A neural signature of mental time travel

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Background & summary

Context-based episodic memory models use contextual reinstatement at the time of recall to explain why participants often successively recall temporally proximal experiences (the contiguity effect).

We found neural support for the context reinstatement hypothesis in ECoG recordings taken as 69 neurosurgical patients studied and recalled lists of words.

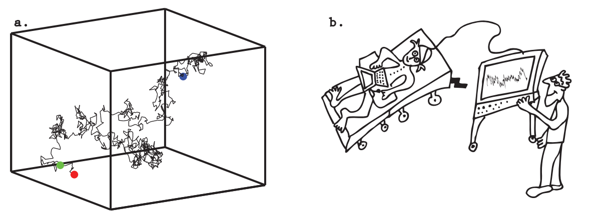


Figure 1. a. Context reinstatement hypothesis. Context drifts gradually over time and is associated with each experienced event. **b. Our setup.** Patients are implanted with subdural and depth electrodes by clinical teams. Experiments are administered on a bedside laptop computer. (Technical schematic courtesy M. Jacobs.)

Results

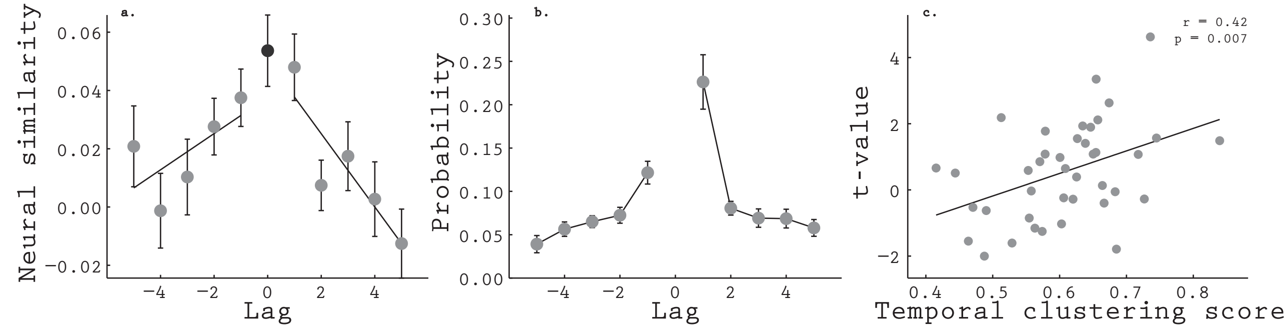


Figure 4. A neural signature of mental time travel. a. Neural similarity between the feature vector corresponding to recall of a word from serial position i and study of a word from serial position i+lag. **b.** Probability of recalling an item from serial position i+lag immediately following an item from serial position i, conditional on the availability of an item in that list position for recall. **c.** Participants exhibiting greater context reinstatement also exhibited more pronounced contiguity effects. Only the regressions for negative lags were used, as the regressions for positive lags are not expected to distinguish between content and context reinstatement (Fig. 3).

Neural analysis methods

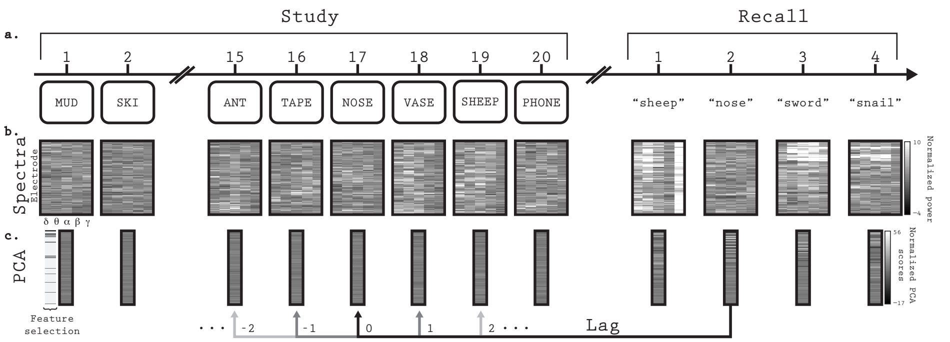


Figure 2. Experiment and analysis. a. The participant studies and freely recalls lists of 15 or 20 common nouns. **b.** For each electrode we compute mean power in 5 frequency bands during each study and recall event. **c.** We reduce the dimensionality using principal components analysis (PCA). We identify principal components which exhibit gradual changes during study. Study and recall events are compared using cosine similarity.

Feature selection

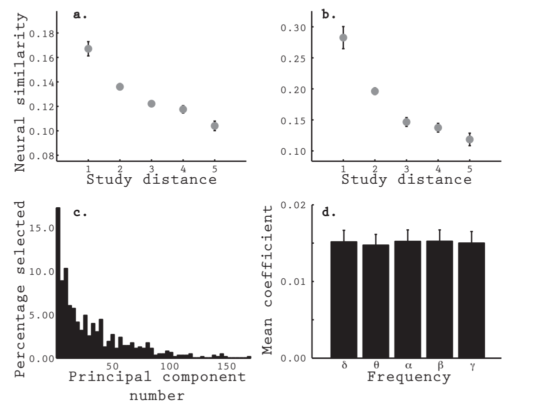


Figure 5. Evolution of ECoG activity during list study. a. Full principal component vectors. **b.** Autocorrelated principal components. **c.** Selected principal components. **d.** Mean principal component coefficients by frequency band.

