The Bionic Connection

Are we already a lot closer to a mind-machine interface than we ever guessed?

By Jocelyn Selim Photography by Pete Drinkell

KEVIN WARWICK IS ABOUT TO BECOME TELEPATHIC, LUCK AND TECHNOLOGY permitting. His lips are parted expectantly as he sits blindfolded and perched on a lab stool at Reading University in England. One inch below his left wrist, a pincushion array of 100 silicon electrodes, all of them together about one-sixteenth the size of a dime, has been surgically inserted into his median nerve. From the electrodes, 22 wires run eight inches under the skin and exit one inch below his elbow. There they are soldered to a connector board where a 2-inch-by-2-inch maze of circuitry amplifies, filters, and converts the electrochemical impulses coming down his median nerve into digital signals.

His wife, Irena, sits across the lab, looking considerably more nervous. Three wires exit through needle-hole-size incisions just above her wrist. Irena's setup is less spectacular, jerry-rigged to last only the afternoon, not the three months Warwick has carried his wiring around, but it seems to work just fine. Whenever Irena wiggles a finger or clenches a fist, the electrode picks up the impulses from her nerve and feeds them into a computer. There algorithms decode them into a series of digital signals that are sent via Internet to another computer that radios them to an antenna connected to Warwick's dangling circuitry. The signal is fed directly into Warwick's nerve, causing a "tingling sensation, like a mild electric shock," he says.

The first direct trans-nervous-system signals are barely more than cyborg baby talk—just basic motor output to sensory input. But for Warwick, they are a milestone in the journey to a day when we will all walk around with chips in our brains that allow us to wirelessly and silently convey our thoughts as automatically and thoughtlessly as we use telephones today.

Before that happens, Warwick says, neural-machine interfaces like the one in his arm will control robotic body parts, enabling the paralyzed to walk and the blind to see. Smart chips implanted directly into the brain, he says, will control Parkinson's disease, epilepsy, and even depression by monitoring and regulating errant nerve signals. Meanwhile, he says, embedded chips will replace keyboards (we'll think, and the

Researchers have already placed brain implants in monkeys

computer will type it out), remote controls will become as antiquated as rotary phones, and learning a foreign language will mean little more than buying the right chip.

In the world Warwick envisions in his new book, *I, Cyborg*, the boundary between our nervous systems and computers will disappear, and self-improvement will become synonymous with upgrade. But not surprisingly, he has met with skepticism from some of his colleagues. "I'd call him a charlatan, but since he seems to believe his ridiculous predictions, he's more of a buffoon," says Inman Harvey of nearby Sussex University's cognitive and computing sciences department.

DESPITE THE WIRES HANGING OUT OF HIS FOREARM, WARWICK SEEMS both fit and sane, if not a bit too normal. His dress code tends toward khakis and collars, his 6-foot-2 frame runs marathons, and his brown hair is just beginning to show signs of gray at 48. He is easily excited and quick to laugh. He lives on a tree-lined street a half hour from his work at the university, in a tasteful bi-level with spectacular views of the rolling Thames River Valley. His home is decorated with pictures of his son, James, 18, and daughter, Maddi, 20. And if he weren't a cyborg, Warwick might be mistaken for a Luddite. There is not a computer in his house, nor dishwasher, clothes dryer, or microwave oven. He shrugs: "Sometimes you have to go offline."

Cyborg is short for "cybernetic organism," a phrase coined in the 1960s by NASA scientists dreaming up different ways to keep people alive in space. Because space suits were clunky, troublesome, and subject to catastrophic failure, NASA engineers decided that perhaps astronauts' bodies should be altered. Those engineers were not dreamers; they were simply peering ahead at what looked like a normal trajectory of technology: Primitive heart-lung machines had been around since the 1930s, and artificial kidneys and pacemakers were already workable realities.

In the intervening decades, scientists and engineers have developed joint replacements, heart valves, plastic blood vessels, insulin pumps, synthetic skin, artificial blood, even polymer-metal muscles. And the brain and nervous system have been fair game, too, with measured beats from small electrodes steadying the tremors of Parkinson's patients and the chaotic seizures of epileptics. Wires that stimulate optic and auditory nerves have bypassed damaged inner ears and retinas, bringing back sound to many deaf people and at least offering hope of a sighted future to the blind. But brain implants linking humans to computers, to artificial limbs, and especially to each other have been, in the public mind, confined to science fiction.

"I don't think people realize just how far along this has already come," says Warwick. In fact, almost everything Warwick is using in his experiments is off-the-shelf technology. And he points out that in the past three years, researchers from Duke University, Brown University, and the Massachusetts Institute of Technology have placed brain implants in monkeys, allowing them to move cursors on a computer screen, play video games, and move robotic limbs using thought alone.

Earlier this year, John Chapin, a neuroscientist at the State University of New York's Downstate Medical Center, made headlines with implants that jacked directly into the dopamine-reward pathways of rat brains, allowing him to manipulate the rats' movements from his laptop as if they were remote-control cars. "The scary part isn't that the technology is coming, it's that the major scientific breakthroughs have already been done," says Chapin. "Now it's really just a question of engineering."

ONE CRITICAL BREAKTHROUGH CAME ABOUT 20 YEARS AGO. "THERE was a revolution in the way we thought about the brain," says Andrew Schwartz, a neuroscientist at the University of Pittsburgh School of Medicine. "The old way of thinking was that for any movement, say, moving your arm to the right, you had to find the rightward movement area, and only then could you start looking into ways to record and manipulate it. But it turns out that every time you move your arm to the right, *all* the neurons change their activity in a very specific way."

