FEELING THE FUTURE

Our sense of touch will not only be replaceable, it will be enhanceable. **By Evelyn Strauss**

EVEN THE PHONE COMPANY has tried to exploit our need to touch. The old AT&T advertisements exhorted us to "Reach out. Reach out and touch someone." In the foreseeable future, this will become more than merely a metaphor. In the next several decades, some scientists predict they will be able to reconstitute the sense of touch in people who have lost limbs or sustained nerve damage and to extend the sensation into virtual worlds for the rest of us.

Imagine: A father who lost his arms uses a prosthetic hand to stroke his son's head. He relishes the familiar feel of the fine hair as he twirls a strand. After hearing about the day's water-gun battle and what the turtle ate for dinner, he kisses his child goodnight. Then he switches off his computer, and his son—who is a continent away—disappears.

This won't happen tomorrow. But scientists are already finding ways to rewire injured nervous systems, and they can already make three-dimensional objects that exist only inside computer software feel incredibly real.

Although spinal cord injuries derail communication between the brain and the muscles, the muscles can often still work if they are stimulated by some other means, such as a pulse of electricity. Researchers are taking advantage of this potential by building devices called neural prostheses that allow people to use motions that they can still command to perform various activities. A shrug of the shoulder, for example, can trigger a stimulator to send an electrical signal to the muscles that would make a missing hand grasp.

Right now the state-of-the-art device allows people to control up to 10 muscles, but researchers are striving to add more. "The next-generation system might supply the ability to hold an object above your head," suggests Jeanne O. Teeter of the Louis Stokes Cleveland Department of Veterans Affairs Medical Center. Bioengineers are already implanting parts of these mechanisms, and they envision a time when patients will carry entire systems under their skin that are capable of performing multiple functions.

And all may not be lost forever for people who have sustained serious injuries that leave them with virtually no voluntary muscle control. "We're looking to the brain to control neural prostheses," Teeter says. People can learn to make reproducible changes in brain-wave patterns, she explains, and several research groups have already developed technology that allows people who are severely disabled to use this ability to move a cursor on a computer screen. Teeter would like to harness brain activity so disabled people could move their hands and legs "just by thinking about it."

Scientists might eventually improve on current nerve regeneration techniques to the point where they figure out how to use human nerves for the purpose instead of electrical wires. "Some people are trying to graft nerves around the area of injury to the peripheral nerves beyond," comments Joseph E. Kutz of the physicians' group Kleinert Kutz and Associates in Louisville, Ky. He emphasizes, however, that this approach is "still experimental. There's nothing yet that we're able to use in humans."

PHANTOM CONTROL

In contrast to people with spinal cord injuries, amputees retain uninterrupted nerve connections between the limb stump and their brain. Some people even feel as if their limbs are still there and maintain a sense of control over their missing parts. Such people typically can move muscles or ligaments that would otherwise operate missing fingers. This ability provides a critical link to restoring capacity. Engineers are devising systems that attempt to mimic a natural limb by hooking up muscles and nerves that once controlled some body part to a prosthetic version of it. William Craelius of Rutgers University is one of those engineers. He is developing a system with multiple, independently operating fingers—an improvement on current prostheses that just open and close a claw. With his new mechanism, users can operate a computer mouse or punch the keys on a keyboard.

Movement is one thing, but what's missing for many is the ability to feel. "It's very difficult to control paralyzed parts of your

MATT MAHURIN

The prosthetic limbs of tomorrow will be wired directly to the user's brain.

body if you don't get sensory feedback," states Thomas Sinkjaer, director of the Center for Sensory Motor Interaction at Åalborg University in Denmark.

As an object begins to slip, for instance, people with intact nervous systems grip slightly harder, but just enough to stop the slippage. "If we want to restore good motor functions, we need to find ways to plug into the sensory system and feed back that information to the subject or to a computer," Sinkjaer asserts. In some situations, computers that respond in a simple way to specific signals are likely to substitute quite well for the normal situation. "If you touch something hot, you let go," explains Vincent R. Hentz, a hand surgeon at the Stanford University School of Medicine. "It's a reflex. The signal doesn't go through the brain."

