Replay of cinematic material during and beyond episodic memory retrieval

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ABSTRACT

Rodents and humans show neural replay patterns for encoded task-related experiences during both on-task memory retrieval and off-task rest periods. Both kinds of replay might contribute to memory performance, though the mechanisms underpinning their contributions remain incompletely-known. We investigated these by using intracranial stereotactic electroencephalography (SEEG) data acquired from epileptic human volunteers while they performed a temporal order judgment task in which they retrieved temporal information from encoded naturalistic videos. In this study, we have collected data from a total of 600 channels from 5 patients (800 trials in total). We first employed non-linear decoding techniques to distinguish the neural patterns at different temporal stages of the videos, as well as their reactivation levels in different task phases. The strength of replay was reflected on the magnitude of the temporal dependence between those reactivation levels. Our analyses were restricted to 69 gray matter channels (mean = 13.8, SD = 24.7), which show distinct patterns among different temporal stages of movie viewing. Based on a non-parametric randomization test, we obtained evidence of forward replay of the temporal structure of the encoded video period. Data collapsed across all 5 subjects shown evidence supporting forward replay during the post-retrieval rest phase with a compression rate of around 0.98. And the strength of forward replay measured by mean sequence-ness correlated with patients' memory performance (Spearman correlation r = 0.99, p < 0.01). Further individual-specific analyses revealed that, in addition to the post-retrieval rest phase (in 2 patients), forward replay also occurred during memory retrieval (in 2 patients) and preceding maintenance phase (in 1 patients). The discrepancy in subjects might be due to differences in recording sites or might reflect a potential difference in the underlying replay mechanism that enhance episodic memory performance.

Key word: memory retrieval; spontaneous replay; naturalistic video; temporal order judgment; intracranial stereotactic electroencephalography

