
THE NEUROBIOLOGY

OF THE Self

Biologists are beginning to tease out how the brain gives rise to a constant sense of being oneself

The most obvious thing about yourself is your self. "You look down at your body and know it's yours," says Todd Heatherton, a psychologist at Dartmouth University. "You know it's your hand you're controlling when you reach out. When you have memories, you know that they are yours and not someone else's. When you wake up in the morning, you don't have to interrogate yourself for a long time about who you are."

The self may be obvious, but it is also an enigma. Heatherton himself shied away from direct study of it for years, even though he had been exploring self-control, self-esteem and other related issues since graduate school. "My interests were all around the self but not around the philosophical issue of what is the self," he explains. "I avoided speculations about what it means. Or I tried to, anyway."

Things have changed. Today Heatherton, along with a growing number of other scientists, is tackling this question head-on, seeking to figure out how the self emerges from the brain. In the past few years, they have begun to identify certain brain activities that may be essential for producing different aspects of self-awareness. They are now trying to determine how these activities give rise to the unified feeling we each have of being a single entity. This research is yielding clues to how the self may have evolved in our hominid ancestors. It may even help scientists treat Alzheimer's disease and other disorders that erode the knowledge of self and, in some cases, destroy it altogether.

By Carl Zimmer

The Self Is Special

American psychologist William James launched the modern study of this area in 1890 with his landmark book, The Principles of Psychology. “Let us begin with the Self in its widest acceptation, and follow it up to its most delicate and subtle form,” he proposed. James argued that although the self might feel like a unitary thing, it has many facets—from awareness of one’s own body to memories of oneself to the sense of where one fits into society. But James confessed to being baffled as to how the brain produced these self-related thoughts and wove them into a single ego.

Since then, scientists have found some telling clues through psychological experiments. Researchers interested in memories of the self, for instance, have asked volunteers questions about themselves, as well as about other people. Later the researchers gave the volunteers a pop quiz to see how well they remembered the questions. People consistently did a better job of remembering questions about themselves than about others. “When we tag things as relevant to the self, we remember them better,” Heatherton says.

Some psychologists argued that these results simply meant that we are more familiar to ourselves than other people are to us. Some concluded instead that the self is special; the brain uses a different, more efficient system to process information about it. But psychological tests could not pick a winner from these competing explanations, because in many cases the hypotheses made the same predictions about experimental outcomes.

Further clues have emerged from injuries that affect some of the brain regions involved in the self. Perhaps the most famous case was that of Phineas Gage, a 19th-century railroad construction foreman who was standing in the wrong place at the wrong time when a dynamite blast sent a tamping iron through the air. It passed right through Gage’s head, and yet, astonishingly, Gage survived.

Gage’s friends, though, noticed something had changed. Before the accident, he had been considered an efficient worker and a shrewd businessman. Afterward he became profane, showed little respect for others and had a hard time settling on plans for the future. His friends said he was “no longer Gage.”

Cases such as Gage’s showed that the self is not the same as consciousness. People can have an impaired sense of themselves without being unconscious. Brain injuries have also revealed that the self is constructed in a complicated way. In 2002, for example, Stan B. Klein of the University of California at Santa Barbara and his colleagues reported on an amnesiac known as D.B. The man was 75 years old when he suffered brain damage from a heart attack and lost the ability to recall anything he had done or experienced before it. Klein tested D.B.’s self-knowledge by giving him a list of 60 traits and asking him whether they applied to him somewhat, quite a bit, definitely, or not at all. Then Klein gave the same questionnaire to D.B.’s daughter and asked her to use it to describe her father. D.B.’s choices significantly correlated with his daughter’s. Somehow D.B. had retained an awareness of himself without any access to memories of who he was.

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Clues from Healthy Brains

In recent years, scientists have moved beyond injured brains to healthy ones, thanks to advances in brain imaging. At University College London, researchers have been using brain scans to decipher how we become aware of our own bodies. “This is the very basic, low-level first point of the self,” UCL’s Sarah-Jayne Blakemore says.

