Sparse components of sensorimotor ECoG signals are relevant for speech control

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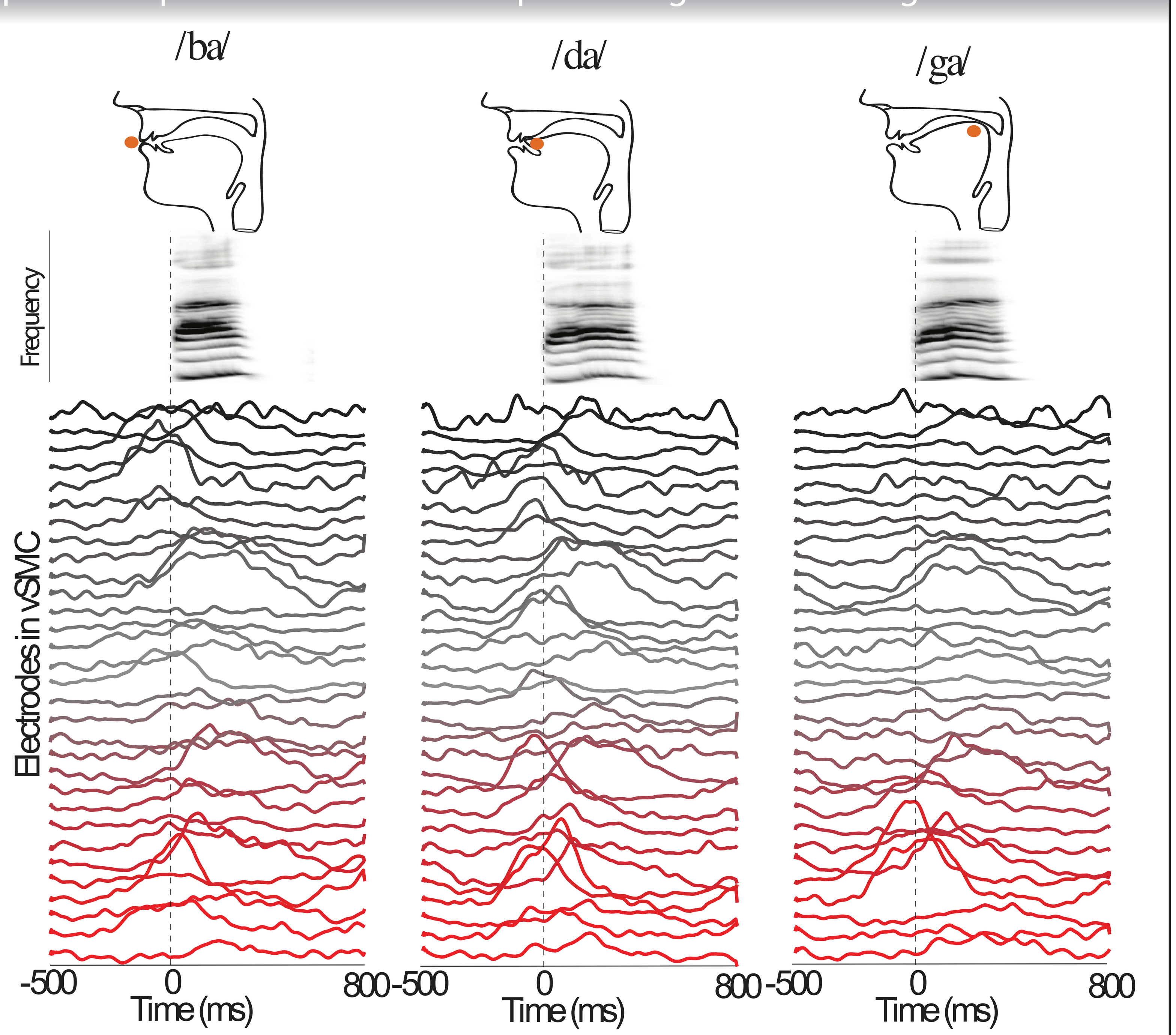
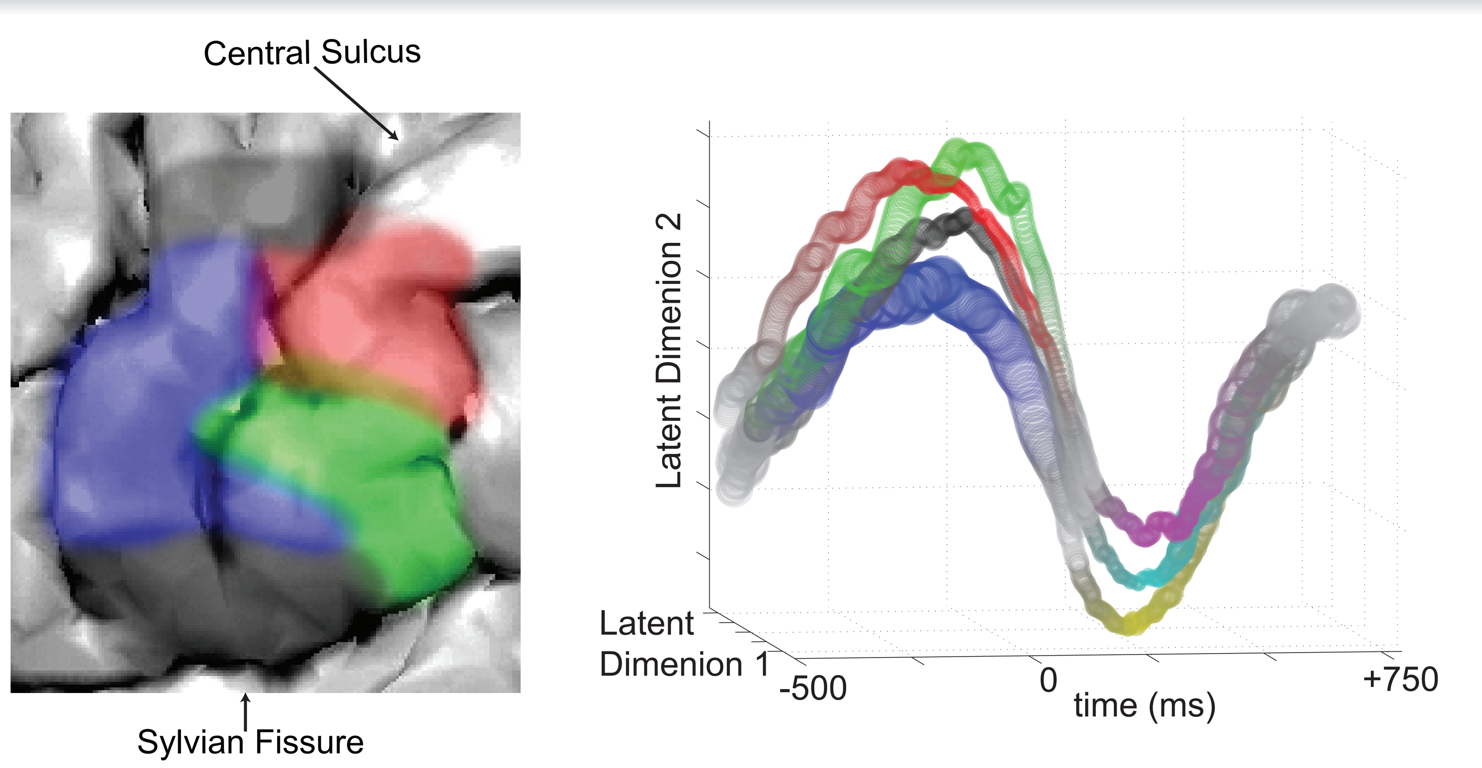
Abstract

