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, 1969), bats (Ulazevsky & Moss, 2007), and humans (Kahana et al., 1999, Etkstrom 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

- Spikes and local field potentials (LFPs) were simultaneously recorded from up to 4 independently movable electrodes in the hippocampus of two adult macaque monkeys. Eye-movements were monitored noninvasively using a Primate Eye-Tracking system (BCAN, Burlington, MA).
- 205 unique stimuli were presented during the session. Monkeys were allowed to freely view any part of the picture. The picture remained on the screen for 5 seconds, or until the monkey made a saccade outside the boundary of the picture.

Results

Phase reset of theta-band oscillations in the hippocampus

- Ongoing theta oscillations in the hippocampus. Each sweep is from a different trial and represents the response to the first presentation of three different stimuli. Averaged stimulus onset at time 0, raw (unfiltered) LFP activity is shown in red and LFP activity filtered at 4-10 Hz is shown in blue. In each trial, stimulus onset produces a phase reset of ongoing theta-band activity.

Phase concentration in the hippocampal LFP increases upon fixation onset

- A. Phase concentration in the hippocampal LFP increases upon fixation onset. Fixation periods (n = 1018) were analyzed for phase concentration within the theta frequency band (4-10 Hz). The distribution of instantaneous phases taken at fixation (red) is significantly different from random (ANOVA, F(5,1002) = 17.91, p < 0.01). However, the instantaneous phases of the LFP 300 ms prior to fixation (black) was randomly distributed (ANOVA, F(5,1002) = 0.3, p > 0.05).

Gamma-band phase-locking of single unit activity is phase-locked to fixation onset

- A. Gamma-band phase-locking of single unit activity is phase-locked to fixation onset.

Saccades produce phase reset of theta-band oscillations in the dark

- A. Distribution of inter-saccade intervals in darkness (median = 1.48 s).
- B. Inter-saccade coherence aligned to fixation onset averaged across hippocampal LFPs.
- C. Average evoked LFP (n = 10) aligned to fixation onset in complete darkness.
- D. Example unfiltered LFP activity (red) and activity filtered at 4-10 Hz (blue) for three examples aligned to fixation onset.

Coherence between theta-band phase and gamma-band power increases after stimulus onset

- A. High Recognition
- B. Low Recognition
- C. Gamma-band phase-locking of single unit activity is phase-locked to fixation onset.
- D. Coherence between gamma-band power and theta-band phase, aligned to stimulus onset, averaged across all LFPs (n = 114).

Conclusion

- Theta-band oscillations in the monkey hippocampus appear to be regulated by saccadic eye movements during a free-viewing task.
- Theta-band phase-resetting at stimulus onset and with each new fixation may ensure that sensory input occurs at an “ideal phase” of the LFP.
- Interactions between network input (LFPs) at multiple frequencies and activity at the single unit level may serve as a mechanism to optimize information encoding in the hippocampus.

References


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