Real-Time Control of a Clinical Brain-Computer Interface Using Continuous Wideband Multiunit Activity

Wasim Q. Malik, *Senior Member, IEEE*, John P. Donoghue, and Leigh R. Hochberg

BRAIN-COMPUTER interfaces (BCIs) offer the potential to restore communication and movement ability in people with paralysis following spinal cord injury, brainstem stroke, ALS, or limb amputation [1]. An intracortical BCI records motor-related neural activity, decodes it to estimate the intended movement, and controls assistive devices accordingly. Single-unit activity (SUA), obtained from motor cortical neuronal ensembles, is well established as a useful signal in BCIs due to its extensively studied relationship to voluntary movement. Despite its information richness, the SUA's temporal instability poses a practical challenge for chronic BCIs, since SUA decoding involves frequent and time-consuming spike-sorting and filter recalibration [2]. To address this issue, we consider a signal that samples from broader collections of neural activity, namely the continuous wideband multiunit activity (MUA) [3]. Besides improving decoder robustness and stability, MUA can help avoid spike-sorting. Following recent animal studies showing that MUA encodes movement intention and its use in an early offline control of a robot wrist [4], we investigate the potential of MUA for motor decoding in a clinical BCI.

We analyzed MUA decoding performance as part of the ongoing BrainGate pilot clinical trial (IDE) with participants S3 and T2 with brainstem stroke. We recorded the raw wideband neural activity sampled at 30 kHz using an intracortical array of 96 microelectrodes implanted in the precentral gyrus in the region of arm representation. The raw signal at each electrode was bandpass filtered (300 Hz – 6 kHz), integrated (50 ms non-overlapping windows), and downsampled to obtain MUA. For comparison, we computed the SUA as the spike rate within identical timebins from all available sorted units. The participant imagined moving a computer-controlled cursor on a two-dimensional screen during a 4-target center-out-back task under open-loop motor imagery without feedback control. Neural activity and cursor kinematics recorded during this period were used to calibrate a Kalman filter assuming a velocity-based neural tuning model. During subsequent closed-loop control assessment with visual feedback, the filter was used to decode neural activity in real time and move the cursor in an 8-target center-out-back task and a step-tracking pursuit task optimized to acquire performance metrics using the Fitts law.

We conducted leave-one-out cross-validated offline open-loop decoding analysis from 5 different days with one participant. MUA yielded higher Pearson's correlation coefficient between actual (computer-controlled) and decoded cursor velocity than SUA (0.80 vs. 0.73; $p < 0.001$). In closed-loop online real-time control sessions on 10 different days with both participants, the MUA decoder provided a higher target acquisition rate (52% vs. 39%), higher path efficiency (0.58 vs. 0.42; $p < 0.01$), and statistically equivalent target acquisition time compared to the SUA-based decoder. Thus our open- and closed-loop decoding analysis confirmed that MUA consistently performed at least as well as SUA in standard motor tasks.

Our analysis demonstrates the feasibility of decoding MUA in a BCI to estimate intended movement kinematics. As MUA decoding can reduce system complexity and improve longterm stability of a BCI without sacrificing decoding accuracy, it may enable autonomous and robust BCIs for clinical function restoration and rehabilitation of people with tetraplegia.

REFERENCES

[1] L. R. Hochberg, D. Bacher, B. Jarosiewicz, N. Y. Masse, J. D. Simeral, J. Vogel, S. Haddadin, J. Liu, S. S. Cash, P. van der Smagt, and J. P. Donoghue, "Reach and grasp by people with tetraplegia using a neurally controlled robotic arm," *Nature,* vol. 485, no. 7398, pp. 372-375, May 2012.

[2] J. A. Perge, M. L. Homer, W. Q. Malik, S. Cash, E. Eskandar, G. Friehs, J. P. Donoghue, and L. R. Hochberg, "Intra-day signal instabilities affect decoding performance in an intracortical neural interface system," *J. Neural Eng.,* vol. 10, no. 3, p. 036004, Jun. 2013.

[3] E. Stark and M. Abeles, "Predicting movement from multiunit activity," *J. Neurosci.,* vol. 27, no. 31, pp. 8387-94, Aug. 2007.

[4] M. Burrow, J. Dugger, D. R. Humphrey, D. J. Reed, and L. R. Hochberg, "Cortical control of a robot using a time-delay neural network," in *Int. Conf. Rehabil. Robotics*, Bath, UK, 1997.

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W. Q. Malik is with the Dept. of Anesthesia, Critical Care and Pain Medicine, Massachusetts General Hospital, Harvard Medical School, Boston, MA. He is also with the School of Engineering, and Institute for Brain Science, Brown University, Providence, RI. He is also with the Center for Neurorestoration and Neurotechnology, Rehabilitation R&D Service, U.S. Dept. of Veterans Affairs, Providence, RI. (e-mail: wasim_malik@brown.edu)

J. P. Donoghue is with the Center for Neurorestoration and Neurotechnology, Rehabilitation R&D Service, U.S. Dept. of Veterans Affairs, Providence, RI. He is also with the School of Engineering, and Institute for Brain Science, Brown University, Providence, RI. (email: john_donoghue@brown.edu)

L. R. Hochberg is with the Center for Neurorestoration and Neurotechnology, Rehabilitation R&D Service, U.S. Dept. of Veterans Affairs, Providence, RI. He is also with the Dept. of Neurology, Massachusetts General Hospital, Harvard Medical School, Boston, MA. He is also with the School of Engineering, and Institute for Brain Science, Brown University, Providence, RI. (email: leigh_hochberg@brown.edu)