Sinkjaer's group is developing a technique for putting electrodes around a sensory nerve that receives messages from special receptor cells in the hand. The electrodes record the impulses running along the nerve, and this electrical traffic correlates with how tightly the hand is holding an object. In its current form, the electrode feeds that information into a computer that "decides how to adjust the grasp accordingly" and then stimulates the correct muscles, Sinkjaer describes.

The first human subject is happy with the results. "Before, he had about 15 minutes to eat because after that he'd be so fatigued from gripping the fork too hard, he wouldn't be able to hold it any more," Sinkjaer recalls. "Now he should be able to talk to the person sitting next to him at a dinner party." Sinkjaer hopes eventually to improve the system so it can distinguish, as the brain can, exactly which of the thousands of receptors that feed into a given nerve fiber are firing. But before he and his colleagues accomplish that, scientists will need to develop electrodes that interface with the relevant neural pathways more selectively than they currently do.

Already researchers can send information back to a person as opposed to a computer. This approach might help paraplegics relearn to walk because it could abolish the need to use their hands to sense their weight distribution as they stand between parallel bars during physical therapy. Wiring sensory electrodes from the soles of the feet to gadgets that transmit an electrical signal to the shoulders, for example, can tell people when they are standing evenly on both feet: they would feel similar sensations in their right and left shoulders. Investigators developing prosthetics for amputees are using systems that are similar conceptually, adds Paul D. LaBarre, a mechanical engineer at Seattle Orthopedic Group in Poulsbo, Wash. His company is designing artificial feet that tell the user when his or her heel hits the ground, for example, by translating that force into a signal felt elsewhere on the body, such as on the calf.

In the most elegant schemes, sensors would send a signal to the same nerves that had once led to the missing appendage. Along these lines, researchers are building prostheses that connect directly to severed nerves using a specialized electrode that activates a small number of nerve fibers when implanted in the stump. "If we stimulate nerve fibers [that carry information about touch, pain and other sensations], we can make the person feel like they're sensing something on their thumb even though there's no thumb there," reports neuroscientist Kenneth W. Horch of the University of Utah.

He also hopes to make gizmos that run in the other direction—allowing a person to control the limb as well as experience the sensation of touch from it. But for this to work, the nerve fibers that

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Future prosthetic limbs will not only look—and feel—extraordinarily real, they will also be equipped with the sense of touch.

control the particular faculties that the researchers are trying to restore must still maintain their connections to the spinal cord.

Results so far have shown that the approach is feasible, Horch says, although the project is still in its preliminary stages. The researchers have electrically stimulated the nerve stump of amputees and shown that people can feel as if the missing appendage is being touched. "The nervous system is still intact enough for this to work," he observes. "Now we're ready to do long-term studies on patients and actually try it out."

ENTER LEE MAJORS

In the long run, scientists fantasize about making "a bionic limb that would replace all the sensations and abilities the limb had before it was amputated, with full feedback of both external and internal stimulation," LaBarre envisages. He points out that sensing physical contact is just one of the many types of information you receive from your limbs. "If you flex your elbow with your eyes closed, you know it. And if someone kicks your leg, you feel that, too," he says. "We'd like you to get all of that information from a bionic limb."

But that's just the beginning: LaBarre foresees temperature sensors. Although these are already available in a research setting, the current versions do not appeal to patients, he says, because they have lots of external electrodes and wires. Eventually, however, he expects them to be improved so that they can be incorporated seamlessly into prosthetic systems.

LaBarre even suggests it might be a good idea to include a sense of pain in bionic limbs so their users can keep them out of harm's way. The inability to feel discomfort can cause major problems for strictly biological limbs. Diabetes, for instance, often leaves hands and feet numb, for reasons that are still not exactly clear. "Diabetics can walk around all day with a pebble in their shoe and not know it," LaBarre says. "They end up with a debilitating sore on the bottom of their foot."

Experts working toward these goals caution that the technical and scientific challenges to restoring touch are huge. Building implantable touch sensors for people with spinal cord injuries, for example, presents tremendous difficulties. "Normal skin has thousands of receptors in its top two layers," states Clayton Van Doren, assistant professor of orthopedics at Case Western Reserve University. "We'll be lucky to put in one somewhere deeper in the tissue." Furthermore, such a sensor needs to be safe enough to be left in the body for months or years and robust enough to hold up that long. More important, Van Doren points out, "we don't understand the relationship between physical stimuli and perception. Because of that, it's difficult to know how to re-create the process in people who have lost some part of it."

