Hippocampal Theta Oscillations Normalize Sensory Input for Efficient Encoding

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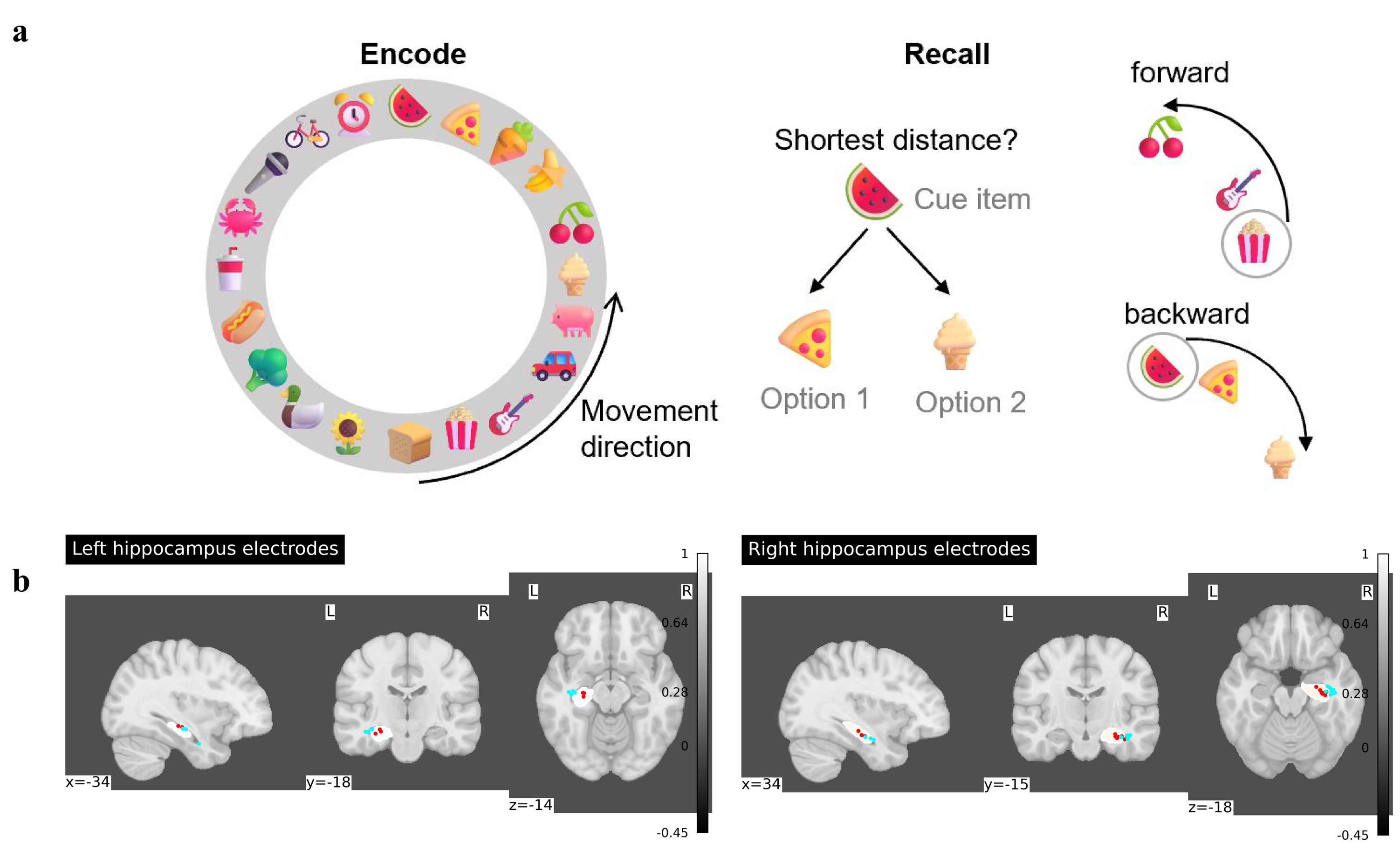
Introduction

Behavioral studies (Biba et al., 2026) suggest that the temporal structure of incoming information is linked to theta-band organization, yet how hippocampal theta dynamically adapts to changing encoding demands remains unclear. Here, we asked whether faster sensory input is reflected in the temporal dynamics of hippocampal theta during encoding.

