Behavioral and Electrophysiological Correlates of the Memory Search Process During Continuous Recognition

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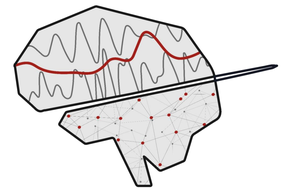

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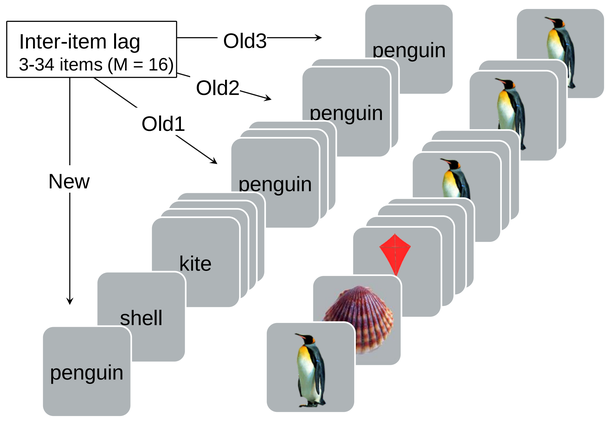
Background

- Memory studies involving continuous recognition or recency judgments have consistently demonstrated slower response time (RTs) as the lag between study and test items increases, suggesting that responses are based on a *backward self-terminating search* across time.[1,2]
- As memories become stronger, more efficient processes (e.g., familiarity-based) are likely to be favored over the backward search. Little is understood, however, about the conditions under which the search process is abandoned, with a recent study showing that it is used to the same degree with 1 or 2 item repetitions.[3]
- Here, EEG was acquired during a continuous recognition task to test the RT-lag relationship over multiple (1 to 3) item repetitions and a range of lags (~5 to 70 secs). Changes in RT, as well as in the magnitude and latency of an established EEG correlate of recognition—the left parietal old/new effect—were assessed as markers of the backward search process, and how its use diminishes with repetition.

Continuous recognition task

- 15 subjects (18-23 years old) undertook 6 continuous recognition blocks, half including object pictures and half including object names.
  - ✓ No picture/name differences were evident, so all analyses collapsed over this factor.
- Within each block, items were presented between 1 and 4 times: **New**, **Old1**, **Old2**, and **Old3**.
- Subjects made binary old/new responses (regardless of Old1/2/3), while the old/new ratio was held at 1:1 with the inclusion of filler items.



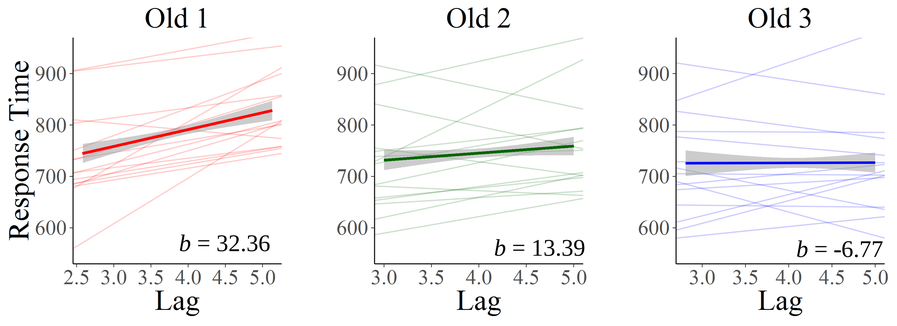
- EEG was recorded from 59 electrodes (1-kHz sampling rate, .01-100 Hz bandwidth). Data were re-referenced offline to mastoids, epoched (-500-1500 ms, relative to item onset), and band-pass filtered (.05-40 Hz).

Memory search occurs along a compressed timeline

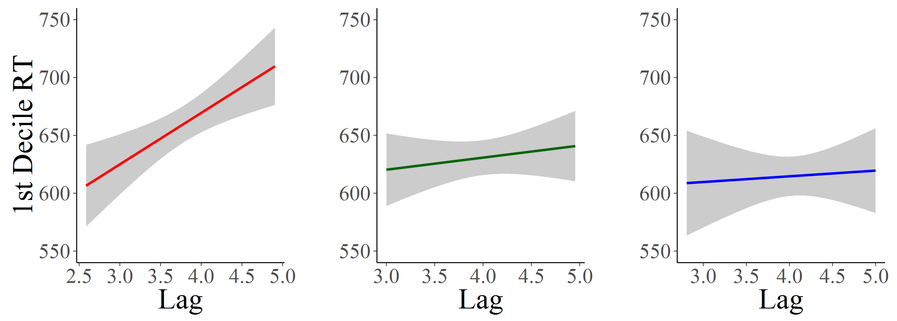
- Recent studies have demonstrated sub-linear increases in RT as items recede into the past, suggesting that the self-terminating search process follows a *compressed representation of time*.[3] To test for compression, RTs were modeled separately according to lag and $\log_2$lag.
  - ✓ The $\log_2$lag model exhibited a better linear fit than the lag model ($BF_{10} = 2.1^{+4}$). This finding supports the notion of a compressed timeline, which was used for the remaining analyses.

