Investigating the Spacing Effect Using EEG

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Introduction

The spacing effect: distributed practice leads to better long-term memory performance than massed practice.

The present experiment: participants learned unique word–image pairs across two presentations (P1 and P2) and were tested with recognition and cued recall.

EEG analysis methods

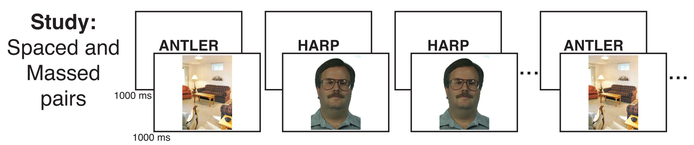
- Representational similarity analysis (RSA; Kriegeskorte et al., 2008)
  - Measures the similarity of two signals, in this case EEG during P1 and P2.
- Pattern classification: Detect activity related to an image category. Here, measuring paired-associate image category activity during P2 word presentation.

Experiment

- 20 right-handed adults (7 females; mean age: 19.8)
- One session, six blocks of four phases: exposure, study, distractor, test.

1. **Exposure**: Familiarization to 50 images from two categories: faces and indoor house scenes. Used to train pattern classifier to predict faces vs houses from EEG.

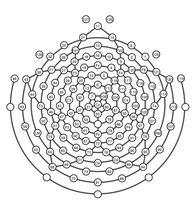
2. **Study**: Unique noun paired with each image; 28 pairs were presented twice in either a spaced (lag=12) or massed (lag=0) fashion (seven per image category per lag). The remaining 22 pairs were single-presentation distractors or buffers.



3. Math distractor, 2 minutes.
4. **Test**: Recognition and recall tests were given for old (28) and new (14) images.

Scalp EEG

- 128-channel 250-Hz EGI scalp EEG system; 200 MΩ high-impedance amplifier.
- EEG preprocessing:
  - Filters: 0.1 Hz high-pass, 100 Hz low-pass, 60 Hz band-stop
  - Average reference
  - ICA-based eye blink artifact correction
  - Baseline correction (-200 to 0 ms pre-stimulus)
  - Z-transformed EEG data across all conditions
- Analyses run on 109 electrodes (excludes peripheral channels).



Behavioral Results

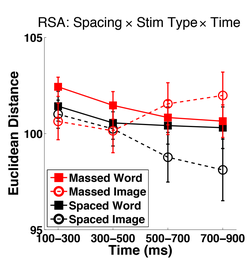
- Recognition: Spaced (HR $= 0.92$) $>$ Massed (HR $= 0.89$) ($p = .002$)
- Cued Recall: Spaced (HR $= 0.53$) $>$ Massed (HR $= 0.40$) ($p = .00000046$)

Hypotheses and Predictions

- **Deficient processing**:
  When an item is repeated immediately (massed), attention to the second presentation decreases because the item is already familiar and in short-term memory (Van Strien et al., 2007; Xue et al., 2011). This does not occur for spaced items.
  - *RSA*: Greater P1–P2 similarity for spaced vs massed, due to less attention for massed.
  - *Classification*: Higher accuracy for spaced items, due to more reinstatement for spaced.
- **Encoding variability**:
  Because episodic (and neural) context drifts, repeated study events further apart in time are likely to be different vs those closer together (Glenberg, 1979). At retrieval, higher probability that the test context will be similar to one of the spaced contexts as compared to the massed context (e.g., more retrieval cues).
  - *RSA*: Greater P1–P2 similarity for massed vs spaced, due to more similar contexts for massed.
  - *Classification*: No difference predicted for spaced vs massed items.
- **Study-phase retrieval**:
  Repetition of a study item will assimilate the present context (P2) with that of all prior occurrences (P1) into the memory trace (Cepeda et al., 2009; Thios & D'Agostino, 1976).
  - *RSA*: Greater P1–P2 similarity for recalled spaced vs massed, due to reinstatement of P1 during P2.
  - *Classification*: Higher accuracy for subsequently recalled vs forgotten items, regardless of spaced/massed. Better recall for spaced items should lead to higher classification accuracy for spaced vs massed items due to reinstatement of P1 forming a stronger memory trace.

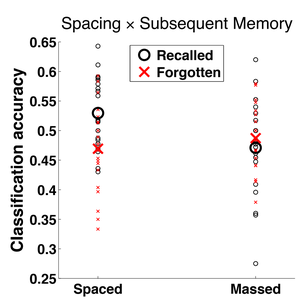
Results: Representational Similarity Analysis (RSA)

- Measured **Euclidean distance between P1 and P2** in four successive 200 ms windows, starting 100 ms after stimulus onset.
- 4-way ANOVA on subject distances: Spacing $\times$ Subsequent memory $\times$ Stimulus type (word/image) $\times$ Time window
  - Spacing $\times$ Subsequent memory: **Spaced recalled more similar than massed** (M $= 99.2$ vs M $= 102.4$, $p < .05$).
  - Main effect of Time ($p < .05$): similarity increases over time for spaced pairs.
  - Spacing $\times$ Stimulus type $\times$ Time ($p < .0001$): **Spaced words more similar than massed early** (300–500 ms M $= 100.6$ vs 100–300 ms M $= 102.4$, $p < .005$). **Spaced images more similar than massed late** (700–900 ms: M $= 98.1$ vs M $= 102.0$, $p < .01$).



Results: Classification

- Elastic net logistic regression; trained on faces and houses from exposure phase.
  - Balanced trial counts
  - α (L1/L2 mixing parameter): 0.2
  - λ (shrinkage parameter): determined by cross validation (M $= 0.167$)
- **Tested on P2 word presentation** in two 500 ms time windows starting at word stimulus.
- 3-way ANOVA on subject classification accuracies: Spacing $\times$ Subsequent memory $\times$ Time window
  - Spacing $\times$ Subsequent memory ($p < .05$): **Subsequently recalled spaced words were classified more accurately than massed words** (M $= 0.538$ vs M $= 0.478$, $p < .05$).
  - **Recalled spaced words were classified significantly above chance** ($p < .05$).



Summary of Results

Behavioral

- Spaced pairs were remembered better than massed pairs.

Representational similarity (P1 vs P2)

- Spaced recalled more similar than massed
  - Supports: Deficient processing, Study-phase retrieval
  - Challenges: Encoding variability
  - In line with prior fMRI analyses (Xue et al., 2010)

P2 classification

- Higher classification accuracy of recalled spaced vs massed words
  - Supports: Deficient processing, Study-phase retrieval
  - Challenges: Encoding variability

Next Steps

- Examine role of attention (deficient processing) via ERP (P1/N1) and oscillatory (alpha) analyses.
  - neural repetition suppression during massed P2 (e.g., Xue et al., 2011) may lead to attenuated ERP components
  - e.g., increased alpha for massed vs spaced
- Analyze cued recall activity (e.g., similarity between encoding and retrieval).
- RSA: Similarity of P1–P2 activity may not be temporally coupled.
- Different classification methods may perform better.

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