# Semantic and perceptual representations mediating object-specific memory encoding: a preregistered fMRI study

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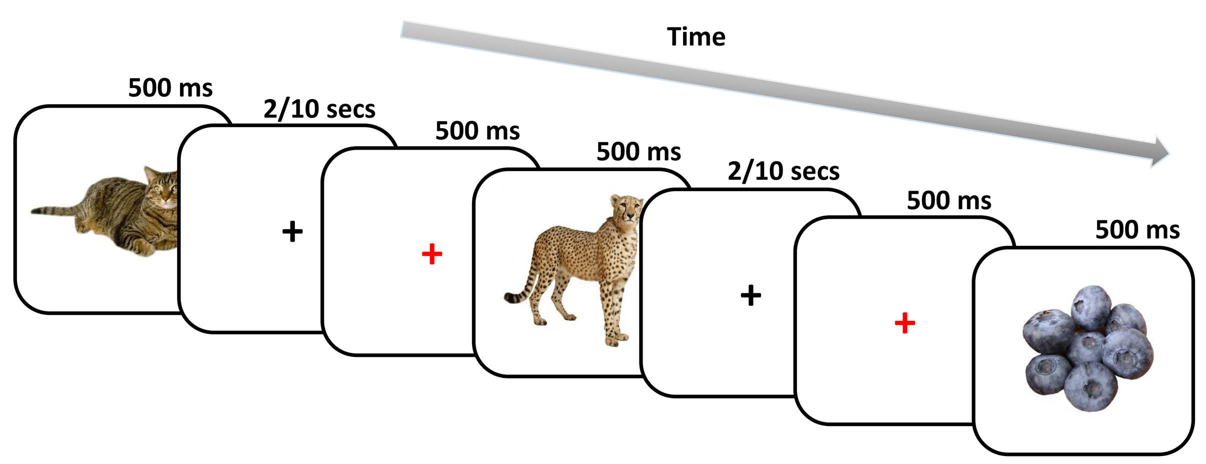
## Introduction

- How do semantic and perceptual representations contribute to episodic memory encoding? Semantic processing is critical for memory, but may also lead to mnemonic discrimination errors if novel items are similar to studied items [1-2]. Perceptual processing may uniquely contribute to successful memory encoding[2].
- Meaning is extracted from vision via increasingly finer-grained processing along the ventral visual pathway[3-4]. Coarse categorical representations are coded in ventral posterior temporal areas, while finer-grained semantic information needed to distinguish more confusable concepts is coded in the perirhinal cortex.
- We investigated whether regions engaged in semantic and perceptual processing are *also* predictive of episodic memory encoding, in a pre-registered fMRI study (https://osf.io/ypmdj) combining Representational Similarity Analysis (RSA) with a subsequent memory (SM) paradigm.

## Methods

N = 28 (18 female).
*Stimuli:* Pictures taken from 24 categories.
***Encoding:*** 328 stimuli were presented in the scanner.
Participants indicated whether each object's name started with a "vowel" or "consonant".