Control analyses

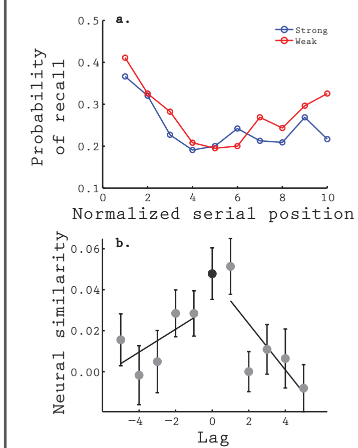
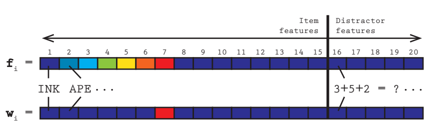


Figure 7. Ruling out potential confounds. a. Rehearsal. The neural signature of context reinstatement in Fig. 4a is not correlated with the primacy effect, a proxy for rehearsal ($r = 0.12$, $p = 0.45$). **b. Contiguity effect.** Here we repeated our test for context reinstatement after excluding from the analysis all recalls that followed recall of a neighboring item. The neural signature of context reinstatement remains intact, indicating that our findings are not simply an artifact of the contiguity effect (also see Fig. 3).

Simulations

$$(1)\quad \mathbf{f}_i = \rho_i \mathbf{f}_{i-1} + \beta \mathbf{w}_i$$

$$(2)\quad \rho_i = \sqrt{1+\beta^2[(\mathbf{f}_{i-1}\cdot\mathbf{w}_i)^2 - 1]} - \beta(\mathbf{f}_{i-1}\cdot\mathbf{w}_i)$$



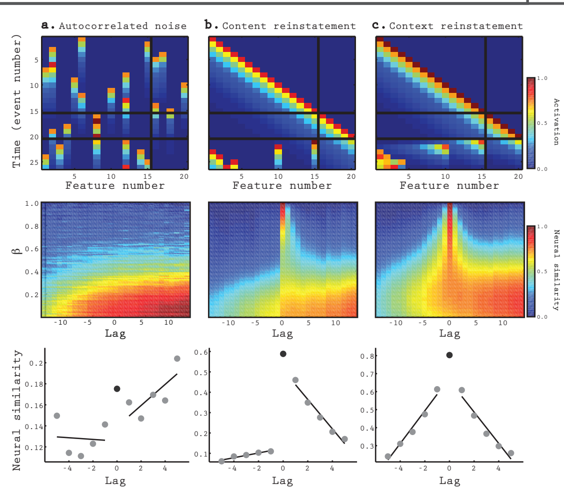
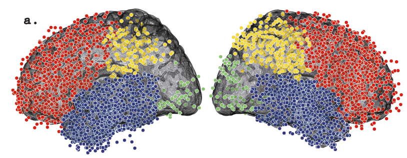


Figure 3. Predicted neural similarity as a function of lag according to three models. In each simulation, a single neuron is activated during each experimental event, i. Once activated, a neuron's activity decays gradually according to equations (1) and (2). **a. Autocorrelated noise.** Each experimental event activates a random neuron, irrespective of which item is being presented or recalled. **b,c.** Each neuron is activated by a single item or distractor during study. **b. Content reinstatement.** During recall of the j^{th} presented item we set $\mathbf{f}_i = \mathbf{w}_j$. **c. Context reinstatement.** During recall of the j^{th} presented item we set $\mathbf{f}_i = \mathbf{f}_j$.

Region of interest analysis



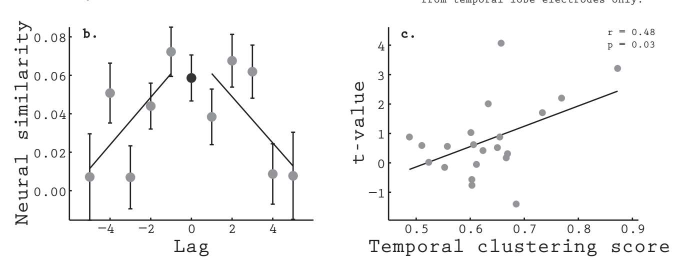


Figure 6. Evidence for context reinstatement in the temporal lobe. a. We divided our dataset into four regions of interest: temporal lobe (blue; 1,815 electrodes), frontal lobe (red; 1,737 electrodes), parietal lobe (yellow; 512 elecrodes), and occipital lobe (green; 138 electrodes). **b,c.** These panels are in the same format as Figures 4a and c, but reflect data from temporal lobe electrodes only.

Conclusions

We identified patterns of gradually evolving neural activity as participants studied and recalled lists of words.

When a word is recalled, the neural pattern observed during study of that word is reinstated.

The retrieved neural activity also shows graded similarity to that recorded during presentation of neighboring words on the studied list.

The strength of this neural context reinstatemnt effect is correlated with the contiguity effect across participants.

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