When our brains issue a command to move a part of our bodies, two signals are sent. One goes to the brain regions that control the particular parts of the body that need to move, and another goes to regions that monitor the movements. “I like to think of it as a ‘cc’ of an e-mail,” Blakemore observes. “It’s all the same information sent to a different place.”

Our brains then use this copy to predict what kind of sensation the action will produce. A flick of an eye will make objects appear to move across our field of vision. Speaking will make us hear our own voice. Reaching for a doorknob will make us feel the cold touch of brass. If the actual sensation we receive does not closely match our prediction, our brains become aware of the difference. The mismatch may make us pay more attention to what we are doing or prompt us to adjust our actions to get the results we want.

Overview/My Brain and Me

- Increasing numbers of neurobiologists are exploring how the brain manages to form and maintain a sense of self.
- Several brain regions have been found to respond differently to information relating to the self than they do to information relating to others, even to very familiar others. For instance, such regions may be more active when people think about their own attributes than when they think about the characteristics of other individuals. These regions could be part of a self-network.
- For some, the goal of this research is to better understand, and to find new therapies for, dementia.

AARON GOODMAN (page 92)

AARON GOODMAN

But if the sensation does not match our predictions at all, our brains interpret them as being caused by something other than ourselves. Blakemore and her colleagues documented this shift by scanning the brains of subjects they had hypnotized. When the researchers told the subjects their arms were being lifted by a rope and pulley, the subjects lifted their arms. But their brains responded as if someone else were lifting their arms, not themselves.

A similar lack of self-awareness may underlie certain symptoms of schizophrenia. Some schizophrenics become convinced that they cannot control their own bodies. "They reach over to grab a glass, and their movement is totally normal. But they say, 'It wasn't me. That machine over there controlled me and made me do it,'" Blakemore explains.

Studies on schizophrenics suggest that bad predictions of their own actions may be the source of these delusions. Because their sensations do not match their predictions, it feels as if something else is responsible. Bad predictions may also create the auditory hallucinations that some schizophrenics experience. Unable to predict the sound of their inner voice, they think it belongs to someone else.

One reason the sense of self can be so fragile may be that the human mind is continually trying to get inside the minds of other people. Scientists have discovered that so-called mirror neurons mimic the experiences of others. The sight of someone being painfully poked, for example, stimulates neurons in the pain region of our own brains. Blakemore and her colleagues have found that even seeing someone touched can activate mirror neurons.

They recently showed a group of volunteers videos of other people being touched on the left or right side of the face or neck. The videos elicited the same responses in some areas of the volunteers' brains as occurred when the volunteers were touched on the corresponding parts of their own bodies. Blakemore was inspired to carry out the study when she met a 41-year-old woman, known as C., who took this empathy to a surprising extreme. The sight of someone being touched made C. feel as if someone were touching her in the same place on her own body. "She thought everyone had that experience," Blakemore remarks.

Blakemore scanned the woman's brain and compared its responses to those of normal volunteers. C.'s touch-sensitive regions reacted more strongly to the sight of someone else being touched than those regions did in the normal subjects. In addition, a site called the anterior insula (located on the brain's surface not far from the ear) became active in C. but not in the normal volunteers. Blakemore finds it telling that the anterior insula has also displayed activity in brain scans of people who are shown pictures of their own faces or who are identifying their own memories. It is possible that the anterior insula helps to designate some information as relating to ourselves instead of to other people. In the case of C., it simply assigns information incorrectly.

Brain scans have also shed light on other aspects of the self. Heatherton and his colleagues at Dartmouth have been using the technology to probe the mystery of why people remember information about themselves better than details about other people. They imaged the brains of volunteers who viewed a series of adjectives. In some cases, the researchers asked the subjects whether a word applied to the subjects themselves.

