A new generation of brain-machine interfaces can deduce what a person wants

By Richard A. Andersen

Illustration by Mark Ross
“reading”—messages to and from the brain. There are two major classes of the interface technology. A “write-in” BMI operates by sending and receiving—“writing” and “reading”—messages to and from the brain. An electromechanical appendage was then able to reach out and grasp the bottle, raising it to Sorto’s lips before he took a sip. His drink came a year after surgery to implant electrodes in his brain to control signals that govern the thoughts that trigger motor movement. My lab colleagues and I watched in wonderment as he completed this deceptively simple task that is, in reality, intricately complex.

Witnessing such a feat immediately raises the question of how mere thoughts can control a mechanical prosthesis. We developed a team of scientists, clinicians and rehabilitation professionals from the California Institute of Technology, the University of Southern California, the University of California, Los Angeles, the Rancho Los Amigos National Rehabilitation Center, and Casa Colina Hospital and Centers for Healthcare. The team received a go-ahead from the Food and Drug Administration and institutional review boards charged with judging the safety and ethics of the procedure in the labs, hospitals and rehabilitation clinics involved.

A volunteer in this type of project is a true pioneer because he or she may or may not benefit. Participants ultimately join arrays we planned to use in humans into healthy nonhuman primates. The monkeys then learned to control computer cursors or robotic limbs.

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By Thought Alone

For 15 years neuroscientists have built brain-machine interfaces (BMIs) that allow neural signals to move computer cursors or operate prostheses. The technology has moved forward slowly because translating the electrical firing of neurons into commands to play a video game or move a robot arm involves highly intricate processes.

A group at the California Institute of Technology has tried to advance the neuroprosthetic field by tapping into high-level neural processing—the intent to initiate an action—and then conveying the relevant electrical signals to a robotic arm. Instead of sending out signals from the motor cortex to move an arm, as attempted by other laboratories, the Caltech researchers place electrodes in the posterior parietal cortex (PPC), which transmits to a prosthesis the brain’s intent to act.

Decoding neural signals remains a challenge for neuroscientists. But using BMI signals from the posterior parietal cortex, the top of the cognitive command chain, appears to result in faster, more versatile control of prosthetic technology.

Illustration by AXS Biomedical Animation Studio
The amount of information to be gleaned from just a few hundred neurons turned out to be overwhelming. We could decode a range of cognitive activity, including mental strategizing (imagined versus attempted motion), finger movements, decisions about recalling visual stimuli, hand postures for grasping, observed actions, action verbs such as “grasp” or “push,” and even emotional states. To our surprise, however, insertion of a few tiny electrode arrays enabled us to decode much of what a person intends to do, as well as the sensory inputs that lead to that intention.

The question of how much information can be recorded from a small patch of brain tissue reminded me of a similar scientific problem that I had encountered early in my career. During my thesis work with Vernon Mountcastle at the Johns Hopkins University School of Medicine, we examined how visual space is represented in the PFC of monkeys. Our eyes are like cameras, with the photosensitive retinas signaling the location of visual stimuli imaged on them—the entire image is reprojected to a retinotopic map. Neurons respond to limited regions of the retina, referred to as their receptive fields. In other words, processing visual perception is different than a video camera. Despite this restriction, neurons are sensitive to any linear array of stimuli. Of course, this linear array also shifts, but when we move our eyes the world seems stable. The retinotopic image coming from the eyes must be converted into a visual representation of space that takes into account the head position. The head is a moving object, and the world does not appear as if it were sliding around.

The PFC is a key processing center for high-order visual information. When we think about where the brain needs to take into account when we see something—under what conditions we would call a move—a retina-to-PFC-based representation of visual stimuli can be used. We found that neurons respond to moving stimuli in a way that resembles a retinotopic map. Neurons represent a specific part of the visual field (e.g., the upper right quadrant), and their firing rate is proportional to the speed of the stimulus movement.

We then extended our approach to the motor cortex, where we found that neurons also respond to moving stimuli. These neurons are sensitive to both the speed and direction of movement, and they are activated by movements that are similar to those made by the contralateral hand. The same cells that respond to moving stimuli also respond to movements that are similar to those made by the ipsilateral hand. This is an example of a retinotopic representation of visual stimuli in the motor cortex, which is consistent with the retinotopic representation of visual stimuli in the visual cortex.

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The implants need to be miniaturized, operated on low power (to avoid heating the brain), and function wirelessly so no cables are needed to connect the device to brain tissue. All current and future technology must be combined with a new surgical procedure. But one day, we hope, recording and stimulation interfaces will be developed that can receive and send signals less invasively but with high precision. One step in this direction is our recent finding in nonhuman primates that ultrasound-recorded changes in blood volume linked to neural activity can be used for BMIs. Because the skull is an impediment to ultrasound, a small transparent window would still be needed to replace a bit of the skull, but this surgery would be far less invasive than implanting microelectrode arrays that require opening the dura mater and protecting the brain, and directly inserting electrodes into the cortex.

BMIs, of course, are aimed at assisting people with paralysis. Yet science-fiction books, movies and the media have focused on the use of the technology for enhancement, conferring "superhuman" abilities that might allow a person to move faster, certainly an advantage for motor tasks, or directly send and receive information from the cortex, much like having a small cell phone implanted in the brain. But enhancement is still very much in the realm of science fiction and will be achieved only when noninvasive technologies are developed that can operate at or near the precision of current microelectrode array technology.

Finally, I would like to convey the satisfaction of doing basic research and making it available to patients. Fundamental scientific discoveries are not developed by either the patient or the doctor. Instead, many medical technologies. To be able to then transfer these discoveries into a clinical setting brings the research endeavor to its ultimate realization. A scientist is left with an undeniable feeling of personal achievement in seeing their research lead to improvements in patient care. And the best of all is being able to move a robotic limb to interact again with the physical world.