PARADIGM

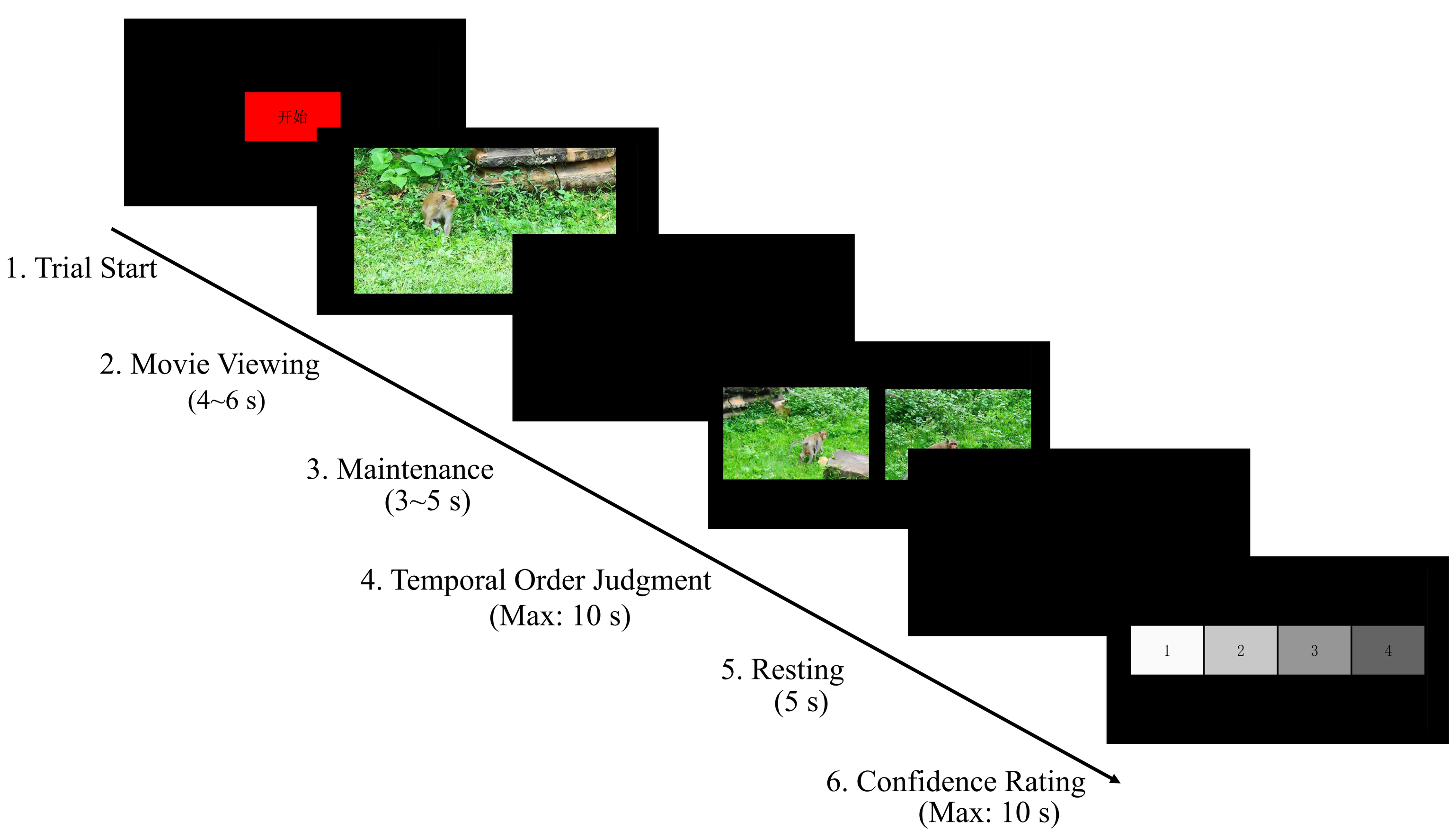

Fig. 1 Study design. Participants performed a temporal order judgment task by choosing the image that appeared earlier in the trial-unique movie clip they had previously watched. After a 5-second rest, participants rated their confidence level on a 4-point scale.

METHOD

- Participants
  - 5 patients (1 female) with intractable epilepsy, whose age ranged from 20 to 37 (mean = 28.2, SD = 7.4)
- sEEG Acquisition and Pre-processing
  - Exclude the epilepsy-related and/or statistically detected noisy channels from further analysis
  - Common average offline re-reference
  - Bipolar derivation down-sampled to 500Hz and removed the 50-Hz power line interference (including its harmonics)
  - Complex Morlet wavelets (6 cycles) were used to extract LFP power on 5 frequency bands of theta (3-8Hz), alpha (8-12Hz), beta (13-25Hz), low gamma (30-48Hz) and high gamma (52-98Hz), LFP power was then averaged over each frequency band for each channel.
- Multivariate Decoding Analysis
  - Data from the first 4s of video viewing were divided into 1s epochs and labelled with their temporal distance from the onset of the movie clip.
  - Lasso-regularized logistic regression models with the one-vs-rest strategies were used to decode temporal states. Data from ITI were included to reduce the correlation between different temporal states.
  - LFP power was averaged over each 1s epoch and then z-scored with respect to the baseline (0.2~0.7s prior to the start of trials) for each gray matter channel, resulting $N_{frequency} * N_{channel}$ z-scored LFP power feature matrices.
  - Chance level was obtained by permutation test (n = 1000 permutations).
- Sequence-ness Measure
  - Temporally delayed linear model (TDLM, Liu et al., 2019)
  - The maximum of the absolute value of sequence-ness among all possible permutations of the sequence except the true one was used as the significance threshold.

RESULT

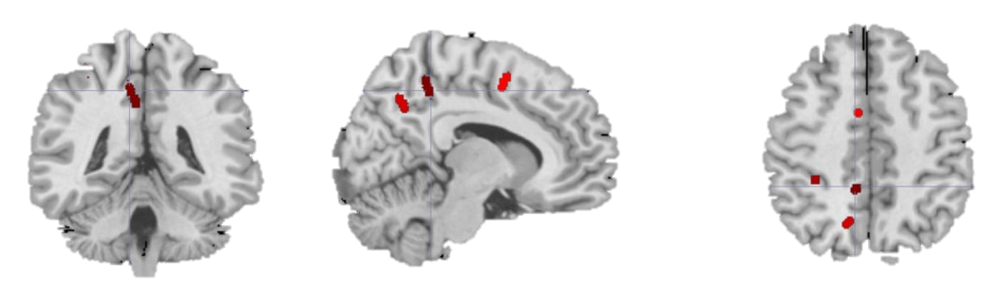

Fig. 2 Multi-patient electrode coverage. Only gray mater channels that show distinct patterns among different temporal stages of movie viewing are shown. Each dot represents a single electrode contact.