The concept of sparsity has proven very useful to understanding elementary neural computations in sensory systems. Metabolic measurements indicate that neural activity must be sparse in the entire brain; however, the functional role of sparseness outside of sensory brain areas, such as motor regions, is not well understood. To address this basic question we investigated the functional properties of sparse structure in neural activity from human speech sensorimotor cortex. High-density electrocorticography (ECoG) from speech sensorimotor cortex (vSMC) in neurosurgical patients is a powerful tool to record broad-coverage, high-temporal resolution neural activity at meso-scale spatial resolution. However, ECoG recordings, like all field potentials, contain a mixture of different brain signals, which makes both the interpretation and extraction of specific features challenging. Utilizing sparse coding methods (independent components analysis: ICA, and convolutional sparse coding: CSC) we decomposed the complex spatial-temporal patterns of high-gamma activity during speech production into separate signal components. Notably, we show that these components are reliably activated across trials of the same utterance. Additionally, we found different components corresponding to the major oral articulators (e.g. Coronal Tongue, Dorsal Tongue, Lips), which were selectively activated during all utterances that engaged that articulator. Some of the components corresponded to spatially sparse activations, while others were more spatially distributed. Features with similar properties were also extracted using CSC, and required less data pre-processing. Finally, decoding of individual utterances from vSMC ECoG recordings improves consistently when linear classifiers are trained using the sparse codes generated by CSC. Together, these results suggest that sparse coding may be an important framework and tool for understanding sensory-motor activity generating complex behaviors.

