Spectral Biomarkers of Spatial Memory Encoding in the Non-human Primate Hippocampus

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Highlights

• Rhesus macaques were trained to navigate an immersive 3D virtual environment to perform a spatial memory task.

• One monkey was implanted with electrode arrays containing 36 recording channels spanning the anterior-posterior axis of the hippocampus.

• Analyses revealed patterns of activity in the theta, beta, and gamma bands during encoding of spatial information that appeared more prominent in posterior recording locations.

• These data additionally suggest that connectivity within the hippocampus varies with memory performance: higher coherence in the theta and gamma bands during encoding predicted higher retrieval accuracy.

Introduction

• Evidence from rodents suggests that spatial memory is supported by neural activity in the hippocampal formation.

• Our lab has shown evidence for enhanced theta- and gamma-band activity in the hippocampus associated with successful encoding in a visual recognition memory task (Jutras et al., 2009, 2013).

• The current study focuses on whether these spectral biomarkers are similarly involved in a task of spatial memory. Recordings from human epilepsy patients performing virtual navigation tasks have shown evidence of theta oscillations in the hippocampus (Ekstrom et al., 2005; Watrous et al., 2011).

• Previous research has drawn attention to potential functional differences along the long axis of the hippocampus in both rodents and primates (Strange et al., 2014); this research suggests that the dorsal hippocampus in rodents, or the posterior hippocampus in primates, may have a relatively greater contribution to processes involved in navigation and spatial memory.

• The ability to record simultaneously from multiple locations along the long axis of the hippocampus allows for the examination of differences across, and interactions among, different anterior-posterior regions during navigation and memory formation.

