The nonsinusoidal features of neural oscillation waveforms contain physiological information

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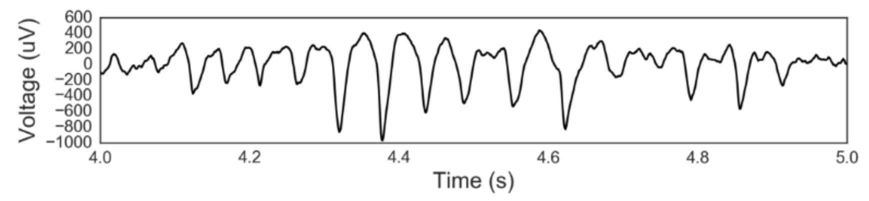
Background

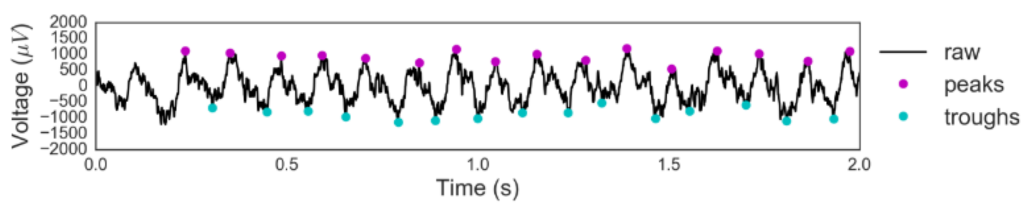
* Electrocardiogram analysis focused on temporal dynamics in the PQRST waveform to understand cardiac physiology.
* Neural oscillations are typically analyzed using spectral methods that quantify frequency, phase, and amplitude.
* These methods utilize a sinusoidal basis, while many neural oscillations are not sinusoidal
* Recent work has begun to account for waveform properties, like sharp extrema, that affect the results of spectral analyses.
* Some studies have characterized the shapes of waveforms.
    * Hippocampal theta oscillations are more rise-decay asymmetric during successful memory encoding (Trimper et al. 2014) and running behavior (Buzsaki et al. 1985)

Examples of nonsinusoidal waveforms

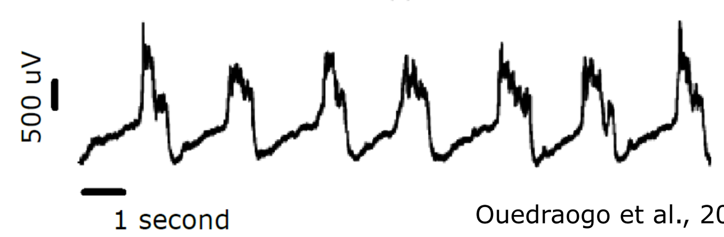
* Motor cortical beta



* Mu rhythm
* Hippocampal theta



* Visual alpha?
* Sleep slow oscillations

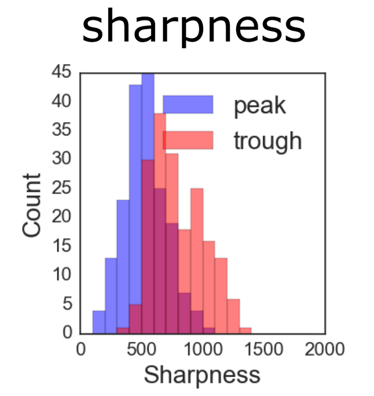


Ouedraogo et al., 2016, eNeuro

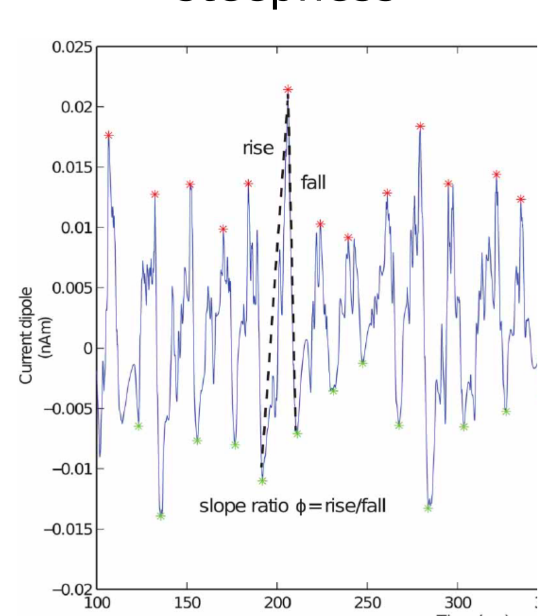
Waveform measures

While Fourier-based spectral analysis is well established, the methodology to analyze temporal features of rhythmic activity is still developing. Current methods have focused on asymmetries in the oscillation as well as the sharpness of oscillatory extrema.

