

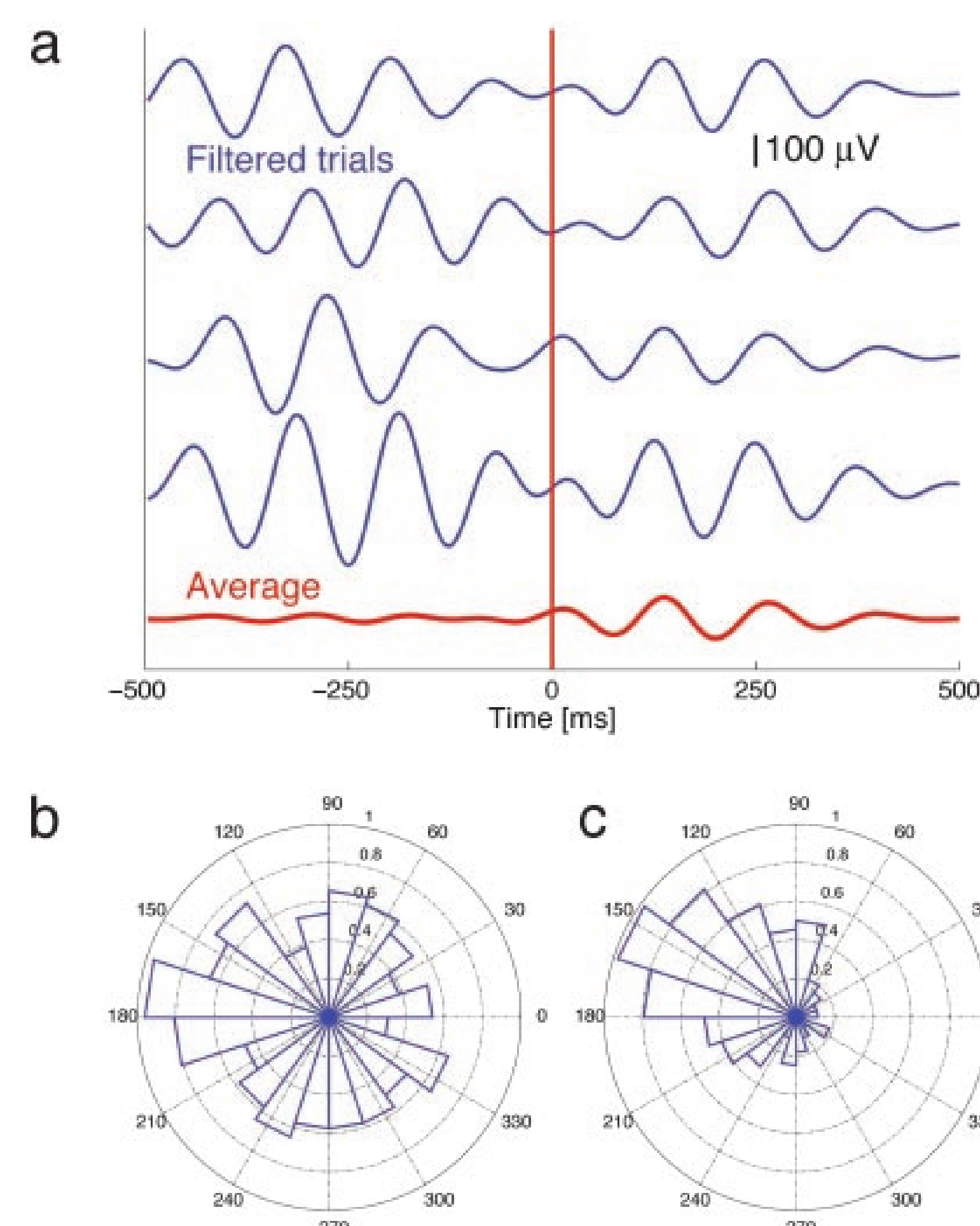
# Does reset of hippocampal theta predict dynamics of memory encoding?

## Abstract

Both human and animal studies have implicated hippocampal theta oscillations in learning and memory function. Furthermore, theta oscillations reset following the appearance of a behaviorally relevant stimulus. Here we asked whether reset of hippocampal theta oscillations predict the dynamics of memory encoding for subsequently recalled and forgotten items. Our dataset comprised 118 neurosurgical patients who studied lists of common words for a subsequent delayed free recall test. We observed significant phase reset in the 125–375ms interval following stimulus presentation for both subsequently recalled and forgotten items. This effect, which appeared prominently in the pre-selected frequencies 5–16Hz, corresponded to primacy, a traditional marker of strong encoding. These findings lend support to the view that hippocampal theta oscillations serve an important role in the encoding of new episodic associations.

