Deep brain stimulation changes the shape of motor cortical beta oscillations

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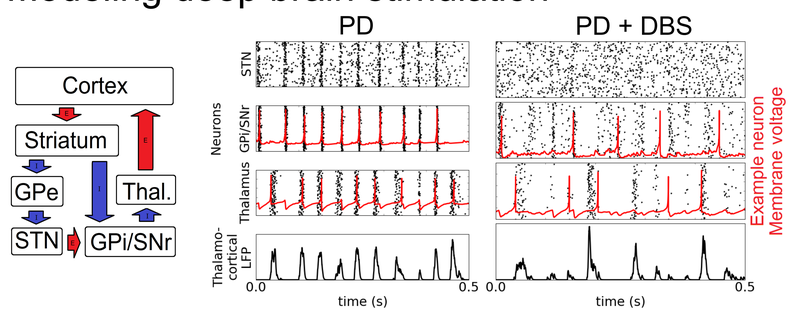
Introduction

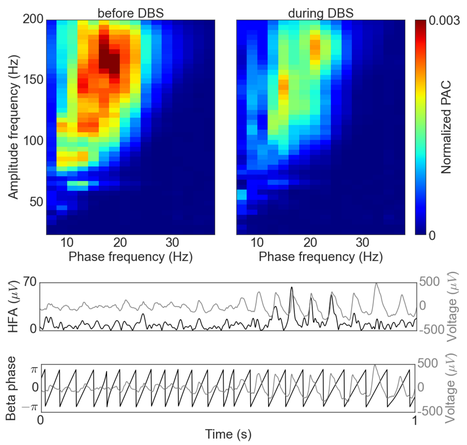
* Parkinson's Disease (PD) is associated with increased power and interregional synchrony of beta oscillations (13-30Hz)
* Deep brain stimulation (DBS) of the subthalamic nucleus (STN) is an effective treatment for PD, though its mechanism is still largely unknown
* DBS has been shown to affect neuronal spiking statistics and oscillations in the basal ganglia-cortical loop, but the link between these two effects is unclear.
* We observe a DBS-induced change in the shape of beta oscillations in primary motor cortex (M1) ECoG recordings (N=23), which is consistent with a model of DBS decorrelating STN spiking.

Modeling deep brain stimulation



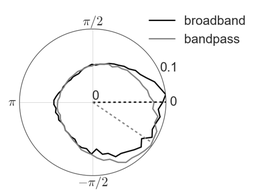
DBS is hypothesized to decorrelate spiking in the STN. In a basal ganglia model, this results in less beta in thalamocortical synaptic activity.

Beta phase-high frequency amplitude coupling



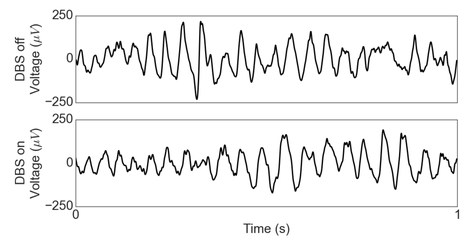
[1]de Hemptinne et al, 2015, Nature neuroscience.

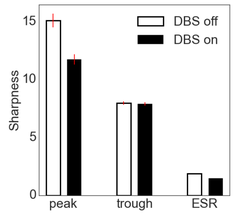
Phase-amplitude coupling (PAC) between the phase of beta (13-30Hz) oscillations and high frequency amplitude (HFA, 80-200Hz) is decreased with DBS.[1] Subject 1 shown.



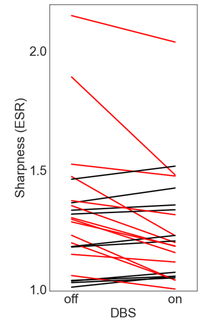
Phase calculation method has a significant impact on the preferred phase estimate. Subject 1 shown.