Virtual Water Maze
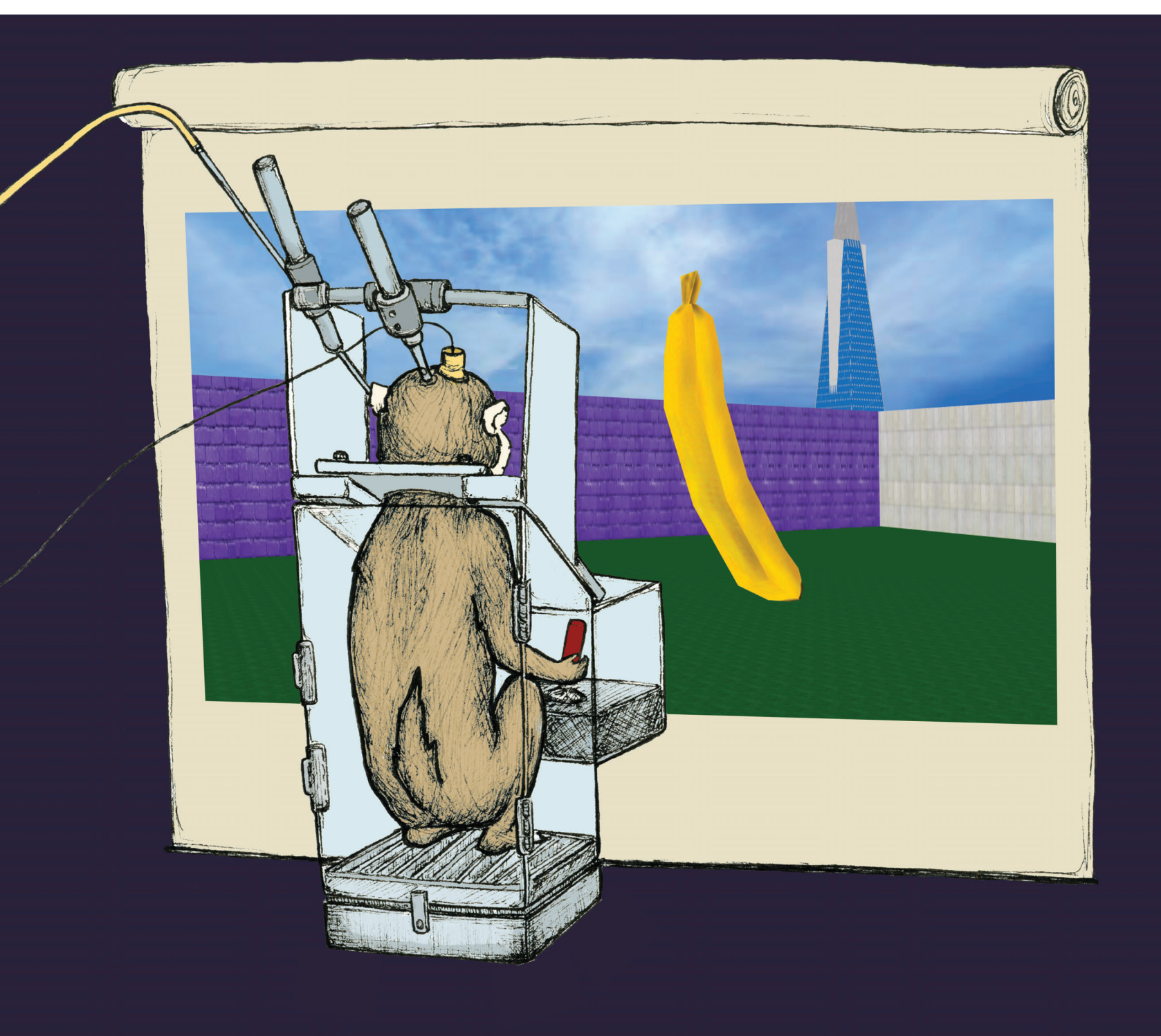
The monkey is trained to use a joystick mounted inside the primate chair to navigate through a virtual environment, obtaining reward for navigating to specific targets in the environment. The virtual environment is controlled using PandaEPL (Solway et al., 2013) as well as additional programming in Panda3D. The joystick's interaction with the virtual environment is handled by PyGame.
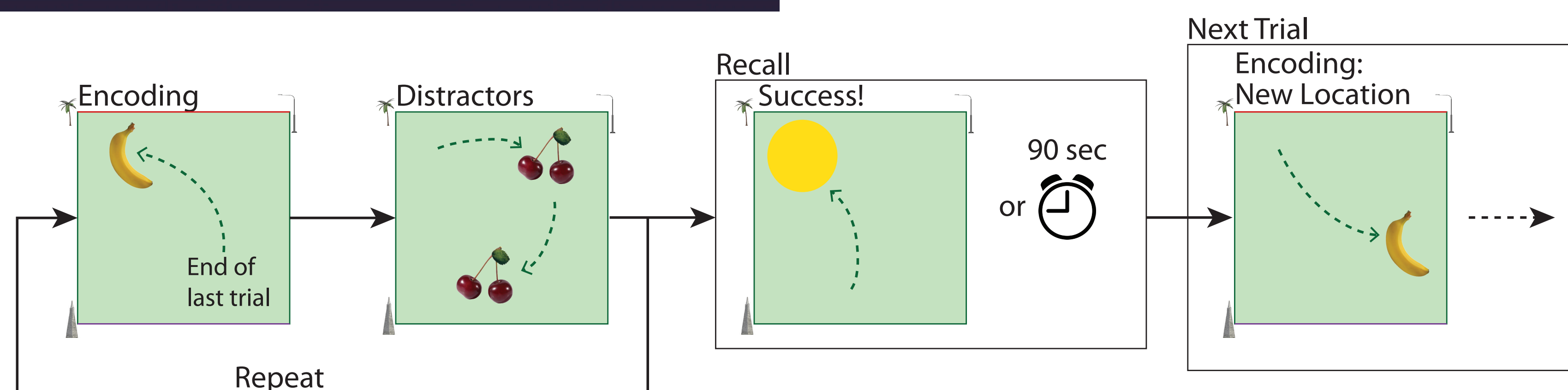

(1) **Encoding**: the monkey is presented with the location of a target (a banana).

(2) **Distractors**: the monkey must collect at least two distractor fruit (cherries).

(3) The encoding sequence is repeated, with the distractors presented in different locations.

