Restoring Thought-Controlled Movements After Paralysis: Artifact Reduction Techniques for iBCI Control of FES Actuated Movements

Daniel Young[1,2], Frank Willett[1,2], William D. Memberg[1], Brian Murphy[1], Benjamin Walter[3,4], Jennifer Sweet[3,4], Jonathan Miller[3,4], Leigh R. Hochberg[5,6,7], Robert F. Kirsch[1,2], and A. Bolu Ajiboye[1,2]
[1]Case Western Reserve University, Cleveland, OH, [2]FES Ctr. of Excellence, Cleveland, OH, [3]UH Case Med, Cleveland, OH, [4]CWRU Sch. of Med., Cleveland, OH, [5]Brown Univ., Providence, RI, [6]Mass. Gen. Hosp., Bostom, MA, [7]Harvard Med. Sch., Boston, MA

Introduction: Hundreds of thousands of people live with loss of motor function due to spinal cord injury (SCI) and have indicated strong interest in neuroprosthetics that restore arm movements [1]. Functional Electrical Stimulation (FES) is a method of delivering current to nerves and muscles to produce movement, and has restored independence to people with spinal cord injuries, enabling activities such as eating, writing, and grooming [2]. Intracortical brain computer interfaces (iBCI's) have been explored as potential command interfaces for neuroprosthetics because they can record neural activity related to complex reaching kinematics (10+ degrees of freedom) in humans with paralysis. However, iBCI's utilize precise recordings of microvolt sized signals while FES generates relatively larger electric fields in the paralyzed limbs. Electrical artifacts during stimulation interfere with extracting accurate movement intentions and may limit the performance of iBCI control of FES prostheses. The clinical goal of our group is to restore thought controlled arm and hand function to people with paralysis through use of a combined iBCI-FES system. This work describes the stimulation artifact and the removal methods we implemented, as well as showcases our recent success with one participant in restoring self-feeding and drinking [3].

Materials and Methods: One BrainGate participant with C4 SCI received two 96-channel intracortical microelectrode recording arrays placed in the motor cortex. 36 intramuscular stimulating electrodes and four anodes were surgically placed in the right arm for restoring movement of the paralyzed limb. On two days, four temporary surface-patch electrodes were placed targeting the same muscles. The participant used the iBCI to control reaching movements in virtual-reality and of his own arm using the intramuscular FES. We characterized the stimulation artifacts recorded on the intracortical arrays and performed offline decoder SNR comparisons of three cleaning methods: blanking, common average reference, and linear regression reference. To show clinical impact, the participant attempted two functional tasks (self-feeding and self-drinking) while in full control of the iBCI-FES system.

Results and Discussion: FES stimulation artifacts recorded by the intracortical arrays were only 3-4x larger than baseline neural activity for the implanted electrodes, but were 30x larger than baseline when using surface electrodes. After artifact cleaning, we recovered >90% decoder SNR during surface stimulation and saw no decrease in performance during intramuscular stimulation. The linear regression reference method extracted useful information underneath large artifacts and performed better than other methods in all conditions. Our participant was able to command FES stimulation in closed loop to control arm and hand movements to accomplish self-feeding and drinking, and completed no movements with the system turned off.

Conclusions: These results demonstrate the feasibility for restoring movement after paralysis using a combined iBCI-FES system. Stimulation artifacts could be removed with simple cleaning techniques which performed better than blanking, enabling accurate estimation of the user's intention. Our linear regression reference method may be a promising tool for artifact removal in a variety of multi-electrode array recordings. We provided thought-controlled FES actuated movements of the elbow and hand, and demonstrated the systems capability to restore independence to people with paralysis through successful self-feeding and drinking tasks.

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