Quantifying Spatiotemporal Neural Dynamics

Designing a statistical method for low-latency prediction of the response to neural stimulation

Significance

Epilepsy is the most common chronic brain disease and affects people of all ages. More than 50 million people worldwide have epilepsy. 30% are medication-refractory

We examine the application of methods to analyze spatiotemporal characteristics of local field potential (LFP) neural data.

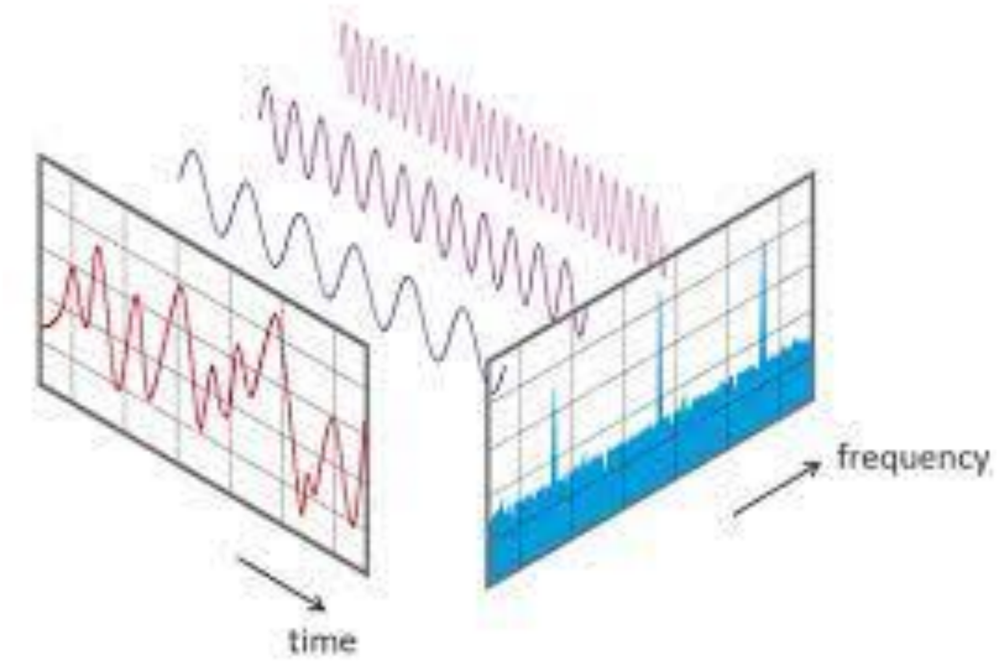
- current source density (CSD)
- histogram correlation
- radial profile analysis

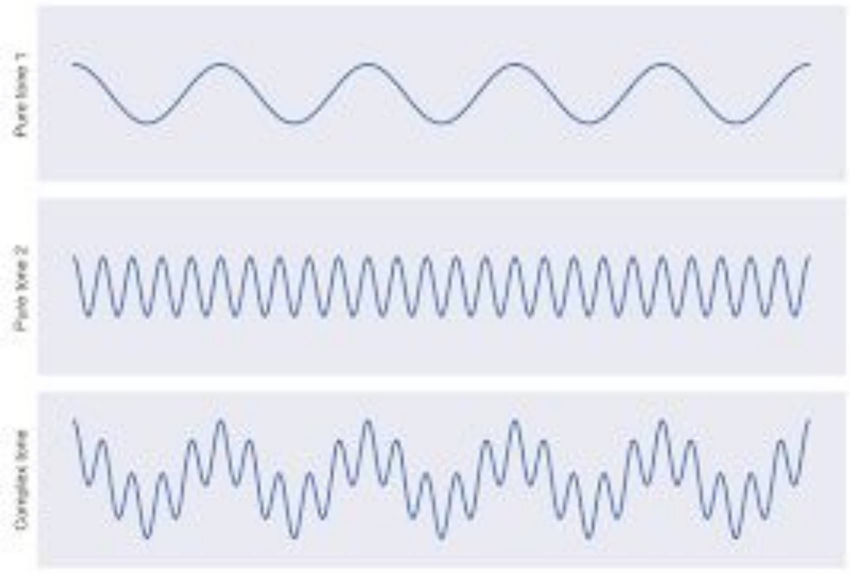
Key topics: spatial analysis, time-series analysis, permutation testing, event-related change

Problem

- Current methods to analyze neural data do not integrate spatial characteristics with temporal features
- Neural activity can be highly nonlinear and nonstationary, particularly in response to electric stimulation, resulting in limitations to time-series analysis methods that assume stationary data (such as Fourier transform/frequency analysis)
- The methods described here do not require more than one time sample for their calculation, they may have potential application for low latency prediction of neural activity

- Goal: method to quantify spatial features and similarities between states before and after event (stimulation) to classify and predict event-related changes based on training data set





Fourier time series analysis (traditional method of analyzing neural data) decomposes a signal into the sum of sine waves of a particular frequency.

