Stability of Local Field Potentials Over 11 Months of Brain-Machine Interface Use

M. R. Scheid[1], R. D. Flint III[1], Z. A. Wright[1], M. W. Slutzky[1,2,3,4]

Departments of [1]Neurology, [2]Physiology and [3]Physical Medicine and Rehabilitation, Northwestern University Feinberg School of Medicine; [4]Rehabilitation Institue of Chicago, Chicago, IL 60611

Correspondence: M.W. Slutzky, Northwestern University, 303 E. Superior Ave., Lurie 8-121, Chicago, IL 60611.
E-mail: mslutzky@northwestern.edu

Abstract. Local field potentials (LFPs) are derived from many thousands of neurons. As such, they may enable long-lasting and stable control signals for brain-machine interfaces (BMIs). Here we assess the stability of LFPs in primary motor cortex of 2 monkeys during 2-D cursor control using an LFP-based BMI. Using a biomimetic BMI decoder without retraining or adaptation, monkeys exhibited high performance that remained stable for over 11 months. Offline, we examined the stability of the LFP features by computing decoders of the brain-controlled cursor velocity from individual features in each session and using them to decode the velocity in the last session. Many of the LFP features showed high correlation with the cursor velocity which grew increasingly stable for over 11 months. This suggests that the monkeys learned a stable mapping between motor cortical field potentials and outputs, and that LFPs will provide a highly stable signal source for BMIs.

Keywords: Brain Machine Interface, Local Field Potentials, Neural Prosthetics

1. Introduction

Brain machine interfaces (BMIs) offer the potential to help people paralyzed from spinal cord injury or stroke regain function. BMIs using action potentials (spikes) from individual neurons as inputs have evolved to the point of early human studies in people with tetraplegia. However, it is unclear whether current recording technologies have the ability to record spikes from many neurons for the decades that a successful device will require. Local field potentials (LFPs) are almost as informative about movement as spikes [Mehring et al., 2003; Bansal et al., 2011; Flint et al., 2012b] and may have better longevity [Flint et al., 2012a].

Greater stability of signals would allow less frequent BMI decoder recalibration. In this study we evaluate the long-term stability of both BMI performance and LFP signals during control of a computer cursor using a static, biomimetic decoder of LFPs over 11 months. Biomimetic decoders are trained on cortical signals during actual behavior. We find evidence that both performance and the behavior of LFPs themselves remain stable during BMI use over a period of at least 11 months. It has been shown that single-unit spikes remain stable during natural movement and spike-based BMI use over a period of 1-2 days and 19 days, respectively [Chestek et al., 2007; Ganguly and Carmena, 2009].

2. Methods

All procedures were approved by the Northwestern University Institutional Animal Care and Use Committee. We recorded LFPs using 96-channel electrode arrays in primary motor cortices of two rhesus monkeys. We trained a Wiener cascade decoder of reach velocity from LFPs recorded during a 2-D random target pursuit reaching task with the contralateral arm. We used the smoothed time-domain signal (local motor potential, or LMP [Mehring, 2004]) plus the power within each of five frequency bands (0-4 Hz, 7-20 Hz, 70-115 Hz, 130-200 Hz, and 200-300 Hz) as features from each electrode, and selected the 150 features with highest absolute correlation coefficient as inputs to the decoder [Flint et al., 2012a]. Monkeys used the BMI to move the cursor in the random target pursuit task. Monkeys trained on the task at least 3 days per week for over 11 months. BMI control with other BMI decoders was also performed on some days but not analyzed here. Performance was assessed by success rate and average time to target.

To evaluate LFP stability, we built Wiener decoders using each of the 150 features included in the BMI, similar to [Chestek et al., 2007]. These sets of single feature decoders (SFDs) were built after each experimental session of LFP-based BMI control. The SFDs were used to predict velocity using data from the very first LFP control session.

Performance of the SFDs (measured as the correlation coefficient, R, between predicted and actual BMI control velocity) was used to assess the stability of each feature during BMI control over time.

3. Results

Performance during BMI control was high: time to target was 0.2 sec/cm (mean over 2 monkeys), comparable to levels for spike-based brain control in the literature. This performance remained stable or improved for a period of over 300 days for both LFP and MSP brain control. Single feature decoder performance was highly stable in many LFP features during this period, and became even more stable over time. This was particularly true of LMP features, many of which had R values with the output exceeding 0.5, but also true of a few hi-gamma band features as well.

4. Discussion

LFPs can be used to control a biomimetic BMI with high performance that was stable over at least 11 months, far longer than has been shown previously. Moreover, many of the LFP features behaved stably during BMI control over 11 months. The LMP, notably, showed the highest correlation with the brain-controlled cursor and the most stability over time. This could perhaps be related to the high number of underlying neural generators contributing to the LMP being more robust to change. Thus, users appear to form a cortical map during LFP-based BMI use that is stable for nearly a year. This is similar to the stable map seen in [Ganguly and Carmena, 2009] with highly-selected single-unit spikes; however, the stability lasted much longer here. This stable map was formed despite the fact that the monkeys also used several other BMI decoders during the study period. Thus, monkeys were able to switch among biomimetic BMIs with ease and still retain a stable cortical representation of the BMI task. This bodes well for long-term BMI use with LFPs without need for frequent recalibration or adaptation.

Acknowledgements

We thank Nicholas Sachs and Matt Bauman for their assistance with BMI system implementation and Lee Miller for helpful conversations about this work. This work was supported by NIH grant K08NS060223.

References

Bansal AK, Vargas-Irwin CE, Truccolo W, Donoghue JP. Relationships among low-frequency local field potentials, spiking activity, and three-dimensional reach and grasp kinematics in primary motor and ventral premotor cortices. *J Neurophysiol,* 105:1603-1619, 2011.

Chestek CA, Batista AP, Santhanam G, Yu BM, Afshar A, Cunningham JP, Gilja V, Ryu SI, Churchland MM, Shenoy KV. Single-neuron stability during repeated reaching in macaque premotor cortex. *J Neurosci,* 27:10742-10750, 2007.

Flint RD, Lindberg EW, Jordan LR, Miller LE, Slutzky MW. Accurate decoding of reaching movements from field potentials in the absence of spikes. *J Neural Eng*, 9:046006, 2012a.

Flint RD, Ethier C, Oby ER, Miller LE, Slutzky MW. Local field potentials allow accurate decoding of muscle activity. *J Neurophysiol,* 108:18-24, 2012b.

Ganguly K, Carmena JM. Emergence of a stable cortical map for neuroprosthetic control. *PLoS Biol,* 7:e1000153, 2009.

Hochberg LR, Serruya MD, Friehs GM, Mukand JA, Saleh M, Caplan AH, Branner A, Chen D, Penn RD, Donoghue JP. Neuronal ensemble control of prosthetic devices by a human with tetraplegia. *Nature*, 442:164-171, 2006.

Kim SP, Simeral JD, Hochberg LR, Donoghue JP, Black MJ. Neural control of computer cursor velocity by decoding motor cortical spiking activity in humans with tetraplegia. *J Neural Eng,* 5:455-476, 2008.

Mehring C, Rickert J, Vaadia E, Cardosa de Oliveira S, Aertsen A, Rotter S. Inference of hand movements from local field potentials in monkey motor cortex. *Nat Neurosci,* 6:1253-1254, 2003.

Mehring C, Nawrot MP, de Oliveira SC, Vaadia E, Schulze-Bonhage A, Aertsen A, Ball T. Comparing information about arm movement direction in single channels of local and epicortical field potentials from monkey and human motor cortex. *J Physiol*, 98:498-506, 2004.