Spatio-temporal scales of cortical processing and recording methods



Somatotopic Map of Articulators and Phoneme Dynamics

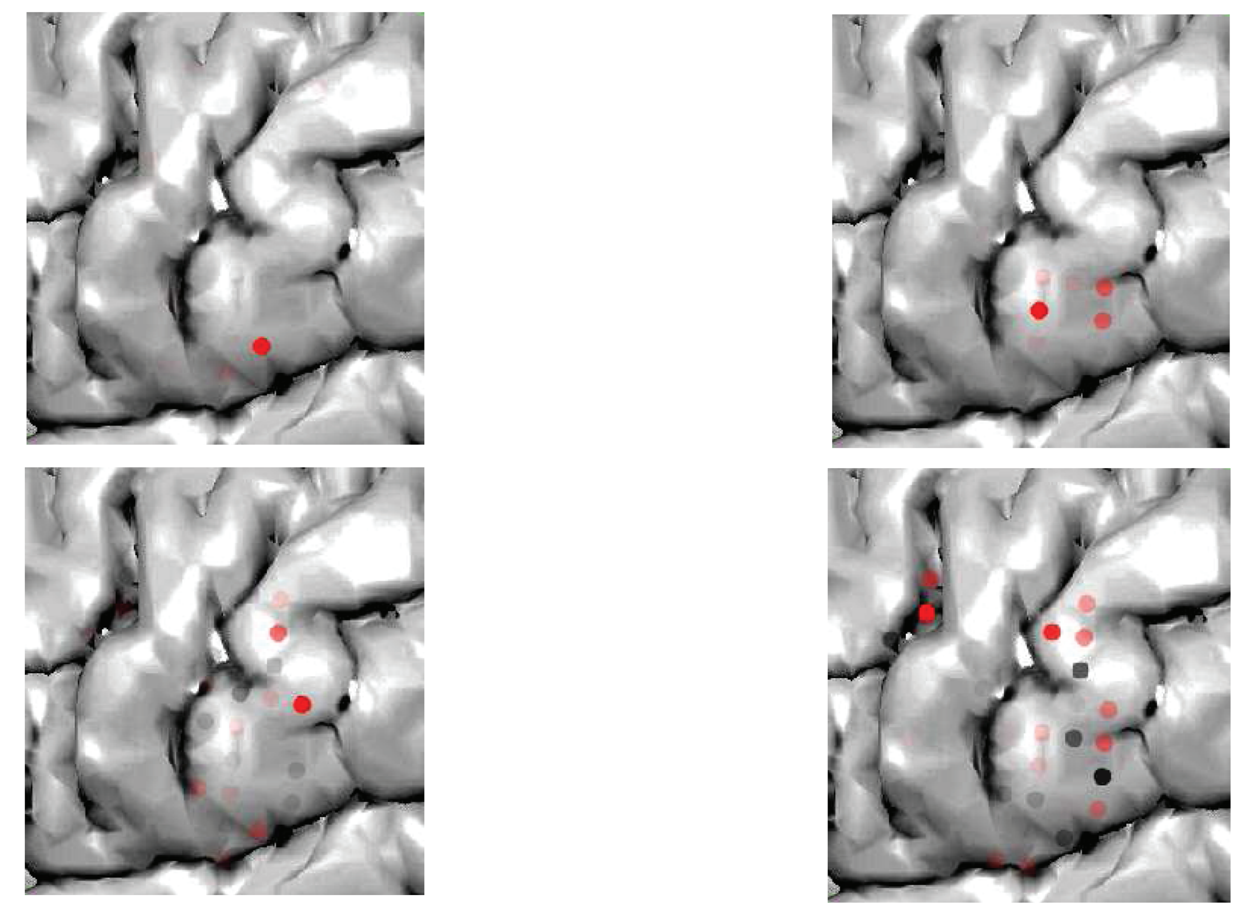