Data

Local field potentials (LFP) from the cortical surface recorded using planar surface microelectrode arrays (Fig. 1) represent aggregated activity of neurons in close proximity to the recording electrodes.

We used a data set of recorded iECoG signals sampled 100 ms prior, and after cortical stimulation from a patient with epilepsy with 67 paired pre- and post- stimulation cortical states.

Analysis Code: Python

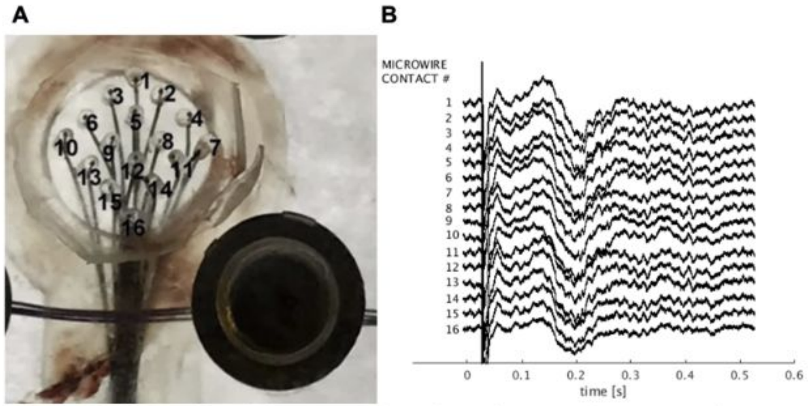


Fig. 1. A) Illustration of the 4 x 4 microelectrode array (0.075 mm diameter, 1 mm spacing) used to record local field potential data from the cortical surface along with the adjacent subdural grid contact (2.3 mm diameter) used for stimulations. B) Local field potentials recorded from the cortical surface.

Current Source Density

- Spatial second derivative of LFP
- Indicates location of current sources and sinks

$$\sum \sqrt{(CSDA_{i,j} - CSDB_{i,j})^2}$$

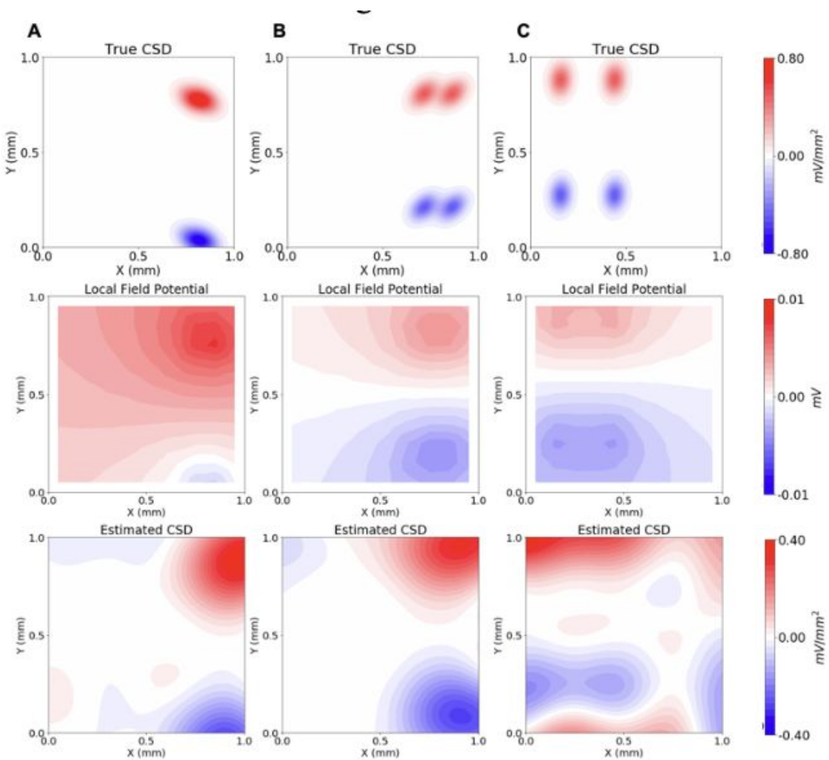


Fig. 2. A) Simulated LFP data for a surface microarray with one current source and one current sink with corresponding current source density profile below. B and C) Simulated LFP data with two current sources and two current sinks (note the different positions of current sources and sinks).

Histograms and Correlation

- Image histograms allow classification and identification of image features, while the correlation of image histograms is used to quantify the similarity between images.