(4) **Recall**: the monkey must return to the remembered location of the now invisible target within 90 seconds.

(5) After each recall phase, a new trial set begins with a new target location.

Hippocampal Recordings
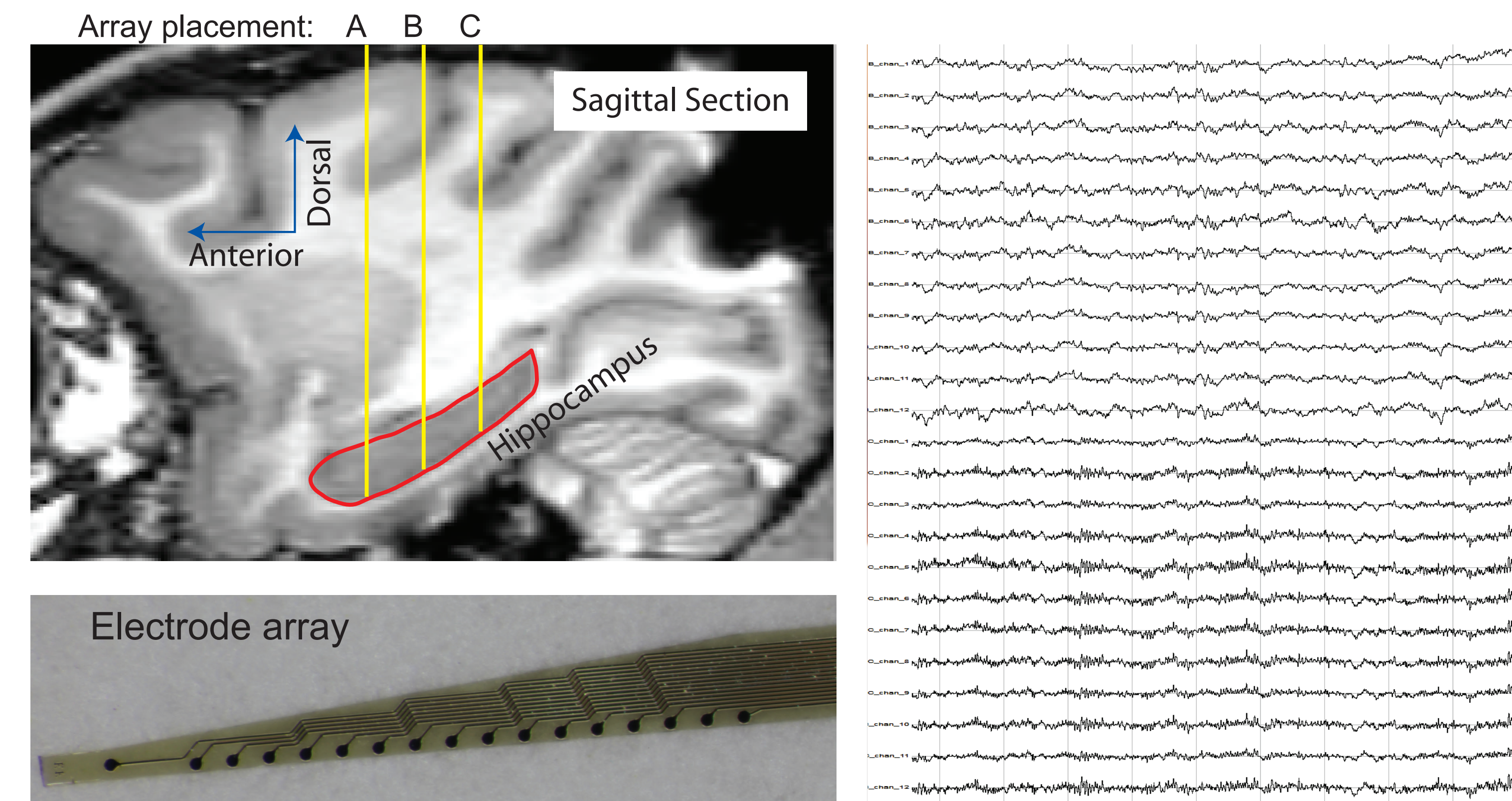
Local field potentials (LFPs) were recorded from chronically implanted polyimide-based arrays (IMTEK/CorTec GmbH, Freiburg, Germany) in the right hippocampus of a rhesus macaque. LFPs were recorded using the Cerebus® Neural Signal Processing System from Blackrock Microsystems (Salt Lake City, UT).