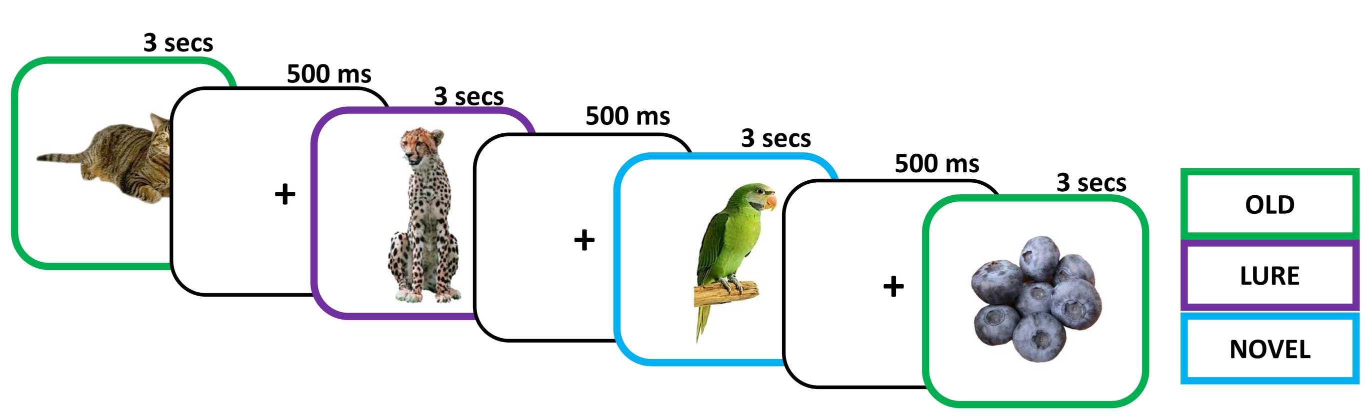



Multi-echo EPI

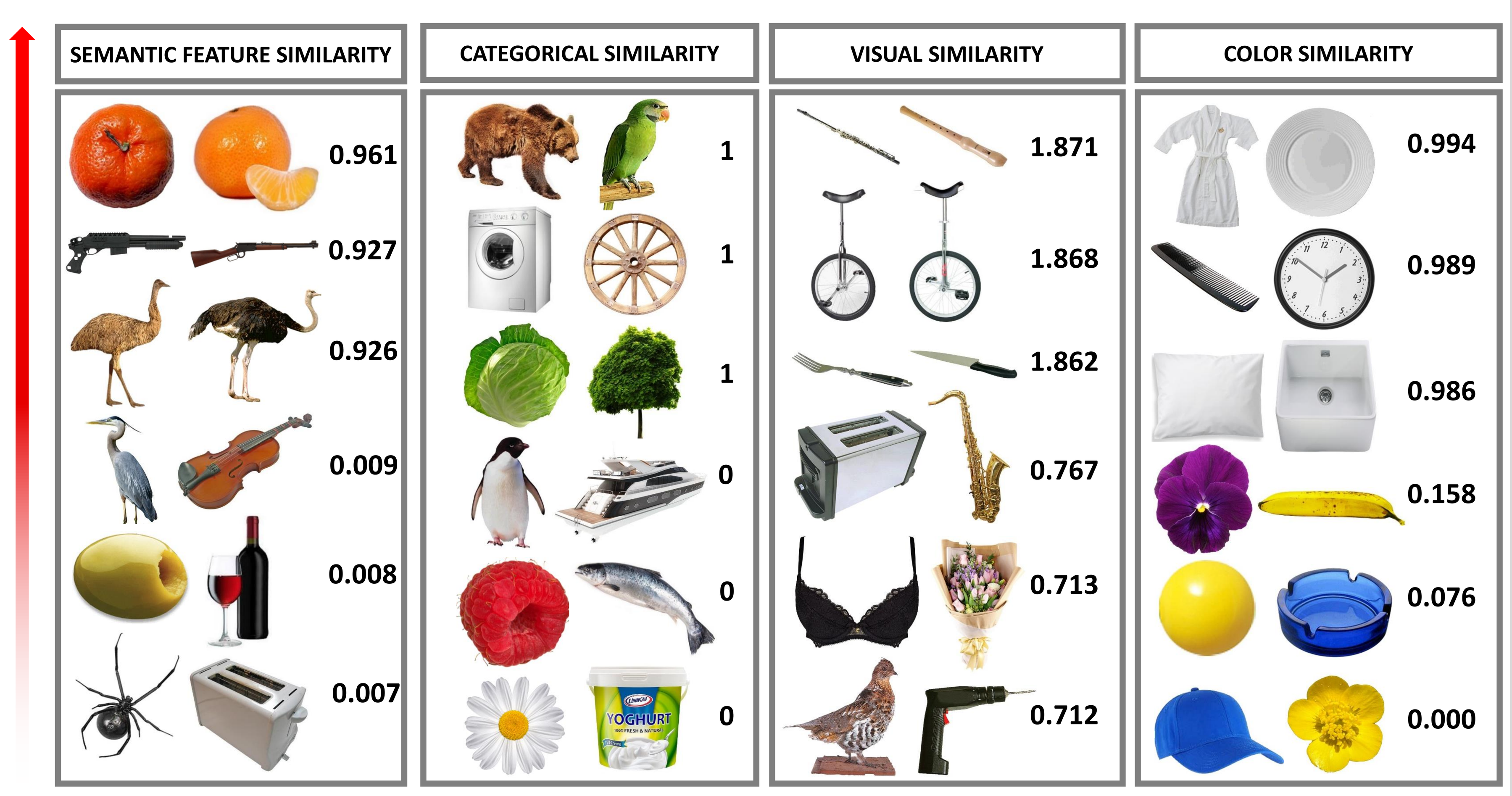
Single trial GLM using Least-Square-All (LSA) method.