Research Questions

1. **Does encoding speed affect behavioral performance?**
2. **Does encoding speed modulate hippocampal theta oscillations?**
3. **Does encoding speed alter theta burst occupancy?**
4. **Are similar effects observed in the gamma band?**

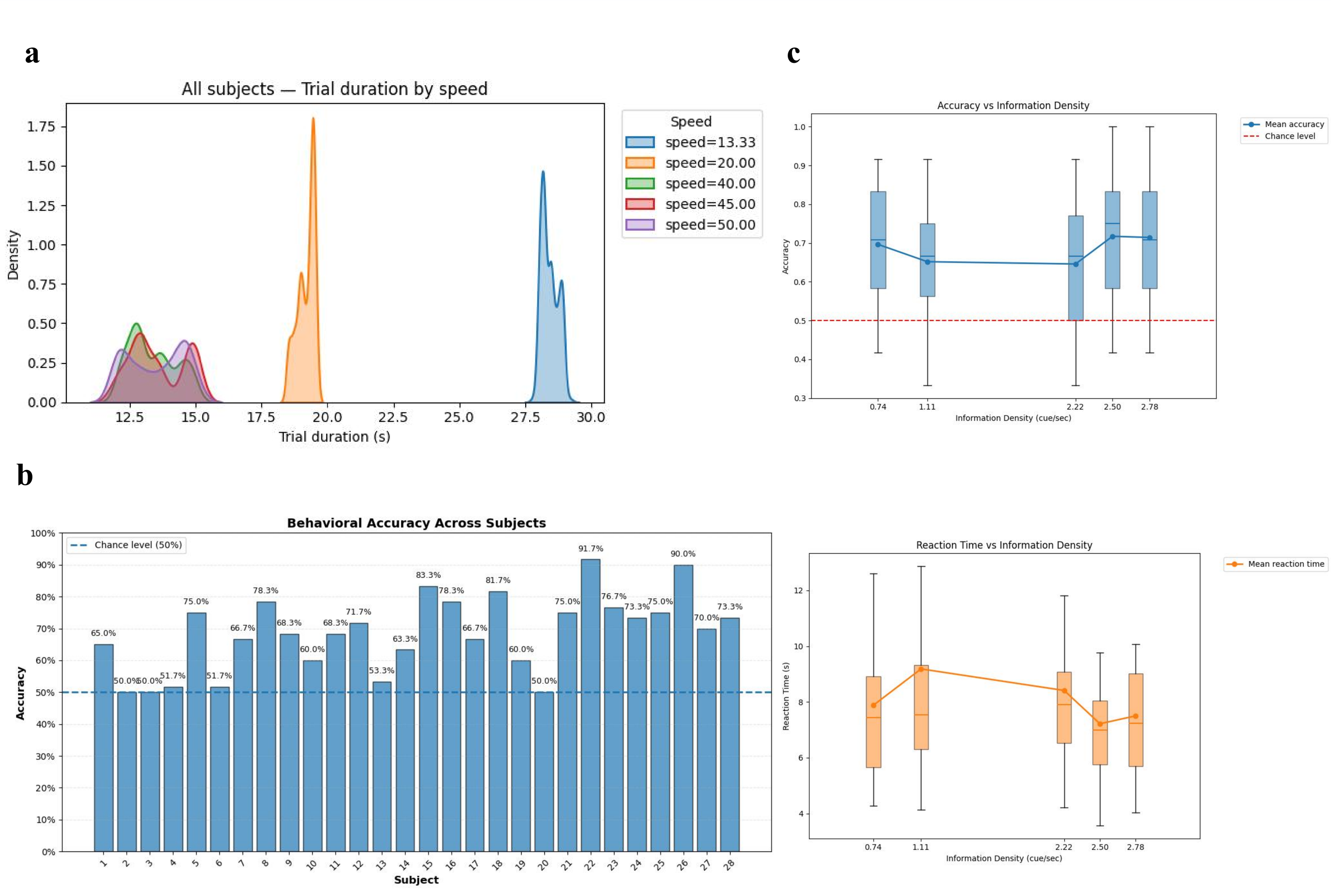
Method



Method: Experimental Design and Data Collection

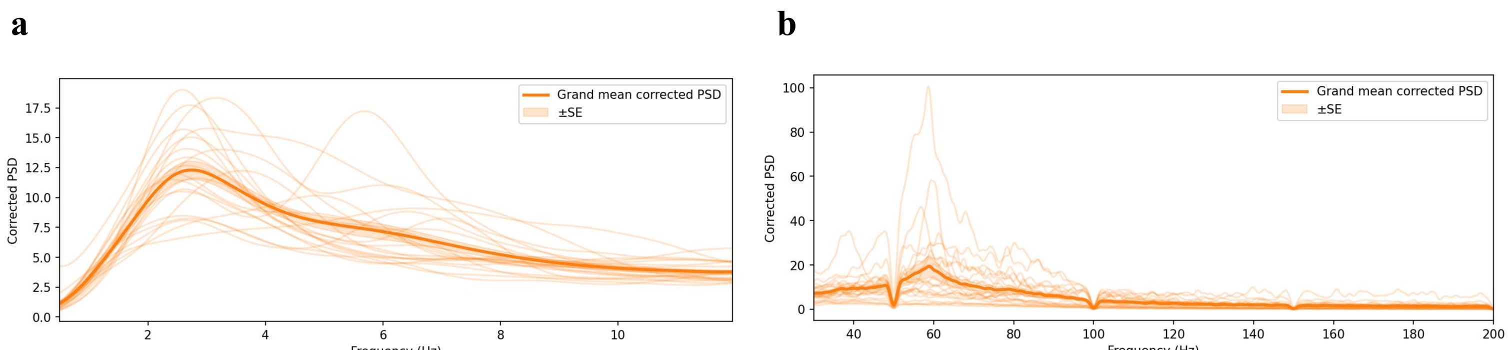
a. Experimental paradigm. During encoding, participants viewed 20 objects distributed along a virtual circular track while the camera moved continuously around the ring. During retrieval, participants selected which of two options was closer to the cue item, with the recall direction in either the forward (along the movement direction) or backward (against movement direction) (Jiang et al., 2025). **b.** Hippocampal electrode localization. Gray-matter contacts are shown in red and white-matter contacts in blue; In each participants, one gray-matter electrode is selected for data aquisition, and one white matter electrode is selected for referencing.

