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Sydney Smith

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Voytek Lab, est. 2018

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VOYTEKlab

Cognitive Science

Eena Kosik



Quirine van Engen



Dillan Cellier

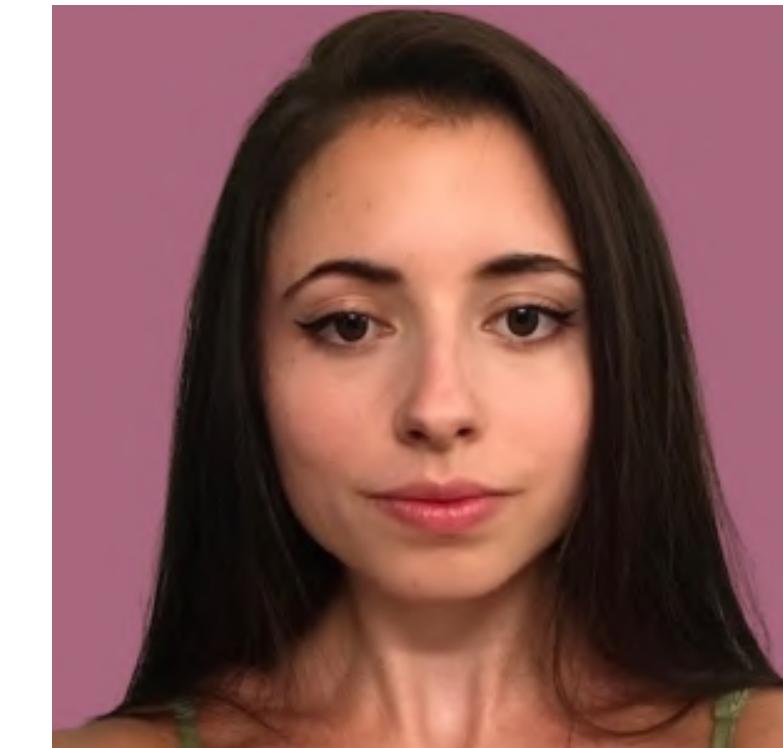


Neuroscience

Andrew Bender



Blanca Burgos-Martin



Morgan Fitzgerald



Postdocs

Pamela Riviere Ruiz



Christian Cazares

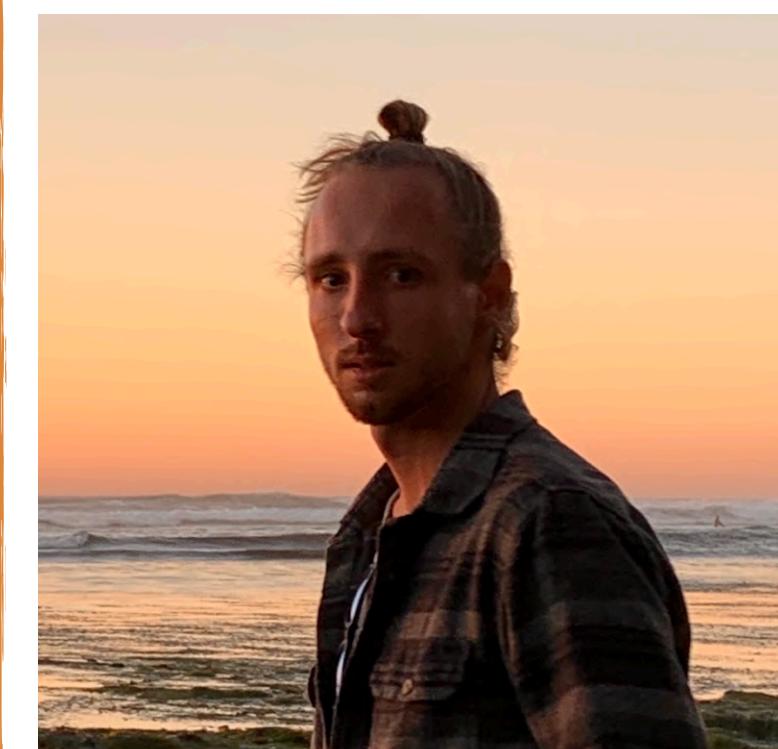


Data Science

Ryan Hammonds



Trevor McPherson



Michael (MJ) Preston



Sydney Smith



VOYTEKlab

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Eena Kosik



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Dillan Cellier

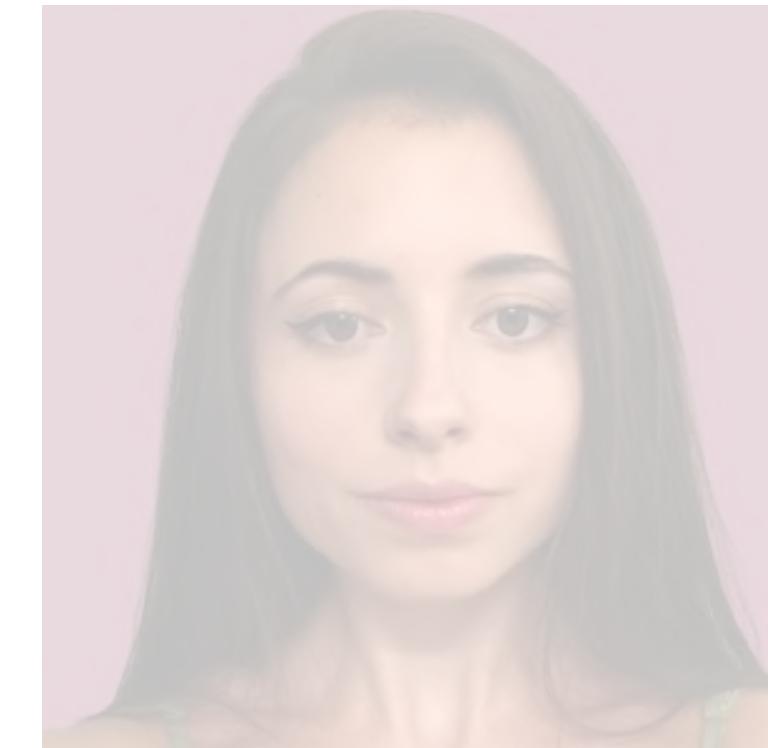


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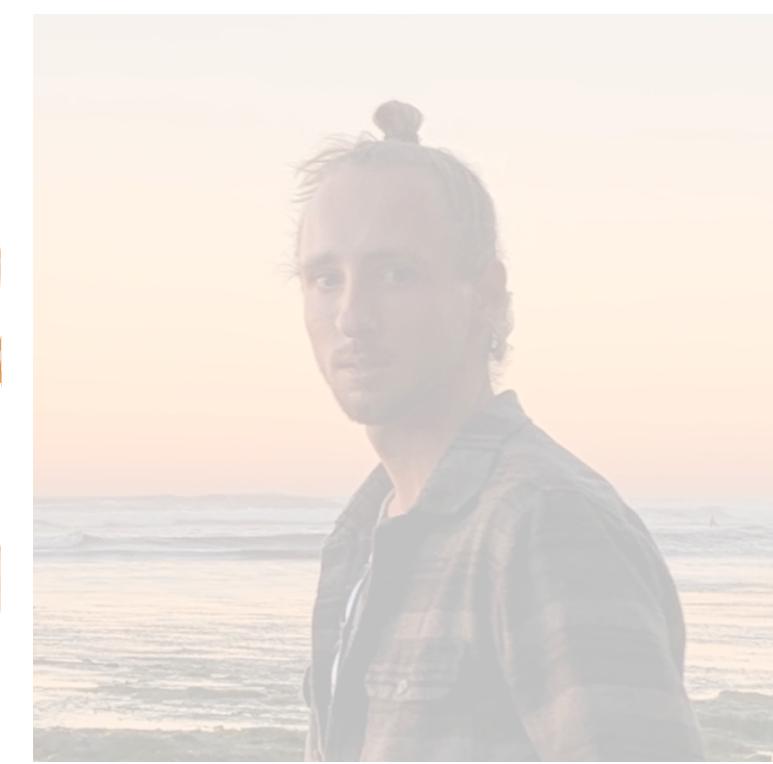


Data Science

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Sydney Smith



9:00a - 10:00a

Background presentation and Workshop overview, with Q&A

10:00a - 10:30a

Break and Python help (if needed)

10:30a - 12:00p

Digital Signal Processing (DSP) overview and introduction to simulating local field potential (LFP)/ EEG data

12:00p - 1:00p

Lunch break (on your own)

1:00p - 2:30p

Spectral Parameterization

2:30p - 3:00p

Coffee / brain break

3:00p - 4:30p

Cycle-by-cycle analysis of neural oscillations

We love brains.

We love oscillations.

What's the problem?

Oscillations are correlated with everything

Oscillations are correlated with everything

Tens-of-thousands of oscillation papers

What is a neural oscillation?

Outline

1. Oscillations: origin & measurement
2. Spectral Parameterization
3. Cycle-by-cycle waveform analysis
4. Waveform shape
 - Nonsinusoidal oscillations in development
 - Importance of waveform shape in the periphery
5. Aperiodic activity
 - Physiology & E/I balance
 - Dynamics & event-related changes
 - Cognitive applications
 - Clinical relevance

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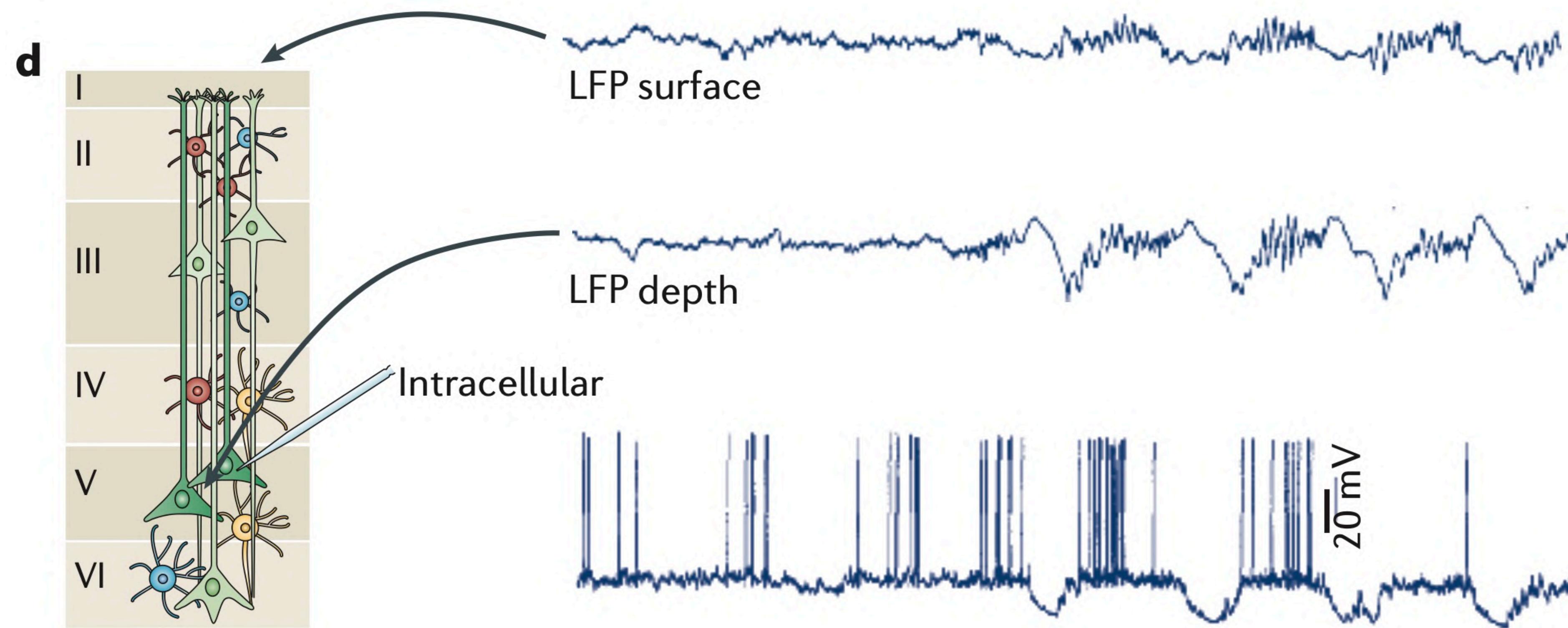
**We can't talk about oscillations
without understanding**

- 1. Where they come from**
- 2. How they're traditionally measured**

**We *really* care about definitions
and how we measure things.**

I. Where do oscillations *come from?*

Origin of LFP / EEG



Largely driven by synaptic + transmembrane currents

Cortical organoids

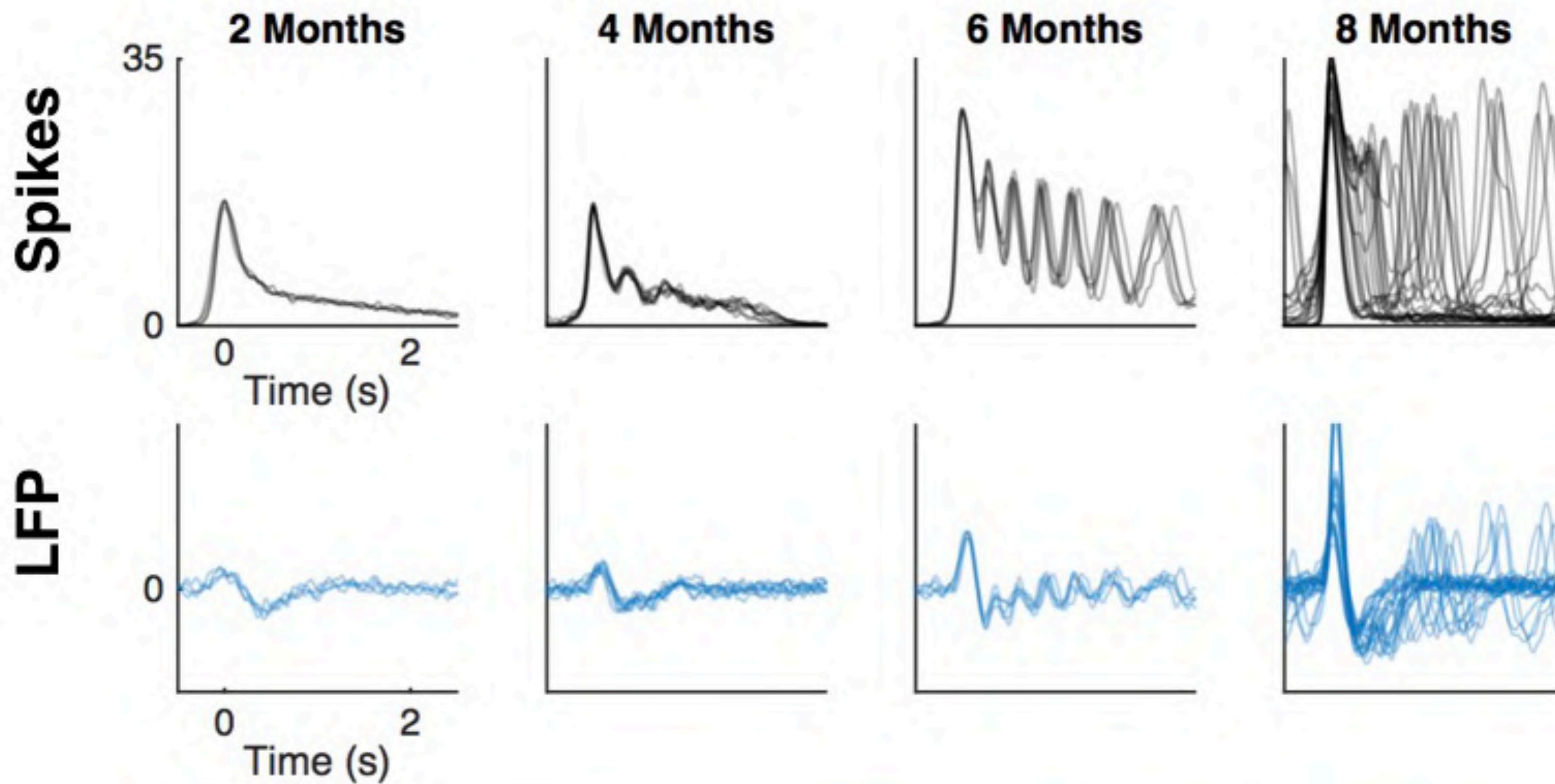


~ 4mm diameter
~ 100,000 neurons

Richard Gao

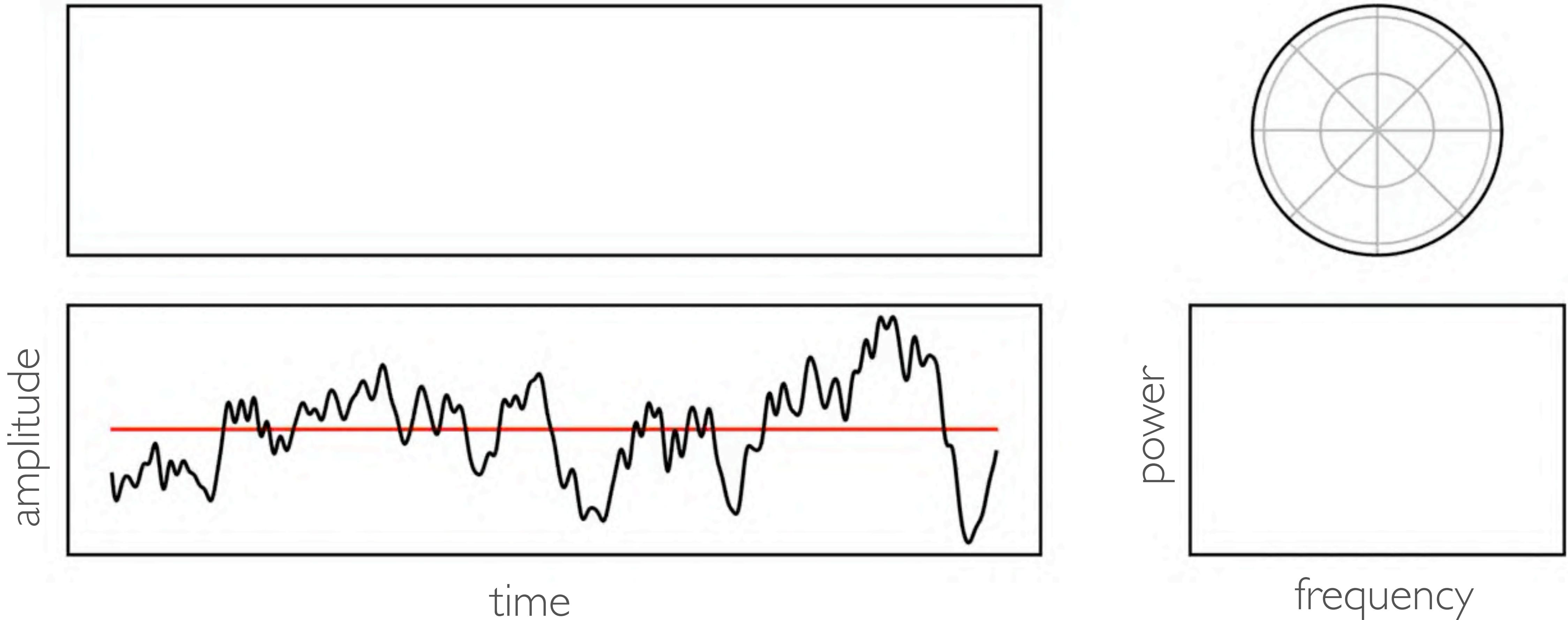


Origin of oscillations



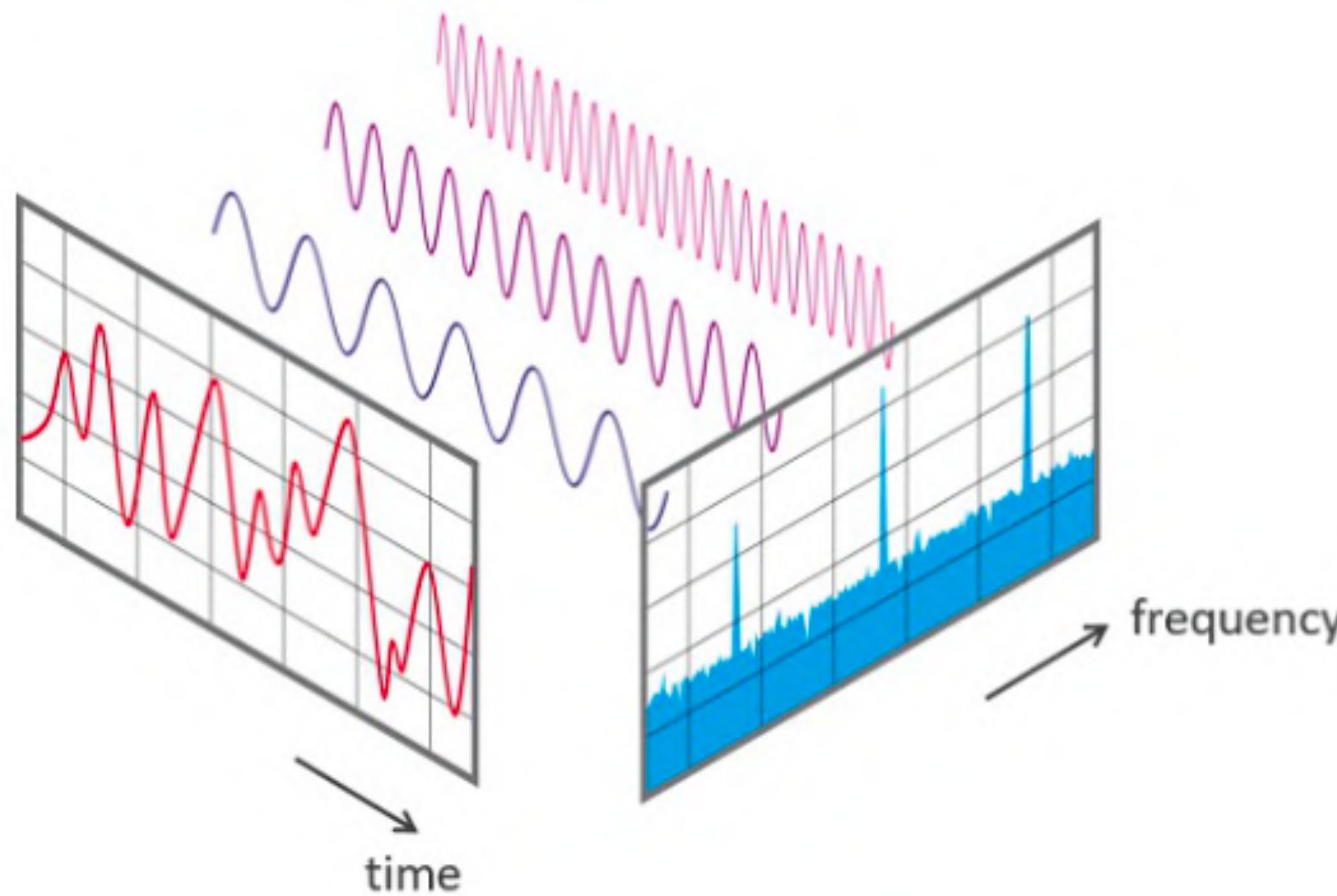
2. How are oscillations (traditionally) measured?

Measuring oscillations



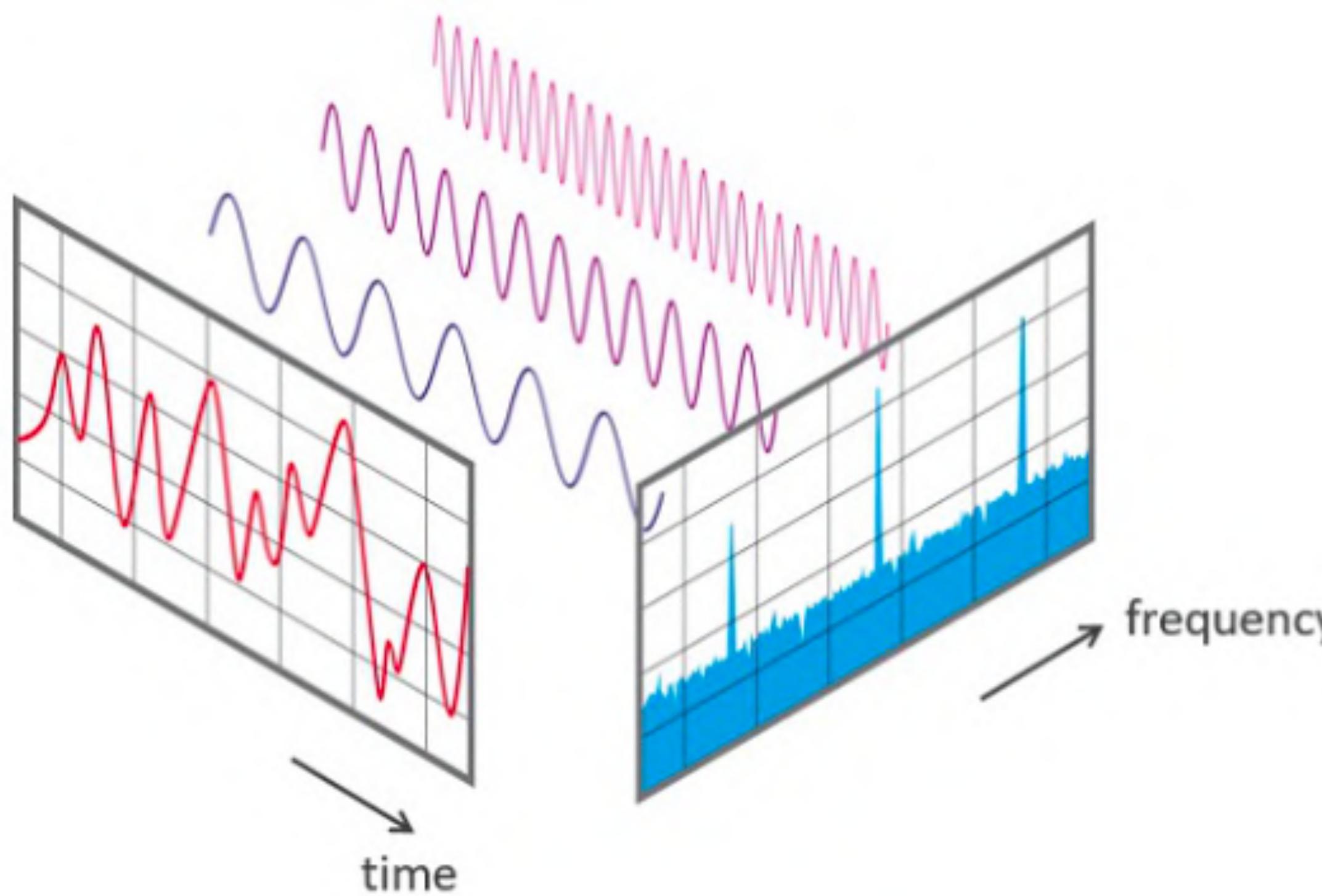
Detecting oscillations

FFT

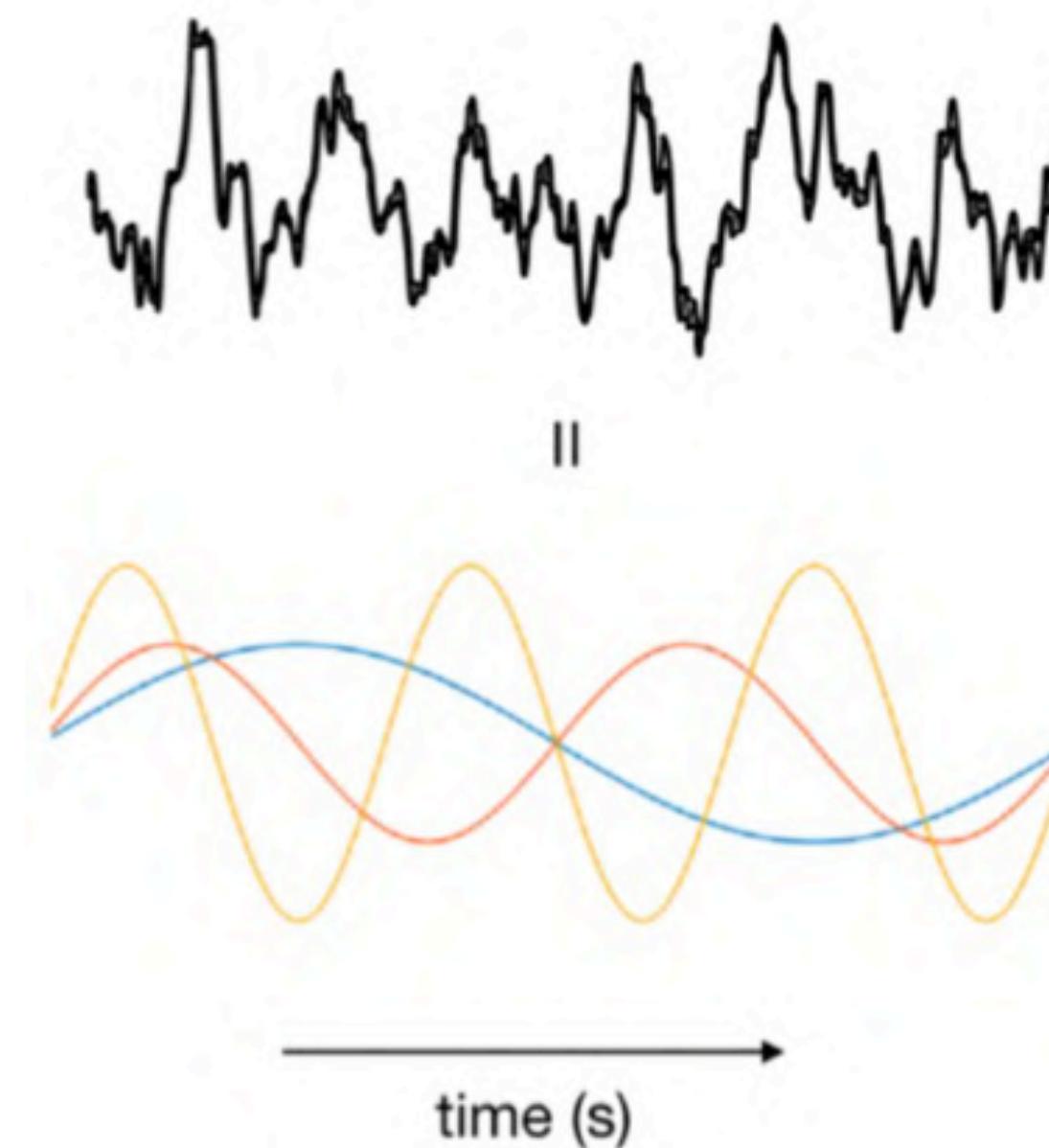


Detecting oscillations

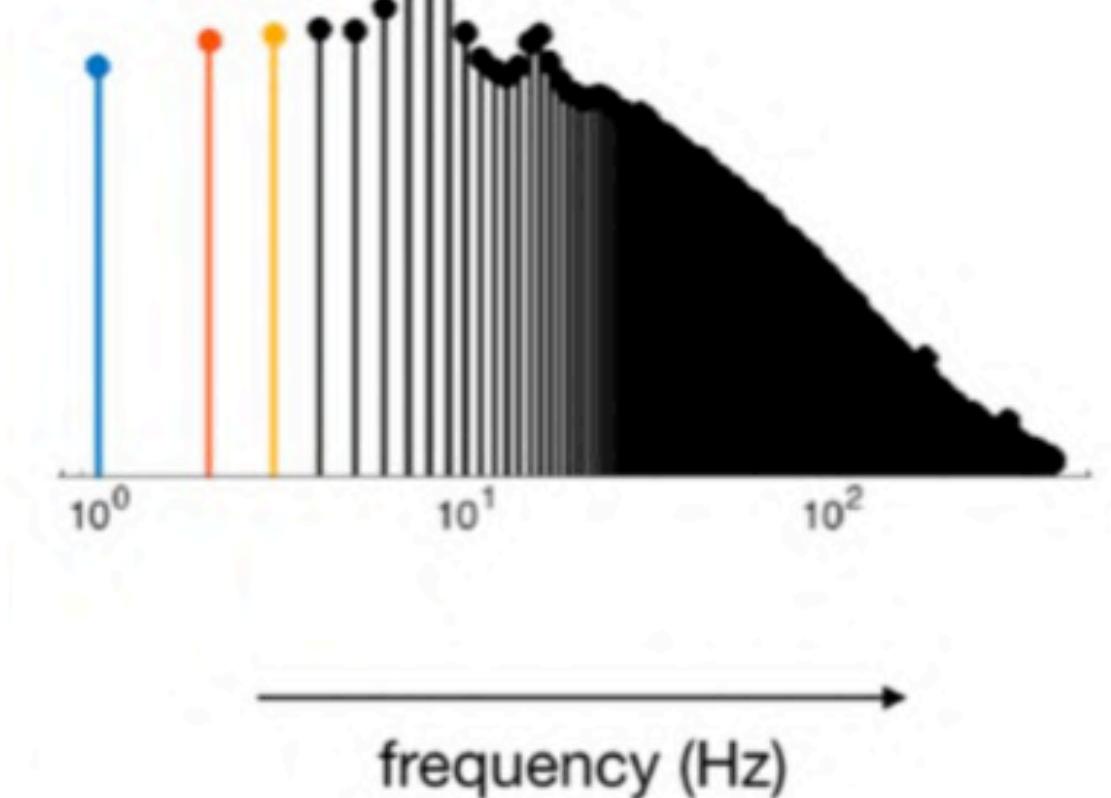
FFT



Time Domain

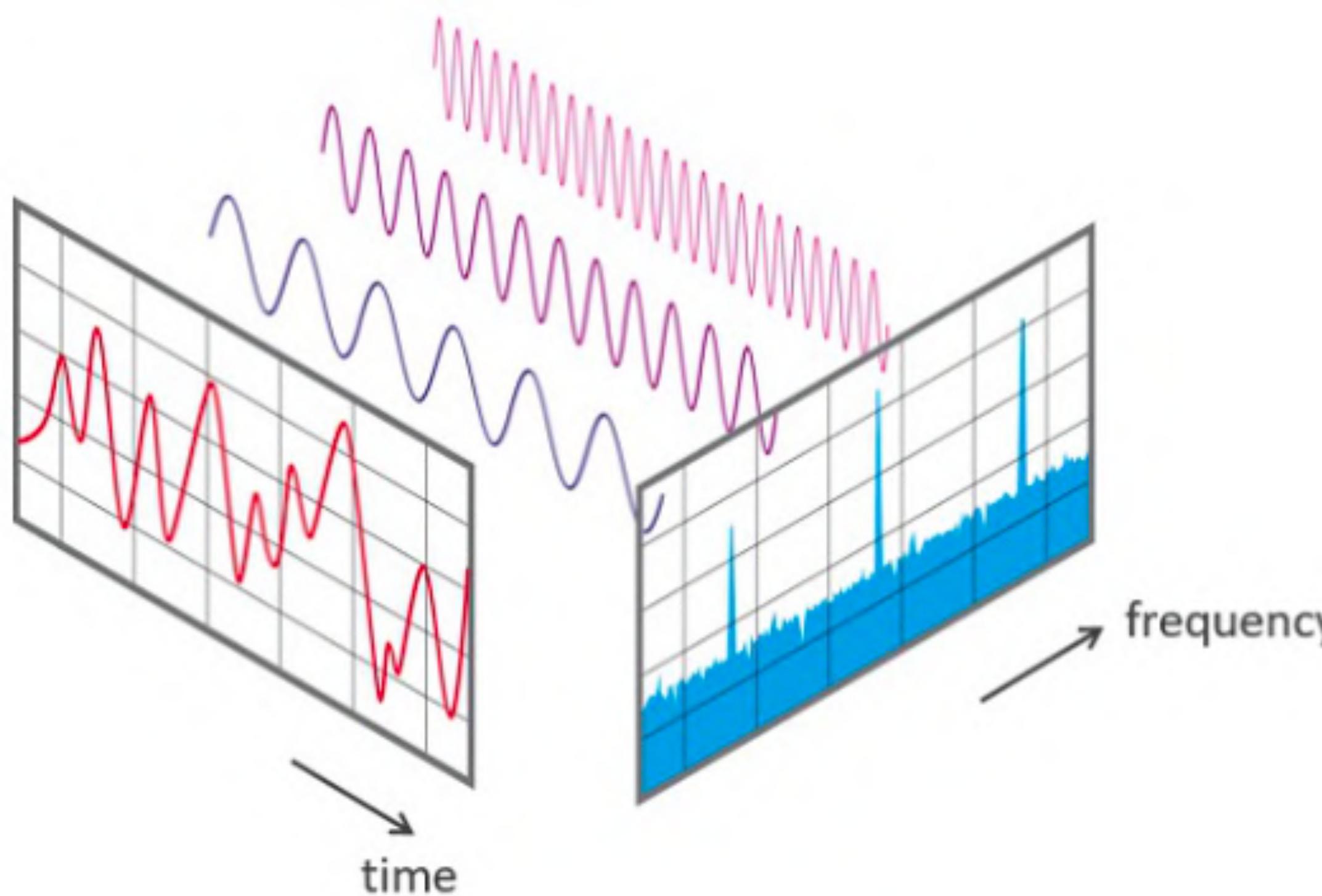


Frequency Domain

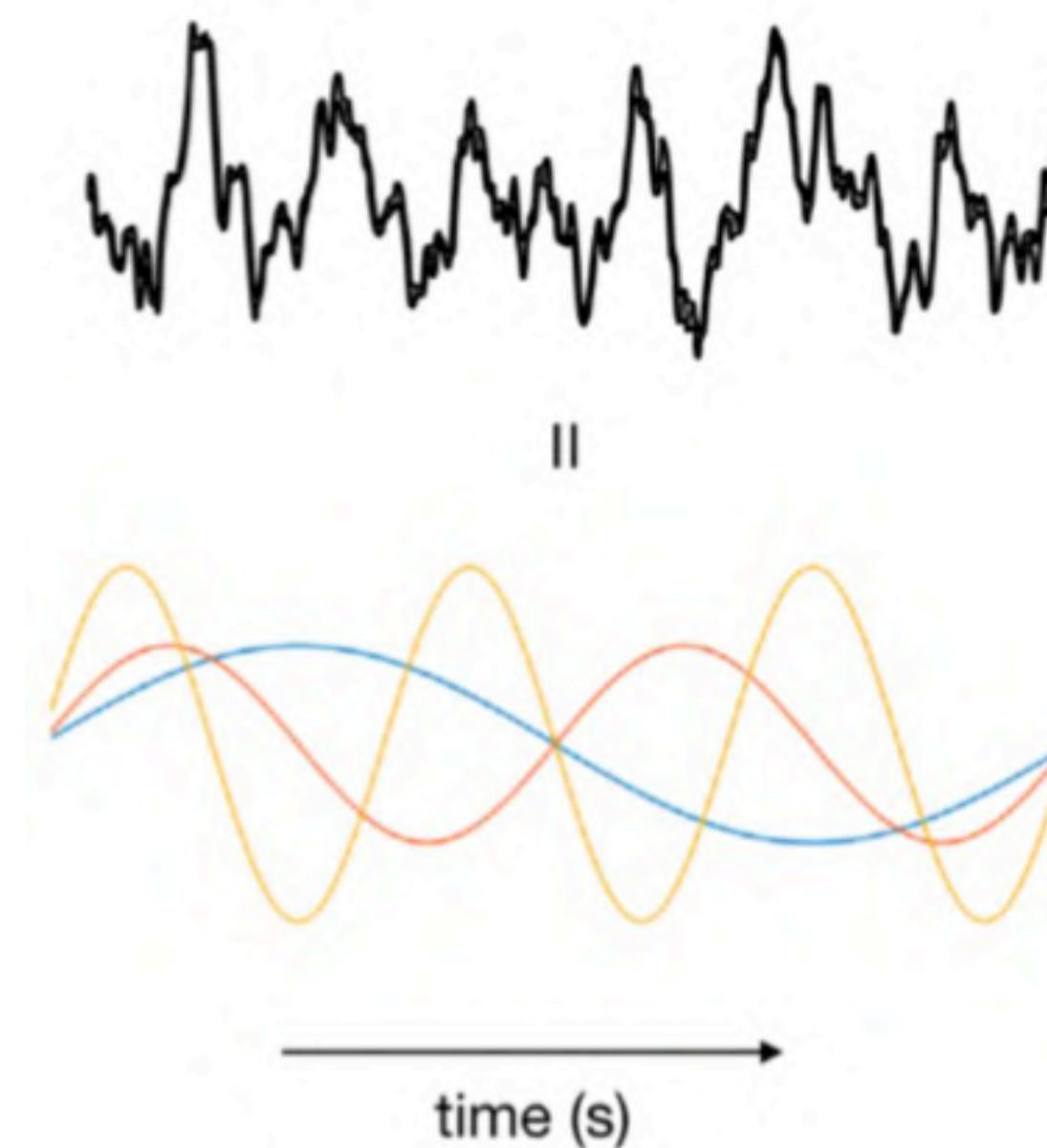


Detecting oscillations

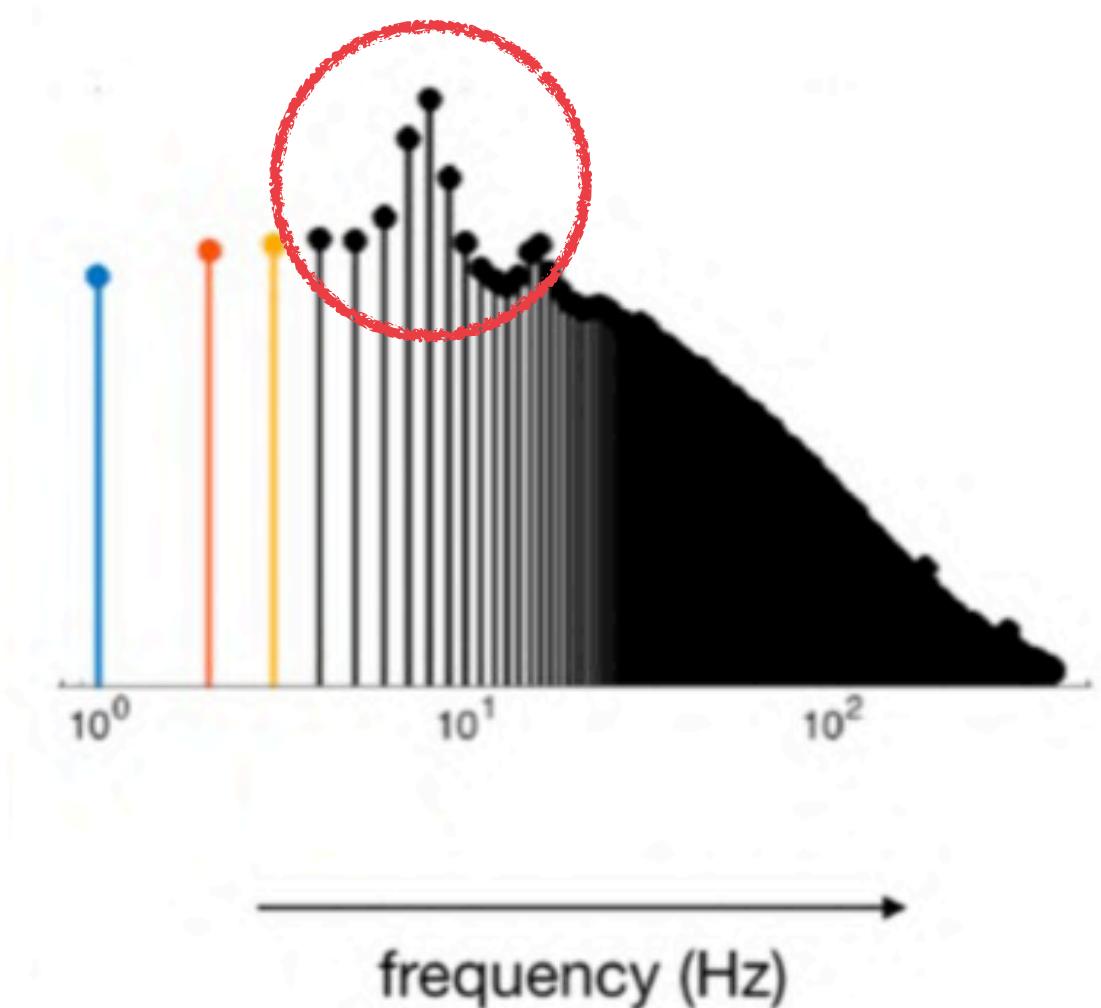
FFT



Time Domain



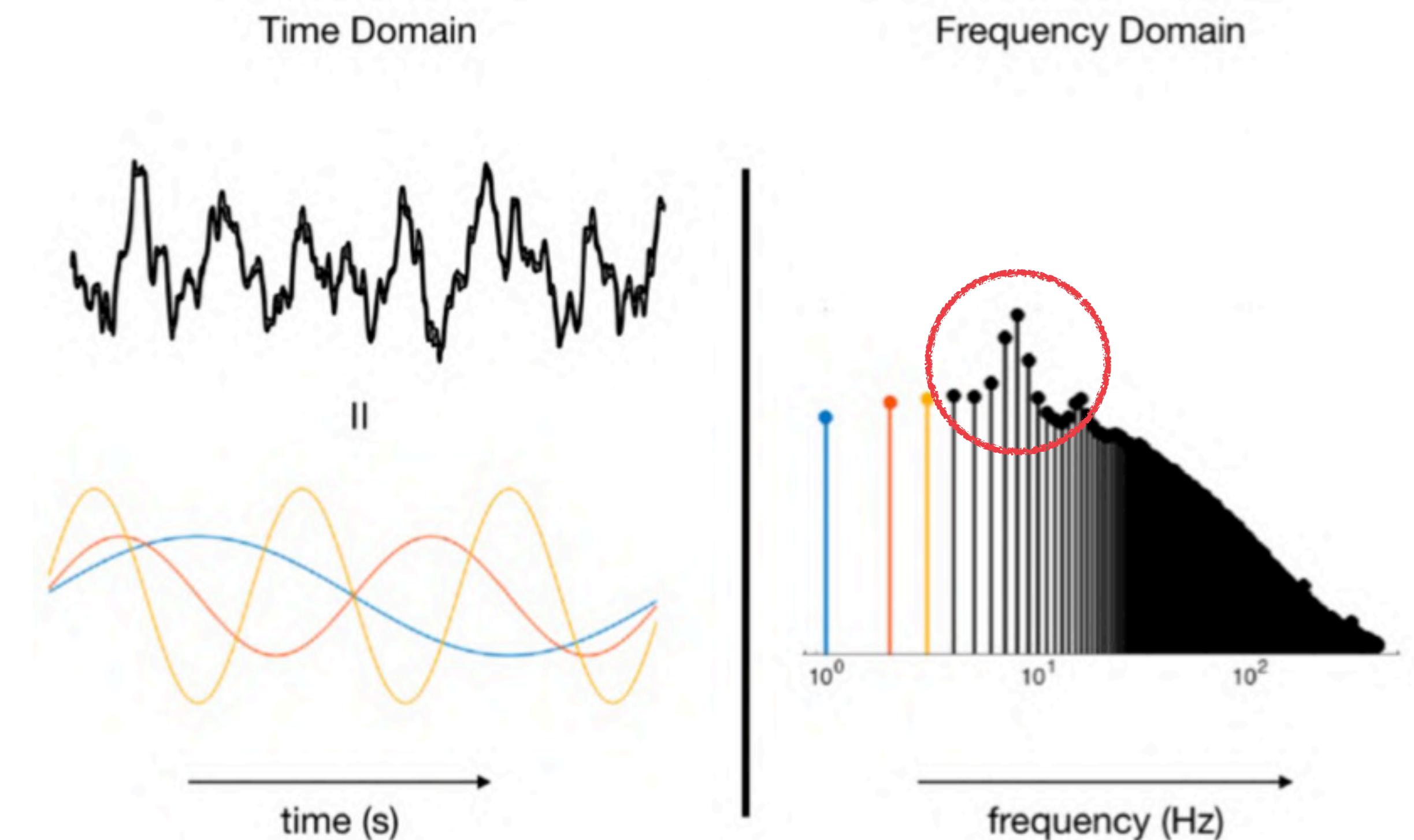
Frequency Domain



Detecting oscillations

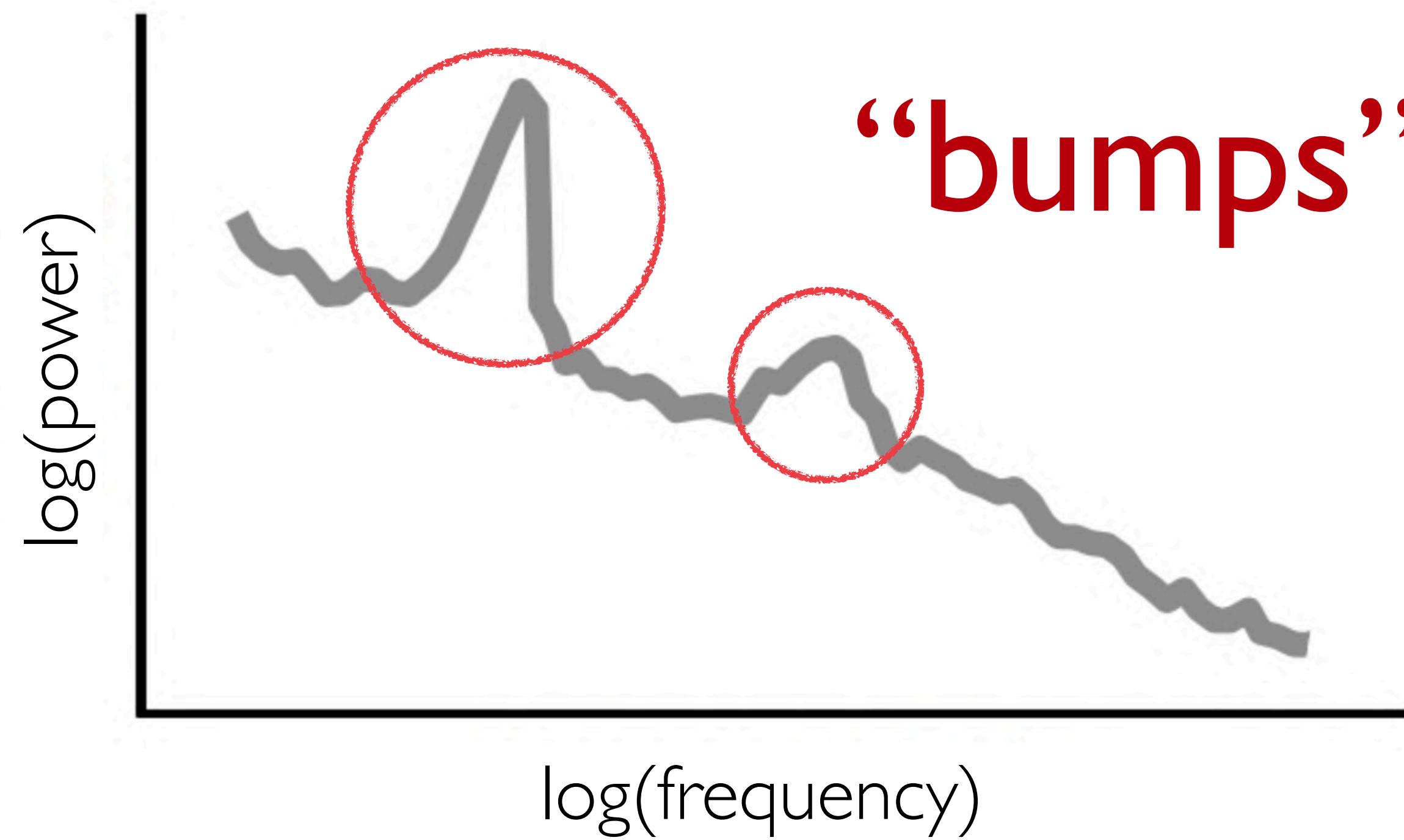
“In a power spectrum, brain oscillations appear as **bumps** on top of this $1/f$ slope...” - He B, *Trends Cogn Sci* 2014

