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Discovering Event Structure in Continuous Narrative Perception and Memory

Highlights

- Event boundaries during perception can be identified from cortical activity patterns
- Event timescales vary from seconds to minutes across the cortical hierarchy
- Hippocampal activity following an event predicts reactivation during recall
- Prior knowledge of a narrative enables anticipatory reinstatement of event patterns

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In Brief

Using a new approach for identifying temporal structure in neuroimaging data, Baldassano et al. propose a theory of how continuous experience is divided into events that are represented in high-level cortex, are stored in long-term memory, and influence later perception.

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Discovering Event Structure in Continuous Narrative Perception and Memory

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SUMMARY

During realistic, continuous perception, humans automatically segment experiences into discrete events. Using a novel model of cortical event dynamics, we investigate how cortical structures generate event representations during narrative perception and how these events are stored to and retrieved from memory. Our data-driven approach allows us to detect event boundaries as shifts between stable patterns of brain activity without relying on stimulus annotations and reveals a nested hierarchy from short events in sensory regions to long events in high-order areas (including angular gyrus and posterior medial cortex), which represent abstract, multimodal situation models. High-order event boundaries are coupled to increases in hippocampal activity, which predict pattern reinstatement during later free recall. These areas also show evidence of anticipatory reinstatement as subjects listen to a familiar narrative. Based on these results, we propose that brain activity is naturally structured into nested events, which form the basis of long-term memory representations.

INTRODUCTION

Typically, perception and memory are studied in the context of discrete pictures or words. Real-life experience, however, consists of a continuous stream of perceptual stimuli. The brain therefore needs to structure experience into units that can be understood and remembered: "the meaningful segments of one's life, the coherent units of one's personal history" (Beal and Weiss, 2013). Although this question was first investigated decades ago (Newtson et al., 1977), a general "event segmentation theory" was proposed only recently (Zacks et al., 2007). These and other authors have argued that humans implicitly generate event boundaries when consecutive stimuli have distinct temporal associations (Schapiro et al., 2013), when the causal structure of the environment changes (Kurby and Zacks, 2008; Radvansky, 2012), or when our goals change (DuBrow and Davachi, 2016).

At what timescale are experiences segmented into events? When reading a story, we could chunk it into discrete units of individual words, sentences, paragraphs, or chapters, and we may need to chunk information on different timescales depending on our goals. Behavioral studies have shown that subjects can segment events into a nested hierarchy from coarse to fine timescales (Kurby and Zacks, 2008; Zacks et al., 2001b) and flexibly adjust their units of segmentation depending on their uncertainty about ongoing events (Newtson, 1973). The neural basis of this segmentation behavior is unclear; event perception could rely on a single unified system, which segments the continuous perceptual stream at different granularities depending on the current task (Zacks et al., 2007), or may rely on multiple brain areas that segment events at different timescales, as suggested by the selective deficits for coarse segmentations exhibited by some patient populations (Zalla et al., 2003, 2004).

A recent theory of cortical process-memory topography argues that information is integrated at different timescales throughout the cortex. Processing timescales increase from tens of milliseconds in early sensory regions (e.g., for detecting phonemes in early auditory areas), to a few seconds in mid-level sensory areas (e.g., for integrating words into sentences), up to hundreds of seconds in regions including the temporoparietal junction, angular gyrus, and posterior and frontal medial cortex (e.g., for integrating information from entire paragraphs) (Chen et al., 2016; Hasson et al., 2015). The relationship between the process-memory topography and event segmentation has not yet been investigated. On the one hand, it is possible that cortical representations are accumulated continuously, e.g., using a sliding window approach, at each level of the processing hierarchy (Stephens et al., 2013). On the other hand, a strong link between the timescale hierarchy and event segmentation theory would predict that each area chunks experience at its preferred timescale and integrates information within discretized units (e.g., phonemes, words, sentences, paragraphs) before providing its output to the next processing level (Nelson et al., 2017). In this view, "events" in low-level sensory cortex (e.g., a single phoneme; Giraud and Poeppel, 2012) are gradually integrated into minutes-long situation-level events, using a multi-stage nested temporal chunking. This chunking of continuous experience at multiple timescales along the cortical processing hierarchy has not been previously demonstrated in the dynamics of whole-brain neural activity.

A second critical question for understanding event perception is how real-life experiences are encoded into long-term memory. Behavioral experiments and mathematical models have argued that long-term memory reflects event structure during encoding