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In others, they asked if a word applied to George W. Bush. In still other cases, they asked simply whether the word was shown in uppercase letters.

The researchers then compared the patterns of brain activity triggered by each kind of question. They found that questions about the self activated some regions of the brain that questions about someone else did not. Their results bolstered the "self is special" hypothesis over the "self is familiar" view.

A Common Denominator

One region that Heatherton's team found to be important to thinking about oneself was the medial prefrontal cortex, a patch of neurons located in the cleft between the hemispheres of the brain, directly behind the eyes. The same region has also drawn attention in studies on the self carried out by other laboratories. Heatherton is now trying to figure out what role it serves.

"It's ludicrous to think that there's any spot in the brain that's 'the self,' " he says. Instead he suspects that the area may bind together all the perceptions and memories that help to produce a sense of self, creating a unitary feeling of who we are. "Maybe it's something that brings information together in a meaningful way," Heatherton notes.

If he is right, the medial prefrontal cortex may play the same role for the self as the hippocampus plays in memory. The hippocampus is essential for forming new memories, but people can still retain old memories even after it is injured. Rather than storing information on its own, the hippocampus is believed to create memories by linking together far-flung parts of the brain.

The medial prefrontal cortex could be continuously stitching together a sense of who we are. Debra A. Gusnard of Washington University and her co-workers have investigated what occurs in the brain when it is at rest—that is, not engaged in any particular task. It turns out that the medial prefrontal cortex becomes more active at rest than during many kinds of thinking.

"Most of the time we daydream—we think about something that happened to us or what we think about other people. All this involves self-reflection," Heatherton says.

Other scientists are investigating the brain networks that may be organized by the medial prefrontal cortex. Matthew Lieberman of the University of California at Los Angeles has been using brain scans to solve the mystery of D.B., the man who knew himself even though he had amnesia. Lieberman and his colleagues scanned the brains of two sets of volunteers: soccer players and improvisational actors. The researchers then wrote up two lists of words, each of which was relevant to one of the groups. (Soccer players: athletic, strong, swift; actors: performer, dramatic, and so on.) They also composed a third list of words that did not apply specifically to either (messy and reliable, for example). Then they showed their subjects the words and asked them to decide whether

Just Another Pretty Face?

J.W. Gazzaniga

As Carl Zimmer notes in the accompanying article, investigators disagree over whether the brain treats the self as special—processing information about the self differently from information about other aspects of life. Some argue that parts of our brain that change their activity when we think about ourselves do so simply because we are familiar with ourselves, not specifically because the self is involved; anything else that was familiar would evoke the same response.

In one study addressing this question, researchers photographed a man referred to as J.W., whose right and left cerebral hemispheres operated independently as a result of surgery that had severed the connections (to treat intractable epilepsy). They also photographed someone very familiar to the man—Michael Gazzaniga, a well-known brain researcher who had spent a lot of time with J.W. Next they created a series of images in which J.W.'s face morphed into Gazzaniga's (below) and displayed them in random order. For each image, they had J.W. answer the question "Is it me?" Then they repeated the process, having him answer, "Is it Mike?" They also performed the test with the faces of others well known to J.W.