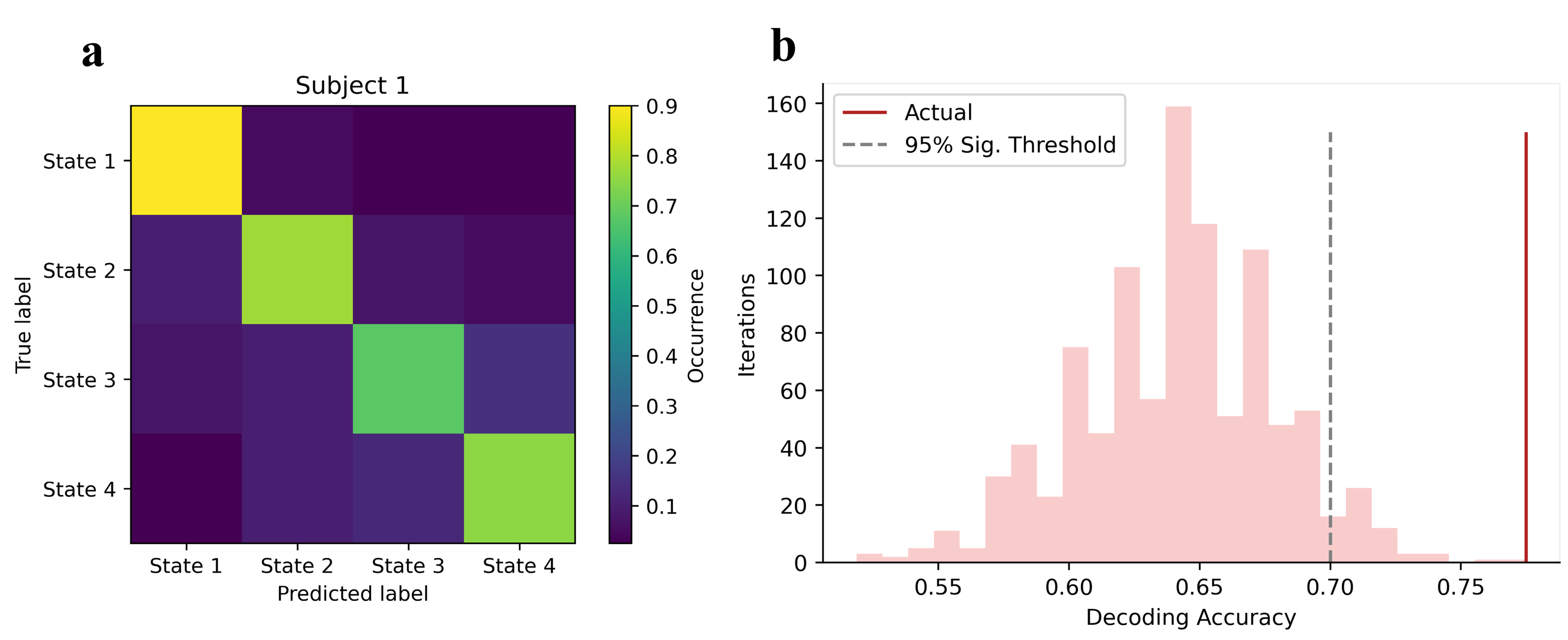

Fig. 3 Decoding of the temporal states. **a**, All temporal states were well decoded with an above-chance(33.3%) accuracy level. Elements on the diagonal denote the proportion of correct predictions. **b**, Permutation test indicated that the obtained in the actual data was highly significant (1000 permutations, P<0.01). Examples of decoding performance are shown from one subject for visualization purposes. Decoding performance of all subjects exceeded permutation-based threshold (all p-values < 0.05).

