of adolescents where adolescents are driven towards peers and away from their parents. They're driven to develop a sense of self and self-identity, and especially a sense of who they are, how they're seen by other people, in particular their peers. It's a time where there's probably an increased drive to take risks, so from the evolutionary point of view, to sort of move away from the relative security of your family and your parents, and take risks by discovering things for yourself in the outside world.

So we have the ability to scan the brain. There's masses that we don't yet understand about how the brain develops and, in particular, there's a lot that we don't really understand about what the images are telling us, like what is white matter? What's gray matter? What does it consist of? Why is it changing? We don't know the answers to this, and we won't until we can look at the developing human brain or, I guess, animal brain to a certain extent, in terms of changes that are going on at the synaptic or the cellular level, and mapping that knowledge onto the knowledge that we have from the imaging studies. That's the structure.

Similarly, when we look at how brain activity changes during development, there's a lot we don't understand about that, so when we see a part of the brain change its activity as you get older, we don't know why that is. We don't know whether it might be because that part of the brain is changing structurally. If you have fewer and fewer synapses, for example, (connections between cells) or gray matter, as you get older, between early adolescence and early adulthood, then that might result in less and less activity with age, and that's one theory that has been put forward by a number of different labs. That's certainly a possibility. There are many other possibilities as well. It's possible that at different ages you use different brain circuitry to perform the same task because you're using a different kind of cognitive strategy. You might, for example, when you think about social situations as an adult, you might be doing this automatically by just triggering automatically some kind of social script, whereas maybe in adolescence you're more reliant on your own experiences of these situations. It's more effortful and you have to conjure up examples where some similar social situation has happened to you in order to think about the consequences or something like that. There are many possibilities. There are many possible explanations that people are just starting to look at.

There are also methodological issues with scanning the brain at different ages and comparing different groups. For example, the FMRI signal, the BOLD signal, that's the signal of activity that we get from the FMRI scanner, is essentially an indirect measure of neuronal activity. It's an indirect measure of the activity generated by brain cells. It's effectively a measure of blood flow because we know that when neurons are active they require more energy to flow to them in the blood, and that's what we're measuring when we're saying brain activity, what we're really talking about is where blood is flowing to in the brain. For example, if neurovascular coupling, that is the vasculature that innovates different brain regions, is developing across adolescence, then that will probably affect the BOLD signal that we get from the FMRI scanner, and we just don't really have any data yet on how vasculature changes in the brain across this period of life in humans. There are many, many questions.

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My dad is Colin Blakemore. He's a well-known neuroscientist in the UK and so growing up our house was very much full of science. We grew up in Oxford and a few minutes away from his lab and we were constantly going to his lab and visiting it. There's a big park next to that so we'd go to the park and then go to his lab. But on the other hand, when I was at school, high school that is, I never really felt like, "Oh, I'm definitely going to be a neuroscientist like my dad." And actually what I was really interested in was psychology and developmental psychology and I did a week's work experience, when I was about 15, with Uta Frith who, as many people looking at this will know, is a very famous developmental psychologist in the UK who specializes in autism. And I, at the age of 15 went and did a week's work experience with her, where I hung out in her lab in London and watched children with autism being tested on the Sally Anne task, this classic task of theory of mind, and helped develop some spoonerism tests for kids with dyslexia (these are kind of tests where you switch around the first letter of two words like Jimi Hendrix would be Himi Jendrix or whatever) that Uta was developing at that time. Anyway, that really made me become very interested in psychology, which is why I applied to do a psychology degree at university.

I didn't really explicitly make the connection between psychology and neuroscience until I started my degree, when it became very obvious that if you want to study psychology what you're really studying is the brain. You're already studying the mental process of
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the brain. And I found that studying the brain was, the part of psychology that I was particularly interested in. So I ended up becoming a neuroscientist like my dad.

My sisters, I've got two sisters, and they're not scientists. One is a videogames designer and the other is a pediatric nurse. It's only me who went into my dad's field.

The work I do absolutely relies on interdisciplinary methodology. We work with a team of cognitive neuroscientists. We work with geneticists and physicists and psychiatrists who see patients, for example, with early onset schizophrenia; pediatricians who specialize in endocrinology when we want to look at, for example, the effects of puberty hormones on brain development. It's almost by definition an interdisciplinary area to work in and none of the questions that we currently ask could be asked if we didn't collaborate with people from different disciplines, and we help each other to progress the field.

One interesting thing to think about, when you're thinking about brain imaging, is why is brain imaging important? What does it teach us that we didn't already know from psychology studies? This is a really important question that a lot of people are asking. Why does it matter that we know that one part of the brain is involved with a process? Why does that matter more than just knowing about this process from a kind of psychological point of view? For example, if you know that one method of teaching works better than another method of teaching, so one method of memory rehearsal worked better than another method, why does knowing that the hippocampus is more involved in one than the other? Why is that useful? Does it tell you any more than you already knew from the psychology results or the education result? I think this is a very open question and often, actually, especially when you're talking about the implications of neuroscience for education, actually, often it's the case that is sort of seduced by these brain images, and we see them and they are very tangible and people suddenly think, "Oh, my God, it has a biological basis," and they somehow seem more convincing and attractive than just pure psychology results. But often they don't really tell us anything more.