DBS flattens oscillatory extrema



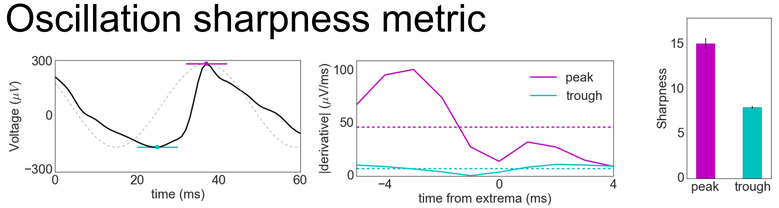


In subject 1, DBS application decreases sharpness of beta oscillation peaks, thus decreasing the extrema sharpness ratio (ESR).



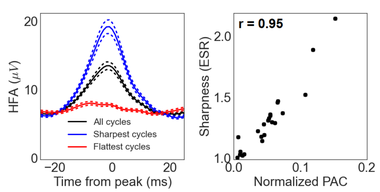
Application of DBS decreases the sharpness of beta oscillations (N=23, p=0.01).

Oscillation sharpness metric

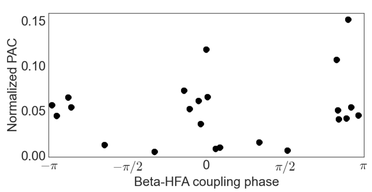


The sharpness of an individual oscillatory extrema is estimated with the first derivative of the voltage around the extrema. The average magnitude of the first derivative (dotted line) is the value of sharpness for a single oscillation. The average sharpness of peaks and troughs for subject 1 is shown on the right.

Sharp extrema ➟ Phase-amplitude coupling

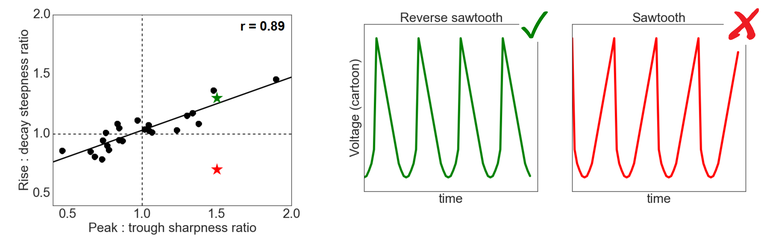


High frequency amplitude (HFA) peaks are time-locked to sharp extrema (subject 1 shown). Across subjects, extrema sharpness ratio (ESR) is highly correlated with PAC.



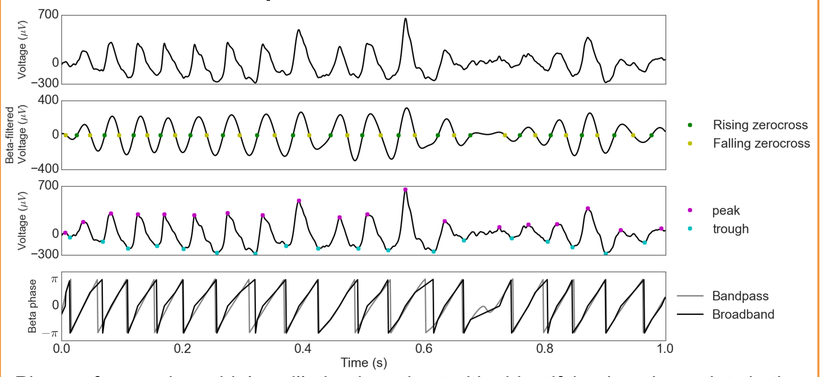
In subjects with high PAC, coupling phase is clustered around extrema p=0.009).
Peak: phase = 0; Trough: phase = pi

Beta oscillation shape



Subjects with steeper voltage rises have sharper peaks. Therefore, pathological beta oscillations in M1 are shaped like a reverse-sawtooth wave (green) when referenced so that the peak is set as the peak is the more sharp extrema.

Instantaneous phase estimate



Phase of a nonsinusoidal oscillation is estimated by identifying key timepoints in the cycle (zero-crossings, maxima, and minima) and interpolating phase over time.

Summary

* Our hypothesized DBS mechanism predicts the observed decrease in M1 beta oscillation sharpness and phase-amplitude coupling
* Oscillation sharpness may be an indicator of more synchronous/bursty neural activity
* Waveform phase estimates are important when analyzing nonsinusoidal oscillations
* Parametric effects of DBS on electrophysiology were not found to correlate with changes in clinical measures of behavior

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