## Theta Reset

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



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

## Does theta reset predict memory encoding?

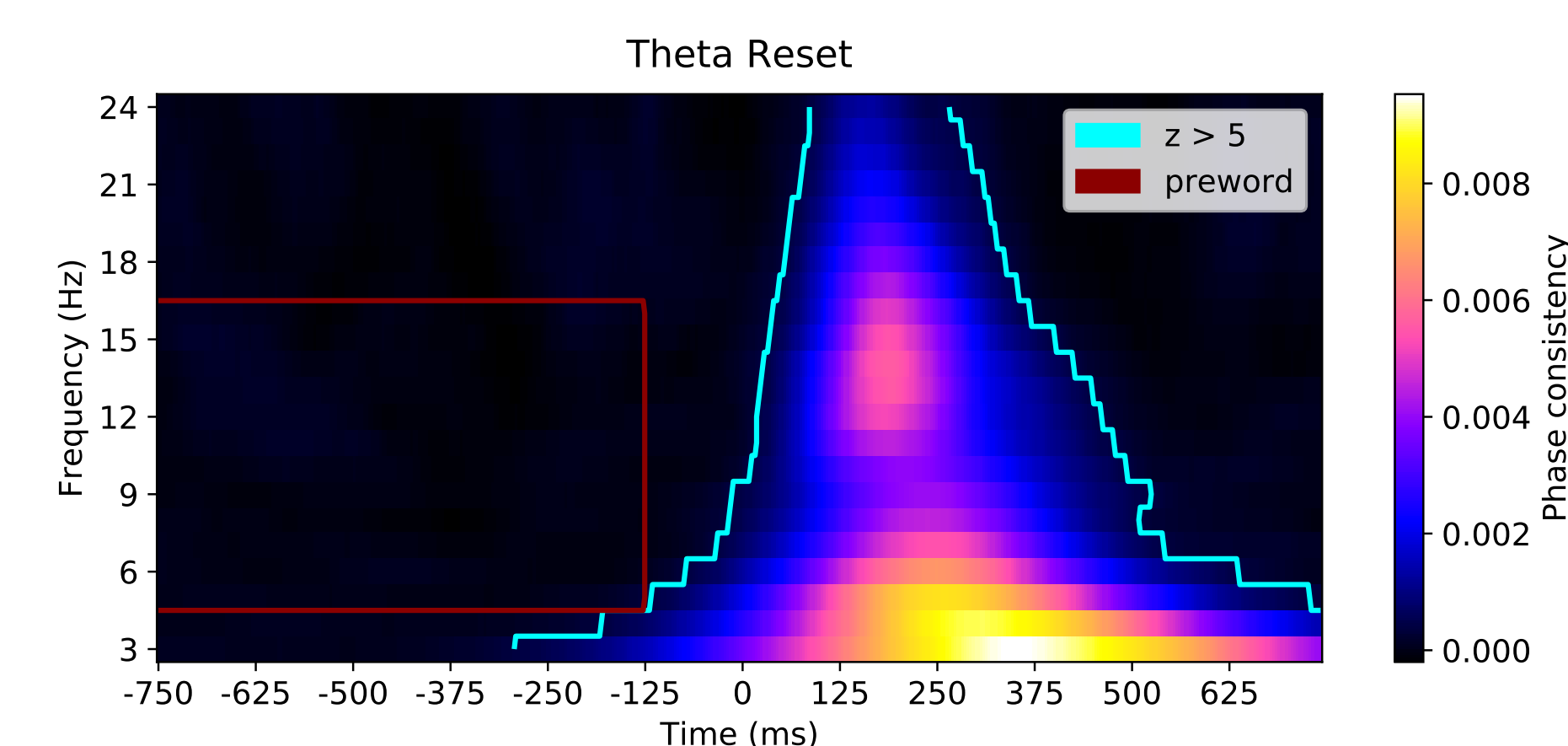
- Upon external stimuli, theta phase resets across large portions of the brain over a few hundred ms.
- The phases of theta signals from the hippocampus are proposed to be timing signals for memory formation.
- **Does theta reset correlate with indicators of strong encoding such as list primacy?**

