DOI: 10.3217/978-3-85125-467-9-84

Magnetoencephalography-based Real-time Control of a Prosthetic Hand in Paralyzed Patients

Ryohei Fukuma[1,2,3,*], Takufumi Yanagisawa[1,2], Youichi Saitoh[1], Koichi Hosomi[1], Haruhiko Kishima[1], Takeshi Shimizu[1], Hisato Sugata[1], Hiroshi Yokoi[4], Masayuki Hirata[1], Yukiyasu Kamitani[2,3,5], Toshiki Yoshimine[1]

[1]Osaka University Graduate School of Medicine, Suita, Japan; [2]ATR Computational Neuroscience Laboratories, Seika-cho, Japan; [3]Nara Institute of Science and Technology, Ikoma, Japan; [4]The University of Electro-Communications, Chofu, Japan; [5]Kyoto University, Kyoto, Japan

*2-2 Yamadaoka, Suita, Osaka 565-0871, Japan. E-mail: r-fukuma@nsurg.med.osaka-u.ac.jp

Introduction: Real-time control of prosthetic limbs based on brain-machine interface (BMI) technology may be a new treatment option for severely paralyzed patients. A previous study revealed that electrocorticography of paralyzed patients was capable of controlling a prosthetic hand in real time by not only detecting the intention to move the paralyzed hand, but also by inferring the type of attempted movement [1]. Notably, our previous study demonstrated that magnetoencephalography (MEG) in healthy subjects also conveyed enough motor information to control a prosthetic hand [2]. However, it was not evident whether severely paralyzed patients could control the prosthetic hand with the motor information extracted from these non-invasively measured signals.

Subjects and tasks: Eight severely paralyzed patients with brachial plexus root avulsion and 1 amputee participated in this study. All patients joined 1 open-loop session; 5 patients joined 1 closed-loop session after the open-loop session. In the open-loop session, the patients were presented visually with the types of movement to perform, and were instructed to attempt to grasp or to open their paralyzed hand once, at the time an execution cue was presented. In the closed-loop session, the patients were shown a prosthetic hand and a monitor that displayed alternating instructions every 7 s to grasp or open the prosthetic hand. The patients were instructed to control the prosthetic hand at arbitrary times using the same attempts performed in the open-loop session.

Prosthetic hand control: A 160-channel MEG recorded the neuromagnetic activities of the patients in real-time. The MEG signals from 84 parietal sensors were averaged within a 500-ms time window, and normalized to form a slow magnetic field (SMF). A real-time decoder was trained using the SMFs in the open-loop session to control the prosthetic hand in the subsequent closed-loop session. The real-time decoder estimated the onset of the attempts to move the paralyzed hand using decoders trained by a Gaussian process regression and a support vector machine (SVM). At the detected onset, another SVM decoder inferred the performed movement type, which was grasping or opening. The prosthetic hand was controlled to form the inferred posture.

Offline analysis: The attempted movement type during the open-loop session was decoded by a SVM using SMFs and nested cross-validation. Moreover, to test the onset detection algorithm of the real-time decoder, timing of the onset detection was estimated using SMFs in the open-loop session and cross-validated. Finally, the decoding accuracy and the onset detection accuracy in the closed-loop session were evaluated separately using a one-tailed Fisher's exact test.

Results: During the attempted movements of the paralyzed hand, the spatiotemporal pattern of the SMFs showed characteristic activation similar to that during actual movement of the intact hand. A signal source reconstruction technique revealed that the sensorimotor cortex contralateral to the paralyzed hand was activated. The type of attempted movement was classified with an accuracy of $68.1 \pm 12.7\%$ (mean ± SD) using the SMFs from the open-loop session. Moreover, the onset detection algorithm successfully inferred the onset timing of the movement intention within ± 500 ms in $63.0 \pm 15.6\%$ trials. In the closed-loop session, the decoding accuracy of the movement type and the detection accuracy of the onset were significant for 2 out of 5 patients.

Discussion: The SMFs measured during attempted movement of the paralyzed hand conveyed enough motor information to control a prosthetic hand in real time. Moreover, the SMFs were thought to originate from the slow components of the cortical current in the contralateral sensorimotor cortex.

Significance: The prosthetic hand used in this study is the first to demonstrate that even *severely paralyzed* patients can control non-invasive BMIs in real-time using information about *both* movement type and intention.

References

[1] Yanagisawa, T. *et al.* Electrocorticographic control of a prosthetic arm in paralyzed patients. *Ann Neurol* 71: 353–361, 2012.
[2] Fukuma, R. *et al.* Closed-loop control of a neuroprosthetic hand by magnetoencephalographic signals. *PLoS One,* 10: e0131547, 2015.