How brain implants can let paralysed people move again

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Something as simple as picking up a cup of tea requires an awful lot of action from your body. Your arm muscles fire to move your arm towards the cup. Your finger muscles fire to open your hand then bend your fingers around the handle. Your shoulder muscles keep your arm from popping out of your shoulder and your core muscles make sure you don't tip over because of the extra weight of the cup. All these muscles have to fire in a precise and coordinated manner, and yet your only conscious effort is the thought: "I know: tea!"

This is why enabling a paralysed limb to move again is so difficult. Most paralysed muscles can still work, but their communication with the brain has been lost, so they are not receiving instructions to fire. We can't yet repair damage to the spinal cord so one solution is to bypass it and provide the instructions to the muscles artificially. And thanks to the development of technology for reading and interpreting brain activity, these instructions could one day come direct from a patient's mind.

We can make paralysed muscles fire by stimulating them with electrodes placed inside the muscles or around the nerves that supply them, a technique known as functional electrical stimulation (FES). As well as helping paralysed people move, it is also used to restore bladder function, produce effective coughing and provide pain relief. It is a fascinating technology that can make a big difference to the lives of people with spinal cord injury.

Dimitra Blana and her colleagues at Keele are working on how to match this technology with the complex set of instructions needed to operate an arm. If you want to pick up that cup of tea, which muscles need to fire, when and by how much? The firing instructions are complicated, and not just because of the large number of core, shoulder, arm and finger muscles involved. As you slowly drink your tea, those instructions change, because the weight of the cup changes. To do something different, like scratch your nose, the instructions are completely different.

Instead of just trying out various firing patterns on the paralysed muscles in the hope of finding one that works, you can use computer models of the musculoskeletal system to calculate them. These models are mathematical descriptions of how muscles, bones and joints act and interact during movement. In the simulations, you can make muscles stronger or weaker, "paralysed" or "externally stimulated". You can test different firing patterns quickly and safely, and you can make the models pick up their tea cups over and over again – sometimes more successfully than others.

Modelling the muscles

To test the technology, the team at Keele is working with the Cleveland FES Center in the US, where they implant up to 24 electrodes into the muscles and nerves of research participants. They use modelling to decide where to place the electrodes because there are more paralysed muscles than electrodes in current FES systems.

If you have to choose, is it better to stimulate the subscapularis or the supraspinatus? If you stimulate the axillary nerve, should you place the electrode before or after the branch to the teres minor? To answer these difficult questions, they run simulations with different sets of electrodes and choose the one that allows the computer models to make the most effective movements.

Currently, the team is working on the shoulder, which is stabilised by a group of muscles called the rotator cuff. If you get the firing instructions for the arm wrong, it might reach for the soup spoon instead of the butter knife. If you get the instructions to the rotator cuff wrong, the arm might pop out of the shoulder. It is not a good look for the computer models, but they don't complain. Research participants would be less forgiving.

Knowing how to activate paralysed muscles to produce useful movements like grasping is only half of the problem. We also need to know when to activate the muscles, for example when the user wants to pick up an object. One possibility is to read this information directly from the brain. Recently, researchers in the US used an implant to listen to individual cells in the brain of a paralysed individual. Because different movements are associated with different patterns of brain activity, the participant was able to select one of six pre-programmed movements that were then generated by stimulation of hand muscles.

Reading the brain

This was an exciting step forward for the field of neural prosthetics, but many challenges remain. Ideally brain implants need to last for many decades – currently it is difficult to record the same signals even over several weeks so these systems need to be recalibrated regularly. Using new implant designs or different brain signals may improve long-term stability.

Also, implants listen only to a small proportion of the millions of cells that control our limbs, so the range of movements that can be read out is limited. However, brain control of robotic limbs with multiple degrees-of-freedom (movement, rotation and grasping) has been achieved and the capabilities of this technology are advancing rapidly.

Finally, the smooth, effortless movements that we usually take for granted are guided by rich sensory feedback that tells us where our arms are in space and when our fingertips are touching objects. However, these signals can also be lost after injury so researchers are working on brain implants that may one day restore sensation as well as movement.

Some scientists are speculating that brain-reading technology could help able-bodied individuals to communicate more efficiently with computers, mobile phones and even directly to other brains. However, this remains the realm of science fiction whereas brain control for medical applications is rapidly becoming clinical reality.

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