Spatial Evolution of Information Dynamics in Primary Motor Cortex

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Motivation

How does the relationship between neural and muscle activities change over space and time? Which locations on the cortex are most predictive/reflective of muscle activities, at what time? Are there any lower dimensional structures despite the high dimensionality of electrodes, muscles and time?

Methods

To obtain (1) spatially and temporally dense sampling of neural activities encoding movement details, and (2) a thorough measure encompassing different types of relationships, we computed the mutual information (MI) between Electromyography (EMG) and high Gamma envelope (100 to 200 Hz) of local field potential (LFP) for each muscle-electrode pair.

$$I(X,Y) = \sum_{x,y} P(X,Y) log_2 \frac{P(X,Y)}{P(X)P(Y)} \quad (1)$$

To detect potential low-dimensional structures in the 3-way MI tensor, we performed non-negative tensor factorization, where we approximated the tensor by a sum of a few outer-products of rank-1 vectors – each vector being non-negative [1].

Specifically, assuming that a k-way tensor X and target rank r are given, we seek matrices $\mathbf{F1}, \ldots, \mathbf{Fk}$ by solving the following problem:

minimize

$$||X - \sum_{j=1}^{r} (\mathbf{F_{1j}} \circ \mathbf{F_{2j}} \circ \ldots \circ \mathbf{F_{kj}})||_F^2 + G(\mathbf{F_1}, \ldots, \mathbf{F_k}) + H(\mathbf{F_1}, \ldots, \mathbf{F_k}) \quad (2)$$

where

$$G(\mathbf{F_1}, \ldots, \mathbf{F_k}) = \sum_{i=1}^{k} (\alpha_i ||\mathbf{Fi}||_F^2) \quad (3)$$

$$H(\mathbf{F_1}, \ldots, \mathbf{F_k}) = \sum_{i=1}^{k} (\beta_i \sum_{j=1}^{n} ||\mathbf{F_{ij}}||_1^2) \quad (4)$$

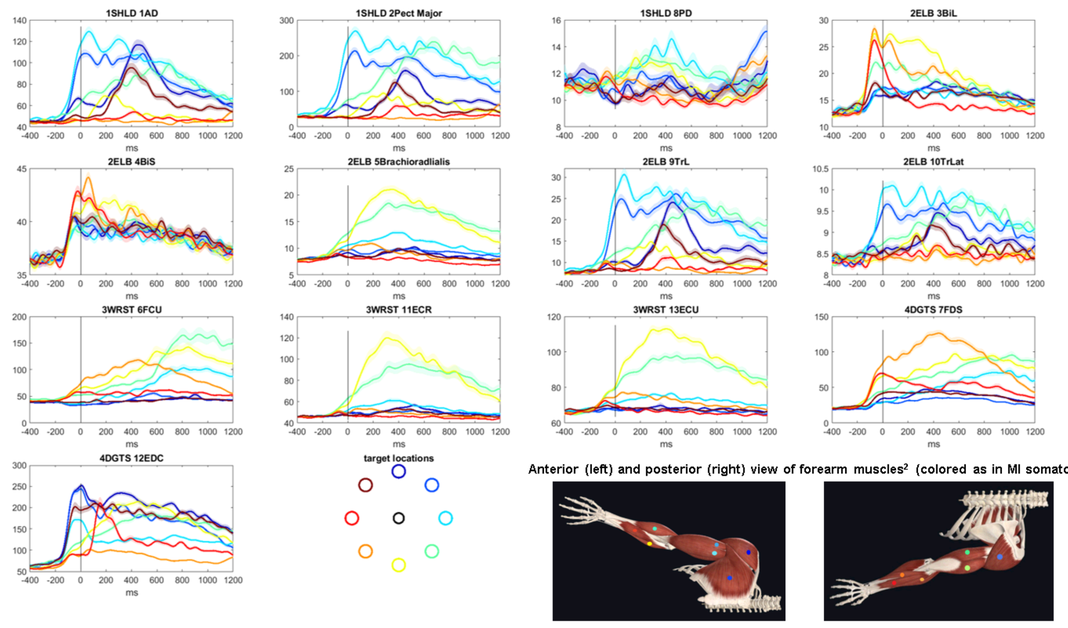
such that

$$\mathbf{Fi} \geq \mathbf{0} \text{ for all } i. \quad (5)$$

In the current setting, a macaque monkey performed delayed 8-direction center-out task on 2D plane. We recorded LFPs from primary motor cortex using Utah array, as well as EMGs across 13 muscles in forelimb/shoulder. High Gamma envelope and EMG were lowpassed at 10Hz and downsampled to 200Hz. Trials were aligned on movement onset. EMGs were selected from -400ms to 1200ms ('whole period') and segmented into 4 non-overlapping windows. Relative to EMG, Gamma envelopes are chosen from -600ms to 400ms.

