fMRI-based prediction models for free recall, recognition memory, emotional valences, arousal, and memorability of pictures

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Introduction

Human declarative memory is a complex phenomenon that engages various cognitive processes and a multitude of distinct neural systems. Although a number of brain areas critical to memory have been identified, the exact neural correlates and brain activity patterns that give rise to it are not very well understood. In this study, we aim to predict **(i) free recall, (ii) emotional valences, (iii) arousal**, and **(iv) memorability of pictures** based on fMRI activations during encoding using multi-voxel pattern analysis (MVPA) techniques, which include searchlight analysis and a customized 'top' voxel approach for voxel selection and support vector machines (SVM) and artificial neural networks for classification. In addition, using the searchlight approach, we employ a region-of-interest (ROI) analysis to identify the brain areas that are the most predictive of our phenotypes of interest.

Materials & Methods

The participants of this study performed picture memory tasks in a MAGNETOM Verio 3-T whole-body MR unit (Luksys et al., 2015). Stimuli included a total number of 72 pictures – 24 pictures for each valence [positive, neutral, and negative (*Fig. 1A*)], which were selected from the International Affective Picture System (IAPS, Lang et al, 1997). The participants performed ***picture learning*** and ***free recall***, and after an 80 min delay, ***picture recognition***, where presented with previously shown or new pictures, they had to rate picture familiarity (previously seen vs. familiar vs. new).

A **B**

A) Pictures associated with positive, neutral, and negative valences. B) Center voxel (black) surrounded by neighboring voxels (blue).

To reduce data dimensionality, we extracted the beta values from the most significant ('top') voxels (using one-way ANOVA for valences, arousal, and memorability and two-sample t-test for free recall and recognition memory phenotypes) with various exclusion radii around each selected voxel (*Fig. 1B*). In a different subsample of the population Subsequently, SVMs with Gaussian kernels as well as various neural network architectures were used to classify the following conditions:

Prediction domains	Conditions for classification
Free Recall	Remembered vs. not remembered
Recognition Memory	Old vs. familiar & new
Emotional Valences	Negative vs. neutral vs. positive
Arousal	Low vs. medium vs. high
Memorability	Weak vs. medium vs. strong

We also performed MVPA-based searchlight analysis, where we used a sliding window containing a spherical subset ("searchlights") of a selected radius centered around each voxel (*Fig. 1B*).