Mean SOA = 6 secs

***Retrieval:*** 491 stimuli were presented outside the scanner.
Participants indicated whether each object was "old" or "new".
Half of the studied concepts tested as OLD, half tested as LURE.



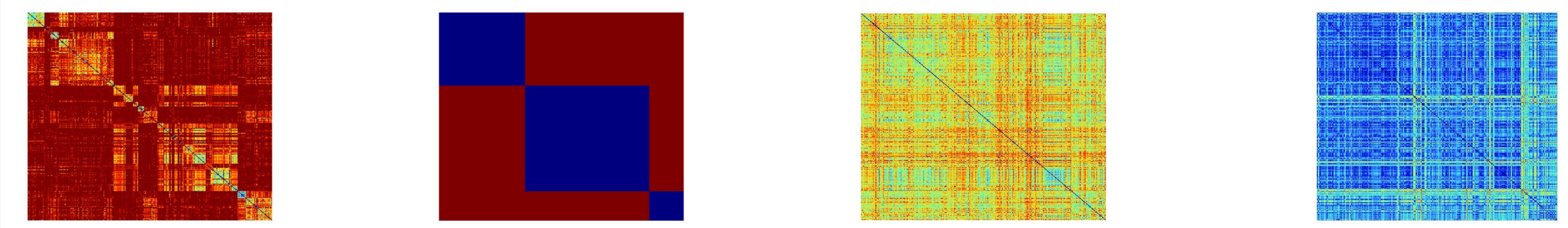

**Discrimination Memory:** Studied items vs novel items
*Mean d-prime* = 2.03




Pairwise similarities were used to create the **Representational Models** of interest

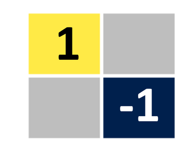
## Representational Models

***Replication of Clarke & Tyler (2014):***
- Creation of four model Representational Dissimilarity Matrices (RDMs) containing all the studied items.



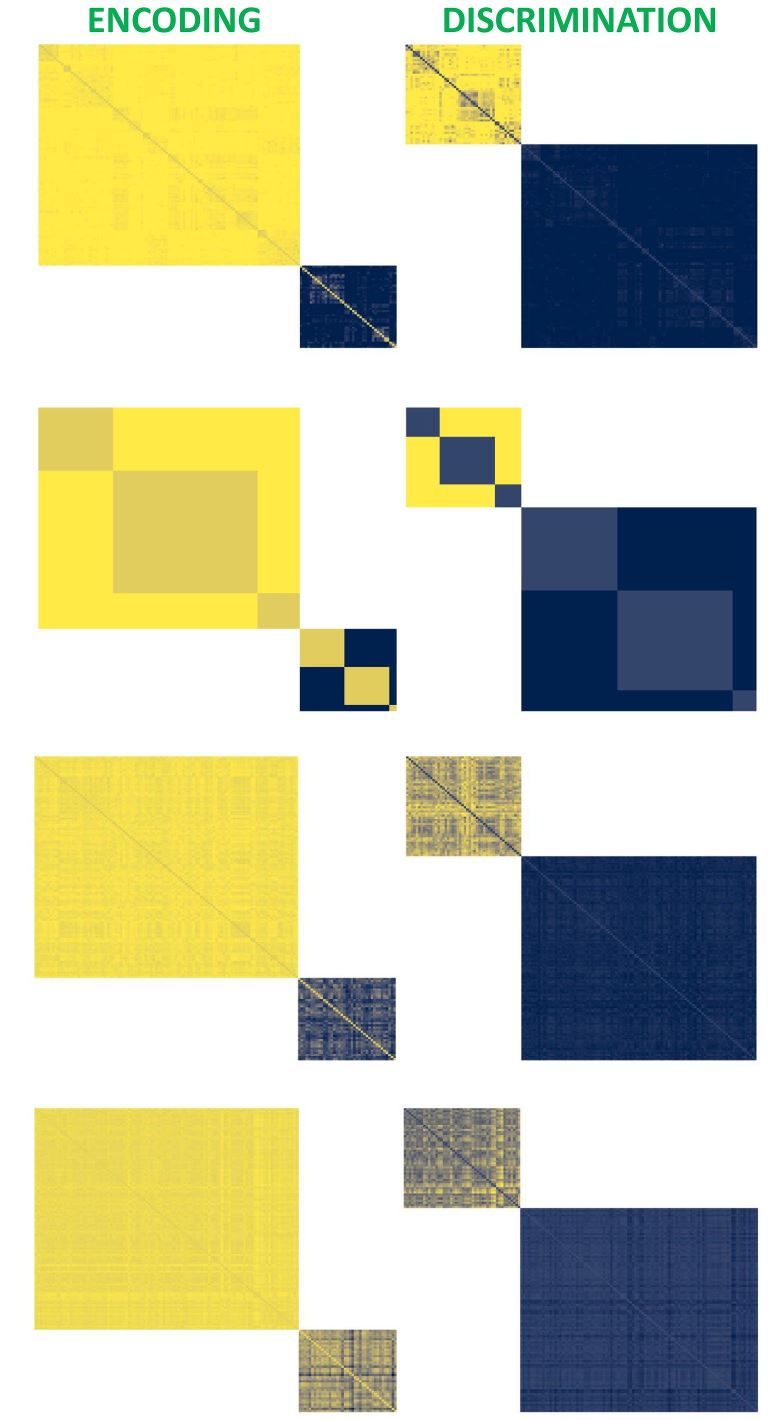
Semantic feature RDM | Animal-nonbiological-plants RDM | Early visual cortex RDM | Color RDM