Independent Components Analysis

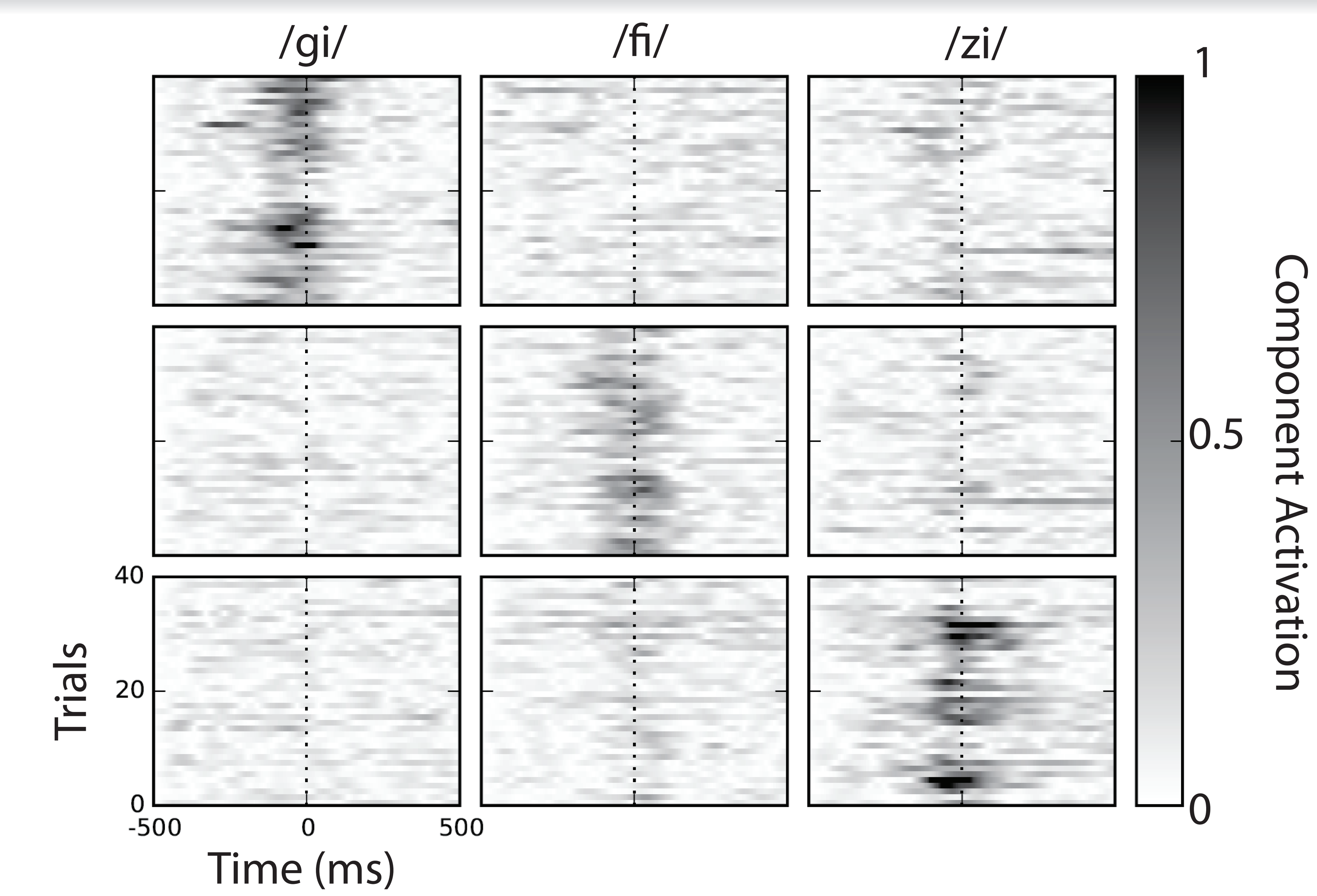
$$X = AS + \varepsilon$$
$$S = A^{T}X$$
$$A = \underset{A}{\operatorname{argmin}}\ MI(A^{T}X)$$