## LFP power is modulated during spatial encoding
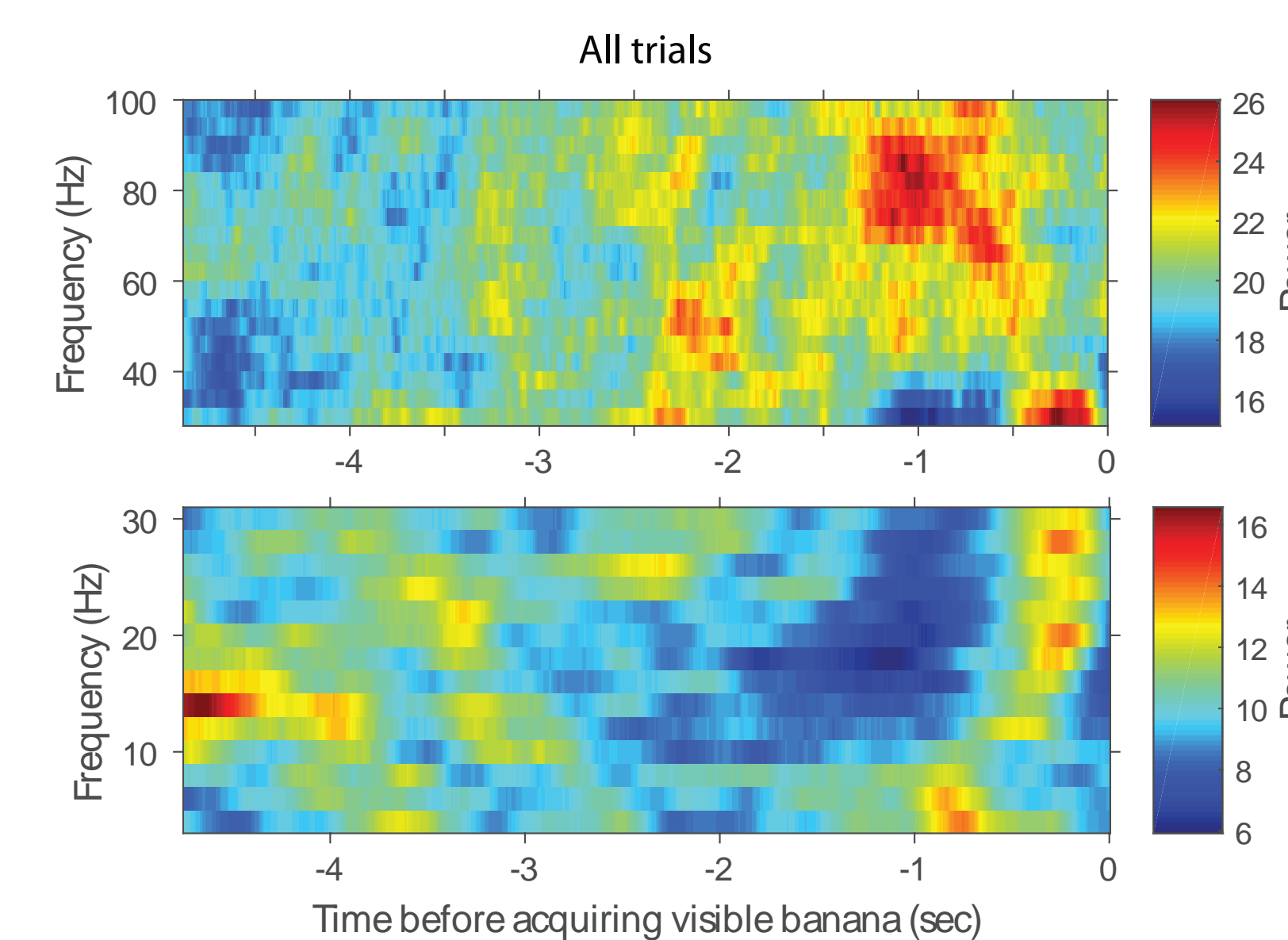
Above: spectrograms representing power at one example contact on the C array, across all trials (left; n = 204), and the difference between good and poor memory trials (right; n = 68).

