

# Oscillatory Patterns in Behavioral and Hippocampal Responses during a Memory Task

M ter Wal<sup>1</sup>, J Linde Domingo<sup>1</sup>, J Lifanov<sup>1</sup>, F Roux<sup>1</sup>, L Kolibius<sup>1</sup>, D Rollings<sup>2</sup>, V Sawlani<sup>2</sup>, R Chelvarajah<sup>2</sup>, B Staesina<sup>1</sup>, S Hanslmayr<sup>1</sup>, M Wimber<sup>1</sup>

<sup>1</sup> University of Birmingham, Edgbaston, B15 2TT, Birmingham, UK <sup>2</sup> Queen Elizabeth Hospital Birmingham, Edgbaston, B15 2GW, Birmingham, UK

## 1 INTRODUCTION

**Background:** Computational models [1] have proposed that memory encoding and retrieval occur at opposite phases of the hippocampal theta rhythm. This phase locking to theta predicts that memory processes appear as rhythmic themselves [2].

**Question:** Is rhythmicity of memory encoding and retrieval detectable in human behavior and hippocampal signals?

## 6 CONCLUSIONS

- Oscillations in behavioral responses are evident in memory-dependent task phases only
- Incorrect mnemonic decisions are not locked to rhythm
- Oscillation frequency in theta band: 2-5 Hz
- Intracranial EEG shows phase locking across trials in relevant frequency band
- Encoding and retrieval peak at opposite phases of hippocampal theta rhythm

## 2 TASK DESIGN

**Associative memory task (2 groups) [3]:** Subjects memorized pairs of verbs (cues) and objects, pressing buttons to indicate encoding, reinstatement and catch questions separately (g1) or combined (g2).

**Visual task (1 group):** A separate group answered questions about objects on the screen, using the same stimuli and questions as in the memory task.

**# included subjects**

Task	Encoding	Retrieval	Catch Q. & Retrieval	Catch Q.	Visual task
g1	81	81	82	81	95
g2	106	89	62	62	95

## 5 RESULTS - Intracranial EEG

10 epilepsy patients performed the memory task while we recorded hippocampal Local Field Potentials. Correct, but not incorrect trials, show phase locking (high PPC, see Methods) to the theta rhythm.

Preferred phases for encoding and retrieval (at peak PPC) differ by more than half a theta cycle.

**Encoding - retrieval phase difference at peak PPC:** Rayleigh's test:  $Z = 22.59$ ,  $p < 0.001$

**Encoding - retrieval phase difference at random times/frequencies:** Peak vs. random pairs:  $p = 0.008$

## 3 RESULTS - Behavior

Example subject: Is the below density trace of retrieval button presses oscillatory?

Rhythmicity is detectable in behavior (Oscillation score [4], see Methods), but only for memory.

Oscillations in behavior center around lower theta frequency band.

## 4 RESULTS - Behavior

Incorrect trials do not lock to the behavioral oscillation during retrieval.

## METHODS: Data acquisition and analysis

### OSCILLATION SCORE [4]

- Smoothed auto correlation of response time series
- Peak of Fourier transform of response time series
- O-score Z-scored relative to shuffled dataset

### PAIRWISE PHASE CONSISTENCY

- Phase angles from wavelet transform
- PPC across trials:
- PPC Z-scored relative to pre-cue baseline

### INTRACRANIAL EEG RECORDINGS

- 10 epilepsy patients (5 males, 22-52 yrs); 11<sup>th</sup> patient excluded
- Behnke-Fried electrodes in hippocampus (42 bundles in total)
- Local reference (in hippocampus)

#### Data preprocessing

- Band pass filter 0.5-200 Hz and 50 Hz line noise filters
- Downsampling from 32 kHz to 1000 Hz
- Visual artefact rejection (inter-ictal activity and movement artefacts)
- Wavelet decomposition: complex Morlet wavelet, bandwidth 4 cycles

[1] Hasselmo, M., Bodelón, C., Wyble, B.P., (2002) Neural Comput. 14;  
 [2] Kerrén, C. Linde-Domingo, J., Hanslmayr, S., Wimber, M., (2018) Curr. Biol. 28;  
 [3] Linde-Domingo, J., Treder, M.S., Kerren, C., Wimber, M., (2019) Nature Commun. 10:179;  
 [4] Muresan, R.C., Jurjut, O.F., Moca, V.V., Singer, W., Nikolic, D., (2008) J. Neurophys. 99;  
 [5] From: Leiphart, J. & Fried, I., Chapter 30 from 'Atlas of Video-EEG monitoring', 2011;  
 [6] From: Misra, A., et al., (2014) J. Neural Eng. 11 026013.