Computational Neuroscience: Analyzing Human Beta Oscillations from ECoG Data

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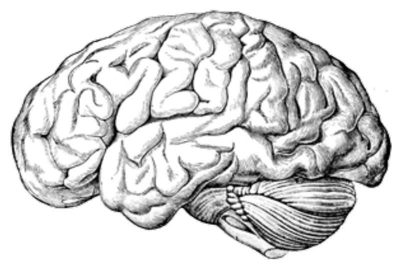

Introduction

What Are Beta Oscillations?

Beta oscillations are neural rhythms in the range of **15-29 Hz** that are powerful indicators of **motor** and **sensory** performance.

Why Are Beta Oscillations Important?

Beta oscillations are thought to play an important role in the way the brain functions. They also have implications in neurological disorders, such as **Parkinson's Disease**. Those afflicted with the disease experience disruption to beta oscillation. Treatment for the disease also reverses the disruption to beta oscillation.

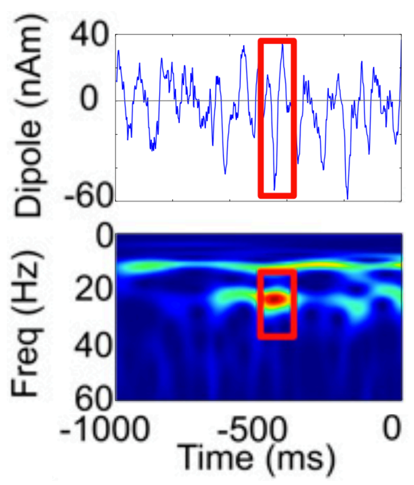

Figure 1. A beta event (highlighted in red) in the primary somatosensory cortex, measured with MEG. (Sherman et al. PNAS 2016)

Essential to understanding the role of beta in healthy or abnormal sensorimotor processing is to understand its **signature of activity and mechanisms of generation**.

Do Beta Oscillations Differ Across Recording Modalities?

Previous research indicates that spontaneous beta oscillations from the somatosensory cortex measured with **Magnetoencephalography** (MEG) and **electroencephalography** (EEG) in humans and with **local field potential** (LFP) in animals emerge as transient events lasting ~150ms, with a stereotypical waveform containing a **sharp deflection** lasting 50ms. Computational neural modeling showed these events could arise from a specific pattern of **synaptic drive** to the **neocortex** (Sherman et al. PNAS 2016).

The question we address is if these beta features are **generalizable** to beta oscillations measured intracranially with **ECoG** in **Essential Tremor** patients.

Methods to Record Beta at Different Spatial Scales

EEG and MEG are two common ways to **non-invasively** record brain activity. LFP is an **invasive** method of measuring brain activity and requires insertion of electrodes.

