

EVERYONE'S A COPYCAT:

Runners, on your mark // Spectators, feel your pulses rising //

The brain's to blame.

# Mirror, Mirror

■ BY ANITA SLOMSKI // ILLUSTRATIONS BY HARRY CAMPBELL

**T**he macaque was wired for observation, with electrodes implanted in its frontal lobe (the premotor cortex) to record the activity of motor neurons. Those are the first nerve cells to fire, or transmit electrochemical signals, in a cascade of neural impulses that control muscle contractions. In this experiment, Giacomo Rizzolatti and his colleagues at the University of Parma in Italy were studying how motor neurons trigger hand movements in monkeys. As an animal performed a specified task, such as popping a peanut into its mouth, a *tatatatata* sound would indicate a neuron had fired.

But this monkey was between tasks, waiting for its next instructions, when a researcher happened to grab something in its view. To the scientist's astonishment, he heard the sound of the monkey's motor neurons firing, a sound he should have heard only when the macaque was moving its hand.

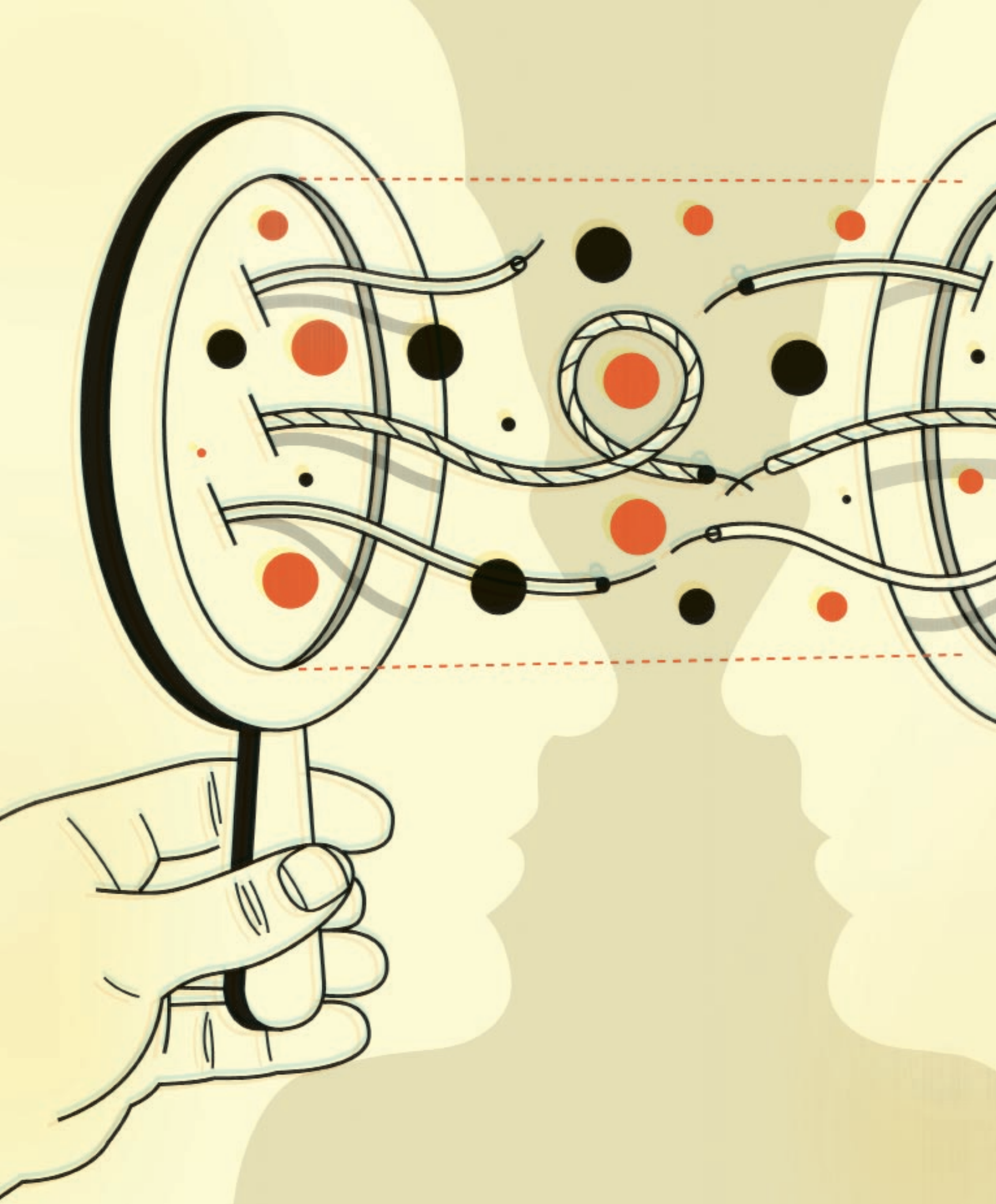
At the time of the experiment, in 1992, neuroscientists thought that when each type of neuron fired, it was to initiate a single function. According to this theory, a sensory neuron might release neurotransmitters to begin the brain's response to sensory input, such as observing and recognizing the peanut, while a motor neuron would fire to trigger the hand muscles to move. But in Rizzolatti's experiment, it appeared that the same neuron fired when the monkey grabbed a peanut and when he watched the researcher make a similar movement. One neuron had launched electrochemical impulses for both perception and action.