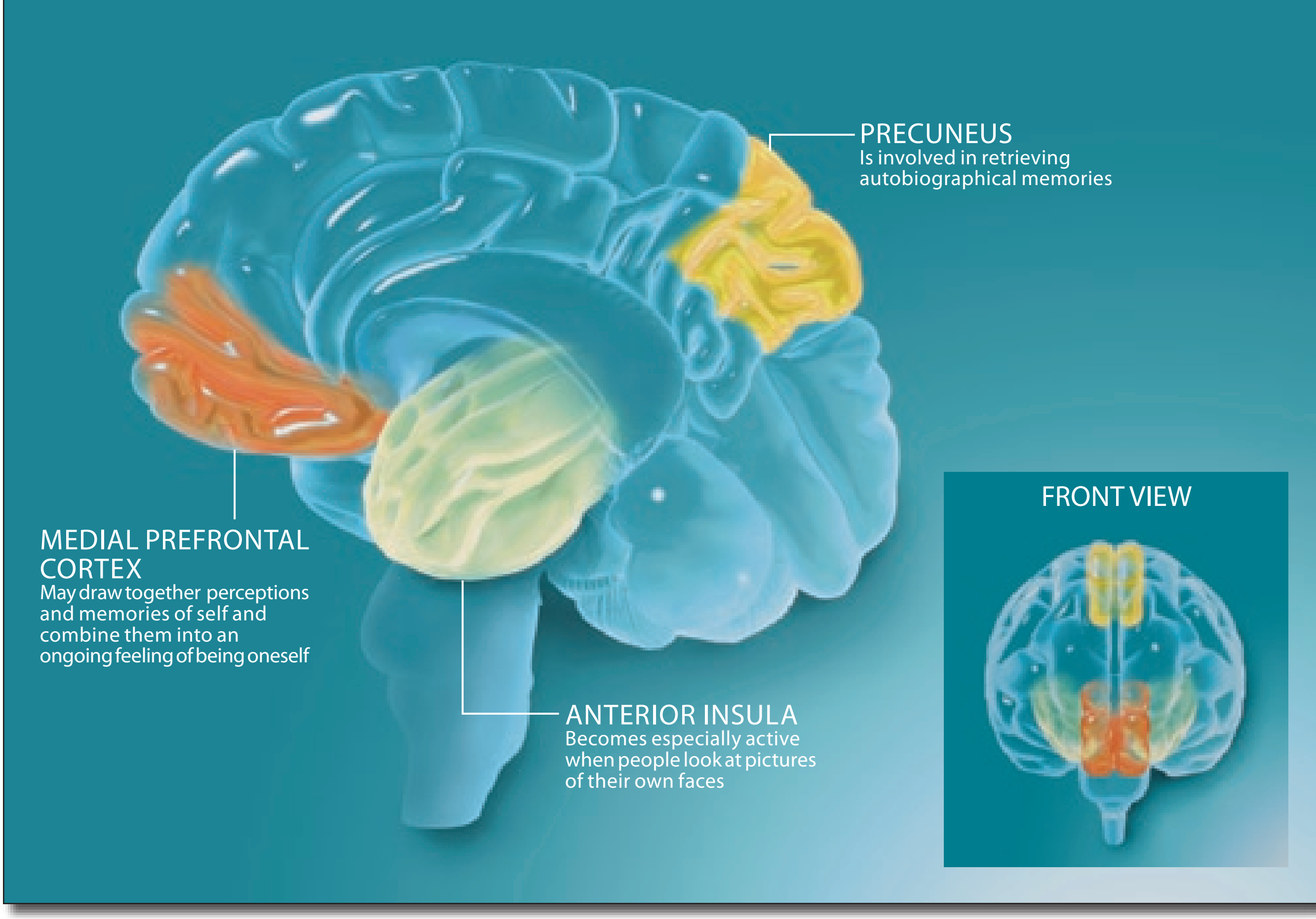
They found that J.W.'s right hemisphere was more active when he recognized familiar others, but his left hemisphere was most active when he saw himself in the photographs. These findings lend support to the self-is-special hypothesis. The issue, though, is far from solved: both camps have evidence in their favor. —Ricki Rusting, managing editor

90 percent J.W. —Morphing→ 10 percent J.W.

"MIKE OR ME? SELF-RECOGNITION IN A SPLIT-BRAIN PATIENT," BY DAVID J. TURK ET AL., IN NATURE NEUROSCIENCE, VOL. 5, NO. 9; SEPTEMBER 2002

COMPONENTS OF A SELF-NETWORK

The brain regions highlighted below are among those that have been implicated, at least by some studies, as participating in processing or retrieving information specifically related to the self or in maintaining a cohesive sense of self across all situations. For clarity, the view below omits the left hemisphere, except for its anterior insula region.



each one applied to themselves or not.