Result



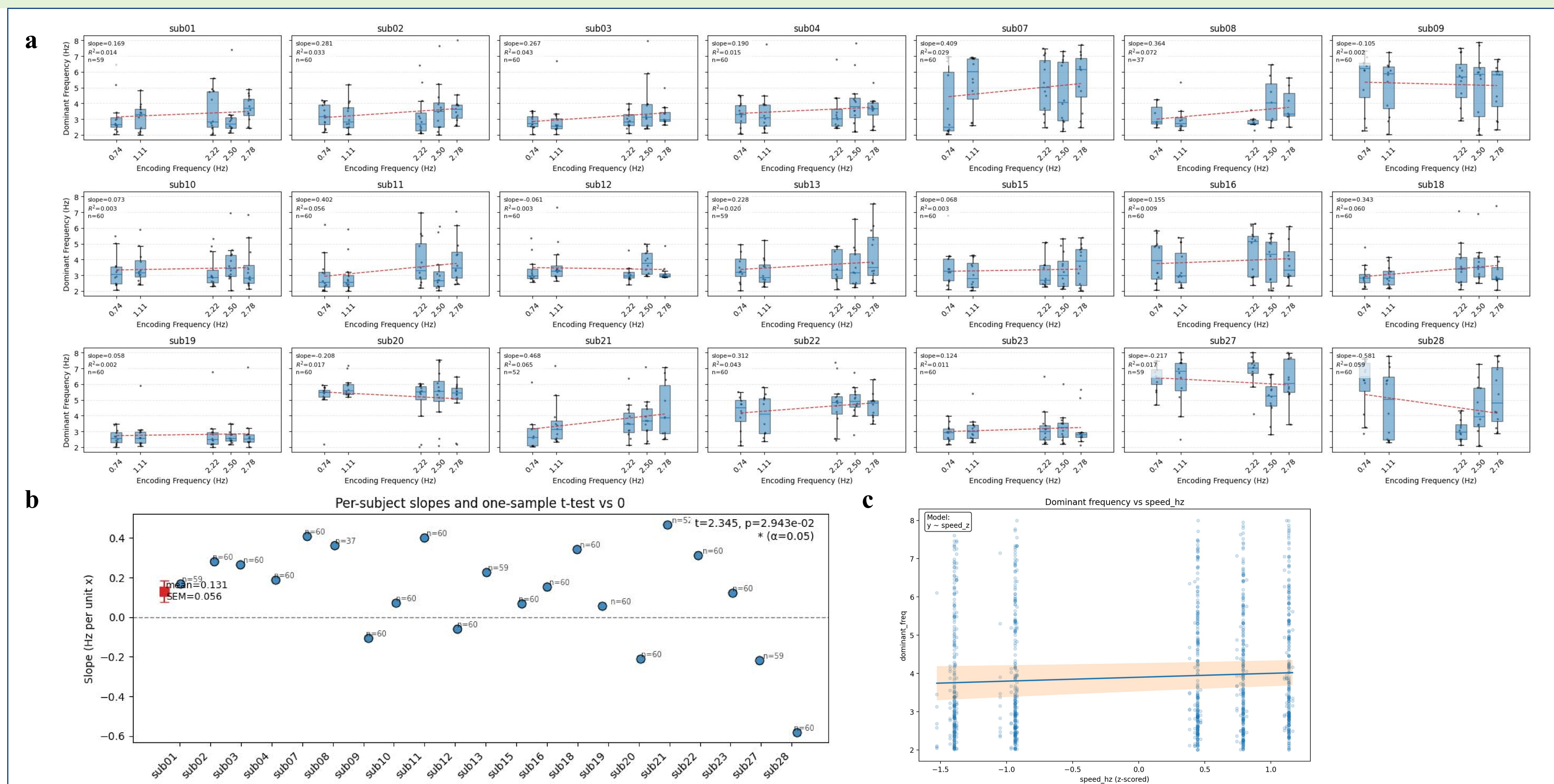
Result 1: Behavioral performance remains stable across different speed of sensory information

a. Distribution of trial duration across speed of incoming sensory information conditions. Lower speed of sensory information resulted in longer trial durations. **b.** Accuracy of each participants in the behavioral task. Most of the participants keeps an accuracy above chance level (50%). **c.** Accuracy and reaction time are not affected by the change of incoming speed of sensory information during encoding.