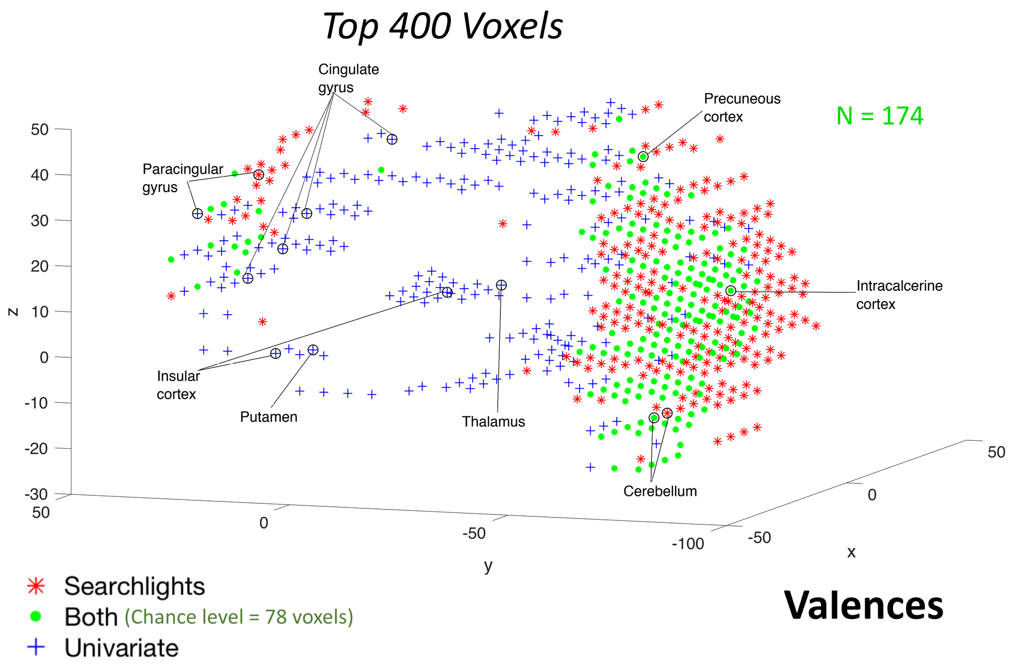
Results

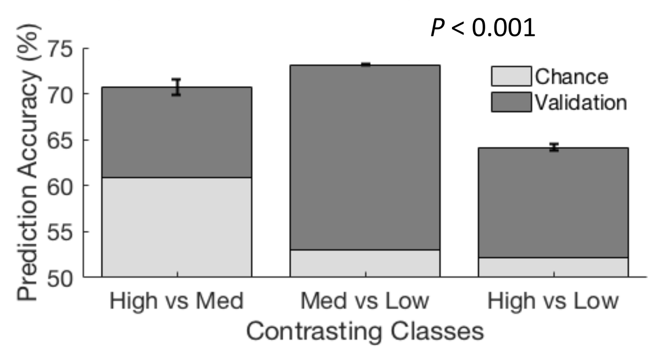
In this study, we used MVPA techniques to predict individual phenotypes (i.e. arousal, valences, and free recall), which are based on individual ratings for each picture and picture-based phenotypes (i.e. IAPS valences and memorability), which are based on average ratings across individuals for each picture. We also attempted the prediction of recognition memory using encoding fMRI; however, results (not shown here) were merely at chance level.

Individual predictions:

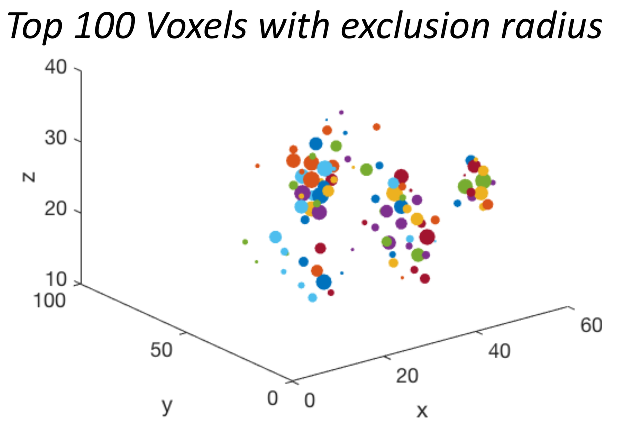
Arousal

Top 400 Voxels



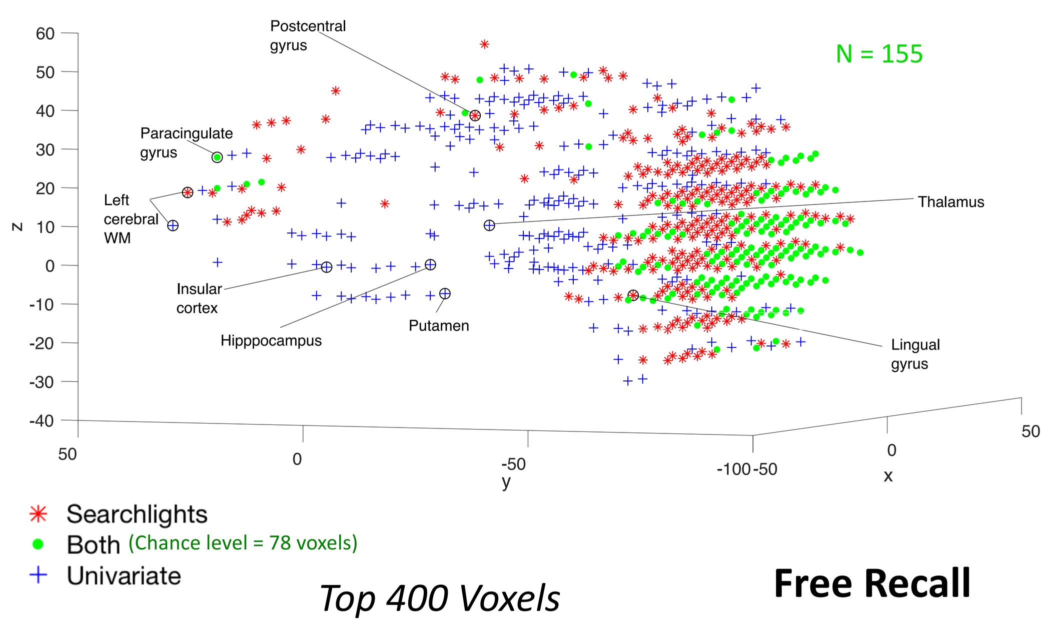


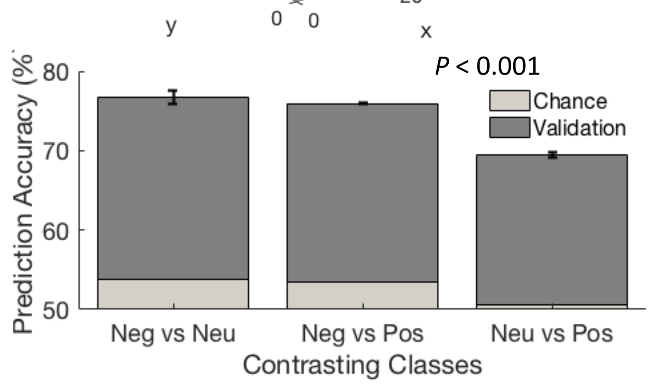
Top 100 Voxels with exclusion radius



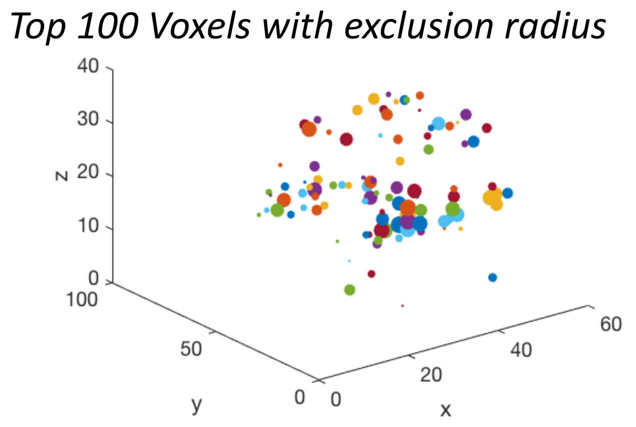
Valences

Top 400 Voxels



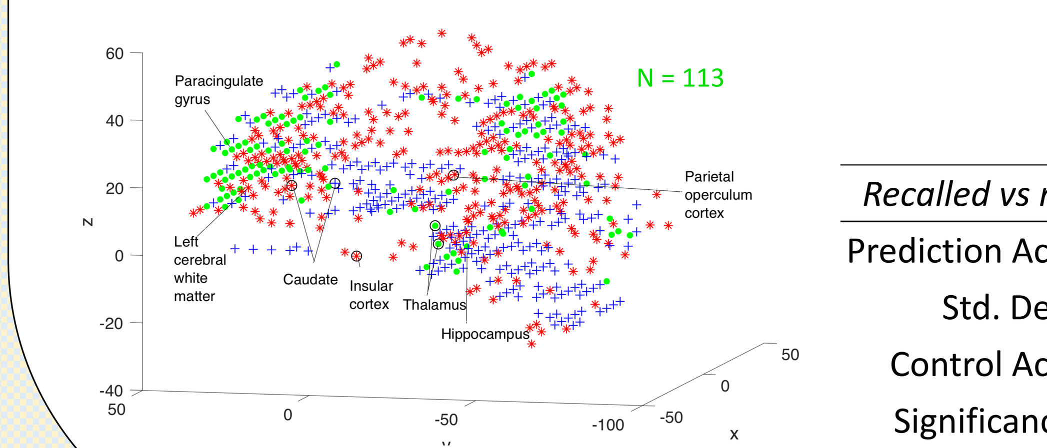


Top 100 Voxels with exclusion radius

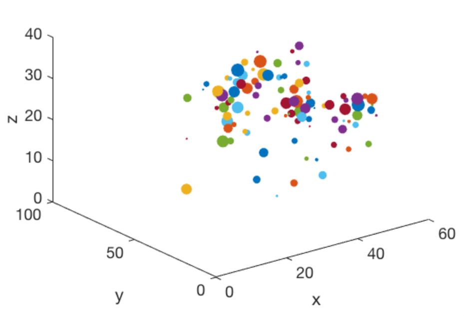


Free Recall

Top 400 Voxels



Top 100 Voxels with exclusion radius

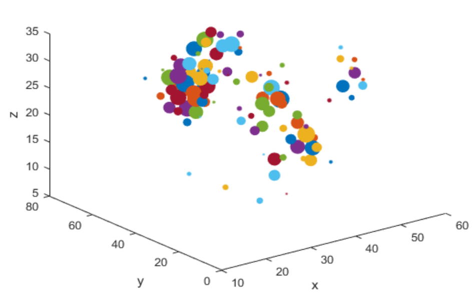


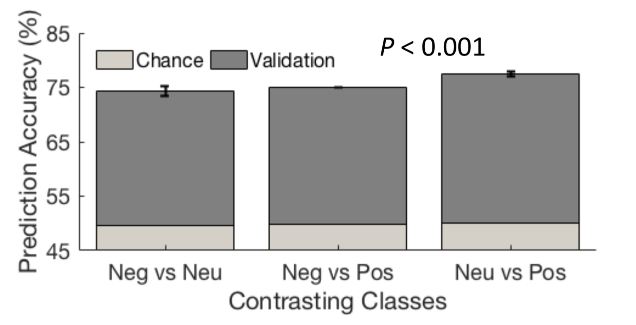
Recalled vs not recalled	
Prediction Acc.	61.26
Std. Dev.	0.75
Control Acc.	59.48
Significance	$P < 0.001$

