MEMORY FORMATION IS PREDICTED BY THETA-BAND PHASE IN THE MONKEY HIPPOCAMPUS

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Introduction
- Theta-band (4-10 Hz) activity in the hippocampus has been linked to the formation of place fields, hippocampal-cortical interaction, and memory consolidation (Buzsáki, 2002).
- This activity is often associated with exploratory behavior in rats (Vanderwolf, 1965), bats (Ulanovsky & Moss, 2007), and humans (Kahana et al., 1998; Skudlarski et al., 2005).
- To our knowledge, hippocampal theta-band oscillations have only been observed in anesthetized monkeys; however, it is possible that visual exploration may induce a cognitive state that is amenable to the observation of theta-band oscillations in the awake monkey.

Methods
- Visual Preferential Looking Task
- Saccadic activity during the VPLT
- Theta-band activity locked to fixation onset predicts memory

Results
- Behavioral performance on the VPLT
- Gamma-band power is modulated by theta-band phase

Conclusions
- Theta-band oscillations in the monkey hippocampus appear to be regulated by saccadic eye movements during a free-viewing recognition memory task.
- The ongoing exploratory activity may be a mechanism to ensure that sensory input occurs at an "ideal phase" of the LFP.
- Interactions between network input (LFP) at multiple frequencies and activity at the single unit level may serve as a mechanism to optimize information encoding in the hippocampus during exploration.

References

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Hippocampal neurons are phase-locked to theta-band oscillations

Spikes-triggered average LFPs for two example hippocampus neurons, showing prominent theta-band activity occurring before each spike. Raw (unfiltered) LFPs are shown in red and theta-band (34-44 Hz) LFPs are shown in blue.

Significance of phase-locking (results of Rayleigh test) for two example neurons as a function of frequency (natural logarithm plotted for visualization). Red line: Bonferroni-corrected threshold for significance of Rayleigh statistic (p < 0.001, 0.0001, 0.00001). Filled boxes (30%, 40%) of all reported single units were phase-locked to the LFP in the theta frequency range.

Distribution of preferred phases of all theta-band neurons (n = 52), at the frequency for which each neuron showed the most phase locking (highest significance from Rayleigh test).

Single unit phase locking to theta-band oscillations predicts memory

Left: Parcell phase consistency (PCC; Vink et al., 2010) as a function of frequency for two example neurons for the High Recognition (red) and Low Recognition (blue) conditions. Right: PCC as a function of frequency for the High Recognition (red) and Low Recognition (blue) condition averaged across all theta-band neurons (n = 52). PCC was significantly higher in the 6 Hz bin for High Recognition than for Low Recognition (p < 0.001).

An example of the monkey’s saccade path over the first (yellow) and second (blue) presentation of a stimulus. Circles represent points of fixation between presentations, with the size of each circle proportional to the duration of the fixation period.