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Monkeys Control Robotic Arm With Brain Implants

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Scientists in North Carolina have built a brain implant that lets monkeys control a robotic arm with their thoughts, marking the first time that mental intentions have been harnessed to move a mechanical object.

The technology could someday allow people with paralyzing spinal cord injuries to operate machines or tools with their thoughts as naturally as others today do with their hands. It might even allow some paralyzed people to move their own arms or legs again, by transmitting the brain's directions not to a machine but directly to the muscles in those latent limbs.

The brain implants could also allow scientists or soldiers to control, hands-free, small robots that could perform tasks in inhospitable environments or in war zones.

In the new experiments, monkeys with wires running from their brains to a robotic arm were able to use their thoughts to make the arm perform tasks. But before long, the scientists said, they will upgrade the implants so the monkeys can transmit their mental commands to machines wirelessly.

"It's a major advance," University of Washington neuroscientist Eberhard E. Fetz said of the monkey studies. "This bodes well for the success of brain-machine interfaces."

The experiments, led by Miguel A.L. Nicolelis of Duke University in Durham, N.C., and published today in the journal PLoS Biology, are the latest in a progression of increasingly science fiction-like studies in which animals -- and in a few cases people -- have learned to use the brain's subtle electrical signals to operate simple devices.

Until now, those achievements have been limited to "virtual" actions, such as making a cursor move across a computer screen, or to small two-dimensional actions such as flipping a little lever that is wired to the brain.

The new work is the first in which any animal has learned to use its brain to move a robotic device in all directions in space and to perform a mixture of interrelated movements -- such as reaching toward an object, grasping it and adjusting the grip strength depending on how heavy the object is.

"This is where you want to be," said Karen A. Moxon, a professor of biomedical engineering at Drexel University in Philadelphia. "It's one thing to be able to communicate with a video screen. But to move something in the physical world is a real technological feat. And Nicolelis has taken this work to a new level by quantifying the neuroscience behind it."

The device relies on tiny electrodes, each one resembling a wire thinner than a human hair. After removing patches of skull from two monkeys to expose the outer surface of their brains, Nicolelis and his colleagues stuck 96 of those tiny wires about a millimeter deep in one monkey's brain and 320 of them in the other animal's brain.

The surgeries were painstaking, taking about 10 hours, and ended with the pouring of a substance like dental cement over the area to substitute for the missing bits of skull.

The monkeys were unaffected by the surgery, Nicolelis said. But now they had tufts of wires protruding from their heads, which could be hooked up to other wires that ran through a computer and on to a large mechanical arm.

Then came the training, with the monkeys first learning to move the robot arm with a joystick. The arm was kept in a separate room -- "If you put a 50-kilogram robot in front of them, they get very nervous," Nicolelis said -- but the monkeys could track their progress by watching a schematic representation of the arm and its motions on a video screen.

The monkeys quickly learned how to use the joystick to make the arm reach and grasp for objects, and how to adjust their grip on the joystick to vary the robotic hand's grip strength. They could see on the monitor when they missed their target or dropped it for having too light a grip, and they were rewarded with sips of juice when they performed their tasks successfully.

While the monkeys trained, a computer tracked the patterns of bioelectrical activity in the animals' brains. The computer figured out that certain patterns amounted to a command to "reach." Others, it became clear, meant "grasp." Gradually, the computer learned to "read" the monkeys' minds.

Then the researchers did something radical: They unplugged the joystick so the robotic arm's movements depended completely on a monkey's brain activity. In effect, the computer that had been studying the animal's neural firing patterns was now serving as an interpreter, decoding the brain signals according to what it had learned from the joystick games and then sending the appropriate instructions to the mechanical arm.

At first, Nicolelis said, the monkey kept moving the joystick, not realizing that her own brain was now solely in charge of the arm's movements. Then, he said, an amazing thing happened.

"We're looking, and she stops moving her arm," he said, "but the cursor keeps playing the game and the robot arm is moving around."

The animal was controlling the robot with its thoughts.

"We couldn't speak. It was dead silence," Nicolelis said. "No one wanted to verbalize what was happening. And she continued to do that for almost an hour."

At first, the animals' performance declined compared to the sessions on the joystick. But after just a day or so, the control was so smooth it seemed the animals had accepted the mechanical arm as their own.

"It's quite plausible that the perception is you're extended into the robot arm, or the arm is an extension of you," agreed the University of Washington's Fetz, a pioneer in the field of brain-controlled devices.

John P. Donoghue, a neuroscientist at Brown University developing a similar system, said paralyzed patients would be the first to benefit by gaining an ability to type and communicate on the Web, but the list of potential applications is endless, he said. The devices may even allow quadriplegics to move their own limbs again by sending signals from the brain to various muscles, leaping over the severed nerves that caused their paralysis.

"Once you have an output signal out of the brain that you can interpret, the possibilities of what you can do with those signals are immense," said Donoghue, who recently co-founded a company, Cyberkinetics Inc. of Foxboro, Mass., to capitalize on the technology.

Both he and Nicolelis hope to get permission from the Food and Drug Administration to begin experiments in people next year. Nicolelis also is developing a system that would transmit signals from each of the hundreds of brain electrodes to a portable receiver, so his monkeys -- or human subjects -- could be free of external wires and move around while they turn their thoughts into mechanical actions.

"It's like multiple cellular phone lines," Nicolelis said. "As my mother said, 'You can dial your brain now.' "

Significant challenges remain if the technology is to find widespread application in people. Although earlier experiments suggest the electrodes are safe and able to continue functioning for three years or more, longer-term safety studies are needed, and implants with far more electrodes may be required to accomplish anything more than the simplest tasks.

"For something basic like grasping a cup of coffee or brushing your teeth, apparently you could do almost all of this with this kind of prosthesis," said Idan Segev, director of the center for neurocomputation at Hebrew University in Jerusalem. "If you were a pianist and had a spinal cord injury and you wanted to play Chopin again, then 500 neurons is not enough."

Still, Segev expressed astonishment at how much the monkeys were able to do with signals from only a few hundred of the brain's 100 billion or so nerve cells -- evidence, he said, that "the brain uses a lot of backup and a lot of redundancy."

That may explain one of the more interesting findings of the Duke experiments, he and others said: that neurons not usually involved in body movements, including those usually involved in sensory input rather than motor output, were easily recruited to help operate the robotic arm when electrodes were implanted there.

Asked if the monkeys seemed to mind the experiments, Nicolelis answered with an emphatic "No."

"If anything, they're enjoying themselves playing these games. It enriches their lives," he said. "You don't have to do anything to get these guys into their chair. They go right there. That's play time."