“[when] particular oscillation frequencies become dominant... a peak (**bumps**) appears in the respective frequency band.” - Buzsáki *et al.*, *Neuron* 2013

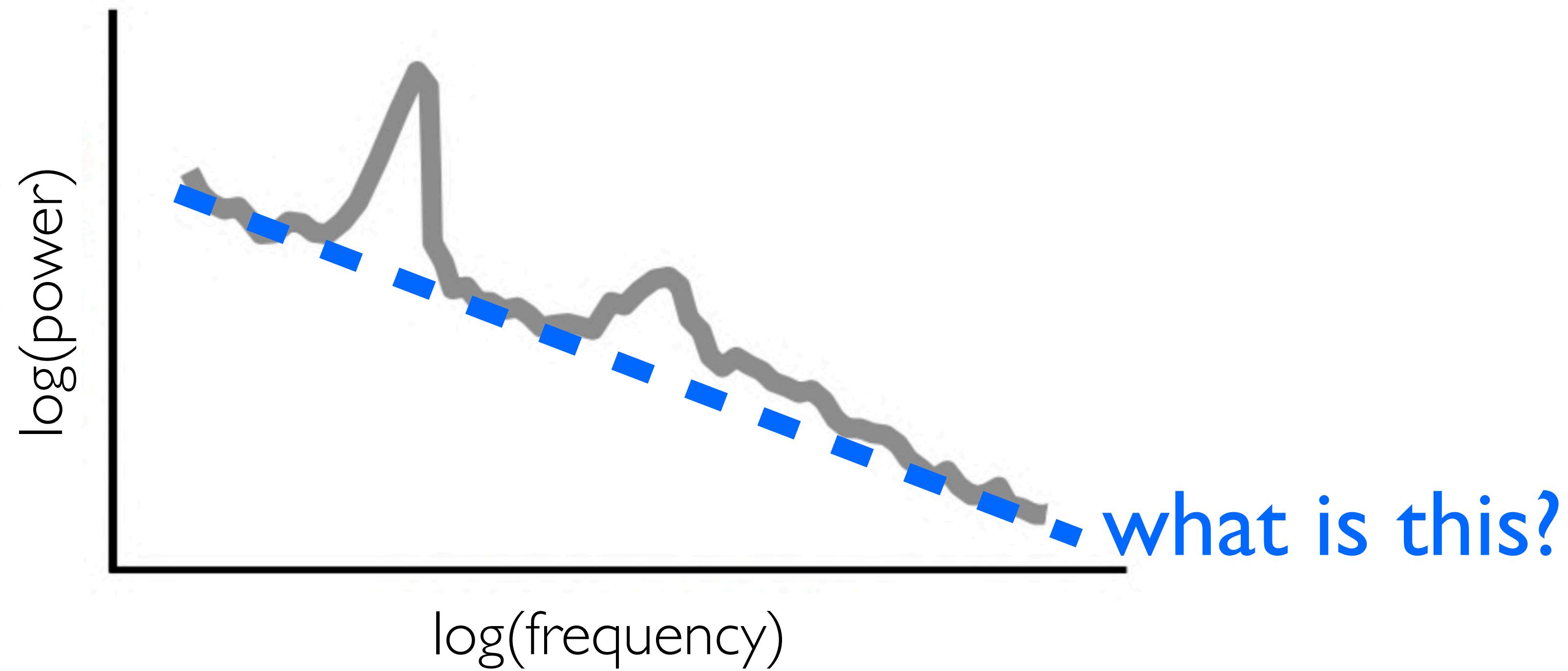


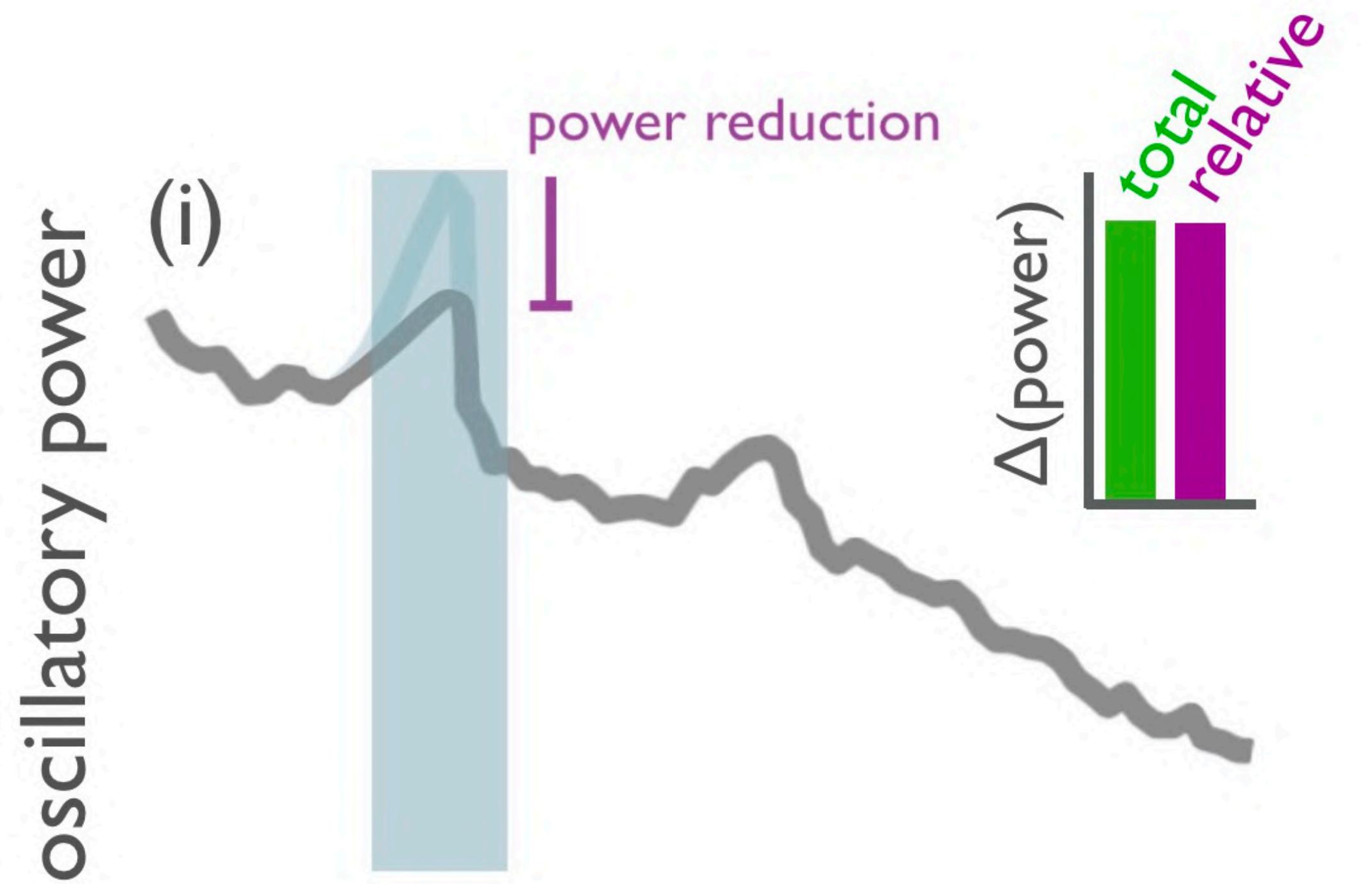
What's the problem?

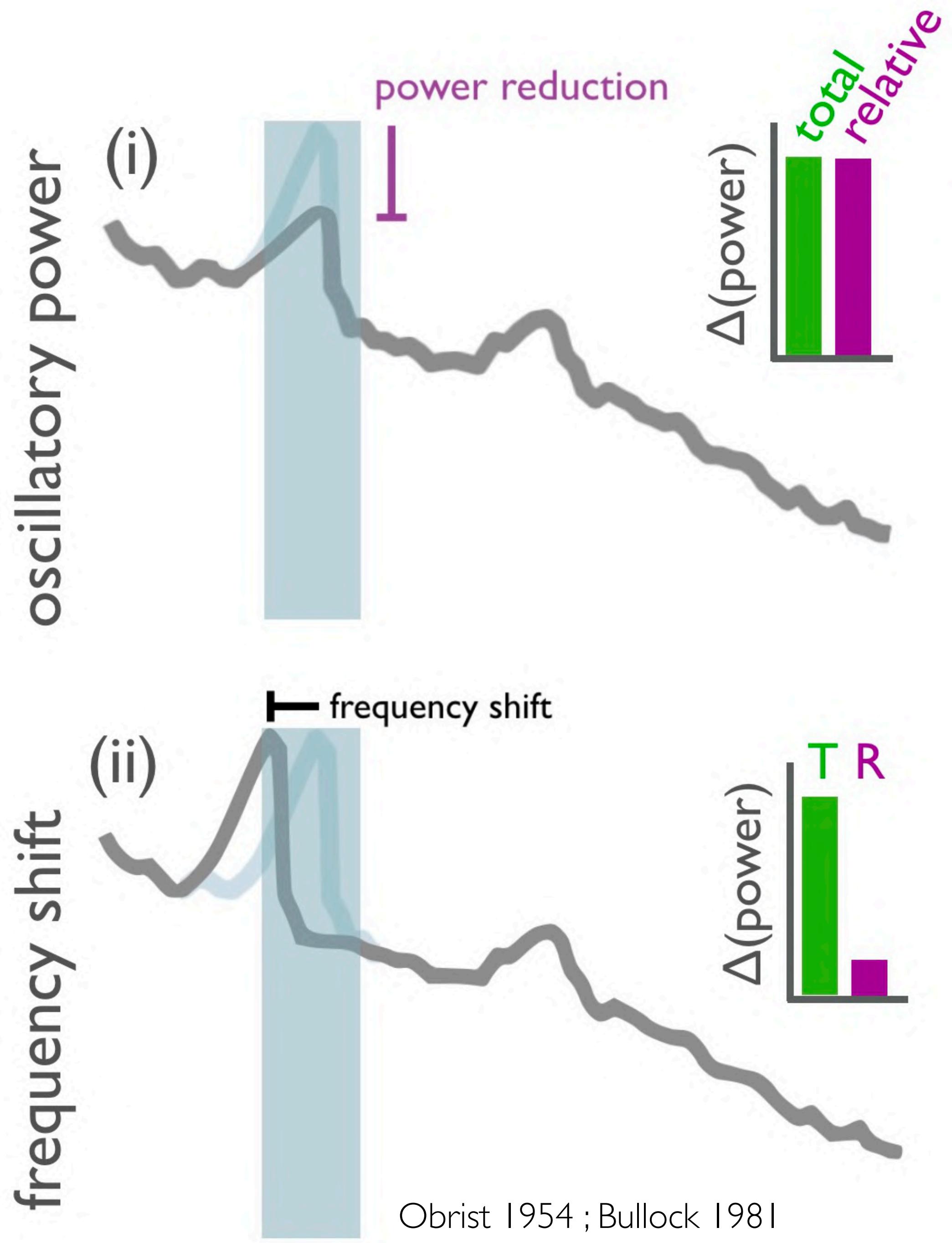
Not just oscillations

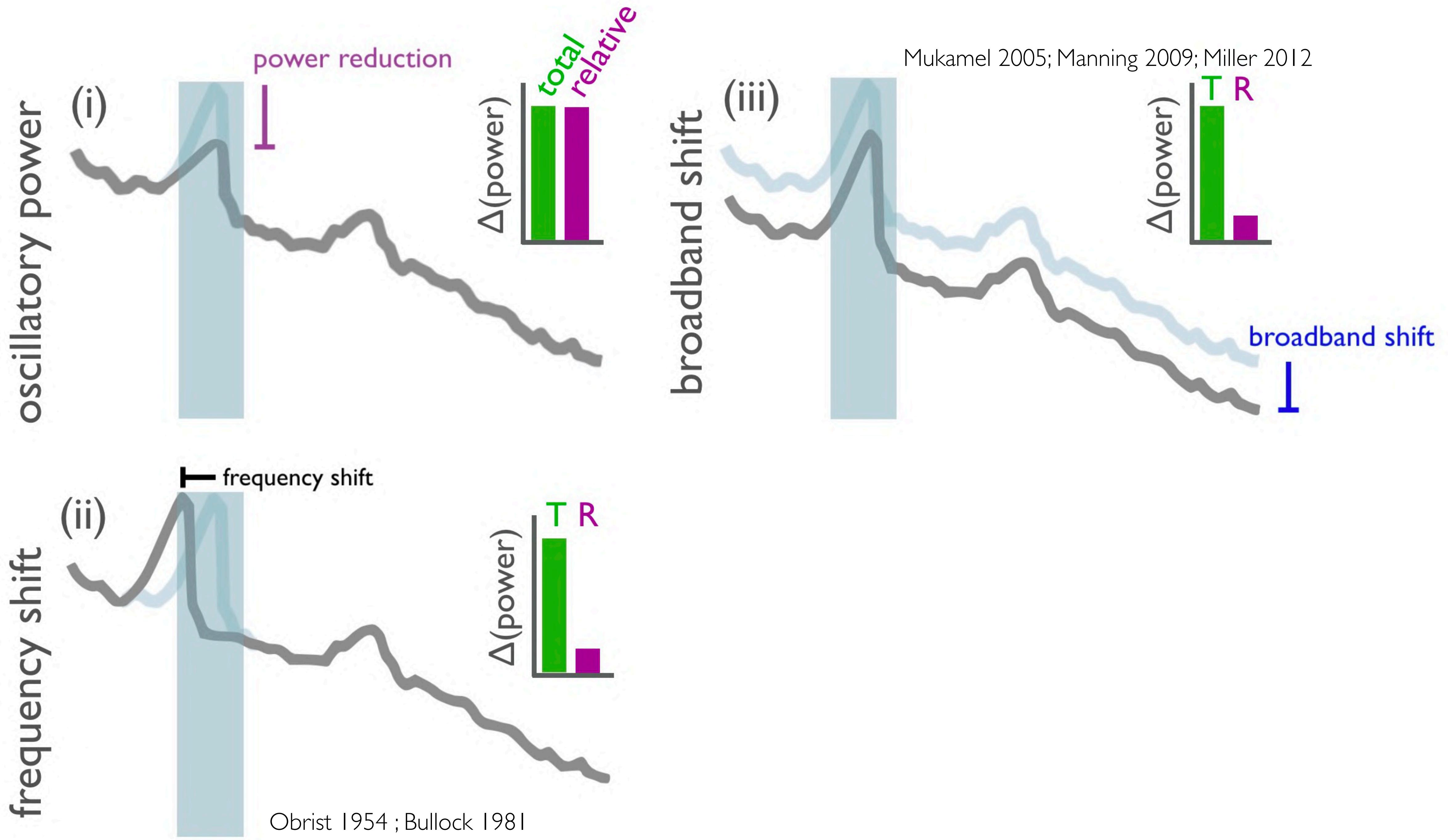


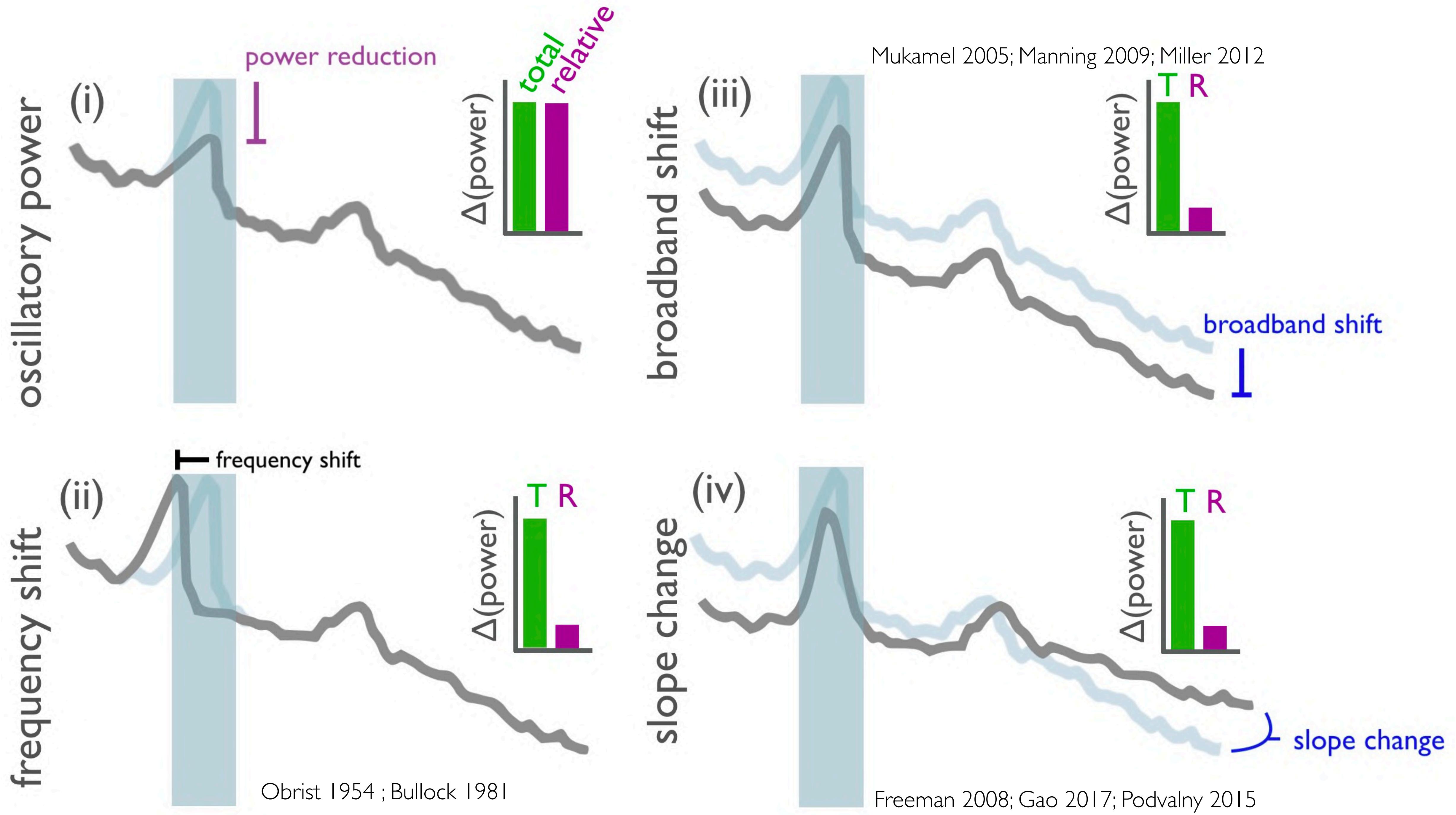
Not just oscillations

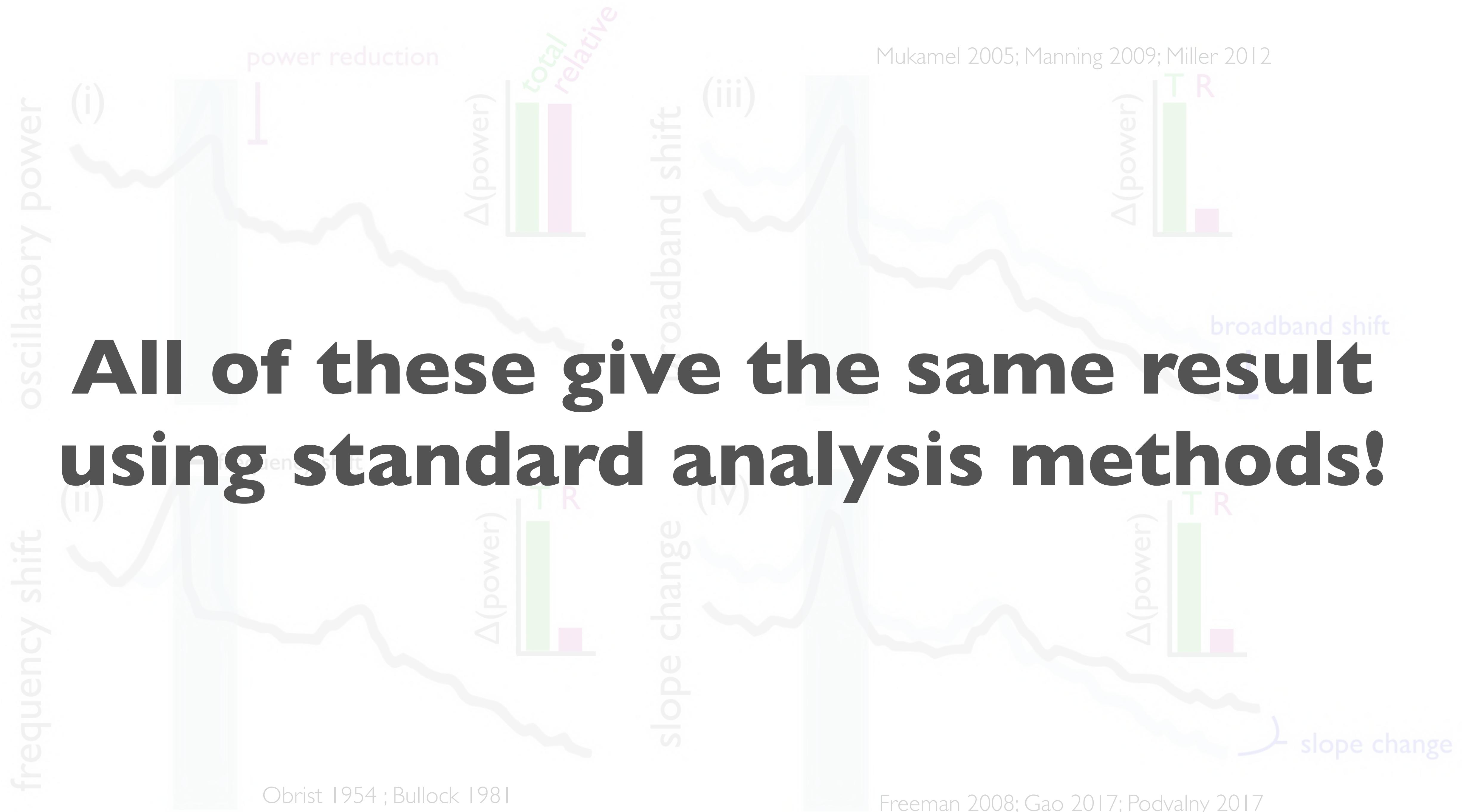












**All of these give the same result
using standard analysis methods!**

**We can't adjudicate between these
without careful parameterization**

What's a solution?

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Python!

pip install

- `neurodsp` (Cole et al., *J Open Source Softw* 2019)
- `fooof` (Donoghue, Haller, Peterson et al., *Nature Neurosci* 2020)

Parameterize our spectra!

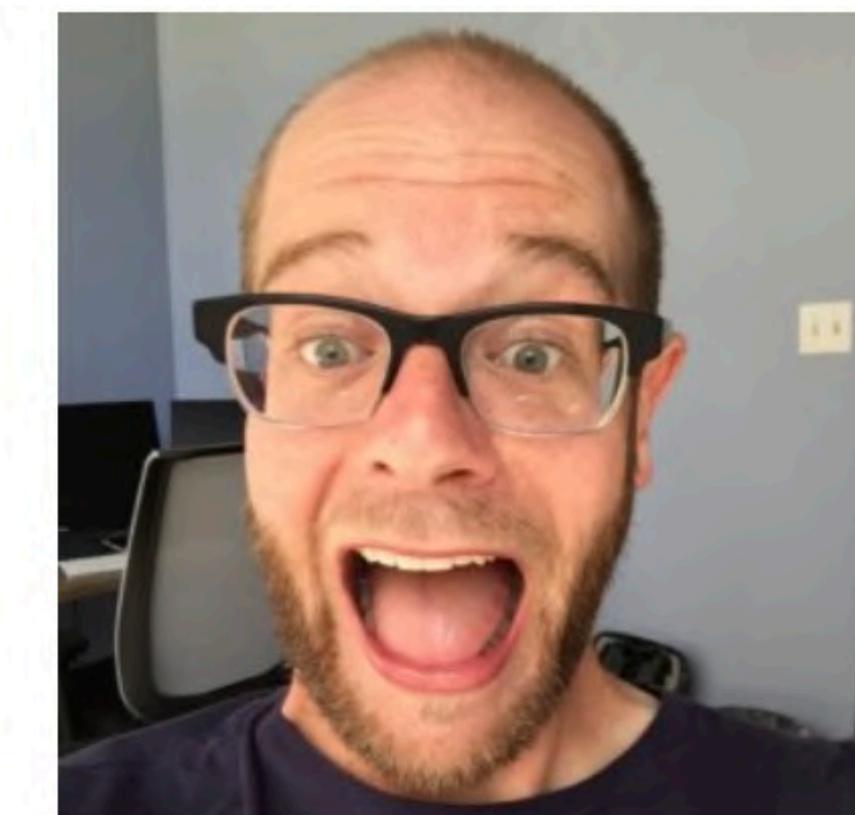
Tom Donoghue, Ph.D.



Matar Haller, Ph.D. & Avgusta Shestyuk, Ph.D.



Erik Peterson, Ph.D.



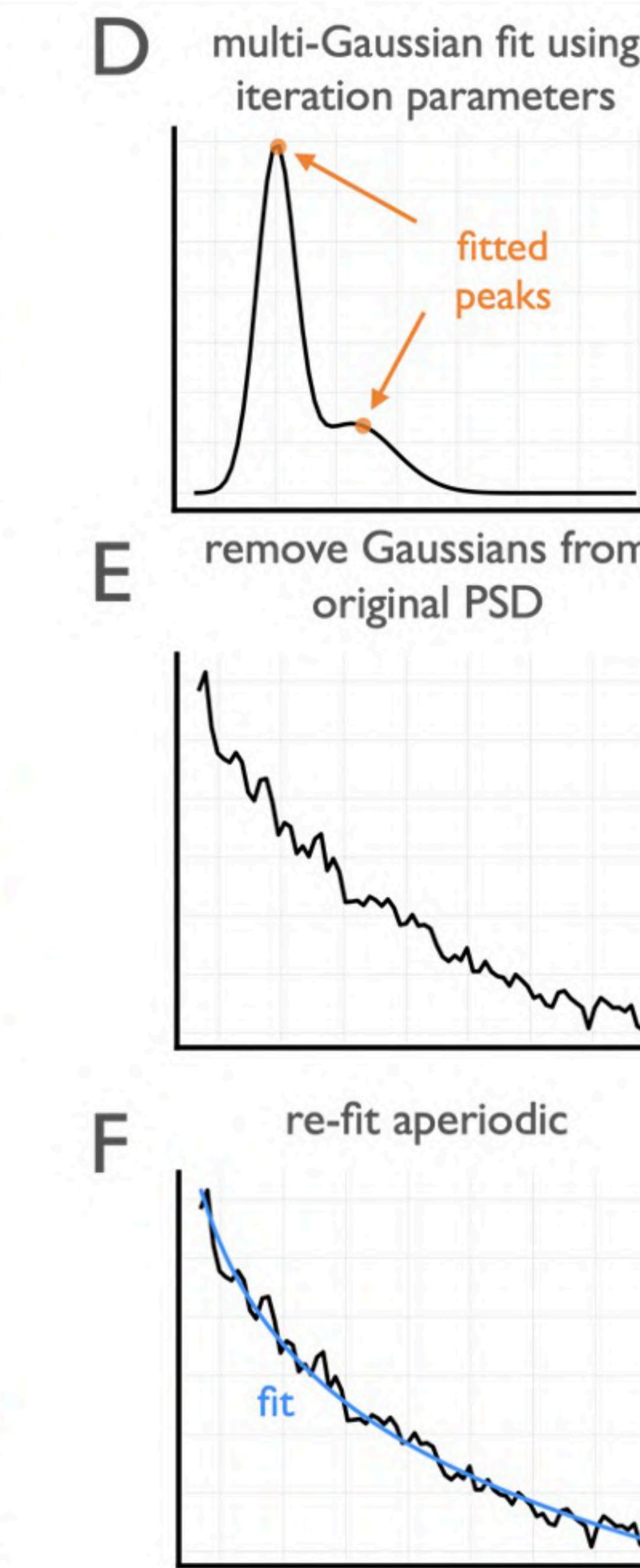
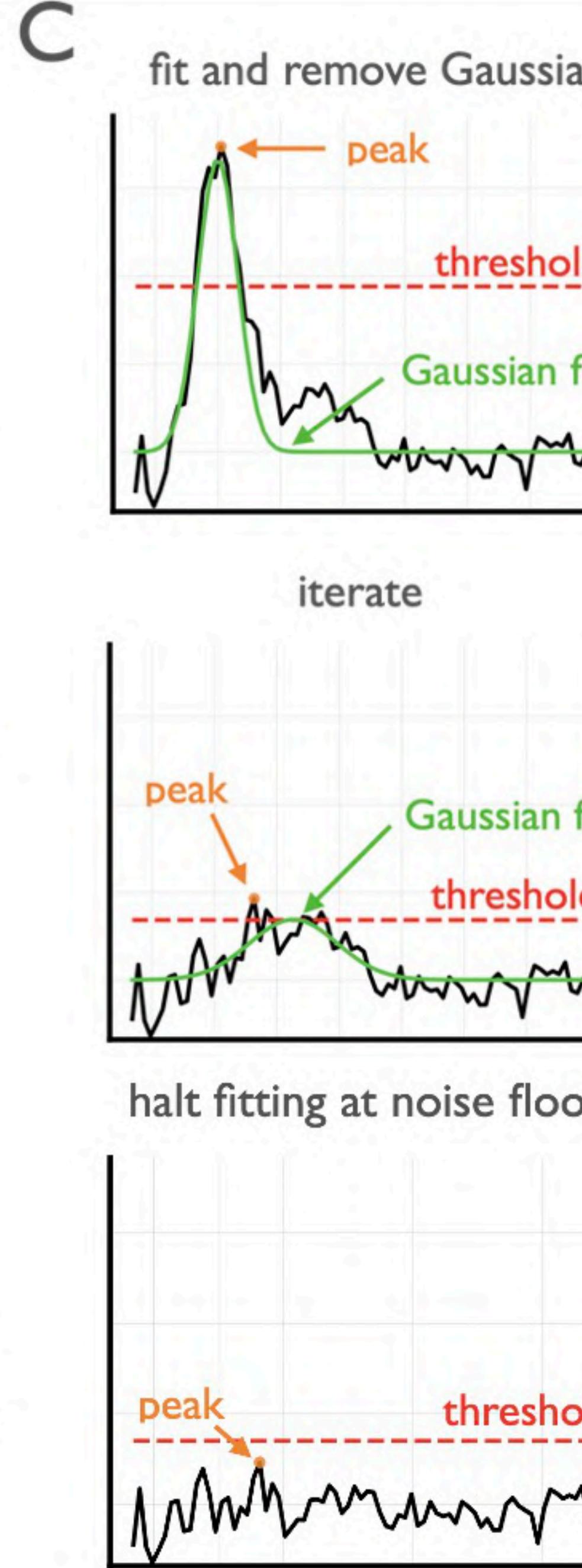
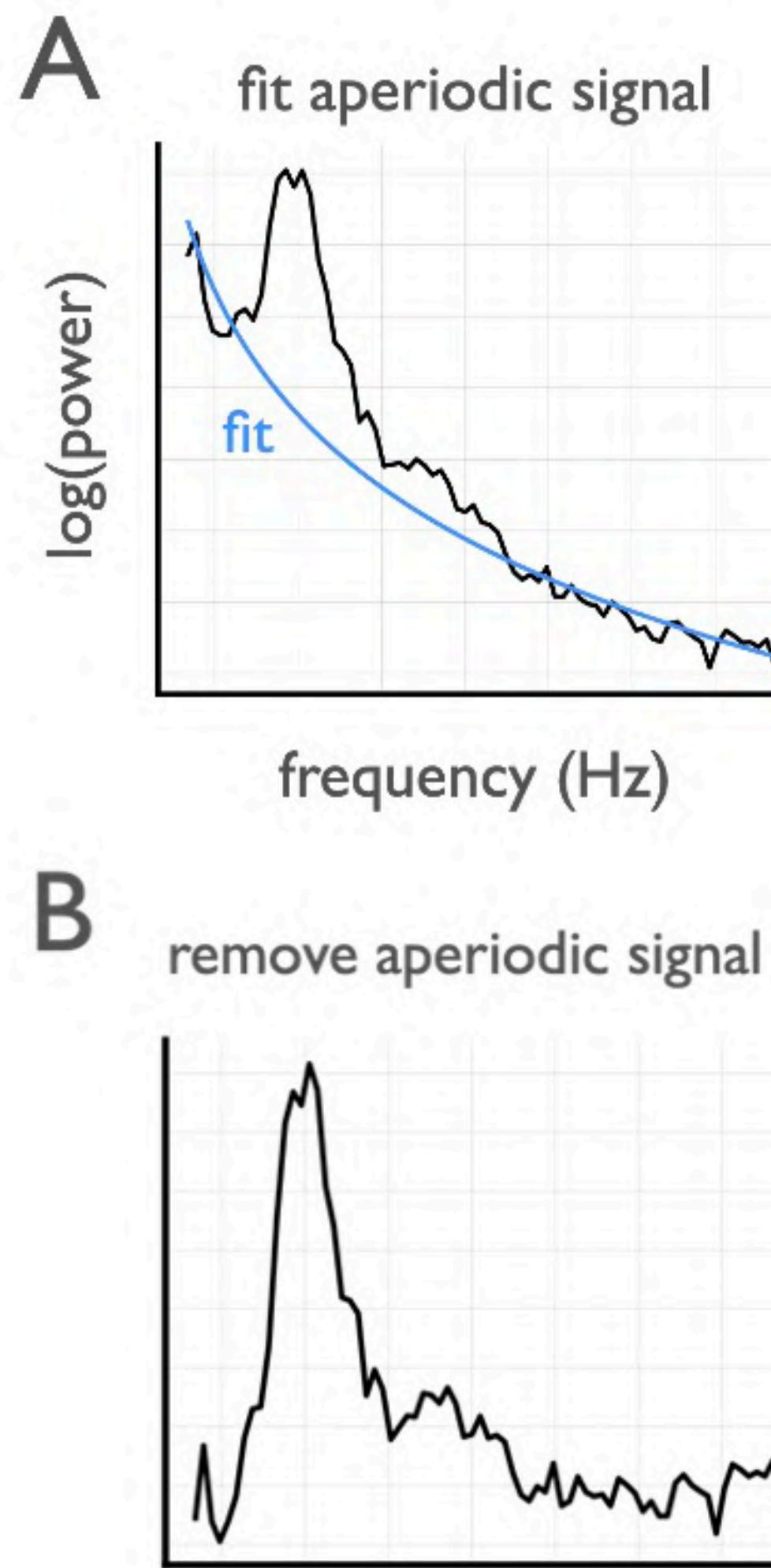
Luyanda Mdanda



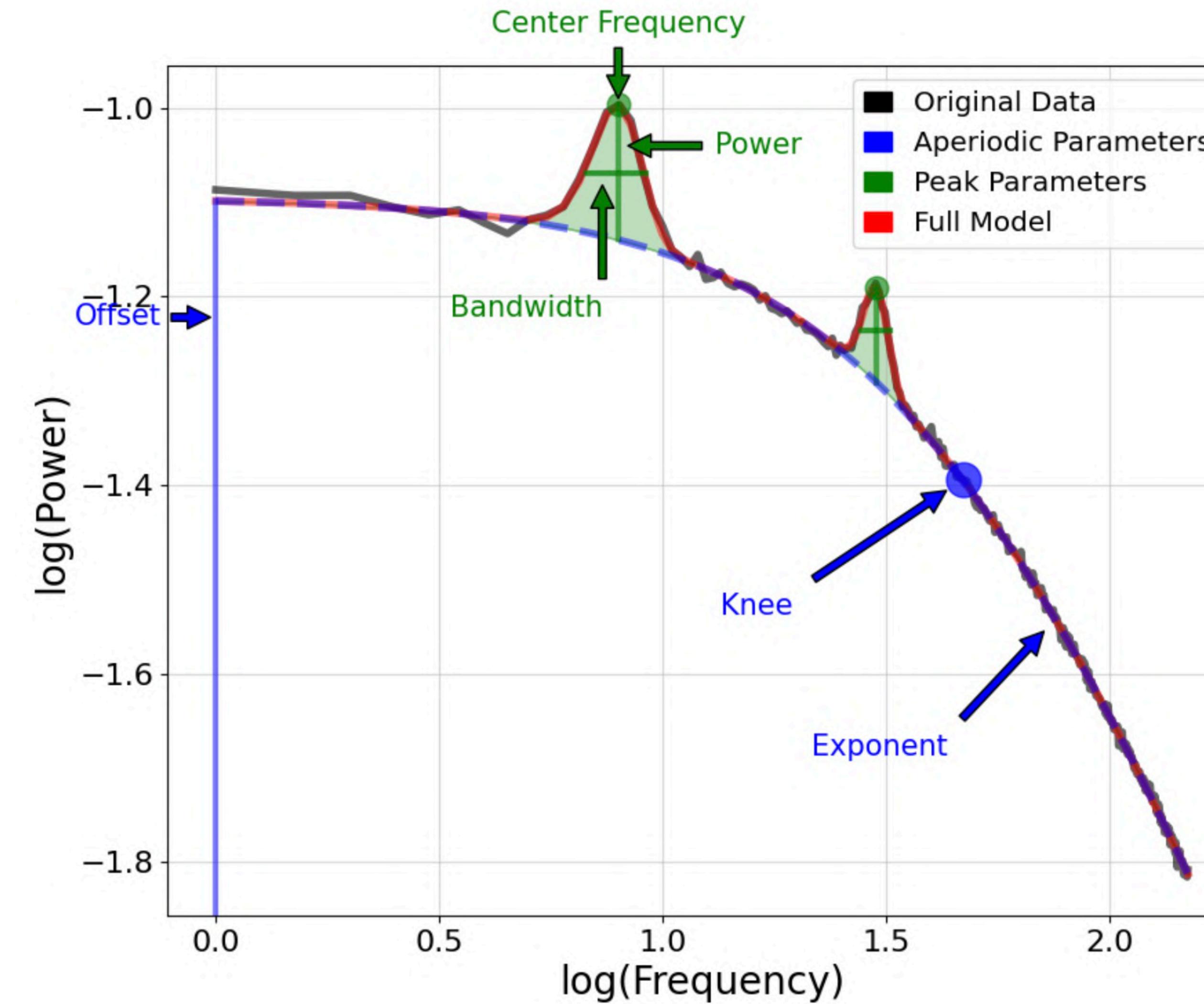
Julio Dominguez



algorithm



Parameterizing neural power spectra



Parameterizing neural power spectra

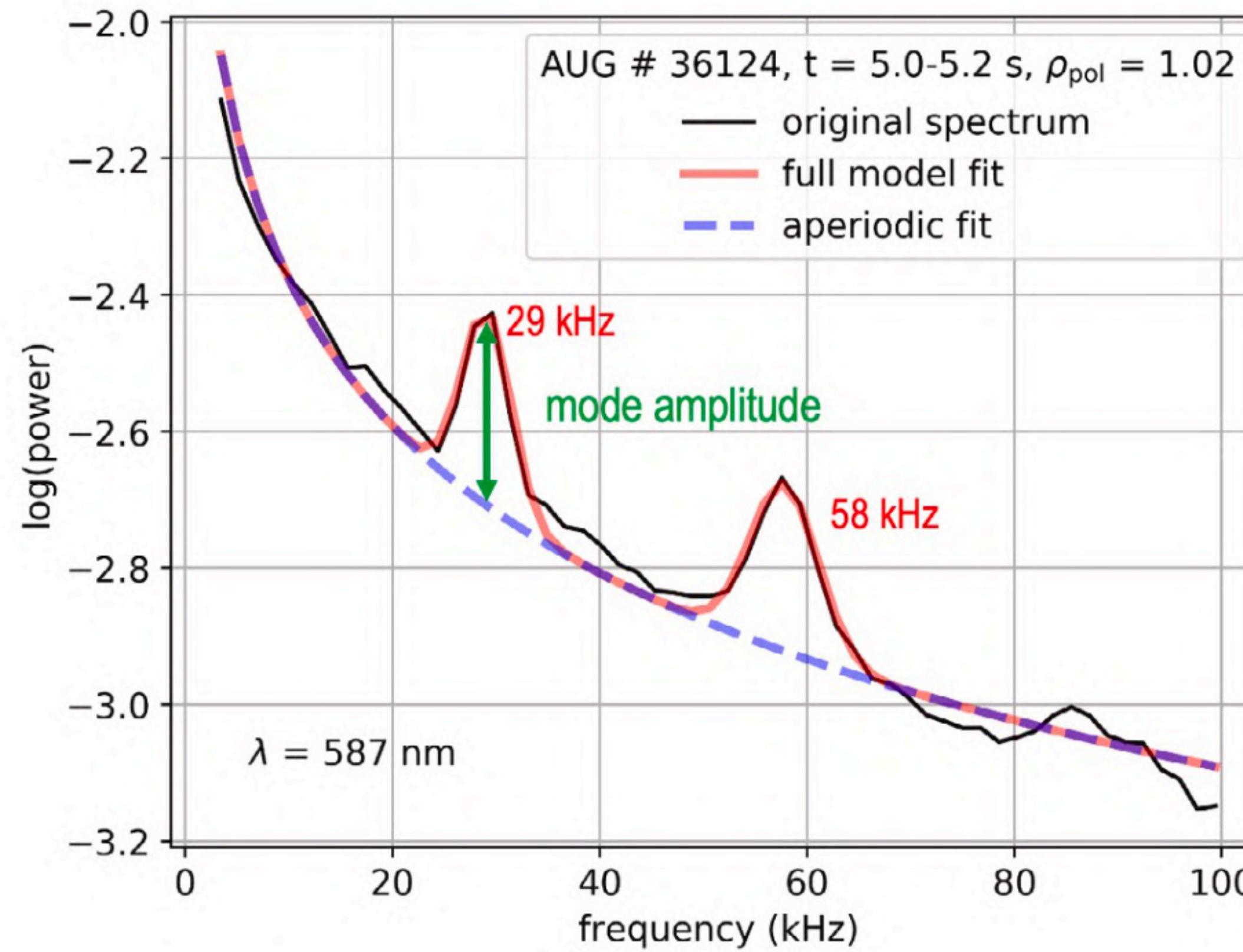
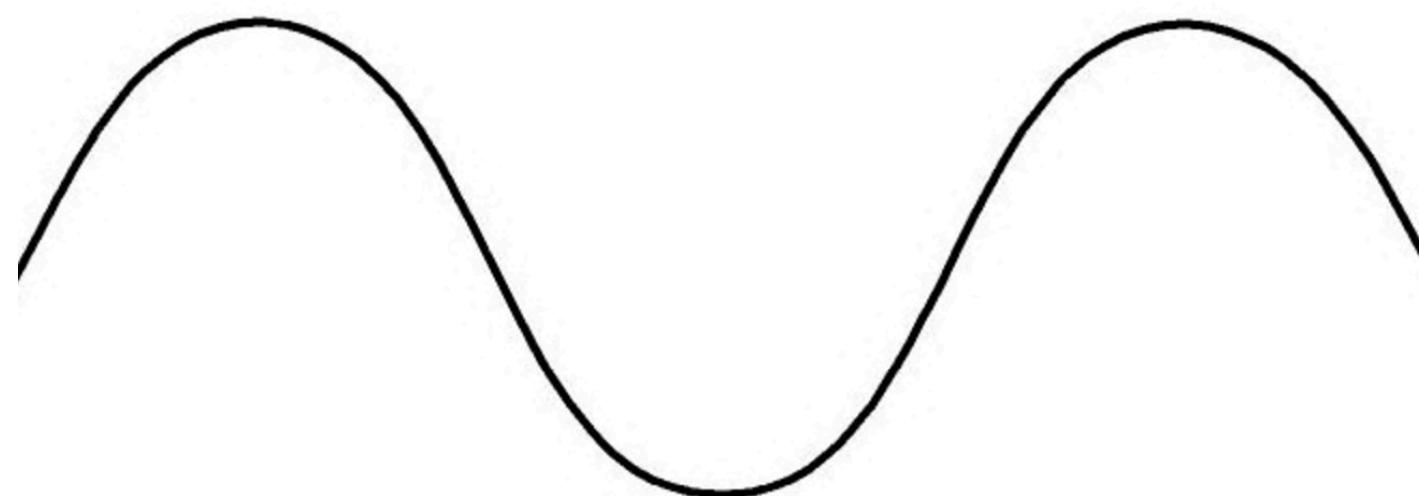


Fig. 5. Spectrum of the QCM with a peak frequency of $f = 29\text{ kHz}$ for the spectral line at $\lambda = 587\text{ nm}$. This line also shows the mode with its double frequency of $f = 58\text{ kHz}$ at $\rho_{\text{pol}} = 1.02$, as discussed in Section 2.5. The fit model to calculate the aperiodic (noise) and periodic (mode) components of the spectrum is described in [23].

