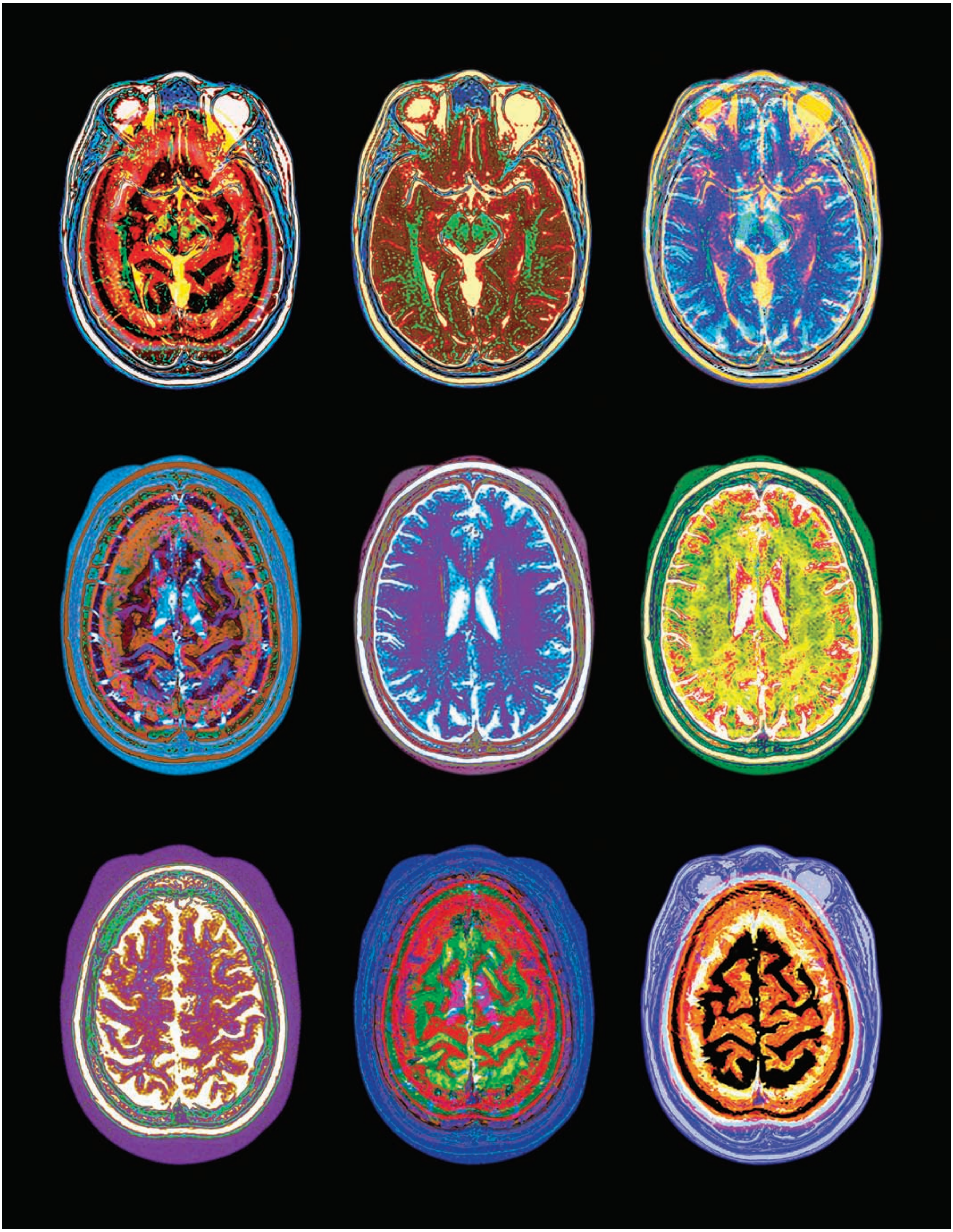


Why You Should Be Skeptical of Brain Scans

Colorful scans have lulled us into an oversimplified conception of the brain as a modular machine

By Michael Shermer

Over the past few hundred years, as scientists have grappled with understanding the source of the amazing processing power in our skulls, they have employed a number of metaphors based on familiar technologies of their given era. The brain has been thought of as a hydraulic machine (18th century), a mechanical calculator (19th century) and an electronic computer (20th century).

