A Statistical Model for Spatiotemporal Activity in the Brain

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Abstract

This project explores methodology for developing a brain-wide baseline of spatial and temporal correlates. To date, this has never been done. Yet, the utility for such a model is widespread, including applications for improving EEG source and silence localization, improved implants for the prevention of epileptic seizures, and much more.

Introduction

What are potential brain silences?

Ischemic, lesioned, and necrotic tissues have little or no activity. These are caused, among other thing, by ischemic stroke, TBIs, intracranial hematomas, resected tissue, and demyelination.

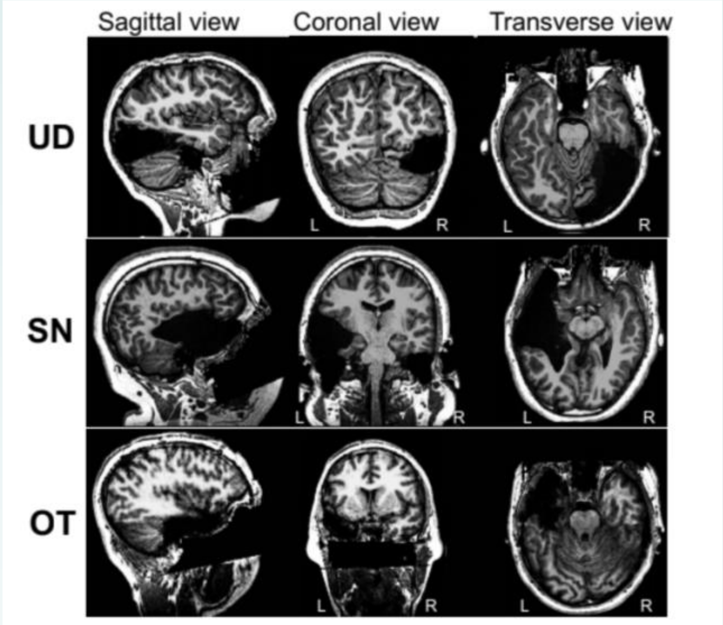

Figure One: Structural MRI scans of three patients with lobectomies. This represents an example of brain silences [1]

Why use EEG for silence localization?

EEGs are more cost effective and portable. This would afford patients the ability to monitor tumor growth more frequently and would also allow EMTs and doctors the ability to quickly assess patients in the case of an emergency.

Why is silence localization difficult?

Silence localization, along with source localization is an inverse problem, which is ill-defined. This leads to the identification of a candidate region, reflecting uncertainty. Unlike source localization, silence localization cannot rely on tracking the propagation of current.

What resolution can you expect from EEG?

In the best scenario, one would hope to identify a 5-10 mm silence (MRIs have ~1 mm resolution).

Methodology

Data Collection

ECoG data was used since it is collected intracranially, and therefore isn't affected by the resistance of the skull. The data was compiled from ten Stanford experiments using a total of 29 epileptic patients, representing the whole brain.

Data Processing

- Isolated data from times where no experimental stimuli was being given
- Spatial Filter
- Notch filter for 60 Hz harmonics
- Cross Correlation

Spatial Filtering Options

common average reference spatial filter

$$V_i(t_j) = V_i(t_j) - \frac{\sum_{j=0}^{t_f} V_i(t_j)}{l}, i = 1, \dots, N_{ch}, j = 0, \dots, t_f$$

Laplacian spatial filter

$$V_i^L(t) = V_i(t) - \frac{\sum_{i \neq j, d_{i\pm1,j\pm1}} \frac{1}{d_{ij}} V_j(t)}{\sum_{i \neq j, d_{i\pm1,j\pm1}} \frac{1}{d_{ij}}}, i = 1, \dots, N_{ch} \text{ [2]}$$

spatial filter using corner reference electrode

$$V_i(t_j) = V_i(t_j) - V_k(t_j), d_{ki} \geq 50\ mm$$

Results

First, a common average reference was used, the correlation data showed a trend of dipping negative before starting to level off at 0.

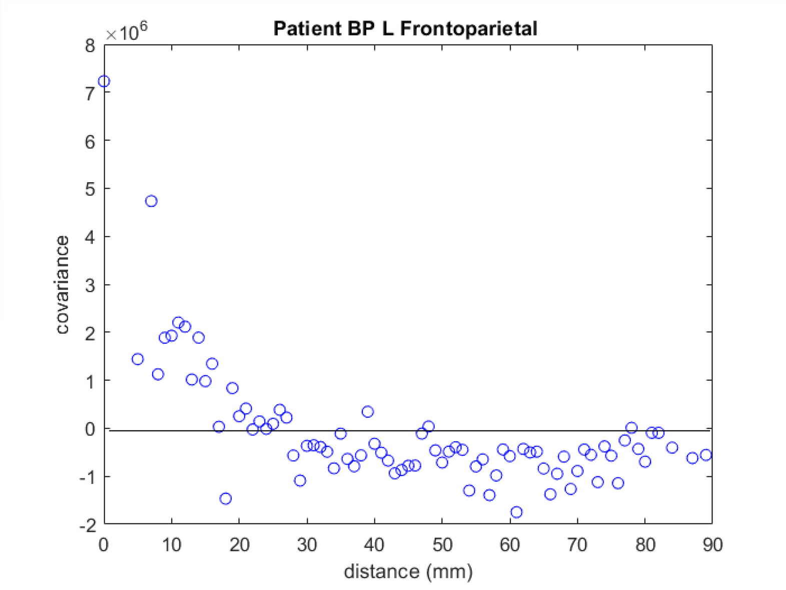

Figure Two: Correlation using common average reference for patient BP in the left frontotemporal region.