The existence of such a multipurpose brain cell, which came to be known as a mirror neuron, ultimately led to a hypothesis that would explain why, for example, watching a newscast of a sobbing woman walking through the rubble of her former home may move us to tears. Or how the sight of a spider crawling on someone's shoulder can cause an involuntary shudder, or why, perched at the edge of our seats at a soccer match, our adrenaline and emotions may surge as if we were the ones on the field.

Researchers now think that watching the pitcher for your favorite baseball team, for example, excites the same neural circuit that's involved when you wind up for a toss during the company softball game. According to the mirror neuron hypothesis, it's only when we imitate or mirror people's actions or expressions in our mind's eye that we can understand their intentions and recognize and respond to their feelings.

"This is a major shift in how we think about the human condition and the human brain," says neurologist Marco Iacoboni, director of the Transcranial Magnetic Stimulation Laboratory at the Ahmanson-Lovelace Brain Mapping Center of the University of California, Los Angeles, and author of *Mirroring People: The New Science of How We Connect With Others*. "Mirror neurons show that we are evolutionarily designed to be deeply connected with one another."

Understanding those connections, an effort still in its infancy a decade and a half after Rizzolatti's discovery, could eventually have practical applications. Researchers have proposed that damaged or dormant mirror neuron systems



may underlie such disorders as autism and the unrelenting phantom pain that may appear after a limb is amputated. Others are trying to capitalize on mirror neurons' ability to create mental representations of observed actions to retrain the brains of stroke patients to move paralyzed limbs and remember how to speak.

Even though, at this stage, it's difficult to envision where this research will lead, its ultimate impact could be huge. "I predict that mirror neurons will do for psychology what DNA did for biology," says Vilayanur S. Ramachandran, director of the Center for Brain and Cognition and professor of psychology and neuroscience at the University of California, San Diego.

functional magnetic resonance imaging (fMRI) can detect in the brain is a voxel, an area about a millimeter square that may contain more than 100,000 neurons.

Still, fMRI and other brain imaging technologies, including positron emission tomography and transcranial magnetic

## Study subjects who demonstrated the greatest empathy on a questionnaire displayed the most neural activity when listening or watching others express emotion.

