Representations of past and future event boundaries from naturalistic experience are reactivated in the Default Mode Network during recall

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Abstract

Replay, the reactivation of neural sequences from past experiences, has been postulated to support memory consolidation and planning during real-time animal behavior. We test this hypothesis in a human fMRI movie-recall task. We find that during recall, Default Mode Network regions reactivate both past and future representations of movie event boundaries (moments of scene transitions), potentially supporting the tracking and planning of narrative recall. We postulate that at event boundaries, replay-like mechanisms in humans construct a cognitive model of unfolding experiences which facilitates narrative regeneration from memory.

Keywords: fMRI; reactivation; DMN; recall

Introduction

Replay, the reactivation of neural sequences from past experiences during awake periods, is suggested to aid in retrieving recent experiences and supporting future planning in rodent navigation tasks. These functions may depend on different replay directions (backward for retrieval, forward for planning), within the same brain areas (Foster, 2017; Gillespie, 2025; Nyberg et al., 2022).

Yet, the functional roles of replay are challenging to decipher in animal models, as animals cannot directly report their mentalization. Studying replay in humans could bridge this gap. For example, human neuroimaging studies have shown that replay can reorganize experiences (Liu et al., 2019; Schwartenbeck et al., 2023). Reactivation of past events has also been identified at moments of transition between narrative events (event boundaries, Zacks et al., 2007), suggesting that replay links relevant events to form an overarching understanding of unfolding narratives (Hahamy et al., 2023). These effects have been found in areas of the Default Mode Network (DMN) associated with rodent replay, including the precuneus/retrosplenial cortex, angular gyrus and hippocampus.

These previous findings support a role for replay in integrating past with present events, but not in planning, as attending to narratives lacks planning components that could be detected neurally. However, retelling a narrative involves both keeping track of where one is in the plot and planning the trajectory of the narrative. Drawing a parallel with spatial cognition, we hypothesized that during narrative recall, both replay functions would be detected.

Methods & Results

Here we used an dataset of participants (n=17) who watched the first episode of BBC's "Sherlock" and later freely recalled it while their neural activity was recorder using fMRI. The majority of these participants recalled events in chronological order (Chen, 2016).

We have previously developed a method to probe replay in fMRI data, which we applied to the movie-watching sessions of this dataset (Hahamy et al., 2023). In short, we measured reactivation as the similarity between fMRI representations of event boundaries and scenes, using inter-subject correlations in a whole-brain searchlight approach. To control for fMRI autocorrelation biases, and for the possibility that reactivations are driven by inter-scene similarities, we contrasted the representational similarity between event boundaries and past scenes with that between boundaries and future scenes (lower/upper triangular parts of the similarity matrix, respectively, see Fig. 2a and Hahamy et al., 2023).

Here, we applied this approach to test for fMRI reactivations during the free recall of the movie. However, we reasoned that reactivating each individual scene would be inefficient for reconstructing an entire narrative during recall. Instead, if scenes had been linked into a broader narrative structure during movie watching (Hahamy et al., 2023), then movie event boundaries may have served as points where compressed narrative models (abstract representations of scenes and their interrelations) were constructed and encoded. These models could then be reactivated at *recall* event boundaries to efficiently support narrative reconstruction.

This hypothesis entails that event boundary representations hold uniquely different information compared to scene representations. To test this, we correlated the representations of each pair of corresponding movie and recall scenes and each pair of movie and recall event boundaries across subjects in a searchlight analysis. We then removed from the inter-boundary similarities any variance shared with inter-scene similarities. We next looked for brain areas where the residual boundary representational similarities had an average that is significantly different from zero. Figure 1 depicts a set of DMN areas where representations at event boundaries hold information that is not shared with scene representations**.** Analyses of ROIs taken from an independent dataset (Hahamy et al., 2023) confirmed that these are the same regions that reactivate scenes during movie watching (all p-values ≤0.001).