While scientists are encountering considerable obstacles trying to reproduce relatively simple sensations, such as how tightly someone is holding an object, those who are studying more sophisticated tactile experiences face an even more formidable task. "When I grasp fabric, I can tell whether it feels like silk versus a coarse wool," observes Lynette Jones, a biomedical scientist at the Massachusetts Institute of Technology. Yet researchers are making significant progress toward this goal. "We've identified which receptors in the skin give information to the brain about fine features on a surface, but we don't know exactly how the brain processes that to perceive texture," says Mandayam Srinivasan, director of M.I.T.'s Touch Lab.

Remote medical technology is already helping patients. Companies such as Intuitive Surgical in Mountain View, Calif., and Computer Motion in Santa Barbara, Calif., have systems that enable physicians to perform heart bypass surgery during a minimally invasive procedure. Instead of sawing open the breastbone and prying the ribs apart, they send a camera and other instruments into the chest through small holes. Surgeons sit at a console and operate the tools while they watch what they are doing on a stereo display monitor. This approach enhances dexterity and reduces small tremors from shaking hands. "It scales down the motions so the surgeon can do really intricate work," says Kenneth Salisbury, a mechanical engineer at M.I.T.

Future generations of these machines might give surgeons the capability to feel more complex sensations so they can do things such as "figure out how tight they're pulling sutures when tying a knot," forecasts Paul Millman, a mechanical engineer at Computer Motion. He would also like to incorporate palpating technology. "It would be good if surgeons [at the console] could run their finger along arteries and find blockages, which feel tough," he says, or find "nice, healthy vessels, which are springy. If they could get the same information through these ports as they can now when they open up the chest, that would be great."

Perhaps the most demanding applications of artificial-touch technology would be virtual sex and remote sex. So far most of the problems investigators are attacking require only a subset of the components of touch. Mimicking a sexual encounter would combine everything—force feedback as well as tactile and thermal sensations, for instance—into one system. "Current haptic devices are not good enough for cybersex or virtual sex," Srinivasan concludes. "You can feel contours and [flexibility], but it's still probably very far from what people would want."

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Yet another thorny problem will be figuring out how to make artificial parts that can transmit the feel of subtle textures to multiple digits or a whole hand. The spatial and temporal information produced when a person touches surfaces is apparently very important for feeling textures, according to Susan J. Lederman, professor of psychology and computing and information science at Queens University in Kingston, Ontario. "When you've got only one point of contact, you don't get the same information as you do when you run your fingers over [something]," she says.

INTO THE VIRTUAL WORLD

Some of the largest strides in feeling texture and other sensations are being made by those who are developing so-called haptic devices that let people receive touch stimuli in a remote location or in virtual reality [see "Getting Real in Cyberspace," on page 48]. Robert D. Howe, a mechanical engineer in the division of engineering and applied sciences at Harvard University, is developing palpation technology that would, for example, permit surgeons to feel inside a patient's body through tiny holes.

Instead of a single probe, his device contains dozens of pins that transmit forces independently. "We're interested in what you would feel spread across your fingertip if you rubbed it across a surface," he says. Surgeons might snake such a device through a miniature cut in the chest wall to feel for lumpy lung tumors without having to make an incision large enough to fit a hand.

Touch technologists are reluctant to talk about the sexual uses of their inventions, in part because there are so many other applications in the areas of medicine, training, design and other traditionally wholesome realms. In principle, though, people could strap devices onto different parts of their bodies that could enable them to interact with a virtual person or with someone real who happens to be thousands of miles away. "The holy grail—not just for cybersex but for haptic interactions with virtual environments—is to wear something like a bodysuit that generates forces on you directed by a computer that mimic the real world," Srinivasan comments. "Right now using haptic technology is more like exploring the world by poking at it with a stick."

Is all of this fantastic? Yes, but it will happen. And when it does, maybe you'll hear about it from an advertisement for a porn Web site—via feel-mail, of course. How's that for keeping in touch?

ABOUT THE AUTHOR

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