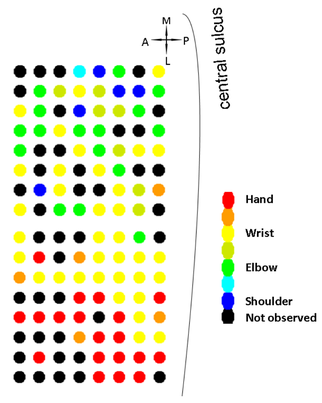
Results

Average muscle activities for each reach direction



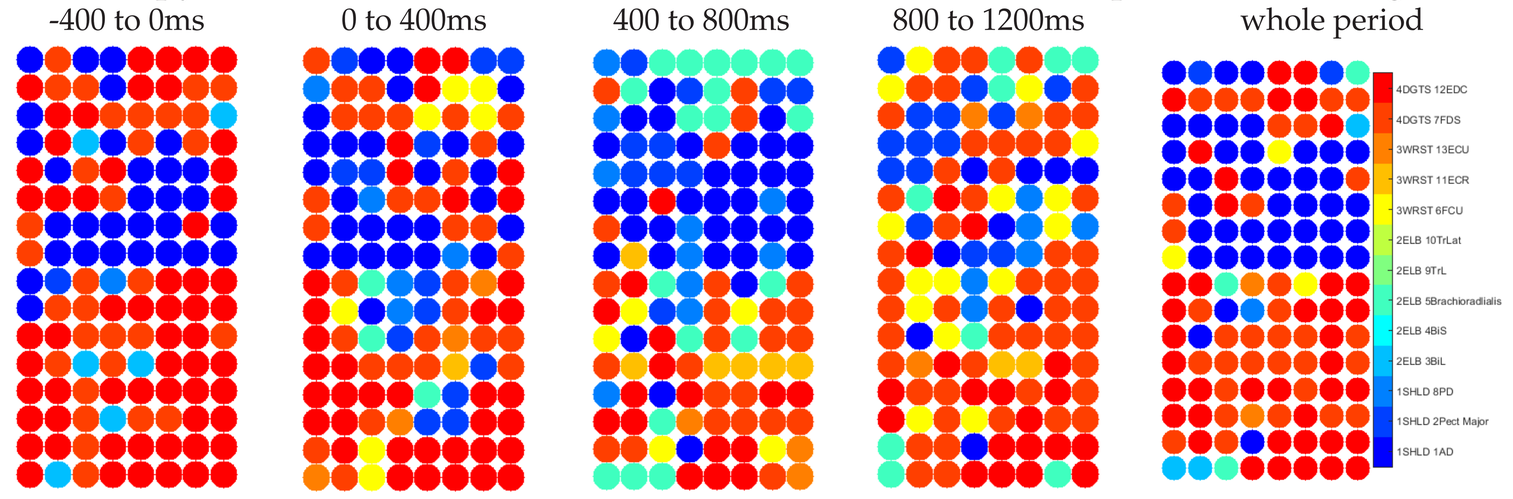
Somatotopy from ICMS

(intra-cranial microstimulation)

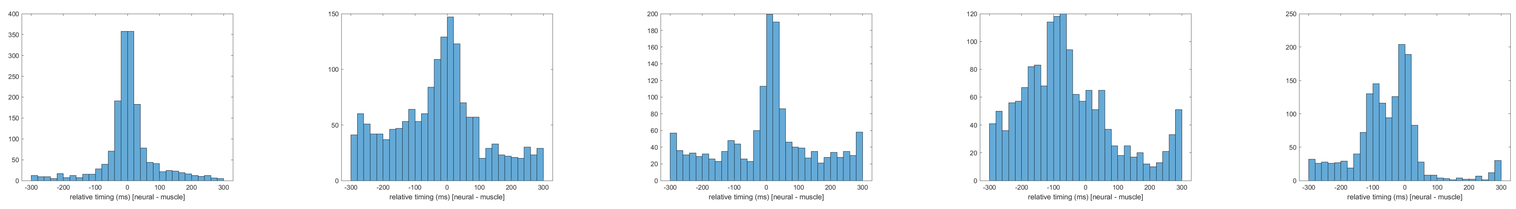


Anterior (left) and posterior (right) view of forearm muscles[2] (colored as in MI somatotopy)

Somatotopy from maximal mutual information follows the same proximal-distal gradient