Peak and trough sharpness

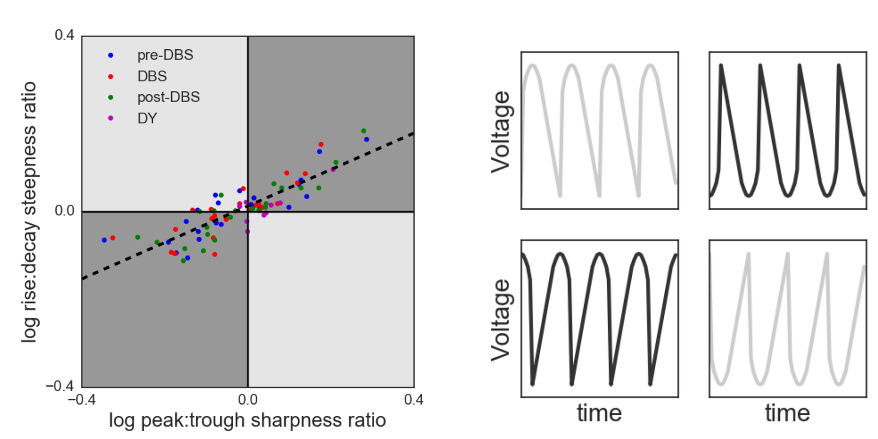


Rise and decay steepness



Lee & Jones, 2013, Front. Hum. Neuro

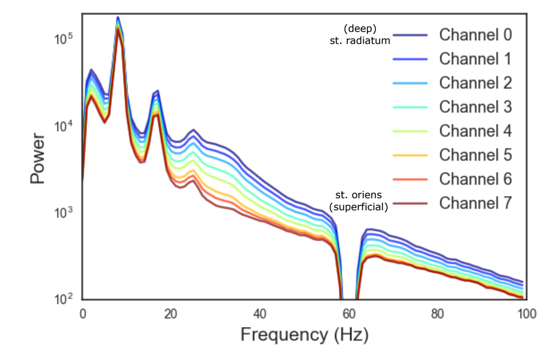
Sawtooth properties



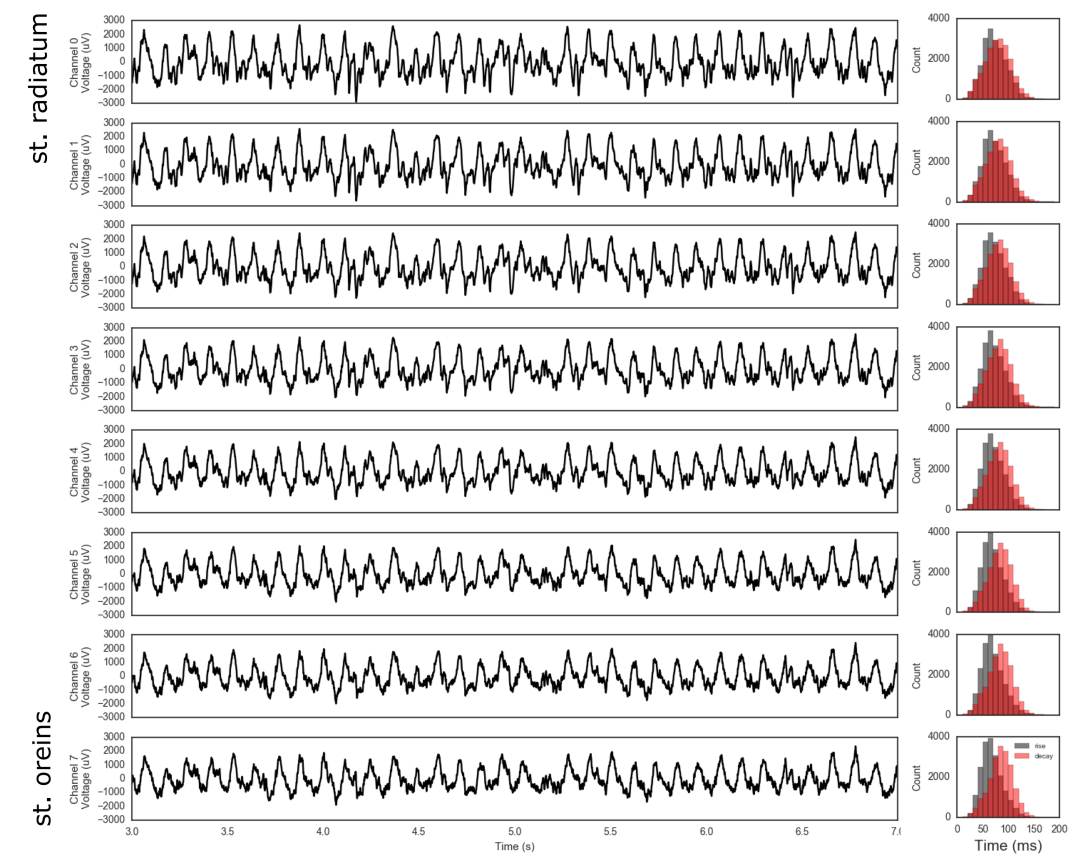
Tools for oscillatory analysis are publicly available at:
voytekresearch/misshapen