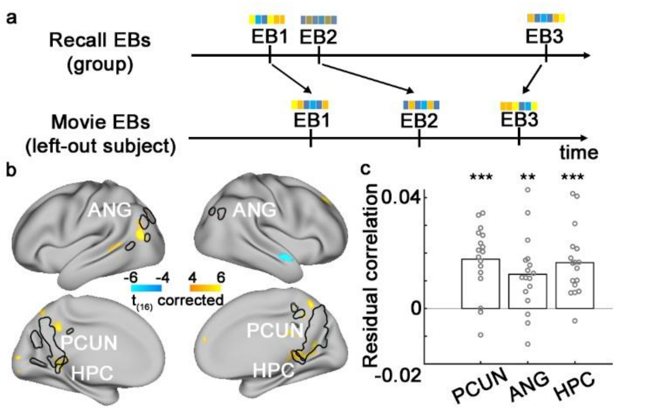

Figure 1. **(a)** Schematic of correlation between corresponding event boundary (EB) representations (depicted as coloured vectors) of movie and recall. Boundary representations were iteratively extracted from all subjects but one; the group-averaged representation was correlated with the representations of the left out subject. **(b)** A searchlight analysis revealed significant effects in DMN regions, **(c)** confirmed in independent ROI analyses (ROI contours shown on map). PCUN, Precuneus, ANG, Angular gyrus; HPC, Hippocampus.

We next tested whether these unique representations at movie event boundaries support the reconstruction of the narrative during *recall* event boundaries. To this end, we employed the reactivation analysis (Hahamy et al., 2023), but here, correlated the representations of *recalled event boundaries* with those of *movie event boundaries*. Since the recalled narratives were not temporally aligned across subjects (the duration of recalled scenes varied), autocorrelation could not bias this analysis. This allowed us to examine the reactivation of past and future movie event boundaries separately, rather than contrasting them, as in the within-movie reactivation analysis (Hahamy et al. 2023). To control for inter-scene similarity biases, we removed the variance shared with the scene-by-scene similarity matrices from the boundary-by-boundary similarity matrices. Thus, positive values in the residual boundary similarity matrix would reflect reactivation that cannot be explained by scene similarity.

Figure 2 depicts areas that reactivate either past or future representations of movie event boundaries during event boundaries of recall. Independent ROI analyses confirmed that the same areas that reactivate past scene representations during movie watching also reactivate past and future movie boundary representations during recall boundaries. The maps also revealed further DMN, sensory and language regions.

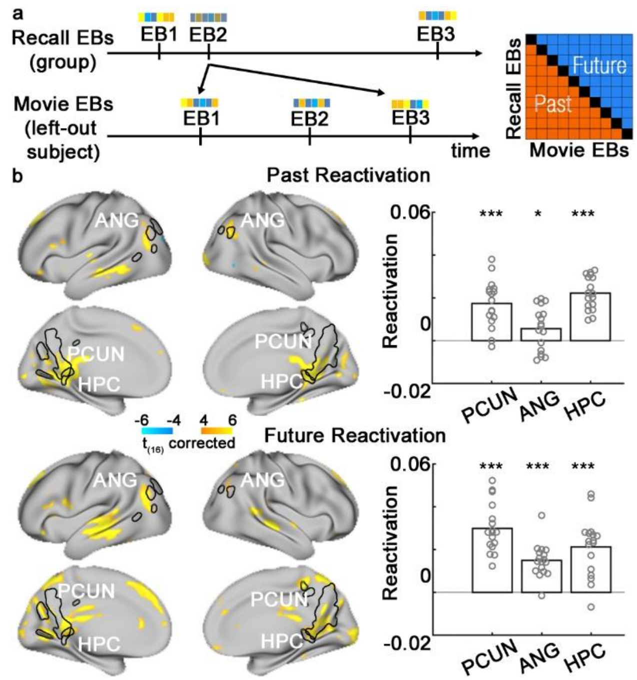

Figure 2. **(a)** Schematic of correlation between recall event boundaries (EB) and past/future movie event boundary representations. **(b)** A searchlight analysis found significant reactivations of past/future movie event boundaries in DMN regions (left panel), as confirmed in independent ROI analyses (right panel).

Discussion

These results hint that, during event boundaries of recall, reactivation of the representations at past movie boundaries support tracking of the narrative, while reactivation of representations at future movie boundaries aid in recalling and planning the narrative's progression. These processes resemble backward and forward replay in rodents, which are thought to support cognitive map construction. We postulate that human reactivations construct a cognitive model of evolving experiences, enabling narrative regeneration from memory.

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