It took months for Rizzolatti's team to comprehend the significance of what it had discovered—and even longer for the scientific community to suspend its skepticism about the possibility that a motor neuron could fire for any reason other than to incite a motor action. But if mirror neurons really were the multipurpose cells they appeared to be, their existence lent credence to a few theories then circulating about human behavior. Scientists in Munich, for example, had shown that when people observed others' actions, it influenced their own behavior, and the researchers had hypothesized that observing and executing actions involved a shared neural code, or algorithm, that transforms electrochemical impulses into behavioral responses. The existence of mirror neurons might also support a theory that human behavior is passed from generation to generation through imitation.

In the monkey experiments, implanted electrodes pinpointed the location of mirror neurons. That's not feasible in humans—volunteers would have to undergo brain surgery—and brain imaging technologies can only approximate reality. For example, says Steven Small, professor of neurology and psychology at the University of Chicago, the smallest area that

stimulation, have allowed researchers to observe areas of the brain thought to be involved in particular kinds of thoughts or actions. In determining whether people, too, might have mirror neurons, the Parma group focused on regions of the brain analogous to regions of the monkey brain known to contain mirror neurons. Rizzolatti expected that, as in monkeys, mirror neurons in humans would be located in the premotor cortex, at the front of the brain, which is important for planning and executing actions. The premotor cortex overlaps the inferior parietal lobe, which is part of the largest brain structure, the cerebrum, and is associated with perceiving stimuli and movement. All of those might reasonably be involved in the thoughts and actions that mirror neurons seemed to instigate.

The Parma group's first human studies, in the mid-1990s, confirmed that both observing and making the action appeared to activate a single neural circuit, and by 1999, three years after the first human mirror neuron study was published, evidence supporting the reality of these multitasking brain cells in people had become compelling, and a wave of new research was launched.

In a study published in 2003, neuroscientist Christian Keysers and his team at the Institute of Physiological and Cognitive Neurosciences in Marseille, France, reported on research during which subjects were shown film clips of people smelling and reacting to the contents of a glass with disgust or with a pleasant or neutral expression. Then the same subjects were fitted with a mask that emitted disgusting, pleasing or neutral odors.

The researchers found that participants activated the same areas of the brain whether they were observing emotions or while experiencing them, with impulses being sent to the limbic, or “emotional,” center, through the insula. “We think that when you see someone’s facial expression, you activate motor areas of your brain involved in making a similar facial expression,” says Keysers, now scientific director of the BCN Neuroimaging Center of the University Medical Center

Groningen in the Netherlands. “That information is sent via the insula, in which representations of bodily feelings associated with emotions are triggered as if you were experiencing the same feeling.”

Interestingly, the more empathetic an individual is, the more robustly mirror neurons discharge. Lisa Aziz-Zadeh, an assistant professor in the Brain and Creativity Institute at UCLA, measured research subjects’ degrees of empathy on a questionnaire. Then, as the subjects underwent fMRI, she had them listen to the tone of an actress’s voice reciting a nonsense phrase in a happy, sad or neutral tone and as a question. Next, she asked subjects to look at pictures of people with happy, sad or blank expressions and produce the same phrase in an intonation corresponding to each emotion they saw. Aziz-Zadeh found that the subjects who scored highest on the questionnaire also displayed the most neural activity

in the mirror areas when listening or watching others express emotion. And the highest scorers did the best job discerning subtle differences in tone and producing phrases to express distinct feelings.

One practical outcome of this research, Aziz-Zadeh suggests, might be understanding both how injury to mirror neuron systems could affect empathic feeling and how to nudge a damaged mirror neuron system into better shape. But Michael Arbib, professor of computer science, biological sciences, biomedical and electrical engineering, neuroscience and psychology at the University of Southern California in Los Angeles and director of the USC Brain Project, thinks transforming an observation of emotion into empathy is far more complicated than simply activating the mirror neuron system. “We usually don’t imitate people,” Arbib says. “We respond to them.” He notes that when we interact with another person, rather than simply copying a facial expression or parroting a mood or intonation, we listen and observe, then formulate a response. “Maybe



mirror neurons aren't replicating the original observed action or emotion but are nonetheless a key part of the circuitry that enables us to make the appropriate response. They do their job as part of the larger neural system, not alone."