Hippocampal CA1 theta oscillation waveform

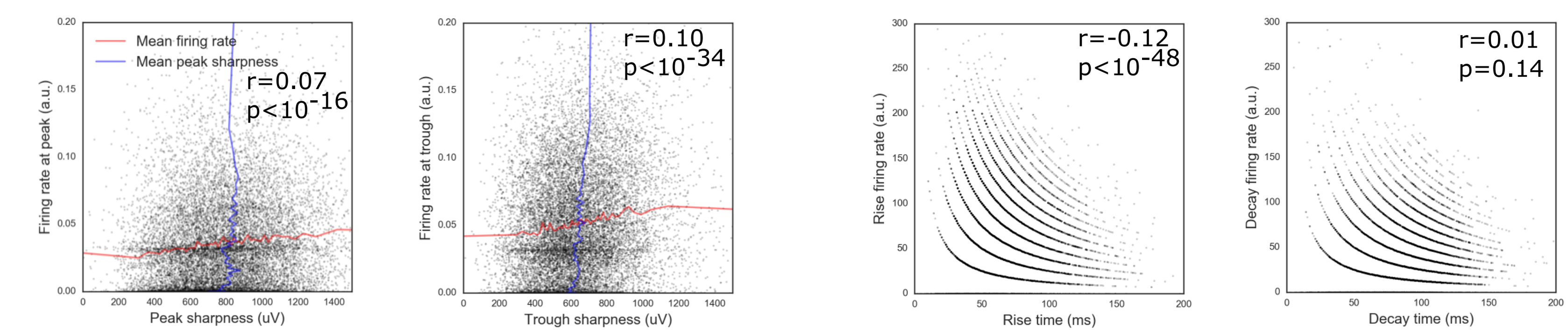
Theta oscillations are more rise-decay asymmetric in stratum oriens of rat CA1 relative to stratum radiatum.



Increased firing of CA1 pyramidal neurons is correlated with: 1) shorter rises, and 2) sharper peaks and troughs in stratum oriens.

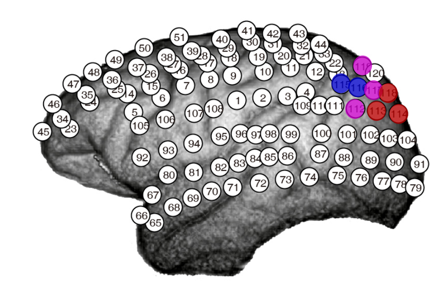


data source: Mizuseki et al. 2009. CRCNS (hc2)