## Phase Consistency

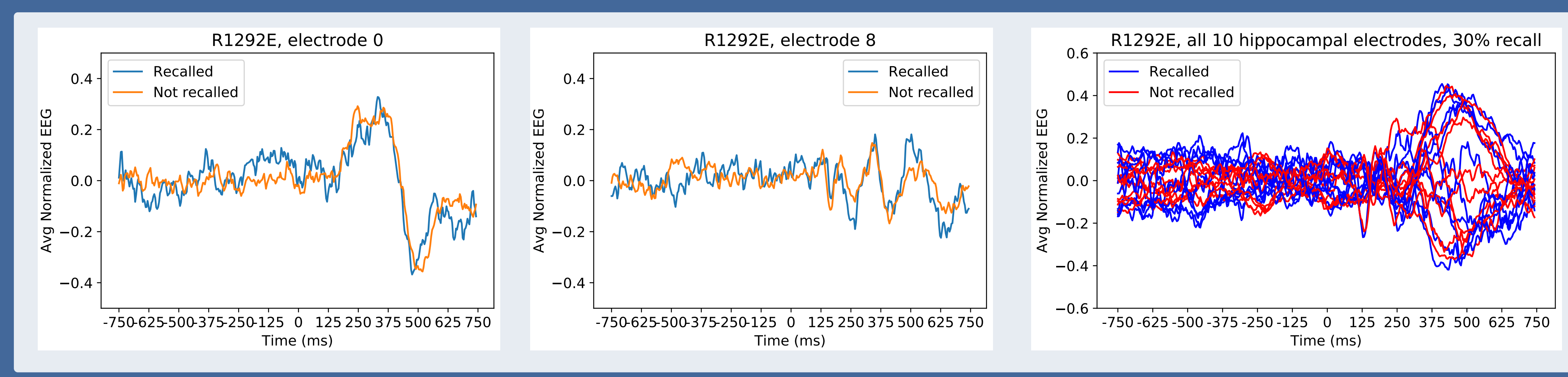
- Morlet Wavelets were calculated for every encoding event at integer frequencies 3 Hz through 24 Hz.
- For all  $N$  events at each electrode, the normalized complex values  $C$  and  $S$  for the first harmonic of each frequency at each timepoint were used to calculate the average  $r$  vector, and from that a shifted degree-of-freedom scaled z-score  $z_s$  was calculated as the phase consistency.
- $r^2 = \left(\frac{1}{N} \sum_i C_i\right)^2 + \left(\frac{1}{N} \sum_i S_i\right)^2$       $z_s = \frac{Nr^2 - 1}{N - 1}$
- The average phase consistency ( $z_s$ ) values range from 0 to 1, with 0 meaning no phase consistency, and 1 perfect consistency. This metric's average does not shift with noise or from sample sizes  $N \geq 2$ .

## Hippocampal Electrodes in FR1

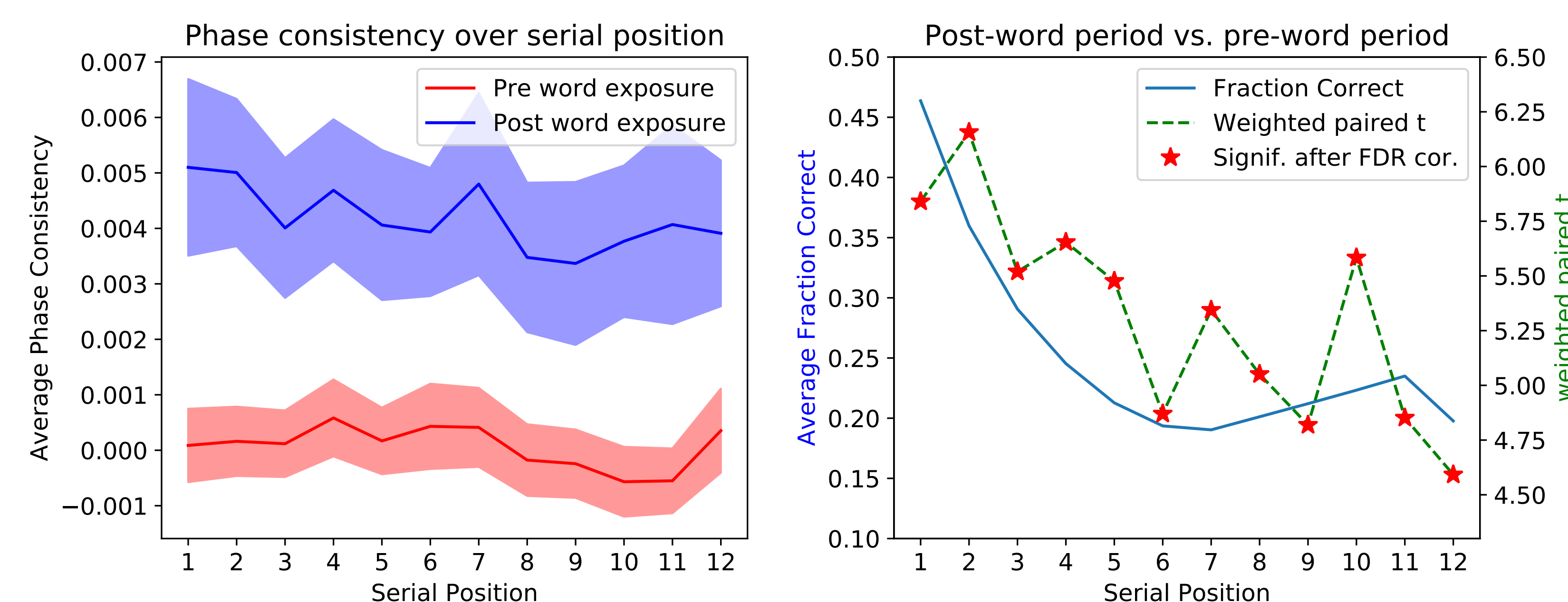
- FR1 is a non-brain-stimulation free recall task which was performed by 274 patients undergoing intracranial EEG monitoring.
- Selected subjects had data available for 1 or more hippocampal electrodes, and 25 or more lists of 12 encoding words each under the same electrode placement, yielding 118 subjects.



