fMRI Correlates of Retrieval Orientation: Tracking Contextual Reinstatement Using Pattern Classification

Hillary C. Frankel, Susan G. Robison, Kenneth A. Norman

Department of Psychology and Center for the Study of Brain, Mind, and Behavior, Princeton University

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Aims

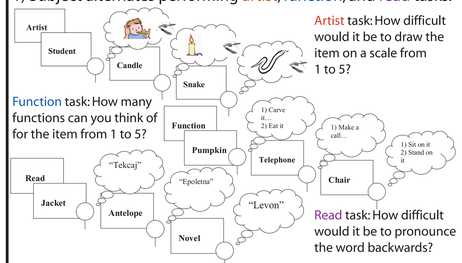
-To train a classifier to identify neural patterns of activity associated with 3 encoding tasks.

-To lead participants to establish a strategic retrieval orientation using an exclusion paradigm (Jacoby, 1991).

-To evaluate whether subjects reinstate encoding patterns at retrieval.

Task

1) Subject alternates performing artist, function, and read tasks.

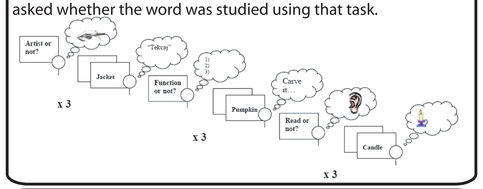


Artist task: How difficult would it be to draw the item on a scale from 1 to 5?

Function task: How many functions can you think of for the item from 1 to 5?

Read task: How difficult would it be to pronounce the word backwards?

2) Exclusion test: Subjects are given a task cue and then are asked whether the word was studied using that task.



Logic of the Analysis

Train classifier on data from the study phase

Question 1: Can we classify single TRs from the study phase according to encoding task?
Method 1: Use an n-1 cross-validation procedure to obtain the classifier's estimates of study condition for each TR

Question 2: Does retrieval orientation involve reinstating task sets from the study phase?
Method 2: a) Apply classifier trained on study-phase data to TRs from test phase and obtain classifier estimates of how strongly subjects are reinstating task-specific information from study phase b) Measure whether classifier estimates of task-specific reinstatement correlate with instructed retrieval orientation

Analysis Details

AFNI pre-processing -- motion correction, despiking, detrending

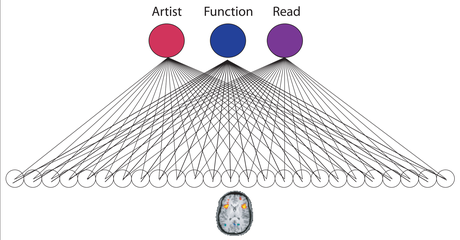
Functional data loaded into Matlab and voxel timecourses were replaced by a z-score normalized version

Voxel selection was performed prior to classification to find voxels whose signal significantly deviated between the three study conditions.

N-minus-one cross-validation classification, leaving out a single run each time (backpropagation neural network). See Polyn et al. (2005), Mitchell et al. (2004).

Event-related averages for study trials constructed in Matlab

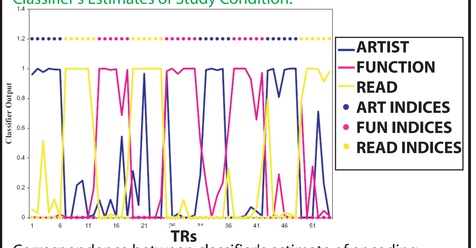
Classification



Two-layer neural network classifier is trained using backpropagation to differentiate between neural activity patterns during artist, function, and read encoding conditions.

Question 1: Can we classify single TRs from the study phase according to encoding task? Yes.

Classifier's Estimates of Study Condition:



Correspondence between classifier's estimate of encoding condition and the actual encoding condition for a single subject.

Classification Results

Study-to-Study Correlations

Subject	Whole-brain		Frontal Cortex	
	OnOff	P-Value	OnOff	P-Value
1	1.1084	<0.0001	0.7768	<0.0001
2	1.0454	<0.0001	0.9043	<0.0001
3	0.878	<0.0001	0.647	0.0014
4	0.5857	0.0274	0.244	0.4919
5	0.9672	<0.0001	0.8066	<0.0001
6	1.1638	<0.0001	0.9513	<0.0001
7	1.2986	<0.0001	1.1823	<0.0001
8	1.0556	<0.0001	0.8121	0.0122
9	1.0718	<0.0001	0.9976	<0.0001
10	1.2625	<0.0001	1.1794	<0.0001
11	1.0521	<0.0001	0.9403	<0.0001

Question 1: Can we classify single TRs from the study phase according to encoding task? Yes.

Question 2: Does retrieval orientation involve reinstating task sets from the study phase? Yes.

To index classifier performance, we computed the correlation (across TRs) between classifier estimates and experimental conditions.