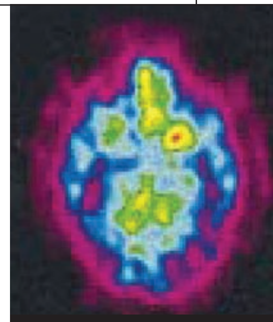
Today, early in the 21st century, we have another metaphor driven by the capabilities of the current technology—this time colorful images from modern brain scans. Evolutionary psychologists, for example, have conceptualized the brain as a Swiss Army knife, with a collection of specialized modules that have evolved to solve specific problems in our evolutionary history, such as language for communication, facial recognition to separate friends from foes, cheating detection to prevent free riders, risk taking to raise the odds of individual or group success, and even God to explain the world and to find individual happiness in thoughts of an afterlife. Many neuroscientists have employed the module metaphor to describe specific regions of the brain "for X," with X being whatever happens to be the task given to subjects while a machine scans their brains. Such tasks might include selecting brand logos they prefer (say, Coke or Pepsi) or political candidates they would vote for (conservatives or liberals).

Scientists often use metaphors such as these as aids in understanding and explaining complex processes, but this practice necessarily oversimplifies the intricate and subtle realities of the physical world. As it turns out, the role of those blobs of color that we see in brain images is not as clear-cut as we have been led to believe. "There are no modules that are encapsulated and just send information into a central processor," declares philosopher of the mind Patricia S. Churchland of the University of California, San Diego. "There are areas of specialization, yes, and networks maybe—but these are not always dedicated to a particular task."

Technologies such as functional magnetic resonance imaging have helped science gain new insights, but overreliance on their use has also presented an oversimplified and sometimes misleading picture of brain operation. Even this magazine, with its focus on explaining brain and behavior, often counts on these simplified metaphors [see "Fact or Phrenology?" by David Dobbs; Scientific American Mind, V. 16, N. 1, 2005].

So let me explain what such images actually can and *cannot* show, by giving you a closer look at the capabilities and operation of fMRI, perhaps the most commonly trumpeted imaging technique. After you have read this article, you will be able to apply a skeptic's careful eye to better appraise any brain studies that you come across in future media headlines. Here are five flaws of brain scans:

GETTY IMAGES (*opposite page*); COURTESY OF MICHAEL SHERMER (*Shermer in scanner, page 69*); GUILBERT GATES (*neuron diagram, page 70*)



Craving

Pictures of brains splotched with sharply defined colored regions suggest well-defined processing blocks (the module metaphor), when in fact the neural activity may be distributed in more of a loosely defined network.

1 Unnatural environment for cognition.

I visited neuroscientist Russell Poldrack's laboratory at the University of California, Los Angeles, and arranged to get my brain scanned inside its MRI machine. Scanners typically weigh around 12 tons and cost about $2.5 million (not including installation, training and maintenance, which can drive the typical bill up by another $1 million). Right off the bat I realized how unnatural an environment it is inside that coffinesque tube. In fact, I had to bail out of the experiment before it even started. I had suddenly developed claustrophobia, a problem I had never experienced earlier. I'm not alone. Poldrack says that as many as 20 percent of subjects are similarly affected. Because not everyone can remain relatively relaxed while squeezed inside the tube, fMRI studies are afflicted with a selection bias; the subject sample cannot be completely random, so it cannot be said to represent all brains fairly.

A person jammed into the narrow tube also has his or her head locked firmly in place with foam wedges inside the head coil—nicknamed "the cage"—to reduce head motion (which can blur the images) before the experiment begins. The MRI scanner snaps a picture of the brain every two seconds while the subject watches images or makes choices (by pushing buttons on a keypad) presented through goggles featuring tiny screens.

So when you read popular accounts of subjects who had their brains scanned while they were shopping, for example, remember that they were not walking around a Wal-Mart with headgear on. Far from it.

2 Scans are indirect measurements of brain activity.

One often reads popular accounts of fMRI research describing how the brain "lights up" when thinking about money or sex or God or whatever. Here is what the MRI machine is really doing when you think. The scanner is a large electromagnetic cylinder constructed from superconducting wire cooled by helium that generates powerful magnetic fields. The levels of these fields are 25,000 to 80,000 times the strength of the earth's magnetic field. They are so powerful that subjects must remove all metal items before entering the shielded area. (Flying metal objects pulled by an MRI machine have killed people.) Patients with pacemakers or metal implants cannot even go into the room, which itself is heavily fortified with steel and uses soundproofing technologies to muffle the bone-shaking noise produced when the magnets work their magic.