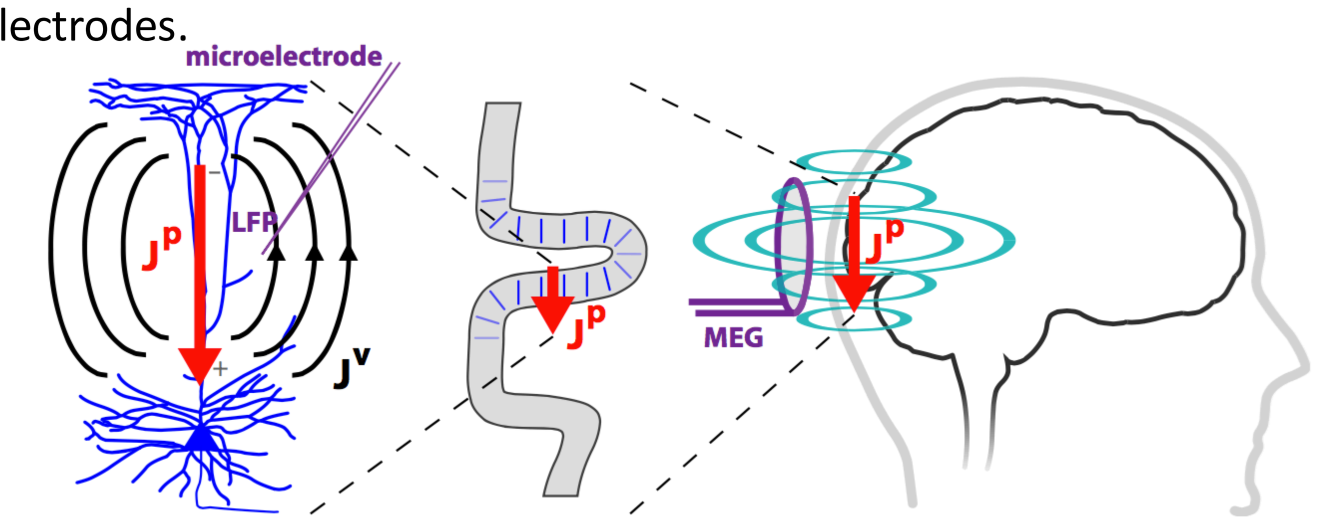

Figure 2. These diagrams show how the sources of electrical current (J^P) in pyramidal neurons are identified via MEG and LFP. (Sherman et al. PNAS 2016)

Electrocorticography (ECoG) is a method very similar to EEG in the way it measures brain activity with electrodes, but it requires an **invasive** procedure because the electrodes are placed directly on the cortex. This decreases the likelihood of the signal being lost in background noise.

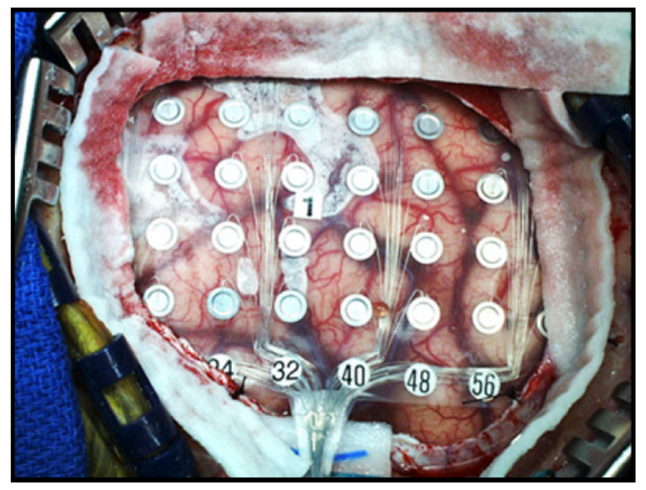

Figure 3. An ECoG strip in use. (AnalyzeDirect.com)

Spectral Analysis Methods

I have written **Python** scripts to study beta rhythms in ECoG signals that apply several different analysis methods to compute the frequency components of the signal.

Fourier Transform (FT)

We use discrete Fourier transforms to see the underlying frequencies in a signal. This method doesn't show the evolution of underlying frequencies, but is very robust despite the presence of noise.

$$F_n = \sum_{k=0}^{N-1} f_k e^{-2\pi i\, n\, k/N}$$

Equation 1. The equation for a discrete Fourier transform.

