Evidence for memory reconstruction in the macaque dorsomedial posterior parietal cortex

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Introduction

The dorsomedial posterior parietal cortex (dmPPC), located in the posterior medial region of the parietal cortex, largely corresponds to Brodmann area 7 or the precuneus. Despite evidence implicating it in episodic memory reconstruction[1], the specific neural mechanisms involved have yet to be elucidated. In the present study, we employed a newly developed "free reconstruction" paradigm in non-human primate subjects. Through the analysis of multimodal data, we provide evidence for memory reconstruction in the macaque dorsomedial posterior parietal cortex.

Method

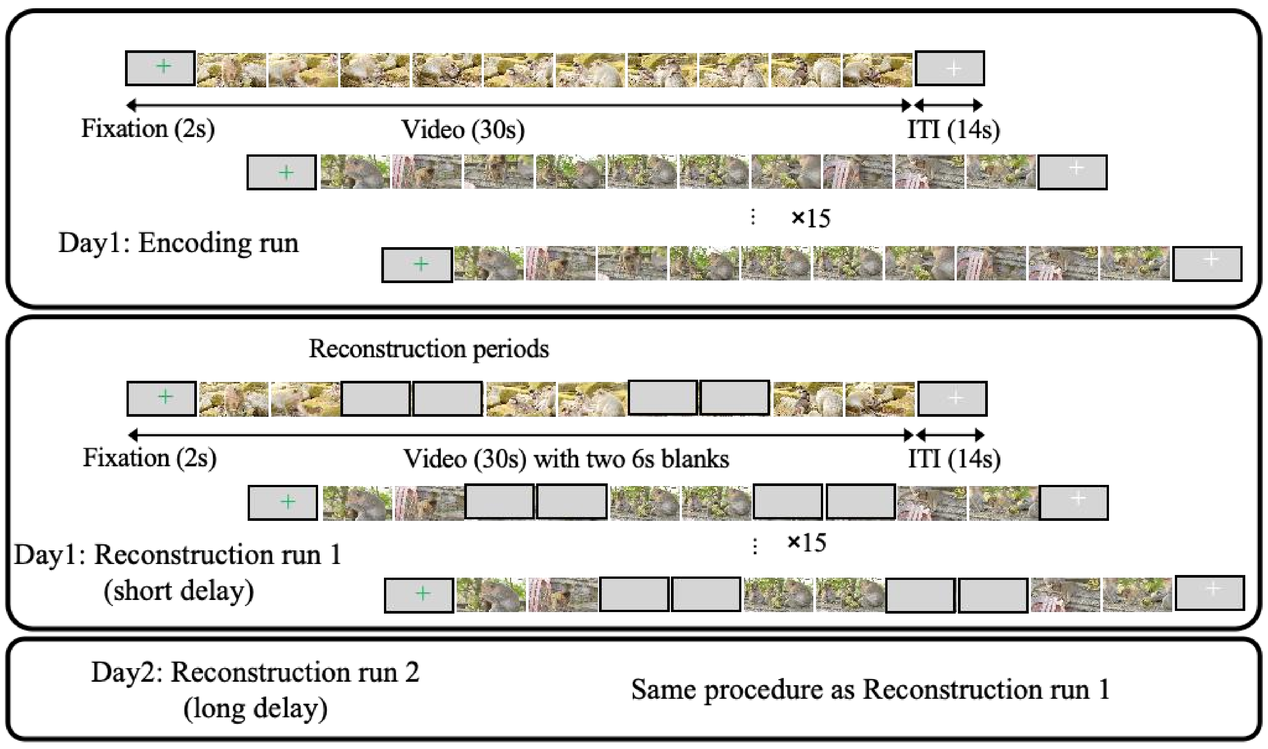

Fig 1. Experiment paradigm. The reconstruction paradigm comprised two parts. First, during the encoding phase, subjects repeatedly viewed the video stimuli. Subsequently, in the reconstruction period, segments of the videos seen during encoding were replaced with gray screens. The subjects were then presented with the same video stimuli containing these gray-screen substitutions, thereby eliciting a memory reconstruction period for the familiar scenario.