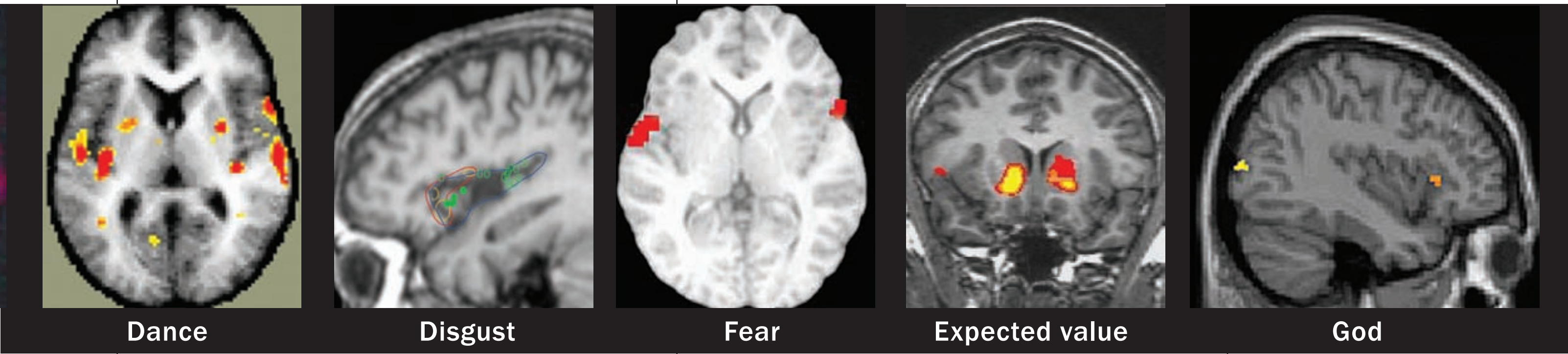
When a person is inside the tube, some of the atoms in his or her tissues align to the magnetic field. Only about one in a million atoms so align, but that number is sufficient because the body has about seven octillion (a thousand quadrillion, or a thousand thousand trillion) atoms; the total works out to about six million billion atoms in a two-by-two-by-five-millimeter cube of tissue—plenty for the scanner to read. The protons in the nuclei of these atoms are spinning, and like a spinning top they also precess (or wobble, whereby the axis of rotation sweeps out a cone). The frequency at which a proton precesses—the time it takes for the axis to sweep out a cone

FAST FACTS
Misleading Brain Scans

1» Metaphors are often used in science to understand difficult and counterintuitive phenomena.

2» The metaphor of the mind as a Swiss Army knife, a collection of specialized modules designed to solve specific problems, has been enhanced by brain-scanning technologies such as functional magnetic resonance imaging.

3» Such brain scans, however, are misleading on a number of levels and have led some neuroscientists and the media to overemphasize the localization of brain function.



once, called the resonant frequency—depends on the strength of the magnetic field, which varies along the length of the tube. This "gradient" is slightly higher at the head end, causing the protons there to precess at a slightly different frequency. To make an image, the machine transmits a certain radio-wave frequency, which excites the protons to match that resonant frequency caused by the magnetic field. This excitement, in effect, tips the direction of their alignment to the side. Over time (milliseconds), these protons come back into alignment with the main magnetic field, and in the process they shed some energy. It is this energy that the machine measures to create the image.

3 Colors exaggerate the effects in the brain.

Pictures of brains splotched with sharply defined colored regions are highly misleading because they suggest well-defined processing blocks (the module metaphor), when in fact the neural activity may be distributed in more of a loosely defined network. Here is how fMRI produces data that can lead to this artificial modularity. As a basic principle, scientists agree that changes in blood flow and oxygenation levels in particular areas of the brain signal greater neural activity. When neurons are active, they consume more oxygen, which is pulled out of the hemoglobin in red blood cells from nearby capillaries; the brain responds to this increased need for oxygen by sending more—and for reasons that are not yet fully understood, it actually sends a greater amount than is needed. There is a delay of about five seconds between neural activity and blood-flow change, which leads to differences in the relative concentration of oxygenated hemoglobin in those active brain areas. Because the iron in hemoglobin is magnetically sensitive, there are measurable magnetic differences between blood cells with and without oxygen, and the MRI scanner measures these differences.