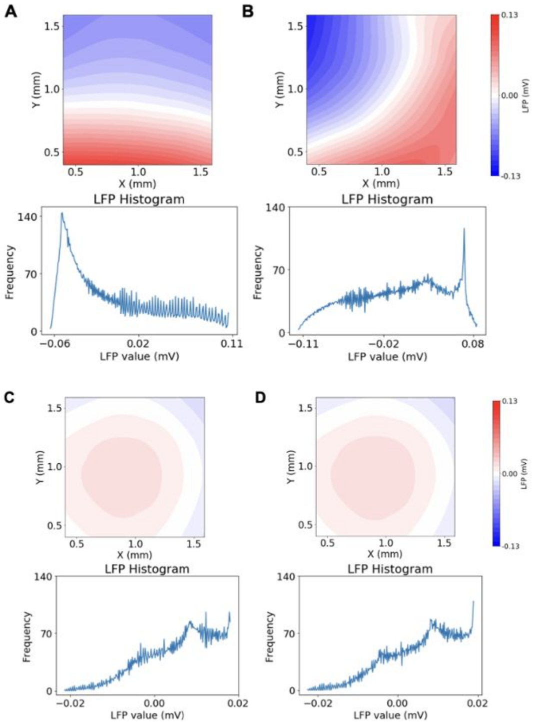


Fig. 3. Simulated LFP distributions and the corresponding LFP image histograms.

Radial Profile

- Radial Profile analyzes pixel values in a particular direction relative to a reference point in the center of an image. When applied to the 2D LFP distribution, this method can be used to sum electric potential values along the direction given by an angle θ (0 °≤ θ < 360°), relative to the point in the center of a planar array.

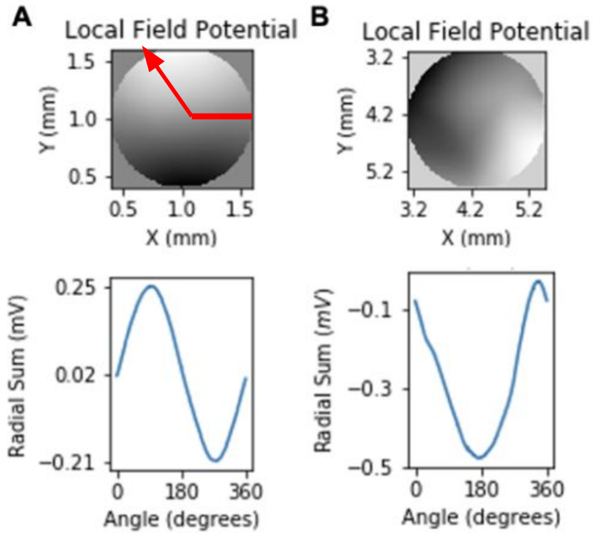
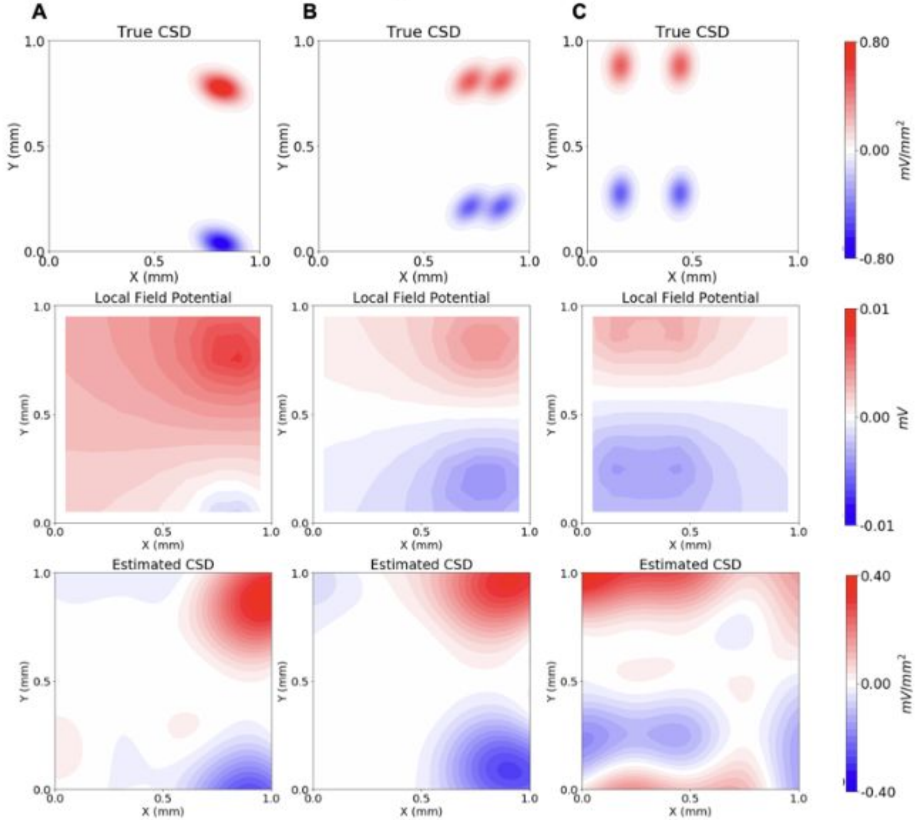