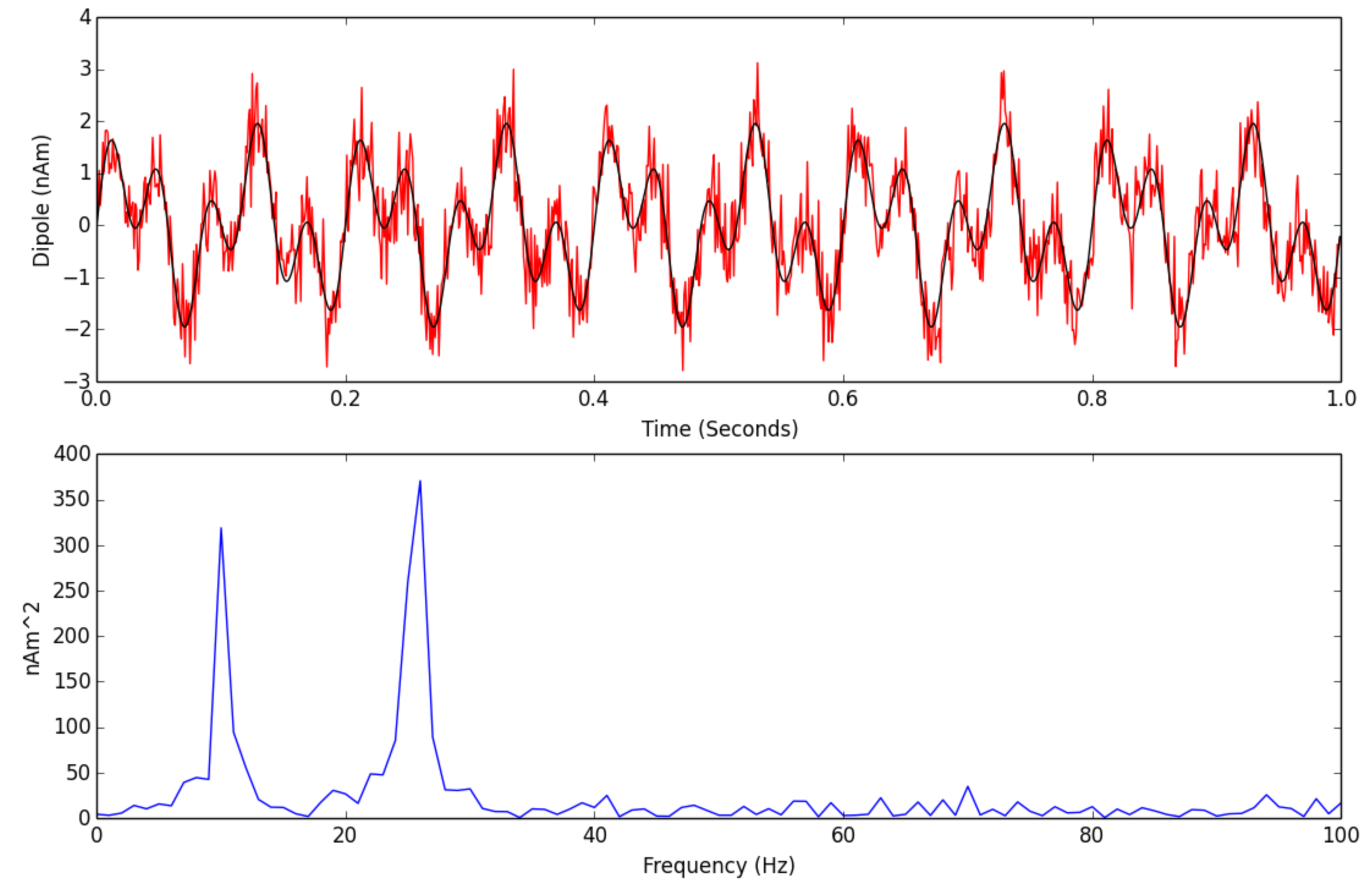

Figure 4. Top: A sinusoidal time series with 10 and 25 Hz components with noise sampled from a normal distribution (μ = 0 and σ = 0.5). **Bottom:** Discrete Fourier transform with two distinct peaks at 10 and 25 Hz, indicating the underlying frequencies.

Wavelet Transforms and Spectrograms

While it is valuable to know which frequencies are occurring throughout the time series, it is vital that we are able to identify **transient oscillations**. This necessitates adding the dimension of time to our analysis.