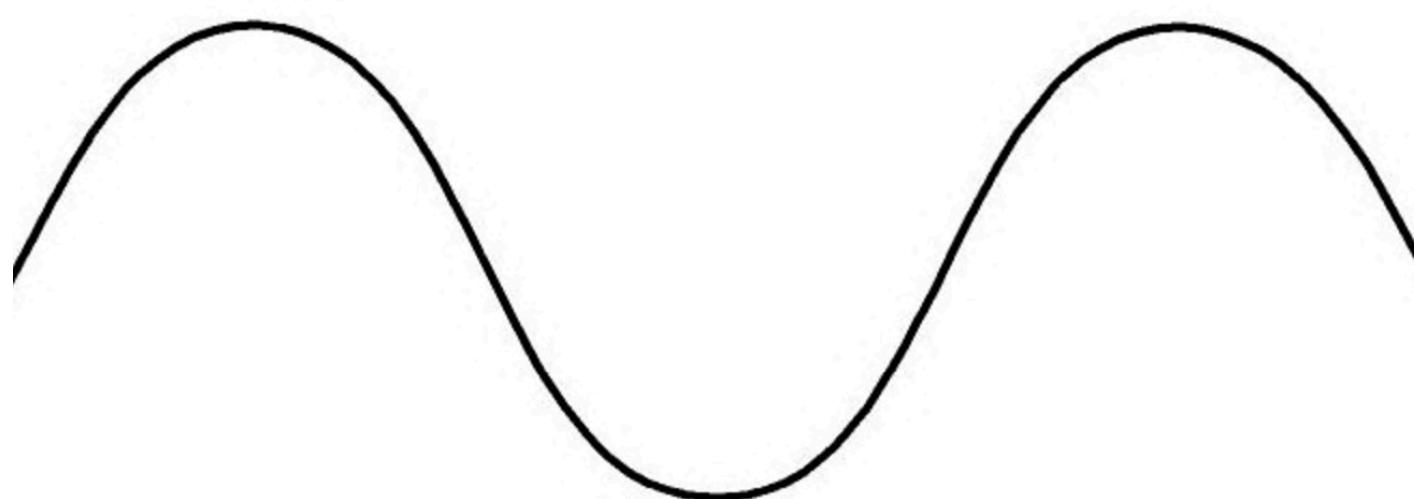
But wait, there's more!

Neural oscillations are *not* sinusoidal

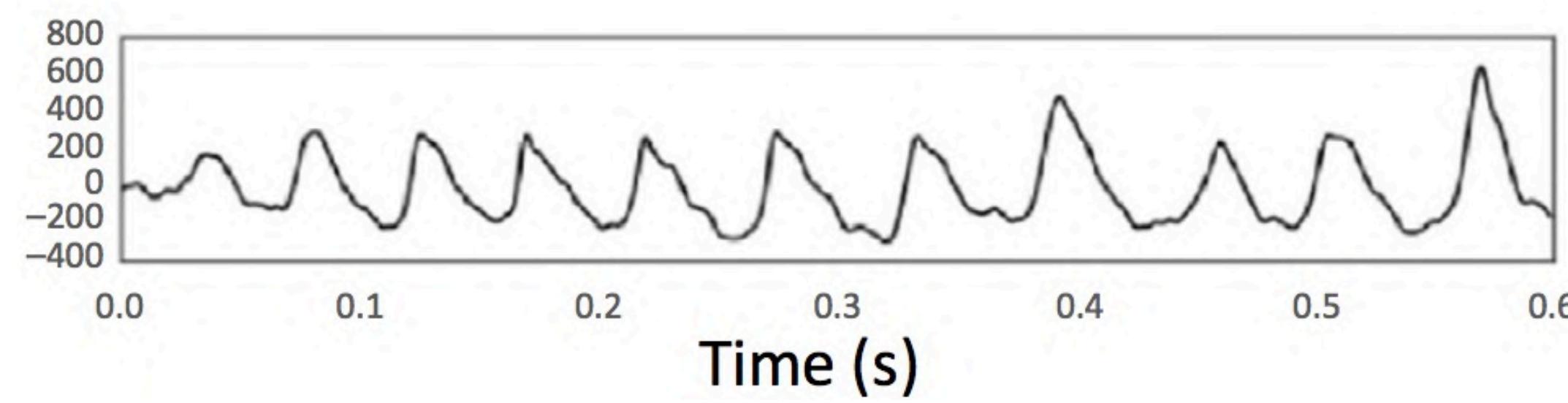


sinusoid

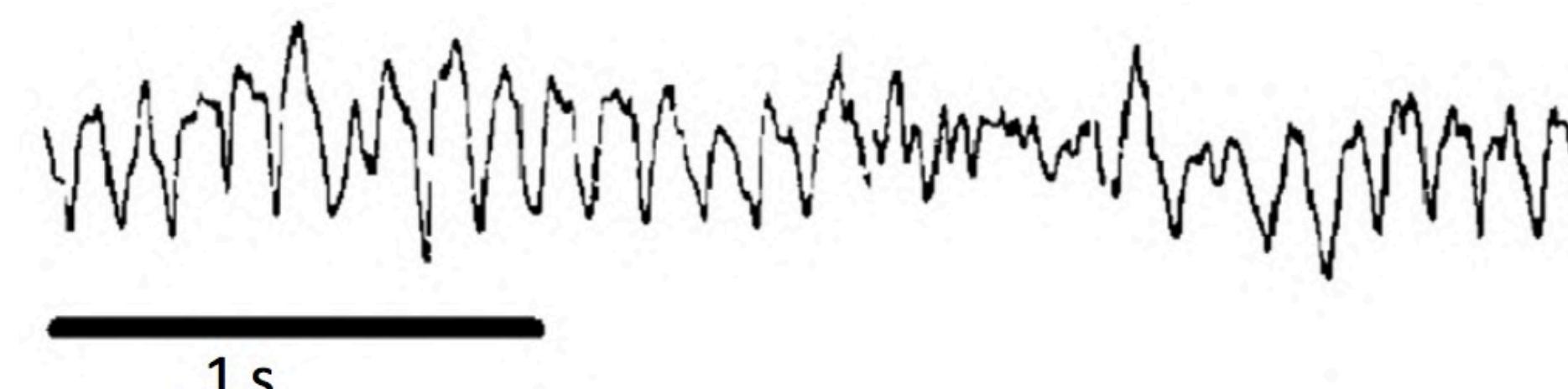
Neural oscillations are *not* sinusoidal



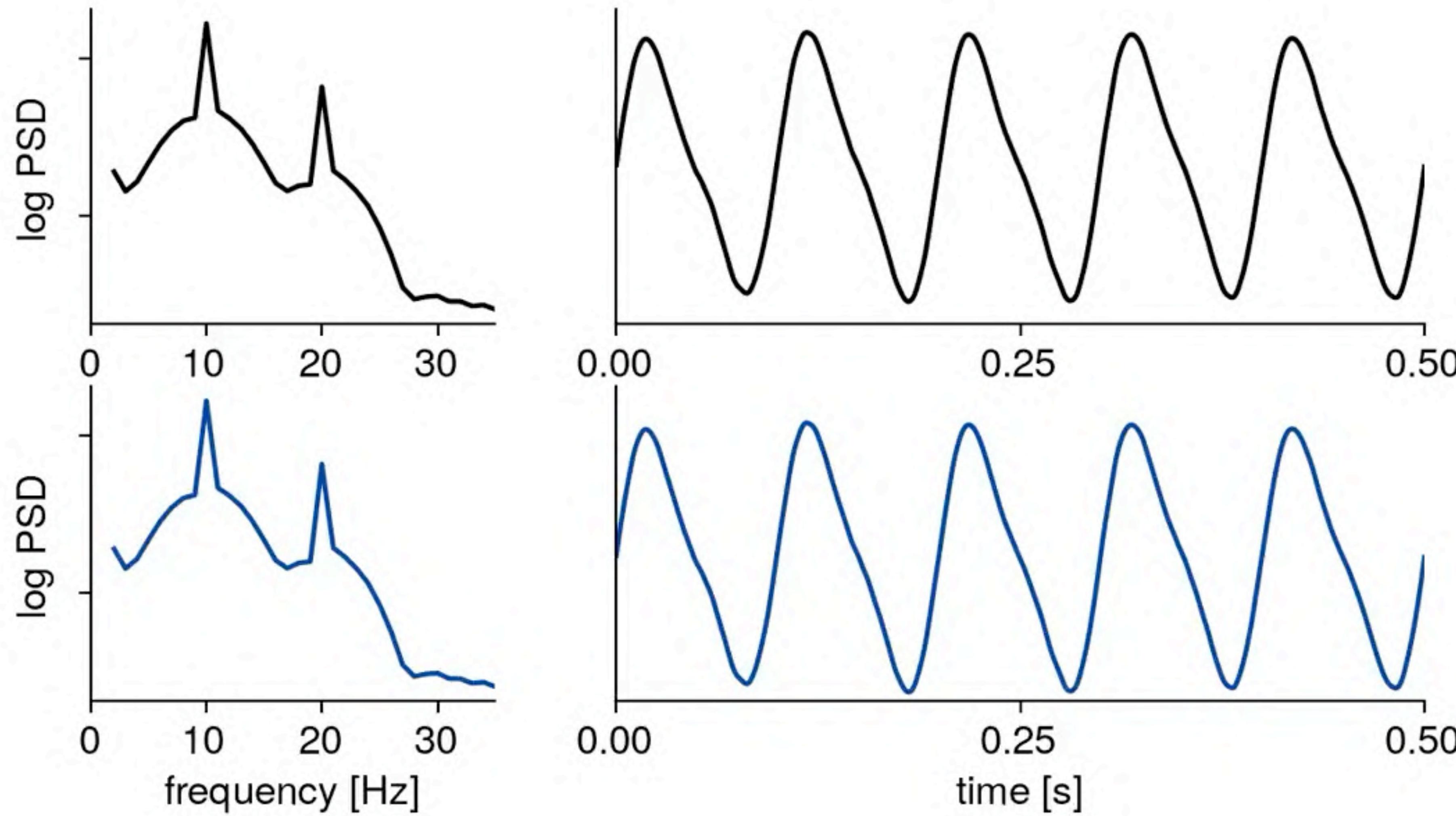
sinusoid



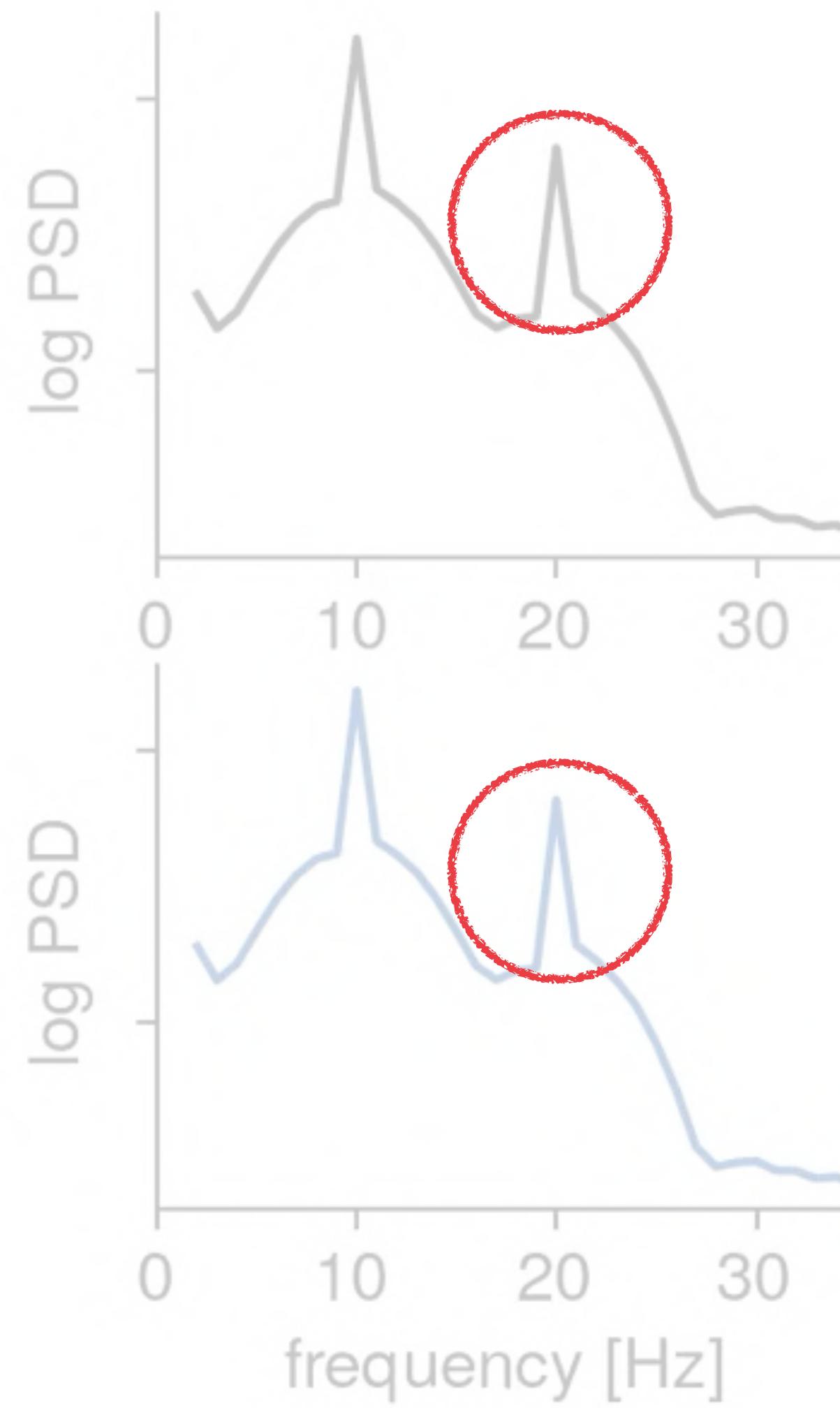
not sinusoids



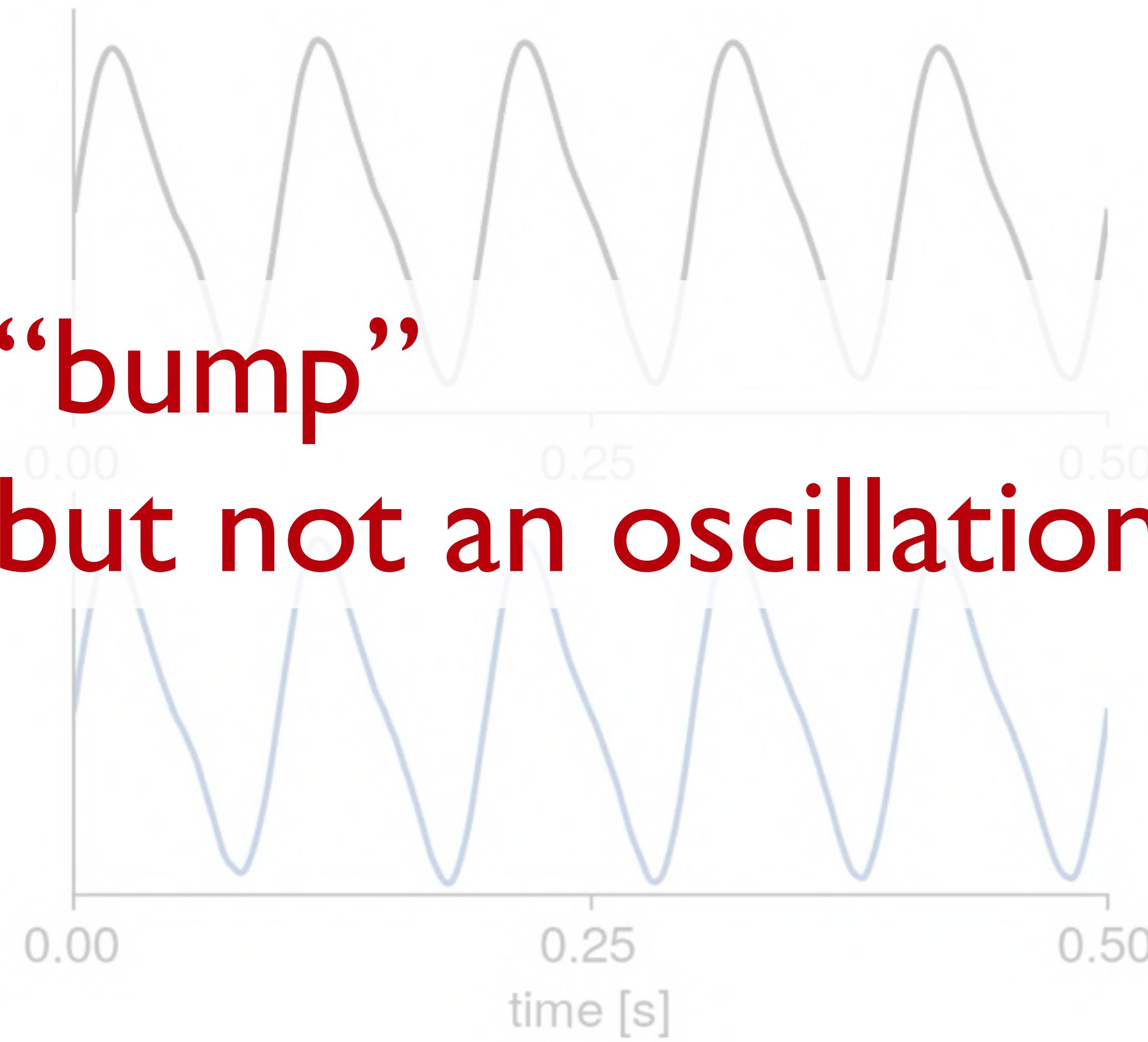
Nonsinusoidal harmonics



Nonsinusoidal harmonics



**“bump”
but not an oscillation**



**We can't adjudicate between these
without careful parameterization**

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Python!

pip install

- `neurodsp` (Cole et al., *J Open Source Softw* 2019)
- `bycycle` (Cole & Voytek, *J Neurophysiol* 2019)

Scott Cole



Ryan Hammonds



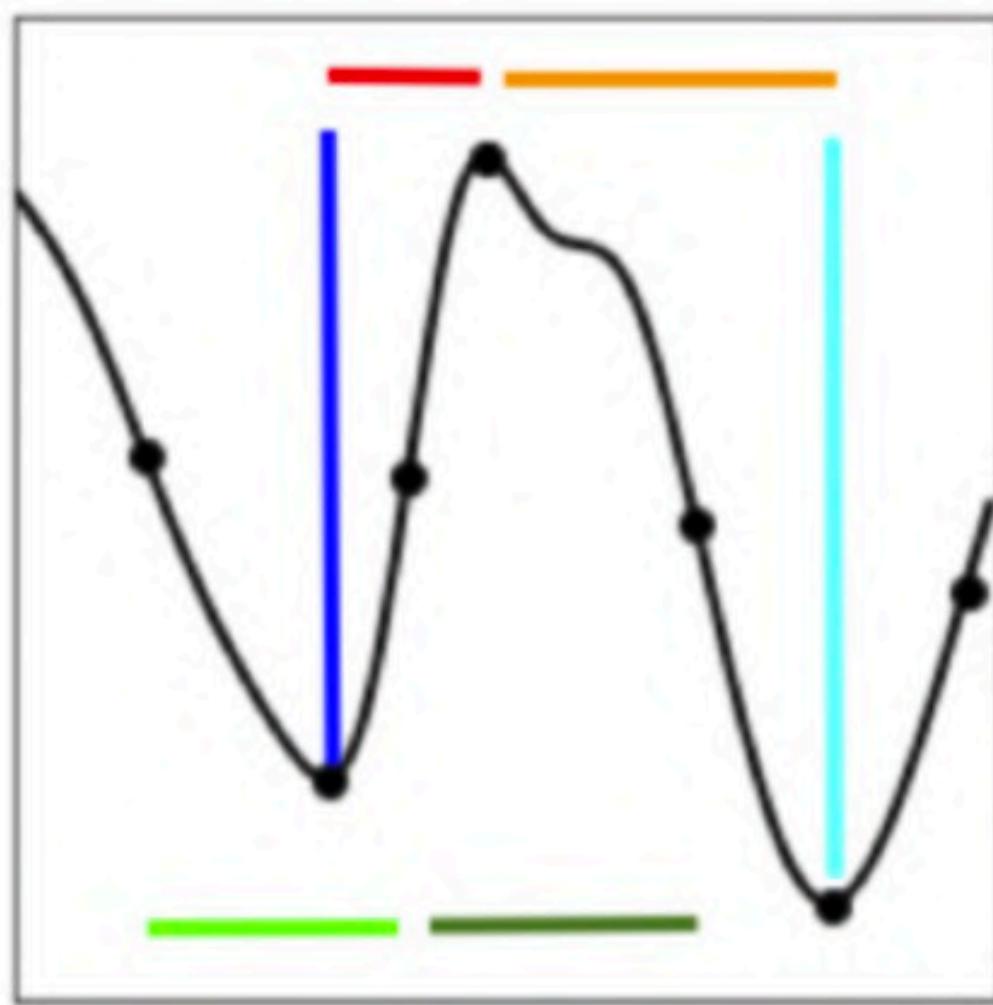
Andrew Bender



Natalie Schawronkow



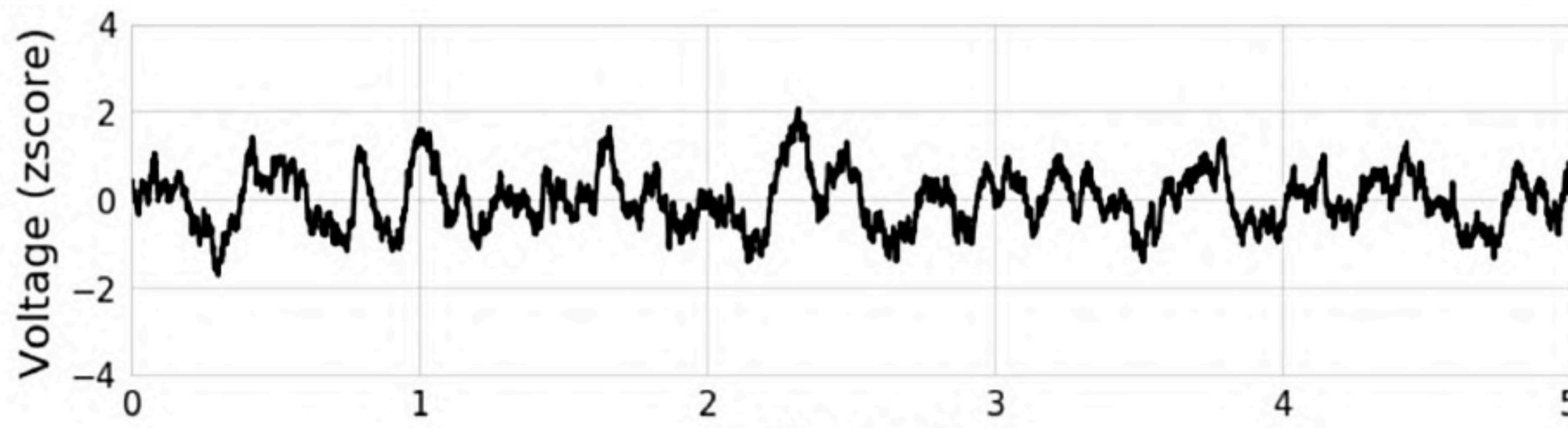
Bycycle!



Amplitude $= (\text{blue} + \text{cyan}) / 2$
Period $= \text{red} + \text{orange}$
Rise-decay symmetry $= \text{red} / (\text{red} + \text{orange})$
Peak-trough symmetry $= \text{green} / (\text{green} + \text{yellow})$

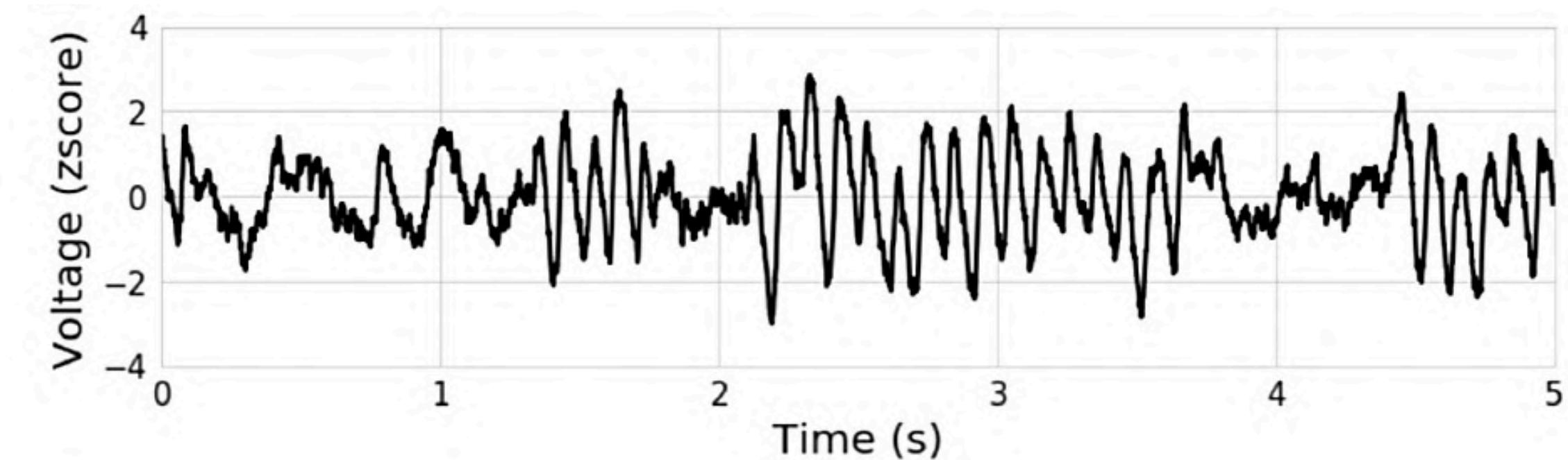
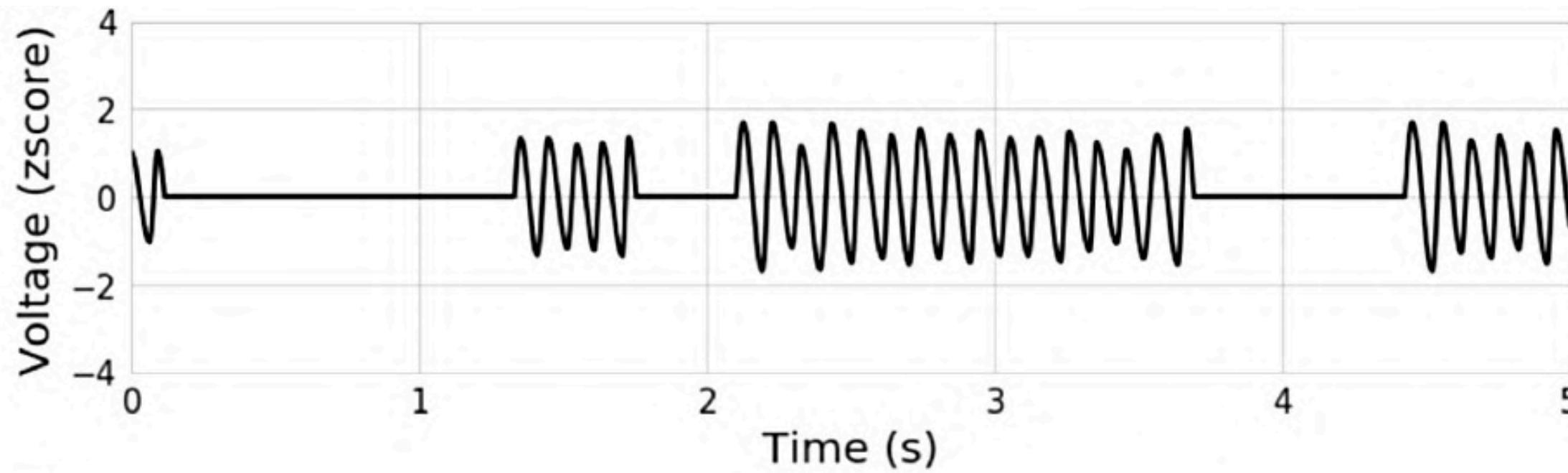
Trough time	Amplitude	Period	rdsym	ptsym
0.12	2.9	105	0.43	0.51
0.21	1.7	89	0.34	0.5
0.31	1.9	99	0.4	0.49
0.4	2.2	82	0.32	0.52
0.5	2.2	109	0.4	0.58
0.61	2.2	108	0.44	0.57

Ground truth simulations



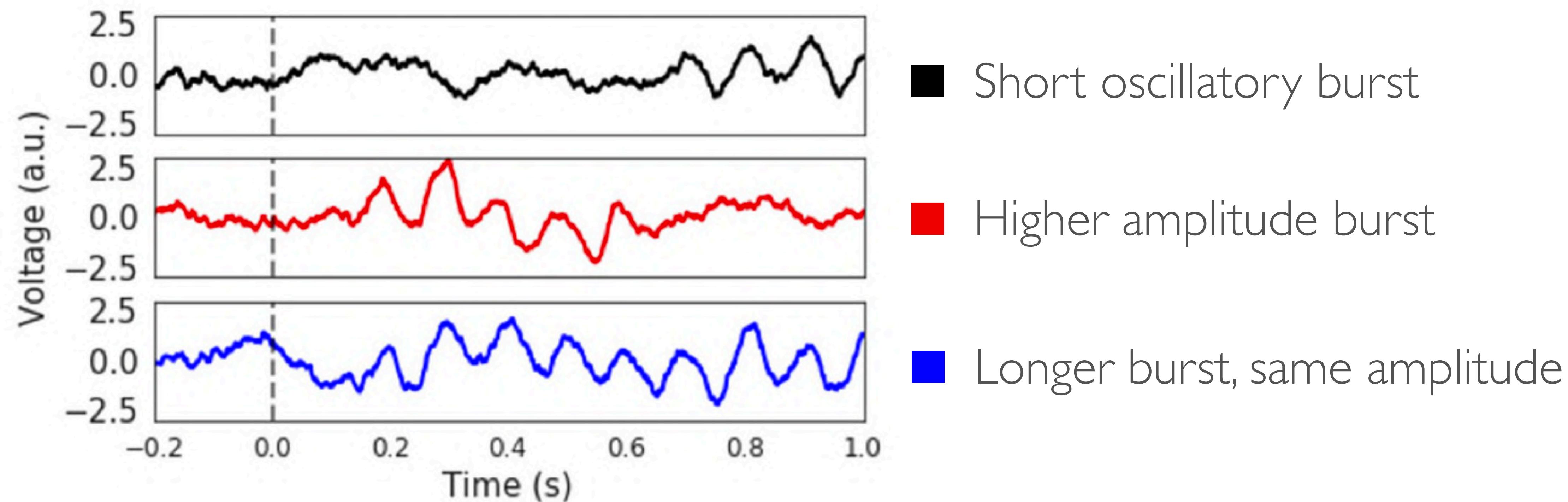
+

=



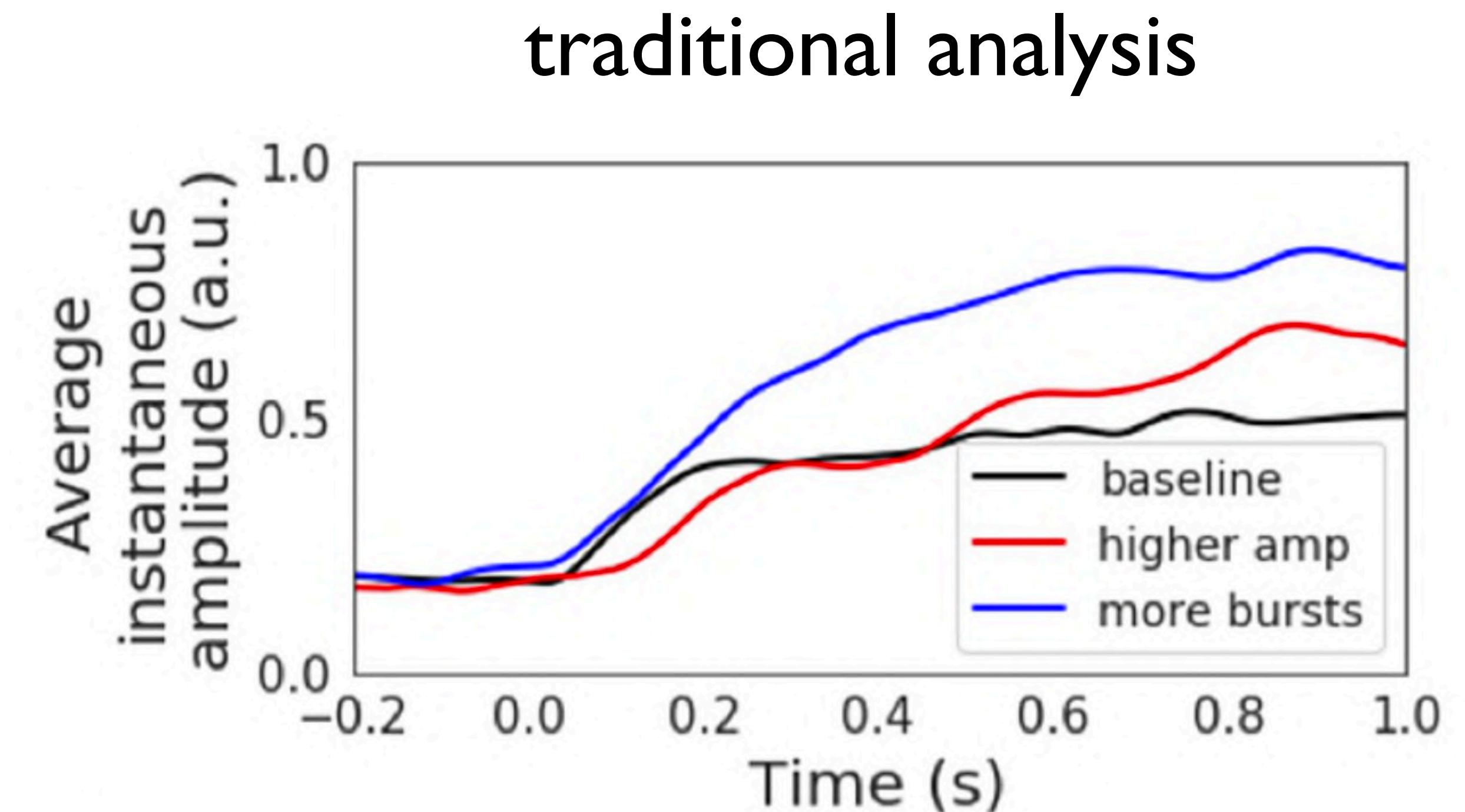
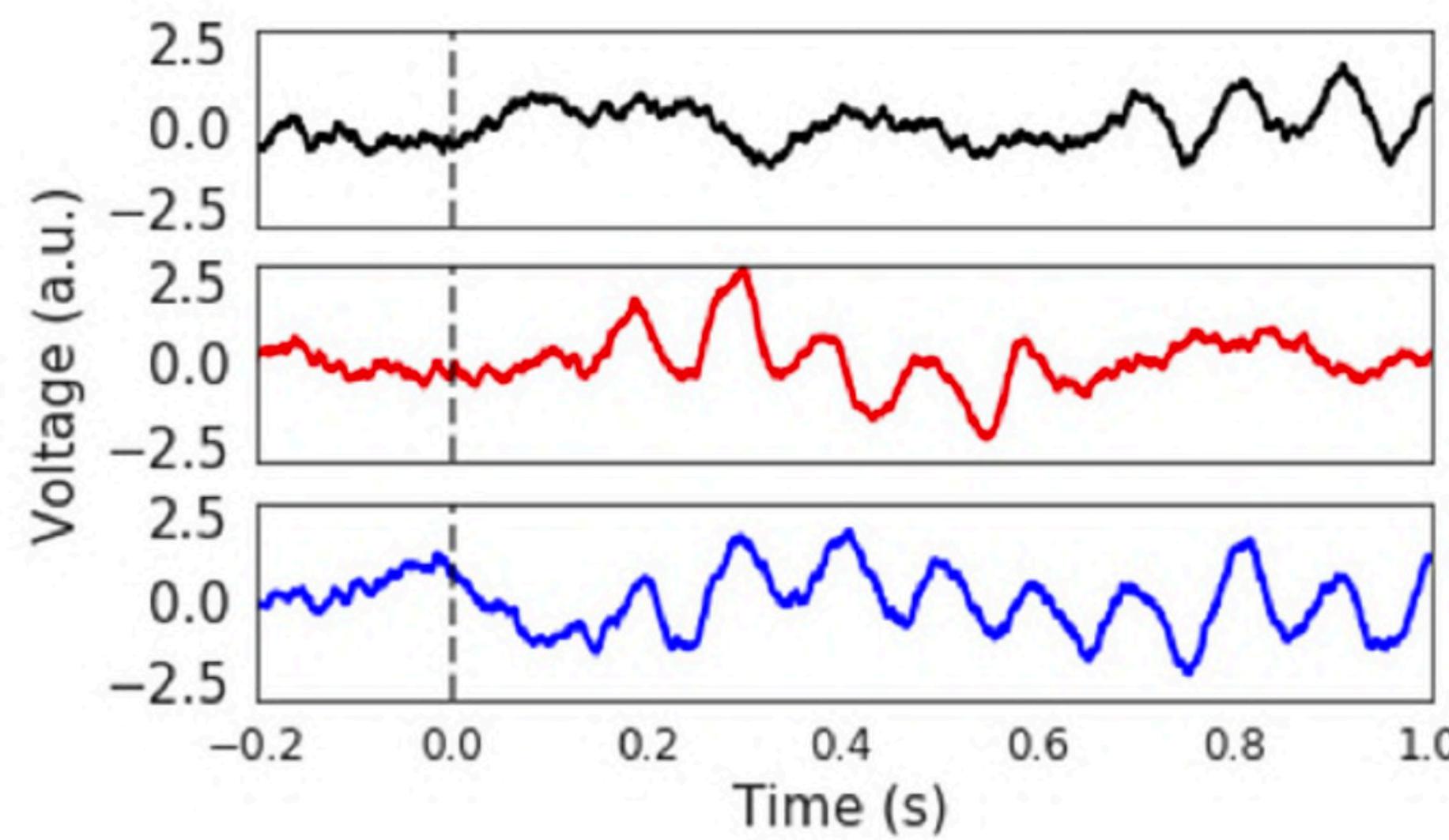
Nonsinusoidality influences our analyses

simulated event-related results



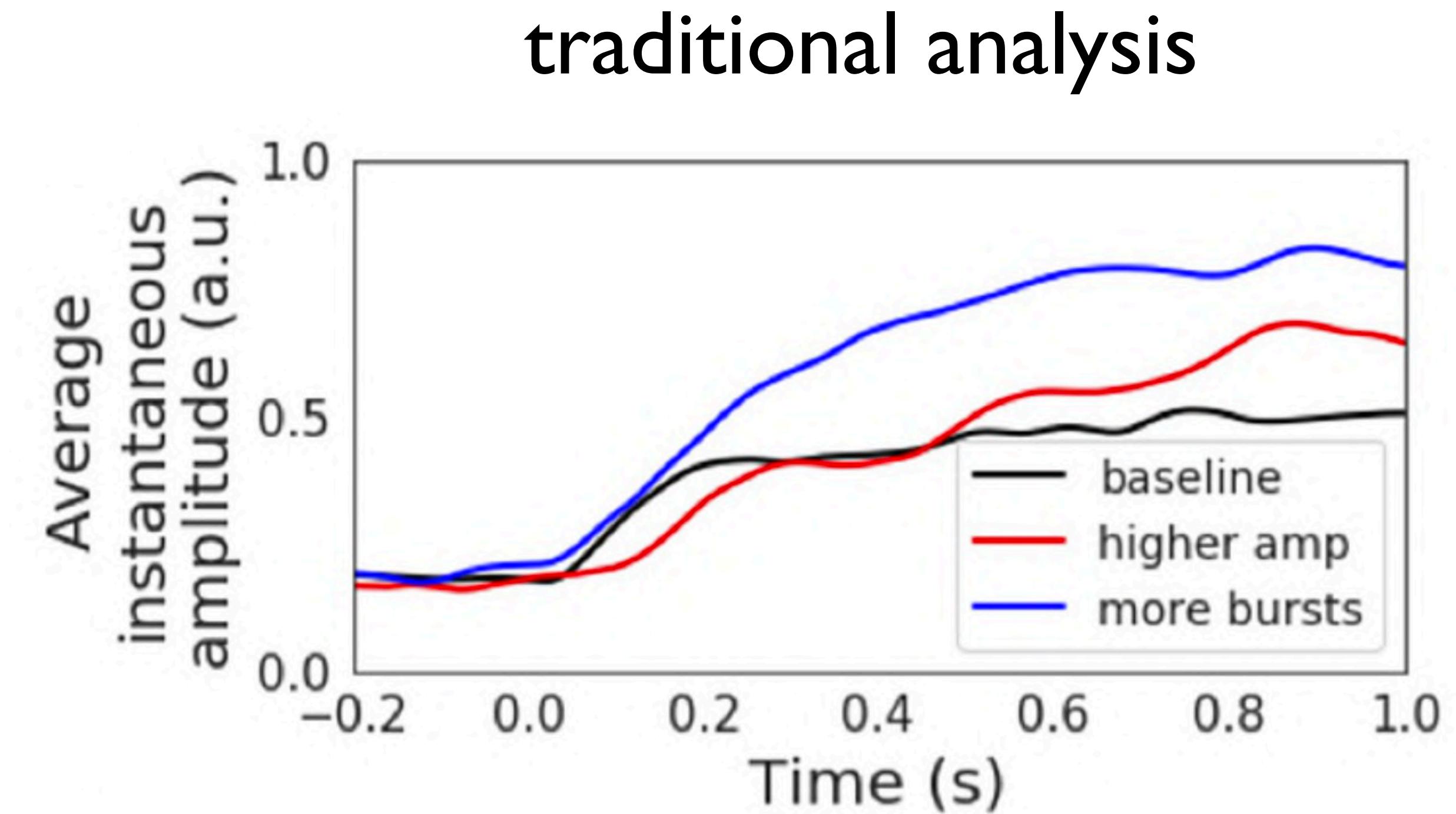
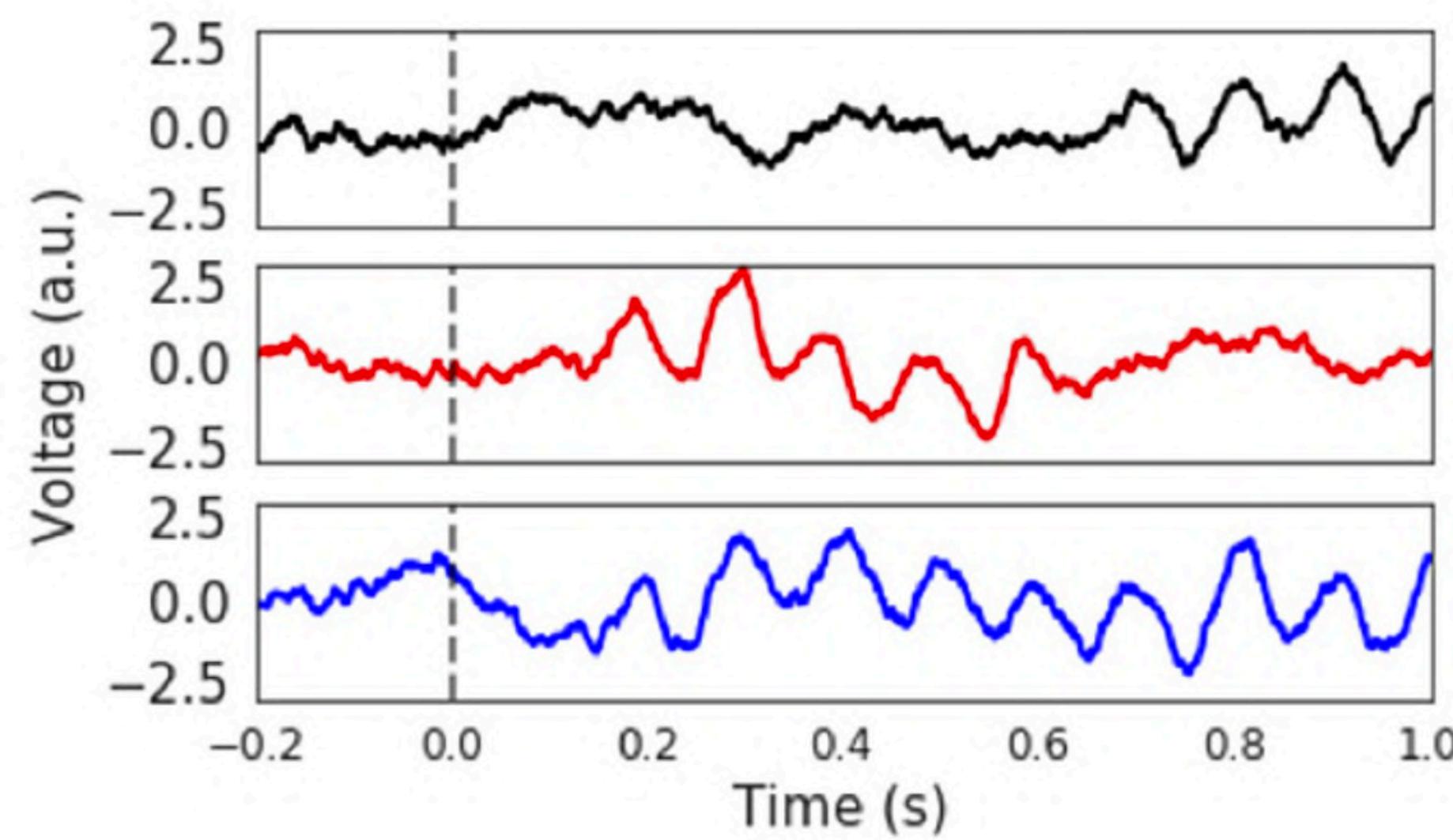
Nonsinusoidality influences our analyses

