

A Revealing Reflection

MIRROR NEURONS ARE PROVIDING STUNNING INSIGHTS INTO EVERYTHING FROM HOW WE LEARN TO WALK TO HOW WE EMPATHIZE WITH OTHERS

BY DAVID DOBBS



Sometime just before my second child was born, I read that if you stick your tongue out at a newborn, he will do the same. So in young Nicholas's first hours, even as my wife was still in the recovery room after 40 hours of labor and a C-section, I tried it. Holding the gooing, alert lad before me in my hands, I stuck my tongue out at him. He immediately returned the gesture, opening his mouth and subtly but distinctly moving his tongue. I hadn't slept in two days. I laughed till I cried.

I did not know it then, but Nick was showing off what some consider one of the greatest drivers of human progress and one of the prime discoveries in recent neuroscience: mirror neurons. These neurons are scattered throughout key parts of our brain—the premotor cortex and centers for language, empathy and pain—and fire not only as we perform a certain action but also when we watch someone else perform that action.

These neurons have been studied in the past for their roles in movement and other functions. Now, however, researchers are examining them

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MIMICRY
Mirror neurons enable infants and toddlers to learn facial expressions and physical maneuvers through imitation.

(We **mentally imitate** every action we witness,) prompting us to dance, grieve and yawn with others.

CONTAGION
When we see another person yawn, mirror neurons in primal brain regions tell us to do the same. Group laughter can be catching, too.

intensely for what seems to be an additional function—the way they fire in response to something observed. The discovery of this mechanism, made about a decade ago, suggests that everything we watch someone else do, we do as well—in our minds. At its most basic, this finding means we mentally rehearse or imitate every action we witness, whether it is a somersault or a subtle smile. It explains much about how we learn to smile, talk, walk, dance or play tennis. At a deeper level, it suggests a biological dynamic for our understanding of others, the complex exchange of ideas we call culture, and psychosocial dysfunctions ranging from lack of empathy to autism. Comprehending mirror neurons helps us make sense of everything from why yawns are contagious to why, watching Lawrence Olivier fall to his knees, we share Hamlet’s grief for Ophelia.

For some, this explanatory power makes mirror neurons the biggest neuroscientific discovery in recent times. “This completely changes the way we think about how the brain works,” says Marco Iacoboni, a mirror-neuron researcher at the University of California, Los Angeles. Cognitive

neuroscientist Vilayanur S. Ramachandran of the University of California, San Diego, even ventures that “mirror neurons will do for psychology what DNA did for biology: they will provide a unifying framework and help explain a host of mental abilities that have hitherto remained mysterious and inaccessible to experiments.” In Ramachandran’s view, mirror neurons may clarify not only how we come to learn and to understand others but how humans took a “great leap forward” about 50,000 years ago, acquiring new skills in social organization, tool use and language that made human culture possible.

The Raisin Incident

Big-picture speculation is not needed to see the wonder of mirror neurons, however. Even their basics astonish.

The neuroscientists who discovered the cells found them by happenstance. Giacomo Rizzolatti, Vittorio Gallese and Leonardo Fogassi of the University of Parma in Italy had run electrodes to individual neurons in a monkey’s premotor cortex, to study neural activity as the mon-



S. LUKASH

key reached for different objects. The eureka moment came when Fogassi walked into the room where the macaque was and casually reached out and picked up a raisin. As the monkey watched him, its premotor neurons fired just as they had earlier, when the monkey had picked up the raisin itself. The men could hardly believe what they had witnessed. But after replicating that experiment and similar ones many times, they realized they had discovered something new, and in a series of 1996 papers they gave the “mirror neurons” their name.

Since then, the Parma team, working often with Iacoboni, Michael A. Arbib of the University of Southern California and Christian Keysers of the University of Groningen in the Netherlands, has significantly expanded those findings. The researchers have learned, for instance, that mirror neurons do not just fire when an animal is watching someone else perform an action. Mirror neurons also fire if a monkey hears the sound of someone doing something it has experienced—say, tearing a piece of paper. And as the scientists began studying humans (using brain imaging rather than electrodes), they found groups of mirror neurons in higher numbers and in more places than occur in monkeys. Mirror neurons revealed themselves in the premotor cortex and the inferior parietal areas—associated with movement and perception—as well as in the posterior parietal lobe, the superior temporal sulcus and the insula, regions that correspond to our abilities to comprehend someone else’s feelings, understand intention and use language.

From Action to Understanding

Unlike monkeys, humans also use mirror neurons to directly imitate actions and to understand their meanings. It appears we use mirror neurons to learn everything from our first smiles and steps to our most suave expressions and graceful dance moves. We also use them to appreciate these things, to feel the meaning behind a smile or to enjoy—in a sense by doing it at a premotor neural level—the thrill of hitting a tennis ball as we watch a Pete Sampras backhand.