Classifier Output

Study Condition	Artist	Func	Read
Artist	0.8069	-0.4388	-0.4209
Func	-0.4416	0.9274	-0.5193
Read	-0.3653	-0.4886	0.9402

OnOff = average of correlations on the diagonal - average of correlations off the diagonal

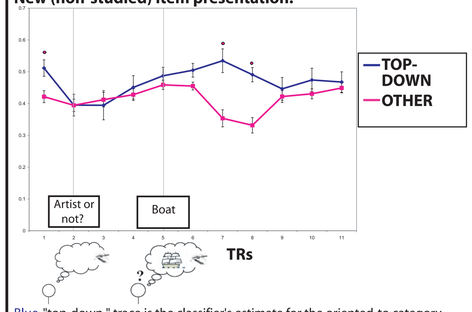
Study-to-Test Correlations

Subject	Whole-brain		Frontal Cortex	
	OnOff	P-Value	OnOff	P-Value
1	0.2520	<0.0001	0.1669	0.0018
2	0.0747	0.0878	0.0484	0.1868
3	0.1037	0.0607	0.1159	0.0390
4	0.1451	0.0053	-0.0406	0.2348
5	0.1915	<0.0001	0.1026	0.0200
6	0.2371	<0.0001	0.1849	<0.0001
7	0.1479	0.0022	0.1191	0.0200
8	0.2299	<0.0001	0.2193	<0.0001
9	0.0799	0.0667	0.0752	0.0741
10	0.3242	<0.0001	0.2815	<0.0001
11	0.2121	<0.0001	0.2138	<0.0001

Preliminary event-related averages

Event-related averages of the classifier's estimate of encoding reinstatement during the test trials.

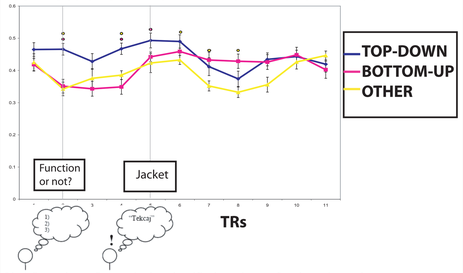
New (non-studied) item presentation:



Blue, "top-down," trace is the classifier's estimate for the oriented-to category.
Pink, "other," trace is an average of the classifier's estimate for the two categories towards which the participant is not oriented and serves as a baseline.

Increase in top-down retrieval orientation is observed associated with item presentation. Subjects may attempt to "re-do" the encoding task after test item is presented.

Item studied with non-oriented task:

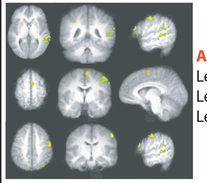


Blue, "top-down," trace is the classifier's estimate for the oriented-to category.
Pink, "bottom-up," trace is the classifier's estimate for the item's originally-studied category.
Yellow, "other," trace is the classifier's estimate for the remaining category.

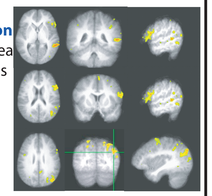
At the beginning of the trial, "top-down" category is activated. Following item presentation, the "bottom-up" encoding task information is activated.

Brain Maps

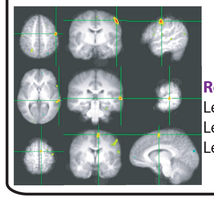
Analyses were run to determine which brain regions were significantly contributing to the classification. The maps below show which voxels exerted the strongest influence in detecting each of the three brain states: artist, function, and read.



Artist
Left Middle Temporal Area
Left Medial Frontal Gyrus
Left Postcentral Gyrus



Function
Left Middle Temporal Area
Left Inferior Frontal Gyrus
Superior Occipital Gyri



Read
Left Precentral Gyrus
Left Superior Temporal Gyrus
Left Medial Frontal Gyrus

Multi-Voxel Pattern Analysis (MVPA) Toolbox

All of the described analyses were implemented using the Princeton Multi-Voxel Pattern Analysis (MVPA) toolbox (Polyn et al., 2005), which is available online at **http://www.csbmb.princeton.edu/mvpa**. The toolbox facilitates import/export of data, simple pre-processing, and a variety of voxel selection and classification algorithms within an n-minus-one no-peeking framework.

Conclusions

Classifier successfully identified neural activity patterns corresponding with the three encoding tasks.

On test trials, subjects reinstated activity relating to the cued (oriented-to) encoding task.

When a new item is presented at test, we observe an increase in activity associated with the oriented-to encoding task. This may indicate that subjects are attempting to "re-do" the encoding task.

When an item studied using a task other than the oriented-to task is presented at test, an increase in "bottom-up" activity corresponding to the original encoding task is observed, indicating partial loss of retrieval orientation.

References

Jacoby LL. (1991) A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language*, 30, 513-541.

Mitchell TM, Hutchinson R, Niculescu RS, Pereira F, Wang X, Just M, and Newman S. (2004) Learning to decode cognitive states from brain images. *Machine Learning,* 57:145-175.

Polyn SM, Natu VS, Cohen JD, and Norman KA. (2005) Category-specific cortical activity precedes retrieval during memory search. *Science*, 310, 1963-1966.

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