- Short oscillatory burst
- Higher amplitude burst
- Longer burst, same amplitude



Nonsinusoidality influences our analyses

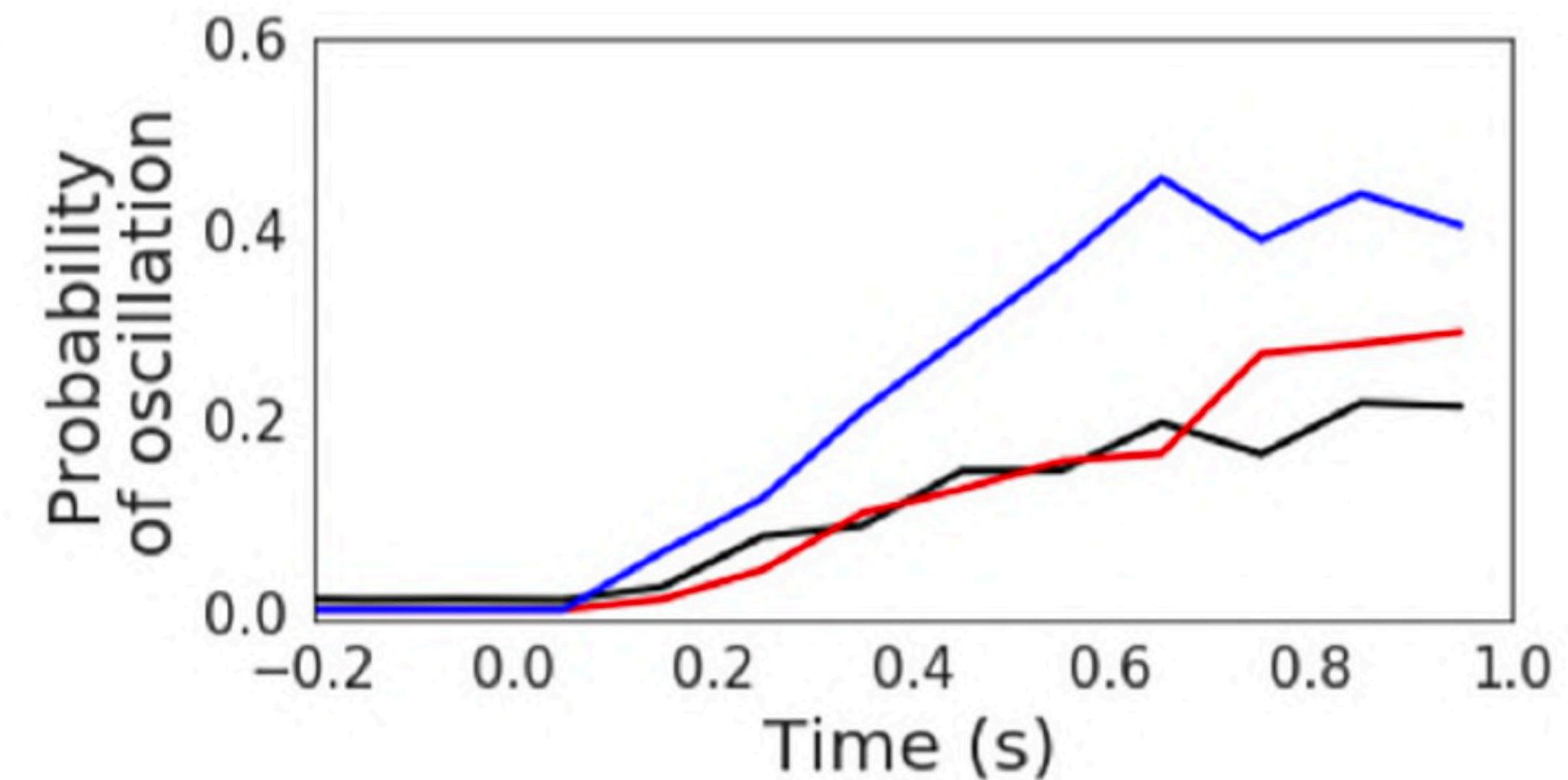
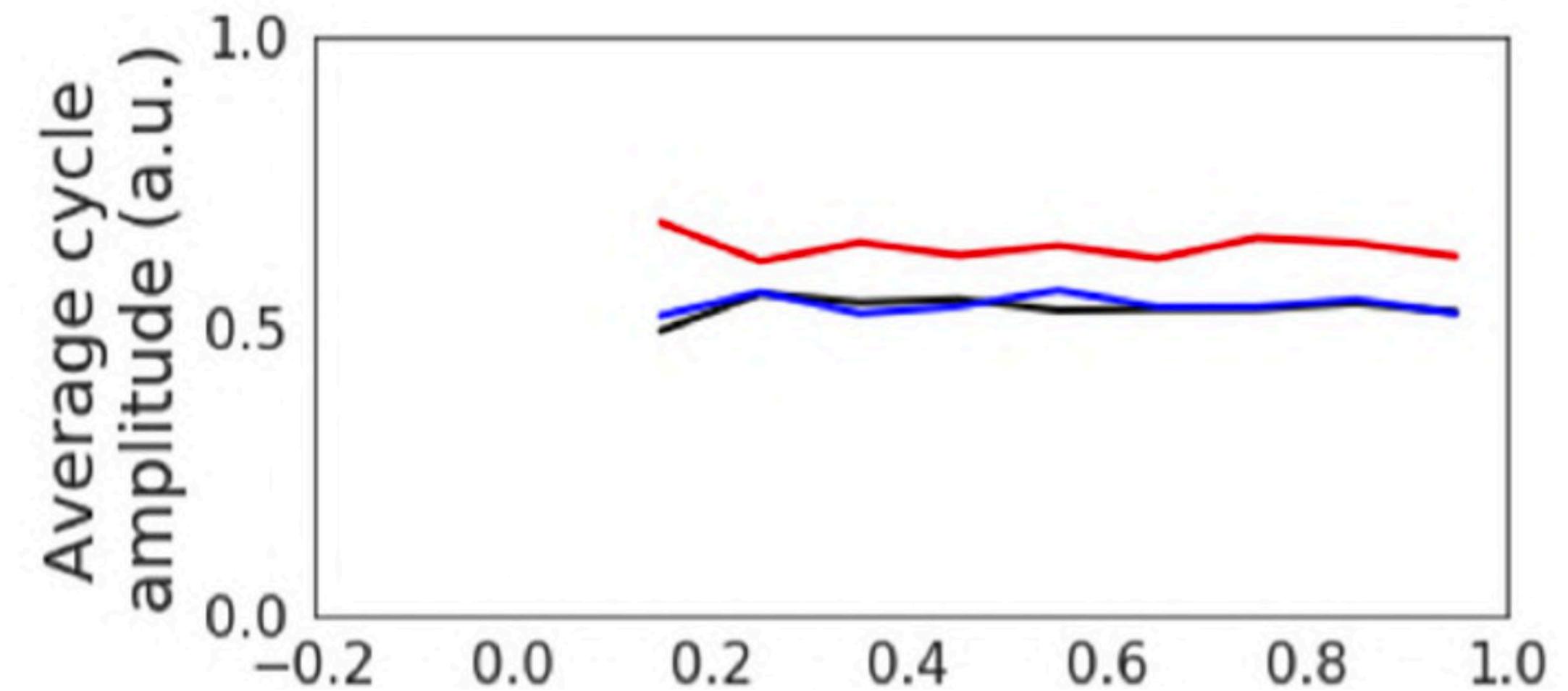
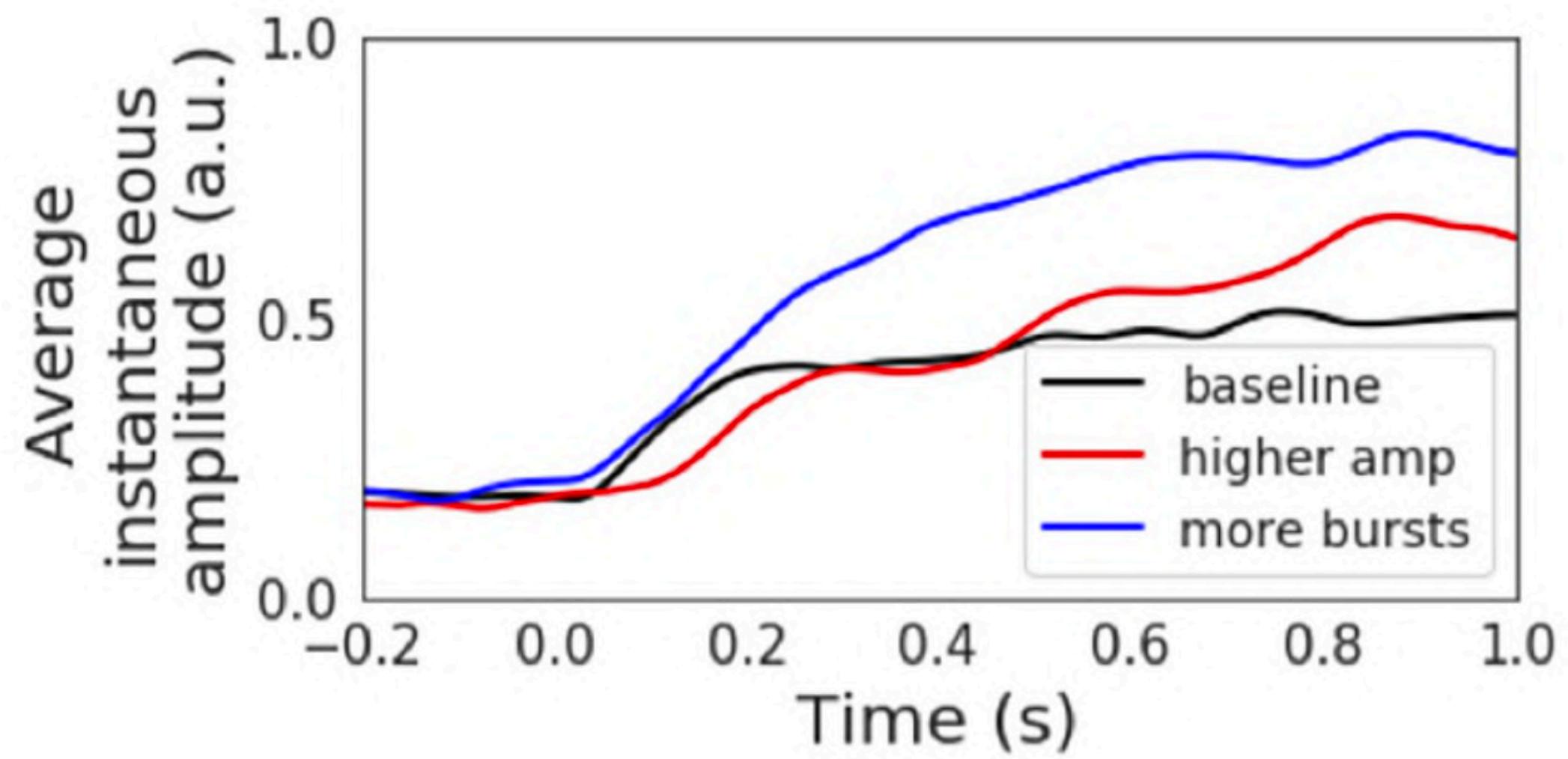
- Short oscillatory burst
- Higher amplitude burst
- Longer burst, same amplitude



**Conflates burst duration
with amplitude!**

bycycle mitigates these issues

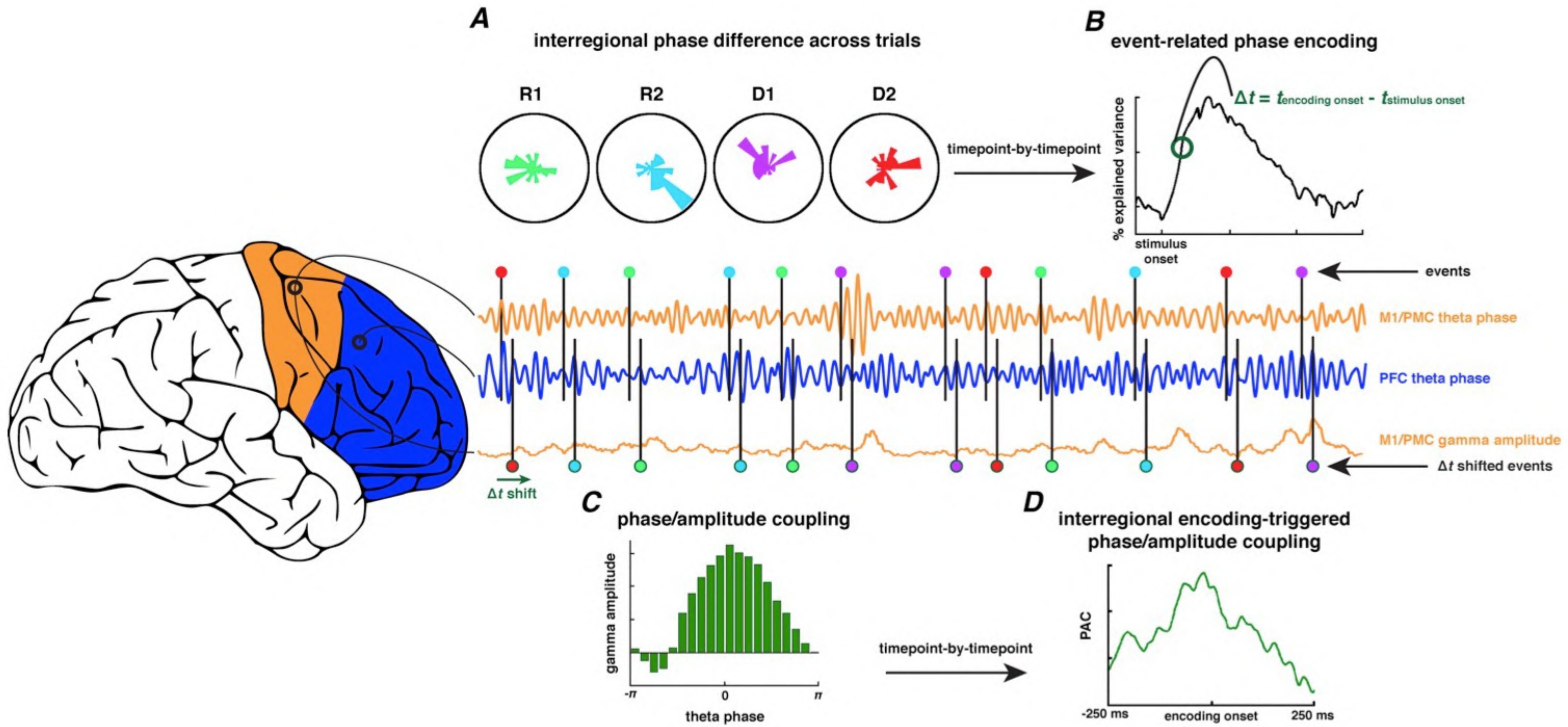
- Short oscillatory burst
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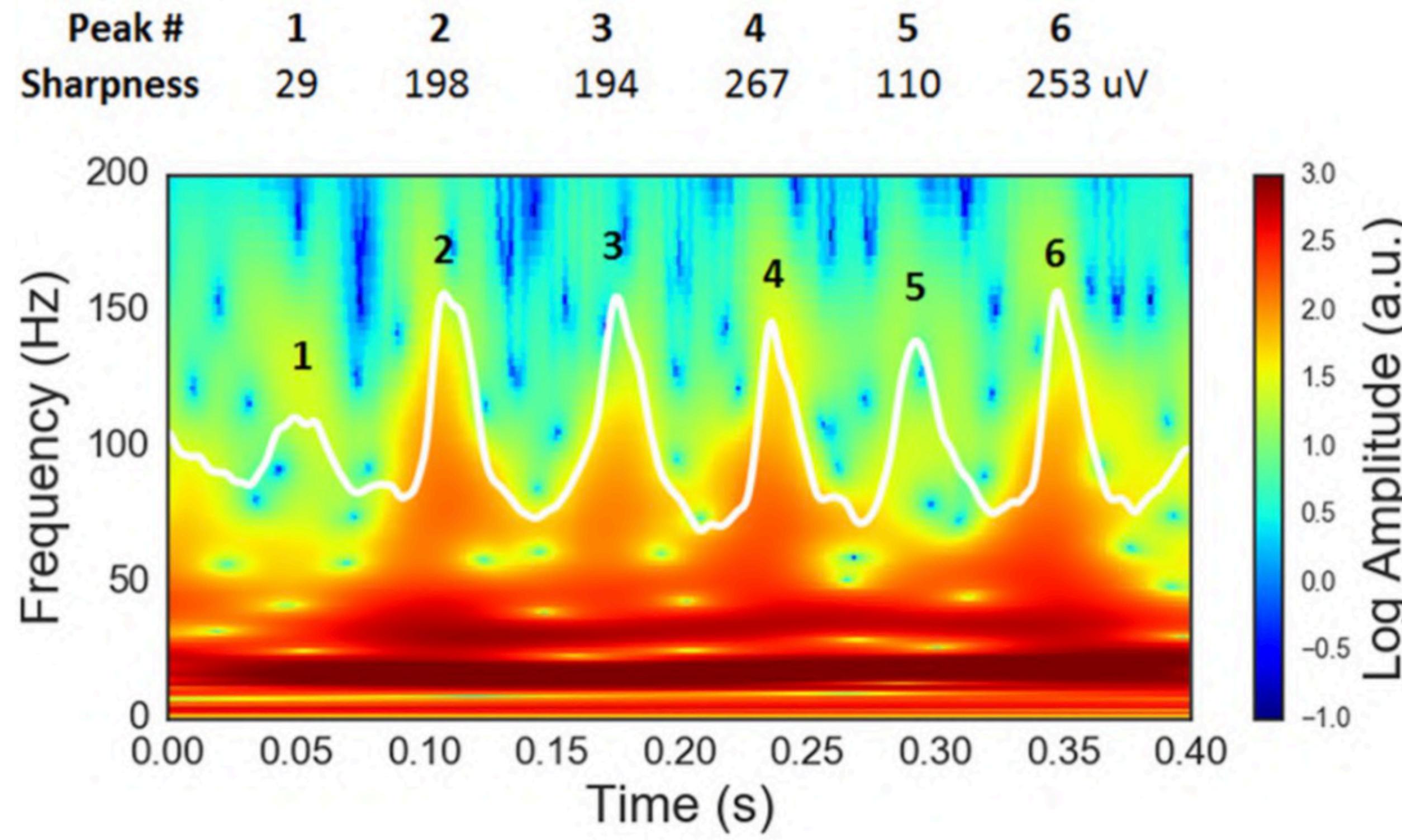
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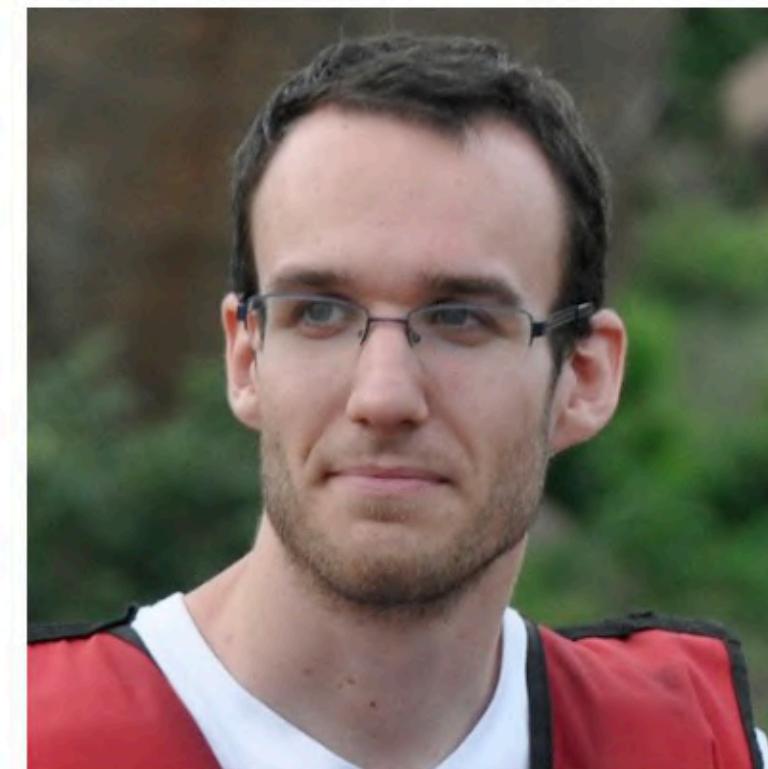
Phase/amplitude coupling



Nonsinusoidal waveforms in Parkinson's disease



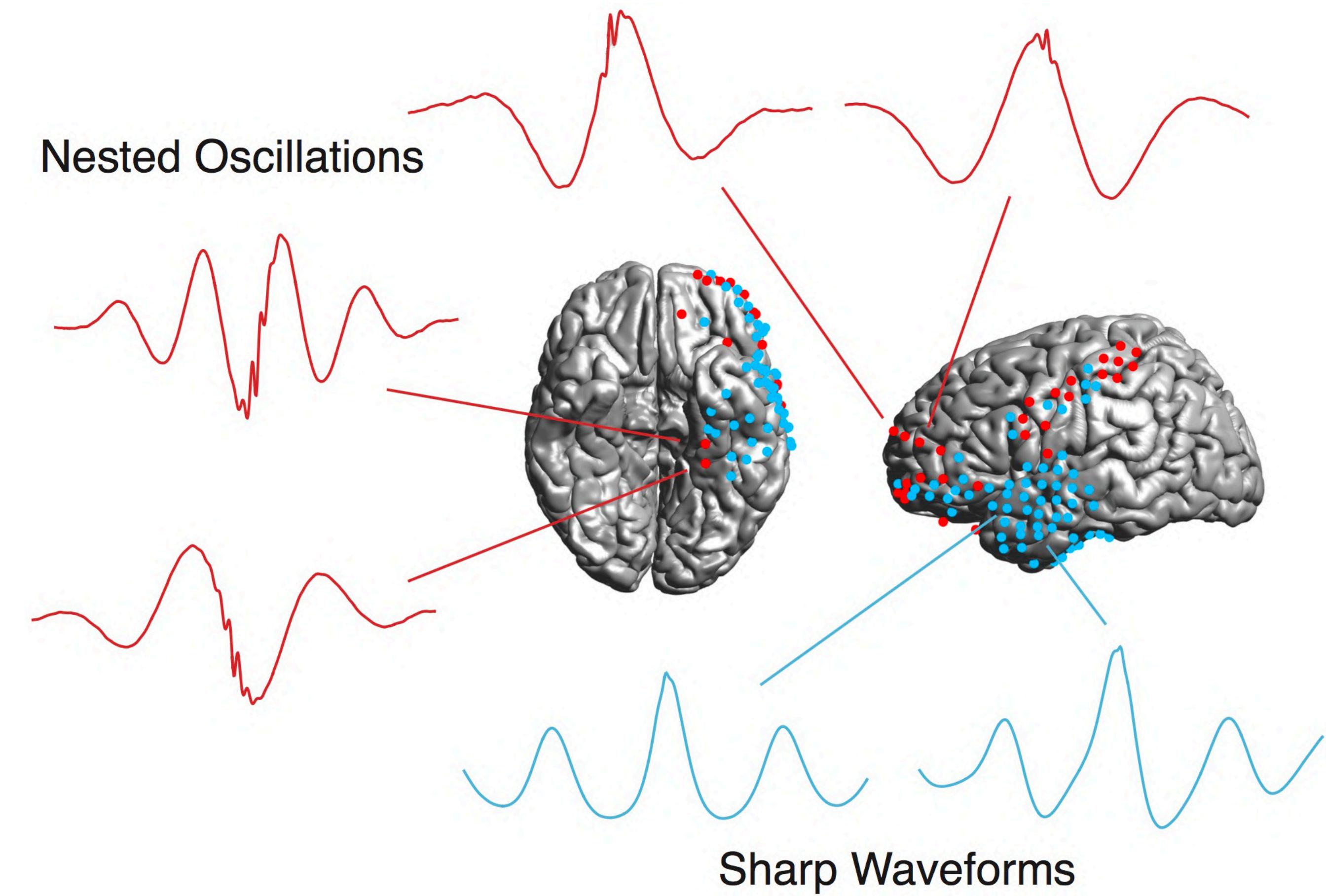
Scott Cole ([twitter](#), [web](#), [CV](#))
Formerly: PhD Student
Currently: Data Scientist, San Francisco



Postdoctoral
Researcher
Natalie Schawronkow



Not throwing the baby out!



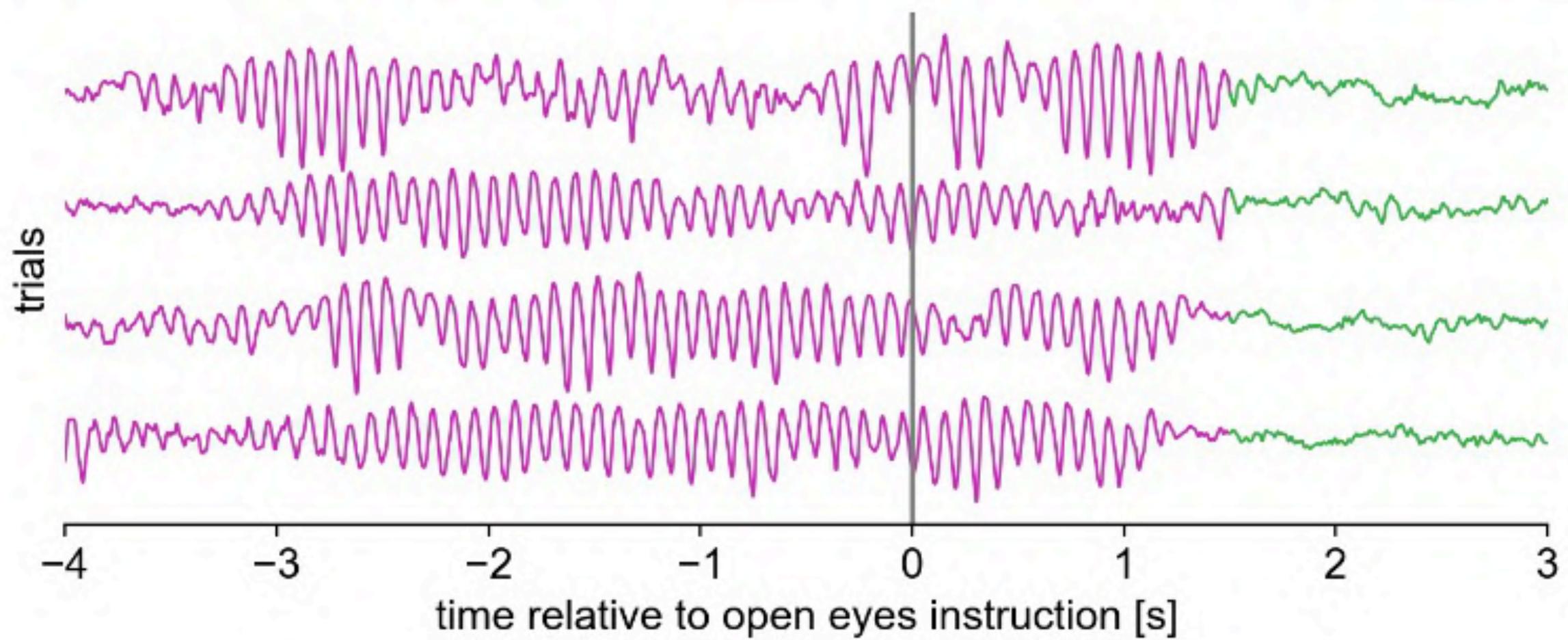
Andrew Bender



developmental changes in oscillations

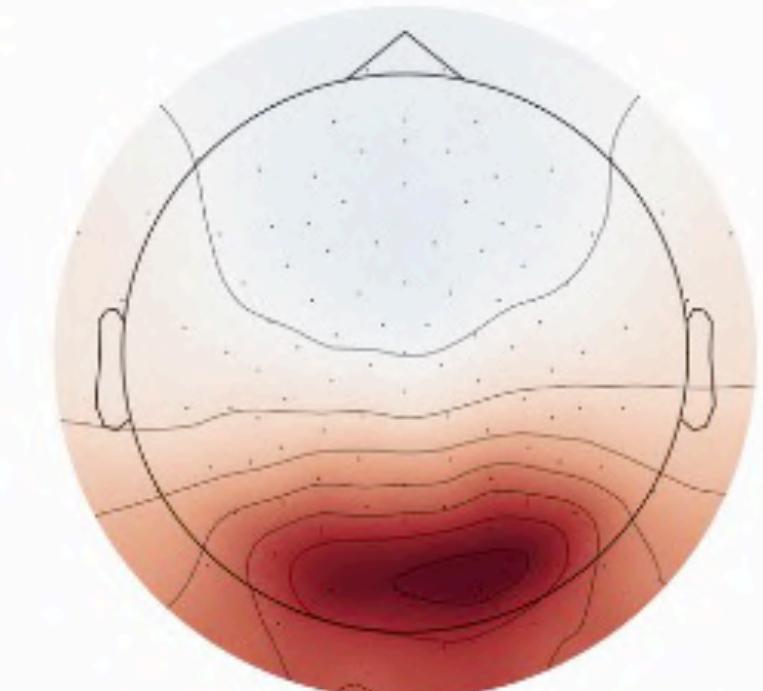
Alpha and mu oscillations

Alpha (8–13 Hz)

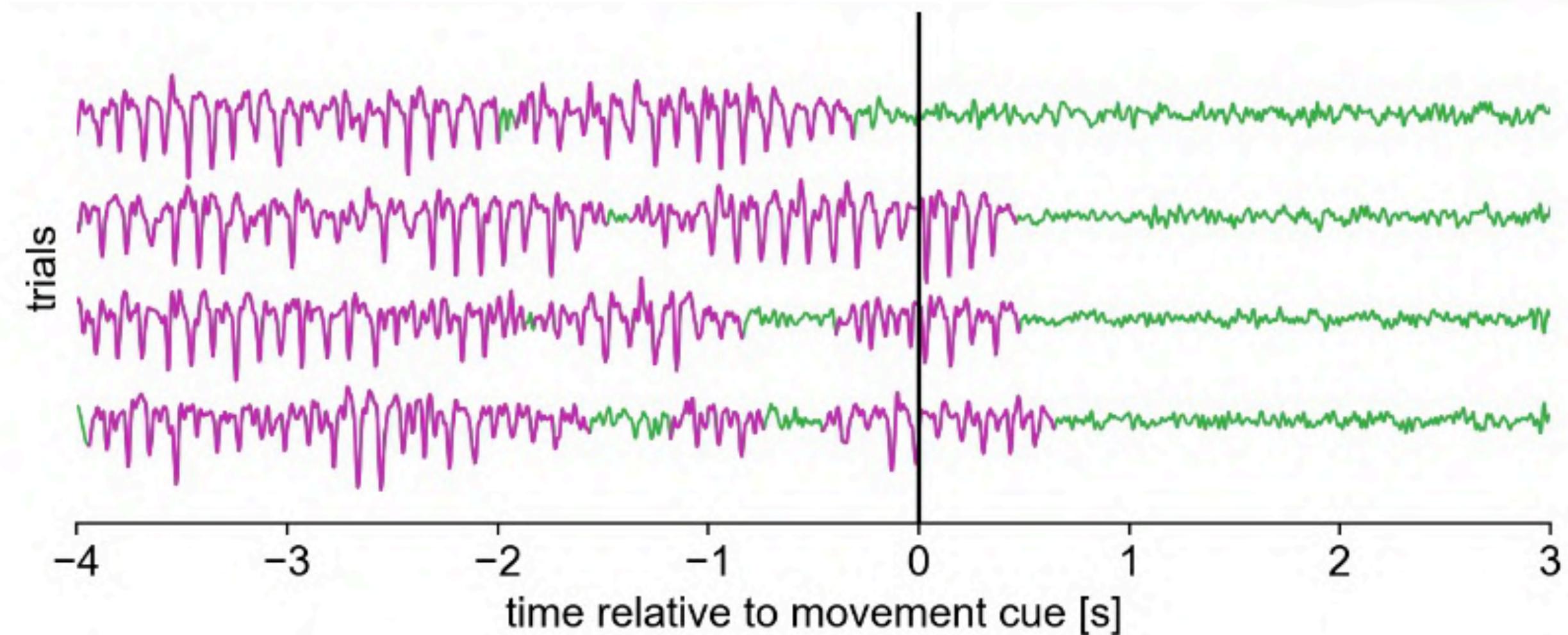


- Strongest when eyes closed

- Most prominent in occipital cortex

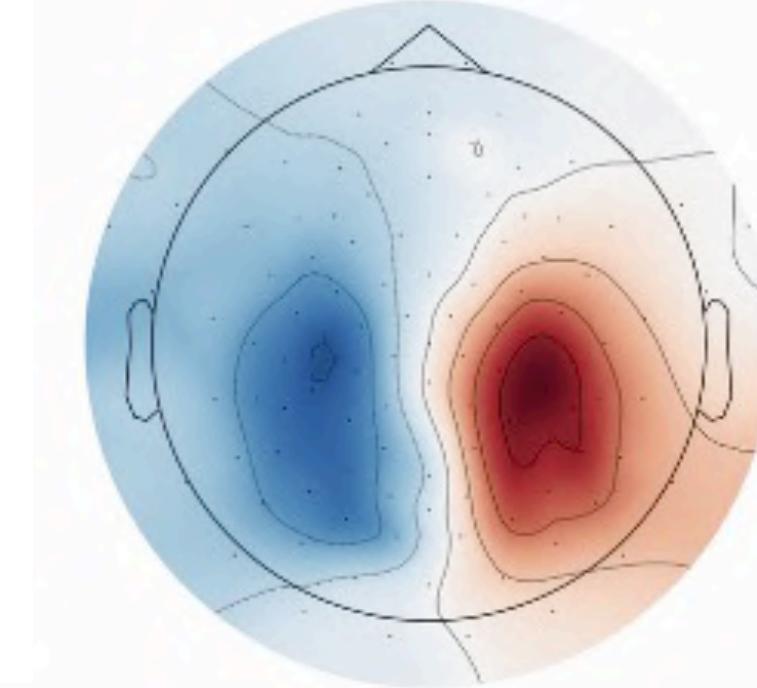


Mu (8–13 Hz)

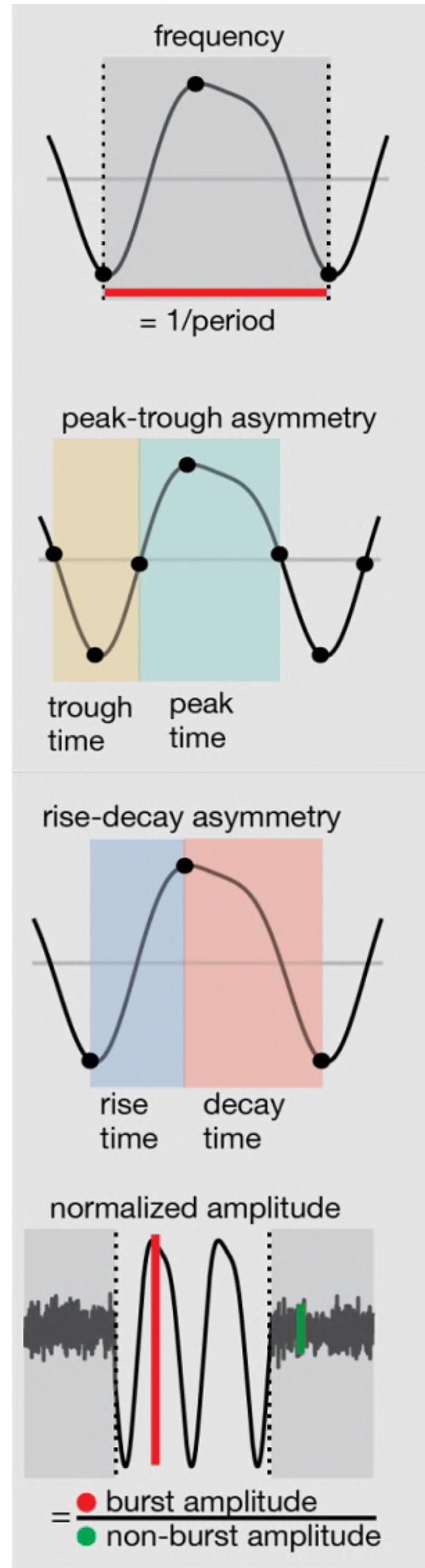
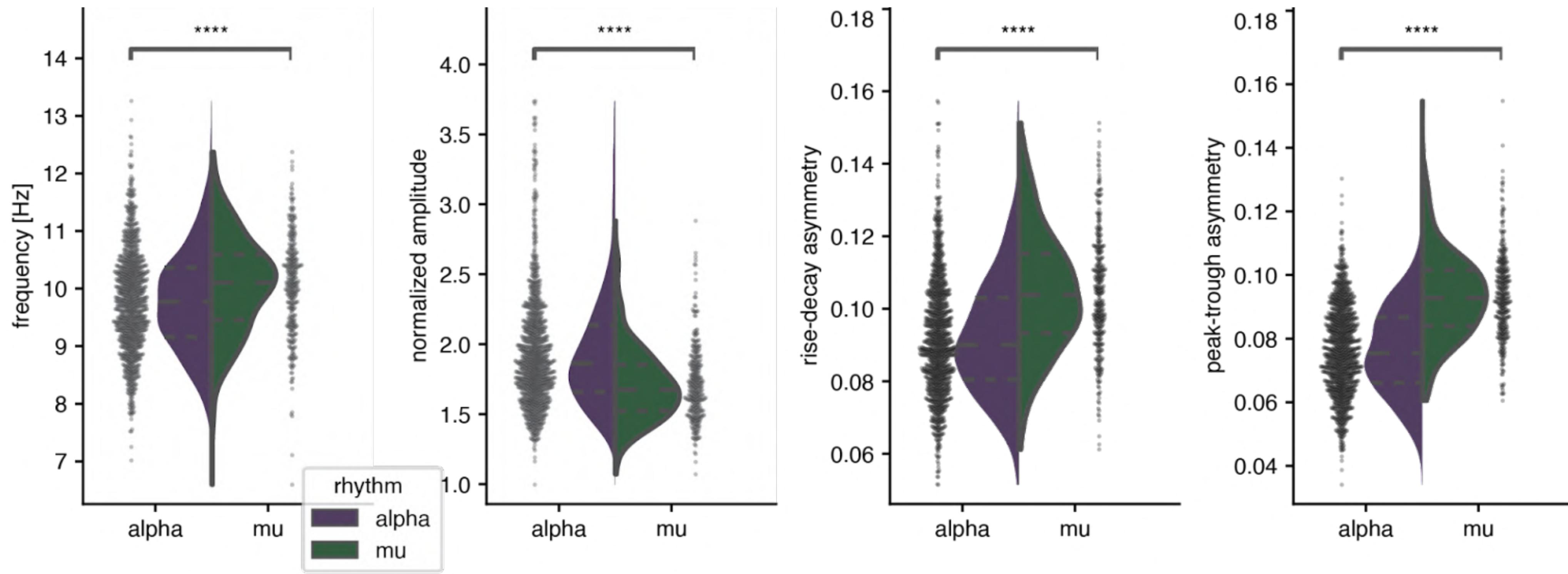