I think the area of adolescent brain development is one of the areas in cognitive neuroscience where actually brain imaging has completely revolutionized what we know. Prior to all these data on the developing adolescent brain, we had a lot of data from psychology and social psychology, and educational research, on how adolescents develop. But these kinds of behavioral changes that adolescents go through were mostly put down to things like hormones, like changing hormones at puberty, and also social environment, like changing social priorities, maybe changing schools, that kind of thing. We just didn't know until ten or 15 years ago that the brain undergoes such dramatic development and even reorganization during the period of adolescence starting at puberty and continuing right throughout adolescence.

It's that insight that we've gleaned from being able to scan the living human brain that has really changed the way we think about adolescent development, adolescent education, adolescent, even the legal treatment of adolescence. I think brain imaging there, it's one area in which it has revolutionized how we understand teenagers.

It's interesting to look at the detractors. Actually, there aren't very may but that's probably because it's a new field and it will just take time for detractors to buildup. If we're just focusing in on imaging studies of the adolescent brain, not imaging generally, which has a lot of detractors, but I won't go there, there are people who ask the question, "So what? So what if the brain develops during adolescence?" That's irrelevant when it comes to thinking about educational programs or rehabilitation for teenagers.

I think we do have to be careful about being seduced by these brain images. We know that people tend to be more satisfied when you give them an explanation that includes some kind of brain term like prefrontal cortex. We've got to be really careful about that, especially when taking the findings from neuroscience, to an educational context. That's something I'm really interested in. I'm interested in the links between neuroscience and education. Whenever I talk to teachers or schools, I often end up talking about where the neuroscience has been taken too far, and there are programs that sell themselves on the basis of, well, so-called neuroscience that often makes on physiological sense.

One type of detractor might argue that we can't just scan children's brains or teenagers' brains and show a difference, it doesn't really tell us very much. The fact is thought, that if the brain changes that must be, arguably, having some influence on cognition and behavior.

The other side of the coin is that this is a period of life where the brain changes very rapidly and dramatically, and some people are starting to think of adolescence as a second critical period or sensitive period in brain development, and if that's the case, then that has really profound implications for the environmental influences on adolescent brain development, how we treat teenagers, and the kinds of social experiences they have. It also means that in principle, things like rehabilitation and interventions targeted at teenagers, for example that might have had negative experiences in early life should be not a wasted time.

The idea that the brain is somehow fixed in early childhood, which was an idea that was very strongly believed up until fairly recently, is completely wrong. There's no evidence that the brain is somehow set and can't change after early childhood. In fact, it goes through this very large development throughout adolescence and right into the 20s and 30s, and even after that it's plastic forever, the plasticity is a baseline state, no matter how old you are. That has implications for things like intervention programs and educational programs for teenagers.

There's a second line questioning which I think is actually really important, I mentioned it earlier on, which is what it means. So talking about the functional imaging changes, scanning the brain and looking at how activity changes across age, what that means in terms of what's the underlying changes in neuronal signatures. We have to be really careful about what we attribute this to, especially because if you get developmental changes in blood vessels and vasculature at this age, then you will probably see that as a change in bold signal arising from FMRI. So we have to be really careful about making assumptions in terms of what we're seeing with the FMRI scanner, and more research needs to be done to understand this.

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What's really needed is a better understanding of the technology. If we could scan the living human brain and be able to see brain structures that are cellular, or synaptic levels, that would hugely benefit the field. I have no idea when that's going to be possible, or even how, but putting funding into the technology and the method is really the way of progressing understanding in this field. On the other hand, at the moment funding is so tight that we are very limited in, for example, the numbers of participants. It's expensive scanning humans. You put them in the scanner for an hour and you spend a few hundred pounds just scanning a single subject. So we're limited in the numbers that we can scan and yet really what we need is much, much larger scale studies that are longitudinal, so where you're scanning the same individuals across a number of years as they get older. Most of the studies that I've mentioned are not longitudinal, they're cross sectional, so where you're comparing different teenagers with different adults.

It would be ideal if you could scan a very large number of teenagers every couple of years as they go into adulthood. The icing on the cake would be to scan a sufficient number of individuals so that you can track people who've become, for example, who develop schizophrenia, and go back and look at their brain imaging data from when they were a teenager, and look at how it differs, how their brain development differs from teenagers who don't develop schizophrenia. That is being done but it's very, very hard to do that, because as you can imagine, it would take enormous numbers of participants and it's such a long-term study that you'd really need to be doing it for 20 years.
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This is a very new field and we're still learning, we've still got a great deal to learn. In fact, most questions have yet to even be looked at, let alone answered. Things like how the brain develops in adolescents who develop some kind of psychiatric or psychological disorder is something that we know very little about. People are starting to look at that. That's something that I would like to move into. How genes and the environment influence brain development, like for example, how adolescent brain development differs between cultures is something that no one has yet asked, and yet it's bound to. Culture is a huge environmental influence, and we assumed that the environment influences brain development during adolescence, so that's something else that is in the cards for the future to look at.