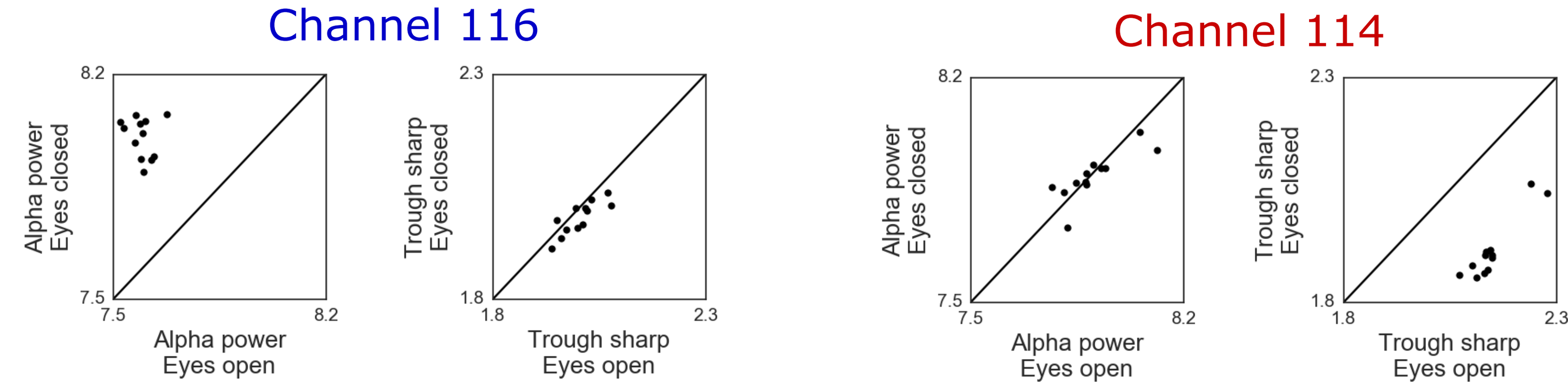
Visual alpha oscillation waveform

Alpha oscillations recorded from the visual cortex in human EEG robustly increase in power when subjects close their eyes. In alpha activity recorded with invasive ECoG electrodes in monkey, this held true for only some visual electrodes. However, in other nearby electrodes, sharpness of the alpha oscillation troughs was predictive instead.



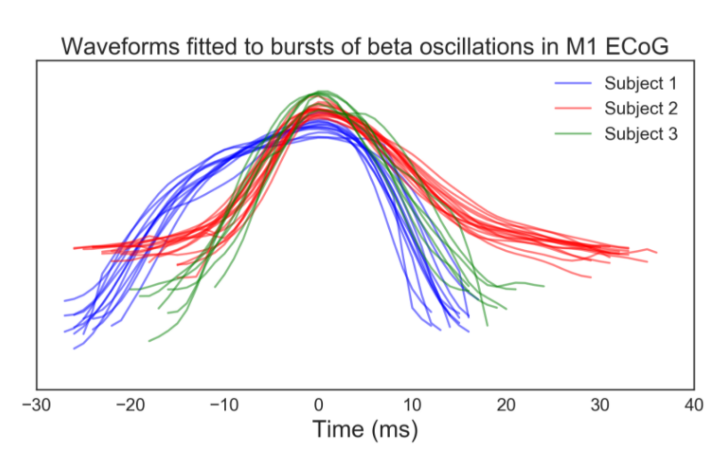
data source: Neurotycho.org (sleep and anesthesia task)

Channel 116 | Channel 114



Waveform fitting

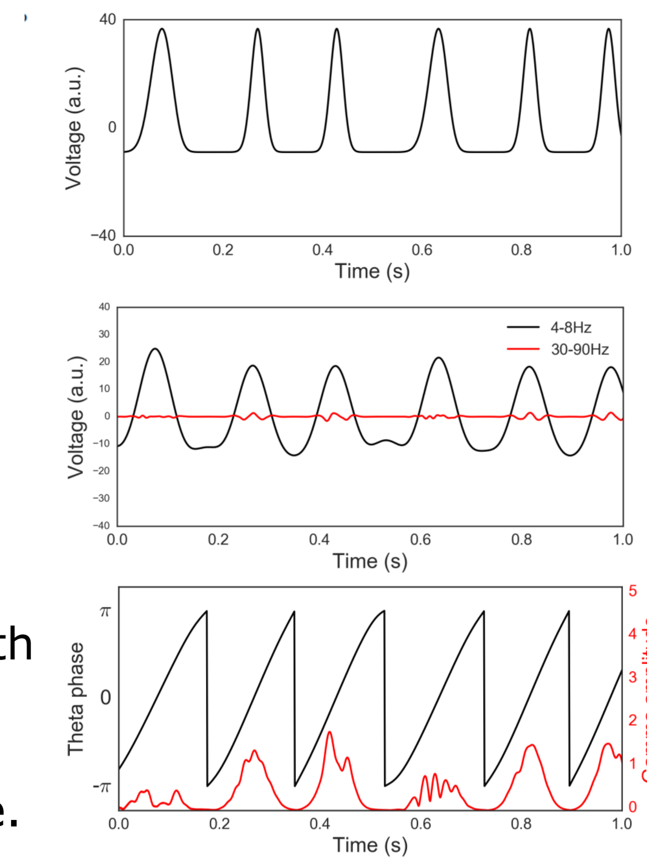
Qualitative comparison of oscillation waveform shapes can be accomplished by fitting a waveform to the data. On the right, we fit a waveform to beta oscillatory bursts in 3 subjects (ECoG, primary motor cortex). Each trace is the waveform of one burst. Subjects cluster.