***Subsequent memory analysis***:
- Each representational model split into two for subsequent memory analysis:
  1. **True memory encoding**: studied items, coded as recognised or forgotten.
  2. **Lure discrimination**: studied items, coded as falsely recognised or correctly rejected




**N.B**: To model interactions of similarity with subsequent memory, scale the values in each quadrant so that their sum equals to 1.

Sign to the lower-right quadrants (subMISS/subCR) changed to obtain contrast [1,-1]. RDM sum equals 0.

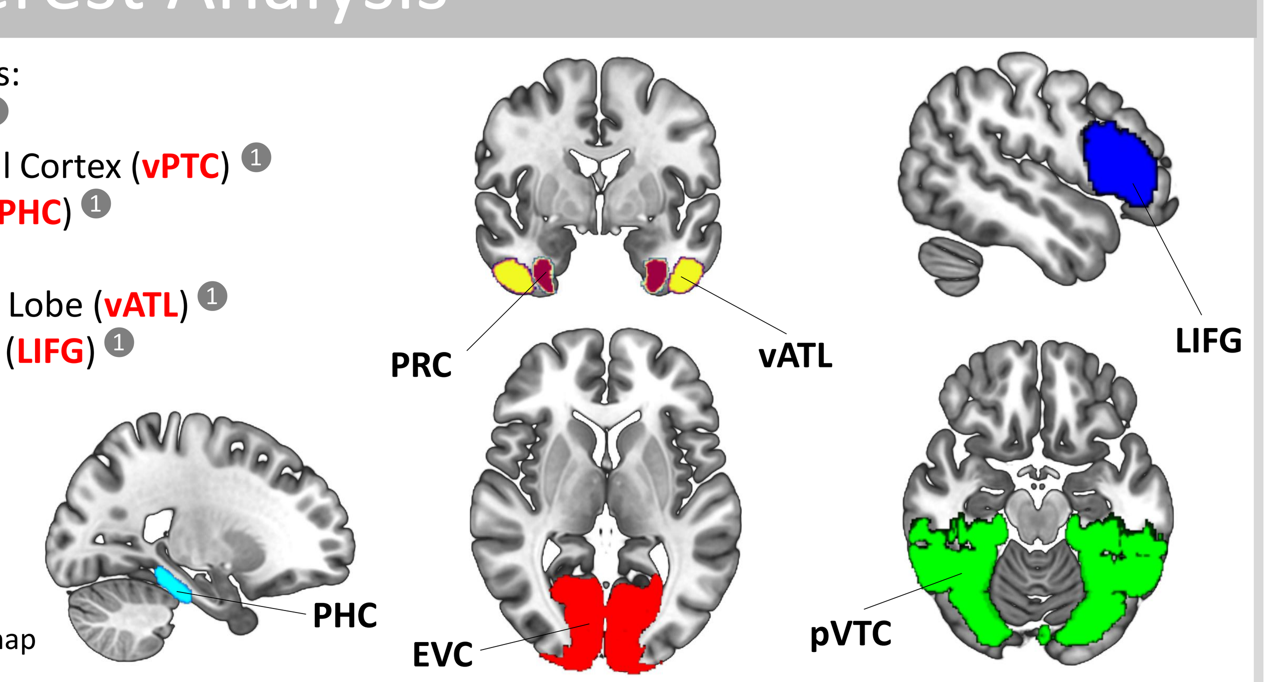



- **Semantic feature RDM.** Clarke and Tyler[3]'s model with updated property norms[5]. Each concept is represented by a binary vector of features. Similarity between concepts is equal to 1 – the cosine angle between feature vectors.
- **Animal-nonbiological-plants RDM.** It is based on the combination of the 24 object categories[3] collapsed intro 3 domains (0 = same domain, 1 = other domain) .
