Enter the Cyborgs

Promise and peril in a marriage of brains and silicon

BY NELL BOYCE

Except for those odd little backpacks, the rats seem no creepier than usual. They climb trees, run through pipes, and scamper across tables. But they aren't following the usual rodent urges. These rats are moving under remote control, reacting to commands radioed to three thin electrodes in their brains. The signals tell them which way to turn—and encourage them by delivering electrical jolts to their pleasure centers.

SANJIV TALWAR—SUNY DOWNSTATE MEDICAL CENTER / AP

RATBOT. A rat maneuvers along a railroad track, guided by electrical signals delivered to its brain by the backpack.

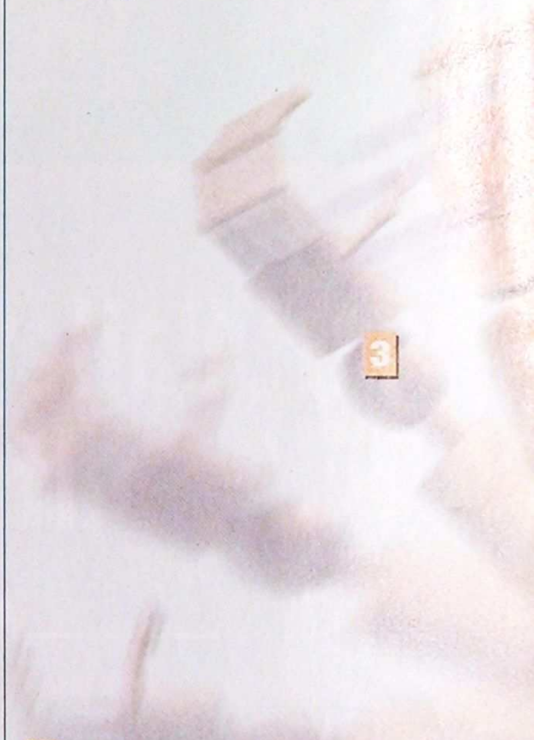
It is a tour de force with unsettling implications, and not just for rats. "It was kind of amazing to see," says researcher Sanjiv Talwar of the State University of New York Downstate Medical Center, Brooklyn. "We didn't imagine that it would be that accurate." The success, reported last week in *Nature,* conjures up visions of roborat search-and-rescue squads. It may also advance a long-sought goal in humans: linking the brains of people paralyzed by disease or injury to robots that could act for them. To be really useful, such devices would have to give sensory feedback to the brains of their users. That's what Talwar and his colleagues achieved with the rats, steering them left or right with impulses that made them feel as if someone were touching their whiskers.

The feat is just the latest in a series of demonstrations suggesting that brains could meld with machines faster than you might think. Monkeys have moved robot arms with signals from their brains. Neural implants have also given a few severely disabled patients control over a computer cursor and delivered "sound" right to the brains of some deaf people. Yet it isn't just the paranoid who worry that such technologies could be used for brain enhancement rather than therapy, or that the mating of mind and machine could turn people into something akin to roborats.

"The individual work that's being done is not necessarily ethically troubling. It's the broader ramifications, the implications of what can be," says Ellen McGee of the Long Island Center for Ethics, who has written on brain chips that could link the "wetware" of the brain to the hardware of a computer. Ethicists are meeting next week in San Francisco to ponder "neuroethics"—the ethical challenges posed by advances in neuroscience like this one. And President Bush's bioethics panel may also take up the issue of brain implants, according to its chair, bioethicist Leon Kass.

Talking the talk. Brains and electronics can communicate because they have a common language: electricity. For decades, scientists have mapped the brain with electrodes, which eavesdrop on neurons' electrical chatter or tickle them with external signals. In the 1950s, when scientists began slipping electrodes into the brains of patients who were awake during surgery, they were surprised to find that an electric current could make people hear music or recall childhood memories. Other work showed that electrodes could produce emotions like fear, anger, and pleasure. John Chapin, who heads Talwar's lab, recalls a famous 1965 photo of a neuroscientist who stopped a charging bull by stimulating an electrode in its brain using a radio transmitter.