Experimental stimuli:

We used seven pairs of 30-second videos as stimuli, featuring dynamic content that included both primate-related and non-primate-related scenes. These pairs were distributed across seven sessions. Each session consisted of three runs, conducted in a fixed daily sequence: 1) a reconstruction run of videos from the prior session, 2) an encoding run with new materials, and 3) a reconstruction run of the newly encoded videos. Each run contained 30 trials, meaning each of the two videos was repeated 15 times. Each video was preceded by a 2-second cue and followed by a 14-second inter-trial interval (ITI).

Subjects:

A total of three macaques were used in this study. Each animal completed the full protocol but contributed different types of neural data. One macaque participated in electrophysiological experiments, during which neural signals were recorded from dmPPC, while the other two were assigned to fMRI experiments for whole-brain BOLD signal acquisition. In all experiments, the macaques' heads were fixed to ensure data quality, and their eye movements were tracked to confirm visual attention to the screen.

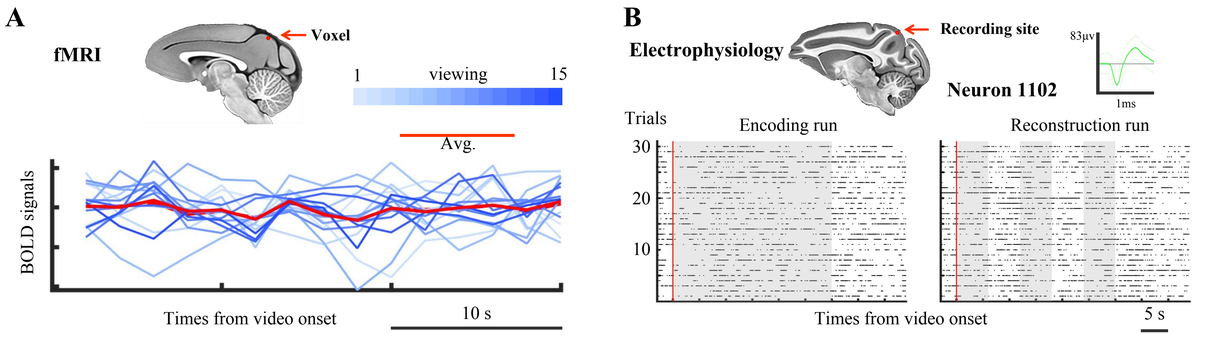

Fig 2. Reliability of the data. (A) Overlapping traces of the BOLD signal from an example voxel in the dmPPC. (B) Raster plots of an example neuron.

- Data from 103 dmPPC neurons and 16 fMRI sessions were collected.

Result

To determine whether dmPPC activity during the reconstruction period carries specific information or merely resembles activity during rest intervals (e.g., the ITI), we compared the mean trial-by-trial neural similarity between these two periods. The reconstruction period exhibited significantly higher similarity than the ITI baseline, indicating a specific functional role of dmPPC neurons in the reconstruction process.

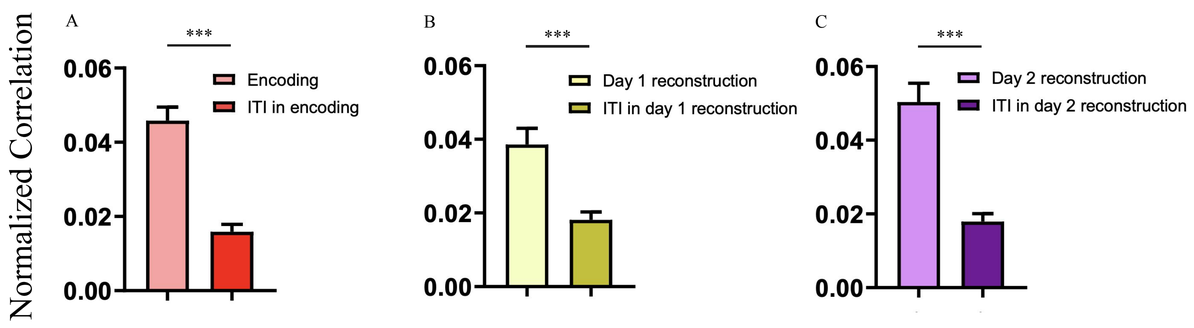

Fig 3. (A) Trial-by-trial correlation was significantly higher during the viewing of identical video clips compared to the ITI baseline. This pattern persisted during the reconstruction period of identical videos on both day 1 (B) and day 2 (C). Error bars: SEM across neurons. ***$p < 0.001$.

