Classification of encoding and retrieval neural states during extended naturalistic tasks

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Synopsis

We explored the dynamics of encoding and retrieval states during naturalistic tasks: video-watching, imagination, and verbal recall. Using an EEG-based mnemonic state classifier, we showed that encoding evidence increased at video onsets and decreased while participants imagined and verbally recalled videos. No significant differences were observed between participants that completed the tasks in virtual reality or in front of a desktop monitor. Results revealed sustained periods of the retrieval state during imagination and verbal recall extending beyond 2s after trial onset. Together, our results lay the groundwork for monitoring mnemonic states during dynamic naturalistic experiences (e.g., classroom learning, driving).

Background

Daily life involves a continual interplay between encoding and retrieval states: in one moment we look at the sky and spot an unusual bird; in the next moment, we retrieve memories of when we last saw that species. Prior work suggests that mnemonic states ("encoding state" and "retrieval state") are neurally dissociable, spatially distributed, and change around stimulus onsets (Long and Kuhl, 2019; Smith et al., 2022; Long, 2023). However, most evidence for mnemonic-state dynamics comes from tightly controlled experiments using static images over brief task periods (~0-2000ms; Long and Kuhl, 2019; Smith et al., 2022). It is unknown how these states manifest during dynamic audio-visual stimuli or extended internally driven retrieval tasks such as imagination or storytelling. To what extent do mnemonic states fluctuate across many seconds or even minutes? To address this question, we translated a mnemonic state classifier, previously developed and validated using a 63-channel wet-EEG system (Long, 2023), to a 19-channel dry-EEG system, and applied it to extended naturalistic tasks including video watching, imagination and verbal recall. Half of participants completed the experiment in VR, the other half on a desktop monitor. We tested whether 1) we could replicate previously reported effects at the onset of visual stimuli, 2) there were differences between the VR and desktop groups, and 3) during extended retrieval and imagery, mnemonic state evidence persisted beyond the 2000ms windows used in more traditional constrained experiments.

Methods

Participants and Design. Twenty-three participants (EEG-only: N=11; EEG-VR: N=12) first viewed 20 short object videos (10s each, repeated twice; examples in Fig 1A), and four movie clips (~180s each; examples in Fig 1A). They then silently imagined each object (10s), and verbally recalled each object (10s) and movie (60s). Stimuli and memory cues for each phase were presented in random order. EEG-only participants viewed stimuli on a desktop monitor, EEG-VR participants inside a virtual movie theater (via Oculus Quest 3). **EEG.** EEG was recorded with a 19-channel dry-electrode 10-20 system (300hz; Wearable Sensing). Ocular artefacts were removed via ICA. Spectral power (2-100hz, 46 log-spaced frequencies) was extracted with Morlet wavelets (6-cycle), log transformed, downsampled using 100ms non-overlapping windows, and channels and frequencies were z-scored across trials and time. **Classifier.** We translated a mnemonic-state classifier (Long et al., 2023), previously trained and

validated on a 63-channel wet EEG system, to our reduced 19-channel montage. Onset effects were quantified as the difference between a 0-2000ms post onset window and a -500-0ms baseline. Significance for all analyses was assessed using nonparametric permutation tests (1000 permutations) or multiple-comparison corrected t-tests.

