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It's All Done with Mirrors

Reflections on the familiar and yet deeply enigmatic nature of the looking glass

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Mirrors have held a peculiar fascination for people ever since one of our early hominid ancestors looked at her reflection in a pool and noticed an uncanny correlation between her own muscle movements—sensed internally—and the visual feedback. Even more mysterious—and perhaps not unrelated—is our ability to "reflect" on ourselves as the first introspective primates. This ability displays itself in ways as different as the mythical Narcissus looking at his reflection in a lake to Internet pioneer Jaron Lanier's invention of virtual reality to transport you outside your own body.

Intriguingly, neuroscientists have discovered a new class of brain cells called mirror neurons that let you "adopt another's point of view," both literally and metaphorically ("I see what you mean"). Perhaps such neurons even allow you to look at yourself from another's vantage point, so you become "self conscious" of what you are doing or wearing or even of who you are. It is as if the brain were peering into its own internal mirror.

We take all these abilities for granted, but about a decade ago Eric L. Altschuler and Steve Hillyer, both then at the University of California, San Diego, and one of us (Ramachandran) described a new neurological syndrome called mirror agnosia in which a patient with a small right hemisphere stroke cannot tell that a mirror reflection is not a physical object. Amazingly, these patients will repeatedly try to reach for, pick up or grab the reflection (which they claim is a real item) located in the mirror. Mentally, such patients are otherwise perfectly normal; they continue to have abstract knowledge of mirrors and the nature of their optics. Such patients give us a glimpse into the surreal no-man's-land between reality and illusion, and they help us realize how tenuous our hold on reality is. Mirrors are familiar yet deeply enigmatic.

You can play with mirrors to explore their magic. Begin by constructing the mirror box. We initially designed this box to treat patients with phantom limbs and stroke (more on this therapy later), but you can have fun experimenting on yourself and your friends. Alternatively, for a quick start, use the swinging, mirror-covered door of a bathroom medicine cabinet or simply prop up a mirror using books or bricks.

Normally our senses, such as vision and proprioception (muscle and joint sense), are in reasonably good concordance. The messages from different senses converge in the angular gyrus and supramarginal gyrus in the parietal lobe, where you construct your "body image." These two gyri were originally fused as one gyrus (the inferior parietal lobule) in apes. Given the importance of intermodality (cross-sensory) interactions, however, in humans the lobule became enormous and split into two. From such humble beginnings, we evolved into a hairless ape capable of vast technological sophistication—an ape that not only can reach for peanuts but also can reach for the stars.

Let us return to the mirror box. Start with the reflective side facing rightward. Put your left hand on the left side of the mirror, so it is hidden from view, and place your right hand on the right side so that it exactly mimics the posture and location of the hidden left hand. Now look into the mirror at the reflection of your right hand; it will feel as if you are looking at your real left hand, even though you are not.

While looking in the mirror, begin to move both hands synchronously—in circles or by opening and closing your fingers, for example—so that the reflected and hidden hand are in lockstep. Now, here is the clever bit: stop moving just the left (hidden) hand as you continue moving the right hand. Move your right hand *slowly;* rotate or wave it about and wiggle your fingers but keep your left hand still. For a moment you will now *see* the left hand moving but *feel* it remaining still. Most people experience a jolt of surprise; the brain abhors contradictions.

Even more discombobulating: move your hidden left hand while keeping the right one still. This time you get an even bigger jolt when vision and proprioception "clash." Next, while still looking in the mirror, have a friend stroke your right hand with his finger. You will see your "virtual left hand" being stroked—but your actual left hand, behind the mirror, is not being touched. With this peculiar sensory conflict, your left hand may seem to be anesthetized—because you see, but do not feel, the touch.

Another quite different type of incongruence, which we have observed with Altschuler, occurs if you look at your hand through a minimizing—that is, concave—lens (novelty or science museum shops are good places to purchase inexpensive plastic sheets of these lenses). The hand, when viewed through this type of lens, looks much longer and smaller than it should be, which feels odd. But if you now move your hand and wiggle your fingers, the sensation becomes even more paradoxical and spooky. You feel that the hand does not even *belong* to you; you have a temporary out-of-body experience, as if you were manipulating some other person's hand!

The same happens if you look down through the lens at your own feet as you walk. They feel long, skinny and rubbery, as if they were detached from you or you were a giant inspecting his own feet. Even our sense of "willing" a hand or leg to move or of being anchored in our body, it turns out, is built on shaky foundations.

