

BCI system gives paralyzed man back his sense of touch with haptic feedback

Enlarge / Ian Burkhard suffered a severe spinal cord injury in 2010. Battelle's NeuroLife project is restoring motor function to his right arm with a brain-computer-interface system.

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Ian Burkhardt, now 28, had a diving accident in 2010 that severely damaged his spinal cord, leaving him paralyzed and confined to a wheelchair, with only limited movement in his elbow and shoulders. Thanks to an implanted brain-computer-interface (BCI) developed by Battelle, he has made significant progress over the last six years in restoring small movements; he's even able to play *Guitar Hero* again. And now Battelle scientists have succeeded in restoring his sense of touch, according to a new paper in the journal *Cell*.

BCIs are a booming R&D field, with startups like Elon Musk's Neuralink looking ahead to a world where human beings will connect directly to their computers with either external devices (similar in function to an EEG) or biologically compatible implanted BCIs. Such systems require a way to record neural activity (electrode sensors), a way to transmit those signals (like a small wireless chipset), and algorithms that can translate those signals into action. BCIs are already a medical reality for patients with spinal cord injuries, like

Burkhart, or those who suffer from Parkinson's or epileptic seizures. The benefits patients gain far outweigh the risks of surgical implantation.

Over the past 90 years or so, Battelle has been instrumental in developing such prominent technologies as the Xerox machine, cruise control, and CD-ROMs, along with numerous medical devices. Patrick Ganzer, lead author on the new Cell paper, is a research scientist with the organization's medical devices division, working with the NeuroLife group to develop a BCI for clinical trial. Burkhart has been working with Ganzer and NeuroLife since 2014 to restore motor function to his right arm.

Enlarge / Researchers with Battelle's NeuroLife group have been working to restore hand function to Ian Burkhart via a BCI for several years.

Battelle's "neural bypass system" has three primary components, according to Ganzer. The first is the surgically implanted chip, placed in an area of the brain that responds to thoughts of movement. Next, the system must take the brain

wave and brain signal recordings and decode what movements the patient (in this case, Burkhart) is thinking about. "If I want to open my hand, or close my hand, those look like different activity patterns in the brain," Ganzer told Ars. Finally, the system translates thoughts into stimulations of muscles on the arm, resulting in movement.

While the system has worked well in terms of restoring a wide range of grips and minor function to Burkhart's paralyzed hand, his injury is so severe that he has almost no sensation in his hand. "We know how important the sense of touch is for appropriate movement control," said Ganzer. "Even a small change in the ability to sense touch can have a really big impact on your movement control and overall upper limb function." So if Burkhart is blindfolded, he can't detect touch while gripping small objects like a pencil, and for larger objects like a styrofoam glass or mug, his guesses are no better than chance. He has also struggled with simple multitasking tasks like drinking a soda while watching TV, since controlling his hand with the BCI requires a great deal of concentration.

That lack of sensation also means that Burkhart isn't getting crucial sensory feedback, so "he doesn't feel fully like he owns his own hand," said Ganzer. It's the reverse of the popular rubber hand illusion, in which the sensory feedback from the simultaneous stroking of both the real and rubber hands essentially "couples" the subject to the rubber hand, such that the brain perceives it as an extension of the physical body—what's known as a body transfer illusion. The lack of feedback in Burkhart's case means that critical coupling doesn't occur.

Despite the paralysis, Ganzer and his team discovered that when they stimulated his skin, neural signals were still reaching his brain—a phenomenon known as sub-perceptual brain activity—they were just too weak for the brain to perceive them. That means Burkhart still has a few functioning nerve

fibers in his arm.

So the Battelle team set about figuring out how to amplify that tiny signal with haptic feedback, like the vibrations of a mobile phone or game controller. Their system uses electrodes on the skin connected to wires that bypass the spinal cord and send those sub-perceptual touch signals to and from the BCI implanted in his motor cortex. A band of vibrational motors on Burkhardt's upper arm provides the sensory haptic feedback.

- Ian Burkhardt plugs in.
- Calibrating the BCI system.
- Look at that improved hand grip control.
- Aw, you sunk my battleship!
- But can he play *Guitar Hero*?
- Answer: yes he can.
- Advanced prototype next-generation sleeve can be easily put on and taken off.

The NeuroLife group kept the haptic feedback relatively simple to establish proof of principle, since more complex sensory feedback requires a level of cognitive multi-tasking that can cause the natural feedback loop to fall apart. But the initial results were extremely promising, particularly for Burkhardt's ability to detect an object while blindfolded, relying on touch alone. "Ian operates at chance level without this touch-restoring system active," said Ganzer. "If you activate the system and enable sub-perceptual touch to be boosted into conscious perception, his sense of object detection and touch almost goes to 100 percent. This demonstrates that you can boost a sub-perceptual signal in real time."

The haptic feedback gives Burkhardt more control over his hand movements, as well as the ability to sense the correct amount of pressure to use while picking up different objects, like a styrofoam cup, which requires a lighter grip than a heavier

ceramic coffee mug. This is also the first BCI that can manage restoration of movement and the sense of touch at the same time.

“Instead of having hand grip be controlled by your volition, and your movement thought for many seconds, which can be draining, we had residual touch signals from the brain making their way past the spinal cord injury to control the magnitude of this grip,” said Ganzer. “This allows him to potentially look away from his hands, not to have to think about movement, so he could multitask.” The stimulation cuffs are cumbersome to put on and take off and are also a bit messy, since the electrode links must be adhered to the skin. So the researchers also developed a more aesthetically pleasing fabric sleeve, now being tested in clinical studies.

Ultimately, the team would like to build a version of the system that works as well at home as in the laboratory and could be controlled by a tablet rather than a desktop computer. According to Ganzer, they have successfully miniaturized the necessary electronics by an order of magnitude, so it is now portable (about the size of a VHS tape) and can be mounted on a wheelchair. Burkhart has already been able to use the system as part of his daily routine at home.

Ganzer and his team are hopeful that others with spinal cord injuries might also benefit from their system, especially since Burkhart’s injury is so severe. “This sub-perceptual touch signal is present in many patients,” he said. “It’s likely others may have a less severe injury and therefore more spare nerve fiber tissue.”

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