Below: spectrograms representing power averaged across contacts on each array, across all trials. Number of contacts: A = 7; B = 10; C = 12.
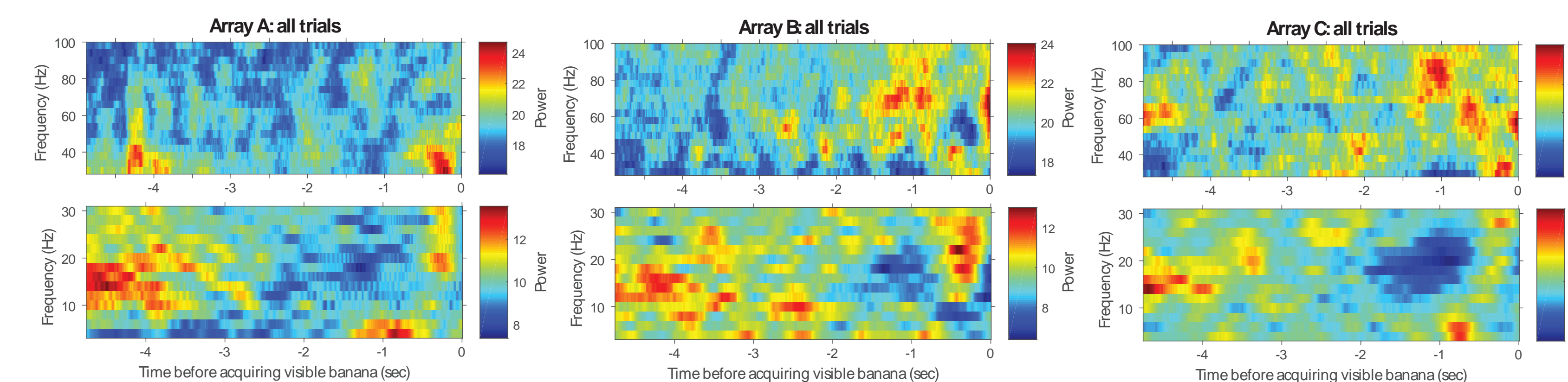