- Strongest when stationary

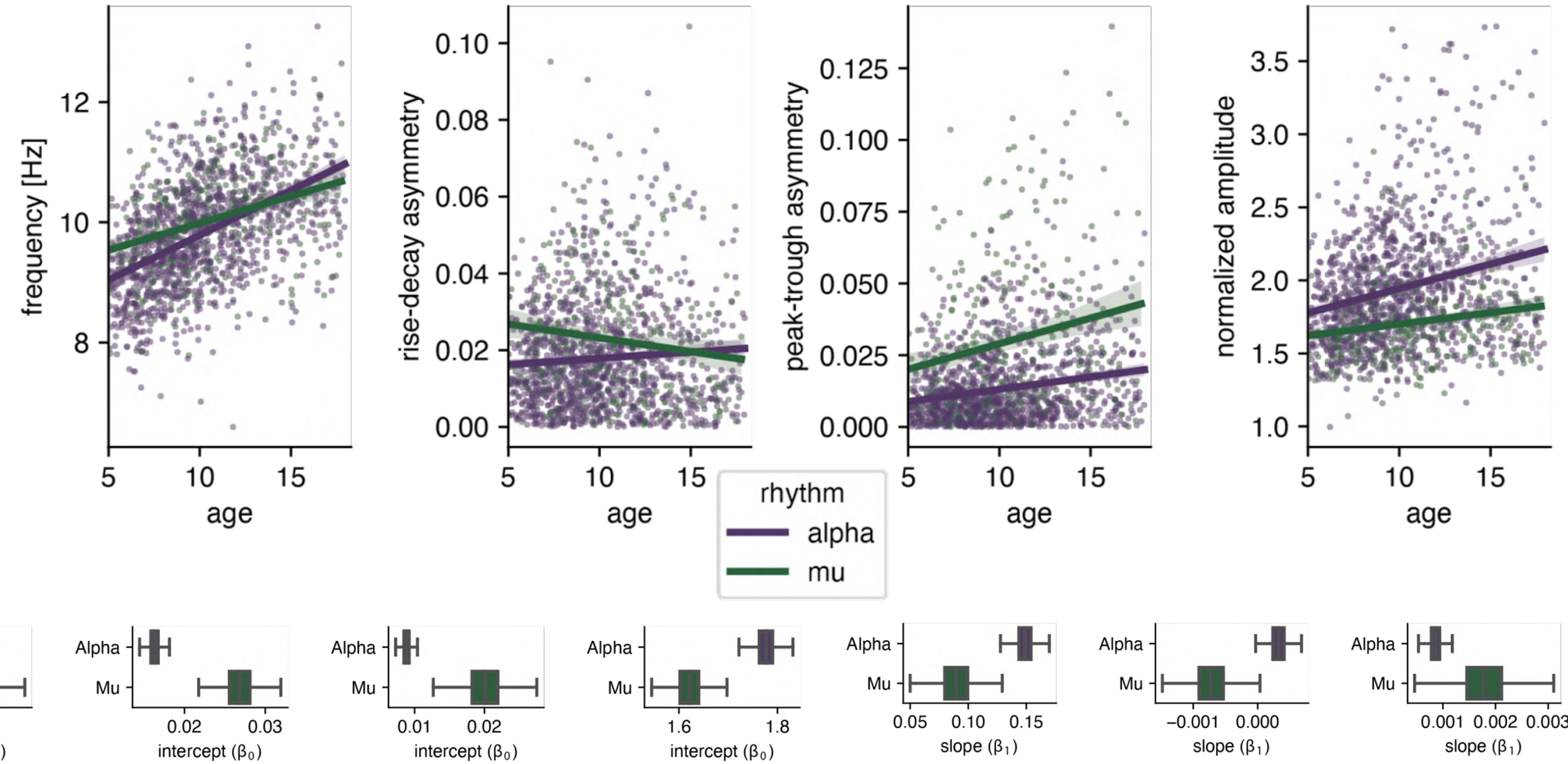
- Most prominent in sensorimotor cortex



Alpha and mu have significantly different waveform shape



Waveform shape of alpha and mu change differently across development

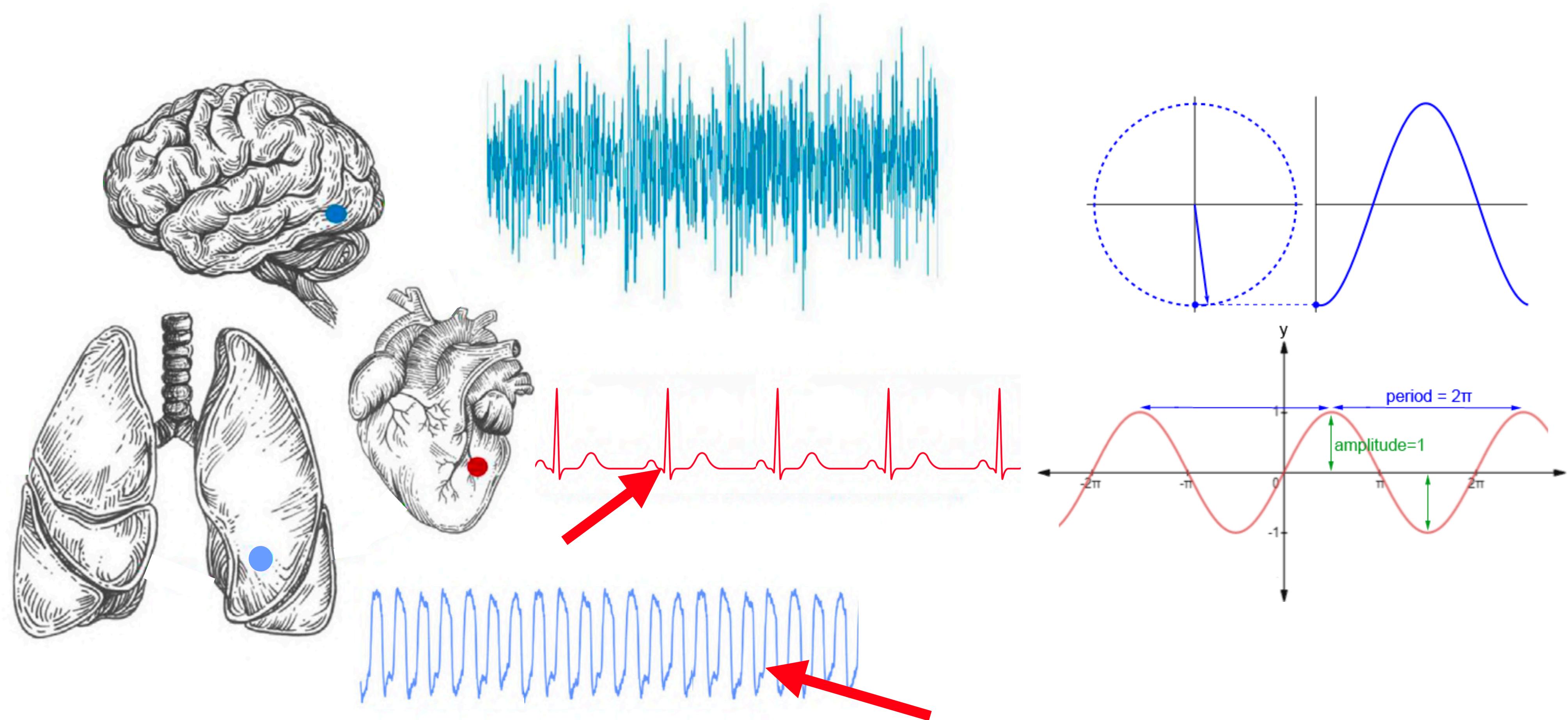


**It's not just neural oscillations
that are nonsinusoidal!**

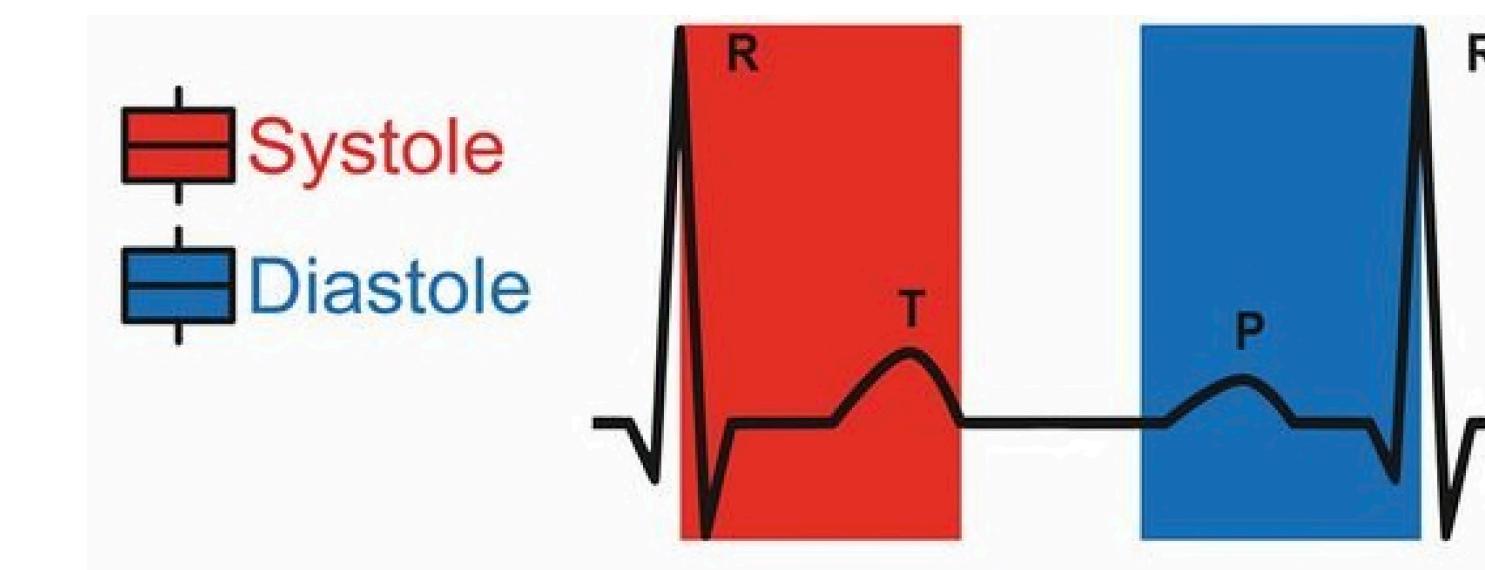
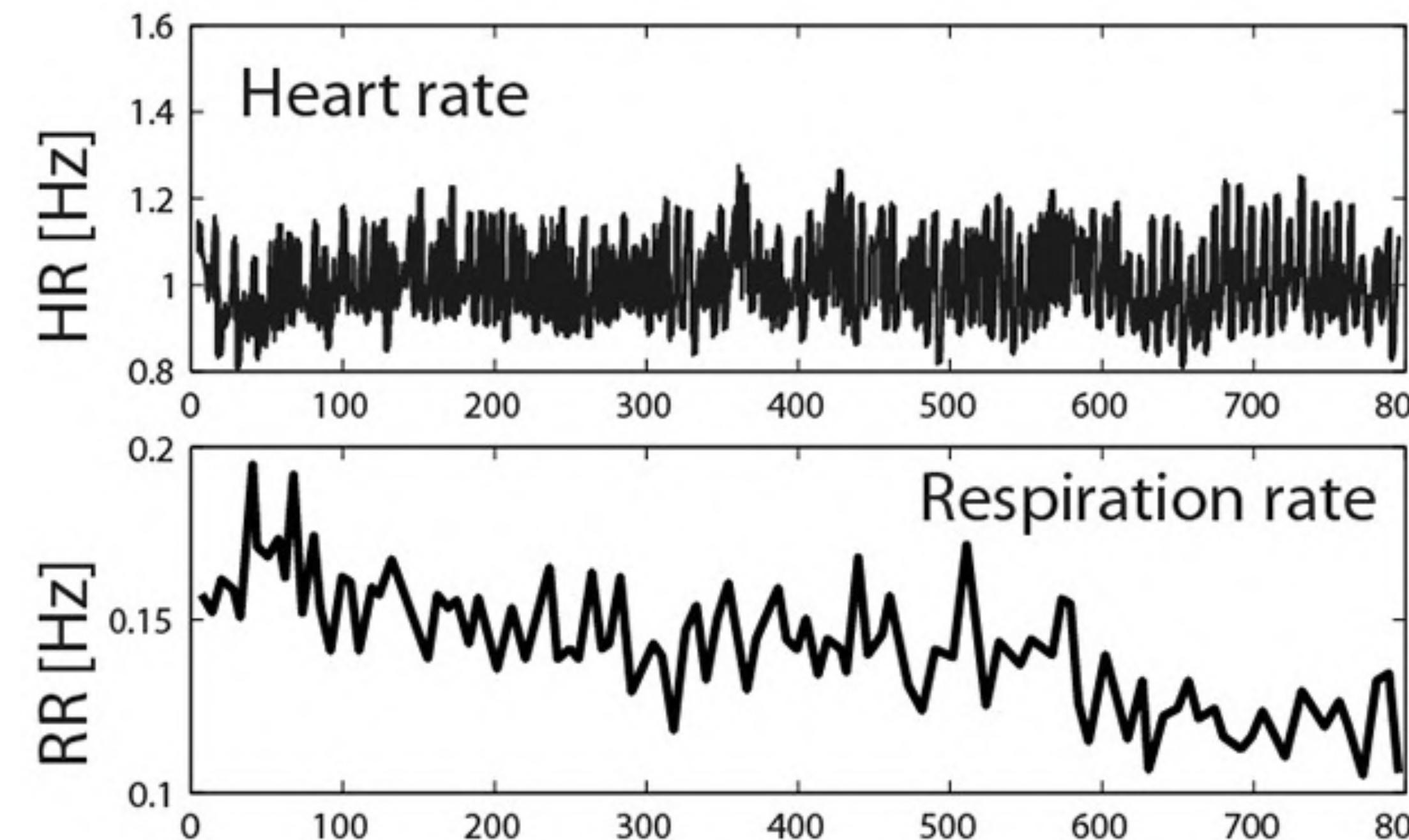
Eena Kosik



THESE PERIODIC RHYTHMS ARE ALSO NONSINUSOIDAL

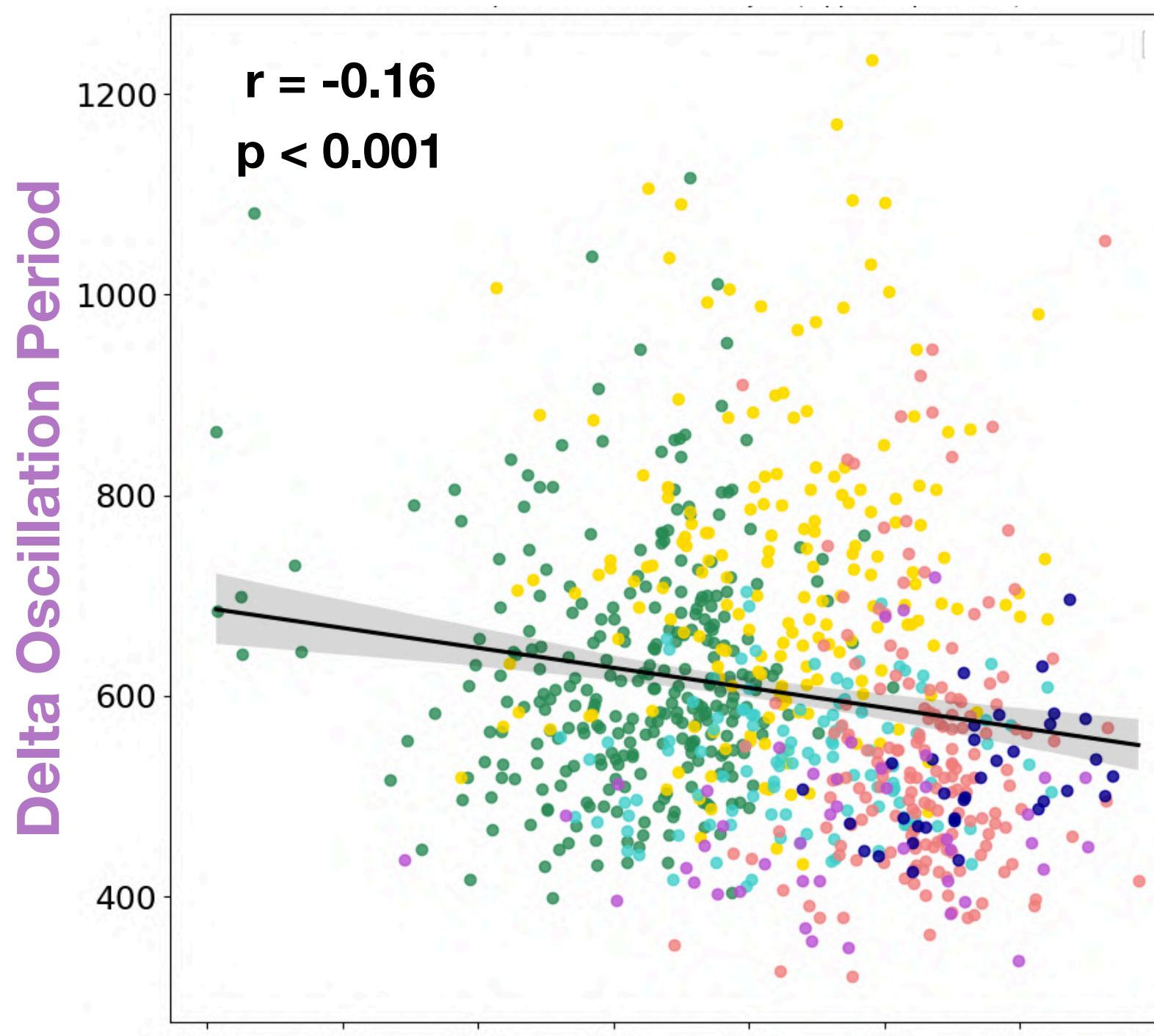


WHAT MIGHT WE BE MISSING FROM RESPIRATORY AND CARDIAC WAVEFORM SHAPES?

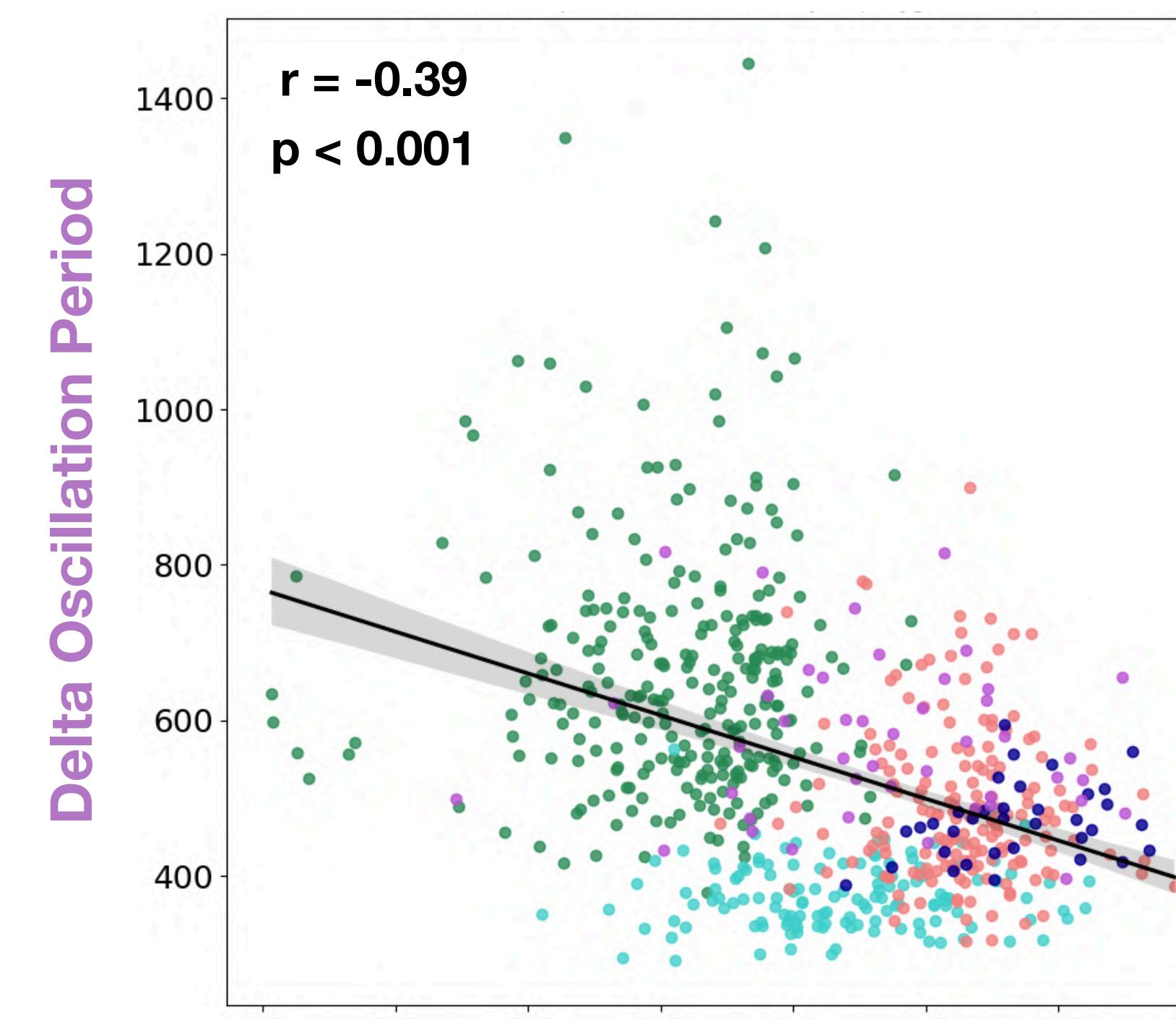


RESPIRATION WAVEFORM ASYMMETRIES CORRELATE WITH HIPPOCAMPUS AND AMYGDALA DELTA PERIOD

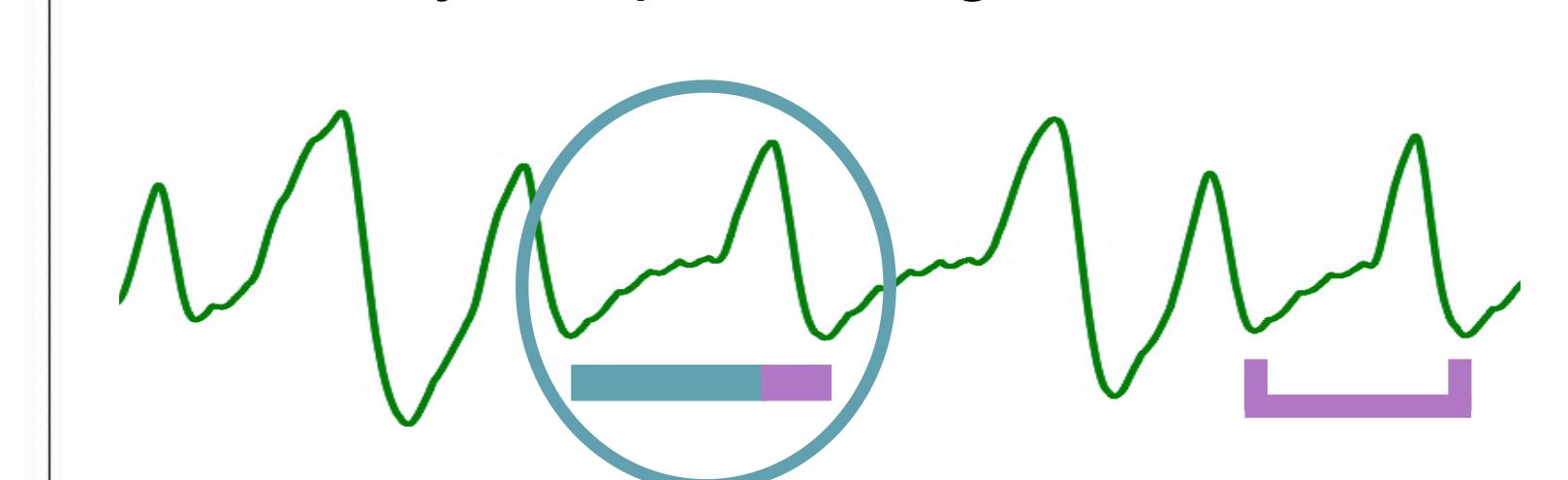
Hippocampus



Amygdala



Rise-Decay Symmetry:
time in cycle spent rising



Period: duration of the cycle

- | | |
|-----------------|-----------------|
| ● Participant 1 | ● Participant 4 |
| ● Participant 2 | ● Participant 5 |
| ● Participant 3 | ● Participant 6 |

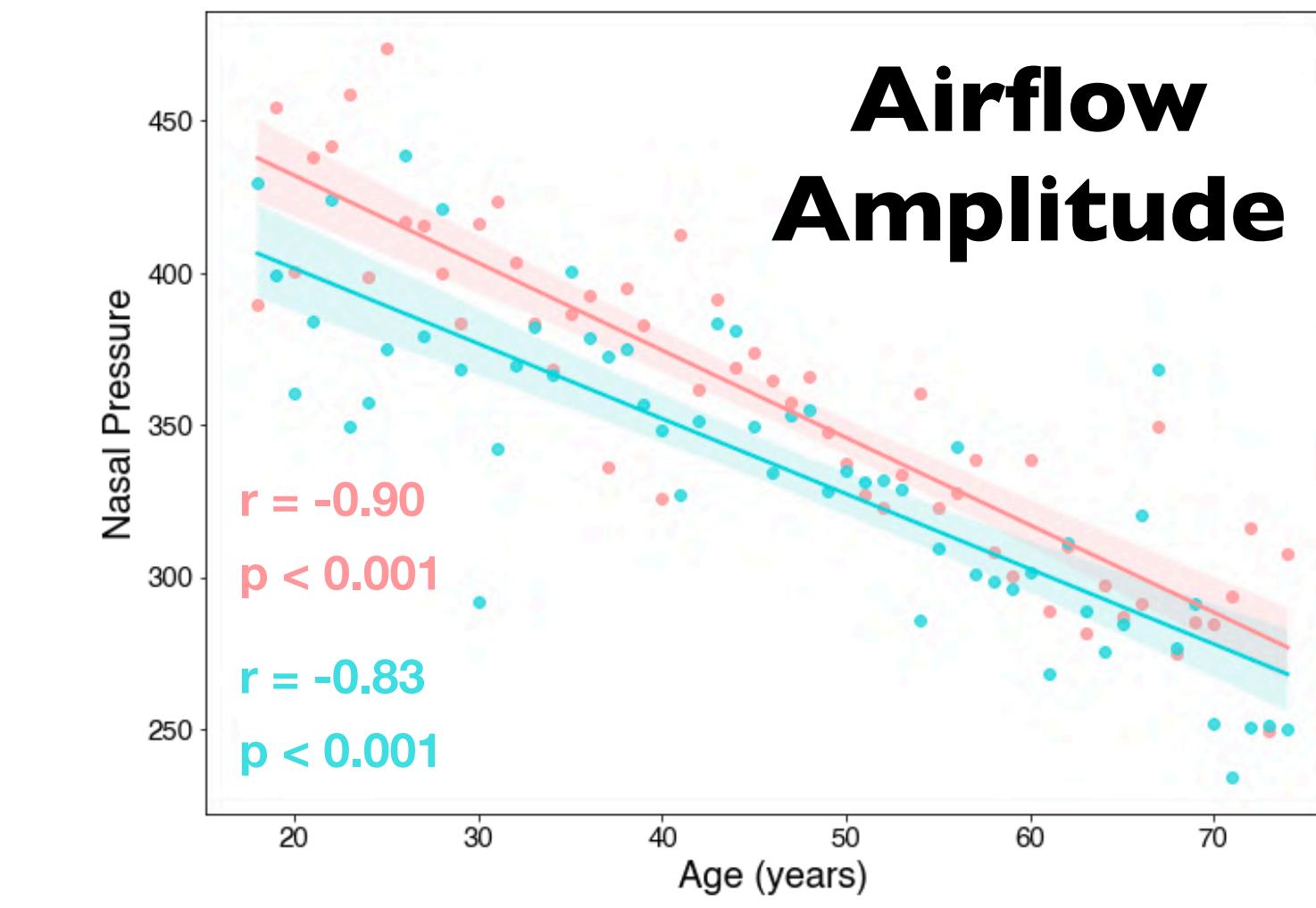
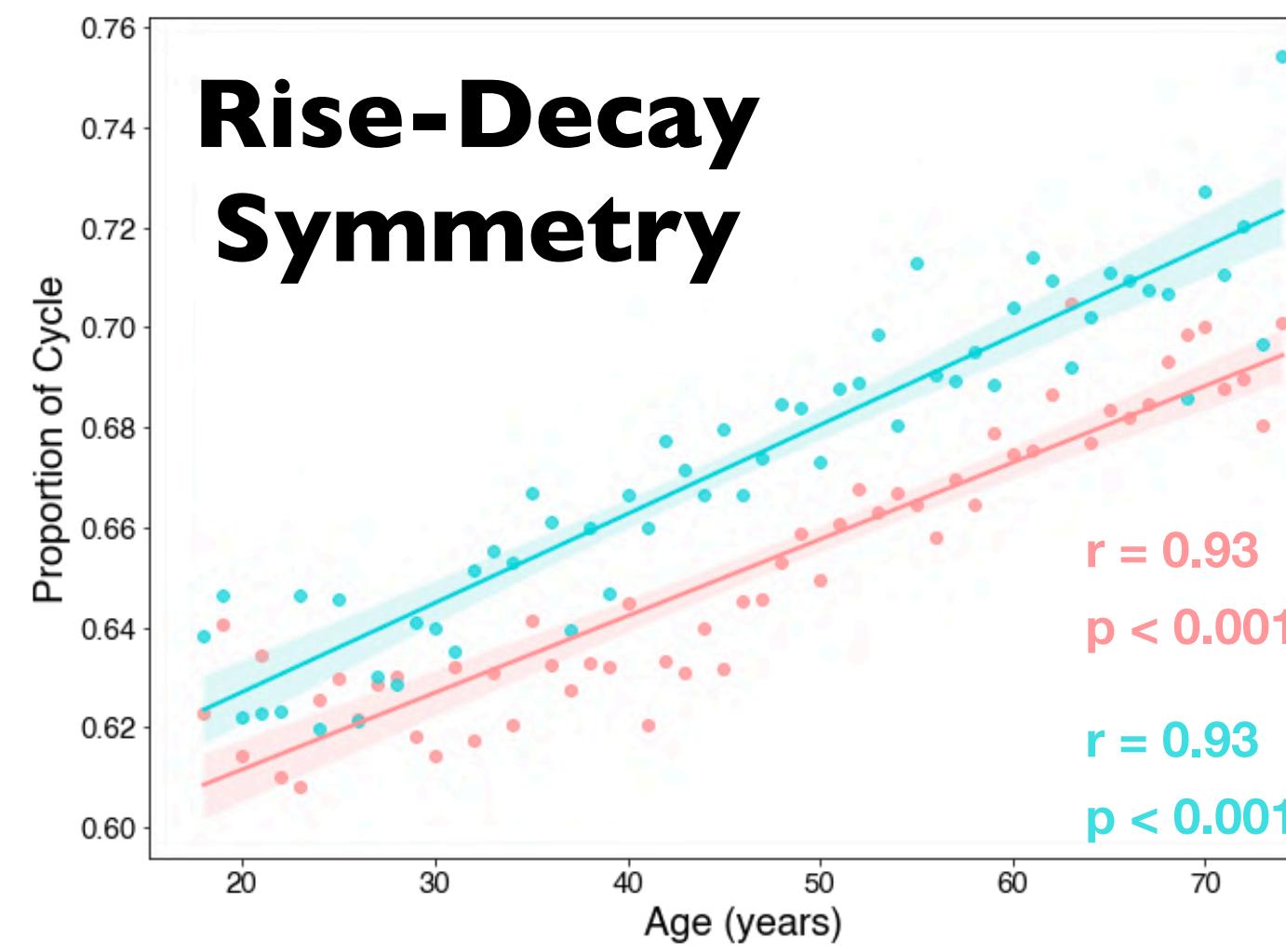
Respiration Rise-Decay Symmetry

Respiration Rise-Decay Symmetry

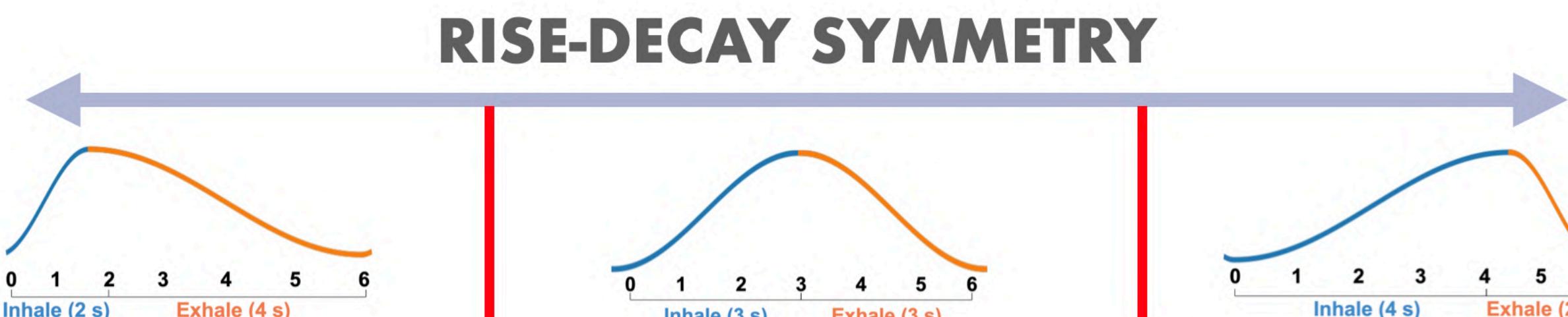


RESPIRATORY FEATURES CHANGE ACROSS THE LIFESPAN AND DIFFER BETWEEN SEXES

N = 10,175



- Male
- Female



Younger
Lower rise-decay symmetry?

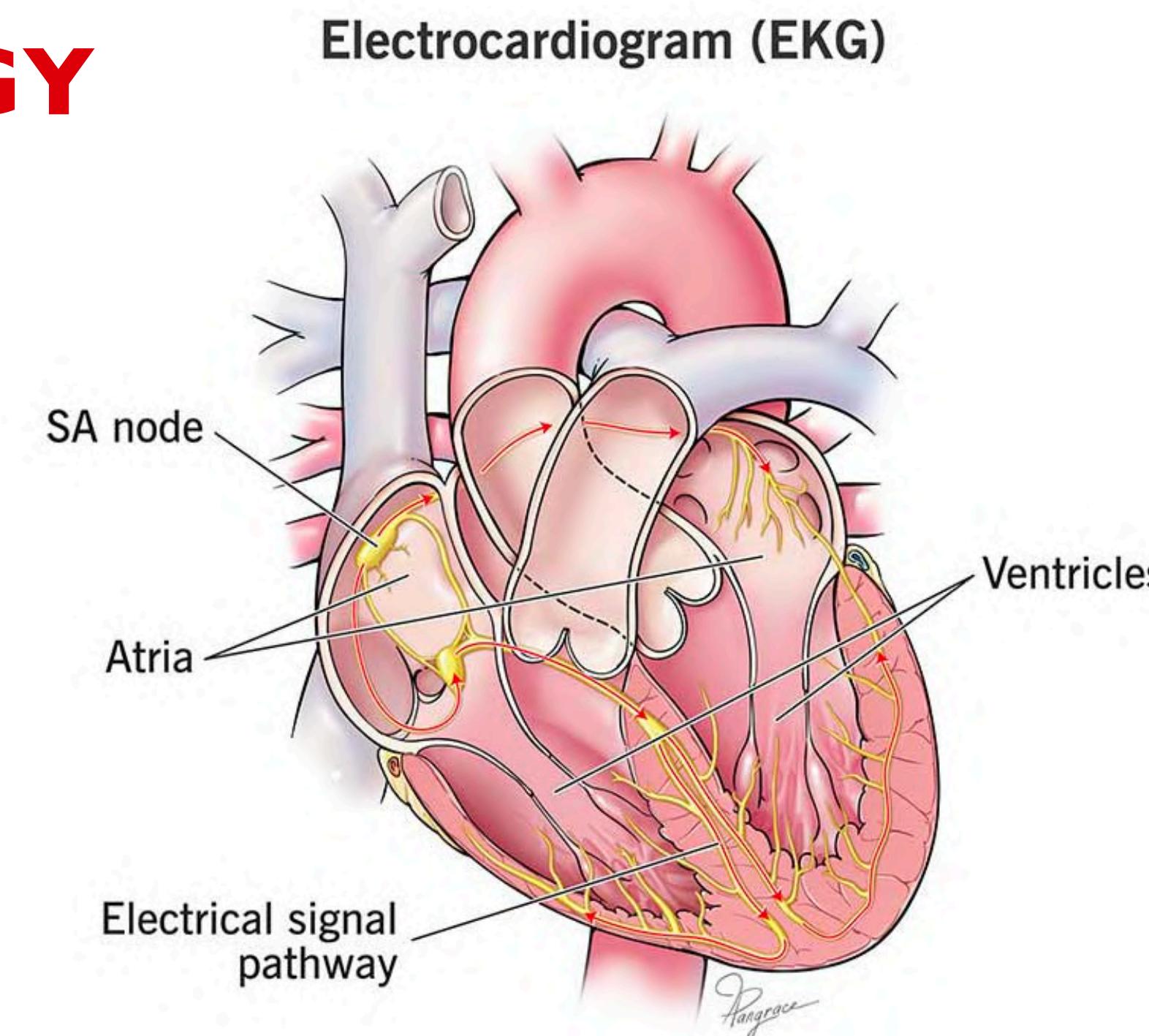
Female

Male

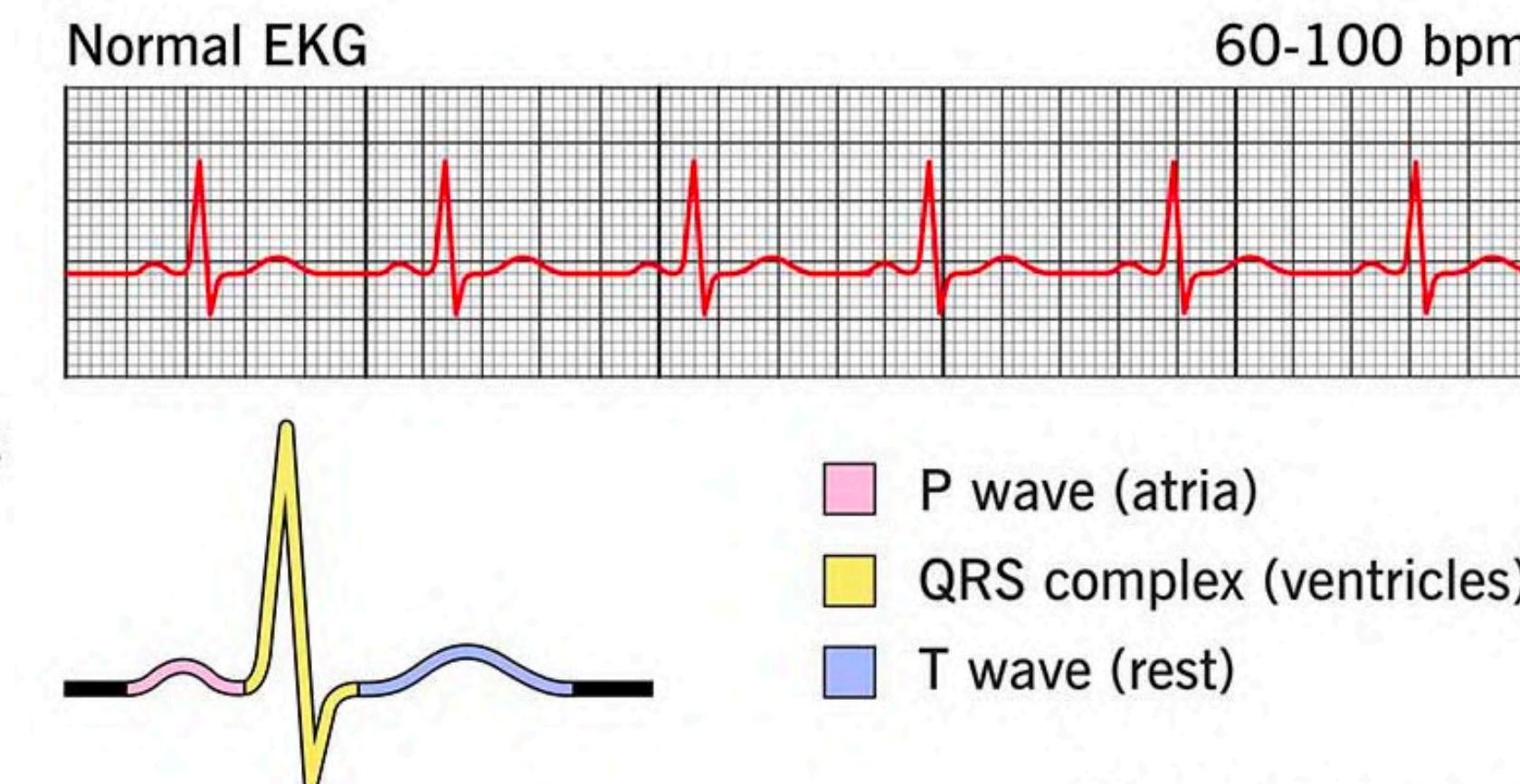
Older
Higher rise-decay symmetry?

ECG: A DECEIVINGLY SIMPLE SIGNAL

CARDIOLOGY

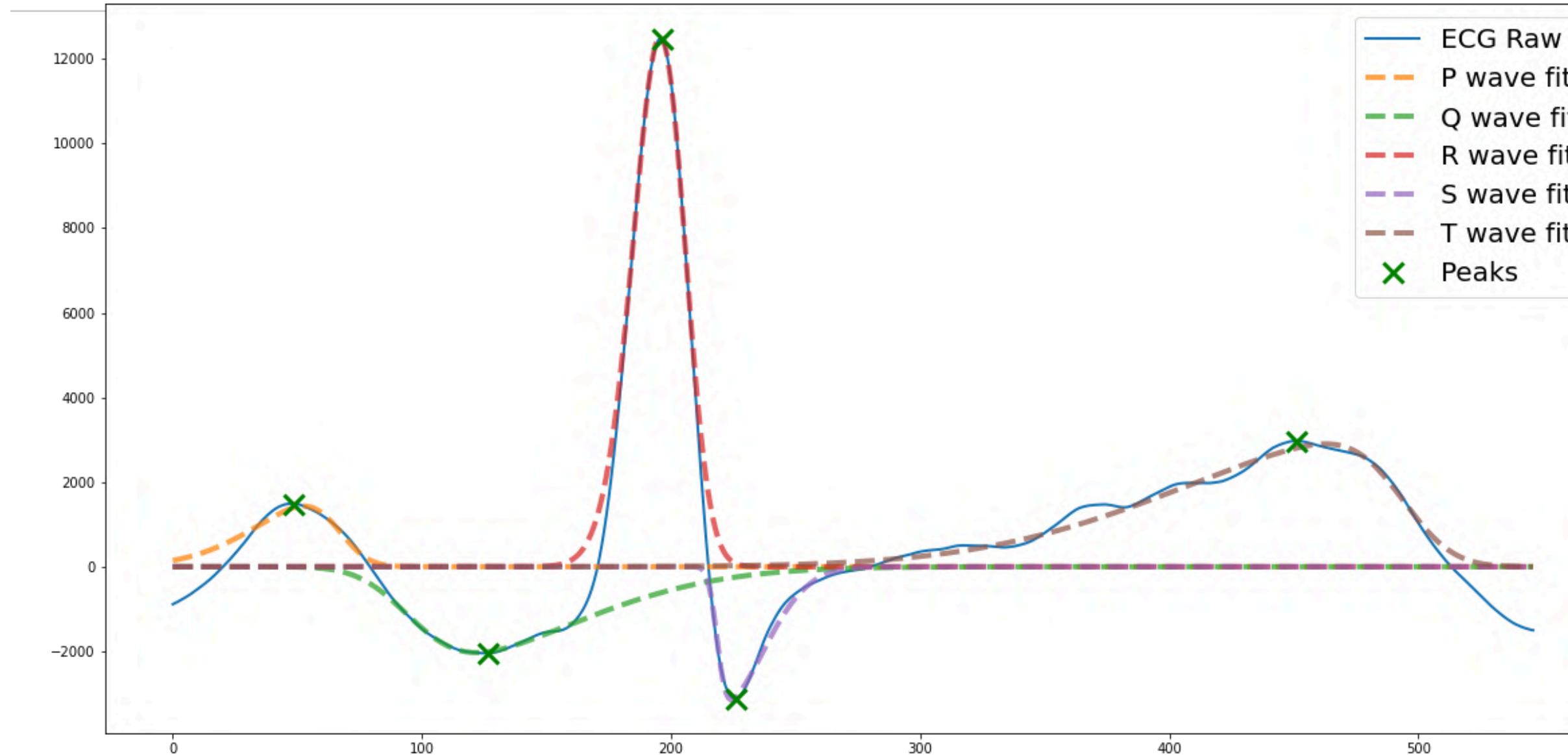


PSYCHOPHYSIOLOGY



ENGINEERING

ALTERNATE APPROACH TO EGG



What else can we learn
from this signal and how it
relates to the brain,
behavior, disease, etc.?

cycle	P_height	P_center	P_bw	P_skew	Q_height	Q_center	Q_bw	Q_skew	R_height	etc.
0	2600.96	55.67	32.88	-0.05	-1236.11	102.92	176.98	-0.24	12036.08	...
1	1987.77	62.03	47.21	0.78	-2087.93	156.98	193.46	0.87	11867.34	...
2	2334.65	49.89	45.65	-0.19	-1984.09	132.16	181.65	0.63	9647.66	...

Outline

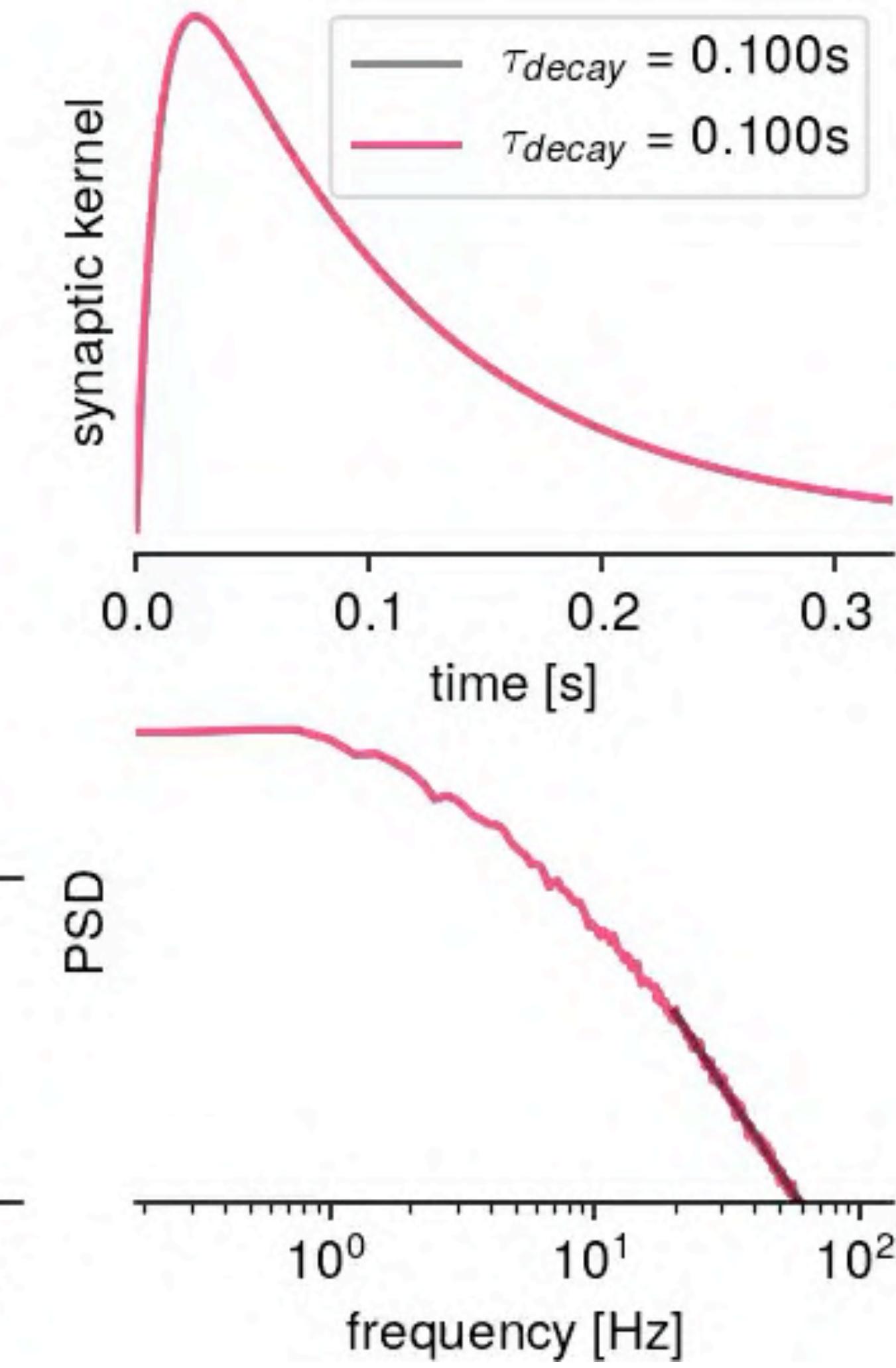
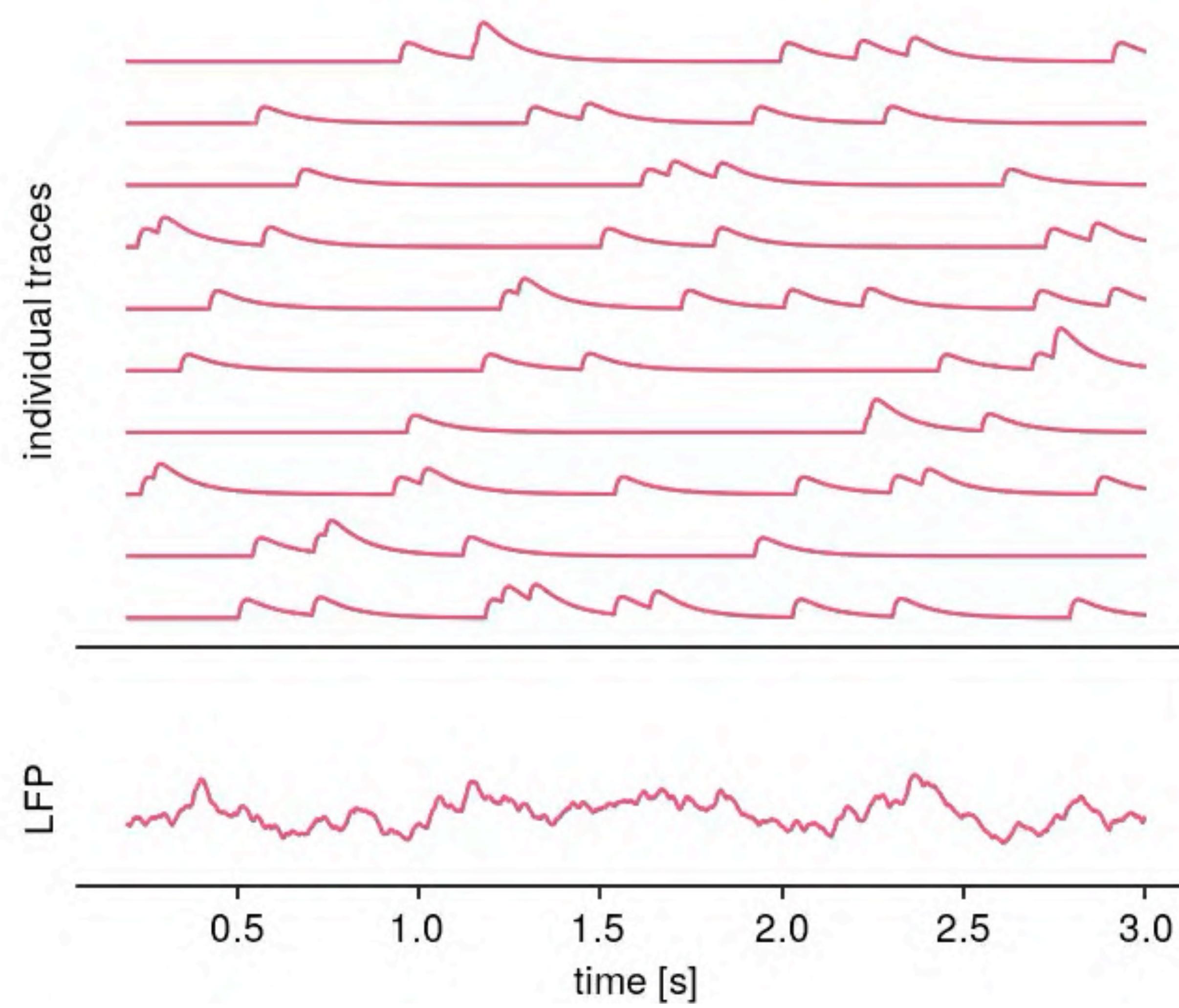
1. Oscillations: origin & measurement
2. Spectral Parameterization
3. Cycle-by-cycle waveform analysis
4. Waveform shape
 - Cross-frequency coupling & Parkinson's
 - Nonsinusoidal oscillations in development
 - Waveform shape in the periphery
5. Aperiodic activity
 - **Physiology & E/I balance**
 - **Dynamics & event-related changes**
 - **Cognitive applications**
 - **Clinical relevance**

What is I/f really?