These functions became evident in the first round of mirror-neuron studies in the late 1990s. Since then, imaging studies have shown that mirror neurons in humans encompass many more areas and functions. In 1998 Rizzolatti and Arbib discovered that one of the regions particularly rich in mirror neurons is the famous Broca’s area, which Paul Broca found in the 1850s to be critical for language processing.



Mirror-neuron theory began to mesh with existing language theory, which held that actions have a syntax similar to that of spoken or signed language. For mirror neurons, “hand grasps ball” is the same whether it is an action or expressed in sign language or a spoken sentence. Thus, language arises from the syntactic understanding generated by our mirror neurons. This idea gained credence in 2005: an international team that included Gallese and Rizzolatti found that when people listened to sentences describing actions, the same mirror neurons fired as would have had the subjects performed the actions themselves or witnessed them being performed. Remarkably, the cells responded to an abstract representation of a process that would seem to be quite visual and visceral.

Another major insight relates to our understanding of other people’s intentions and emotions. Several studies have demonstrated the dynamics of empathy, two with particular elegance.

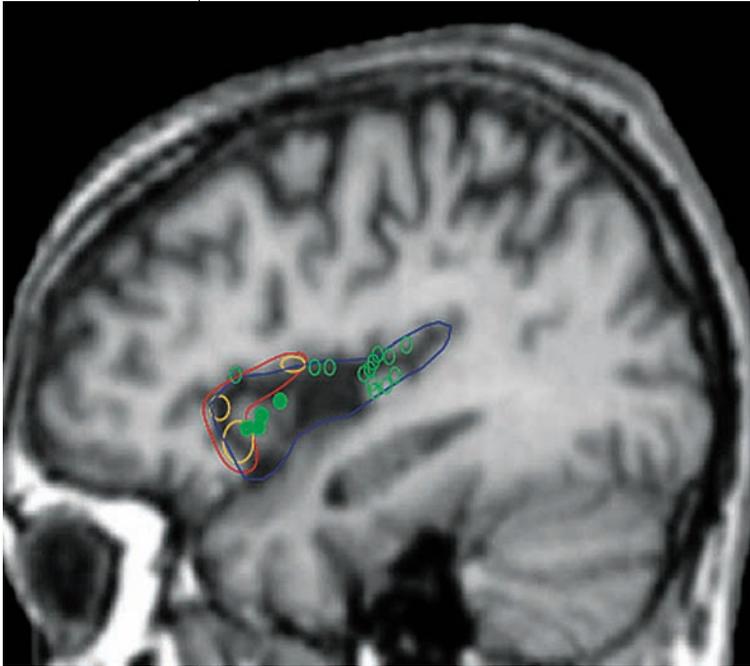
One, described by Iacoboni in 2005, shows that our mirror neurons work in elaborate sets. We possess a basic set of mirror neurons corresponding to an action’s most essential form—reaching, for instance—that is supplemented by other groups of mirror neurons that selectively

EMPATHY
Theatergoers feel the pain of an actress spurned because their mirror neurons fire as if they were experiencing their own rejection firsthand.

(The Author)

DAVID DOBBS (www.daviddobbs.net) profiled Joseph LeDoux and his work on fear in the February/March issue of *Scientific American Mind*.

More complex mirror-neuron systems may have sparked the advance of **human cultures** 50,000 years ago.



Neurons inside the red outline fired when one test individual experienced disgust because of a foul odor. Neurons inside the yellow outlines fired later when the same subject watched another person experience disgust. The areas overlap strongly, indicating mirror neurons. (Blue and green outlines represent the region and method of testing.)

fire according to the action's perceived purpose. Iacoboni had volunteers watch films of people reaching for various objects within a teatime setting—a teapot, a mug, a pitcher of cream, a plate of pastries, napkins—in different contexts. In every instance, a basic collection of “reaching” mirror neurons fired. But different additional mirror neurons would also fire depending on what expected action was suggested by various details in the scene. If the viewer saw a neatly set table and expected the hand to pick up a teacup to drink, one array fired; if the viewer saw a messy table and expected the hand to pick up a cup to clear it away, another group fired. Thus, mirror neurons seem to play a key role in perceiving intentions—the first step in understanding others and also in building social relations and feeling empathy.

A number of experiments, meanwhile, have shown that mirror neurons help us share other people's experiences as reflected in their expressions, providing a biological basis for empathy and for the well-known contagiousness of yawns, laughter, and good or bad moods. One of the most convincing (and certainly the most memorably titled) observations appeared in a 2003 paper, “Both of Us Disgusted in My Insula: The Common Neural Basis of Seeing and Feeling Dis-

gust,” published by Bruno Wicker of the University of the Mediterranean in Marseilles, France. Using functional magnetic resonance imaging (fMRI), Wicker's team found that feeling disgust and seeing a look of revulsion on someone's face caused the same set of mirror neurons to fire in the insula, a part of the cortex active in synthesizing convergent information.