Such parlor games are amusing, but they are also of considerable interest both theoretically and clinically. When an arm is amputated, a patient continues to feel its presence vividly, a syndrome called phantom limb. Oddly enough, many patients believe that they can move their phantom freely ("it answers the phone," "it waves goodbye," and so on).

How does this illusory feeling happen? When you move your hand, motor command centers in the front of the brain send a signal out, down the spinal cord to the muscles on the opposite side of the body. At the same time, a copy of the command (like an e-mail CC) goes to the parietal lobe. As we already noted, this area gets both visual and proprioceptive (body-position sense) feedback that can be compared with the motor command, thereby forming a feedback loop to ensure accuracy. If the arm is lost, there is no proprioceptive feedback, but the copy of the command is nonetheless sent to the parietal lobe and sensed by the patient's brain as movements of the phantom.

For reasons we do not fully understand, some patients are unable to move their phantom—they say it is "paralyzed." And often they report that the phantom limb is painful or frozen in a peculiar, unnatural posture.

How can a phantom be paralyzed? It turns out that many of these patients have had a preexisting injury to the nerves that exit the spinal cord and innervate arm muscles, such that the arm was intact but paralyzed. During that phase, every time the premotor cortex in the front of the brain sent a command to move the arm, it received visual and proprioceptive feedback saying, "No, it is *not* moving." Eventually this message gets stamped into the brain as a form of "learned paralysis," a kind of memory that is carried over into the phantom.

The Mirror Cure

Would it be possible to "unparalyze" a phantom by giving a patient visual feedback every time he attempted to move his phantom? Would this strategy provide pain relief? In a 1996 paper we described the technique of using the mirror box. The patient "puts" his clenched, paralyzed phantom on one side and his normal hand on the other, then looks in the mirror while performing mirror-symmetric movements (opening and closing the fist, clapping, and so on). The mirror box gives the visual illusion that the phantom has been resurrected and is actually moving in perfect synchrony with the brain's commands.

Incredibly, the phantom also *feels* as if it is moving, and in many patients the cramping sensation goes away for the first time in years. In some patients the phantom vanishes completely and permanently, along with the pain; it is the brain's way of dealing with sensory conflict. (We suggested in that same paper that such procedures may also be helpful for other conditions such as stroke or focal dystonia, a neurological condition that causes involuntary muscle contractions.) These effects on phantoms have now been confirmed in clinical trials on patients and elegantly explored with brain-imaging studies by neuropsychologist Herta Flor of the University of Heidelberg's Central Institute of Mental Health in Mannheim, Germany.

Phantom pain is bad enough, but it is uncommon compared with an equally disabling disorder, stroke, which is a leading cause of disability in the U.S. Damage to the fibers that go from the cortex to the spinal cord caused by a vascular lesion can lead to complete paralysis of the opposite side of the body. We wondered if there is a component of learned paralysis in stroke; perhaps the initial swelling and inflammation cause a temporary interruption of signal transmission. This interruption, combined with visual evidence of paralysis, leads to a form of learned paralysis in addition to the real paralysis caused by nerve damage.

In 1999, in collaboration with Altschuler, we turned to the mirror box to treat stroke paralysis. Testing nine patients, we found striking recovery of function, which was remarkable given that stroke paralysis is usually considered incurable. We postulated that multimodal cells (cells hooked up directly to vision, proprioception and motor output—similar to mirror neurons) that had been rendered dormant by the stroke were being revived by the illusory visual feedback from the mirror.

This result, too, has been replicated in controlled trials by two independent groups led by psychologist Jennifer A. Stevens, then at Northwestern University and the Rehabilitation Institute of Chicago, and neurologist Christian Dohle of Düsseldorf University Hospital and the Godeshöhe Neurological Rehabilitation Center in Germany.

We also know that even though most motor fibers from the cortex cross over to the opposite side of the body (that is, contralateral), some fibers go directly to the same side (ipsilateral). It has long been a puzzle why intact fibers cannot "substitute" for the damaged ones if there is a stroke. Perhaps they are being "recruited" by the use of the mirror. If so, we may conclude that mirrors (and smoke) are not only useful to magicians. They also can reveal deep insights into how the brain integrates different sensory inputs. Equally important, visual feedback—whether from mirrors or virtual reality—can even be clinically useful in promoting recovery of function from neurological deficits that have long been considered incurable.

Offer a summary of the main points of this article.

Express the potential benefits of the mirror to patients who have experienced paralysis, and Why.