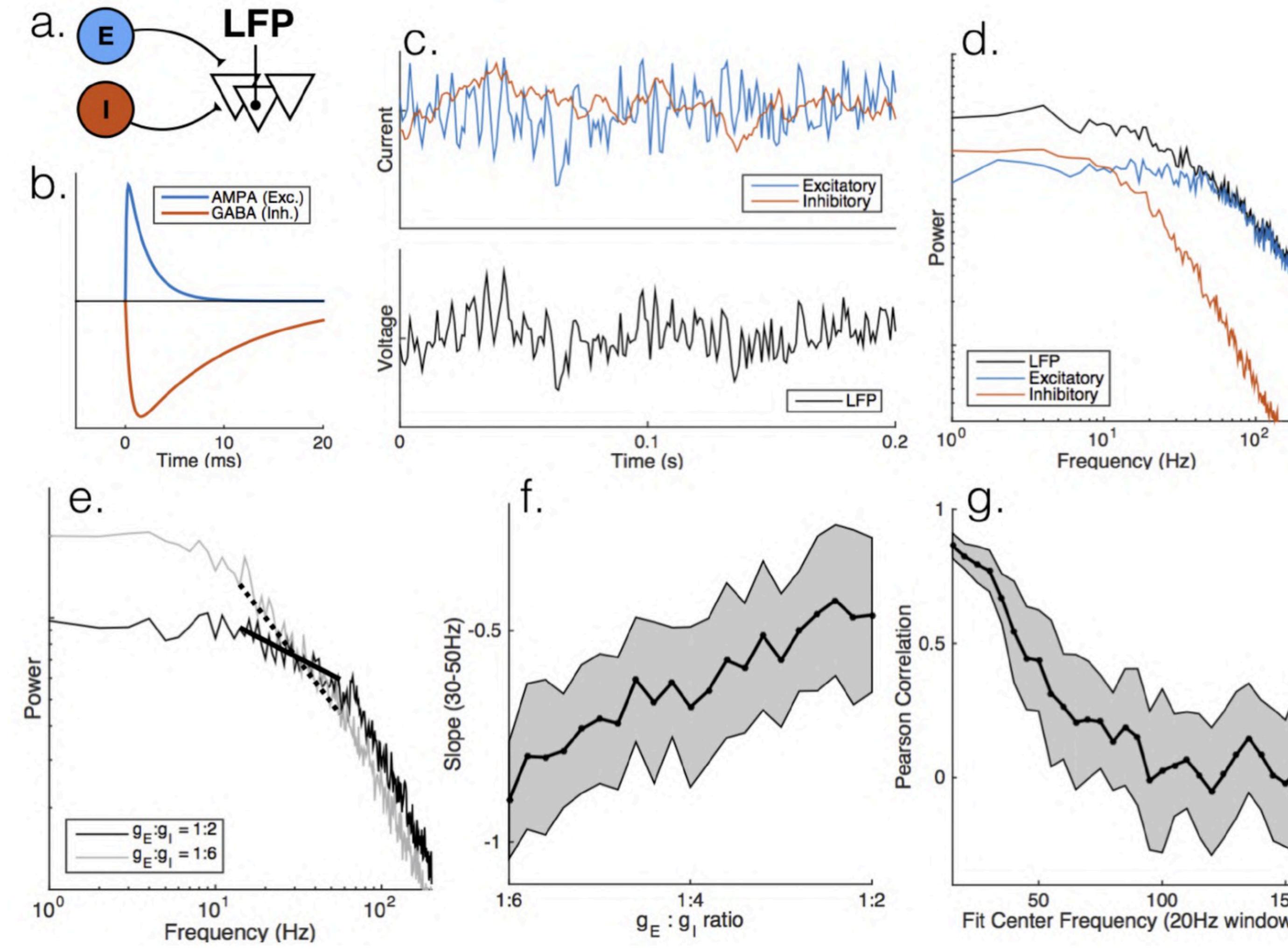
- Scale-free
- Fractality
- Self-organized criticality
- Long-term memory / long-range temporal correlation
- Power-law activity
- I/f noise
- Aperiodic

What is aperiodic activity?

Origin of LFP / EEG



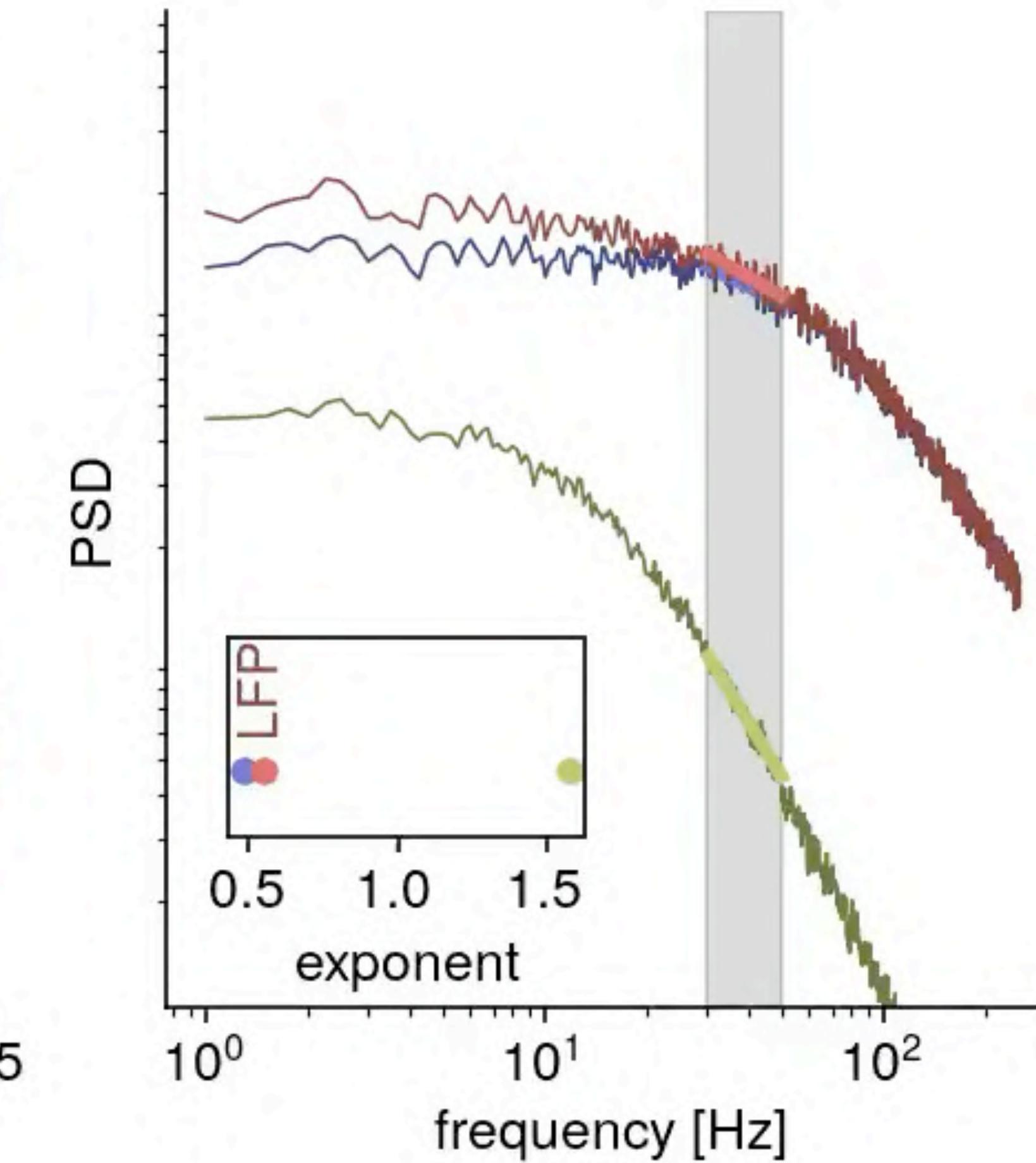
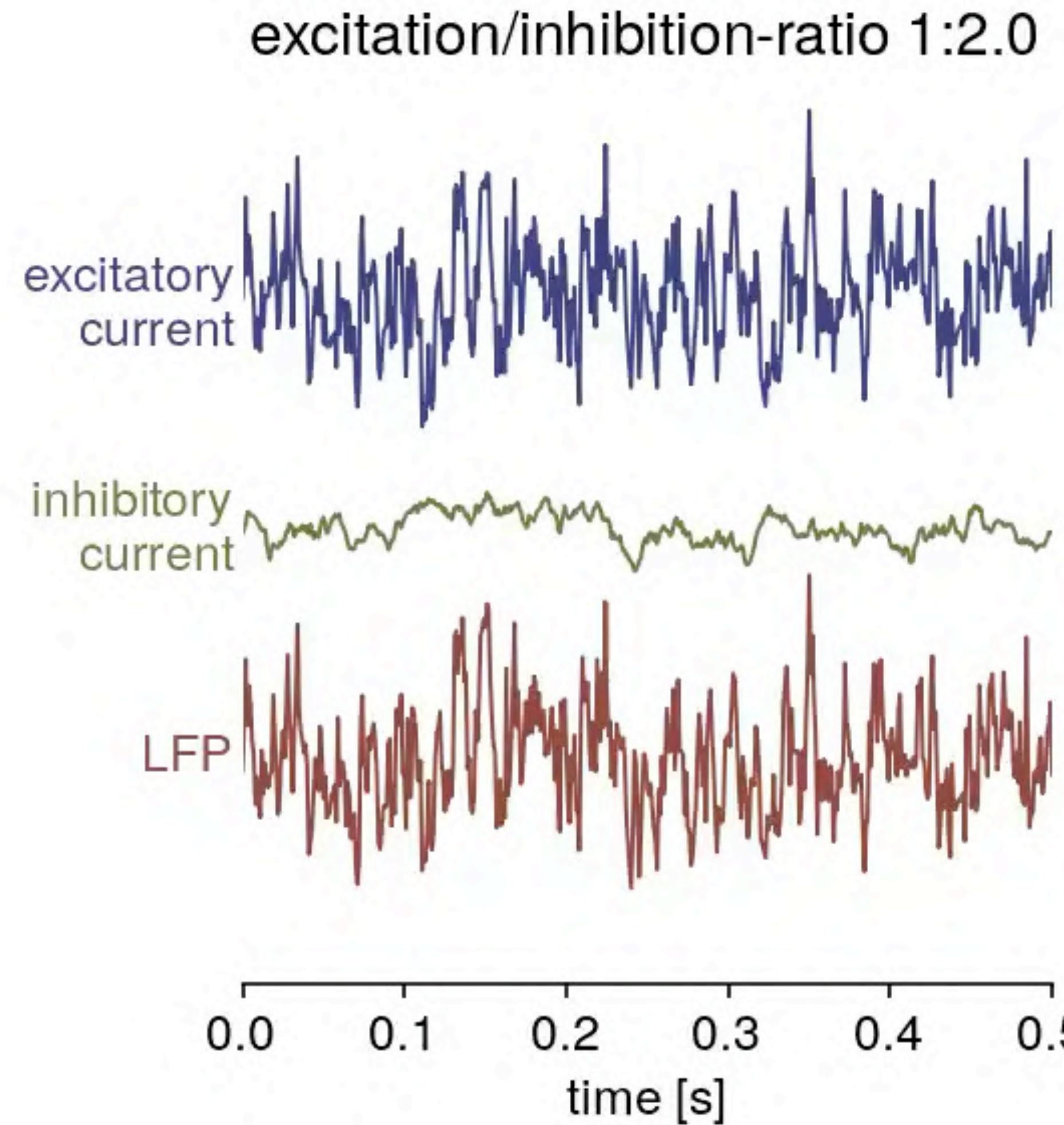
What does the aperiodic slope reflect?



Richard Gao



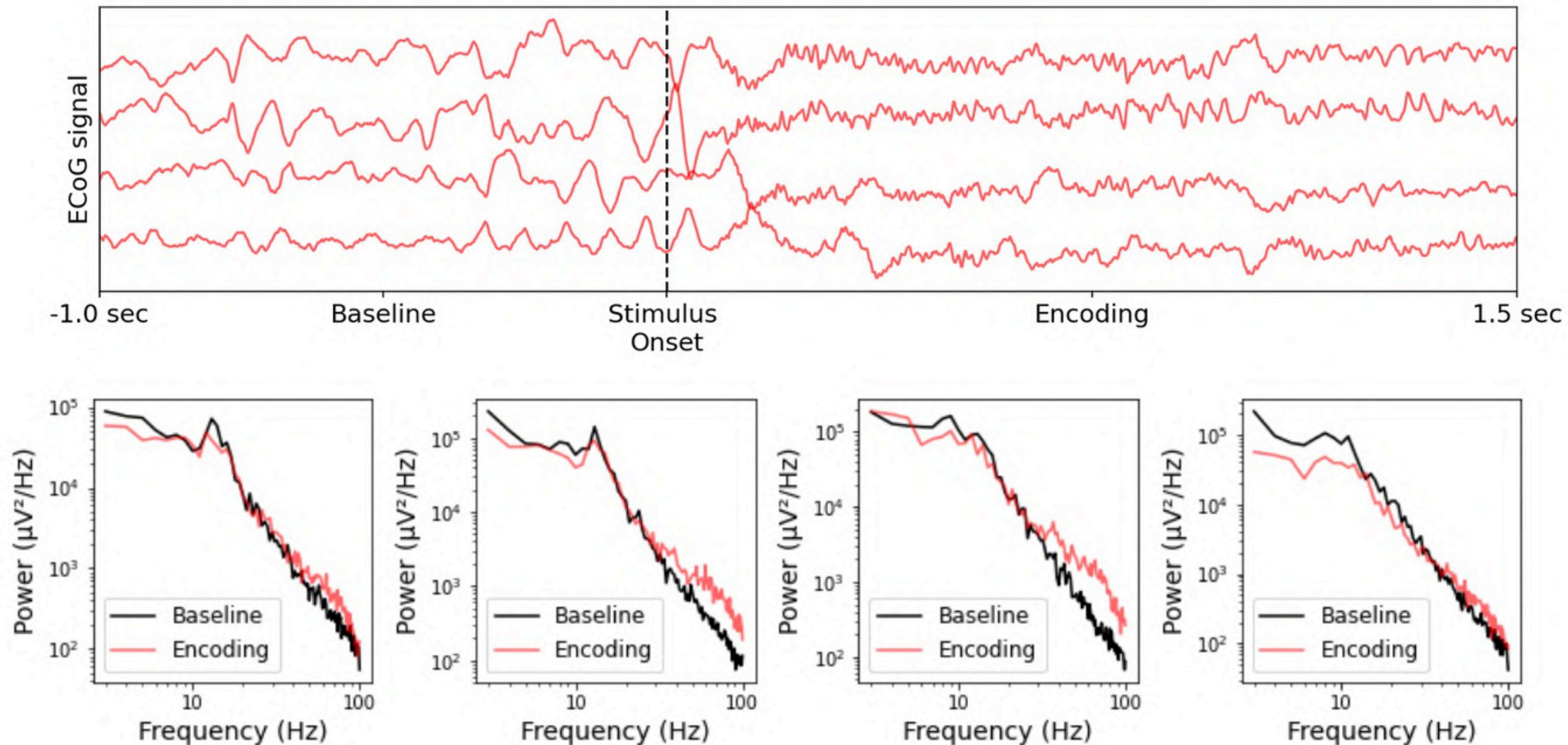
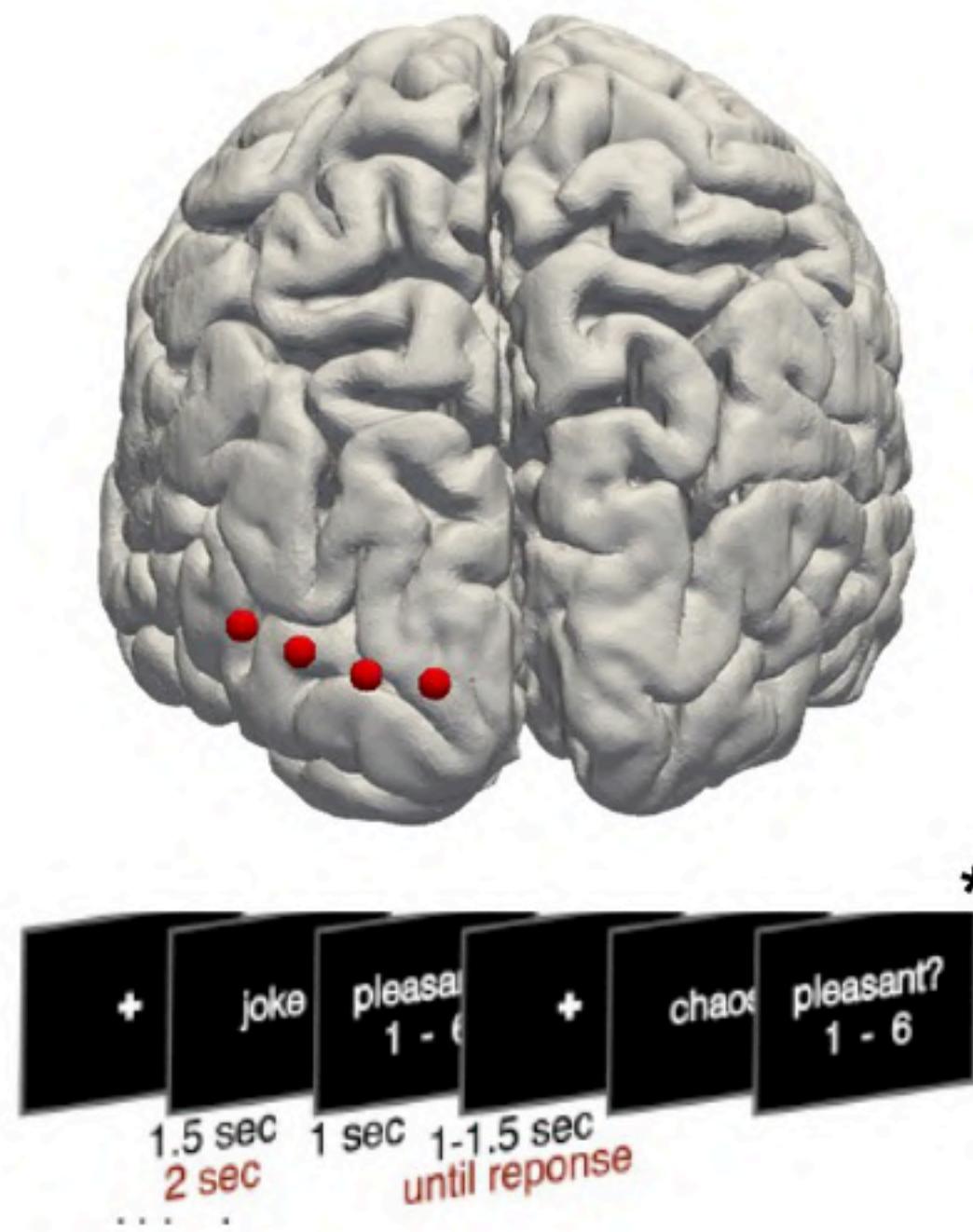
Aperiodic activity is dynamic



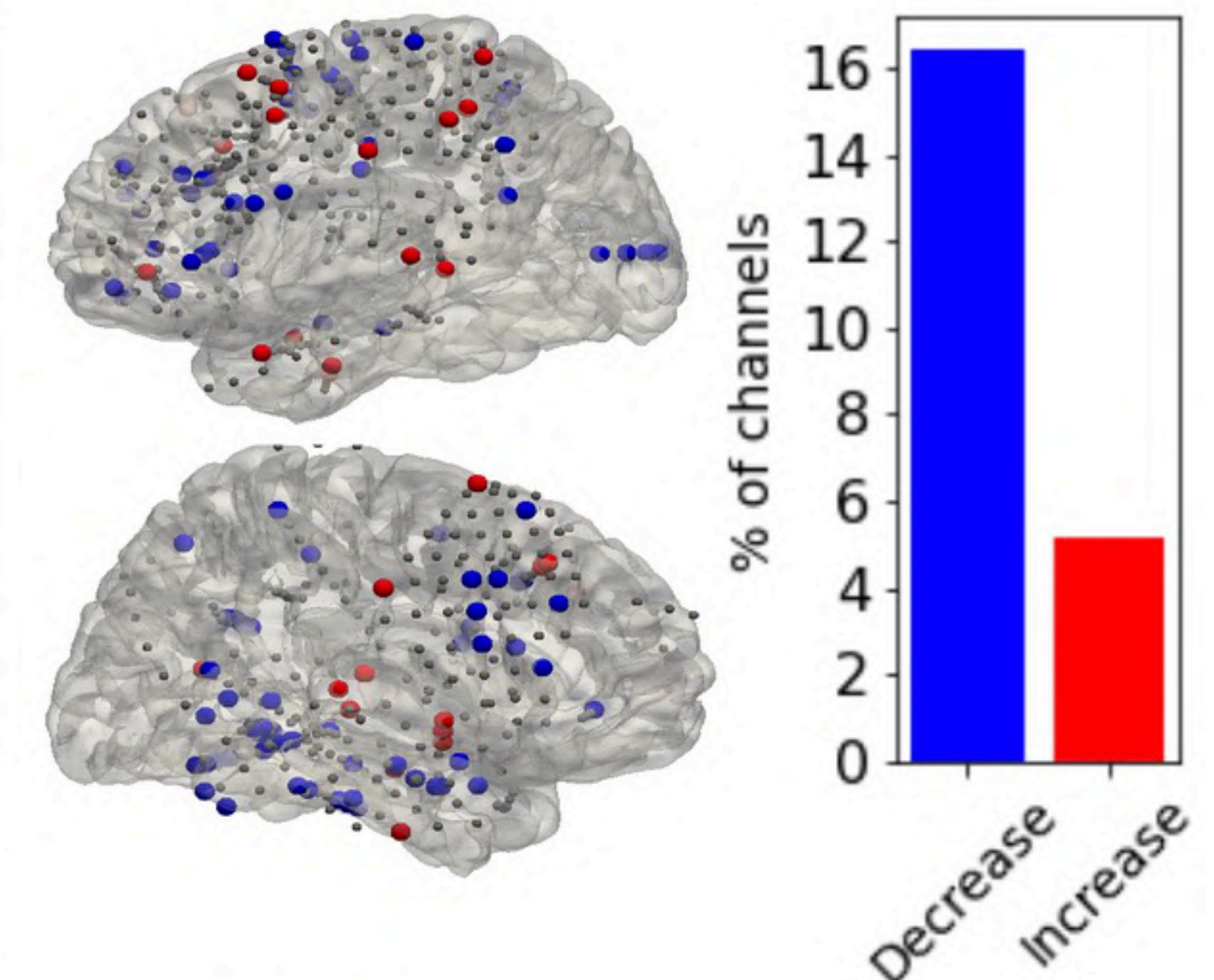
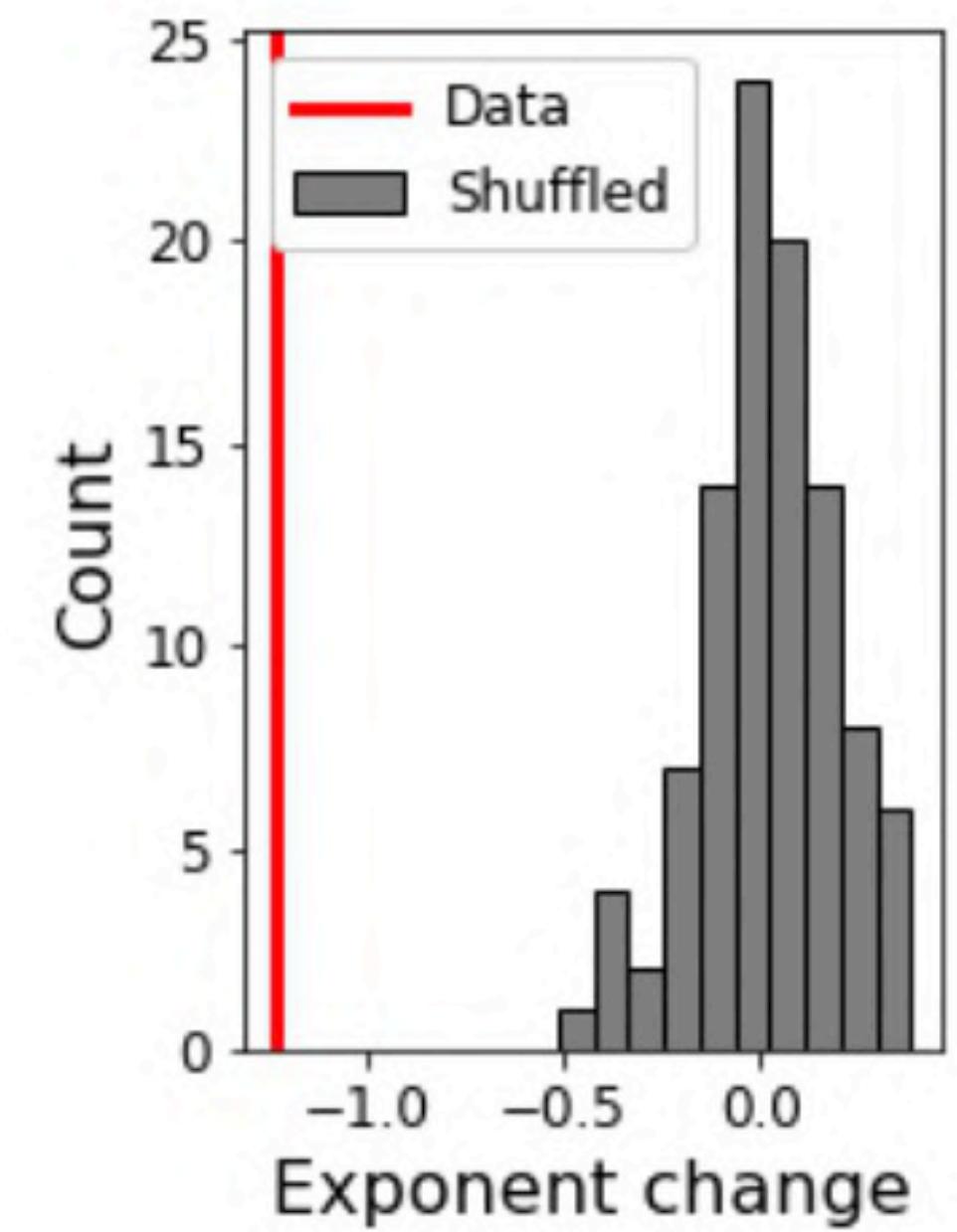
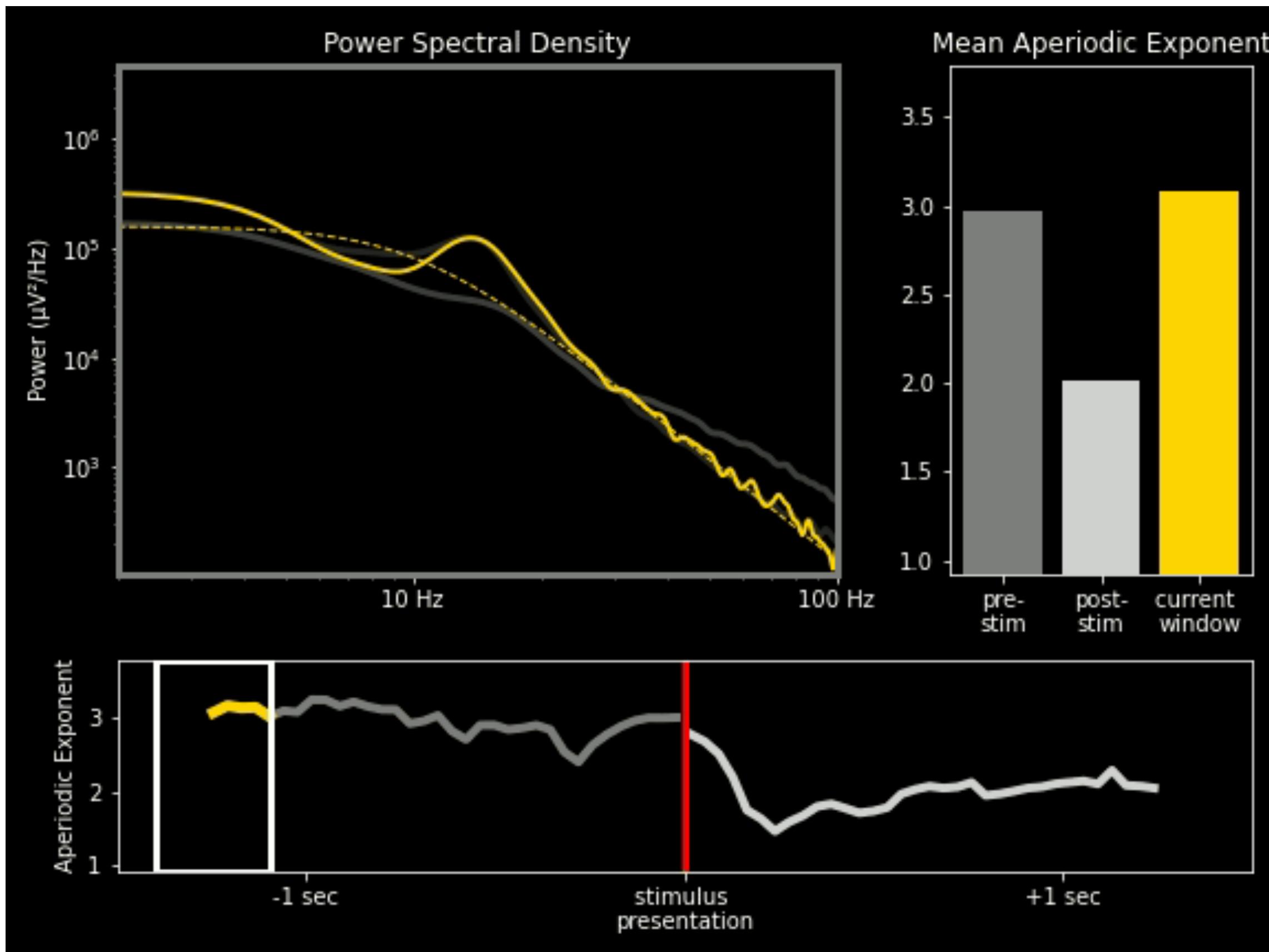
Michael Preston



iEEG recordings during subsequent memory paradigm

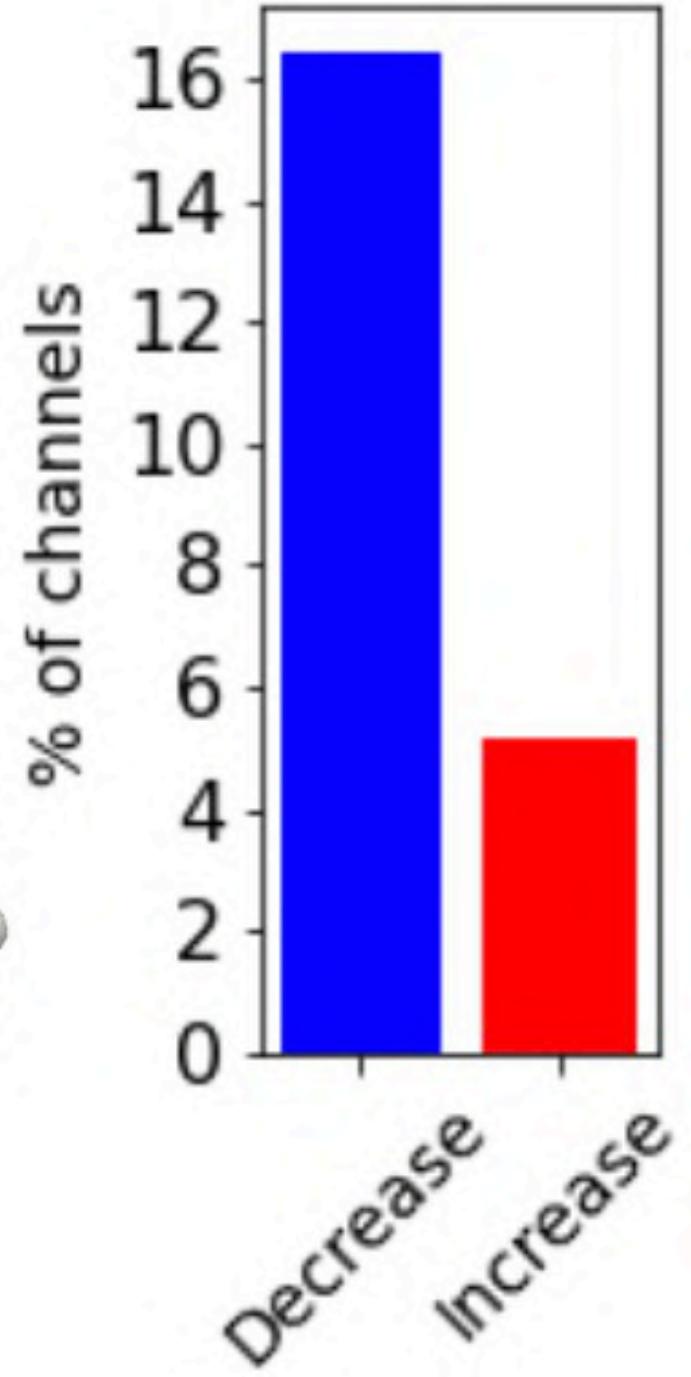
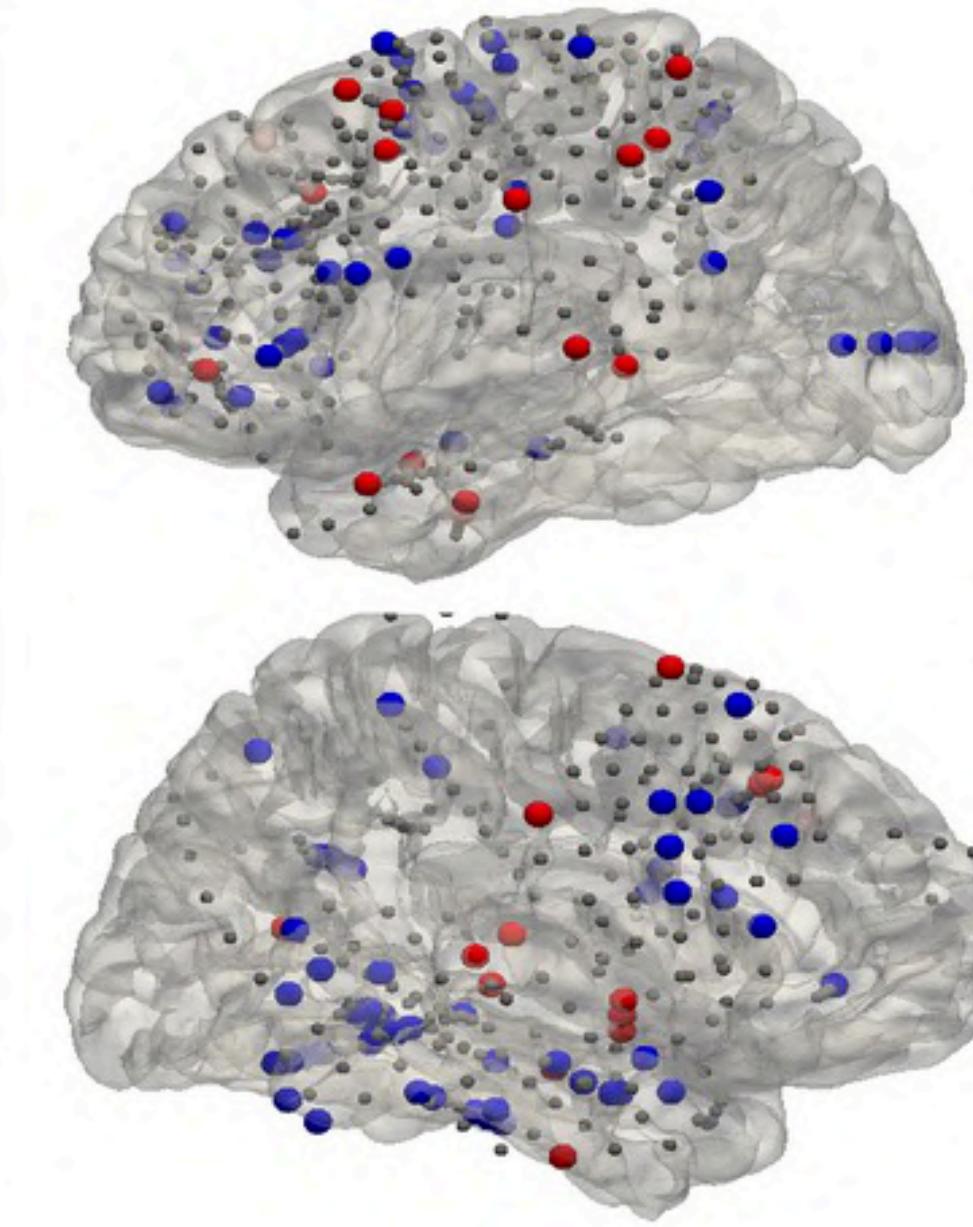
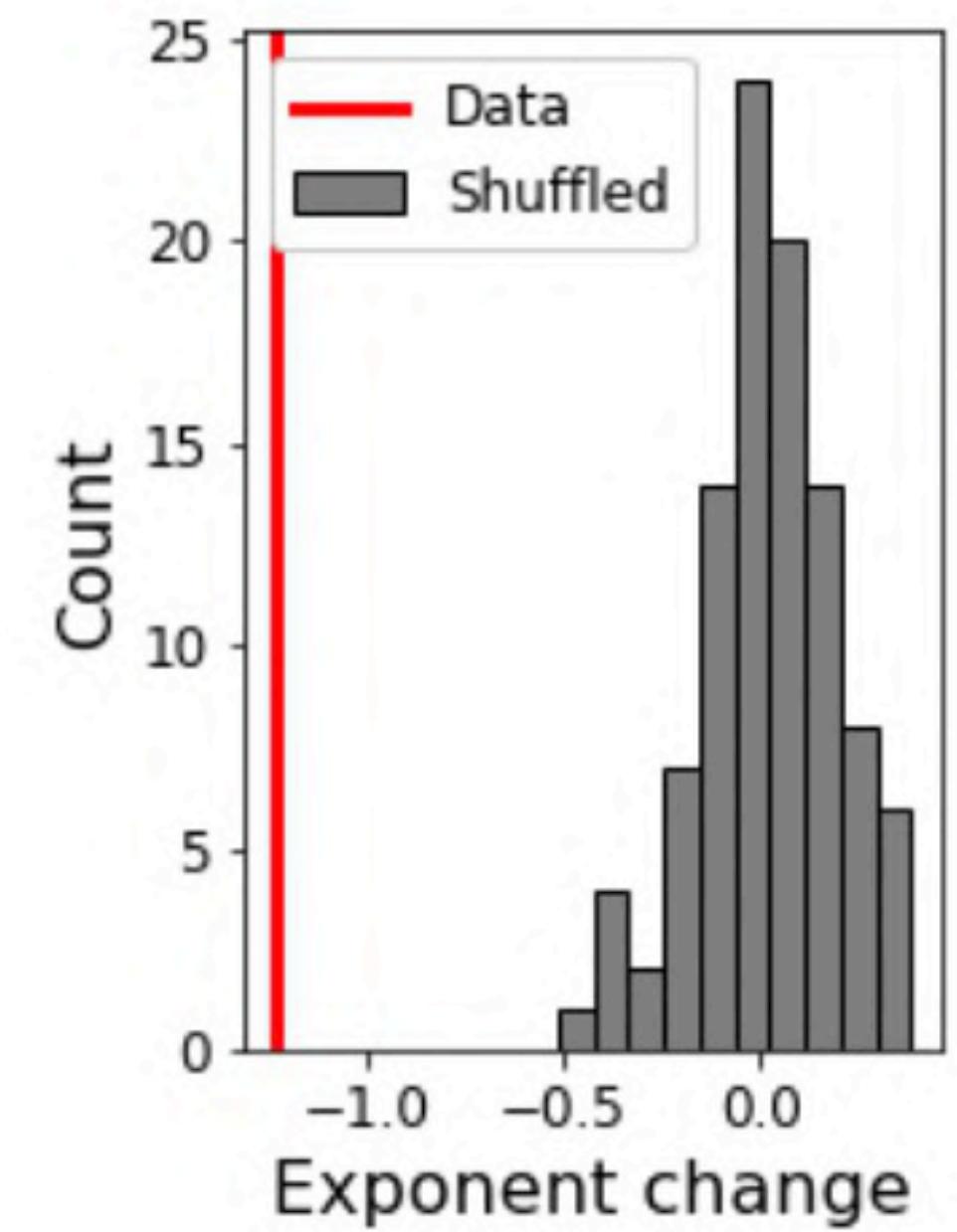
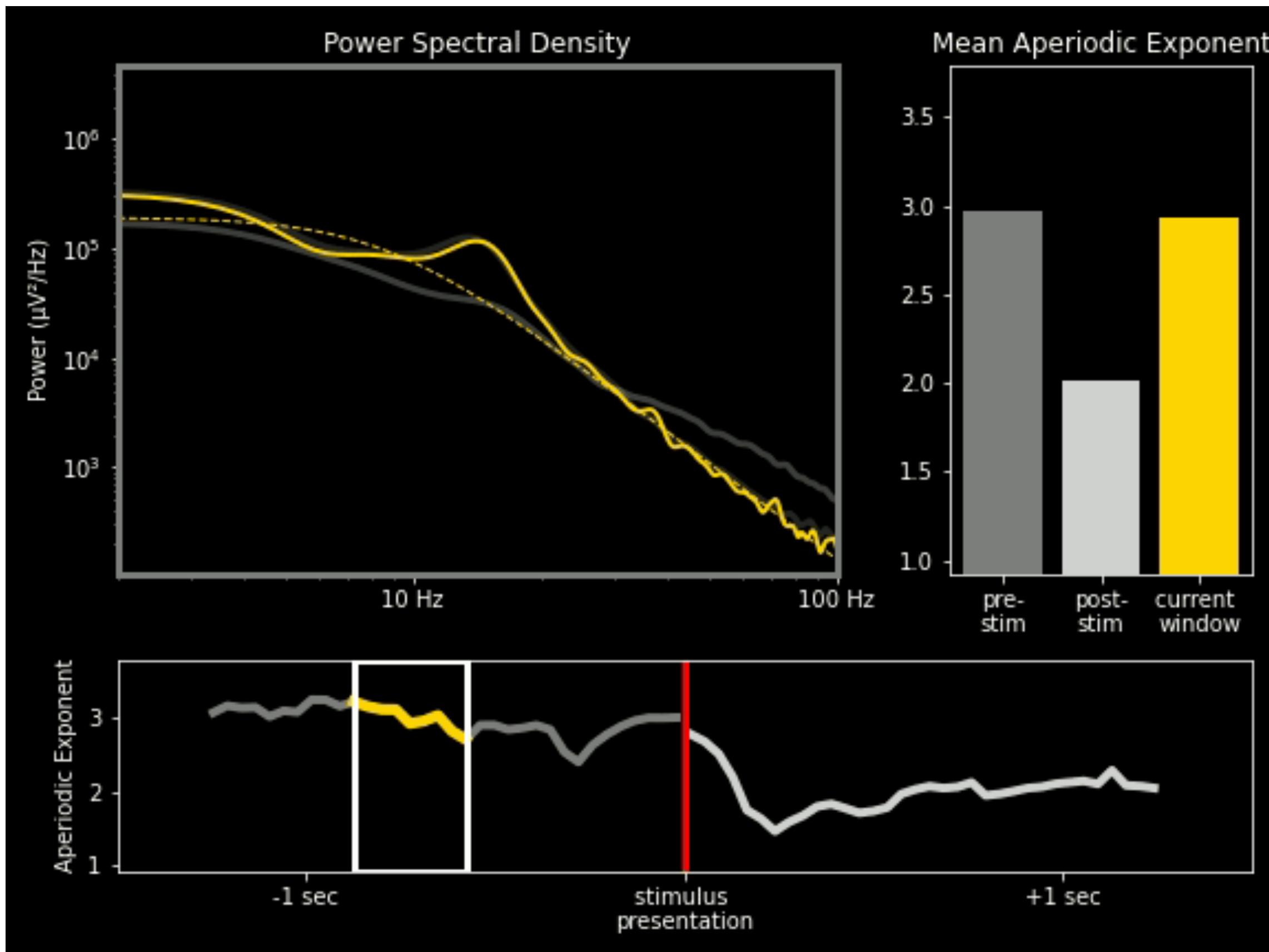