X: observed signal
S: independent sources
A: miximg matrix
ε: noise

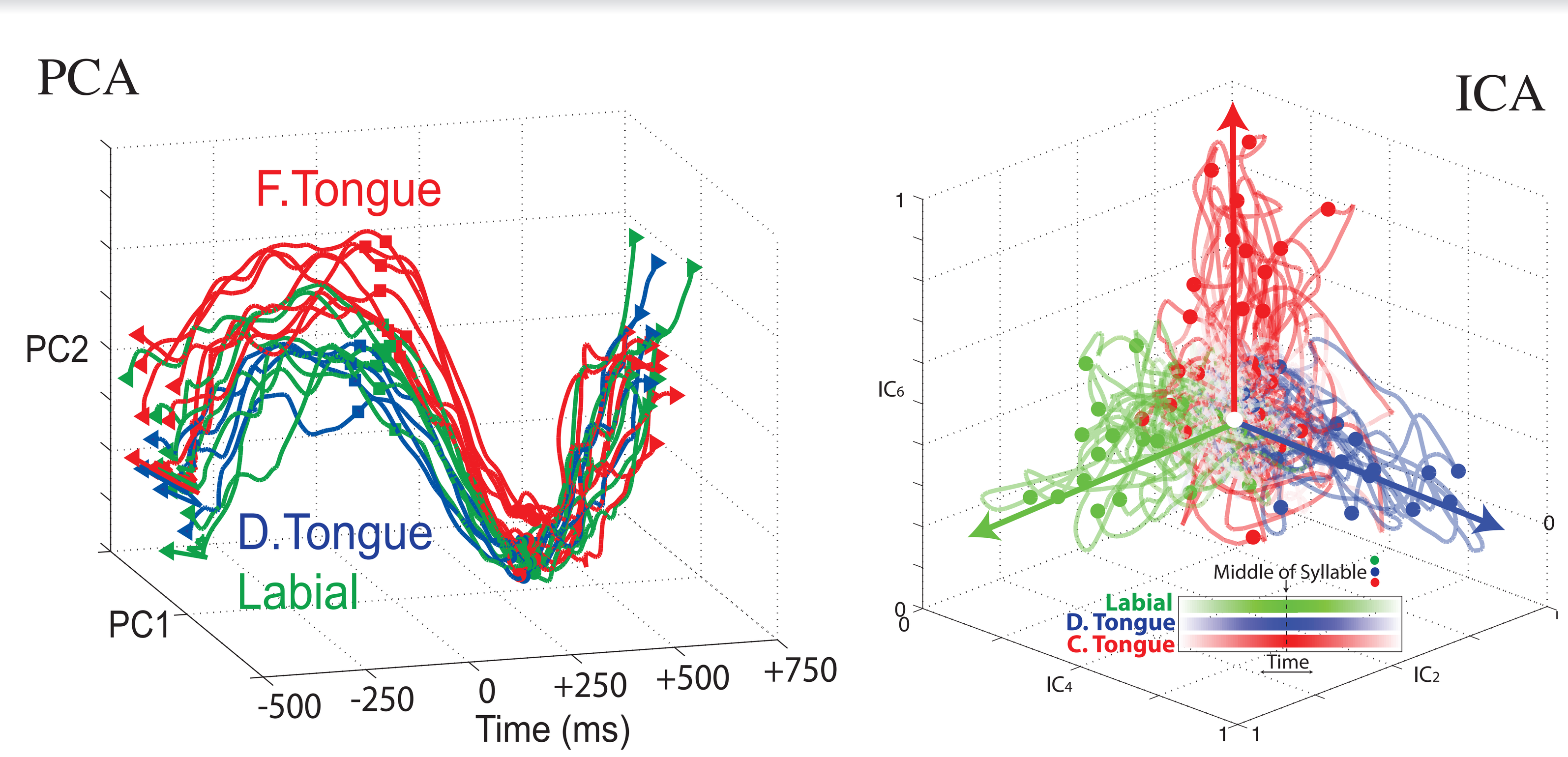
ICA Spatial filters are generally Sparse



