Brain–machine interface: closer to therapeutic reality?

Various neurological diseases and traumatic injuries permanently abolish sensorimotor functions, dramatically affecting the quality of life of millions of individuals. Progress continues in the development of neural repair interventions to enhance functional recovery after neuromotor disorders in animals. So far, no interventions have shown efficacy in the restoration of useful sensorimotor functions in severely paralysed people.

Two decades ago, developments opened avenues for the design of neuroprosthetic systems capable of replacing lost sensorimotor functions. The proliferation of high-density neuronal recordings together with high-performance computing capabilities allowed the identification of core principles through which the brain can coordinate upper limb movements. This knowledge translated into pioneer brain–machine interfaces whereby non-human primates could learn to operate external actuators such as prosthetic arms using only brain activity. The results of the BrainGate clinical trial provided the first proof of principle that the ideas developed in non-human primates were transferable to people. However, several technical and practical challenges have delayed clinical implementation. Human brain–machine interfaces have not reached the level of performance attained in non-human primates.

In The Lancet, Jennifer Collinger and colleagues report the results of an extensive clinical study in a 52-year-old woman with chronic tetraplegia who performed a range of activities of daily living using a brain–machine-interface-controlled robotic arm. For the first time, a person performed better than non-human primates.

Two arrays of 96-channel intracortical microelectrodes were surgically implanted in the motor cortex, allowing recordings of up to 271 single units during the 3-month trial. As early as the second day of testing, the paralysed woman was capable of manipulating the prosthetic limb in a three-dimensional workspace. Performances and control complexity gradually improved with daily brain–machine-interface training over 13 weeks. Eventually, the participant developed fluid and rapid control over skilful prosthetic arm movements. She accurately reached for objects, adjusted the opening of the prosthetic hand to grasp items of various shapes and sizes, and moved them to any desired location in the three-dimensional workspace (figure). Collinger and colleagues also sought to assess the clinical relevance of regained movements using the action research arm test (ARAT), which is used to grade upper-limb function recovery after neuromotor disorders, but has never been used for the performance assessment of brain–machine interfaces. Significant gains in clinical scores emphasised the value of the developed brain–machine-interface technology for improving the quality of life of severely paralysed people.

Brain–machine interfaces rely on translation algorithms that map features extracted from brain signals to intended prosthetic actions, but current decoders might not have direct relations with the principles underlying the neural control of movement. Collinger and colleagues pursued a radically different approach inspired by neurobiological principles. First, they optimised a population vector algorithm that encodes prosthetic movements on the basis of direction-dependent tuning of the motor cortex neuronal ensemble—as originally formulated with Georgopoulos and colleagues in the 1980s. Second, the decoded movement was conveyed to a shared controller that merged the participant’s intent, robotic position feedback, and constraining task-dependent features to guide the optimum execution of robot movements.

The resulting control architecture strikingly resembles...
the organisation of the CNS in mammals. Indeed, current views about the neuromotor infrastructure suggest that an abstraction of the desired movement is transferred from the motor cortex to the brainstem and spinal cord, where smart circuits elaborate the detailed motor command, based on the supraspinal signal, current limb position, and hard-wired constraints that promote optimum motor states.\(^2\) The ensuing control of prosthetic arm movements was highly intuitive, and probably responsible for the unprecedented performance of the developed brain–machine interfaces. The participant reported that she was only focusing on the goal of the action, as opposed to the details of the kinematic trajectory or other precise control parameters. This bioinspired brain–machine interface is a remarkable technological and biomedical achievement.

Challenges lie ahead. This brain–machine-interface technology remains confined to the controlled environment of laboratories where highly skilled engineers tune decoding algorithms daily. Dissemination of such brain–machine-interface-controlled devices is contingent on a number of non-trivial technical issues, the resolution of which remains uncertain. These issues include safe, low-power, and wireless Microsystems for neuronal recordings that remain operational for decades, and stable decoders that give robust performance without daily retraining.\(^11,12\) So, are current and contemplated invasive brain–machine-interface technologies leading us closer to therapeutic reality?

While we pursue this challenging avenue, a more immediate scenario for large-scale clinical applications might emerge from simpler and less invasive strategies that can be implemented in specialised clinical facilities. Brain–machine interfaces based on electroencephalographic and electrocorticographic signals have enabled healthy and severely paralysed people to control a range of devices, including versatile robots.\(^9\) Preliminary testing in people suggests that these modalities are suitable for operation of functional electrical stimulation of impaired muscles during rehabilitation. We have shown that gait training, enabled by electrical spinal cord stimulation, restored refined locomotion in rats with a paralysing spinal cord injury through neuronal pathway remodelling.\(^7\) By augmenting task-specific activity in spared sensorimotor pathways during training, brain–machine-interface-assisted rehabilitation might similarly boost use-dependent plasticity in individuals with stroke or spinal cord injury, thus enhancing and accelerating recovery.

Collinger and colleagues developed a sophisticated brain–machine-interface technology that allowed a tetraplegic woman to turn her thoughts into activities of daily living. Concurrently, prosthetic hands are being interfaced with peripheral nerves to restore grasping and sensation in amputees;\(^13\) spinal neuroprostheses have the potential to restore motor functions in paralysed people;\(^2\) and non-invasive brain–machine interfaces, although providing fewer degrees of control, can improve motor execution, and are moving into neurorehabilitation centres.\(^14\) Although many obstacles remain, neural prosthetic systems are rapidly approaching clinical fruition. Through concerted efforts, combining several strategies, translational neuroprosthetics might soon become revolutionary treatment models for sensorimotor paralysis.

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We declare that we have no conflicts of interest.