Soon afterward, researchers found that by using fairly simple extraction algorithms and a computer, they could nail down the pattern of electrical signals associated with any one movement by looking at the activity of groups of neurons numbering in the hundreds. "When we realized we could get that kind of information, we knew that applications like neural prosthetics were definitely possible," says Schwartz.

It has taken two decades for researchers to engineer biocompatible microelectrodes, refine surgical techniques to implant them, and formulate algorithms to decode the information coming out in real time. But it has also been easier than anyone imag-

that allow them to play video games using thought alone

ined. "When this research got off the ground, we thought we would have to record, at minimum, 700 neurons to get a decent resolution," says Schwartz. "You can get it from a dozen. And the electrodes will work from almost anywhere in the region."

The work has been so promising that Schwartz hopes to put brain implants in humans within two years. A research group led by John Donoghue, a neuroscientist at Brown, may beat him to it. Under the banner of Cyberkinetics Inc., Donoghue's team is designing and manufacturing electrodes, algorithms, and interfaces, as well as training neurosurgeons to implant arrays. A company called Bionic Technologies, founded by scientists at the University of Utah, has similar goals. And Philip Kennedy, CEO and chief scientist at Neural Signals in Atlanta, has implanted rudimentary electrodes in the brains of five patients, including a 53-year-old stroke patient. Before he died in May, the patient had learned to control a cursor mentally.

"When I started in this field, it was basically me, a computer, and a soldering iron," Chapin says. "We used to ride around in cars together at conferences. Not anymore. There's a race going on to see who can get this stuff out there first."

AT THE AGE OF 32, KEVIN WARWICK WAS HIRED TO LEAD READING University's cybernetics department. "When I got here, they didn't even have a robot," he says. Today the department is one of the best in the United Kingdom. Warwick has more than 350 academic papers to his name and has received awards from a host of societies. Following in the footsteps of giants like Michael Faraday and Carl Sagan, he has presented Britain's Royal Institution's Christmas Lectures.

Kennedy, the only researcher so far to use neural-interface technology on a human brain, says Warwick's work should be taken seriously: "You can say that other people are doing more for technological advancement, and you can certainly say that he opens himself for attention, but you simply cannot say that what he is doing is groundless. This is a field so new that any observation is important, especially on a human."

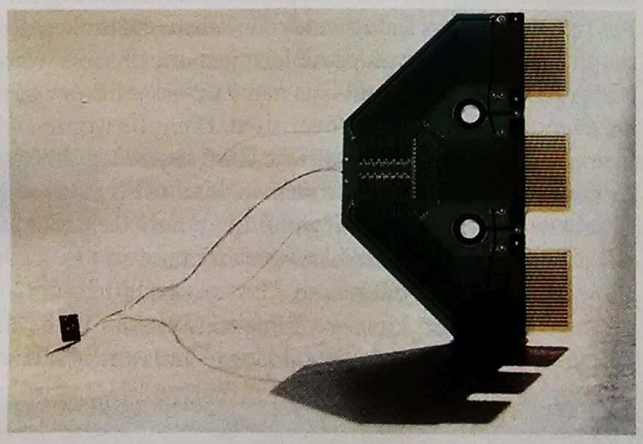
Warwick considers showman antics less self-promotional than service to a new field that deserves attention. "I was at a conference eight months ago, and there was a well-known geneticist speaking. Nothing new had happened, but everybody was gathered around salivating. I'm not saying that genetics isn't important, but this stuff has just as much potential to change the world."

The Economist agrees. It recently ran a commentary lamenting that the attention paid to the moral status of embryos is dwarfing the more immediate threat of neurotechnology, which "is largely ignored by regulators and the public, who seem unduly obsessed by gruesome fantasies of genetic dystopias."

"Maybe what the field needs is a Dolly the Sheep, something that will really capture people's curiosities and imaginations," says Warwick. Telepathic communication would certainly get the public's attention, but even pioneers in the field are skeptical that it can be done. "We are going to start seeing this stuff being used regularly in 'locked-in,' or completely paralyzed, patients very soon, and bionic limbs with feedback are going to follow soon after. And I can't even begin to imagine what will come next," says Chapin. "But in terms of the thought-to-thought communication that Warwick talks about—I think it's effectively impossible. While simple movements are localized in the motor cortex, higher cognitive functions like abstract thought and emotion are spread throughout the brain."

"It might be extremely difficult," Warwick responds. "But it blows my mind that anybody could even posit that it's impossible." He points out that researchers already know that stimulating certain areas of the brain can produce very specific, albeit basic, emotional responses such as fear and anger. "From there it's not much of a stretch to imagine recording the signals and playing them back. I'm not entirely certain that it will work that way, but I certainly don't think it's impossible. One of the few things we're certain of is that the brain is remarkably plastic and seems to have an unlimited potential to adjust to new information coming in."

Warwick reminds his critics that 20 years ago, few predicted a future for the Internet. "For that matter," he says, "who could have predicted that we would all sit around staring for hours at a flickering box in the corner of the room?" ⊠



Left: Armed with his wrist implant, Warwick can send nerve signals via a computer to a robotic arm. Below: The implant is composed of an electrode array, one-sixteenth the size of a dime, which is connected to a 2-inch-by-2-inch circuit board. Right: The array is wedged into the median nerve in Warwick's wrist, and wires underneath his skin relay signals to the circuit board attached below his elbow.

PHOTOGRAPHS: LEFT AND TOP RIGHT, FROM ICUBE SOLUTIONS.