Neural representations that resist interference

Xian Li (xli239@jhu.edu)
Department of Psychological and Brain Sciences, Johns Hopkins University, 3400 N Charles Street
Baltimore, MD 21218 United States

Christopher J. Honey (chris.honey@jhu.edu)
Department of Psychological and Brain Sciences, Johns Hopkins University, 3400 N Charles Street
Baltimore, MD 21218 United States

Abstract

How can we successfully return to a complex scenario after our thinking is interrupted? We hypothesize that an "episodic background" representation is constructed over time, and that this representation can passively persist through interruptions. In fMRI, participants listened to narrative stimuli that were interrupted (or not) by silent pauses or theory-of-mind tasks. When the story was interrupted by pauses, we observed reliable and story-selective dorsal posterior medial cortex (dPMC) patterns that persisted during the pauses. These intra-interruption dPMC patterns gradually shifted over the course of the narrative and predicted subsequent story understanding and memory. Moreover, similar dPMC patterns were detectable in participants who performed theory-of-mind tasks during interruption. These data are consistent with an episodic background process that can passively maintain evolving narrative context in the face of interference.

Keywords: memory; context; narrative comprehension; language processing; hippocampus; posterior medial cortex

Introduction

Complex thinking is commonly interrupted. For example, while absorbed in a short story or article, we may be interrupted by an incoming phone call. How do we maintain mental context during interruptions, and restore them at the interruption's end?

One possibility is that we could store information in long-term memory (LTM) at the start of an interruption and then retrieve when the interrupted task resumes. Another possibility, however, is that we can rely on processes that sustain preceding context even in the face of interference. Bellana (2022) showed that narrative content can persist in mind non-volitionally for minutes after we have switched to another task. Zuo et al. (2020) reported that default-mode network (DMN) was able to integrate narrative information over at least 30 seconds, even in a hippocampal amnesic participant who could not rely on new LTM. These findings motivated us to hypothesize an additional process that can (i) integrate episodic content over time and (ii) passively maintain this "episodic background" even when working memory (WM) is engaged elsewhere.

To determine how our brains manage context for interrupted tasks, we measured fMRI from participants who were interrupted (or not) while listening to an intact (or scrambled) narrative (Fig. 1A). The uninterrupted condition defined normal contextualized story comprehension, while the interruption conditions were designed to induce either little interference with active episodic representations ("silent pause" interruption) or high interference with active episodic representations ("theory-of-mind" interruption). A "scrambled-pause" condition presented the story in scrambled sequence so that narrative context could not be reliably established.

To identify brain regions supporting an "episodic background" we then sought brain regions whose activity patterns were (i) specific to preceding epochs of the intact story, (ii) gradually shifted across interruption epochs and (iii) were sustained passively through the interruption phases, even when WM was engaged with an unrelated theory-of-mind task (Fig. 2).

Methods and Results

Participants listened to a story (~9 mins) inside the scanner (TR=1.5s) in one of four conditions: 1) intact story without interruption (*Continuous/CT*), 2) intact story interrupted periodically with silent pauses (*Intact-Pause/IP*), 3) intact story interrupted periodically with an auditory theory-of-mind question (*Intact-ToM/IT*), and 4) scrambled story interrupted periodically with pauses (*Scram-Pause/SP*). The story was cut into 18 segments (30-50s each) which allowed for 17 intervening interruption epochs (20-30s each). After listening, participants freely recalled the entire inside the scanner.

Outside the scanner, participants completed memory tests (Fill-in-the-blank [FIB] recollection and four-alternative-forced-choice [4AFC] recognition) which focused on the story sentences right before and after each interruption. Self-report of experiences and thoughts during the task were also collected (e.g., '*I spent most of the time thinking about the story during interruptions*') during the interruption epochs.

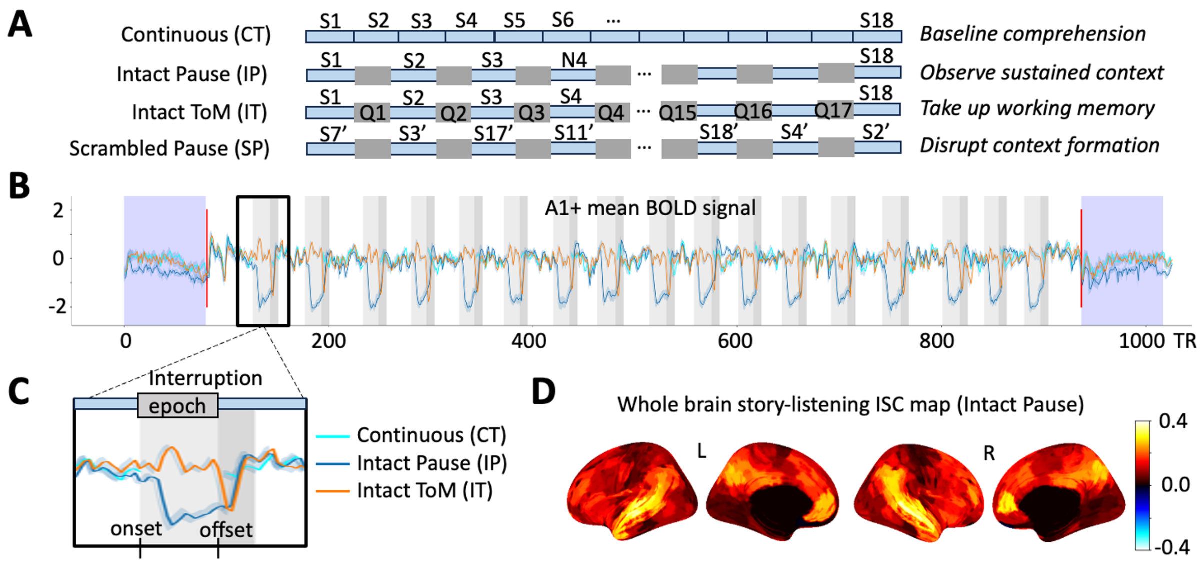

Figure 1: *(A) Illustration of four conditions and goals. (B) Mean BOLD signal at A1+ across the entire story overlaid across three intact conditions. (C) Zoom-in view for one of the interruption epochs. (D) Whole brain inter-subject correlation (ISC) map during story-listening in the Intact-Pause (IP) condition.*