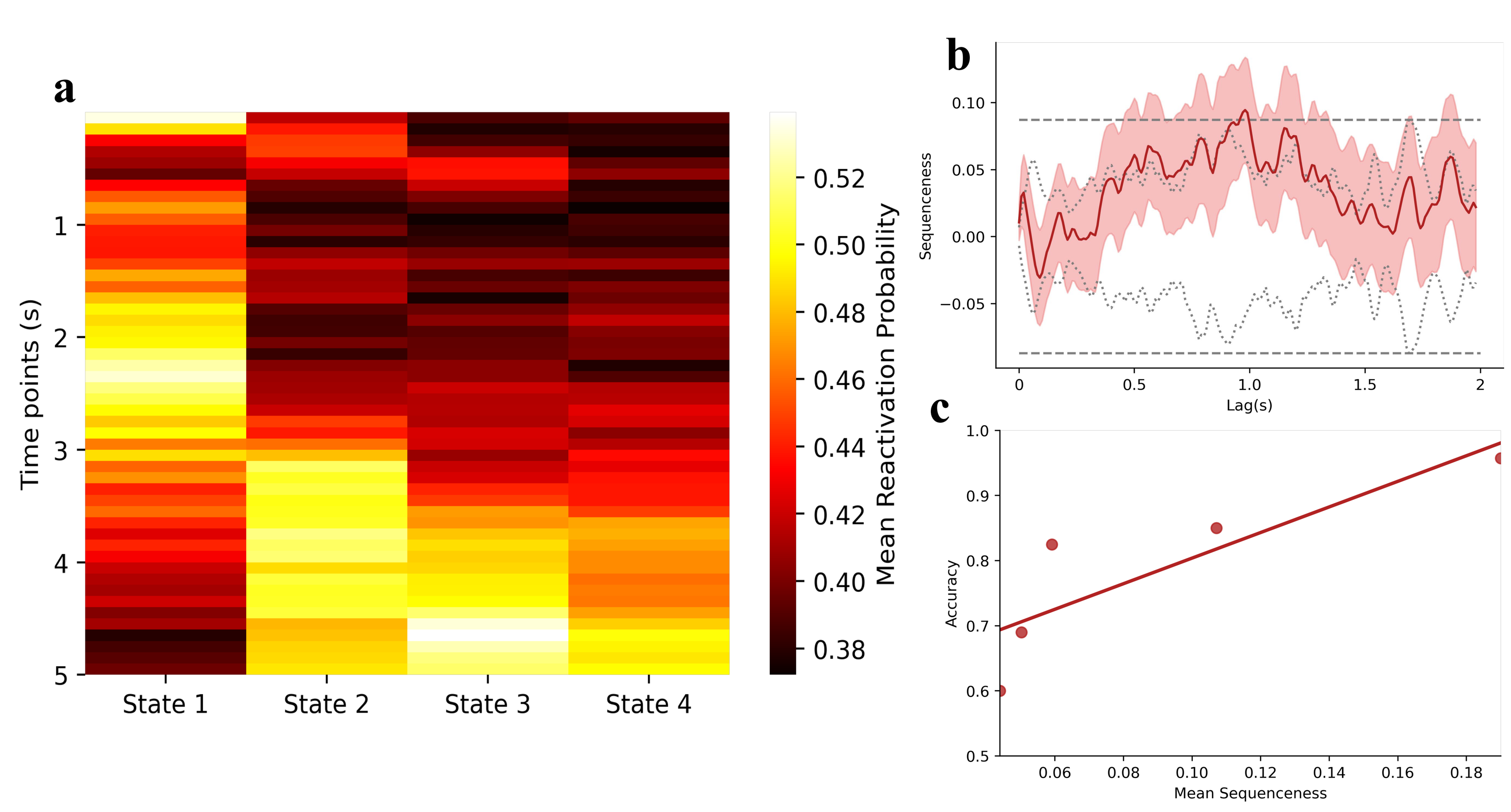

Fig. 4 Forward replay during rest period and mean sequence-ness correlated with memory performance. **a**, Each row depicts mean reactivation probabilities at a given time point. Data were binned in non-overlapped 100-ms time bins for visualization purpose only. **b**, mean sequence-ness revealed a peak of forward replay at lags from 980~1000 ms. This significant time window was used for subsequent analysis. Shaded error margins represent std.. The dotted line is the peak of the absolute value of all possible sequences for each time lag, while dashed line indicate the max across all time lag, using as the significant threshold. **c**, stronger mean sequence-ness correlated positively with overall memory performance (accuracy rate). All figure results are from n = 5 participants.

REFERENCE

- Liu, Y., Dolan, R. J., Kurth-Nelson, Z., & Behrens, T. E. J. (2019). Human replay spontaneously reorganizes experience. *Cell*, *178*(3). https://doi.org/10.1016/j.cell.2019.06.012