- **Early visual cortex RDM.** Hmax[6] model. Captures the low-level (V1) visual attributes of each picture in the C1 layer. Visual dissimilarity for each pair of images was calculated as 1 - Pearson's correlation between object vectors.
- **Color RDM.** In CIELab space, we computed the normalised Earth Mover's Distance[7] between each pair of images. Lower values indicate higher colour similarity.

## Region of interest Analysis

Six anatomically-derived ROIs:
1. Early visual cortex (**EVC**) ②
2. Ventral Posterior Temporal Cortex (**vPTC**) ①
3. Parahippocampal Cortex (**PHC**) ①
4. Perirhinal Cortex (**PRC**) ③
5. Ventral Anterior Temporal Lobe (**vATL**) ①
6. Left Inferior Frontal Gyrus (**LIFG**) ①

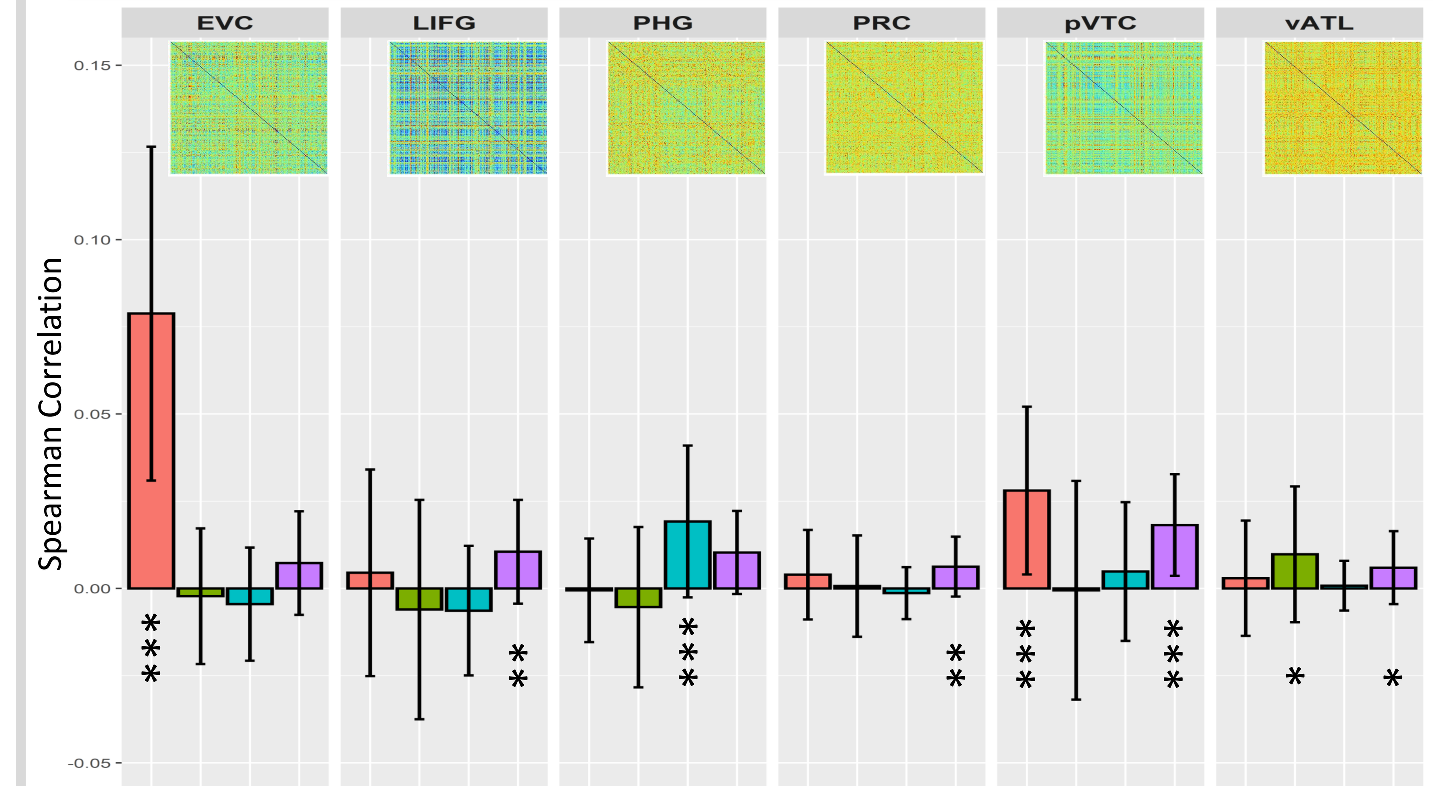
Atlases used:
① Harvard-Oxford
② Julich probabilistic map
③ Devlin & Prince's probabilistic map