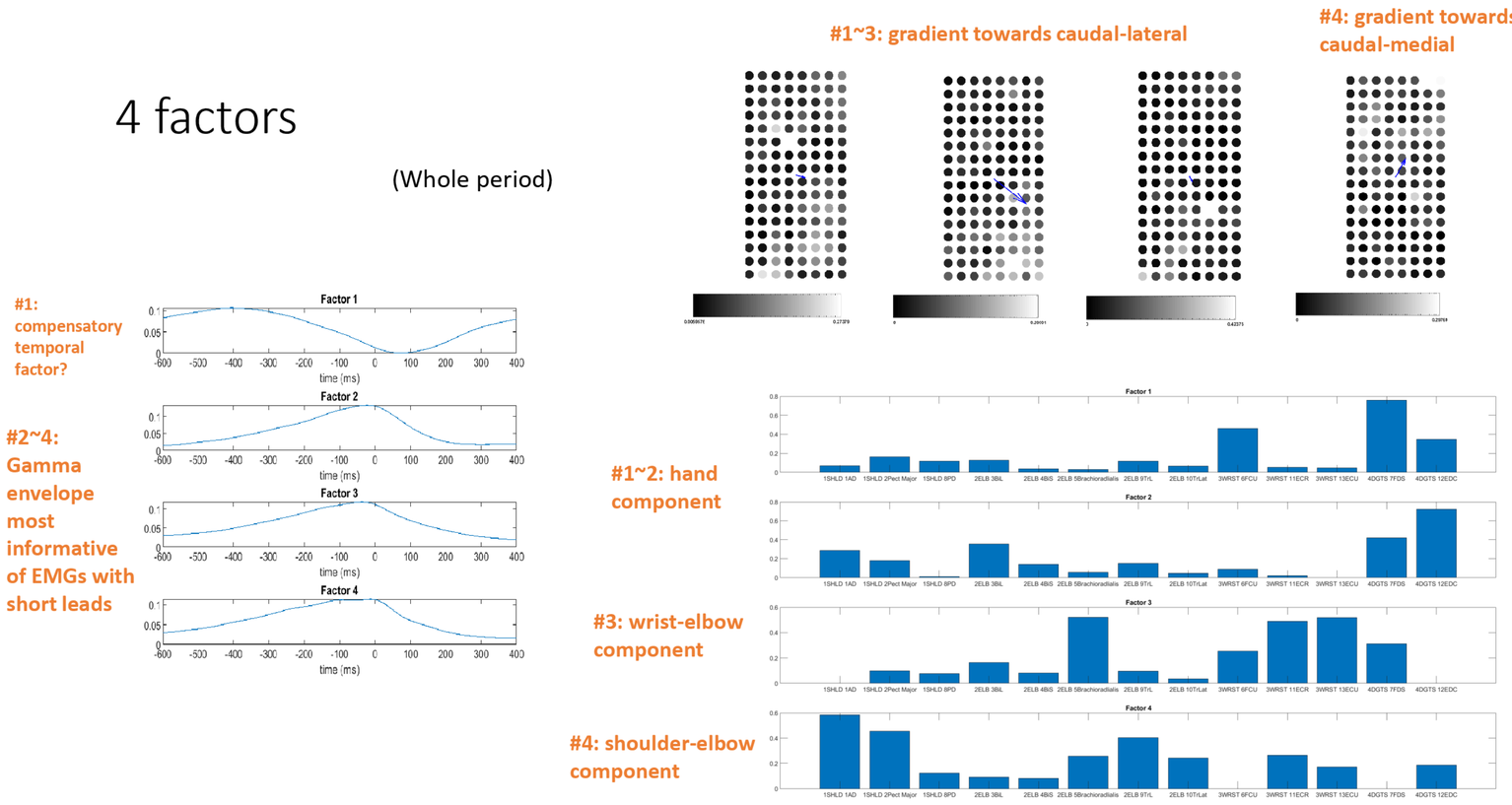
Distributions of timepoints attaining maximal mutual information differ across windows



Tensor Factorization gives temporal, spatial and muscle weights

4 factors

(Whole period)



References

[1] J. Kim, H. Park. Fast Nonnegative Tensor Factorization with an Active-set-like Method. In *High-Performance Scientific Computing: Algorithms and Applications, Springer, 2012, pp. 311-326*

[1] 3D4Medical LLC. Complete Anatomy In *https://3d4medical.com/*

Next Steps

- Modify mutual information estimator
- Quantify comparisons among windows
- Extend analysis to premotor cortex
- Look beyond single electrode-muscle pairs