Hippocampal activations predicted memory

In all interruption conditions, we observed a transient increase of HC activity at the onset of the interruption, thought to reflect encoding of the preceding story segment (Ben-YaKov & Dudai, 2011, 2013; Baldassano et al., 2017). Participants who had greater HC activation increases showed better memory, as gauged via free recall and FIB tests (*p*s < .001). This HC-memory effect was not seen in the IP condition.

Robust and memory-predictive patterns in medial-parietal cortex

When narratives were interrupted by silent pause periods (IP), we measured inter-subject neural pattern similarity during interruption epochs and found that the shared neural pattern (Chen et al., 2017) in the posterior medial-parietal cortex (dPMC, Fig. 2B), neural patterns (a) persisted throughout the pause phase; (b) were specific to the preceding story epoch; (c) gradually shifted across interruption epochs; (d) were maintained, at least partially, during theory-of-mind interruptions, where participants' WM was otherwise engaged. These effects were not seen in the pause epochs of the scrambled narrative (SP) condition.

The neural pattern dynamics observed in the dPMC are compatible with an 'episodic background' process. Further, participants with more reliable dPMC patterns during interruption, exhibited a post-interruption pattern (in AG, ACC/dmPFC, and PCC) which better matched the Continuous condition baseline. This indicates that reliable dPMC dynamics are associated with successful restoration of context following interruption. Finally, participants with more reliable dPMC pause patterns also recalled the story better (*p*s < .001), even though dPMC patterns were not correlated with the rate of self-reported explicit thinking about the story.

In sum, our data are consistent with a memory-predictive 'episodic background' process that builds up the narrative context and can passively maintain it even in the face of interruption and interference.

Acknowledgments

We gratefully acknowledge the support of the NIH (R01 MH119099) and an NSF CAREER Award (2238711), as well as experimental design assistance from Hongmi Lee, Shima Rahimi Moghaddam, and Savannah Born.

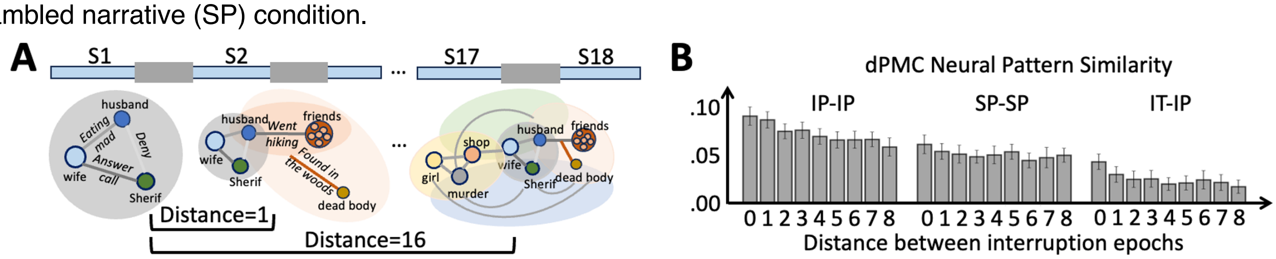

Figure 2: *(A) Illustration of mental context that builds up over the narrative in intact conditions. (B) Inter-subject dPMC pattern similarity between IP-IP, SP-SP and IT-IP subjects over increasing inter-epoch distance, where zero is the same epoch with matching story progress across subjects.*

References

Baldassano, C., Chen, J., Zadbood, A., Pillow, J. W., Hasson, U., & Norman, K. A. (2017). Discovering event structure in continuous narrative perception and memory. *Neuron, 95*(3), 709-721.

Bellana, B., Mahabal, A., & Honey, C. J. (2022). Narrative thinking lingers in spontaneous thought. *Nature communications*, *13*(1), 4585.

Ben-Yakov, A., & Dudai, Y. (2011). Constructing realistic engrams: poststimulus activity of hippocampus and dorsal striatum predicts subsequent episodic memory. *Journal of Neuroscience*, *31*(24), 9032-9042.

Ben-Yakov, A., Eshel, N., & Dudai, Y. (2013). Hippocampal immediate poststimulus activity in the encoding of consecutive naturalistic episodes. *Journal of Experimental Psychology: General*, *142*(4), 1255.

Chen, J., Leong, Y. C., Honey, C. J., Yong, C. H., Norman, K. A., & Hasson, U. (2017). Shared memories reveal shared structure in neural activity across individuals. *Nature Neuroscience*, *20*(1), 115-125.

Zuo, X., Honey, C. J., Barense, M. D., Crombie, D., Norman, K. A., Hasson, U., & Chen, J. (2020). Temporal integration of narrative information in a hippocampal amnesic patient. *NeuroImage*, *213*, 116658.