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An interface connects

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Brain–computer interfaces are our 2023 technology of the year.

Last month at *Nature Electronics*, we celebrated our fifth anniversary. We marked the occasion by publishing the first article in a series of short articles that explore topics in the field of electronics through research that has been featured in the pages of the journal. The series continues in this issue with work on wireless power transfer. But we also return this month for the fifth edition of our technology of the year.

Our technology of the year aims to highlight an area that has achieved a key breakthrough or reached an important moment of development. In 2019, we chose edge computing, and in 2020, it was 5G, the fifth generation of wireless communications technology. In 2021, with the world in the grip of the coronavirus pandemic, we highlighted the impact of the pandemic on digital technology, and in 2022, we explored the future of transport. For 2023, we have chosen brain–computer interfaces.

Brain–computer interfaces – which are also known as brain–machine interfaces – provide a direct communication link between the brain and an external device. They can be used to record, decode and stimulate neural activity. They can treat neurological disorders and restore lost functions in patients, allowing a person to control robotic arms or to generate synthetic speech with just their thoughts. And they could potentially be used to enhance human capabilities.

Within academic research, a series of powerful demonstrations of the capabilities of such interfaces have recently been published. A bidirectional brain–computer interface that provides sensory feedback direct to the brain was, for instance, shown to improve robotic arm control[1]. And brain-to-text communication at typing speeds of 90 characters per minute was achieved by decoding attempted handwriting movements[2]. These advances have been combined with a range of device developments[3] and innovations[4]. Similar can be expected this year[5]. At the same time, the technology is being pursued by an array of start-up companies. Their path to clinical and commercial success remains uncertain, but 2023 is likely to be a critical year, with several important clinical trials scheduled to begin.

In this issue, and as we will do so throughout the year, we explore the topic with a particular focus on the underlying device technology. But our decision to highlight brain–computer interfaces in 2023 is also based on the fact that this is a critical moment to consider the potential consequences and direction of the technology. And thus an examination of the ethical, legal and societal implications of brain–computer interfaces will be a key part of our analysis.

We begin with an assessment of the start-up scene. In a News Feature in this issue, Liam Drew explores the various start-up companies pursuing brain–computer interfaces and the various technologies they employ. This includes companies working on non-invasive interfaces based on electroencephalography and functional near-infrared spectroscopy. And it also includes companies working on implanted interfaces based on electrocorticography, as well as implanted interfaces that record from individual neurons.

Brain–computer interfaces are typically fabricated using conventional rigid electronics, which creates a mechanical mismatch with the soft tissue of the brain. This can lead to tissue damage, immune response and probe drift. The use of flexible electronics with tissue-like mechanical properties could provide an answer and help build the next generation of brain–computer interfaces. In a Perspective article in this issue, Jia Liu and colleagues at Harvard University explore the potential of flexible electronics in the development of such interfaces.

The researchers highlight how flexible electronics could eliminate the immune response and probe drift, and allow specific neurons to be tracked and modulated over an extended period of time. They also highlight how the stretchability of these electronic systems could allow brain–computer interfaces to adapt to volume changes in the brain during development, ageing and disease. Ultimately, they argue that “flexible electronics can fundamentally change how the neurons are electrically interfaced and thus offer the necessary scalability for large-scale long-term stable neural electrical recording in the near future.”

The potential of the technology is considerable, and Liu and colleagues explore the impact flexible interfaces could have on neuroscience, neuroprosthetic control, bioelectronic medicine, and the integration of brain and machine intelligence. But the remaining challenges are also considerable, and the team examine the engineering issues that will need to be addressed in order to create flexible interfaces of general applicability.

Challenges related to scaling, precision and invasiveness could also be addressed with the help of optical interfaces. And in a Comment article elsewhere in this issue, Nathan Ersaro, Cem Yalcin and Rikky Muller at the University of California, Berkeley argue that the future of brain–computer interfaces should be optical.

Brain–computer interfaces form a more intimate – and potentially more profound – connection with a person’s body than other types of human–computer interaction, and raise a number of unique and complex ethical issues. In a second Comment article in this issue, Laura Cabrera and Douglas Weber at the Pennsylvania State University and Carnegie Mellon University discuss the ethical priorities with such technology. They highlight the importance of considering issues related to safety, agency and privacy. But also argue that responsible development requires careful consideration of issues related to access, equity, and the management of expectations.

Addressing ethical and societal concerns needs to start at the development stage, and requires the creation of appropriate regulatory frameworks. But, as Cabrera and Weber note, “the future of BCI [brain–computer interface] technology cannot be decided by developers or regulators alone. It requires a constant dialogue between developers, regulators and society at large about what is technologically possible and what is the responsible route forward.”

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