Hippocampal phase reset as a marker of memory encoding

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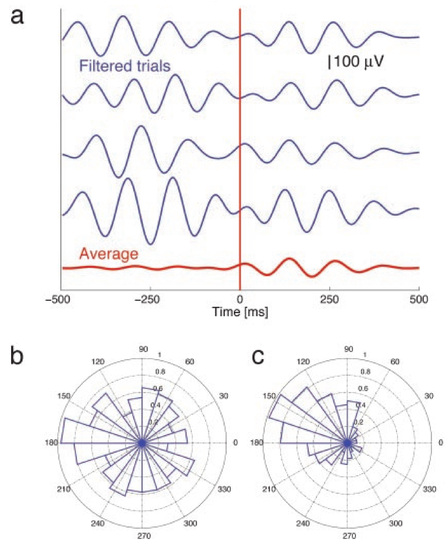
Does phase reset predict memory encoding?

- Upon external stimuli, theta phase resets across large portions of the brain over a few hundred ms.
- The phases of theta signals from the hippocampus are proposed to be timing signals for memory formation.
- **Does phase reset correlate with indicators of strong encoding such as list primacy?**
- **Can phase reset be used as a potential biomarker of successful encoding?**

Theta Reset

- Previous item recognition task with sequentially displayed consonants subject to timing jitter.[1]
- **(a)** Filtered for 8 Hz.
  - Prior to test probe, destructive interference.
  - After event, synchronized phase reset is constructive.



- Phase at **(b)** −250 ms less consistent than **(c)** 250 ms.

Phase Consistency

- Morlet Wavelets were calculated for every encoding event at integer frequencies 3 Hz through 24 Hz.
- For all N events at each contact, the normalized complex values C and S for the first harmonic of each frequency at each timepoint were used to calculate the average r vector, and from that a shifted degree-of-freedom scaled z-score z_s was calculated as the phase consistency.

$$r^2 = \left(\frac{1}{N}\Sigma_i^N C_i\right)^2 + \left(\frac{1}{N}\Sigma_i^N S_i\right)^2 \qquad z_s = \frac{Nr^2-1}{N-1}$$

- This does not shift with noise or from sample sizes $N >= 2$.

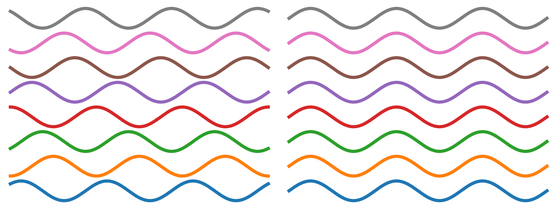


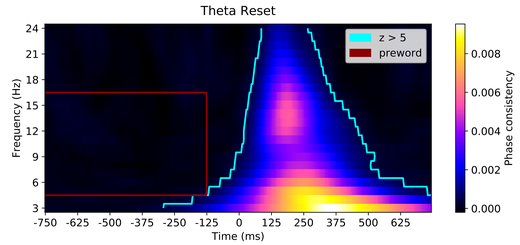
Figure 1: $z_s = 0$

Figure 2: $z_s = 1$

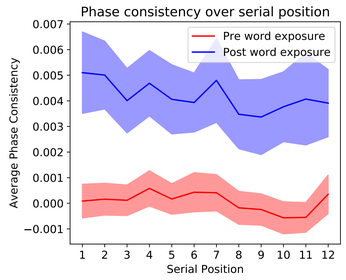
- The average phase consistency (z_s) values range from 0 to 1, with 0 meaning no phase consistency, and 1 perfect consistency.

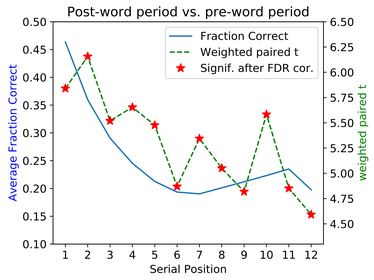
Hippocampal Contacts in FR1

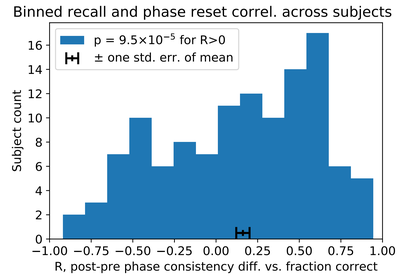
- Subjects were selected with hippocampal contacts and 25 or more lists of 12 encoding words each, yielding 118 subjects.



Post-word Phase Consistency and Serial Position of Recalls

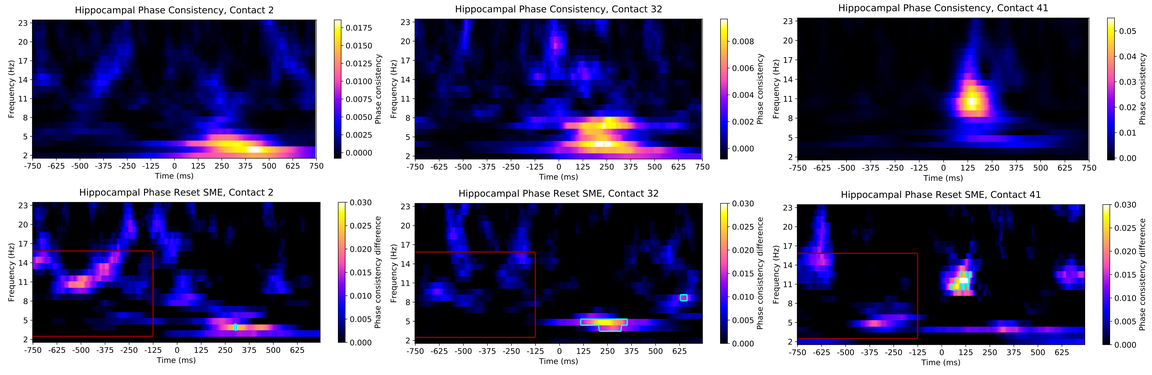






- Post-word phase consistency increases followed the serial position curve's primacy effect for subsequent recall.
- Across subjects, R was positive in a weighted two-tailed t-test with $p = 0.024$. After binning adjacent pairs of serial positions to verify consistency, R was positive across subjects with $p = 9.5\times10^{-5}$.

Single-Contact Biomarkers of Reset/Recall



- In example single-subject single-hippocampal contacts, phase reset SME regions with z>5 (cyan) above the pre-word region (red) are shown as target biomarkers for successful encoding.

Conclusions

- Hippocampal theta phase reset was observed following word encoding events for all serial positions.
- Primacy positions exhibited the strongest phase reset in a basic free recall task.
- Phase reset SMEs on single hippocampal contacts show potential as a selective biomarker of memory encoding activity.

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References

[1] D.S. Rizzuto, J. R. Madsen, E. B. Bromfield, A. Schulze-Bonhage, D. Seelig, R. Aschenbrenner-Scheibe, and M. J. Kahana. Reset of human neocortical oscillations during a working memory task. *Proceedings of the National Academy of Sciences, USA*, 100(13):7931–7936, 2003.

[2] D.S. Rizzuto, J. R. Madsen, E. B. Bromfield, A. Schulze-Bonhage, and M. J. Kahana. Human neocortical oscillations exhibit theta phase differences between encoding and retrieval. *NeuroImage*, 31(3):1352–1358, 2006.