## Results

- Evaluate each model RDM in each ROI for each subject using Spearman rank correlation. Group-level analysis using a one sample permutation t-test with 10.000 iterations.
- Plots show unique effects of each model RDM in each ROI after controlling for the potential effects of all the other significant models using partial Spearman rank correlation.

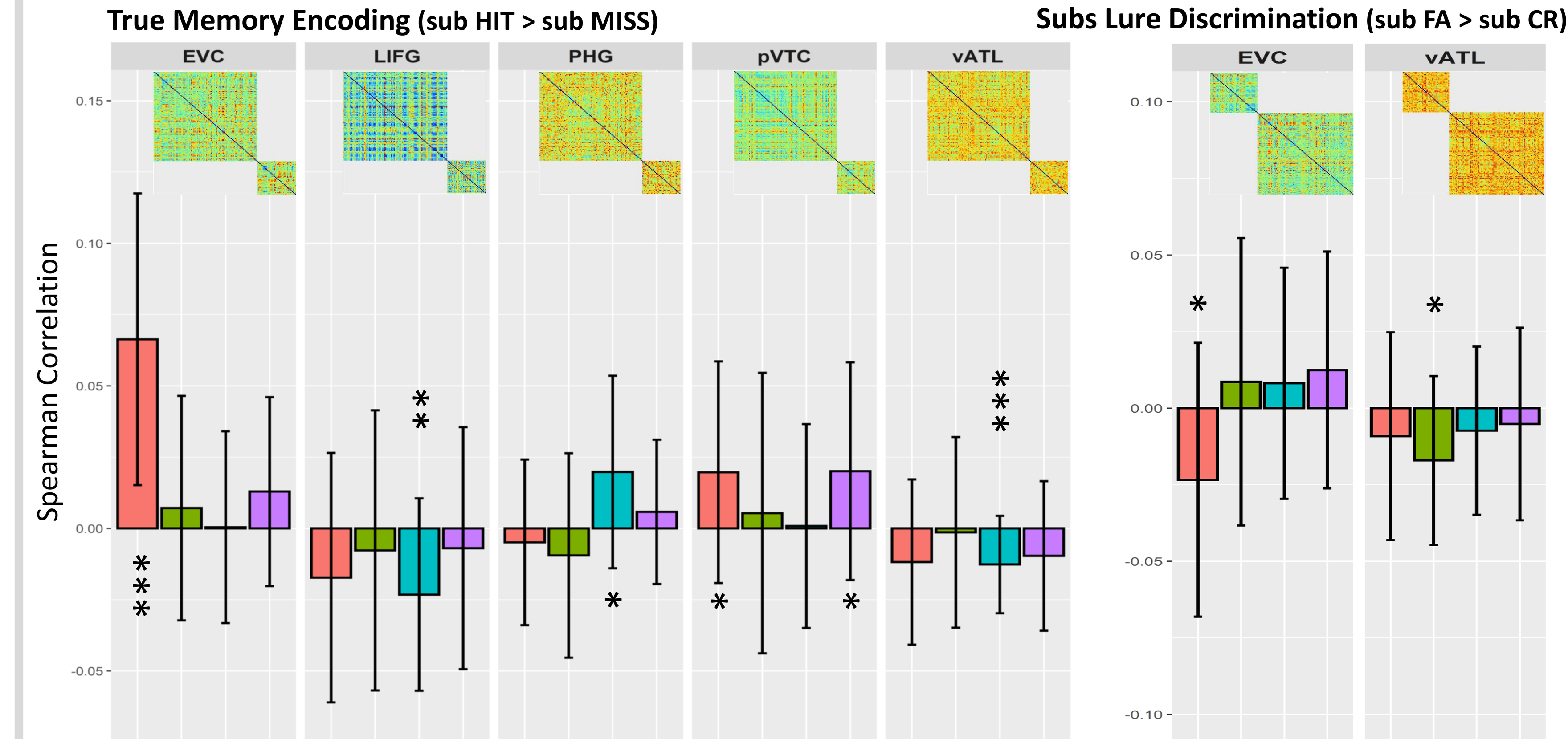
**Main effect of model**




p < .5 = *
p < .01 = **
p < .001 = ***

FDR corrected per ROI

**True Memory Encoding** (sub HIT > sub MISS) | **Subs Lure Discrimination** (sub FA > sub CR)




- Semantic feature RDM
- Animal-plant-nonbiological RDM
- Color RDM
- Early Visual cortex RDM

- Error bars = 95% CI

- **What comes next?**
  1. Univariate Analysis
  2. Searchlight Analysis

## Conclusion

- Successful memory encoding for objects involves enhanced processing of distributed semantic feature representations in the posterior ventral temporal cortex (pVTC) as well as coarse categorical information represented in the parahippocampal cortex.
- Coarse categorical semantic information In the left inferior ventrolateral prefrontal cortex (LIFG) and ventral anterior temporal lobe (vATL) also contributed significantly to later forgetting.
- Visual perceptual similarity was also critical for memory encoding, with early visual cortex and posterior ventral temporal representations predicting successful object recognition as well as rejection of lures.
