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Deep learning refines how bionic eyes communicate with the brain

Researchers from three institutions, including UC Santa Barbara, have demonstrated that artificial intelligence has the potential to make future visual prostheses, like a bionic eye, more precise, predictable and responsive to an individual user.

UCSB associate professor of computer science Michael Beyeler and his colleagues used a deep-learning model to design patterns of electrical stimulation for electrodes temporarily implanted in the visual cortex — the region at the back of the brain that processes visual information — of a blind participant. The model improved researchers' control over how neurons responded to the stimuli and helped to predict what the participant perceived.

The proof-of-concept study, published online this week in the journal Neuron, represents a step toward developing visual cortical prostheses — devices implanted in the visual cortex — that can better communicate with the brain.

"Building a model in the abstract is one thing," said Beyeler, who is also an associate professor of psychological and brain sciences. "Seeing it shape an experiment with a person is something else entirely. That ability to go from theory to something that may one day help people is what drives much of the work in our lab."

In an effort that Beyeler describes as “a true collaboration,” the project was led by co-first authors Pehuén Moure of ETH Zurich, Jacob Granley of UCSB, and Fabrizio Grani of Miguel Hernández University (MHU). Beyeler, Shih-Chii Liu at ETH Zurich, and Eduardo Fernández at MHU supervised the research, which is part of a broader feasibility trial underway in Spain.

Researchers have attempted to develop visual prostheses for decades, but with limited success. Some devices target the retina, the light-sensitive layer at the back of the eye, while others stimulate later stages of the visual system.

Cortical prostheses take a different approach by bypassing the eyes and optic nerves and delivering electrical stimulation directly to the visual cortex. The approach could eventually benefit some people whose visual pathways have been damaged but whose visual cortex remains capable of responding to stimulation, such as people whose blindness resulted from strokes, neurodegenerative diseases, and brain injuries.

The potential benefit may be particularly meaningful for those “who have been able to see for part of their life, but then, because of an inherited eye disease or an accident, have lost their vision,” Beyeler said. “For those people, the desire may be very strong to get some vision back.”

The current work builds on computational research supported by Beyeler’s 2022 National Institutes of Health (NIH) Director’s New Innovator Award, a five-year, $2 million grant that supported his work to make visual prostheses more predictable and effective.

In 2024, members of Beyeler’s Bionic Vision Lab traveled to Spain for a critical stage of their research: to test whether their computational approach could improve the performance of an existing brain implant in a blind participant.

At the Hospital IMED Elche in Spain, they visited a 27-year-old man who had lost his vision following a traumatic brain injury. The man had received a device composed of a 96-channel array of electrodes implanted in his visual cortex, which would be removed after six months.

When the electrodes delivered electrical stimulation to neurons in the man’s visual cortex, he could perceive *phosphenes*, spots or shapes of light sometimes compared to flashes, stars or fireworks.

The researchers sought to better predict how the visual cortex would respond to stimulation. To do so, Beyeler and his colleagues trained a deep neural network, a form of artificial intelligence, to predict the patterns of brain activity produced by different combinations of electrical stimulation settings. The model also received information about the brain's resting activity immediately before each test.

Researchers then used the model to identify the stimulation patterns most likely to produce a desired neural response.

When the researchers tested those AI-designed patterns in the participant, they reproduced targeted patterns of brain activity more accurately and required less electrical current than the other approaches. Perhaps most importantly, the activity recorded from the participant's brain predicted what he perceived better than the electrical stimulation settings alone. In other words, measuring how the brain responded provided a better indication of what the participant would see than simply knowing which electrodes had been activated.

Producing a desired pattern of brain activity is only one part of the equation. Researchers must also determine how that activity becomes a visual experience for the person using the prosthesis.

"Engineers naturally want to treat phosphenes like pixels: stimulate more electrodes, and you should get a more complete image," Beyeler said. "But the brain does not work that way. Electrodes interact, neural responses fluctuate, and what we put into the brain is not necessarily what the person perceives. The challenge is to learn more about that transformation."

The implant used in the study could both stimulate the brain with electrical current and record how the neurons in the brain responded. That allowed the researchers to train their AI model on what the brain actually did after each stimulation pattern, rather than relying only on the electrical settings sent to the device.

The participant reported whether he perceived a phosphene and, in some experiments, described features such as its shape, size, brightness and color. The researchers found that the recorded patterns of neural activity were more informative about those perceptual outcomes than the stimulation parameters themselves.

The AI model also incorporated measurements of the participant's resting brain activity, allowing it to adjust the stimulation pattern to the brain's current state. This could be an important step toward prostheses that remain reliable as neural responses fluctuate from day to day.

"A useful visual prosthesis cannot rely on a fixed recipe," Beyeler said. "It has to learn how an individual brain responds and adapt the stimulation accordingly. Ultimately, the device should adapt to the person, not the other way around."

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