AI in Neurorehab: Restoring Speech and Movement with Brain-Computer Interfaces

Along with his colleagues on the BrainGate team, Dr. Leigh Hochberg is developing implantable brain-computer interface (BCI) technologies to restore communication and mobility for people with paralysis. This year, the team is celebrating 20 years since the start of their first BrainGate clinical trial, and it is remarkable to reflect on the progress that has been made over the past two decades. Their ultimate goal is to develop high-resolution methods to record brain activity related to the intention to speak or move and convert it into actual movement or computer-generated speech in real time. This would allow people with cervical spinal cord injury, brainstem stroke, amyotrophic lateral sclerosis (ALS), and other nervous system conditions or injuries to do things like move their limbs, and control communication technology such as a cursor or keyboard on a computer, and to communicate quickly and audibly.

The field of BCI began with researchers learning more about how single neurons and groups of neurons fire before and during voluntary movements. What they learned has been translated over the years so that now the neural activity that occurs when a person with paralysis attempts to move an arm can be recorded and decoded to reflect their intended movement. While artificial intelligence (AI) wasn't heavily used in the field in its early days in the 1960s-1990s, there were scientists using basic artificial neural networks to decode neural activity in their research at universities. During more typical, scientific hypothesis-driven decoding, researchers had ideas about how neural activity patterns were related to particular movements, and the data were decoded with their hypotheses in mind. This approach was successful, but AI has become instrumental to the work being done in the BCI field today.

Currently, researchers can record from more cortical sites, as well as other areas of the brain, and they are examining outcomes and movements that are substantially more complex, compared to the simple, two-dimensional movements of a cursor on a screen that they studied initially. This has led to the application of hypothesis-agnostic approaches to decoding where researchers know they have neural activity data, they know there is an outcome related to the activity (such as an arm reaching to a target), and machine learning approaches identify the relevant patterns in neural activity to connect the neural activity to the outcome. This approach, leveraging AI, has produced great results in BCI research, and similar AI language models are also used widely in everyday activities like setting reminders using voice assistants on a cell phone or other device. The language models have been particularly useful in improving the decoding of intended speech for people with conditions like anarthria that limit or impede their ability to speak. The BrainGate team, including Dr. Hochberg's lab and others, have used this approach in their work over the past few years.

In an ongoing project, Dr. Hochberg and his team are developing implantable BCIs for individuals with dysarthria, a motor speech disorder that makes it difficult for individuals to form and pronounce words. They are using recurrent AI neural networks to decode the most likely phonemes (units of speech sounds) that a person intends to say based on their neural activity. These neural networks are given the phonemes of a set of words, and are trained to classify which phoneme or phonemes are being spoken and thus provide the most likely words that a person is saying. Once they have an initial estimate of what the spoken words likely are based on the phonemes, a language model can be applied to refine the likelihood of what a word may be based on the words before and after each word. This second step helps improve the accuracy of the neural decoding. The whole process can be performed incredibly quickly, allowing people to “speak” 32-62 words per minute in their studies.

“The fact that we're able to use these agnostic, AI-based approaches to build neural decoders and then to refine that intended speech using language models has been fun to be a part of, but also and more importantly has been extremely rewarding for our participants. I’ve seen people who weren’t able to use their native speech to communicate, and now they can use the system to communicate with their friends, their family, and the research team,” Dr. Hochberg remarked.

He is also excited to see that the decades of federally and philanthropically funded academic research, proofs-of-concept, and clinical trials have now de-risked the field enough that medical device companies are now interested in getting involved in commercializing this technology and creating products to restore communication and mobility to make these devices more widely available to the public. Clinicians and academic researchers have been and will continue to play a vital role in clinical trials of existing and emerging devices as this field continues to grow.

Interacting directly with some of these companies, Dr. Hochberg is making sure that as much of what they have learned over the past 20 years from ongoing BrainGate research can be translated and shared with them. This will allow the companies to create the best possible devices, place them in the most optimal ways, and then conduct rigorous clinical trials to ensure the safety and effectiveness of these devices to make them available as quickly as possible to the people who could benefit from them. Within the next few years, it may be possible for patients in neuro intensive care units or neurorehabilitation clinics around the world to choose to get one of these BCI devices as part of their treatment plan.

The impressive progress in the field hasn’t been without challenges, and there are still substantial hurdles to overcome. For example, to get a new medical device through clinical trials and eventually approved, researchers need to identify meaningful clinical outcome measures, which is completely new territory for these kinds of novel neurorestorative devices. An outcome measure like words per minute for a BCI device that restores communication may seem promising, but it might be an outcome measure that has not been used before for an implantable device. Not only would the chosen outcome measures have to be approved by the U.S. Food and Drug Administration (FDA) before a clinical trial design was finalized, but the outcome measures also need to be considered in terms of reimbursement by both public and private health insurance entities.

Another component of BCI technology that needs to be carefully considered is the potential modular nature of the devices. For example, the output from a BCI system could be used by someone to control a cursor on a computer, a robotic arm, a person's own arm, a wheelchair, or other technology such as lights, thermostats, and other connected devices. This type of modularity is not common in approved medical devices. There are also many questions related to ethics, privacy, ownership, use, and sharing surrounding data that is recorded from a person's brain activity. On the clinical side, clinical practice guidelines will need to be established so that there are standardized, accepted methods for prescribing implantable BCI for different patient populations and referring patients to relevant specialists, such as neurologists, neurosurgeons, physiatrists, physical therapists, occupational therapists, and speech therapists.

There are many questions that remain to be answered as the field of BCI advances and as the AI approaches that fuel BCI continue to expand as well. To help address these questions, a collaborative community has been formally established that is made up of academic researchers, clinicians, engineers, medical device companies, foundations, ethicists, representatives from federal agencies, and — most importantly — people with lived experience of neurologic injury or disease. After about a year of planning and coordinating, Dr. Hochberg is pleased to report that the charter for the Implantable Brain Computer Interface Collaborative Community (iBCI-CC) was signed in March 2024. The iBCI-CC already has more than 260 people who have joined the community, and working groups within the organization are starting to work together to address these questions.

For early-career clinical researchers who want to get involved with BCI research or start incorporating AI in their own research, beyond the expected mastery of systems neuroscience and clinical practice, Dr. Hochberg advises that getting experience with nearly any computer programming language is valuable. Understanding how well-written software allows a computer to achieve a particular task and getting an intuitive sense for when something isn't working right is really helpful. For example, when troubleshooting with a BCI, one needs to determine if there is an issue with the BCI device itself, a problem with the software, or if something has changed in the biology itself that you are recording. The fields of BCI and AI are growing rapidly. There are many exciting career opportunities in this space, and there is a need for people with neurorehabilitation expertise to contribute to ongoing research, participate in the iBCI-CC work groups, and eventually apply BCI technology in clinical practice to help their patients.

Dr. Hochberg believes the future of BCI is bright, and he emphasizes that the field would not be where it is today without the amazing research participants who generously volunteer their time and effort in clinical trials to create and test novel BCI technologies. These individuals participate not for their own personal gain, but because they want to help other people with neurological conditions and injuries in the future. Neurorehabilitation clinicians also play an important role in learning about BCI trials in their area and providing their patients with information about these trials so that the field can work together to bring BCI technology to the market so that patients everywhere can benefit from it.