Results

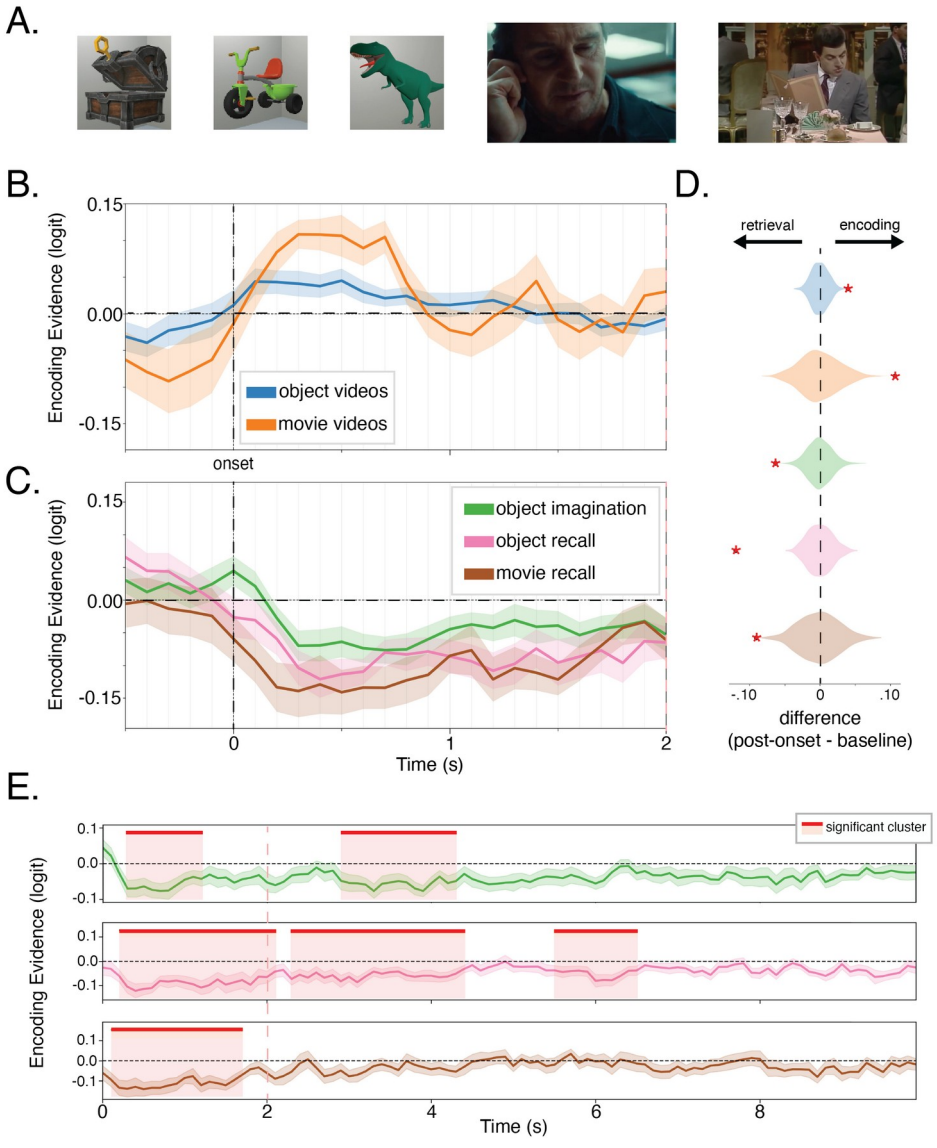

Figure 1. A. Example stimuli. **B.** Mnemonic state evidence during video viewing. **C.** Evidence during imagination and recall. **D.** Change in evidence across all tasks. **E.** Significant clusters in time during object imagination (green), object recall (pink), movie recall (brown).

How do mnemonic states change at the onset of naturalistic tasks? We quantified onset-related changes by comparing mean classifier evidence during a 2000ms post-onset window to a 500ms pre-onset baseline period. We found significant increases of encoding state evidence at the onsets of both object and narrative videos (Fig 1A;D). In contrast, we found significant decreases at the onsets of the object imagination, object verbal recall, and movie verbal recall tasks

(multiple comparisons corrected $p<0.01$; Fig 1B;D). To assess whether encoding state effects differed between groups (EEG-only vs EEG-VR), we compared onset changes between groups and found no significant group differences.

To determine whether encoding and retrieval states persisted beyond 2000ms post-onset during our task conditions, we ran three tests of increasing granularity. We first classified the mean spectral patterns across the full 0-10s window, then within a smaller 2-10s window. We then applied a cluster-based permutation test on the full window to identify temporally contiguous intervals in which the mean logit across participants was different from zero.

Across the full 0-10s window, imagination and retrieval spectral patterns showed significantly reduced encoding evidence (corrected $p<0.05$), while in the 2-10s window, only object retrieval remained significant (corrected $p<0.05$). Our complementary cluster analysis revealed, in the 0-2s window, one significant positive cluster for both object video and movie watching trials and one negative cluster each for object imagination, object retrieval, and movie retrieval trials – internally replicating our initial onset-related results ($p<0.05$; Fig 1E). In the 2-10s window, one positive cluster was found for object videos, and one or more significant negative clusters were found for object imagination, object retrieval, and movie retrieval trials ($p<0.05$; Fig 1E). Together, these results suggest that mnemonic-state evidence is not confined to brief onset periods but may extend into sustained intervals over several seconds.

Discussion

We investigated how mnemonic states unfold as people process dynamic naturalistic stimuli and perform extended retrieval and imagination tasks. We found a significant increase of encoding state evidence within the first 2000ms of stimulus onset, echoing prior work with constrained stimuli and extending the observation to dynamic object and narrative videos. We further found significant decreases of encoding state evidence (equivalent to retrieval evidence increases) at the onsets of imagination and verbal recall tasks, and complementary mean pattern and clustering approaches suggest that there are changes in state evidence beyond the initial onset window. Taken together, our results show that mnemonic state dynamics at the onsets of dynamic naturalistic tasks resemble those observed during constrained tasks, and provide evidence for additional sustained mnemonic states. These results provide the groundwork for the development of task monitoring tools that can be applied in educational and attention-demanding contexts.

Disclosures

N/A

References

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