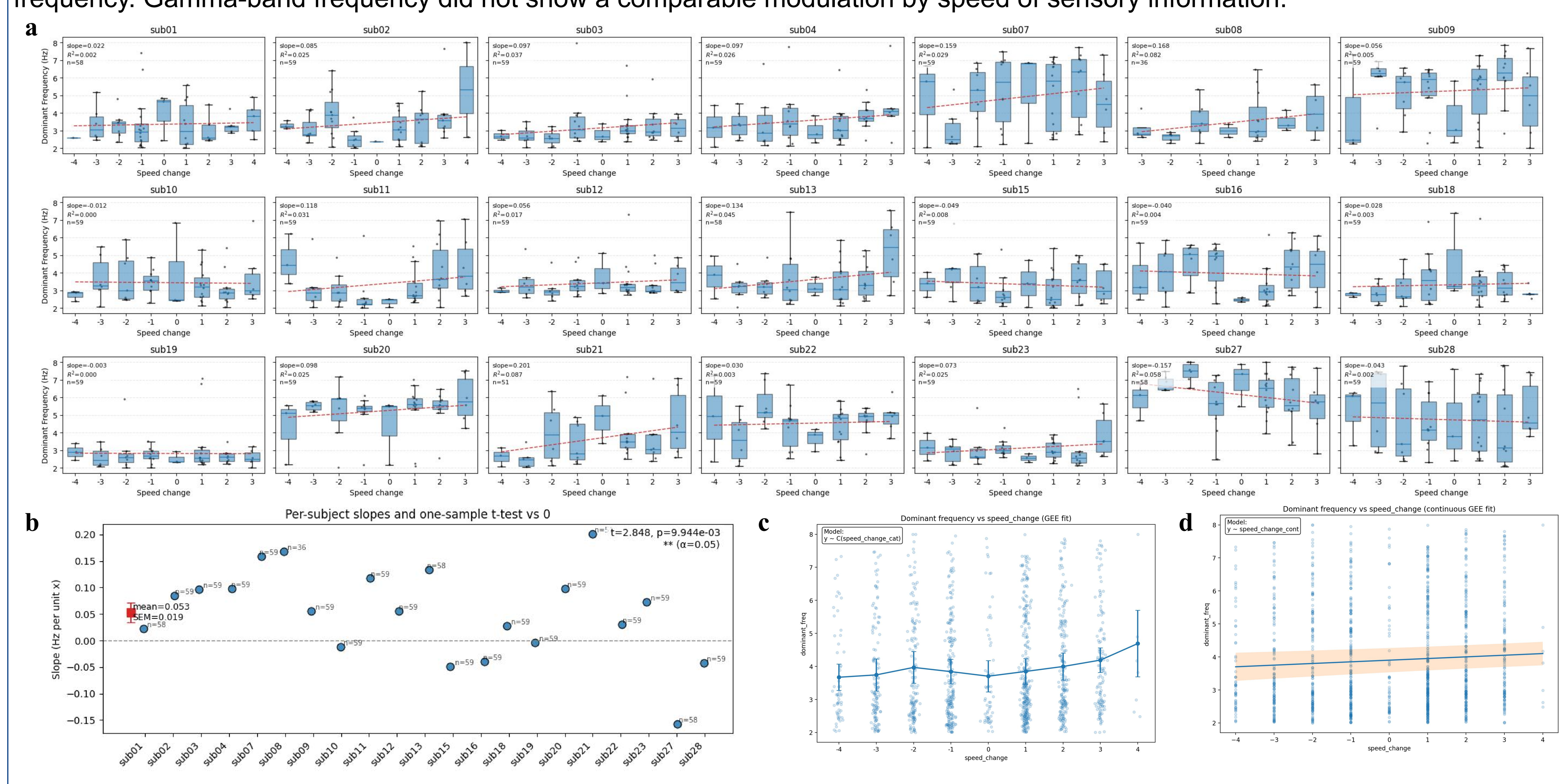
Result 2: Power Spectral Density and Selection of the Frequency Range of Interest

a. Power spectral density after aperiodic noise removing at 0.5-12 Hz during encoding. Hippocampal signals showed low-frequency activity in the theta range of 2-8 Hz. Thus, we picked 2-8 Hz as theta range of interest. **b.** Power spectral density after aperiodic noise removing at 30-200 Hz during encoding. Gamma-band activity shows a prominent peak around 60 Hz, so we picked 55-80 Hz as gamma range of interest.