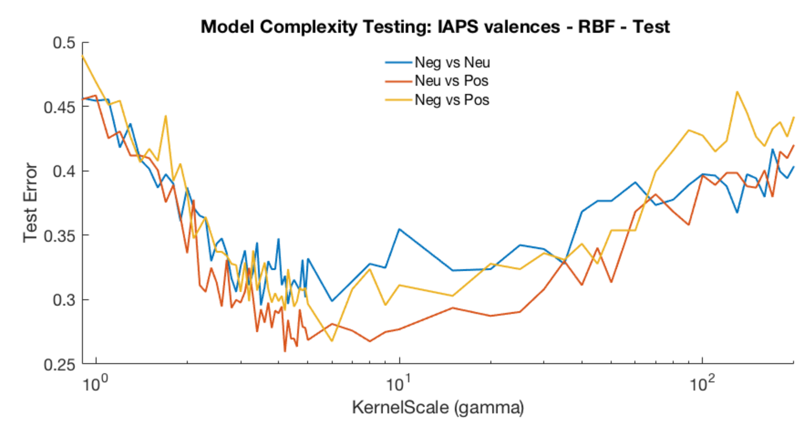
Picture-based predictions:

IAPS Valences

Top 100 Voxels with exclusion radius



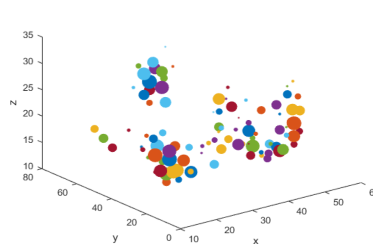


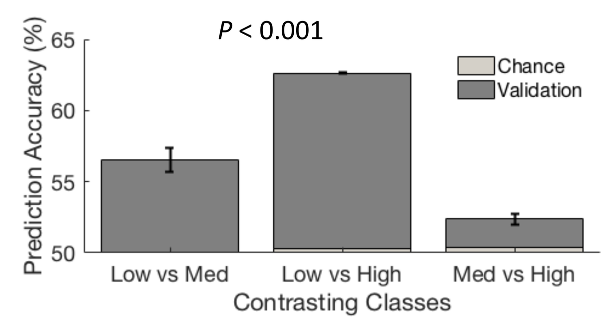


Predictive brain areas	Voxel count
Lateral Occipital Cortex, inf.	19
Temporal Occipital Fusiform	17
Intracalcarine Cortex	11
Occipital Fusiform Gyrus	9
Precuneous Cortex	8

Memorability

Top 100 Voxels with exclusion radius





Predictive brain areas	Voxel count
Intracalcarine Cortex	32
Lingual Gyrus	25
Precuneous Cortex	18
Paracingulate Gyrus	17
Supracalcarine Cortex	15

Discussion & Future Work

This study predicted emotional valences, arousal, and memorability of pictures with reasonably high accuracies. In accordance with recent literature, however, our findings confirm the difficulty of predicting individual memories of concrete items, even though we achieved statistically significant prediction with meaningful maps of the most informative areas & voxels. These maps show that the most predictive voxels based on MVPA reside in integration areas such as parietal, occipital and frontal cortices, where advantages of non-linear classifiers are more apparent, whereas the most significant univariate voxels are distributed more broadly. The employment of deep learning techniques as well as other dimensionality reduction techniques such as PCA, ICA and masks derived from Neurosynth (Yarkoni et al., 2011) show great promise of achieving higher prediction accuracies.

References

1. Lang, P.J., Bradley, M.M. & Cuthbert, B.N., 1997. International Affective Picture System (IAPS): Affective Ratings of Pictures and Instruction Manual. Gainesville: University of Florida.
2. Luksys, G. et al., 2015. Computational dissection of human episodic memory reveals mental process-specific genetic profiles. *PNAS*, 112(35), pp.4939-48.
3. Norman, K., Polyn, S.M., Detre, G.J., Haxby, J.V., 2006. Beyond mind-reading: multi-voxel pattern analysis of fMRI data. *Trends in Cognitive Sciences*, 10(9), pp.424-430.

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