In the process of understanding mirror neurons' role, scientists think they have identified several different types of this special brain cell. They all fire when we make or observe specific actions, such as grasping or breaking a peanut, and when we see someone doing the same. Some mirror neurons, however, also activate when simply hearing the sound of an action—say, the sound of breaking a peanut—whereas others discharge when we see only a part of the action—say, when we see a person reach behind a screen where we know there is something the person can grasp. Iacoboni, the UCLA scientist, thinks there may even be "super mirror neurons," which suppress the firing of mirror neurons when you observe



## Making Connections //

**Boosting the mirror neuron system may help autistic children, stroke victims and amputees.**

**Mirror neurons are all about connections—between regions of the brain, between thought and action, between one person and another. And if research so far has focused on understanding those links at a basic cellular level, clinicians are experimenting with practical applications in three areas.**

**PHANTOM-LIMB PAIN** Late last year, Navy Commander Jack Tsao, associate professor of neurology at the Uniformed Services University of the Health Sciences in Bethesda published the results of the first controlled trial of therapy employing mirrors to treat phantom-limb pain, which occurs in almost every amputee and may be unrelentingly severe. According to one theory, the pain is caused by a mismatch in signals from different brain regions that creates the sensation that a missing limb still exists and is fixed in an uncomfortable position. In the trial of 22 people who had lost one foot, those in one group viewed the reflected image of their intact foot as they tried to move the amputated foot that wasn't there. Soldiers in other groups attempted to move both the intact foot and the phantom foot while looking at a sheet-covered mirror or while closing their

eyes and visualizing their missing foot. There was no improvement in these groups. But all subjects who used the mirror had decreased pain, including 70% who were completely cured of pain; the therapy is now standard care at Walter Reed Army Medical Center in Washington, D.C.

**AUTISM** Many classic traits of this disorder—deficits in empathy, difficulty imitating others' actions and poor language development—seem to suggest malfunctioning mirror neurons, and some studies in children with autism have shown reduced activity in areas of the brain thought to contain mirror neurons. One promising therapy, being explored by Jaime Pineda, professor of cognitive science at the University of California, San Diego, involves electrical activity in the sensorimotor cortex, called the mu rhythm, which can serve as an index of mirror neuron activity. Although the mu rhythm is normally suppressed when someone observes or makes a movement as neurons fire randomly relative to one another—the oscillation of this wave is strongest when you are idle and neurons are in a synchronous firing pattern. In autistic children that may not happen, particularly

when they're watching people they don't know.

To move a car around a track or fire lasers at asteroids, the youngsters must enhance that signal—and subsequently engage the mirror neuron system.

It seems to be working. "We think the mirror neurons are firing when they weren't firing before," Pineda says. And parents and teachers have noted improvements in the kids' attention spans and interactions with others.

**STROKE** Mentally mimicking movements or speech may help people who have had a stroke recover speech or the use of impaired limbs, says Steven Small, professor of neurology and psychology at the University of Chicago. Last year, with European researchers, Small published a pilot study of eight stroke patients who showed marked improvement in the use of their arms after four weeks of repeatedly watching videos of an actor moving his arms, then attempting to make the same movements themselves. The subjects also showed increased activation of putative mirror neuron areas. "We may be strengthening existing connections among visuo-motor regions, which may contain mirror neurons, or teaching them to bypass damaged connections," Small says.

an action. “You would be very dysfunctional if you imitated others’ behavior all the time, so these super neurons may limit unwanted imitation,” he says. “And they may allow our brains to distinguish our own actions from those of others.”