- Finer-grained semantic information represented in perirhinal cortex did not significantly predict memory.

*References:*
1. Brainerd, C. J. & Reyna, V. F. Fuzzy-Trace Theory and False Memory. *Curr. Dir. Psychol. Sci.* **11,** 164–169 (2002).
2. Kim, H., Cabeza, R., 2007. Differential contributions of prefrontal, medial temporal, and sensory-perceptual regions to true and false memory formation. *Cereb. Cortex* 17, 2143–2150.
3. Clarke, A., & Tyler, L. K. (2014). Object-Specific Semantic Coding in Human Perirhinal Cortex. *Journal of Neuroscience*, *34*(14), 4766–4775. https://doi.org/10.1523/JNEUROSCI.2828-13.2014.
4. Martin C. B., Douglas D., Newsome R. N., Man L. L. & Barense M. D. (2018) Integrative and distinctive coding of visual and conceptual object features in the ventral visual stream. *eLife* 7. doi: 10. 7554/eLife.31873.
5. Devereux, B. J., Tyler, L. K., Geertzen, J., & Randall, B. (2014). The Centre for Speech, Language and the Brain (CSLB) concept property norms. *Behavior Research Methods*, *46*(4), 1119–1127. https://doi.org/10.3758/s13428-013-0420-4
6. Riesenhuber, M. and Poggio, T. (1999). Hierarchical models of object recognition in cortex. *Nature Neuroscience*.
7. Rubner, Y., Tomasi, C., and Guibas, L. 2000. The Earth Mover's distance as a metric for image retrieval. *International Journal of Computer Vision*, 40(2):99–121.