The coloring is artificial, and the process of coloring the regions is even more misleading, as Churchland says: "The difference in activity levels is tiny. You can make these differences look huge by coloring them red and by subtracting everything else out, so it gives an impression that is exaggerated." The choice of what to emphasize is also misleading. "Take the cingulate nucleus, an area dealing with conflict," Churchland adds. "You can get it to respond by showing subjects a picture of, say, Hillary Clinton. But the cingulate nucleus does 57 other things as well."

Finally, Churchland exclaims in partial exasperation when I ask her about exposing subjects to various stimuli inside the scanner: "The thing of it is that most of the activity of the brain is not stimulus-driven but is spontaneous, and we don't know why there is so much activity and what it is doing." In other words, many areas of the

Many subjects, such as the author himself (*below*), cannot long tolerate the claustrophobic environment in an MRI machine—making it impossible for studies to represent all brains fairly.

(The Author)

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In a brain scan, the image itself does not represent any one person's brain. It is instead a statistical computation of the entire subject pool adjusted for head motion and different head sizes.

brain are continually active during different processing tasks, and separating them out properly is a challenge that requires careful experimental design.

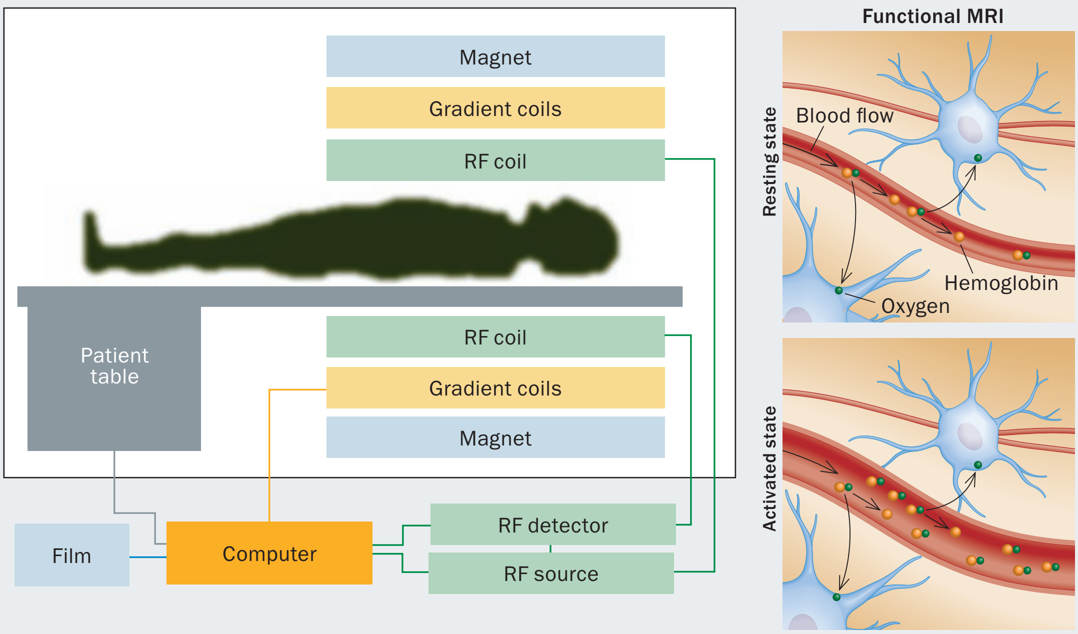
4 Brain images are statistical compilations.

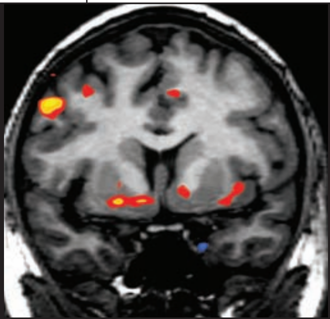
During a given experiment, the scanner snaps pictures of the rapid-fire brain activity only every two seconds, resulting in hundreds to thousands of images per scanning period (which can last anywhere from 15 minutes to two hours). After the experiment concludes, researchers make corrections for head motion and for small differences in brain size and the location of structures within different brains. The scientists line up all the individual images with one another and then combine the data and take averages for the subjects in the experiment. They employ additional statistical software to convert raw data into images as well as to correct for other possible intervening variables, such as cognitive tasks that produce neural activity changes in the brain faster than the blood-flow changes that are actually being measured by the MRI.