Correlations are expected to be positive since all the data was collected on gyri. Correlations are expected to be negative when neurons face opposing directions, which occurs in sulci.

Next, a Laplacian filter was tried; however, this produced many negative correlations.

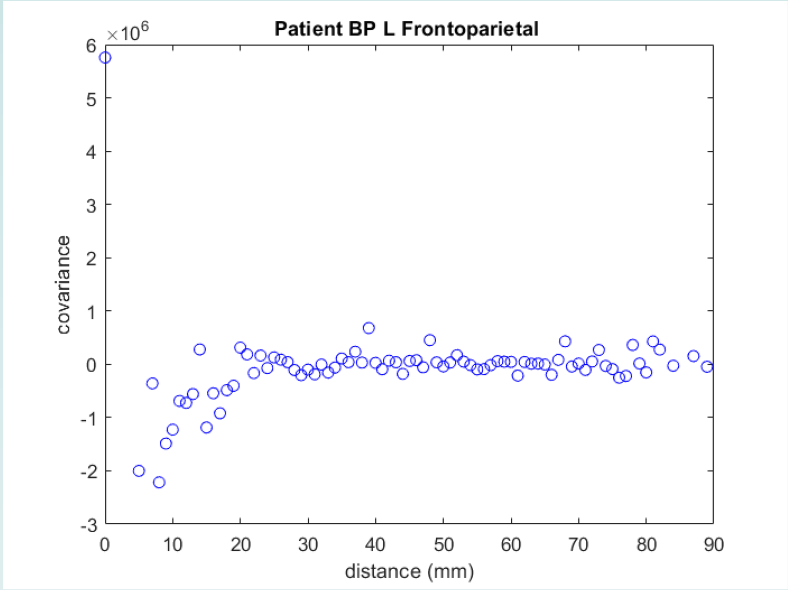

Figure Three: Correlation using a Laplacian filter for patient BP in the left frontotemporal region.

After proving this is a result of the Laplacian filter, spatial filtering was conducted using a corner reference electrode, depicted below. *

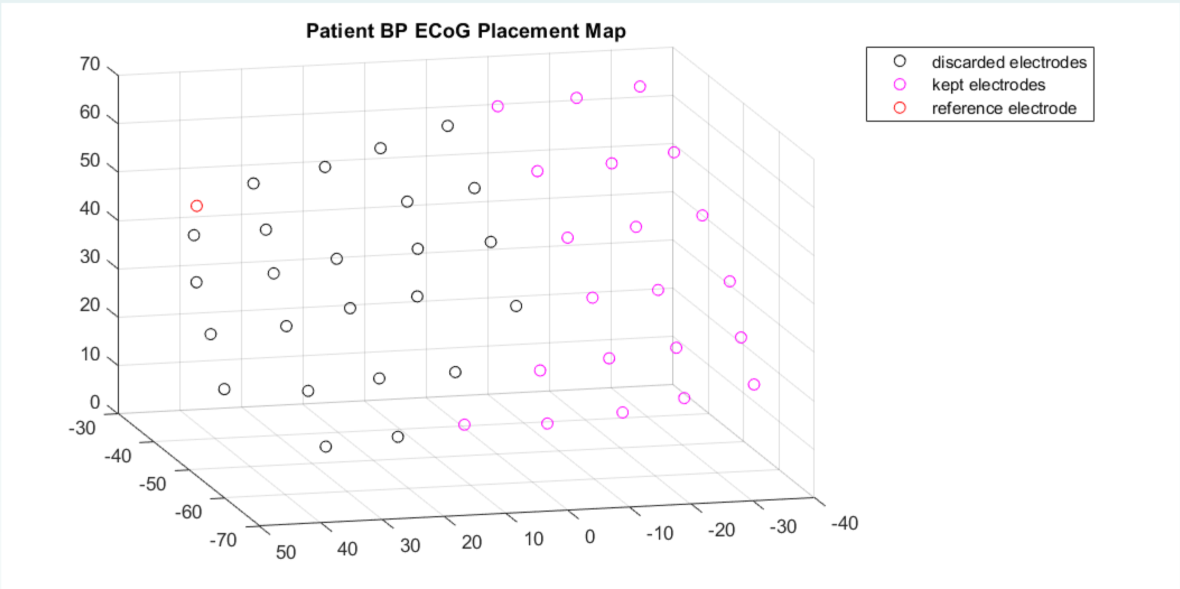

Figure Four: Map of electrodes on BP's left frontotemporal region. The red electrode is used as a reference and electrodes 50 mm or greater away from the reference electrode were used to calculate correlations.