To determine whether dmPPC activity patterns represent video information, we first trained a Linear Discriminant Analysis (LDA) classifier on neuronal populations within each experimental run. During the encoding phase, decoding accuracy of dmPPC neurons was significantly above chance across all runs. During the reconstruction period, however, above-chance decoding was only sporadic, observed in individual runs but not consistently. Given this evidence for a difference in representation between phases, we next asked whether stimulus-specific patterns reactivate during memory retrieval. Specifically, an LDA classifier was trained on neural data from each time point in the encoding run and then tested on the corresponding time points in the reconstruction run. We found that the viewing-trained classifier could not decode the video category during the reconstruction period. The inability of this classifier to decode stimulus category indicates that neural representations in dmPPC are not reactivated but are fundamentally distinct between perception and memory retrieval.

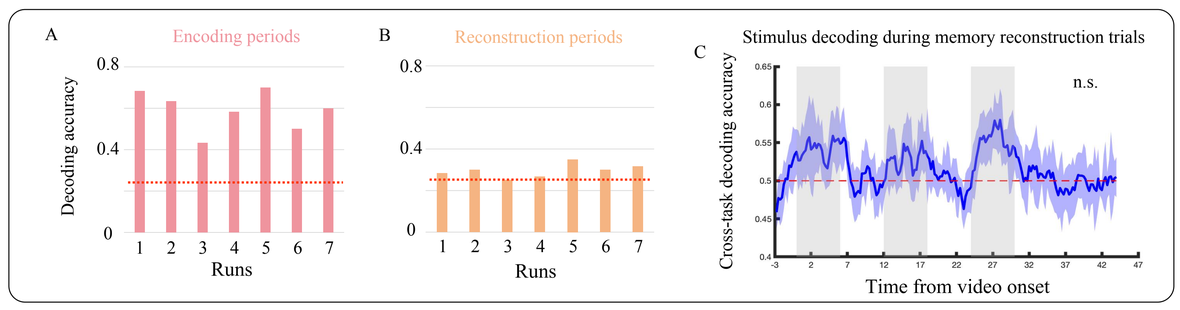

Fig 4. (A) Decoding accuracy for identifying different periods in video pairs across each encoding run, using 12s of data from each trial, corresponding to the reconstruction periods in the reconstruction run. The red dashed line indicates the chance level = 0.25. (B) Decoding accuracy for identifying different videos in each session, using 12s of data from the reconstruction periods in each trial of reconstruction run 1 (short delay).The red dashed line indicates the chance level = 0.25. (C) Cross-task decoding accuracy for every time point in a trial. The shaded area represents periods when the video stimulus was presented in the reconstruction run. Red dashed line indicates the chance level = 0.5. Error bars: SEM across sessions.

A recent study combining whole-brain fMRI with single-unit recordings established a functional mapping approach, revealing neuronal diversity during free viewing of cinematic material[2]. This method involved a systematic comparison between the time courses of single neurons and each voxel throughout the brain by computing correlation coefficients. Previous findings using this approach indicate that dmPPC neurons can effectively represent specific episodic videos during viewing[3]. In the present study, we applied this method to test whether dmPPC neurons also form distinct representations during reconstruction periods. We constructed a non-directional representational similarity matrix (RSM) by calculating the absolute Spearman's rank correlation coefficient between all pairs of neuronal functional maps. A Wilcoxon rank-sum test was then used to compare the mean absolute similarity within the same video condition against that across different video conditions at the group level. Functional similarity was significantly higher in the within-clip condition than in the across-clip condition, demonstrating the experience-dependence of dmPPC neurons. Furthermore, we compared the information content of these functional maps against two other modalities—neuronal spiking activity and critical fMRI frames—to determine whether the functional maps provide additional informational value. Results indicated that neuron-fMRI maps are more sensitive in detecting experience dependency than neuronal spiking activity and critical fMRI frames.