Repetition diminishes the lag-related RT increase

- The effects of lag and repetition on RT were estimated with hierarchical mixed-effects modeling, using random subject intercepts. [A, B]
  - ✓ There was strong evidence for a repetition effect ($BF_{10} = 407.67$), positive evidence for a lag effect ($BF_{10} = 3.41$), and strong evidence for an interaction ($BF_{10} = 4.7\times10^{+68}$)
  - ✓ For Old1 items, RTs increased 32 *ms* ($HDI_{95\%}$ [23, 42]) per doubling of lag. This effect was significantly attenuated for Old2 (b = -19, $HDI_{95\%}$ [-34, -5]) and Old3 items (b = -39, $HDI_{95\%}$ [-54, -23]).

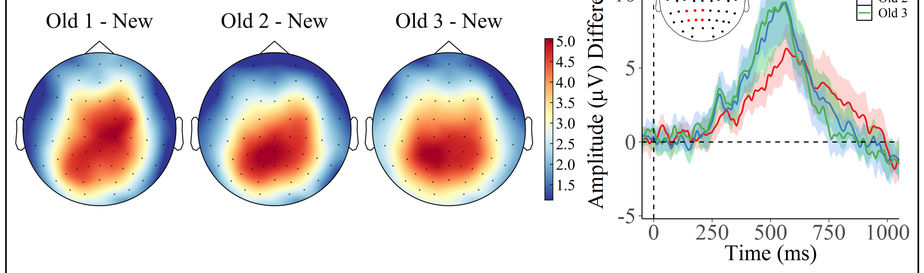


- The 1st decile of RTs were similarly analyzed to rule out floor effects as a possible explanation of differences with repetition.
  - ✓ The lag effect for Old1 items (3 *ms* per doubling) was larger than for Old2 (b = -2) and Old3 items (b = -3), providing additional evidence for the self-terminating nature of the backwards search.



The magnitude of EEG old/new effects increases with repetition

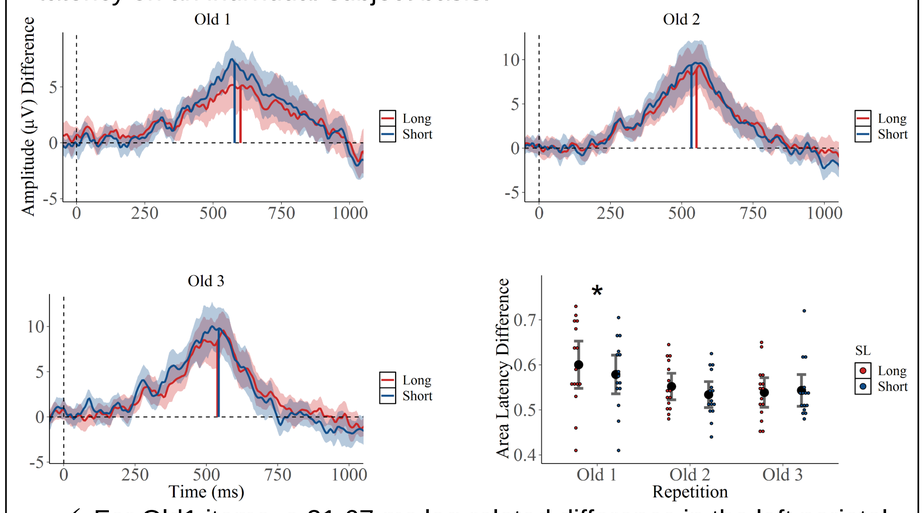
- Replicating numerous recognition studies, old/new differences were evident during a period of 500-800 ms and were maximal over left parietal sites.[C]



- ✓ Relative to the old/new differences based on Old1 items, those involving Old2 and Old3 items were larger in amplitude.

Latency changes in the EEG old/new effects scale with RT

- Old trials were median-split according to short and long lags, and the latencies of EEG old/new effects were then measured as the 50%-area latency on an individual-subject basis. [D]



- ✓ For Old1 items, a 21.67 *ms* lag-related difference in the left parietal old/new effect followed the corresponding changes observed in RTs. No EEG latency differences were evident for Old2 and Old3 effects.

Summary & Conclusions

- Supporting the hypothesis that subjects perform a backward self-terminating search through recent memories, lag-related changes in RT and in the latency of the left parietal old/new effect were observed for the initial repetition of an item.
- Longer lags were associated with a logarithmic increase in RT, consistent with the idea of a compressed representation of time.
- The novel result we show here is that lag-related changes, mirrored in both the RT and EEG latency data, are diminished with additional repetition. This finding suggests that the backward search is quickly abandoned in favor of an alternative basis for responding, possibly related to increased memory strength.

References

1. Hockley (1982). *JEP:LMC*
2. Murdock (1974). *Erlbaum*
3. Singh et al. (2017). *bioRxiv*

Toolboxes

A. Brms (Burkner, 2017; J Stat Software)
B. Bridgesampling (Gronau et al., 2017; arXiv)
C. MNE (Gramfort et al., 2014; NeuroImage)
D. Latency (Liesefeld, 2018; Frontiers in Neuro)

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