The correlation levels off at a positive value, which is indicative of the baseline activity in this region.*

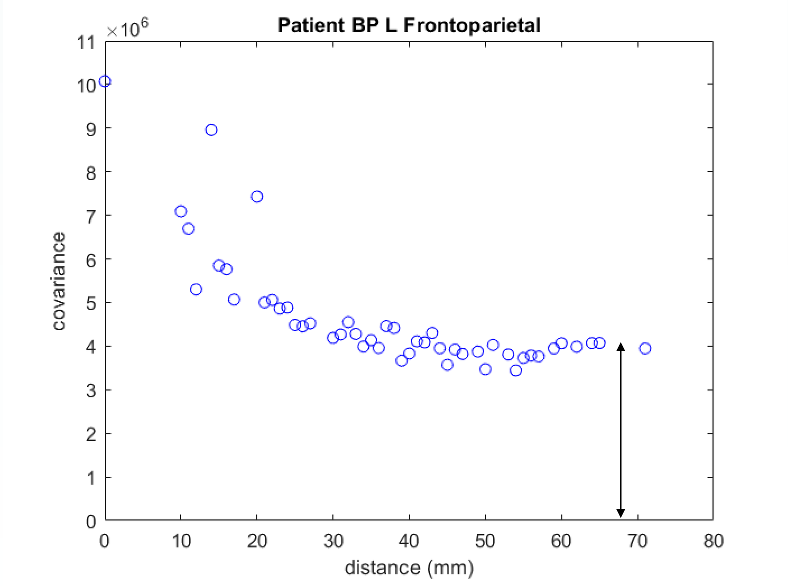

Figure Five: Correlation using a corner reference electrode for patient BP in the left frontotemporal region.

An evaluation of baseline activity was evaluated as the average activity in the last quarter of the data points. This baseline was subtracted from each data point. For patient BP, the baseline is 1.8545e6.

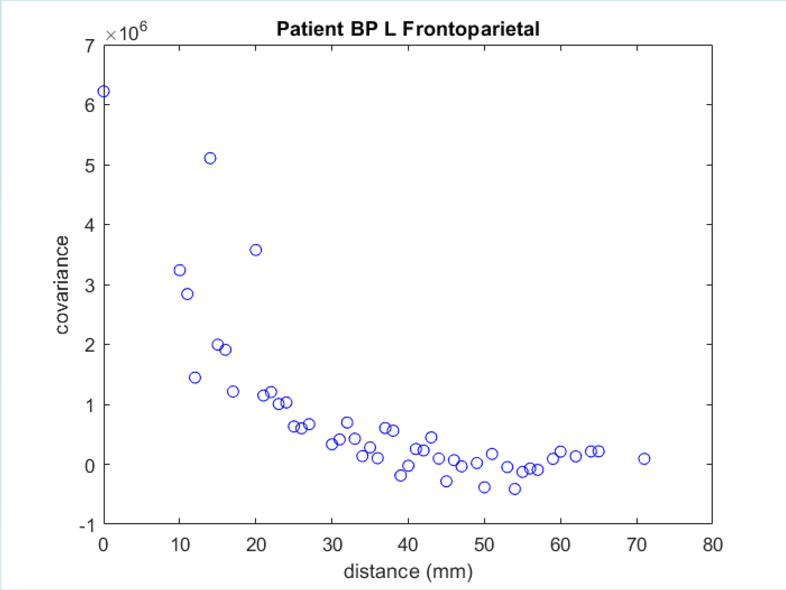

Figure Six: Correlation using a corner reference electrode for patient BP in the left frontotemporal region.

Utilizing corner reference electrode is the most effective spatial filter for analyzing this ECoG data.

*Proofs available upon request

Next Steps

- Determine if the correlation follows exponential decay by analyzing the semi-log plot.
- Filter the noise out of the data
- Map the correlations across brain regions
- Test the impact of the baseline of spatial correlates on improving silence localization techniques.
- Apply the same procedure to assessing auto-correlation. This provides correlation information across both space and time. This is likely to be the most effective method for improving silence localization.

Acknowledgments

I'd like to thank Manuel Alvarez Rios, a fellow intern for our mentors through uPNC. I'd also like to thank Dr. Nakahira for her mentorship alongside Dr. Grover.

Citations

[1] Chamanzar, Alireza & Grover, Pulkit. (2019). Silence Localization. 1155-1158. 10.1109/NER.2019.8717188.

[2] Chamanzar, Alireza, et al. "An Algorithm for Automated, Noninvasive Detection of Cortical Spreading Depolarizations Based on EEG Simulations." *IEEE Transactions on Bio-Medical Engineering*, U.S. National Library of Medicine, 24 Aug. 2018, www.ncbi.nlm.nih.gov/pmc/articles/PMC7045617/.