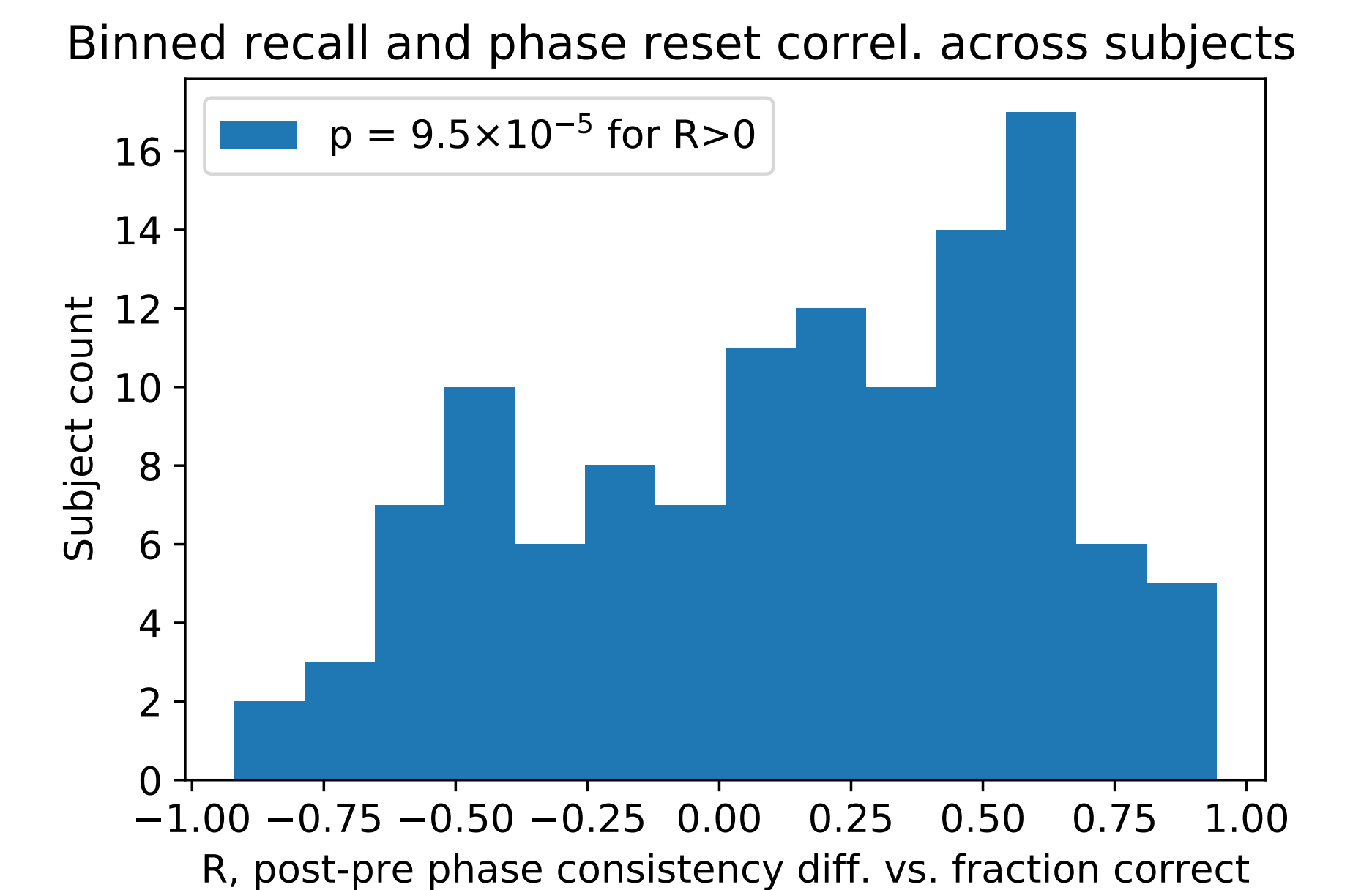
## Averaged normalized Event-Related Potentials



- Post-word phase consistency increases followed the serial position curve's primacy effect for subsequent recall.



## Correlation of Reset and 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  $p = 9.5 \times 10^{-5}$ .

## 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.

## Acknowledgements

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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.