When the Mirror Fogs

Given that mirror neurons are so fundamental to understanding, it makes sense that faults among them might create profound problems. Indeed, it appears that deficits may help account for difficulties ranging from excessive reserve to autism. The possible failure of mirror neurons in autism is particularly intriguing. The cause and even the nature of this strange condition have eluded researchers for decades, leaving sufferers and their families and caregivers with little knowledge about why the behaviors are happening, let alone how to treat them. But recent research suggests that an inactive mirror-neuron system may explain the deep troubles with language, learning and empathy that do so much to isolate the autistic person.

The findings indicate breakdowns in both basic and complex mirror-neuron activity. One study at Harvard Medical School, for instance, found that mirror neurons that fired in nonautistic people when they watched someone else make meaningless finger movements fired much less often in autistic children. This lack of response could reflect a failure of mirror neurons' most basic function, that of recognizing others' actions. In another study, researchers showed pictures of people with distinctive facial expressions to autistic and nonautistic adolescents. Both sets of subjects could imitate the expressions and say what emotions they expressed. But whereas the nonautistic teens showed robust activity in mirror neurons corresponding to the emotions expressed, the autistic teens showed no such activity. They understood the expressions cognitively but felt no empathy.

How these discoveries might lead to treatments is not clear. Yet identifying this apparent deficit, if the findings hold up, could be a major advance in pinning down the neural roots of autism.

FROM “A UNIFYING VIEW OF THE BASIS OF SOCIAL COGNITION,” BY V. GALLESE, C. KEYSERS AND G. RIZZOLATTI IN *TRENDS IN COGNITIVE SCIENCES*, VOL. 8, NO. 9; SEPTEMBER 2004



SOCIALIZATION
Using mirror neurons, we develop elaborate forms of social interaction that constitute human culture.

Reflections Deep and Dark

Mirror neurons' role in understanding others lies at the heart of the deeper claims about them. Some, such as Ramachandran, believe that mirror neurons were crucial in the development of the elaborate social skills, social networks and knowledge infrastructure we call culture—from tool use to reveling in Shakespeare, from collaborative hunting to hip-hop. The archaeological record suggests that this “great leap forward”—the beginnings of human culture—began about 50,000 years ago. But human brains underwent no growth spurt then; indeed, they have been roughly their present size for about 200,000 years. So what changed? Ramachandran and others speculate that the change was a genetic adaptation that gave key neurons the mirroring capacity they now hold, paving the way for accelerating advances in understanding, communication and learning. For the first time, information could be spread, built on and modified to create the intellectual and social dynamic of culture.

Mirror neurons do not always reflect on us kindly, of course. For example, they may be implicated in the influence of violent video games. Initial studies by Iacoboni suggest that such games reinforce, at a basic neuronal level, an association of pleasure and accomplishment with inflicting harm—an impetus that society would not want to encourage. Iacoboni speculates that the strength of mirror neurons may be such that imitative violence, if reinforced, may be harder

to resist than we would like to think. The power of mirror-neuron systems, Iacoboni says, “suggests that imitative violence may not always be a consciously mediated process”—that is, not so easily subject to our control.

Work on mirror neurons has greatly accelerated in the past five years and seems sure to upshift even more. Whether Rizzolatti, Fogassi and Gallese's breakthrough of 1996 will turn out to be as big as James D. Watson and Francis Crick's 1953 discovery of DNA remains to be seen. Yet mirror neurons already constitute one of the richest areas in neuroscience, both intellectually and experimentally. If their enormous explanatory power is backed by more robust results, they might indeed become regarded as the DNA of neuroscience. In the meantime, mirror neurons explain some intriguing wonders. My son Nicholas is now four years old, which is advanced enough to enable him to stick his tongue out at me of his own accord. I have no idea where he learned such a thing. But at least I know how. **M**

(Further Reading)

- ◆ **Action Recognition in the Premotor Cortex.** V. Gallese, L. Fadiga, L. Fogassi and G. Rizzolatti in *Brain*, Vol. 119, No. 2, pages 593–609; 1996. Available at <http://brain.oxfordjournals.org/cgi/content/abstract/119/2/593>
- ◆ **How Mimicry Begat Culture.** Beth Azar in *Monitor on Psychology*, Vol. 36, No. 9, pages 54–57; October, 2005. Available at www.apa.org/monitor/oct05/mimicry.html
- ◆ **From Monkey-Like Action Recognition to Human Language: An Evolutionary Framework for Neurolinguistics.** Michael Arbib in *Behavioral and Brain Sciences*, Vol. 28, pages 105–167; 2005.