The volunteers' brains varied in their responses to the different words. Soccer-related words tended to increase activity in a distinctive network in the brains of soccer players, the same one that became more active in response to actor-related words in actors. When they were shown words related to the other group, a different network became more active. Lieberman refers to these two networks as the reflective system (or C system) and the reflexive system (or X system).

The C system taps into the hippocampus and other parts of the brain already known to retrieve memories. It also includes regions that can consciously hold pieces of information in mind. When we are in new circumstances, our sense of our self depends on thinking explicitly about our experiences.

But Lieberman argues that over time, the X system takes over. Instead of memories, the X system encodes intuitions, tapping into regions that produce quick emotional responses based not on explicit reasoning but on statistical associations. The X system is slow to form its self-knowledge, because it needs many experiences to form these associations. But once it takes shape, it becomes very powerful. Soccer players know whether they are athletic, strong or swift without having to consult their memories. Those qualities are intimately wrapped up with who they are. On the other hand, they do not have the same gut instinct about whether they are dramatic, and in these cases they must think explicitly about their experiences. Lieberman's results may solve the mystery of D.B.'s paradoxical self-knowledge. It is conceivable that his brain damage wiped out his reflective system but not his reflexive system.

Although the neuroscience of the self is now something of a boom industry, it has its critics. "A lot of these studies aren't constrained, so they don't say anything," says Martha Farah, a cognitive neuroscientist at the University of Pennsylvania. The experiments, she argues, have not been designed carefully enough to eliminate other explanations—for example, that we use certain brain regions to think about any person, including ourselves. "I don't think there's any 'there' there," she says.

Heatherton and other scientists involved in this research think that Farah is being too tough on a young field. Still, they agree that they have yet to figure out much about the self-network and how it functions.

AARON GOODMAN

The Evolving Self

uncovering this network may allow scientists to understand how our sense of self evolved. The primate ancestors of humans probably had the basic bodily self-awareness that is studied by Blakemore and her associates. (Studies on monkeys suggest that they make predictions about their own actions.) But humans have evolved a sense of self that is unparalleled in its complexity. It may be significant that the medial prefrontal cortex is "one of the most distinctly human brain regions," according to Lieberman. Not only is it larger in humans than in nonhuman primates, but it also has a greater concentration of uniquely shaped neurons called spindle cells. Scientists do not yet know what these neurons do but suspect that they play an important role in processing information. "It does seem like there's something special there," he comments.

Heatherton thinks that the human self-network may have evolved in response to the complex social life of our ancestors. For millions of years hominids lived in small bands, cooperating to find food and sharing what they found. "The only way that works is through self-control," he says. "You have to have cooperation, and you have to have trust." And these kinds of behaviors, he argues, require a sophisticated awareness of oneself.

If the full-fledged human self were a product of hominid society, that link would explain why there are so many tantalizing overlaps between how we think about ourselves and how we think about others. This overlap is not limited to the physical empathy that Blakemore studies. Humans are also uniquely skilled at inferring the intentions and thoughts of other members of their species. Scientists have scanned people engaged in using this so-called theory of mind, and some of the regions of the brain that become active are part of the network used in thinking about oneself (including the medial prefrontal cortex). "Understanding ourselves and having a theory of mind are closely related," Heatherton says. "You need both to be a functioning human being."

The self requires time to develop fully. Psychologists have long recognized that it takes a while for children to acquire a stable sense of who they are. "They have conflicts in their self-concepts that don't bother them at all," Lieberman comments. "Little kids don't try to tell themselves, 'I'm still the same person.' They just don't seem to connect up the little pieces of the self-concept."

Lieberman and his colleagues wondered if they could track children's changing self-concept with brain imaging. They have begun studying a group of children and plan to scan them every 18 months from ages nine to 15. "We asked kids to think about themselves and to think about Harry Potter," he says. He and his team have compared the brain activity in each task and compared the results with those in adults.

