Oscillatory and Fractal Biomarkers of Human Memory

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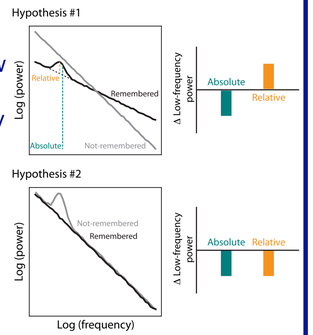
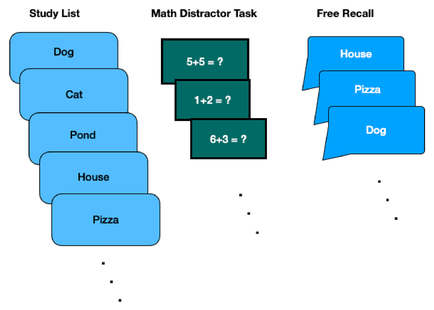
Background

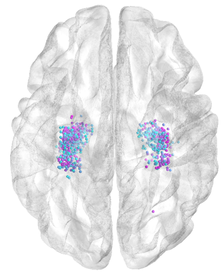
- Studies analyzing the relationship between theta-band and other low frequency brain oscillations have yielded mixed results[1].
- Herweg, Solomon, and Kahana (2020) proposed in a review of theta oscillations that:
  - Changes to the 1/f background spectrum of neural activity might obscure oscillations
  - Positive effects might be due to theta synchrony rather than true power changes
  - Theta might be specific to associative memory and not subsequent memory effects

We aim to **separate narrowband, oscillatory effects from the background spectrum** and better understand the oscillatory correlates of human memory.



Methods

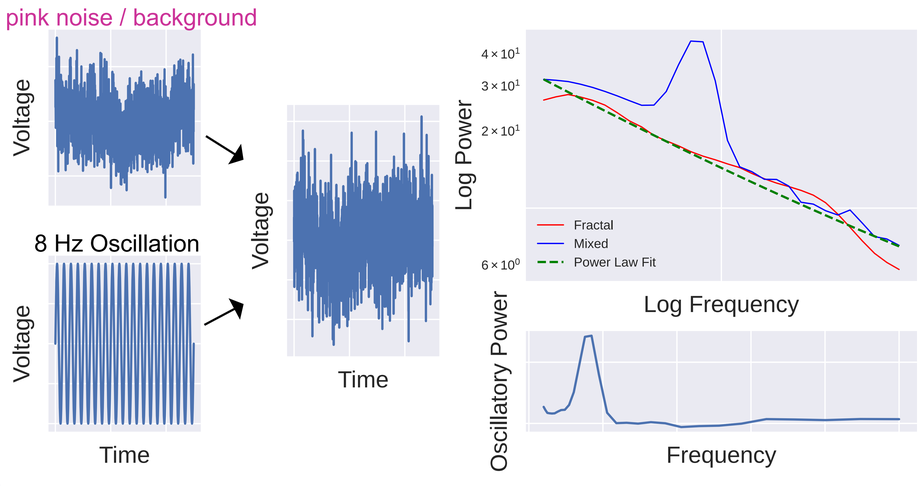




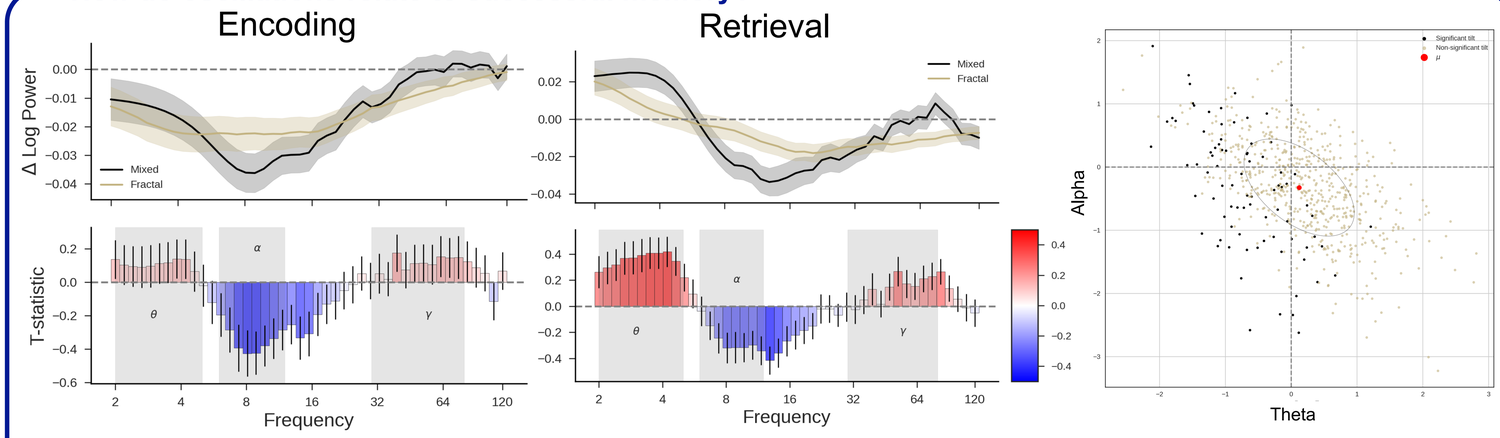
Recordings from 674 hippocampal electrode pairs across 145 patients with epilepsy

