Technology Brief 32
Brain-Machine Interfaces (BMI)

In most vertebrates (like you), nerves extend from the brain (the ***central nervous system***), through the spinal cord and out to your many organs (the nerves that lie outside the brain are collectively called the ***peripheral nervous system***). Peripheral nerves carry information in both directions. On the one hand, peripheral neurons can fire at the behest of neurons in the brain and trigger muscle contraction or chemical release (via certain glands); on the other hand, sensor cells in the periphery can cause peripheral neurons to fire, sending signals to the brain to indicate pain, temperature, pressure, etc. Most of the peripheral neurons pass through the spinal cord; injuries to the spinal cord can be very dangerous, as trauma and inflammation can sever these connections, leading to paralysis, lack of sensory function, etc.

There is, of course, a long history of medical and scientific approaches to helping individuals afflicted with ***motor dysfunctions*** (whether due to trauma or congenital effects). Among these is the use of ***prosthetic devices*** that can supplement or replace lost function: prosthetic arms, prosthetic legs, advanced wheelchairs and exoskeletons have all been developed to aid those with motor problems (**Fig. TF32-1**). Historically, the way to drive these prosthetics is either by making use of motor functions that a patient still has (using hands to drive a wheelchair or sucking on a straw to drive a keyboard, for example) or reading signals from non-damaged peripheral nerves (recording from a pectoral muscle nerve, for example, to drive a robot elbow).

In the last decade or so, a slightly different paradigm has arisen that—while still in its infancy—promises a radical new way to communicate with prosthetics. The basic idea is to *directly record from neurons in the brain*, use those signals to drive a controller and communicate the

Figure TF32-1: A variety of existing, functional prosthetics. (a) The “Luke arm” built by DEKA Corp.; (b) an exoskeleton built at the Kazerooni Lab, University of California, Berkeley; (c) an EEG-controlled wheelchair, developed by José del R. Millán’s group at the École Polytechnique Fédérale de Lausanne (EPFL, Switzerland).

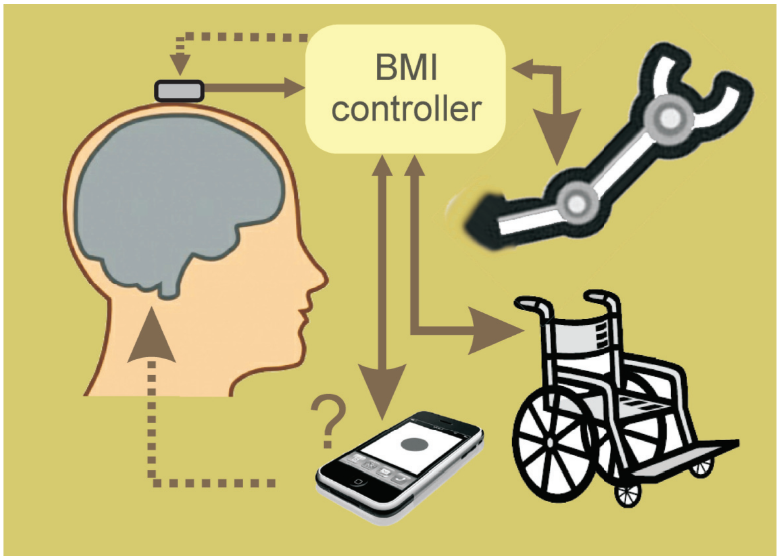

Figure TF32-2: The basic BMI loop depends on (a) neural recording, (b) a computational device or controller that maps neural signals to control signals to the prosthetics, and (c) feedback to the user or patient. Perhaps one day BMIs will even drive the use of portable consumer devices!

control signals to a prosthetic (**Fig. TF32-2**). In a sense, a computer—via a neural recording interface—records signals directly from the brain and uses them, without a spinal cord, to directly drive a robot prosthetic. This arena is currently seeing something of a gold rush as scientific results over the last 10 years and a medical trial (***BrainGate***) have encouraged researchers to explore and develop new technologies. Most central nervous system recording for BMI applications involves implanting arrays of ***recording electrodes*** (see Section 4-12) into the motor cortex of the subject. This is a very dangerous procedure (which involves a craniotomy), so research in humans has been limited to individuals with severe dysfunctions for whom the risk is appropriate. Once inserted, the subject trains over days and weeks to drive the prosthetic via the electrode array. Among the many remarkable findings in the recent BMI literature is that the neurons into which the recording array is inserted themselves learn to modify their firing behavior as the subject learns to use the BMI! That is, although scientists initially focused on what control algorithm would best decode the neural signals to drive say, a robot arm, they soon found—to their surprise—that the brain itself would learn to use whatever algorithm the controller employed. Researchers could even change algorithms and the subject could relearn the task, eventually able to switch between controllers.

Many challenges remain and it is an area of heavy overlap between electrical engineering, computer science, and neuroscience. Making electrode arrays that last an appreciable fraction of a patient's lifetime is still an unsolved problem: recording arrays typically fail after a few years. It is not at all clear what signals are optimal to drive a prosthetic nor which technology (or energy modality) is optimal for a long-lasting implant; many approaches are currently being explored. It is not known what the limits of such control are: could a subject be trained to operate a complex, multi-parameter non-motor task, for example (like imagining speech or interfacing in complex ways to a tablet)? Ultra-low power electrical recording front ends and ultra-low power radios are another area of intense study, as these systems must ultimately be miniaturized and implanted into a person as unobtrusively as possible. Lastly, ethical issues abound, ranging from the acceptability of animal testing to the possible enhancement possibilities. Some of this remains squarely in the realm of science fiction, but there is no doubt these approaches are a possible route to helping people with severe motor dysfunctions, making it a worthwhile endeavor in which EE's are making very big contributions.