"When you look at 10-year-olds, they show this same medial prefrontal cortex activation as adults do," Lieberman notes. But another region that becomes active in adults, known as the precuneus, is a different story. "When they think about themselves, they activate this region less than they do when they think about Harry Potter."

Lieberman suspects that in children, the self-network is still coming online. "They've got the stuff, but they're not applying it like adults do."

Insights into Alzheimer's

once the self-network does come online, however, it works very hard. "Even with the visual system, I can close my eyes and give it something of a rest," comments William Seeley, a neurologist at the University of California, San Francisco. "But I can never get away from living in my body or representing the fact that I'm the same person I was 10 seconds or 10 years ago. I can never escape that, so that network must be busy."

One patient, described by Seeley and others in the journal Neurology in 2001, had collected jewelry and fine crystal for much of her life before abruptly starting to gather stuffed animals at age 62. A lifelong conservative, she began to berate people in stores who were buying

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conservative books and declared that "Republicans should be taken off the earth." Other patients have suddenly converted to new religions or become obsessed with painting or photography. Yet they have little insight into why they are no longer their old selves. "They say pretty shallow things, like 'This is just the way I am now,'" Seeley says. Within a few years, frontotemporal dementia can lead to death.

The more energy that a cell consumes, the greater its risk of damaging itself with toxic by-products. Seeley suspects that the hardworking neurons in the self-network are particularly vulnerable to this damage over the life span. Their vulnerability, he argues, may help neurologists make sense of some brain disorders that erode the self. "It is curious that we can't find certain pathological changes of Alzheimer's or other dementias in nonhuman species," Seeley says.

According to Seeley, the results of recent brain-imaging studies of the self agree with findings by him and others on people with Alzheimer's and other dementias. People with Alzheimer's develop tangled proteins in their neurons. Some of the first regions to be damaged are the hippocampus and precuneus, which are among the areas involved in autobiographical memories. "They help you bring images of your past and future into mind and play with them," Seeley notes. "People with Alzheimer's are just less able to move smoothly back and forth through time."

As agonizing as it may be for family members to watch a loved one succumb to Alzheimer's, other kinds of dementia can have even more drastic effects on the self. In a condition known as frontotemporal dementia, swaths of the frontal and temporal lobes degenerate. In many cases, the medial prefrontal cortex is damaged. As the disease begins to ravage the self-network, people may undergo strange changes in personality.

Michael Gazzaniga, director of Dartmouth's Center for Cognitive Neuroscience and a member of the President's Council on Bioethics, believes that deciphering the self may pose a new kind of ethical challenge. "I think there's going to be the working out of the circuits of self—self-referential memory, self-description, personality, self-awareness," Gazzaniga says. "There's going to be a sense of what has to be in place for the self to be active."

It is even possible, Gazzaniga suggests, that someday a brain scan might determine whether Alzheimer's or some other dementia has destroyed a person's self. "Someone's going to say, 'Where's Gramps?'" he predicts. "And they're going to be able to take a picture of Gramps under certain conditions and say, 'Those circuits are not working.'"

Gazzaniga wonders whether people will begin to consider the loss of the self when they write out their living wills. "Advanced directives will come into play," he predicts. "The issue will be whether you deliver health care. If people catch pneumonia, do you give them antibiotics or let them go?"

Seeley offers a more conservative forecast, arguing that a brain scan on its own probably will not change people's minds about life-and-death decisions. Seeley thinks the real value of the science of the self will come in treatments for Alzheimer's and other dementias. "Once we know which brain regions are involved in self-representation, I think we can take an even closer look at which cells in that brain region are important and then look deeper and say which molecules within cells and which genes that govern them lead to this vulnerability," he says. "And if we've done that, we've gotten closer to disease mechanisms and cures. That's the best reason to study all this. It's not just to inform philosophers."

MORE TO EXPLORE

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