These days, you might unknowingly walk past someone on the street who has an implant sending signals right to his or her nervous system—and loves it. Some devices, like the cochlear implant that restored radio host Rush Limbaugh's hearing, act on nerves rather than the brain. But in around 200 completely deaf people with damaged auditory nerves, electrical signals derived from sounds go right to the brain's surface. Although most of these people can perceive only muffled sound, "we have a handful who can actually hear and understand sentences," says Robert Shannon of the House Ear Institute in Los Angeles. Later this year, Shannon and his colleagues hope to start a trial of a newer device that actually penetrates the brain.



3 REAL-TIME MOTION

The computer-controlled arm performs the motion. Visual feedback through the eyes and tactile feedback from sensors in the arm, which send their signals back to the implanted electrodes, help the person control the arm.

Other common implants act as the equivalent of pacemakers for the brain, sending electrical impulses to restore order when brain activity goes awry. In nearly 15,000 people with Parkinson's disease, an electronic device sewn into their chest sends signals to electrodes deep within their brain, disrupting the abnormal electrical activity that causes their tremors. Ali Rezai of the Cleveland Clinic hopes to use similar devices to treat obsessive-compulsive disorder and depression. He expects that within a few years, such implants will not just stimulate neurons but also "listen" to them, so that the brain pacemaker can lie dormant until it detects abnormal activity.

Scientists are also working on devices that listen to—and then act on—normal wishes and intentions, such as "reach for that glass." Four years ago, neurologist Philip Kennedy, now at a company called Neural Signals, announced a first step: a system that enabled a man named Johnny Ray, paralyzed and speechless after a massive stroke, to move a computer cursor simply by thinking about it. Kennedy put two electrodes in a region of Ray's brain associated with hand movement. After two months of practice, Ray's brain figured out how to generate electrical signals that would move the cursor and let him slowly spell out words.

