Multi-unit firing rate features in hindlimb sensory-motor cortex reflect over-ground locomotion in rats

J. Lee, J. DiGiovanna[+], L. Friedli Wittler, J. Rigosa, G. Courtine* and S. Micera* *Senior Member, IEEE*

Severe spinal cord injury (SCI) induces permanent loss of motor and/ or sensory function below the lesion; locomotion is affected at nearly every level of injury. Recent studies have used Brain-Machine Interface to facilitate SCI patients partially regaining lost sensorimotor functions [1], [2]. Conceptually these systems "decode" from neural signals to control devices. However, they have primarily focused on arm reaching or more abstract movements. To investigate the potential lower-limb information within the cortex, a comprehensive set of experiments was developed to understand the relationship between hindlimb sensorimotor cortex (SM1) and states, kinematics, and muscle synergies in healthy rats (n=8). All rats were instrumented with a 32-channel microwire array (TDT, Alachua, FL) in layer V of SMI, which covered a majority of the hindlimb area. Kinematics and EMG were recorded and synchronized at 200 and 2000 Hz respectively.

Here, we focus on two basic features of quadrupedal, over-ground locomotion: (a) *walking vs. non-walking* and (b) *gait cycle percentage*. These represent high- and low-level descriptions of locomotion. Multi-unit firing rates were created *post-hoc* from single units identified as in [4] to simulate a more robust spike sorting method with potential for online application. All discriminated units on each electrode were summed and 'multi-unit' firing rates were estimated for each electrode within 50 ms, 50% overlapping windows. Gait cycle percentage was defined as 0% (start of *stance*) to 100% (end of *swing*) based on the kinematics of the right hindlimb.

Spectral analysis of multi-unit firing rates had shown a strong reproducibility in multiple electrodes during simple locomotion; we tested if this could be exploited to predict *walking* vs *non-walking.* Specifically, a spectrogram was applied to the multi-unit firing rates, all channels super-imposed, and a threshold to select the state was determined using Receiver Operating Characteristic curves [4]. This classifier was tested on novel data (5 +/- 3.5 days apart from training day); average accuracy was 81+/-4%, *n*=5 rats.

Additionally, there was spatiotemporal repeatability in firing rates over the cortex suggesting that topographically sampled neural activity can be exploited to predict the relative timing within the gait cycle with high accuracy. Here we used training data (*n*=3 gait cycles) to create *templates* of distributed firing rate activity over the cortex at times spanning the gait cycle. Novel data was compared to this database and classified based on which template was most similar (via Euclidean distance). This classifier accurately predicted gait cycle percentage (average R^2 =0.79+/-0.09; *n*=3 rats) for novel data on the same recording day.

Both classifiers are accurate enough to consistently find *probable steps* that were 'off-camera', and they could be considered complementary. There is tradeoff between the increased accuracy of the spatiotemporal classifier vs the robustness of the spectral classifier to neuronal loss and change over days. Further research is necessary to characterize the limits of this robustness for both classifiers. However, both methods exploit different features within hindlimb SM1 that reflect the gait cycle. These features are 'brain-centric' by design; allowing for studying them and potentially exploiting them in online situations or even after a SCI.

REFERENCES

[1] J. L. Collinger, B. Wodlinger, J. E. Downey, W. Wang, E. C. Tyler-Kabara, D. J. Weber, A. JC. McMorland, M. Velliste, M. L. Boninger, A. B. Schwartz, "High-performance neuroprosthetic control by an individual with tetraplegia," *Lancet*, vol. 381, 2012, pp. 557-564

[2] 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, J. P. Donoghue, "Reach and grasp by people with tetraplegia using a neurally controlled robotic arm," *Nature*, vol. 485, 2012, pp. 372-375

[3] J. Rigosa, L. Citi, J. Carpaneto, S. Raspopovic, M. Tombini, C. Cipriani, G. Assenza, M. C. Carrozza, KP. Hoffman, K. Yoshida, X. Navarro, P. Dario, P. M. Rossini, S. Micera, "Decoding of grasping information from neural signals recorded using peripheral intrafascicular interfaces," *J. of Neuroeng Rehabil.*, vol. 8, 2011, pp. 53-62

[4] D. J. Hand, R. J. Till, "A simple generalization of the area under the ROC curve for multiple class classification problems," *Machine Learning*, vol. 45, 2001, pp. 171–186.

This work was supported in part by: Swiss Excellence Scholarship Committee, European Commission's 7th Framework Program (CP-IP 258654), European Research Council (ERC 261247), International Paraplegic Foundation, and NCCR Robotics, Swiss National Science Foundation (51NF40-125773). * *equal contributors*

J. Lee, L. Friedli Wittler, and G. Courtine are with the Center for Neuroprosthetics, Ecole Polytechnique Federale de Lausanne, Lausanne, Switzerland (e-mails: juneseung.lee@ gmail.com, {lucia.friedliwittler, gregoire.courtine} @epfl.ch).

J. DiGiovanna and S. Micera are with Translational Neural Engineering Lab, Ecole Polytechnique Federale de Lausanne, Lausanne, Switzerland, (e-mails: {jack.digiovanna, silvestro.micera} @epfl.ch).

J. Rigosa and S. Micera are also with the the BioRobotics Institute, Scuola Superiore Sant'Anna, 56127 Pisa, Italy (e-mail: {j.rigosa, silvestro.micera} @sssup.it)