The aperiodic exponent is modulated during encoding



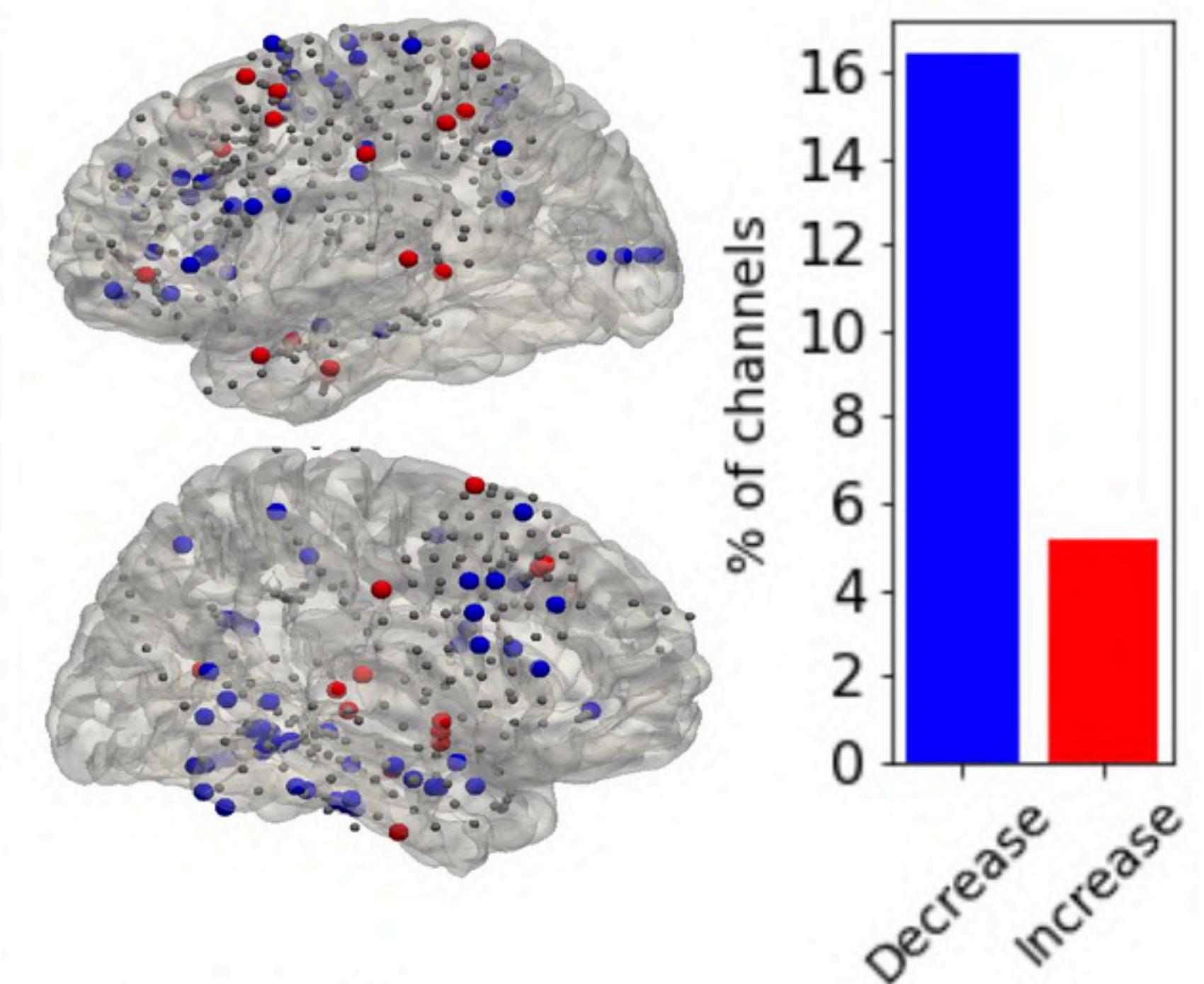
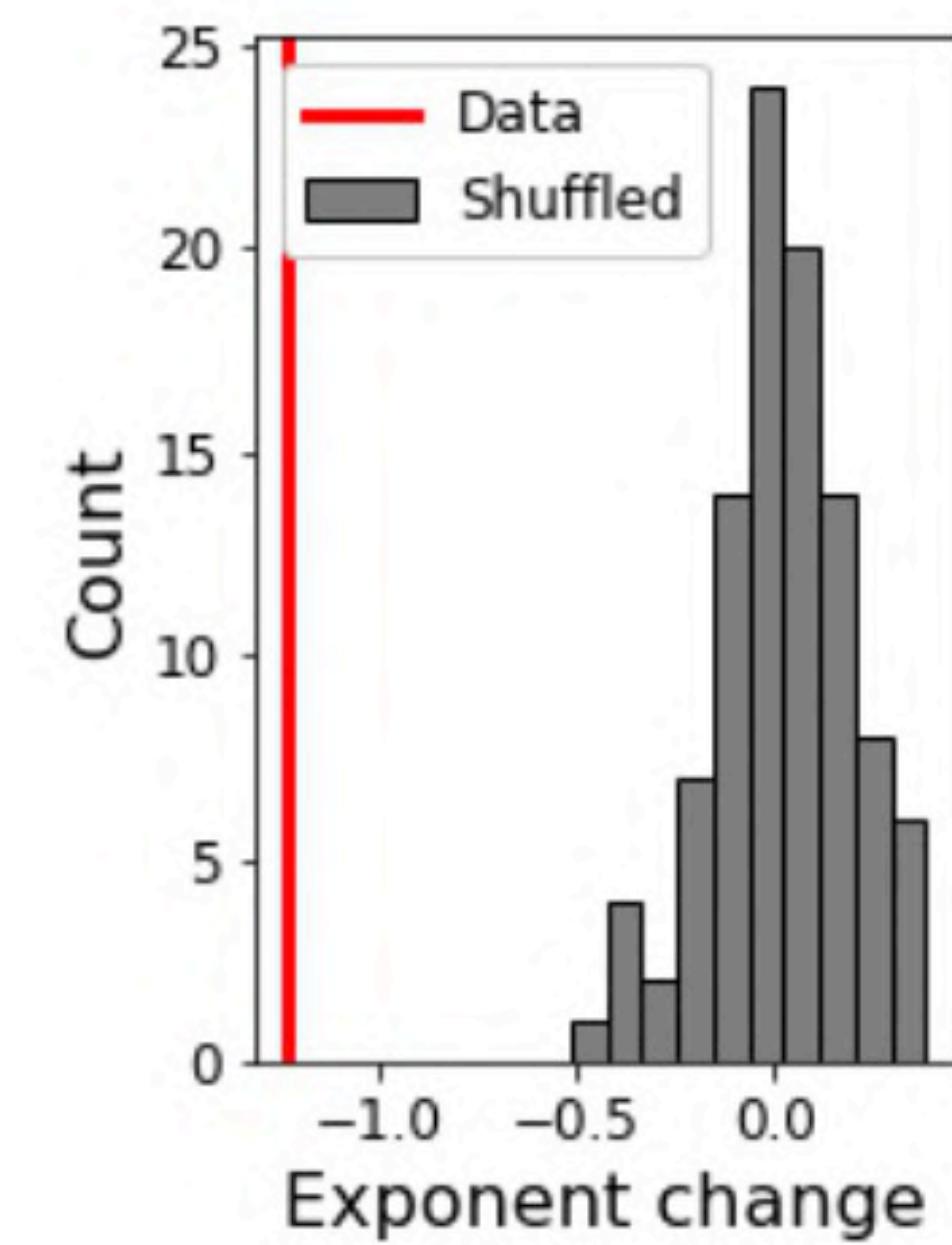
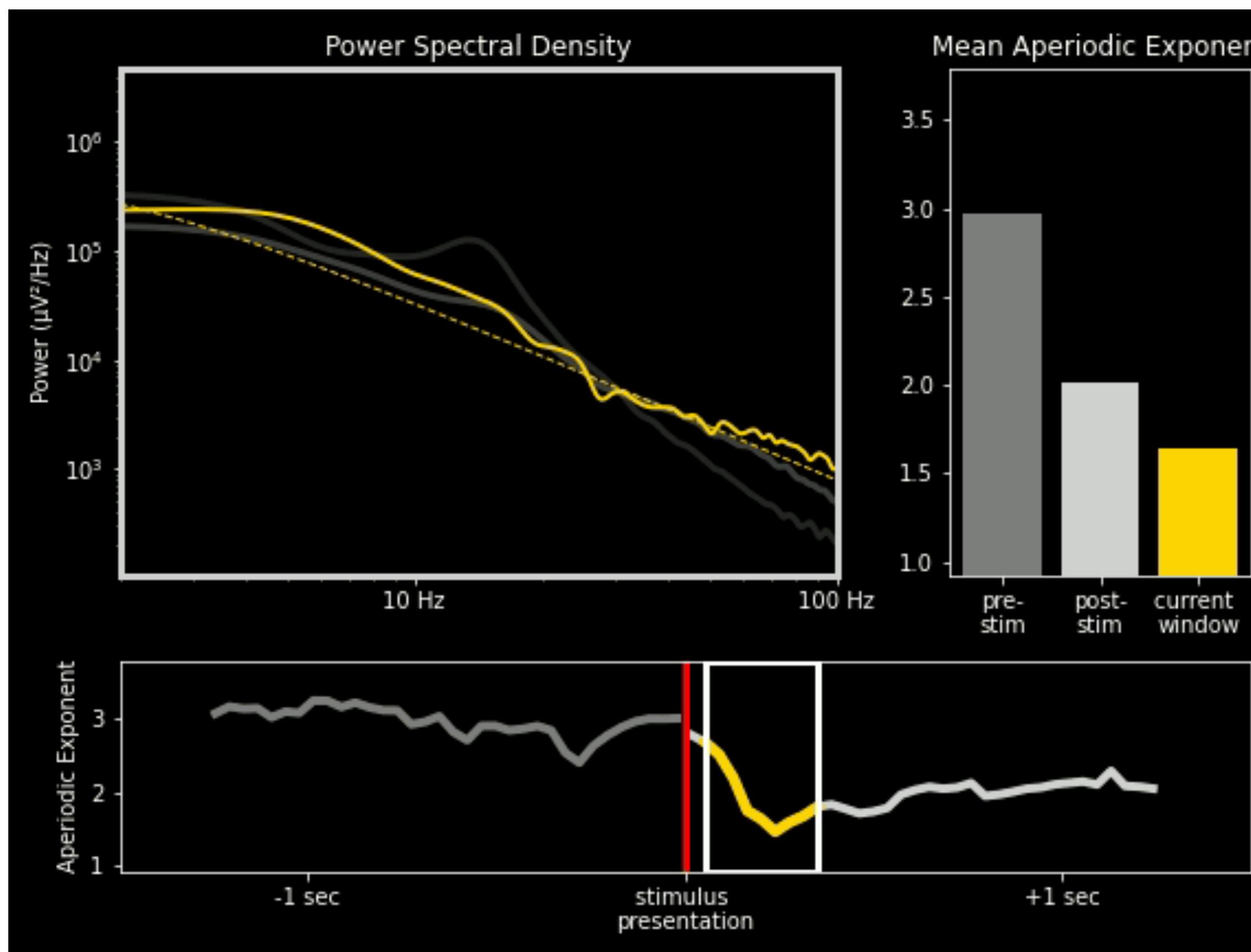
Permutation test (100 shuffles; alpha: 0.01)
Baseline (-1.5 to 0.0 sec) v. Encoding (0.0 to 1.5 sec)

The aperiodic exponent is modulated during encoding



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Baseline (-1.5 to 0.0 sec) v. Encoding (0.0 to 1.5 sec)

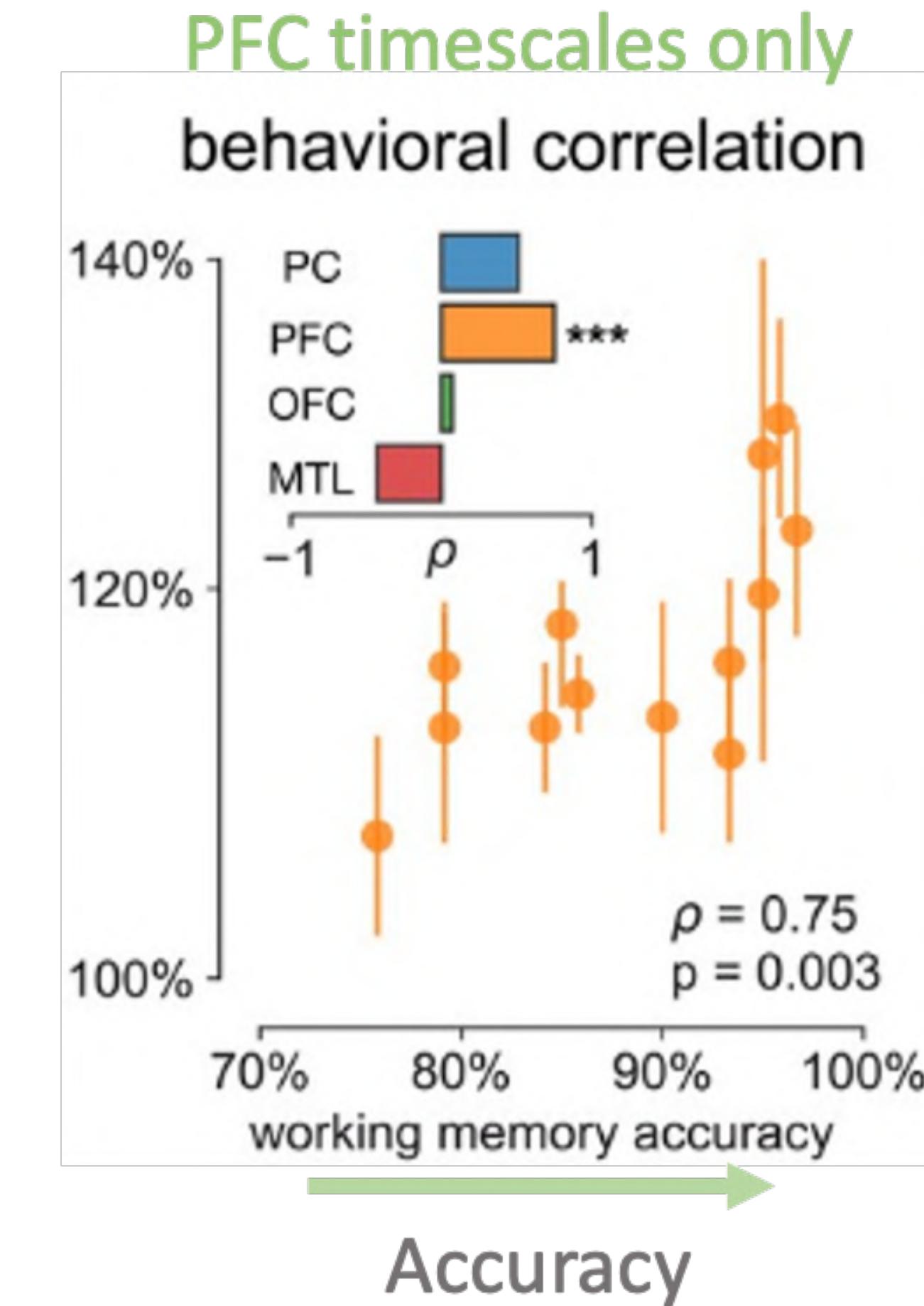
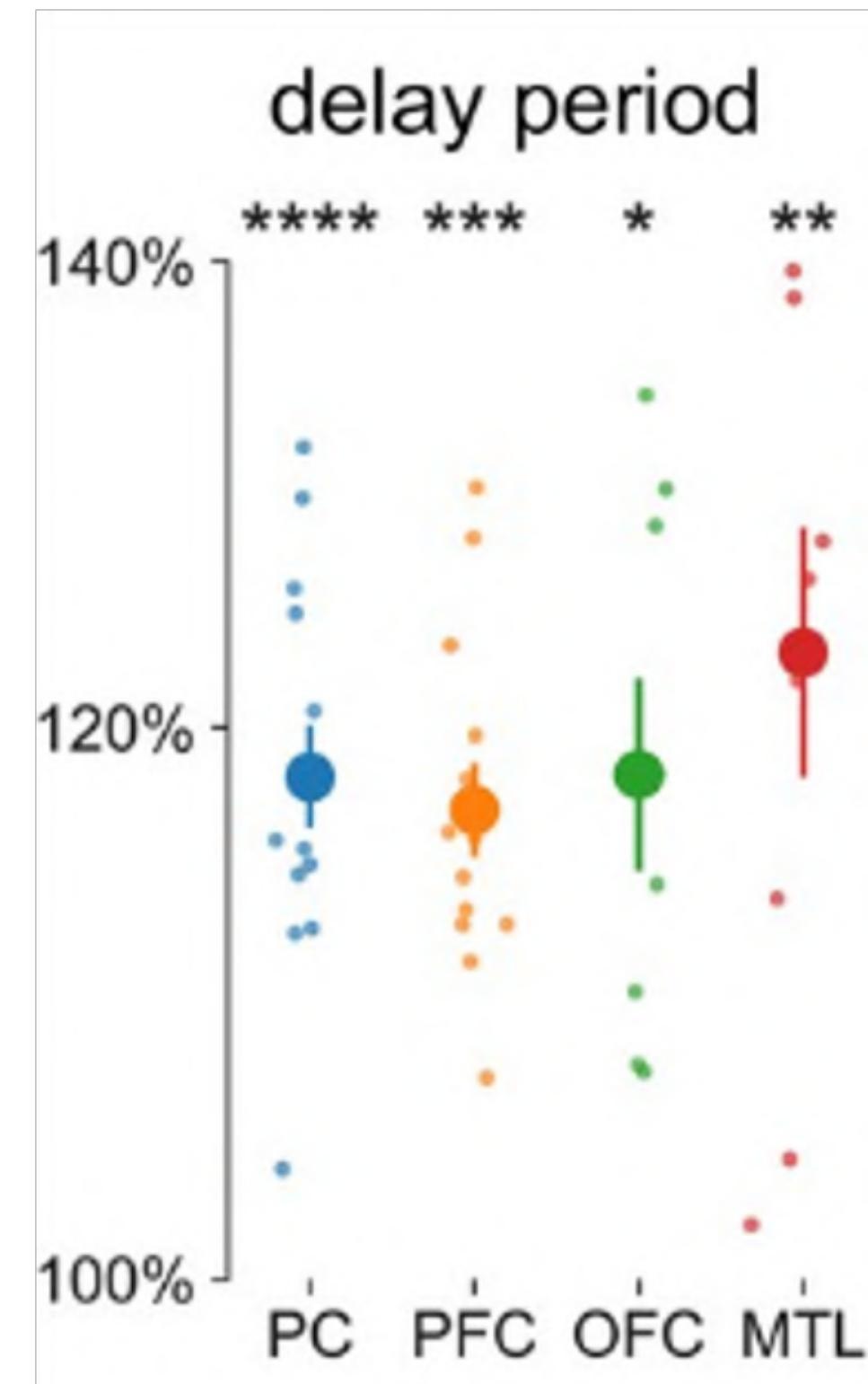
Dillan Cellier



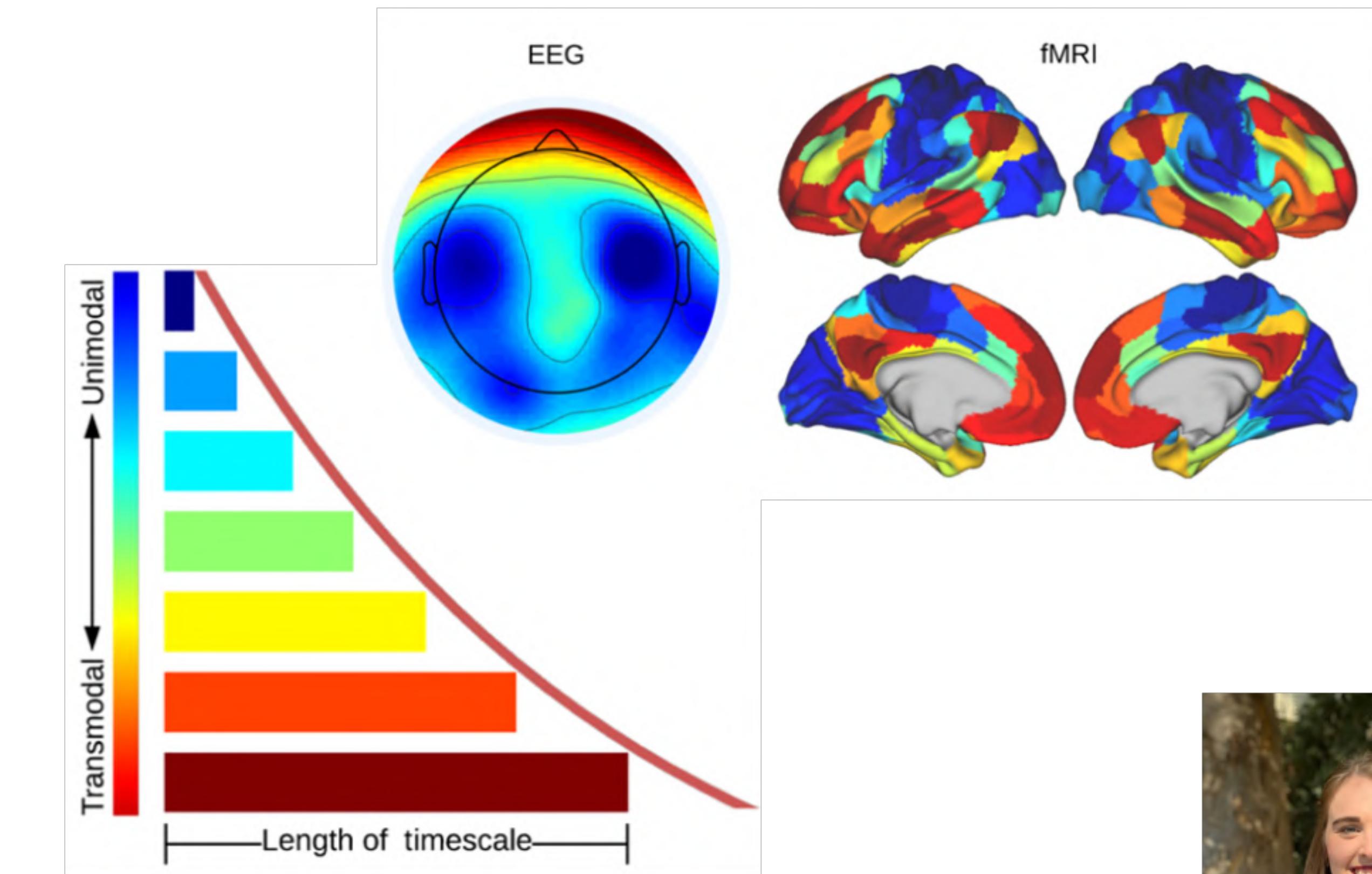
Aperiodic Activity Reflects Dynamic Neural Timescales

Gao et al., 2020

Lengthening
of timescales
from
Baseline to
WM delay



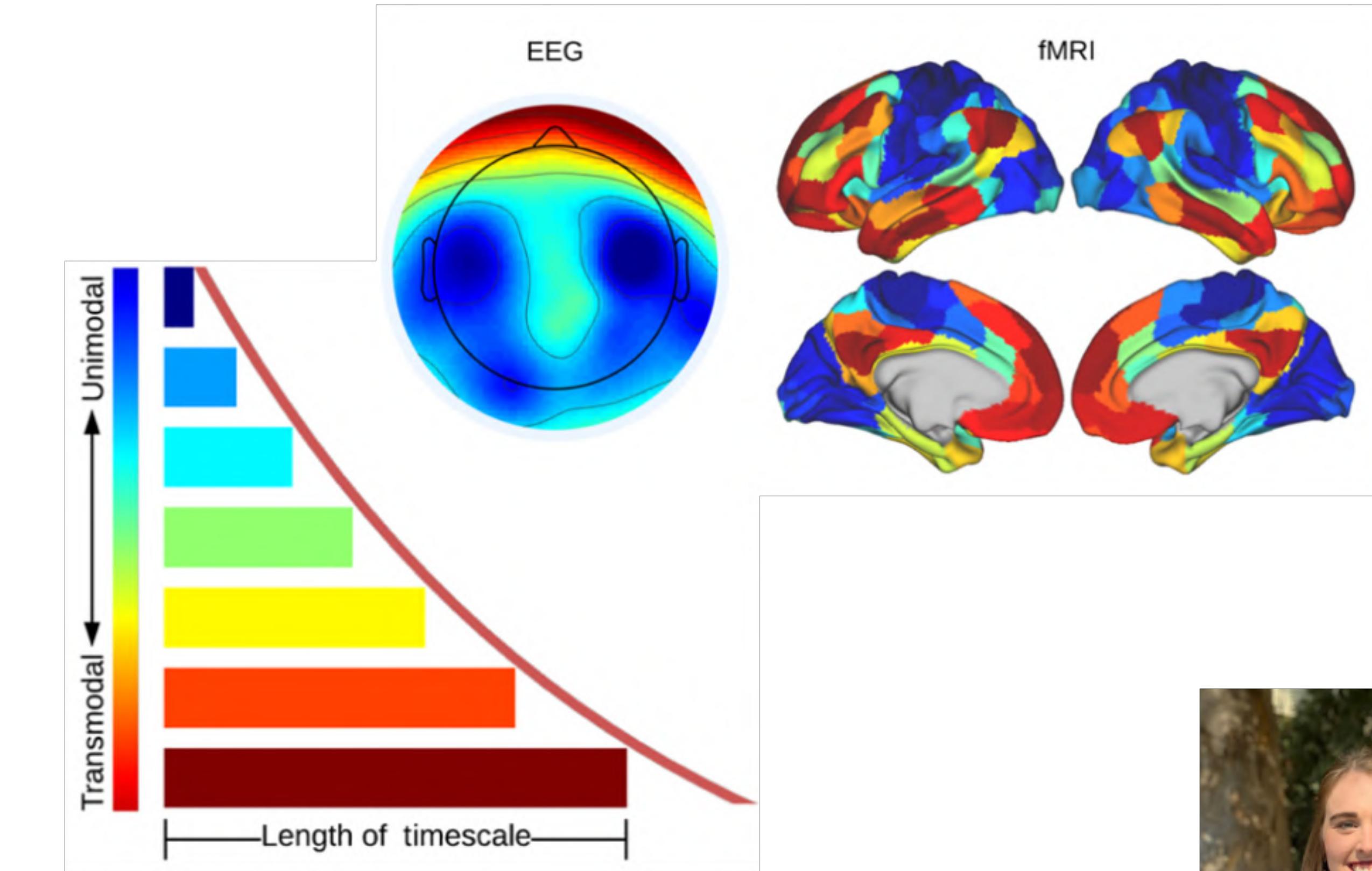
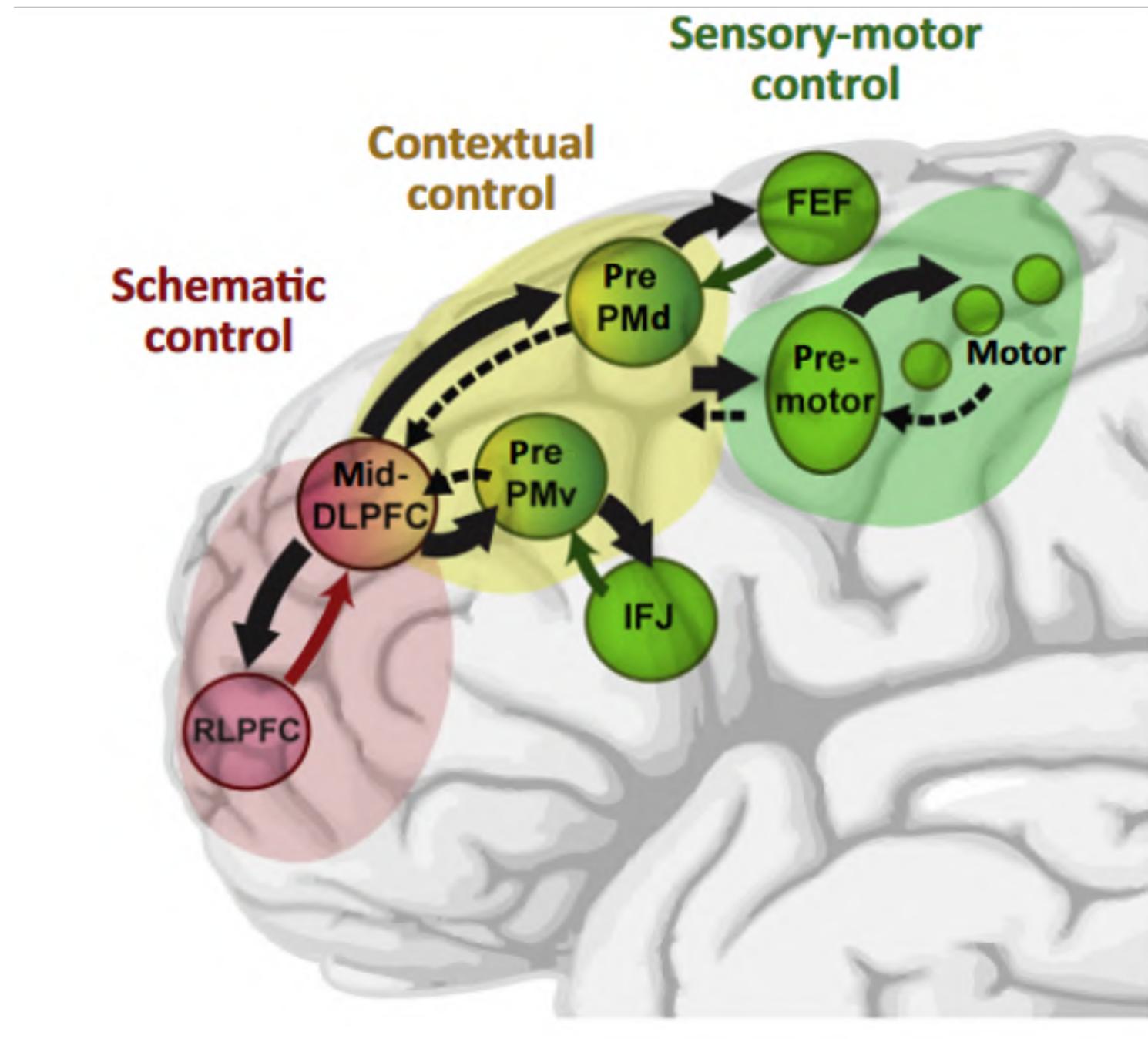
Aperiodic Activity Reflects Dynamic Neural Timescales ...and maybe cognitive timescales?



Badre and Nee (2018)*, Wolff et al (2022)*, Golesorkhi et al (2021), Manea et al (2022), Chadhuri et al (2015)



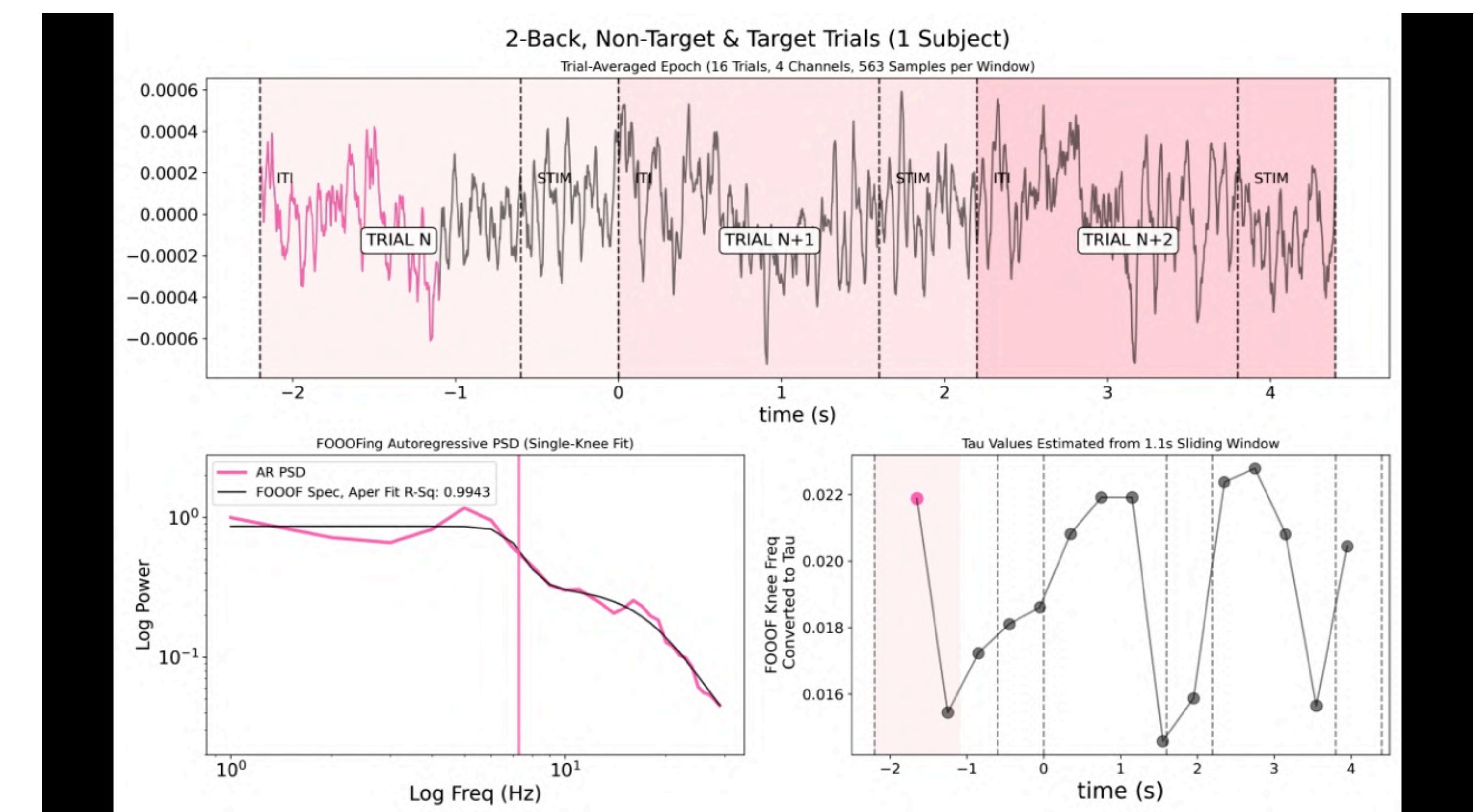
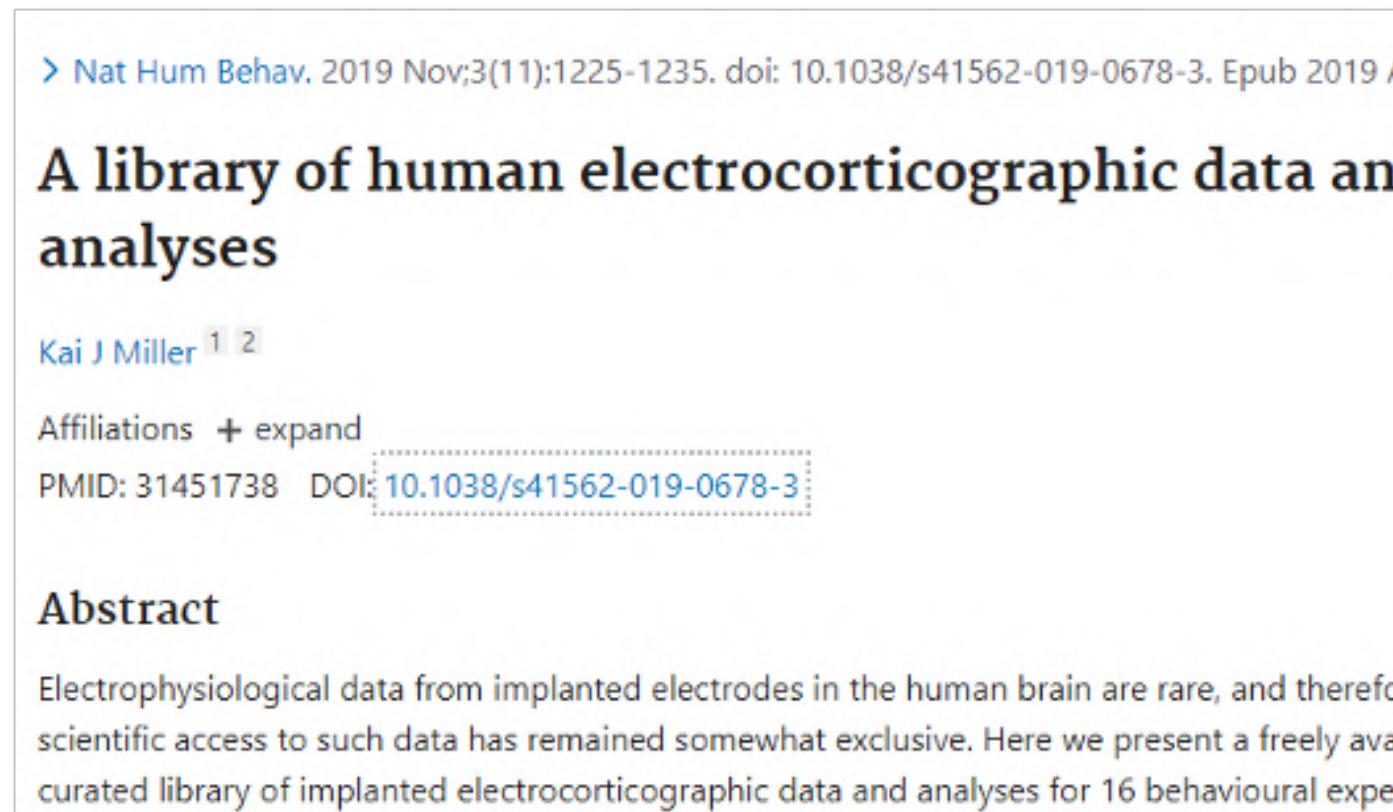
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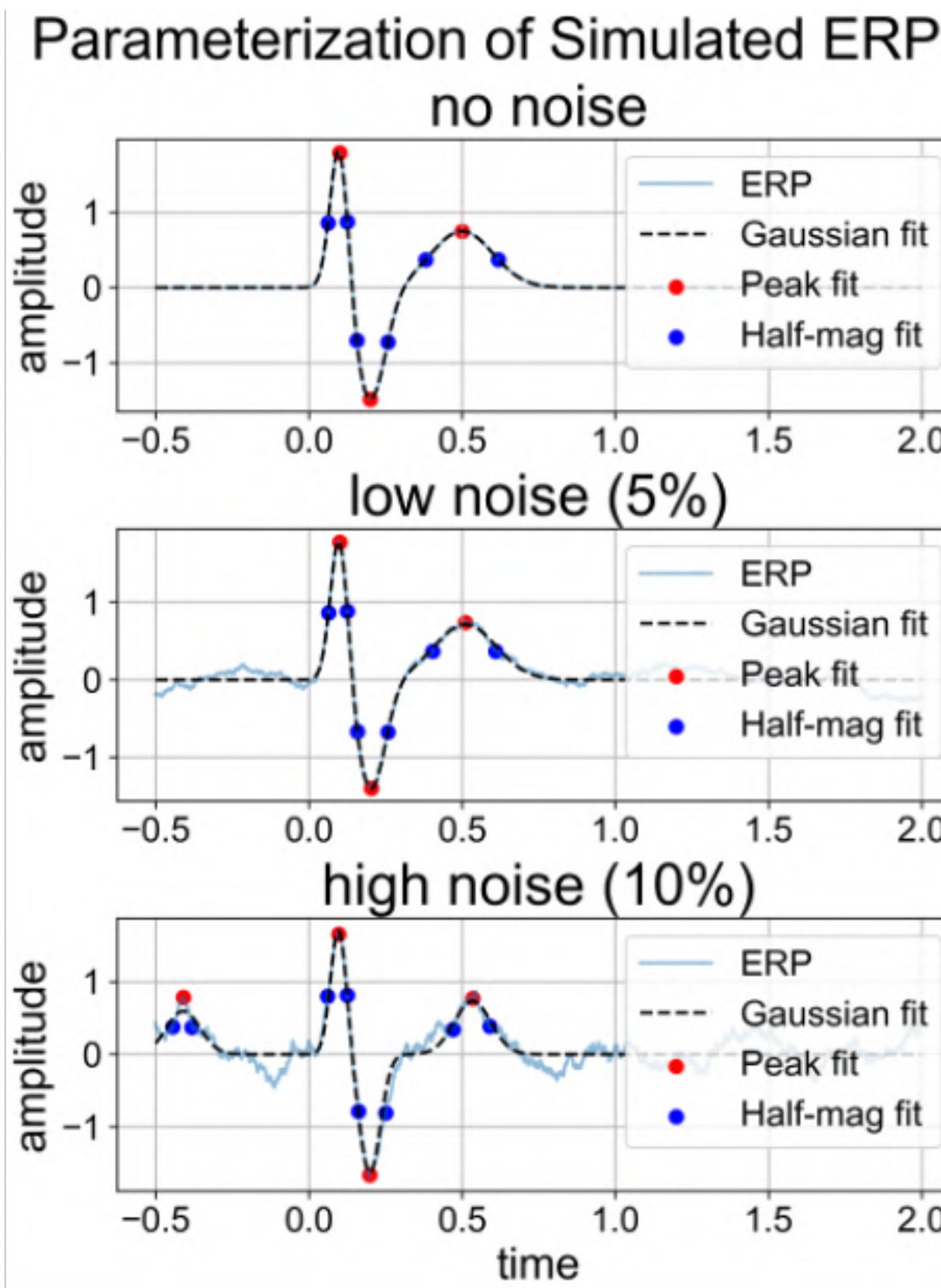
Aperiodic Activity Reflects Dynamic Neural Timescales ...and maybe cognitive timescales?



Visit our poster on Thursday!