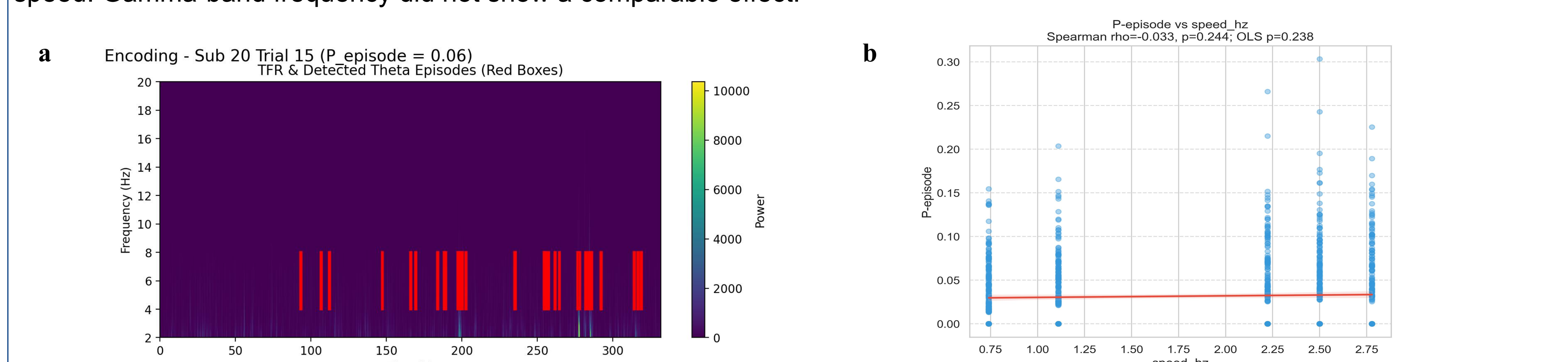
Result 3:Hippocampal theta dominant frequency scaled with speed of sensory information during encoding

a. Within-subject linear relationships between theta dominant frequency and speed of incoming sensory information during encoding. Each line represents a participant level regression. The linear regresssion results shown an overall trend of increasing dominant frequency along with increasing speed of sensory information. **b.** Participant level regression slopes are statisically larger than zero. **c.** Continuous GEE model relating theta dominant frequency to encoding speed (β = 0.10, p = 0.019), accounting for within-subject dependence. Together, these results indicate that faster sensory input was associated with higher hippocampal theta dominant frequency. Gamma-band frequency did not show a comparable modulation by speed of sensory information.



Result 4: Theta frequency shifted with trial-to-trial changes in speed of sensory information

a. Within-subject linear relationships between theta dominant frequency and speed of sensory information changing index, showing an trend of increasing dominant frequency with increasing speed of sensory information. **b.** Participant level regression slopes are statistically larger than zero. **c.** Discrete GEE analysis of theta dominant frequency across speed changing rate. **d.** Continuous GEE model relating theta dominant frequency to speed changing rate (β = 0.05, p = 0.004), accounting for within-subject dependence. Together, these analyses show that theta dominant frequency shifted systematically across trial-to-trial changes in sensory input speed. Gamma-band frequency did not show a comparable effect.



Result 5: P-episode is not affected by speed of incoming sensory information.

a. Example of BOSC theta burst detection during encoding. Detected theta bursts are marked by red boxes. **b.** P-episode ($P_{episode} = \frac{t_{burst}}{t_{total}}$) did not significantly modulated by speed of incoming sensory information during encoding.

Highlights

- **Faster incoming sensory information is associated with higher hippocampal theta dominant frequency.**
- **Trial-to-trial changes in speed of sensory infromation are accompanied by shifts in theta dominant frequency.**
- **P-episode is not modulated by speed of sensory information, suggesting that faster sensory input does not simply increase theta burst engagement and peak amplitude.**

Acknowledgements & References

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2. Jiang, H., Cai, J., Santos-Pata, D., Zhu, X., Deng, Z., Li, C., ... & Kwok, S. C. (2025). Sustained hippocampal theta oscillations reflect experience-dependent learning in backward temporal order memory retrieval. The Journal of Neuroscience, 45(26), e1223232025.

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