Keep all this background in mind the next time you see one of those colorful brain scans with an arrow pointing to some spot that says,

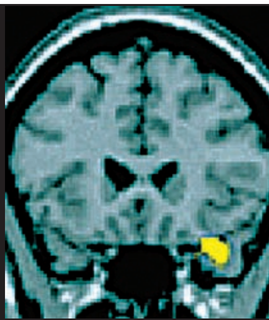
What the MRI "Sees"

Series of magnets and a radio-frequency (RF) generator and detector in an MRI machine create images. Functional MRI detects changes in oxygen levels, which rise in the nearby blood vessels because active neurons consume more oxygen than when they are at rest (*right*).

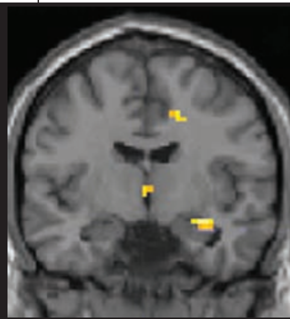




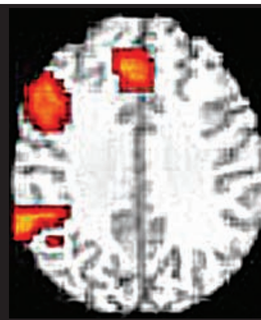
Risk taking



Sexual arousal



Joy



Lying

Love

"This is your brain on X." The image usually does not represent any one person's brain. It is a statistical computation of the entire subject pool rendered with artificial colors to highlight the places where there is a consistent response to a given task or experimental condition.

5 Brain areas activate for various reasons.

Interpreting fMRI scans is as much an art as a science, Poldrack admits. "It is tempting to look at one of those spots and say, 'This is where X happens in your brain,' when in fact that area could be lighting up when involved in all sorts of tasks," he explains. "Take the right prefrontal cortex that lights up when you do almost any difficult task. One way to think about it is in terms of networks, not modules. When you are engaged in thinking about money, there is a network of several different areas involved in communicating with one another in a particular way. Thus, the prefrontal cortex may be involved in many different tasks. But in communication with other brain networks, it becomes active when engaged in one particular task, such as thinking about money." Teasing these differences apart requires making relative comparisons across a spectrum of tasks. Certain experiments work especially well with fMRI because decisions provide contrasts between tasks, giving the neuroscientist something to compare.

What about research showing differences in rational versus emotional parts of the brain, as in the "emotional low road" in the deeper and more ancient parts of the brain and the "rational high road" in the cortical regions of the brain? "There *are* rational and emotional ways of thinking," Poldrack says. But "it turns out that they interact with one another a lot." The amygdala, an area typically associated with processing the fear response, also is activated by arousal and positive emotions: "If I put you into a state of fear, your amygdala lights up. But that doesn't mean that every time your amygdala lights up, you are experiencing fear. Every brain area lights up under lots of different states. We just don't have the data to tell us how selectively active an area is."

Networks, Not Modules

A number of interconnected neural networks may in some cases be localized and bundled into modulelike units, but in most ways they are better described as being splayed out over, under or through the brain's crevasses. The metaphor of "distributed intelligence"—sometimes used to describe the World Wide Web's power—more closely matches the network distribution of tasks in the brain than the module metaphor does.

Of course, there are areas that specialize in certain types of processing, such as the visual cortex at the back of the brain and Broca's area for language in the left frontal lobe. And roughly speaking, reason and rationality happen in the cortical areas, whereas emotion and irrationality are experienced in the limbic system.

Nevertheless, as many neuroscientists now believe, the metaphor of "neural networks" is superior to that of mental modules. The latter forces us to think of the brain as a kludge of encapsulated organs specialized for one function and no other, whereas the former more accurately reflects what modern neuroscience tells us is actually happening during cognition. Brain-scanning technologies such as fMRI will continue to generate copious data for our metaphorical theories—and as long as our skeptical networks are active, we should be able to better map neural networks and their accompanying functions onto the landscape of our behaviors. M

(Further Reading)

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- **The Mind Doesn't Work That Way: The Scope and Limits of Computational Psychology.** Jerry Fodor. MIT Press, 2001.
- **The New Phrenology: The Limits of Localizing Cognitive Processes in the Brain.** William Uttal. MIT Press, 2003.
- **The Quest for Consciousness: A Neurobiological Approach.** Christof Koch. Roberts & Company, 2004.
- **Kluge: The Haphazard Construction of the Human Mind.** Gary Markus. Houghton Mifflin, 2008.