The **I**rregular **R**esampling **A**uto-**S**pectral **A**nalysis[2] (**IRASA**) separates broadband changes in the fractal background spectrum from narrowband oscillations.

IRASA treats an EEG trace as a linear combination of an oscillatory component and a "fractal" pink noise component which is assumed to follow a power law distribution.



How do oscillations relate to successful memory?



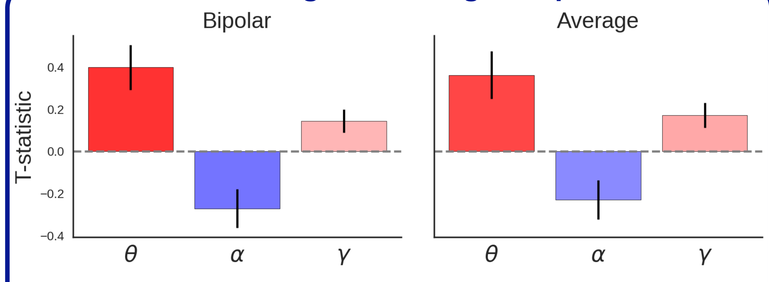
A clear trend in oscillatory power emerges at both encoding and retrieval: successful memory is accompanied by an increase in **T**heta, a decrease in **A**lpha, and an increase in **G**amma (**TAG**)

Theta and alpha are highly correlated at encoding ($R = -0.45$, $p = 1.97 \times 10^{-15}$)

Electrodes which exhibited more **spectral tilt** - a flattening of the fractal spectrum - showed less oscillatory theta for successful memory

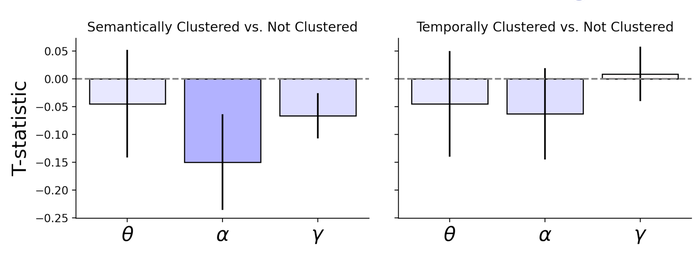
*T-stats compare oscillatory power for recalled and forgotten words

Does re-referencing EEG change the picture?



Bipolar referencing of iEEG is a spatial high-pass filter, so we repeated our retrieval analysis with a more global scheme that would theoretically capture more theta synchrony

Is theta linked to associative clustering?



Semantic clustering: successively recalled words have a high degree of similarity in 300-dimensional *word2vec* space

Temporal clustering: successively recalled words were presented together at encoding

Conclusions

1) IRASA is an effective tool for studying narrowband oscillatory correlates of cognitive function without the confound of broadband changes in brain activity
2) Pure oscillatory power shows a theta increase, alpha decrease, and gamma increase (**TAG**) for successful memory at both encoding and retrieval
3) The positive theta SME at encoding was simply masked by a broadband decrease in fractal power, as hypothesized by Herweg, Solomon, and Kahana
4) Choice of reference scheme as a spatial filter has no effect on TAG
5) Oscillatory theta does not have a unique relationship with associative memory

1. Herweg, N. A., Solomon, E. A., and Kahana, M. J. (2020). Theta oscillations in human memory. Trends in Cognitive Science, 24(3), 208-227.
2. Wen, H., & Liu, Z. (2016, Jan). Separating fractal and oscillatory components in the power spectrum of neurophysiological signal. Brain Topography,29(1), 29(1):13-26.