Bidirectional Brain Computer Interfaces

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After many injuries or diseases that result in paralysis, brain function remains largely intact. Indeed, after spinal cord injury or subcortical stroke, the parts of the brain that generate movement and allow us to feel touch remain largely functional. The challenge then is to create a link with these parts of the brain that have been disconnected from the body. One method to restore these lost movement and sensory abilities to people living with paralysis is to create neural interfaces that communicate directly with these specific parts of the brain. These neural interfaces – built upon arrays of microelectrode implanted directly into brain tissue – can extract desired movements from the activity of populations of individual neurons in the brain as well as create the conscious perception of touch by directly modulating neural activity using electrical stimulation. These goals have been a major focus of neural engineering labs around the world, and at the Rehabilitation Neural Engineering Labs at the University of Pittsburgh, my colleagues and I have been able to create the highest performance brain-controlled robotic arms demonstrated to date, and further, were the first group to successfully restore cutaneous sensations by chronic stimulation of the brain, so that a person controlling the robot feels its hand as it if were his own.

These capabilities leverage neuroscientific understanding of the mechanisms by which populations of neurons in the motor cortex lead to limb movement. With this knowledge it became possible to consider that real-time recording from populations of neurons could be used to control a prosthetic limb, and work in the lab of a collaborator at the University of Pittsburgh led to one of the first functional demonstrations of this idea; a non-human primate learned to control a simple prosthetic limb to feed itself. Since this time, there has been rapid progress in the field, including multiple groups implanting microelectrode arrays into the motor cortex of human study participants with spinal cord injuries and other injuries or diseases that result in paralysis.

In our labs, we implanted four microelectrode arrays into the primary motor and somatosensory cortices of a person with a cervical spinal cord injury that was sustained 10 years prior to the implantation. This study was performed under an Investigational Device Exemption from the United States Food and Drug Administration and approved by the Institutional Review Boards at the University of Pittsburgh and the Space and Naval Warfare Systems Center Pacific. Recording from populations of single neurons in motor cortex enable him to control up to seven simultaneous degrees-of-freedom of the prosthetic arm. More specifically, he can move the hand around in space (3 degrees-of-freedom), orient the wrist (3 degrees-of-freedom) and open and close the hand (1 degree-of-freedom). This allows him to grasp, transport and manipulate objects and complete tasks of his own choosing (painting, video games etc.) as well as standardized assessments of upper limb function. In these later tasks he can achieving object transfer times that can approach able-bodied performance. For the more than four years that we have been working with this participant, we have found that microstimulation in the somatosensory cortex evokes tactile sensations that have a range of qualities from pressure and touch, to tingling and buzzing. These sensations can be controlled, to some extent, by manipulating the stimulus frequency and by patterning the stimulation amplitude over time to reflect the underlying behavior of neural populations in the somatosensory cortex. These sensations are largely stable over time and more electrodes evoke detectable percepts now than at any previous point in the study. Finally, when we combine microstimulation with control to create a bidirectional brain computer interface, he is able to reach to, grasp and move objects faster than when he cannot feel the objects in the robotic grasp. These experiments demonstrate that sophisticated, bidirectional brain computer interfaces can restore functional movement and sensation in people living with paralysis and that combining control and sensation together enables better performance than systems that do not restore the ability to feel.

In parallel experiments in our own labs, as well as at many labs around the world, similar efforts have been underway to create bidirectional prosthetics for amputees by implanting devices into the residual limb and peripheral nervous system. Interestingly, and perhaps surprisingly, many of the results from recording and stimulation experiments in these two very different anatomical locations have led to similar results, which may say something about how the brain is able to form control signals and how it can interpret the information given to it, regardless of how it is delivered. While significant work remains to develop a clinically translatable product with the day-to-day reliability that users would expect, we believe that our results clearly demonstrate the potential of this approach to restore motor control capabilities to the people that need them. Finally, and perhaps more speculatively, we can consider how the inevitable creation of these technologies, and their potential use in able-bodied populations, could change how we think about prosthetics generally and how their use and development should be considered from an ethical perspective.