NOVEL PARAMETERIZATION OF EVENT-RELATED POTENTIALS:
A STEP TOWARDS CHARACTERIZING THE BIOPHYSICAL ORIGINS

Poster number 88



Over-parameterizing our signals is a first step in a bottom-up approach to developing theories which will (ideally) translate across multiple scales of analysis



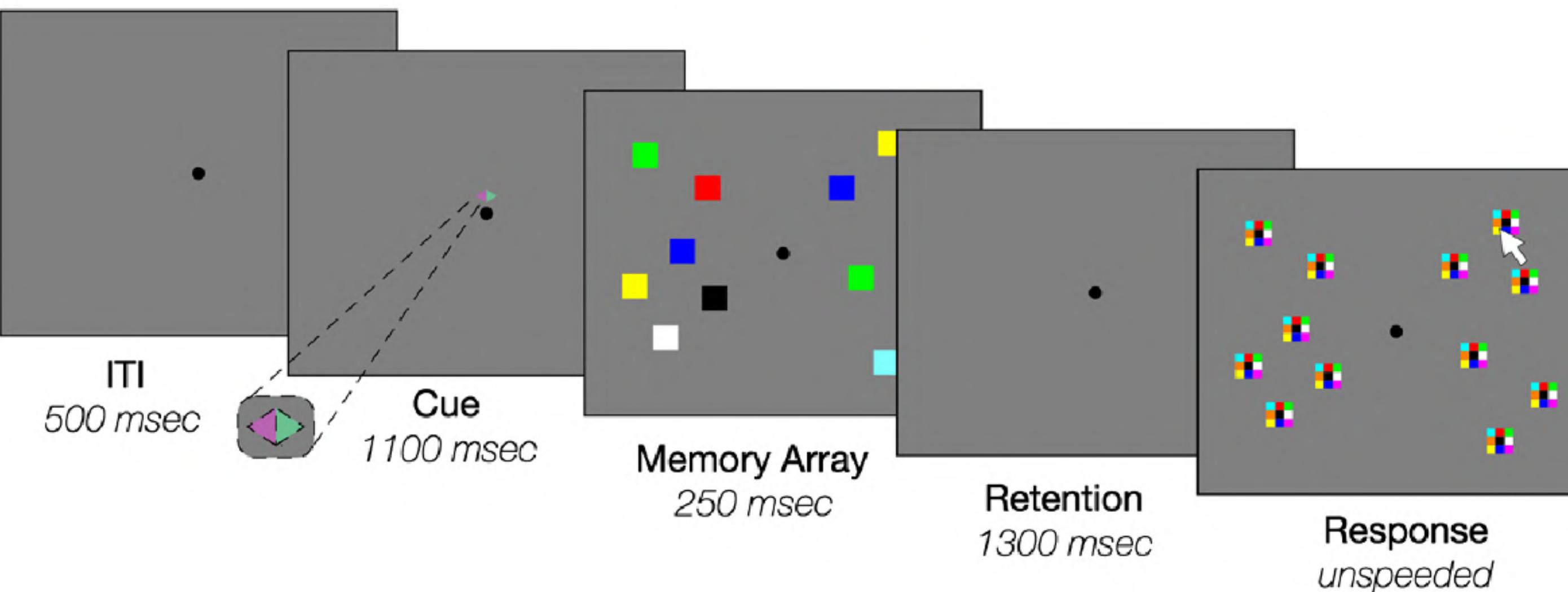
frontal midline theta

Quirine van Engen



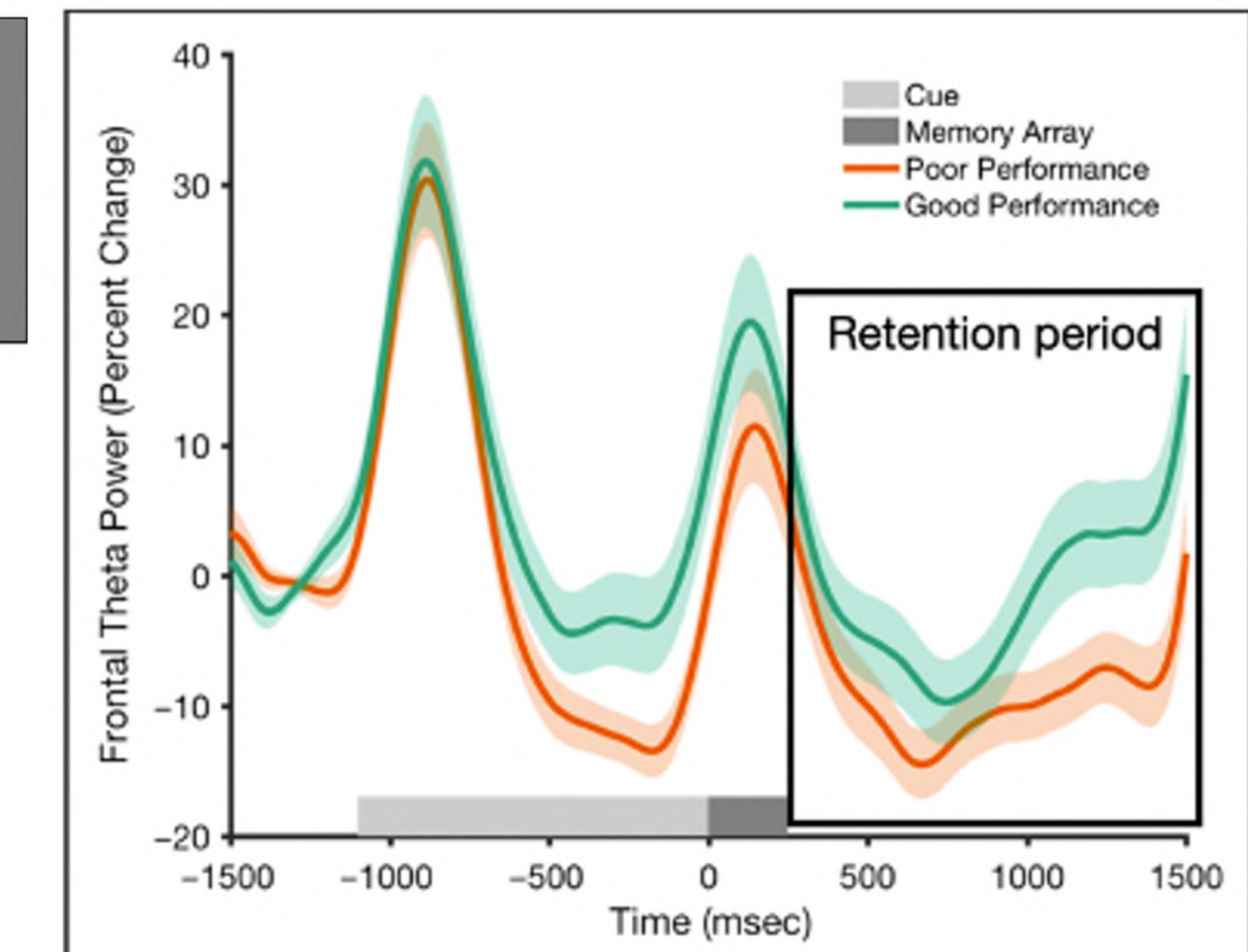
Original goal: Contralateral delay activity (alpha)

2nd goal: frontal midline theta tracks WM load

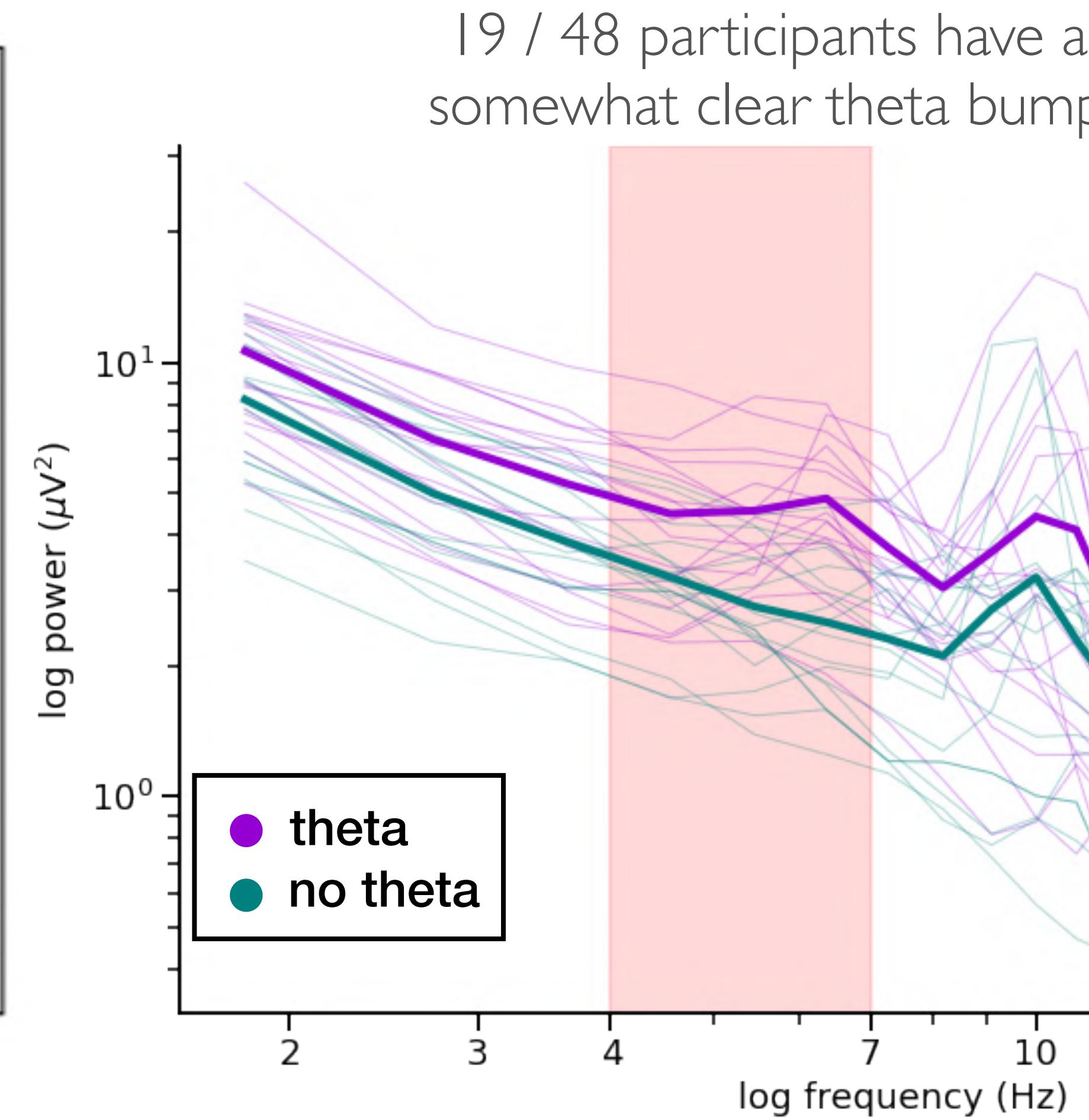
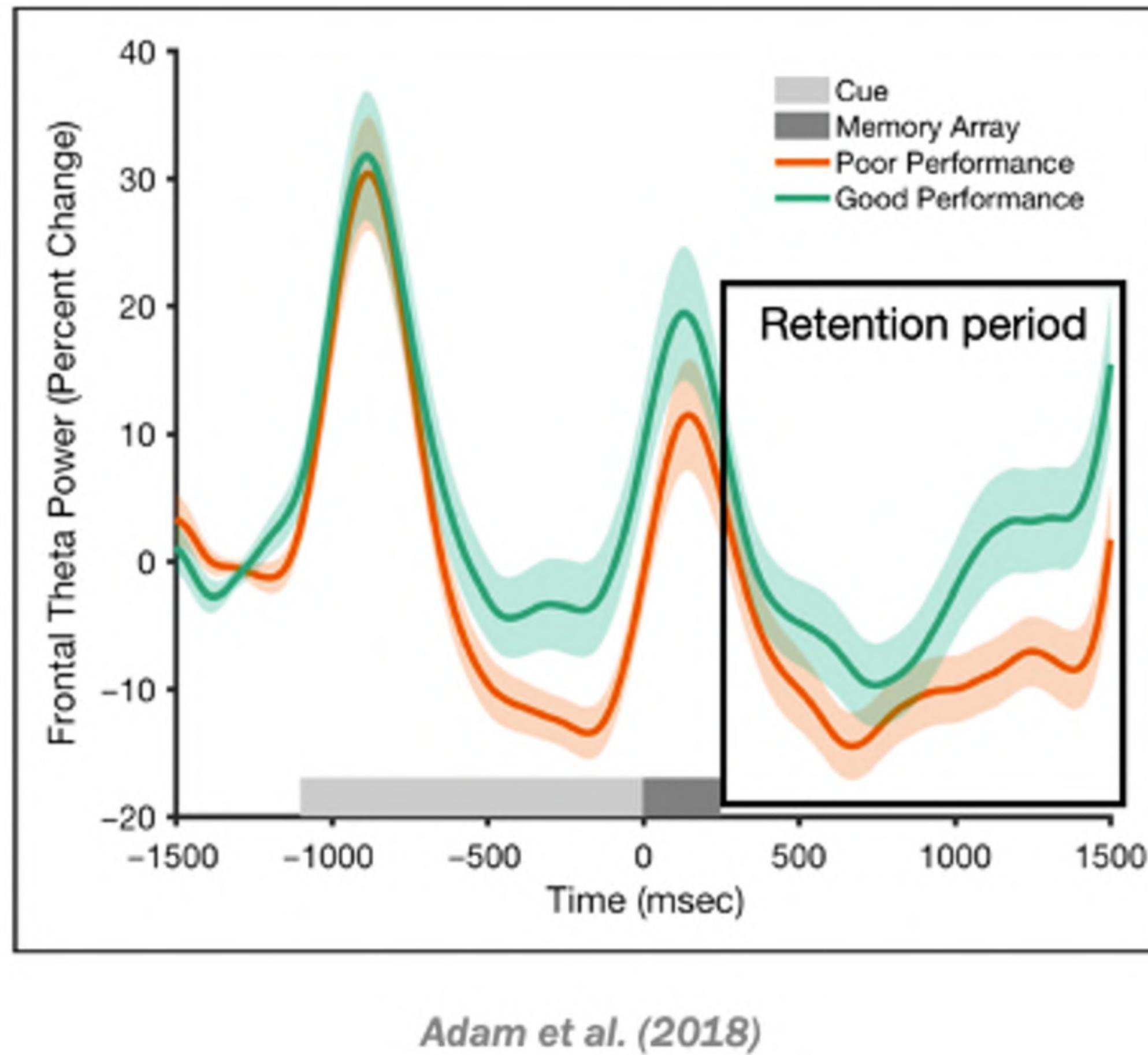


Experiment 1: different set-sizes - 1, 3, 6

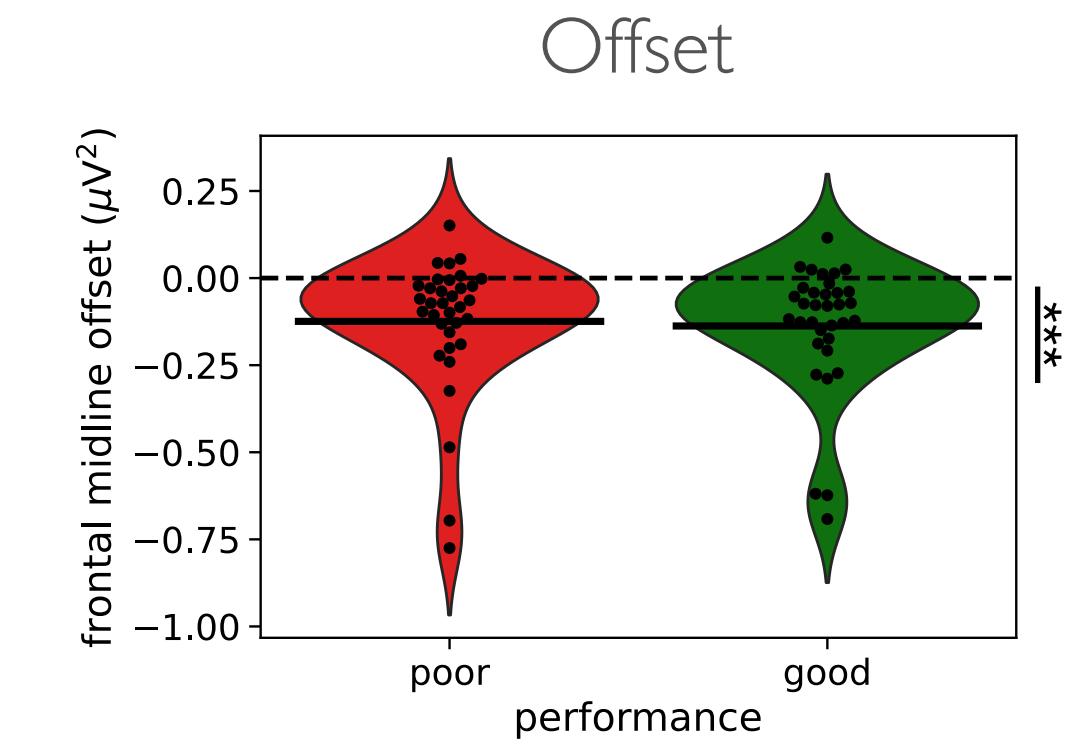
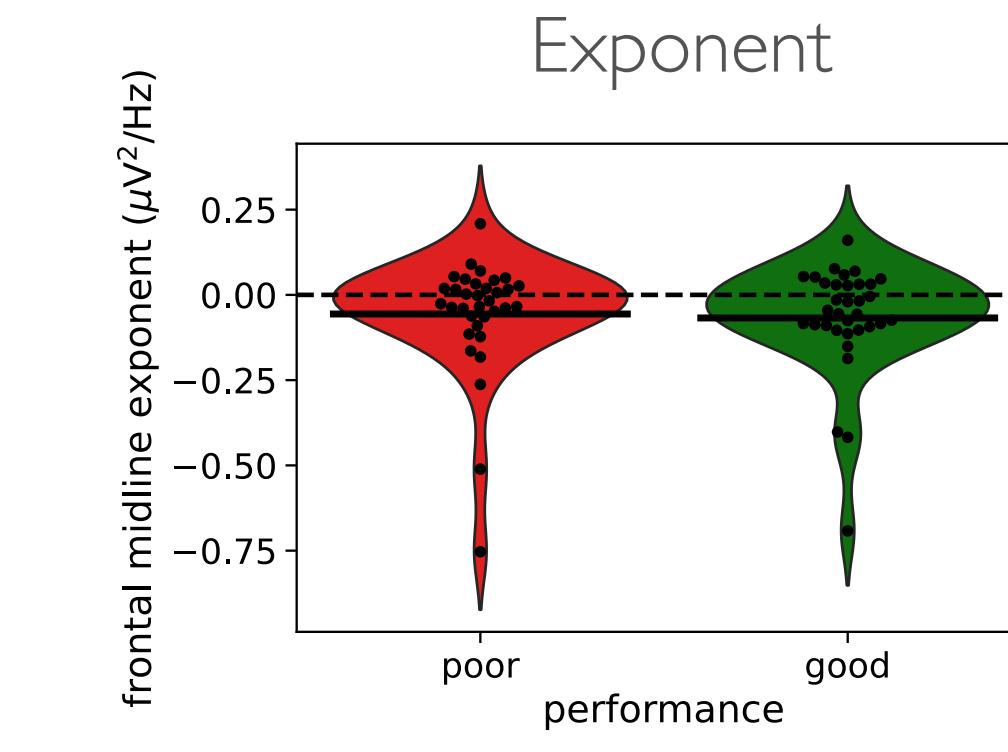
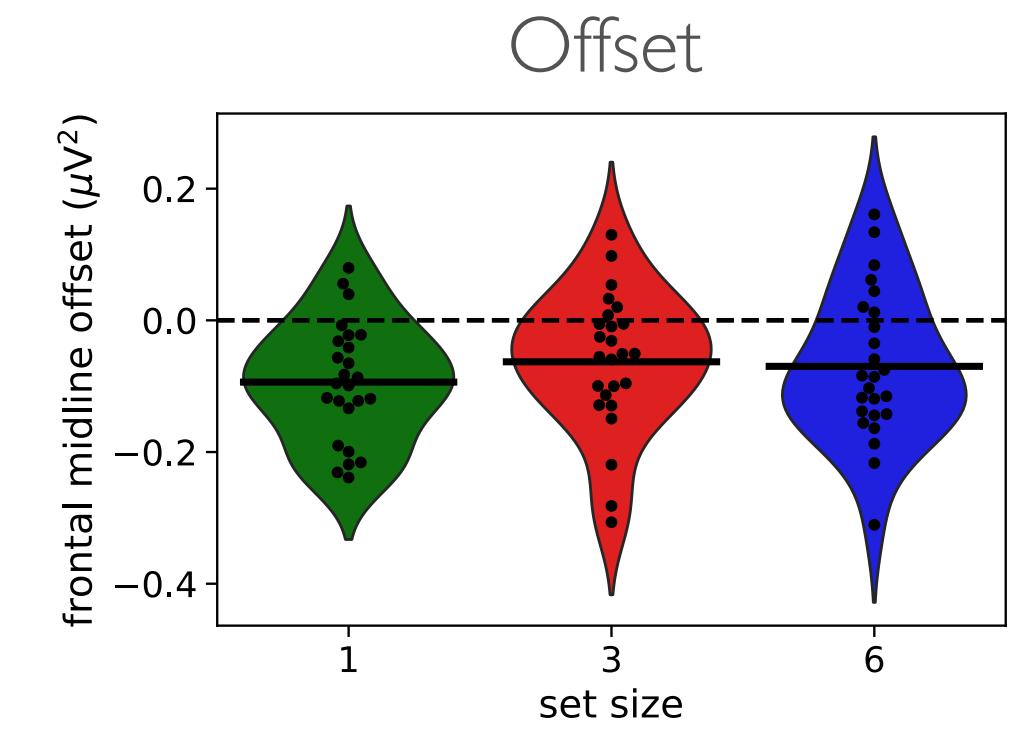
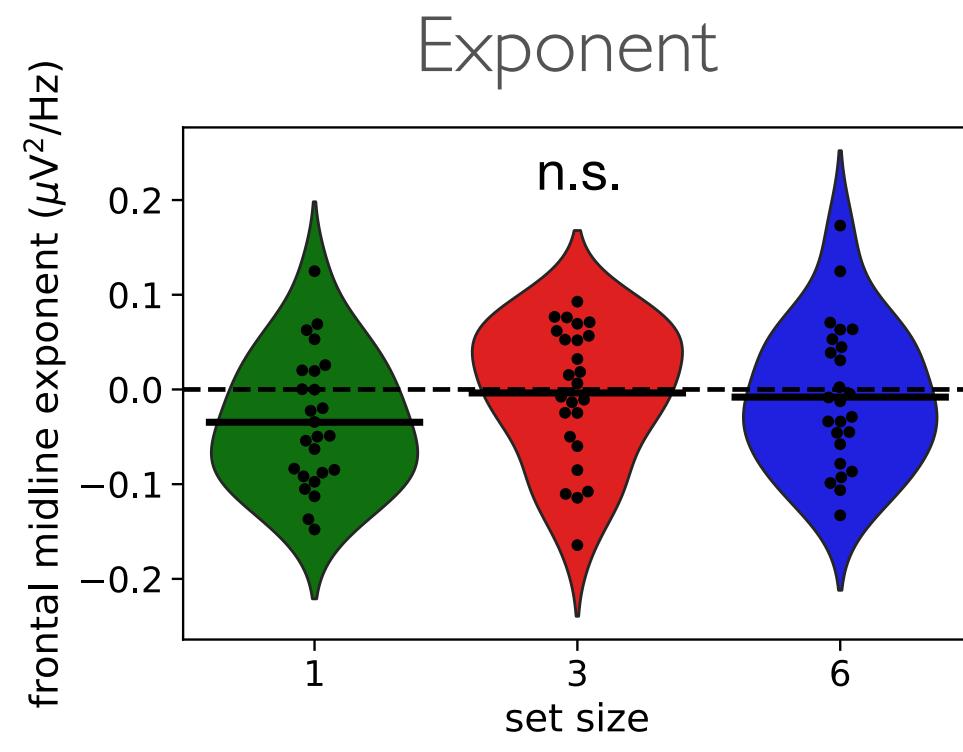
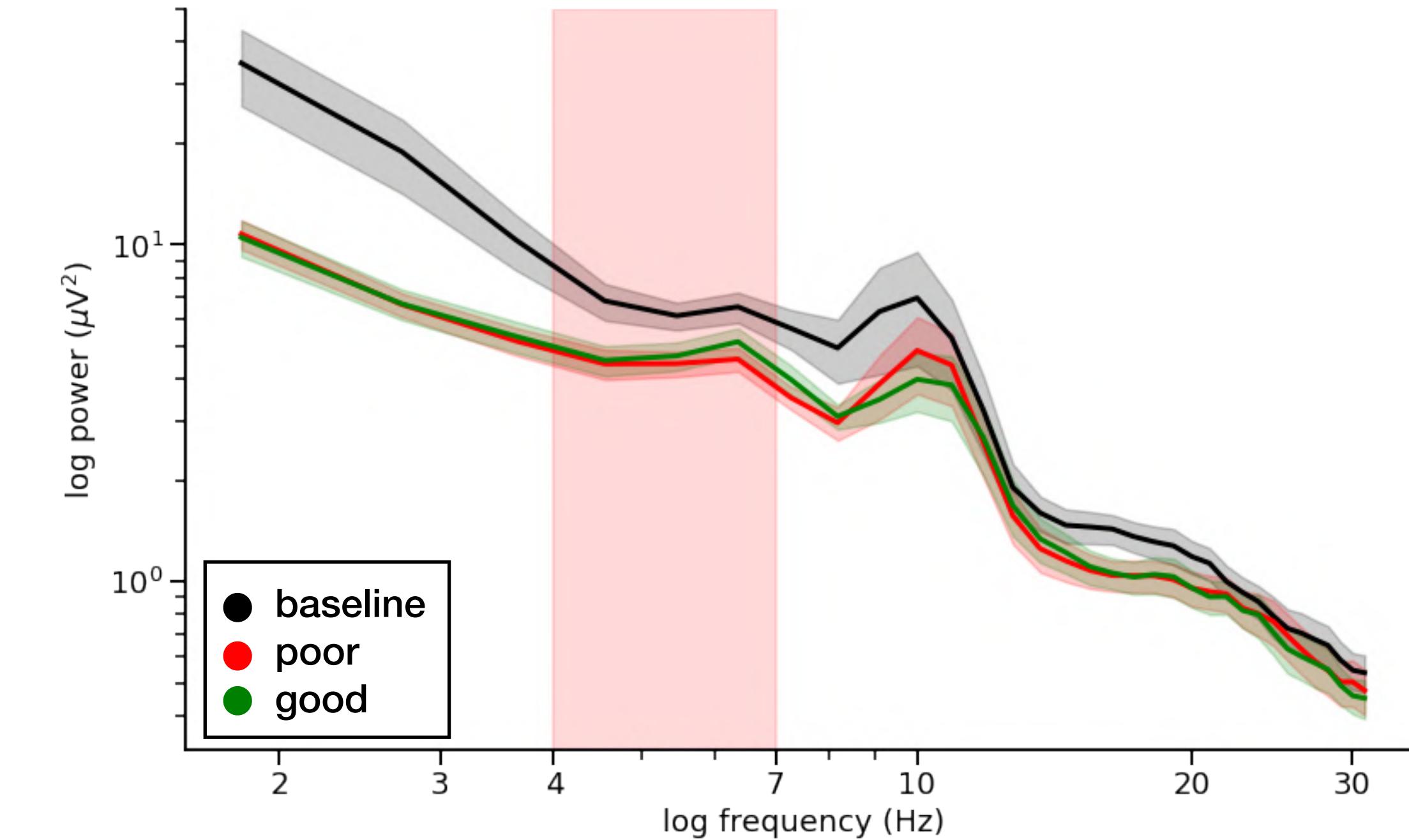
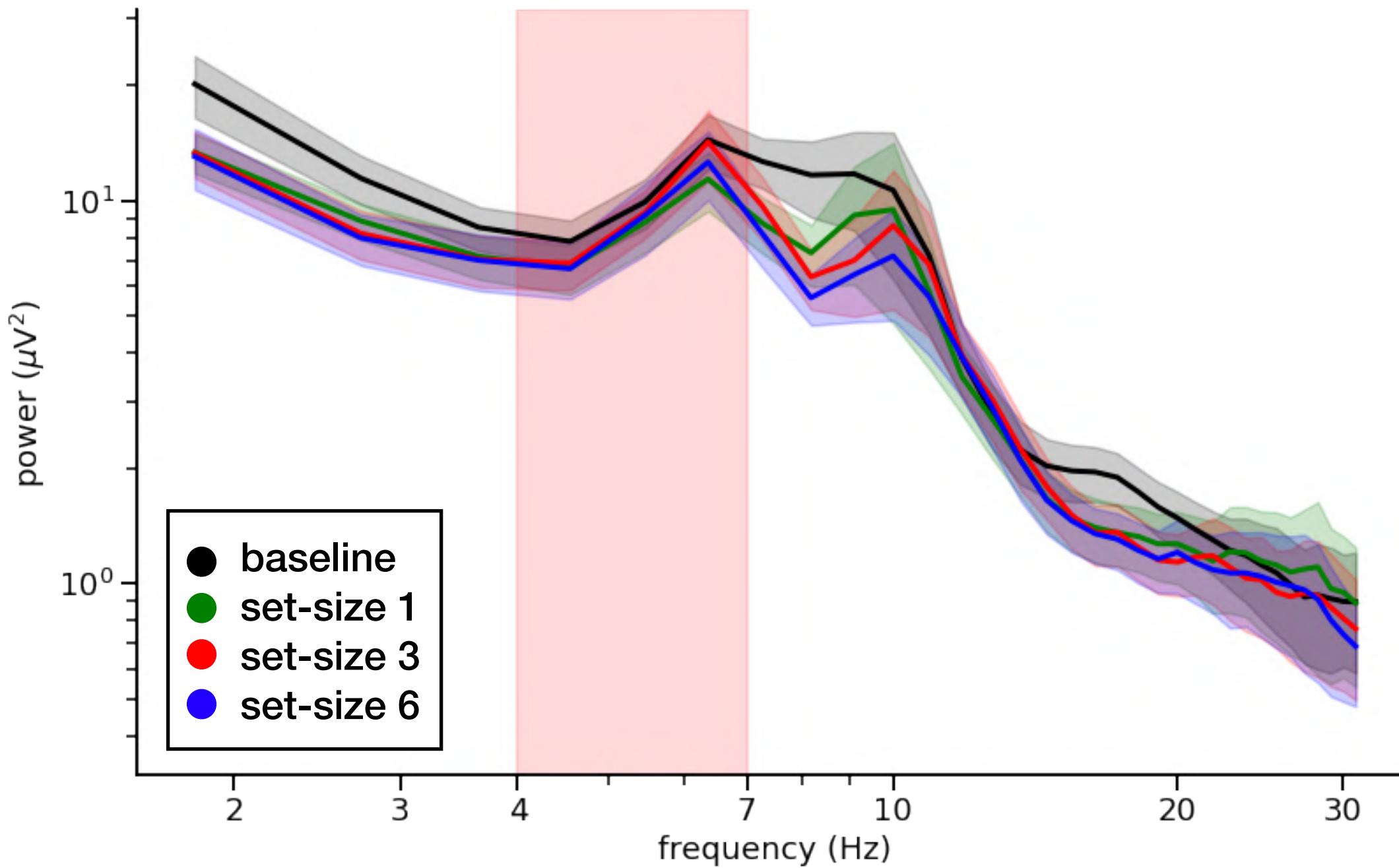
Experiment 2: only set-size 6 - differentiate between poor (<3 correct) and good (>3 correct) performance



WM performance is associated with theta power.
However, where is all that theta power?



Task-general reduction in aperiodic activity

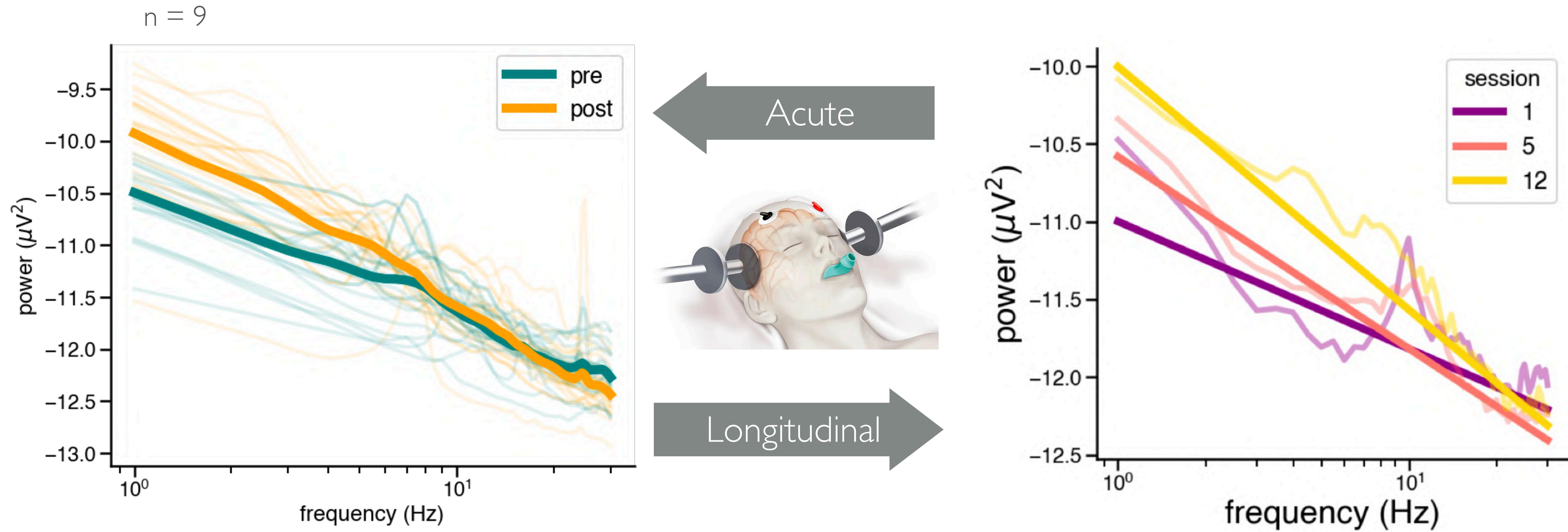


This matters

Sydney Smith



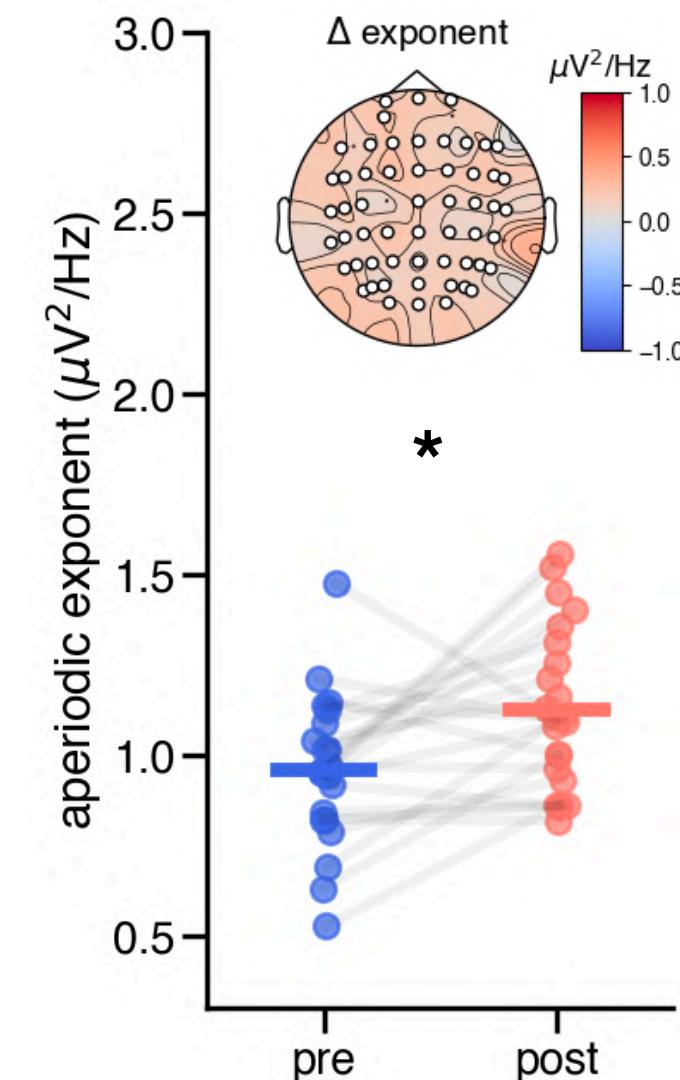
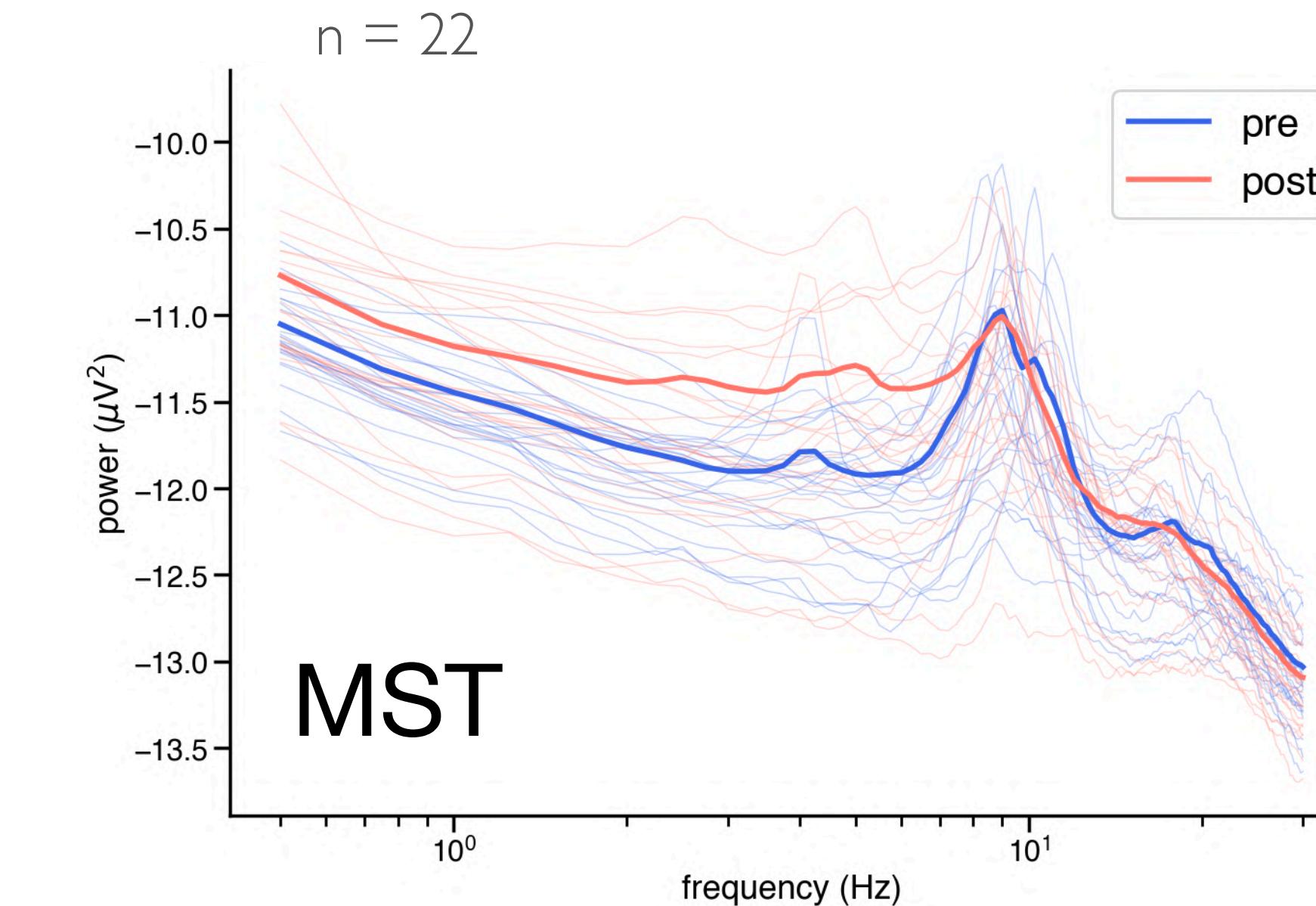
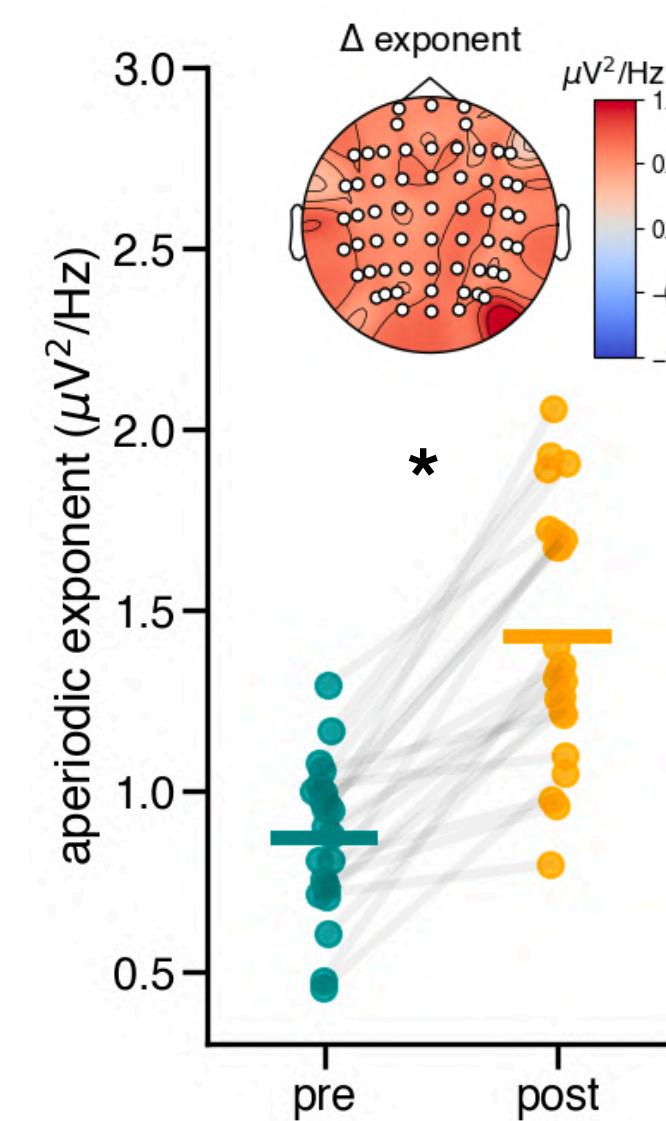
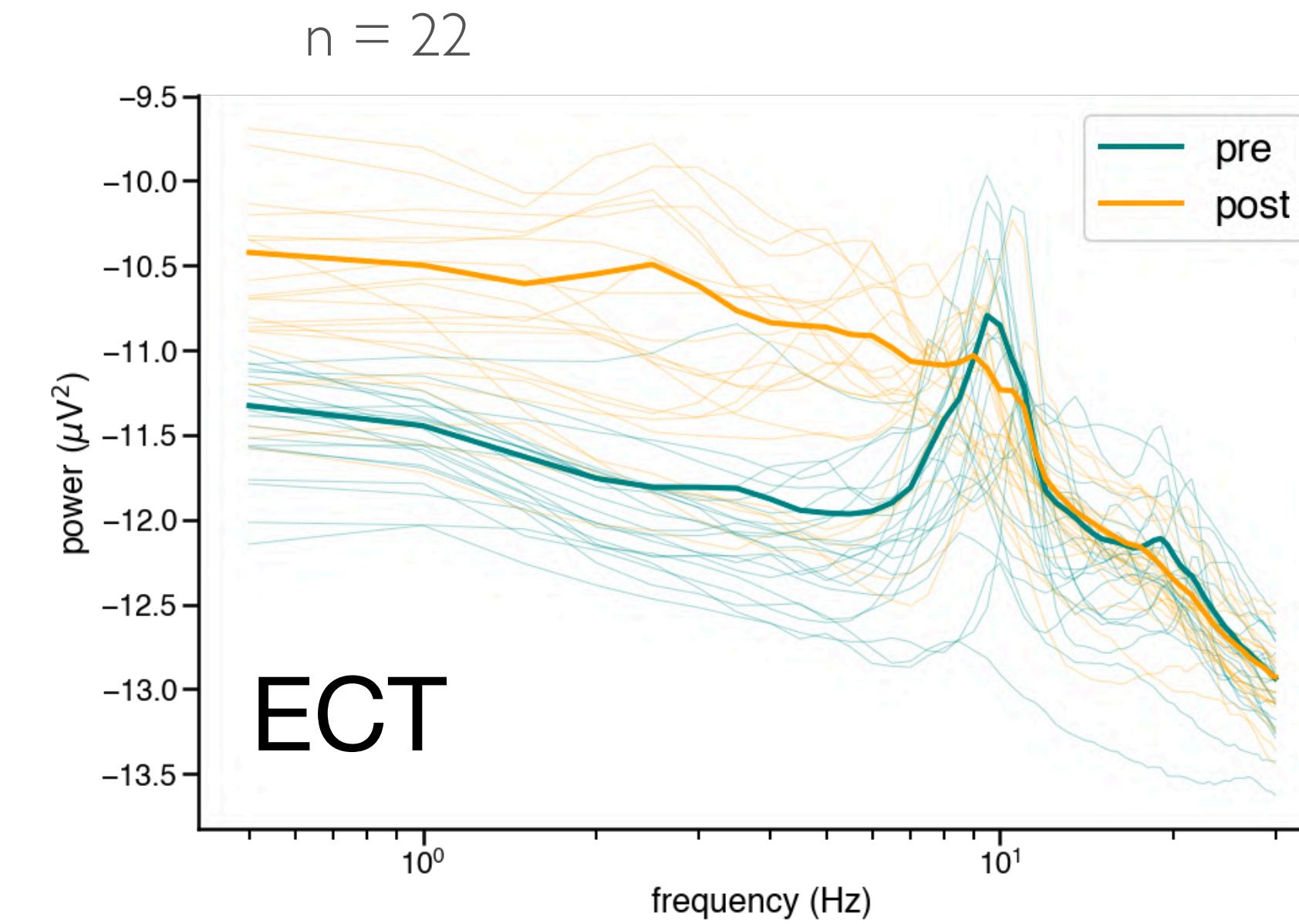
Aperiodic exponent increases in depressed patients receiving electroconvulsive therapy (ECT)



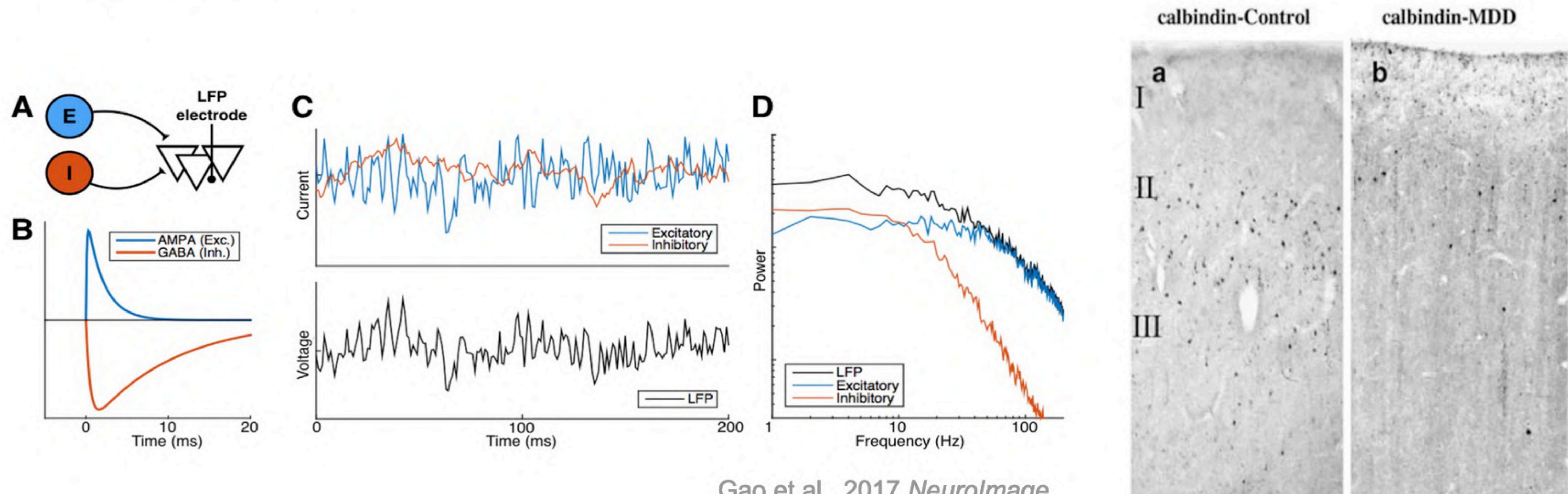
Source: Smith...Voytek,Soltanit, et al., under review

UC San Diego

Aperiodic increase replicates in patients receiving ECT or magnetic seizure therapy (MST)



ECT & MST might ameliorate depressive symptoms by increasing relative inhibition



In summary...

1. The way we measure oscillations matters!
2. Parameterizing our signals allows us to:
 - Distinguish between periodic and aperiodic activity in the frequency domain
 - Measure nonsinusoidal oscillations in the time domain
3. Nonsinusoidal oscillations:
 - Disease, development, & the periphery
4. Aperiodic activity:
 - Physiological basis in E/I balance
 - Dynamic
 - Disease & cognition