## Spatial memory assessed using excess path length
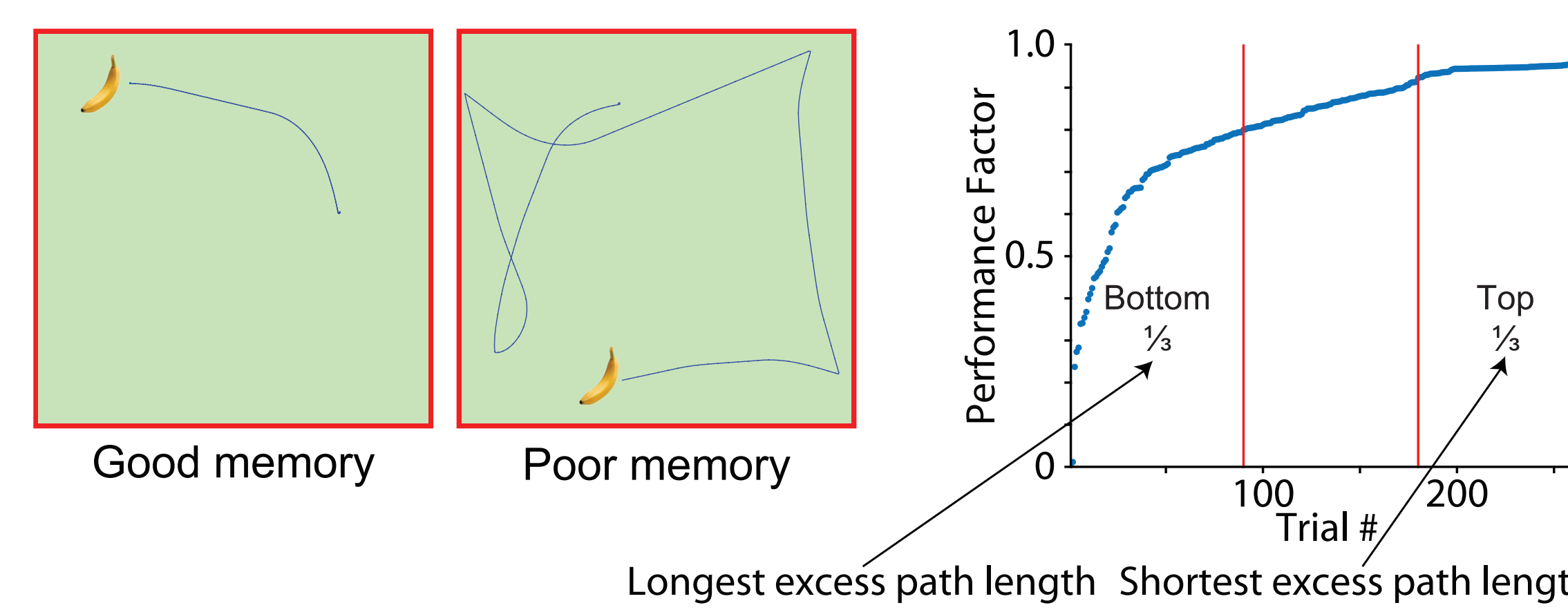
Excess path length was calculated as the ratio of the actual path taken to the shortest possible path, during the retrieval phase. Performance factor is the excess path length for each trial, normalized by the maximum excess path length, subtracted from 1.

Cross-channel coherence during encoding predicts successful recall
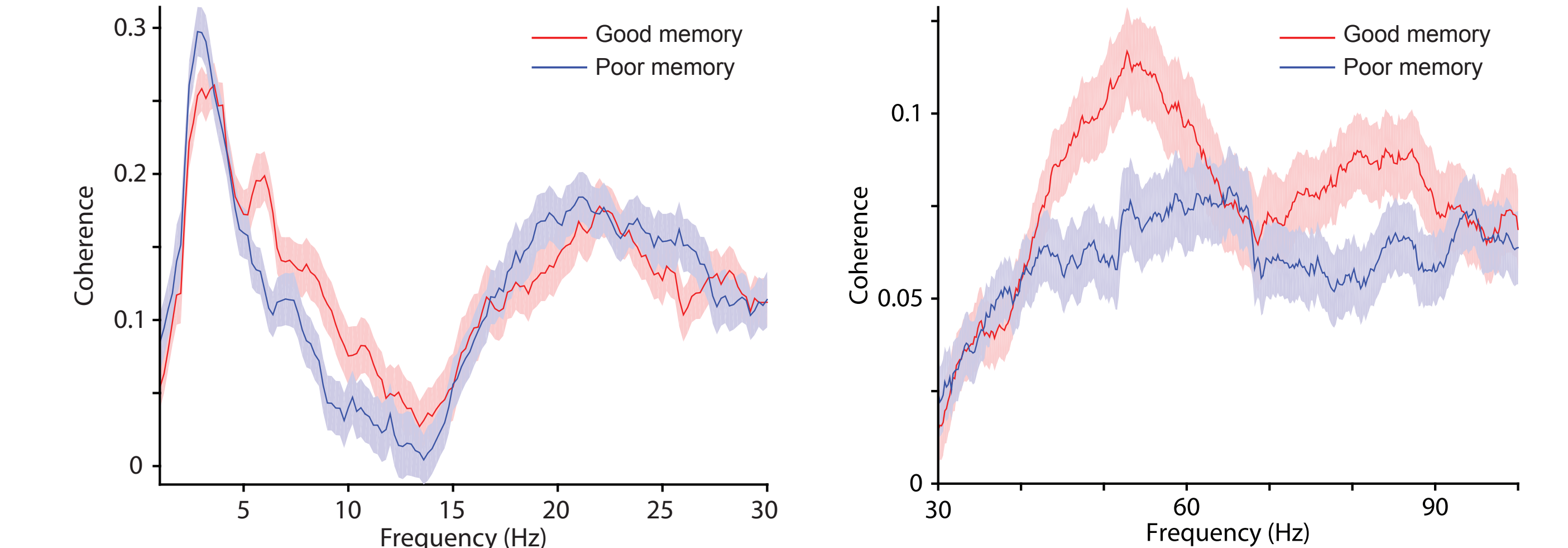
Above: time-averaged coherence during the 5-second encoding period for two example A-C electrode pairs, showing higher theta-band (left) or gamma-band (right) field-field coherence during good memory encoding than during poor memory (n = 68 trials per condition). Shaded area: SEM.

