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Brain Dynamics Underlying Memory for Lifetime Experiences

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Abstract:	The ability to remember our past depends critically on the hippocampus and ventromedial prefrontal cortex (vmPFC), but their respective roles are a topic of much debate. Contrary to classic theories, recent work has shown that vmPFC drives the hippocampus during memory retrieval irrespective of how old the recalled memories are.

Brain dynamics underlying memory for lifetime experiences

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Abstract

The ability to remember our past depends critically on the hippocampus and ventromedial prefrontal cortex (vmPFC), but their respective roles are debated. Contrary to classic theories, recent work (McCormick et al. 2020) has shown that vmPFC drives the hippocampus during memory retrieval irrespective of how old the recalled memories are.

Keywords

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How do we remember personally experienced events over our lifetime? Memory researchers have long been interested in how the brain represents such *autobiographical memories* — for example, our first day of college or the first date with our partner or spouse. This question is of key importance because many kinds of neurological conditions — including Alzheimer's disease and temporal lobe epilepsy — can affect our ability to retrieve these types of memories. Indeed, our autobiographical memories fade even over the course of healthy aging [1]. Understanding the mechanisms by which the brain retrieves recent and remote autobiographical memories can therefore provide potential targets for intervention to improve memory [2].

A key component of autobiographical memory research has focused on how the brain might differentially represent recent (e.g., from last week) vs remote (e.g., 10 years old) autobiographical memories. Two regions, the hippocampus and ventromedial prefrontal cortex (vmPFC), are critically important for autobiographical memory retrieval [3], and their respective roles across recent and remote timepoints are a topic of much debate [4]. Some theories propose that the hippocampus maintains rich, autobiographical memories no matter how old they are [5]. Others propose that the role of the hippocampus in remote memory retrieval is to reconstruct retrieved memories and their spatial context, with memory storage occurring elsewhere [6]. Finally, yet other theories propose that autobiographical memories are initially stored in the hippocampus, but come to be represented in neocortical areas (like vmPFC) over years or decades [7].

One relatively underexplored question has been which region — the hippocampus or vmPFC — initiates the process of autobiographical memory retrieval. When we are cued with a specific phrase or image — e.g., a photograph of us on our first day at college — how does the brain start the process by which we relive that experience in our mind? This has been a difficult question to answer because many studies that investigate autobiographical memory use functional magnetic resonance imaging (fMRI), whose poor temporal resolution makes it difficult to determine the relative timing of activity in different brain regions. McCormick et al., (2020) [8] overcame this difficulty by using magnetoencephalography (MEG), a technique with fine temporal resolution. By combining this technique with dynamic causal modeling, the authors were able to investigate coordination between the hippocampus and vmPFC as individuals recalled autobiographical memories of various ages (weeks to years old).

McCormick et al. [8] found that vmPFC activity reliably drove hippocampal activity — both during the initial stage of memory retrieval and as participants mentally elaborated on their retrieved memories. Furthermore, vmPFC drove hippocampal activity for both recent and remote memories. Finally, McCormick et al. found that vmPFC activity preceded hippocampal activity for all but the most recent memories. Together, these findings suggest that vmPFC plays a key role in coordinating hippocampal processes during retrieval, and place vmPFC at an elevated position in the autobiographical memory hierarchy.

The discoveries of this study inform ongoing debates about the respective roles of the hippocampus and vmPFC in autobiographical memory retrieval. They provide an important challenge to classic (and currently popular) theories of memory retrieval, which propose that the hippocampus should initiate memory recall [9]. More recent theories suggest that vmPFC can drive hippocampal activity during memory retrieval, but they propose that this should only occur when memory cues are relatively generic (e.g., "college"; [5]). However, McCormick et al. [8] used memory cues that were highly specific (e.g., "graduation party"). Thus, these findings show that vmPFC initiates memory retrieval in a broader set of circumstances than recent theories would suggest.

Why might vmPFC drive the hippocampus during the recovery of autobiographical memories? One possibility is that vmPFC might contain general 'schema' or representations of what typically happens during various classes of events, like days in school or first dates [10]. Schema might then be used to guide detailed memory retrieval or reconstruction by the hippocampus. An open question, therefore, is what autobiographical memory content the hippocampus and vmPFC represent. One proposal (Trace Transformation Theory; TTT) is that the hippocampus and vmPFC might contain parallel memory traces, a detailed one in the hippocampus and a more abstract schematic one in vmPFC [5]. An alternative hypothesis (Scene Construction Theory; SCT) is the hippocampus does not store remote autobiographical memories at all. Instead, it is involved in reliving such memories by generating spatial imagery that allows us to re-experience past events in rich detail – but it calls on remembered details that are stored somewhere else [6].

Adjudicating between these theories is challenging because they can account for similar results. For example, both approaches can explain changes in hippocampal memory representations over time — but this representational instability is thought to arise for different reasons. TTT suggests that every time a memory is retrieved, a new memory trace is created in the hippocampus [5]. Thus, activity patterns measured at the coarse level of fMRI or MEG are likely to reveal changes in the nature of the memory representation over time due to the creation of multiple memory traces, even if the original trace is unchanged. SCT suggests that such representational instability arises because the initial hippocampal memory trace is lost over time and replaced by newly reconstructed traces [6]. Probing the *consequences* of this instability might allow separation of the two proposals. SCT predicts that instability of hippocampal memory traces over time should be related to memory distortion, even if the memories are confidently and vividly recalled [6]. TTT might instead predict that instability of hippocampal memory traces should be associated with more veridical memory, if this instability reflects the laying down of multiple memory traces related to the same episode.

Together, these studies and theories have provided important advances for neuroscientific investigations of memory. Now more than ever, we have an appreciation of the distributed nature of memory representations across the brain, along with an understanding of the unique contributions of different brain areas. More studies like those of McCormick et al. [8] will be critical for developing our appreciation of the moment-by-moment dynamics that allow us to relive our past experiences.

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