Fig. 4. A) Simulated LFP distribution with corresponding LFP Radial Profile. Lighter color indicates a more positive potential, whereas darker indicates a more negative potential. Areas outside the oval (circular) profile were excluded from analysis. B) Distribution of cortical LFP with the corresponding LFP Radial Profile.



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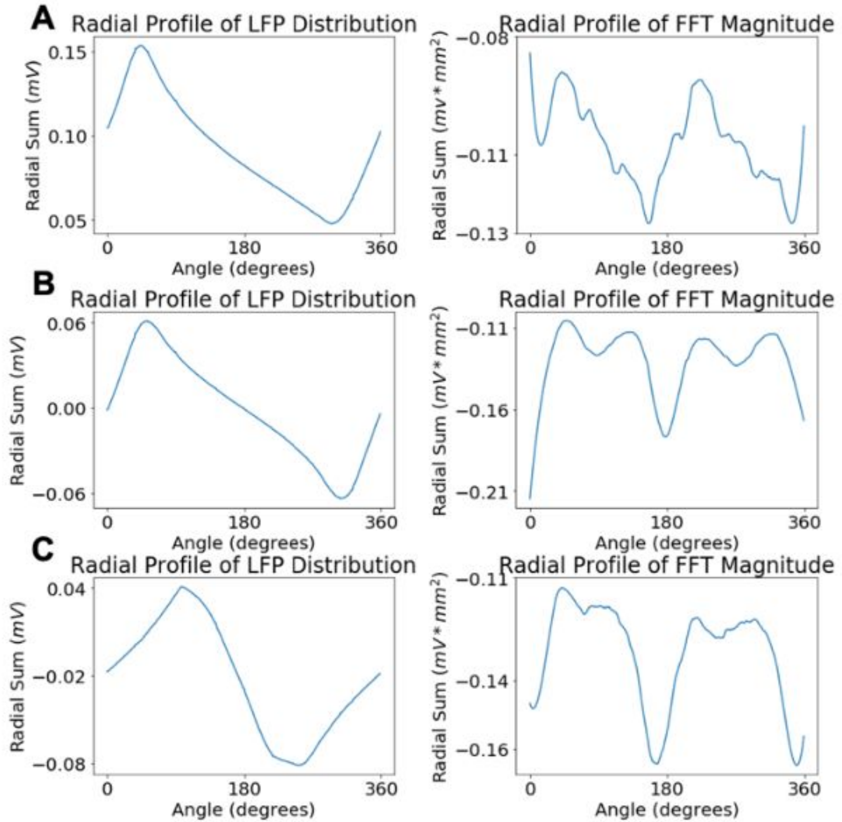

Fig. 5. Radial Profile of Local Field Potential, and Radial Profile of FT Magnitude Spectrum for the simulations from Fig. 2, i.e. (A) one current source and sink on right, (B) two current sources and sinks on right, and (C) two current sources and sinks on left

The number of peaks in the Radial Profile of the Spatial FFT indicates number of current sources/sinks

Solution

- We used radial profiles to investigate the state-dependent response to cortical stimulation (or the context-dependent effects of stimulation).

Context-dependence of a particular state

= P(prestimulation state correlated | poststimulation state correlated)

- For each given post-stimulation state, Context-dependence = Number of correlated pre-stimulation states/number of correlated post-stimulation state
- Threshold for defining a state as context-dependent: context-dependence>0.7

Permutation Test

- 67 pairs of pre and post-stimulation states
- 22 pairs identified as context dependent
- Permutation test by shuffling pre-stimulation state order
    - Null hypothesis: Pre-stimulation context does not affect calculation of context-dependence
    - Alternative hypothesis: Pre-stimulation context affects calculation of context-dependence
    - The permuted sets had less states defined as context-dependent than unshuffled set
    - P-value: 0.01 from 1000 permutations
    - Histogram: mean = 13.9, standard deviation = 3.4
- The obtained result indicates that the pre- stimulation context contributes to the cortical response to stimulation.