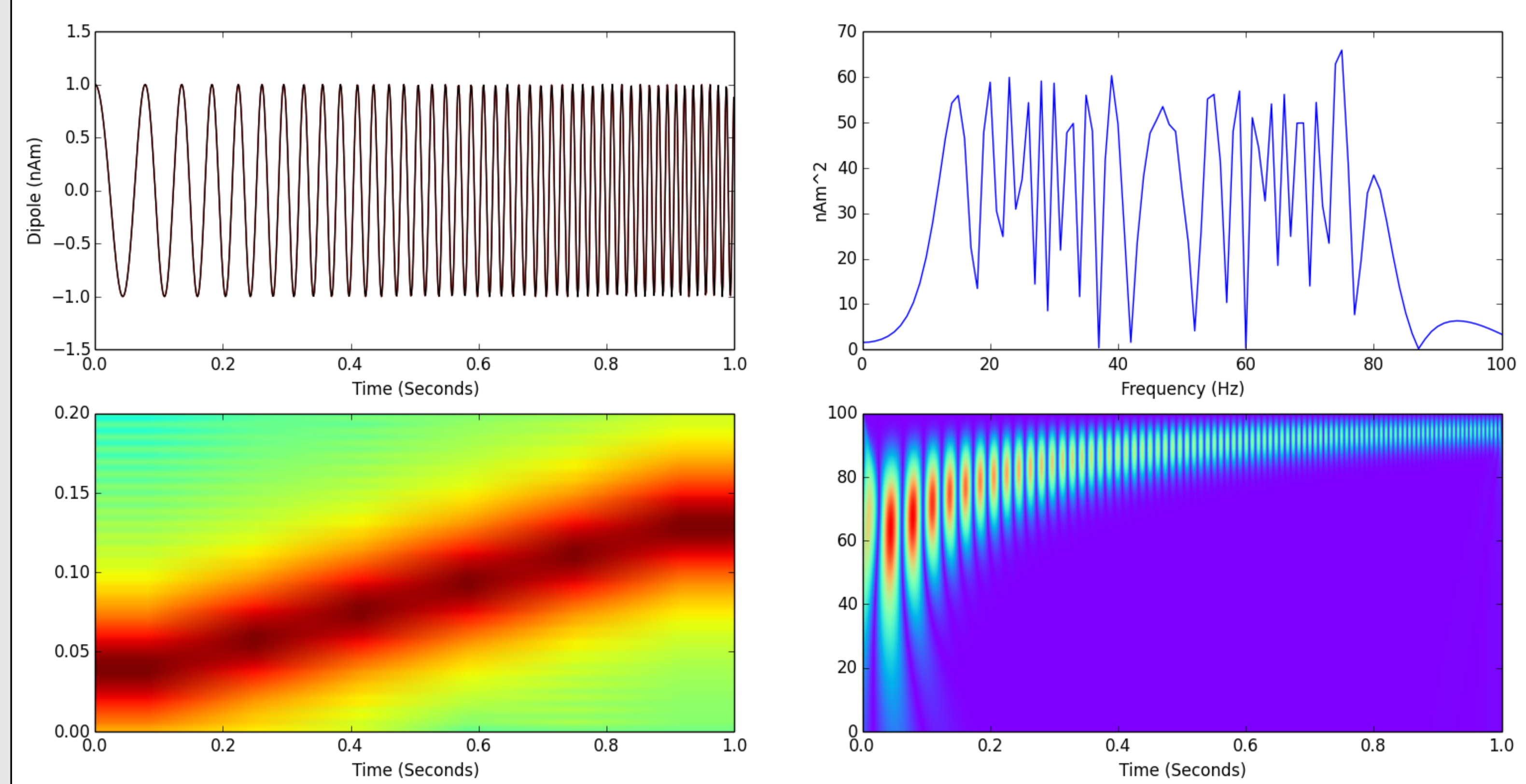

Figure 5. Top-left: A chirp with an initial frequency of 10 Hz and a final frequency of 80 Hz. **Top-right:** The discrete Fourier transform is unable to show the evolution of the frequency. **Bottom-left:** Built-in spectrogram function in Python's matplotlib package showing the increase in frequency. **Bottom-right:** Continuous wavelet transform of the signal, indicating an increasing frequency.

