Functional electrical stimulation

Brain-computer interfaces (BCIs) based on functional electrical stimulation have been used for upper extremity motor rehabilitation after stroke. However, little is known about their efficacy for multiple BCI treatments. In a study, 19 stroke patients participated in 25 upper extremity followed by 25 lower extremity BCI training sessions.

Methods: Patients' functional state was assessed using two sets of clinical scales for the two BCI treatments. The Upper Extremity Fugl-Meyer Assessment (FMA-UE) and the 10-Meter Walk Test (10MWT) were the primary outcome measures for the upper and lower extremity BCI treatments, respectively.

Results: Patients' motor function as assessed by the FMA-UE improved by an average of 4.2 points ($p < 0.001$) following upper extremity BCI treatment. In addition, improvements in activities of daily living and clinically relevant improvements in hand and finger spasticity were observed. Patients showed further improvements after the lower extremity BCI treatment, with walking speed as measured by the 10MWT increasing by 0.15 m/s ($p = 0.001$), reflecting a substantial meaningful change. Furthermore, a clinically relevant improvement in ankle spasticity and balance and mobility were observed.

Discussion: The results of the current study provide evidence that both upper and lower extremity BCI treatments, as well as their combination, are effective in facilitating functional improvements after stroke. In addition, and most importantly improvements did not stop after the first 25 upper extremity BCI sessions [1)].

People with chronic tetraplegia, due to high-cervical spinal cord injury, can regain limb movements through coordinated electrical stimulation of peripheral muscles and nerves, known as functional electrical stimulation (FES). Users typically command FES systems through other preserved, but unrelated and limited in number, volitional movements (eg, facial muscle activity, head movements, shoulder shrugs).

Ajiboye et al. report the findings of an individual with traumatic high-cervical spinal cord injury who coordinated reaching and grasping movements using his own paralysed arm and hand, reanimated through implanted FES, and commanded using his own cortical signals through an intracortical brain-computer interface (iBCI).

We recruited a participant into the BrainGate2 clinical trial, an ongoing study that obtains safety information regarding an intracortical neural interface device, and investigates the feasibility of people with tetraplegia controlling assistive devices using their cortical signals. Surgical procedures were performed at University Hospitals Cleveland Medical Center (Cleveland, OH, USA). Study procedures and data analyses were performed at Case Western Reserve University (Cleveland, OH, USA) and the US Department of Veterans Affairs, Louis Stokes Cleveland Veterans Affairs Medical Center (Cleveland, OH, USA). The study participant was a 53-year-old man with a spinal cord injury (cervical level 4, American Spinal Injury Association Impairment Scale category A). He received two intracortical microelectrode arrays in the hand area of his motor cortex, and 4 months and 9 months later received a total of 36 implanted percutaneous electrodes in his right upper and lower arm to electrically stimulate his hand, elbow, and shoulder muscles. The participant used a motorised mobile arm support for gravitational assistance and to provide humeral abduction and adduction under

cortical control. We assessed the participant's ability to cortically command his paralysed arm to perform simple single-joint arm and hand movements and functionally meaningful multi-joint movements. We compared iBCI control of his paralysed arm with that of a virtual three-dimensional arm. This study is registered with ClinicalTrials.gov, number NCT00912041.

FINDINGS: The intracortical implant occurred on Dec 1, 2014, and we are continuing to study the participant. The last session included in this report was Nov 7, 2016. The point-to-point target acquisition sessions began on Oct 8, 2015 (311 days after implant). The participant successfully cortically commanded single-joint and coordinated multi-joint arm movements for point-to-point target acquisitions (80-100% accuracy), using first a virtual arm and second his own arm animated by FES. Using his paralysed arm, the participant volitionally performed self-paced reaches to drink a mug of coffee (successfully completing 11 of 12 attempts within a single session 463 days after implant) and feed himself (717 days after implant).

INTERPRETATION: To our knowledge, this is the first report of a combined implanted FES+iBCI neuroprosthesis for restoring both reaching and grasping movements to people with chronic tetraplegia due to spinal cord injury, and represents a major advance, with a clear translational path, for clinically viable neuroprostheses for restoration of reaching and grasping after paralysis [2)].

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Sieghartsleitner S, Sebastián-Romagosa M, Cho W, Grünwald J, Ortner R, Scharinger J, Kamada K, Guger C. Upper extremity training followed by lower extremity training with a brain-computer interface rehabilitation system. Front Neurosci. 2024 Mar 4;18:1346607. doi: 10.3389/fnins.2024.1346607. PMID: 38500488; PMCID: PMC10944934.

2)
Ajiboye AB, Willett FR, Young DR, Memberg WD, Murphy BA, Miller JP, Walter BL, Sweet JA, Hoyen HA, Keith MW, Peckham PH, Simeral JD, Donoghue JP, Hochberg LR, Kirsch RF. Restoration of reaching and grasping movements through brain-controlled muscle stimulation in a person with tetraplegia: a proof-of-concept demonstration. Lancet. 2017 May 6;389(10081):1821-1830. doi: 10.1016/S0140-6736(17)30601-3. Epub 2017 Mar 28. PubMed PMID: 28363483; PubMed Central PMCID: PMC5516547.