ICs are Consistnetly Activated on Single trials

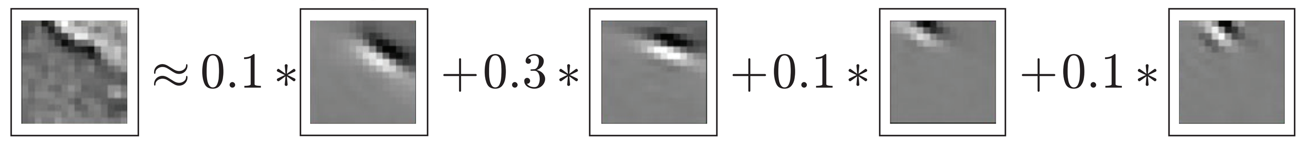


ICA extracts Indpendent Control Signals for Speech



Convolutional Sparse Coding

$$\text{Model:}\quad x_i = \sum_{j}^{N} \Psi_{ij} * a_j + \epsilon_i$$

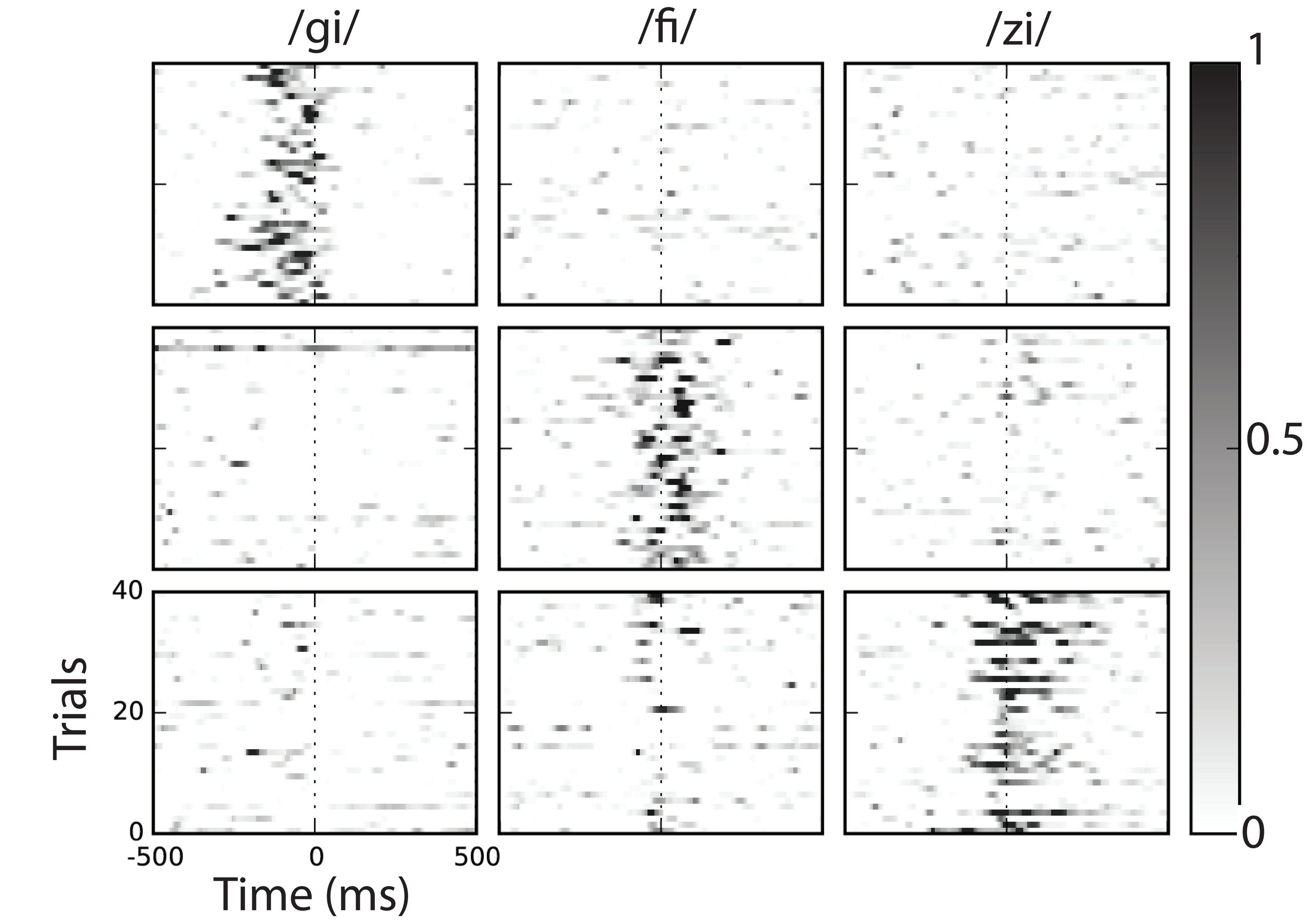


Reconstruction error

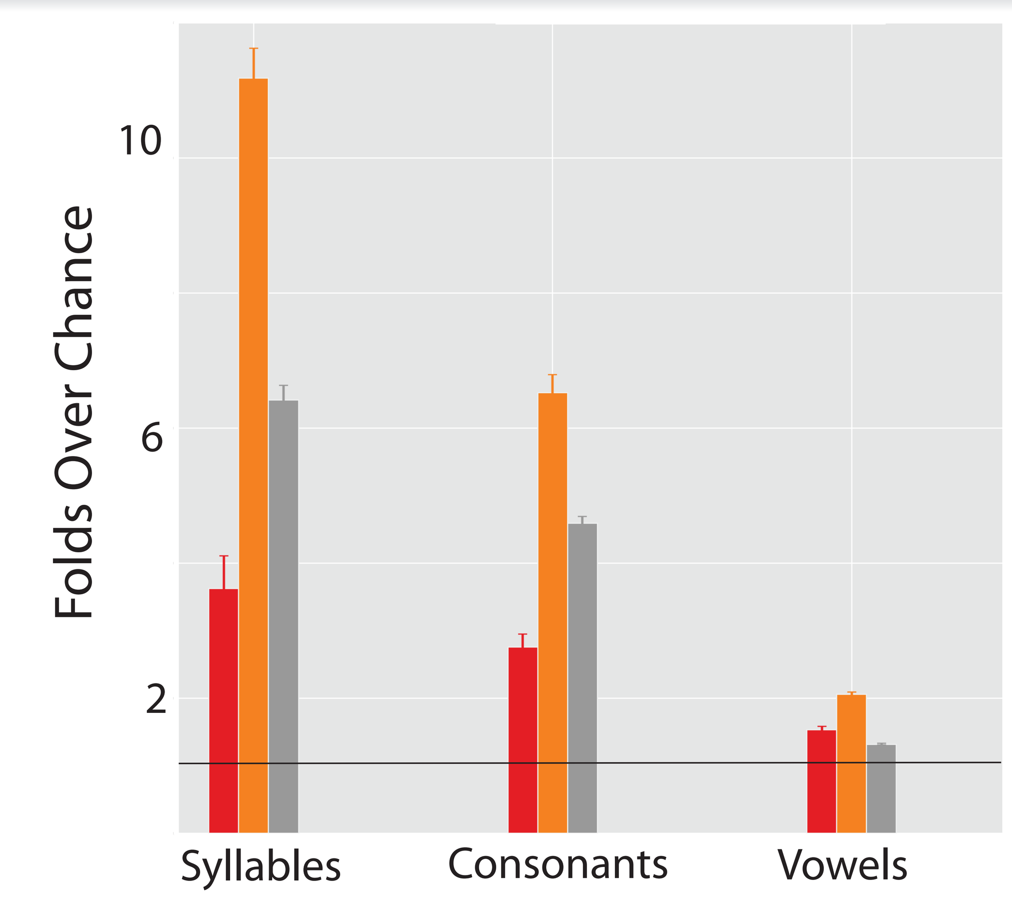
$$\text{Objective:}\quad a^* = \underset{\Psi,\, a}{\operatorname{argmin}}\ \tfrac{1}{2}\Big|x_i - \sum_j \Psi_{ij} * a_j\Big|_2^2 + \lambda |a|_1$$

Sparsity penalty

Cell-type specific optical manipulation with μECoG



Decoding Speach Classes with CSC 'bases'



-Linear SVM
-3 Subjects

Ongoing work and Future Directions

- -Different Frequency Bands
- -Unsegmented Data
- -Raw Voltages
- -Complex CSC
- -CSC on Speech