Beta Events in ECoG Signals are Transient

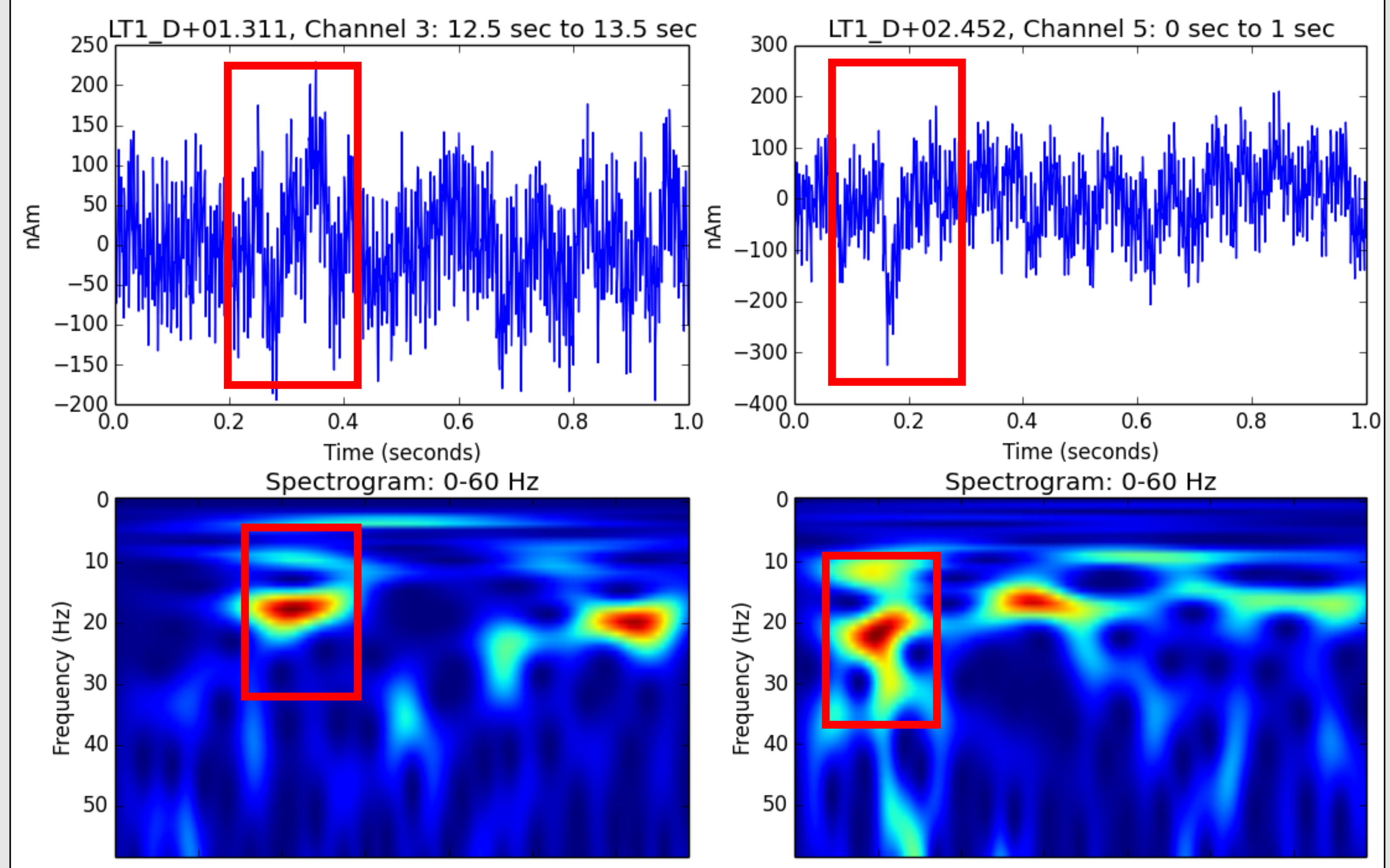

Figure 6. Top: ECoG reading presumably from sensorimotor and frontal cortex of an Essential Tremor patient. **Bottom:** Spectograms calculated using a 7 cycle Morlet Wavelet. Beta events are highlighted in red, each lasting approximately 150ms. The 20 Hz signature is not due to a full oscillation that lasted 50ms, but instead due to sharp transient event that lasted 50ms.

Conclusion

- The beta events occur in the ECoG data, appearing **transient**ly for ~150ms in **unaveraged signals.**
- Some beta events were characterized by a **sharp deflection** in the ECoG recording whose duration was ~50ms.
- Both observations are similar to the **MEG and LFP analysis** in Sherman et al. PNAS 2016**,** suggesting the beta events in the ECoG signal are generated by **similar processes.**

Next steps:

a. Quantify features of the ECoG beta events to determine if they have a **characteristic waveform.**

b. Apply computational neural model to **delineate mechanisms** of beta events in ECoG data.

c. Investigate **median nerve evoked responses** and **compare across modalities** (MEG/EEG/ECoG).

d. Compare signals in **health and diseased** subjects**.**

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