Nonsinusoidal phase and amplitude

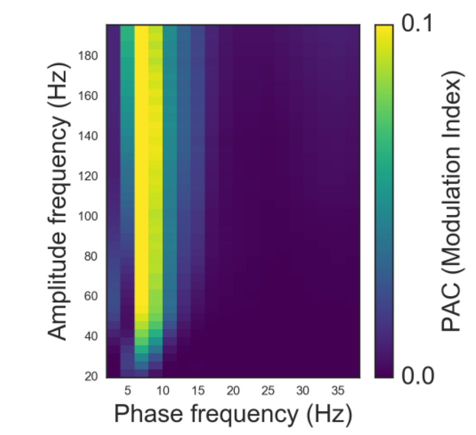
The phase and amplitude estimates of a nonsinusoidal waveform (top) can be misleading. Narrowband filter application dramatically changes the temporal dynamics of the oscillation of interest (middle, black).

The phase estimate shows a smooth transition through the cycle, which is not consistent with the raw waveform (elongated troughs). Sharp peaks cause an increase in broadband amplitude.

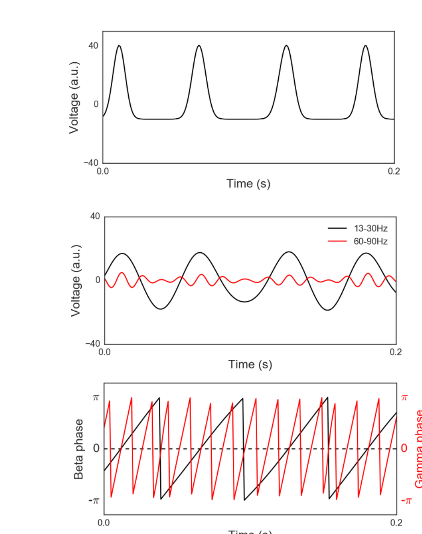


Spurious cross-frequency coupling

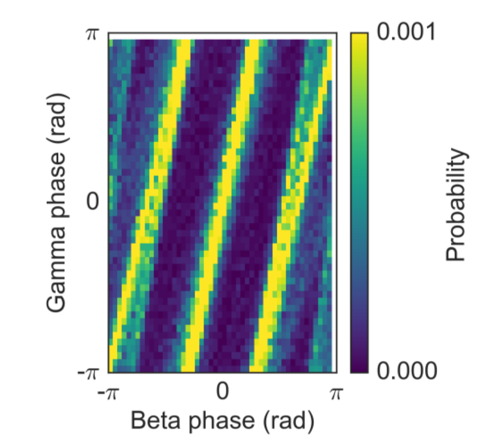
Recent reports showed that nonsinusoidal oscillations produce spurious phase-amplitude coupling (Lozano-Soldevilla et al., 2016 and Gerber et al., 2016) and phase-phase coupling (Scheffer-Teixeira & Tort, 2016)



Broadband coupling may reflect nonsinusoidal features instead of ubiquitous coupling.



Concurrent modulation of both power and PAC may reflect nonsinusoidal waveforms.



Conclusions

* Recordings of neural oscillations informative useful features beyond those captured by phase, power, and frequency estimates
* Features of oscillatory waveforms can be characterized using measures of sharpness and symmetry
* These waveform features may correlate with behavior and physiology. Much future work to be done here.
* In the future, time series could be decomposed using a set of biophysically-inspired or data-driven basis functions instead of sinusoids

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