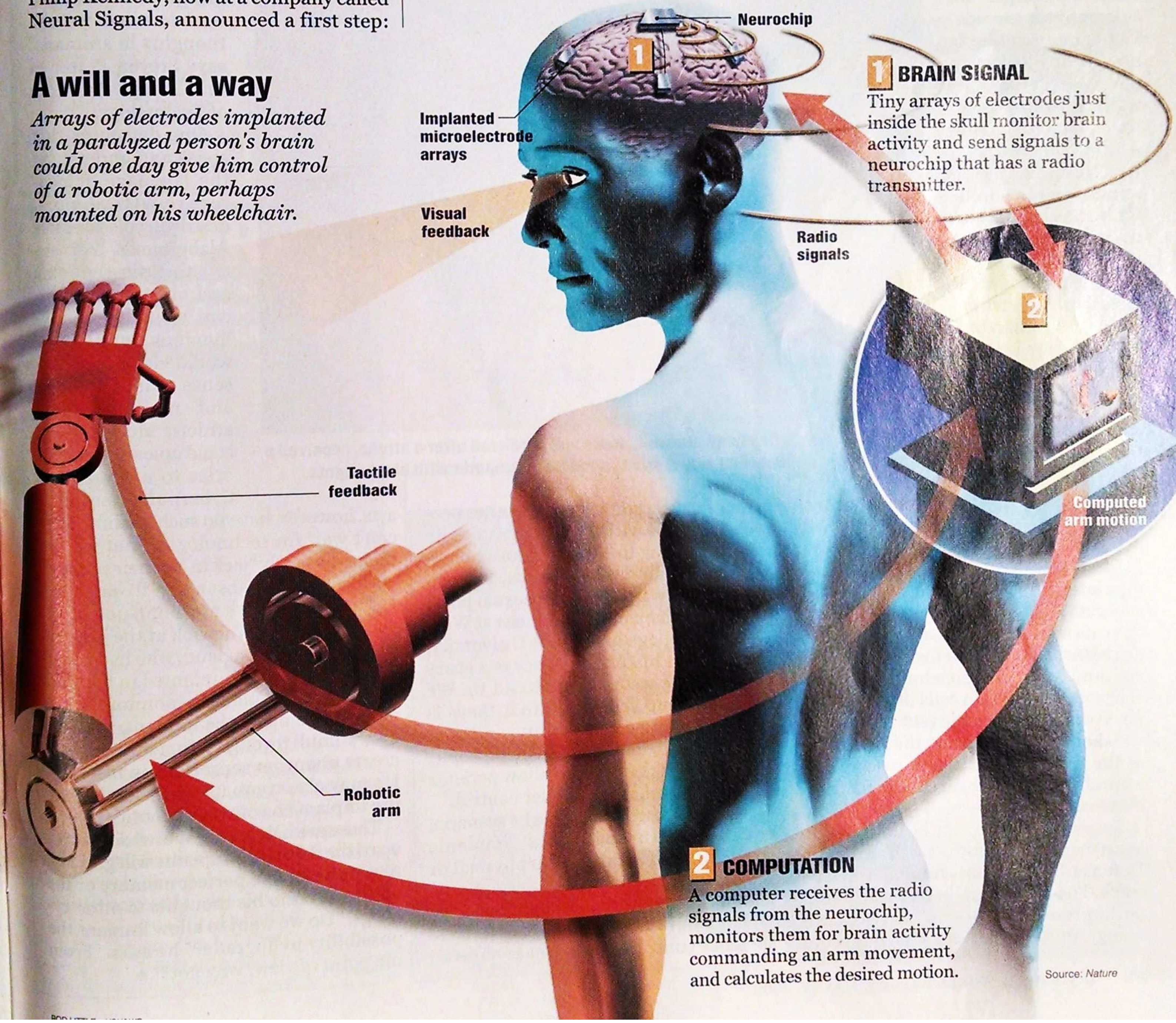
Kennedy has since put implants in three other patients, but their declining health limited their ability to use the devices. He recently got permission from the Food and Drug Administration to work with people who have degenerative diseases but have not yet become "locked in," losing all speech and movement. That should give them more time to become adept with the technology.

The ultimate goal, says Kennedy, "is to have patients communicate and move through the brain-machine interface." Giving people control of both computers and robot arms is likely to mean implanting many electrodes, sensitive to more nuances of the brain's electrical chatter. Such multielectrode arrays have already been tested in animals, and the results have been striking.

Mind control. Around the time that Ray was getting his implants, for example, Chapin's group implanted electrodes in the motor cortex of rats and monitored electrical activity there while the animals pressed a lever to get water. Computer analyses revealed an electrical pattern that the rats produced right before they pressed. When the researchers rigged the water dispenser to respond to the implant's signal instead of the lever, the rats kept pushing the now useless lever for a

A will and a way

Arrays of electrodes implanted in a paralyzed person's brain could one day give him control of a robotic arm, perhaps mounted on his wheelchair.



while. But soon they stopped bothering and controlled the dispenser with their brains alone. "There are some people who still can't believe it," Chapin says.

Since then, Chapin and others have ratcheted up the mind control. He and his colleague Miguel Nicolelis at Duke University put electrode arrays in the motor cortex of monkeys and showed that signals the arrays picked up as a monkey moved its arm could also control a robotic arm, which accurately mimicked the monkey's natural movements. Chapin and Nicolelis even sent the signals through the Internet to a robotic arm 600 miles away. In March, Mijail Serruya in John Donoghue's lab at Brown University demonstrated a setup that let monkeys "think" a green dot toward its target on a computer screen. Donoghue says he is now asking locked-in patients whether they would be willing to try the technology. And Andrew Schwartz of the Neurosciences Institute in La Jolla, Calif., has been working with monkeys that perform a similar task but this time in a 3-D virtual-reality environment rather than on a screen. They learn to move a "floating" ball with their mind alone as skillfully as they can with a joystick.