Below: coherence values for each of three frequency bands, during encoding, for trials with good memory (x-axis) and poor memory (y-axis), for all pairwise combinations between channels on the A and C arrays. Sign tests revealed significantly positive distributions in the differences in coherence values between conditions, for each frequency band (p < 0.05).
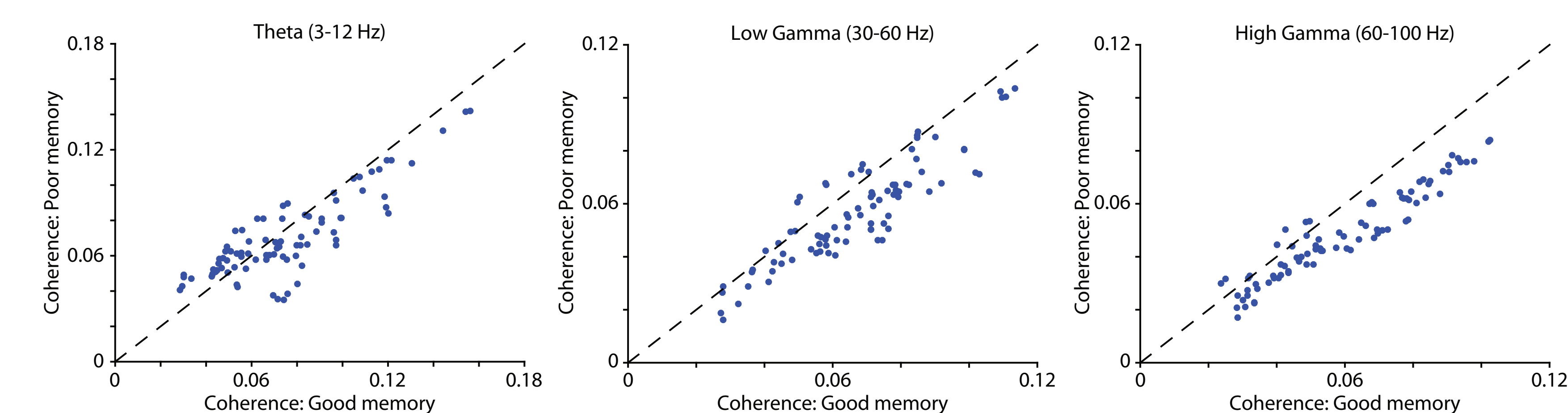
Conclusions

• The use of a virtual navigation task in monkeys provides a means of investigating neural activity related to spatial memory in the primate medial temporal lobe.

• Power modulations across frequency bands during navigation were observed at each recording location, and were most prominent in the posterior hippocampus. This is consistent with previous research revealing functional differences along the long axis of the primate hippocampus related to navigation and spatial memory, similar to that seen in rodents.

• We found evidence for modulations in cross-channel synchrony at multiple frequencies throughout the encoding period, suggesting that interventions which enhance network connectivity may potentially improve spatial memory.

References

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