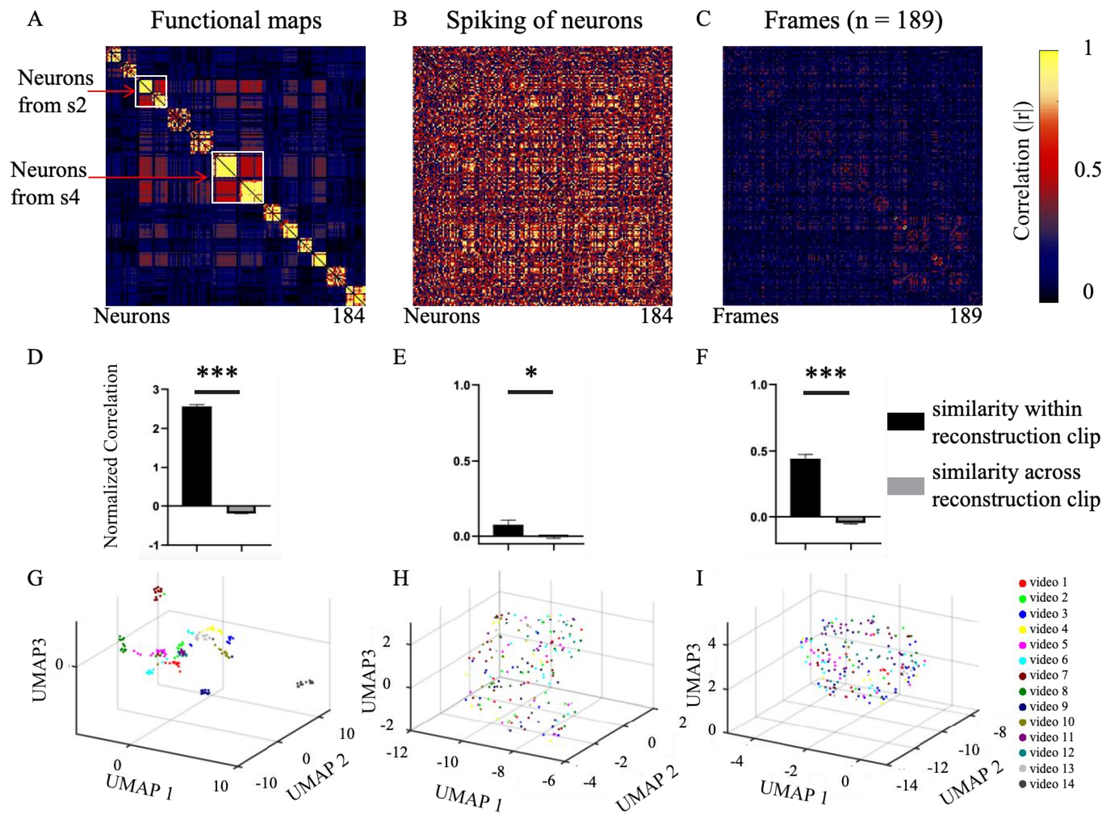

Fig 5. Similarity differences revealed by functional maps, spiking patterns and fMRI frames. (A-C) Modality-specific similarity matrices show the absolute correlation coefficients between every pair of vectors for the functional map (A), spiking patterns (B), and fMRI frames (C). (D-F) Modality-specific similarity differences between within-list pairs and across-list pairs of vectors for functional map (D), spiking patterns (E), and fMRI frames (F). Error bars: SEM across pair of neurons. *$p < 0.05$, ***$p < 0.001$. (G-I) UMAP visualization reveals video-related clusters derived from neuronal functional maps (G) but not from neuronal spiking activity (H) or critical fMRI frames (I).

Conclusion

The current study systematically integrates electrophysiological and fMRI data to elucidate the neural mechanisms of dmPPC in episodic memory reconstruction. We characterized neurons specialized for informational coding of video content, while functional mapping revealed their integration into broader whole-brain networks. These findings advance our understanding of how the dmPPC processes episodic memory reconstruction through modular coding strategies and offer empirical evidence for interpreting the neurofunctional complexity of dmPPC in primates.

Reference:

1. Foudil, S. A., Kwok, S. C., & Macaluso, E. (2020). Context-dependent coding of temporal distance between cinematic events in the human precuneus. Journal of Neuroscience, 40(10), 2129-2138.
2. Park, S. H., Russ, B. E., McMahon, D. B., Koyano, K. W., Berman, R. A., & Leopold, D. A. (2017). Functional subpopulations of neurons in a macaque face patch revealed by single-unit fMRI mapping. Neuron, 95(4), 971-981.
3. Zhou, X. F., Wang, L., Ortiz-Rios, M., Yin, D. Z., & Kwok, S. C. (under review). Functional diversity in dorsomedial posterior parietal neurons revealed by single-unit fMRI mapping during episodic processing.

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