DWIGHT ROSS JR.—ATLANTA JOURNAL-CONSTITUTION

PIONEER. **Johnny Ray (with stepson), mute and paralyzed after a stroke, received a brain implant that lets him slowly spell words on a computer with his thoughts.**

Once brain implant technology is powerful enough to give human patients control over, say, a robot arm, the next step will be to send signals back into the brain so patients can "feel" things as well as manipulate them. And that's where the roborats creep into the picture. To see if the rats could understand tactile stimuli delivered directly to their brains, Talwar and his colleagues implanted two electrodes near brain cells that normally receive signals from the rats' left or right whiskers. By stimulating the electrodes at the right moments, the researchers were able to steer the rats like a child's remote-control car.

Suspicious minds may be unnerved to learn that DARPA, the research arm of the Defense Department, funded Talwar's work. The agency has been eagerly supporting research into brain-interface technology, thinking it might someday prove useful for warfare. Remote-control animals could go on reconnaissance missions, for example, or search for injured people in destroyed buildings. Their backpacks could carry computer programs and global positioning system hookups that would guide them to targets.

Jihad rats. Talwar says he and his colleagues didn't start the experiment intending to make "jihad, ninja rats. It's not something that occurred to us." But the sight of the rats being vectored through mazes inevitably raises fears that such technology, if misused, could become a threat to autonomy in people. In the 1960s and 1970s, after all, a few psychiatrists made crude attempts to alter people's behavior with brain electrodes, in one case trying to "cure" a man's homosexuality by stimulating his pleasure center while he watched heterosexual porn.

Joseph Fins, a medical ethicist at Weill Medical College of Cornell University, thinks "that historical legacy is a scary one and one we need to attend to. We have to set up criteria so that there is transparency, accountability, and peer review." Brain implants can help people, he believes, if the devices "allow patients to have control, not be under control."

And then there's the opposite scenario, equally controversial: that implants could ultimately extend the physical or mental abilities of healthy recipients, leading to a superior caste of cyborgs. "What would happen if we could have someone control a third arm as naturally as you could control your other two arms?" wonders Donoghue. "That's the scary part," agrees Kennedy. "I have no ethical qualms with what I'm doing right now to patients," he says. "The ethical problem I have is using this to enhance normal consciousness."

Prostheses that would improve recipients' brains are much further away than thought-controlled arms. Enhancing intellect or memory will take a far more sophisticated ability to talk to and understand neurons than scientists now have. But several groups are trying to study the language of thought by growing small networks of brain cells on top of silicon chips and in electrode-studded dishes. "I think that by studying networks in culture, we can get an idea of the group activities that lead to what we call thoughts in animals," says Steven Potter of the Georgia Institute of Technology.

One day chips that speak and understand the language of neurons could treat mind-destroying diseases like Alzheimer's. Yet entrusting our thoughts and memories to silicon would be a momentous step. How would it affect our sense of individuality and mortality, asks ethicist McGee, if we could upload our memories to a computer? Cyberpunk enthusiasts, however, have no such qualms. They can't wait for technologies that will let them physically "jack in" to their computers like William Gibson's sci-fi characters.

The movement's most outspoken advocate is Kevin Warwick at the University of Reading, England, who had a multielectrode device implanted in his wrist this March. He plans to monitor the signals picked up by the implant, then deliver stimuli through it that he hopes will create phantom sensations in his hand. He may also try to use the signals from the implant to control a robotic finger.

These are baby steps, Warwick says, toward the day when implants will give him new powers, like perfect memory or the ability to radio his thoughts to other cyborgs. "Do we want to allow humans the possibility to upgrade?" he asks. "From my point of view, why not?" ●