In the very young, of course, there are few limits on imitation, and mirror neurons may explain why humans are “the most gifted imitator of any species on the planet,” says Andrew N. Meltzoff, who has spent 30 years studying imitative learning in infants and young children. Meltzoff has discovered that when babies imitate the actions of others, they’re teaching themselves necessary skills. Newborns only hours old who have never seen their own faces in the mirror can imitate rudimentary facial gestures, such as sticking out a tongue.

“Babies come into the world able to imitate and become members of their culture by observing what others do and incorporating those behaviors into their repertoire,” says Meltzoff, who is co-director of the Institute for Learning and Brain Sciences and professor of psychology at the University of Washington. “Imitative learning is an efficient mechanism for learning, and when children imitate adults, they are communicating nonverbally before they can say their first words.”

Yet, if there is a mirror neuron system present at birth, it’s probably a primitive one. It takes a few years for children to develop the neural connections that link the brain’s visual capabilities with the areas that control motor skills. “It’s impossible that newborns would have the same mirror systems that adults have, because we know that experience shapes the mirror neuron system,” Groningen’s Keysers says. “If I play a piano concerto for someone who has never played the piano, only the auditory areas of the brain will activate. But if I give that person five days of piano training and then play the melody he has learned, his motor neurons will activate as well.”

Scientists may soon have an answer to how robust an infant’s mirror neuron system really is. The University of Washington has just acquired the world’s first magnetoencephalography (MEG) scanner for the brains of babies, who can’t be tested in an fMRI because that would require them to lie still. With MEG, a child is fitted with a sort of helmet that measures the magnetic field generated by neurons’ electrical currents. Though the technology is new, early tests indicate reliability. “Now we can begin to look at the origins and development of mirror neurons in human infants,” Meltzoff says. “What happens when they look at their mother’s face and watch her

actions? Seeing images of how that is embodied in the baby’s brain will be incredibly important in understanding early learning.”

As important as such neurons may turn out to be, some researchers warn against unrealistically high expectations. “Mirror neurons are still going through the ‘ooh and ah’ stage in which they are being perceived as a magic bullet explanation for things such as autism,” says Arbib. Designating mirror neurons as the root cause of certain behaviors or disorders is simplistic, he says. “We have to understand how mirror neurons work in a larger context before we can determine their exact contributions.”

Yet for now, as this research unfolds, many scientists are excited to think they’ve found the neural mechanisms that explain such behaviors as empathy and social perspicacity. The implications could be profound. “Our survival today depends on whether we can cope effectively with our social environment and stay in good relationships,” Keysers says. “And that requires accurately perceiving the behavior and intentions of others.”

Learning how mirror neurons help us make those social connections could, in turn, change our image of ourselves as a species. “The discovery of mirror neurons shows we are wired for empathy, which turns upside down the idea that our biology makes us bad—that individualism and self-preservation are at our core and we only become social animals through our higher intellect,” says Iacoboni. “Our biology, in fact, is what makes us good, caring individuals.” ■

## → DOSSIER

1. *Mirroring People: The New Science of How We Connect With Others*, by Marco Iacoboni [Farrar, Straus, and Giroux, 2008]. A prominent scientist’s absorbing look at evidence that the mirror neural circuit may underlie such diverse disorders and behaviors as autism, imitative violence in children, addiction relapse and political affiliation.
2. “Unifying Social Cognition,” by Christian Keysers and Valeria Gazzola, *Mirror Neuron Systems: The Role of Mirroring Processes in Social Cognition*, ed. Jaime A. Pineda [Humana Press, 2008]. Well known for their research on how mirror neurons shape empathy, the authors review seminal studies on humans’ “uncanny capacity” to read minds.
3. “Functions of the Mirror Neuron System: Implications for Neurorehabilitation,” by Giovanni Buccino, Ana Solodkin and Steven L. Small, *Cognitive and Behavioral Neurology*, March 2006. The authors argue that stroke patients may be able to activate their mirror neuron system by observing and imitating motions, thereby regaining lost motor skills.