Context in free recall - multi-voxel pattern analysis of fMRI

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Aims

Study how subjects strategically cue memory and reinstate context
- items get bound with context at study
- to retrieve item, access the context

Our approach:
- train classifier to recognize particular contextual states
- use classifier to track contextual reinstatement at test, and predict behavior

How do cue/context representations at encoding vs recall differ?

How can we design and analyze these psychologically-interesting effects using MVPA techniques?

Prior work - Polyn et al (2005)

Subjects studied 3 kinds of stimuli - celebrity faces, famous locations and household objects

Train classifier to discriminate between faces/locations/objects during the study period

During free recall - track reinstatement of face, location and object "contexts"

Yields a time-varying index of cognitive states during recall - can predict which kind of recall will be made a few seconds prior to vocalization

Is this contextual reinstatement? Could just be a reflection of the semantic (categorical) properties of the items themselves, as opposed to subjects reinstating their mindset from the study phase (which should include information about how items were processed at study and how they were presented, in addition to core semantic features of the items).

Main task - bonfires, windows and stairs

8 subjects (1 female), between the ages of 20 and 36

At study, form a distinctive mental image of each stimulus in one of three contexts: being thrown onto a bonfire, dropped out of a window or carried up the stairs.

At recall, try and recall out loud and in any order as many of the items from the most recent list. Hold down a button to let us know which context you're thinking about.

Final free recall run - recall any of the items studied from the entire experiment

Stimuli do not belong to pre-existing semantic categories. The only thing that differs across contexts is how subjects visualize and process the stimuli at study.

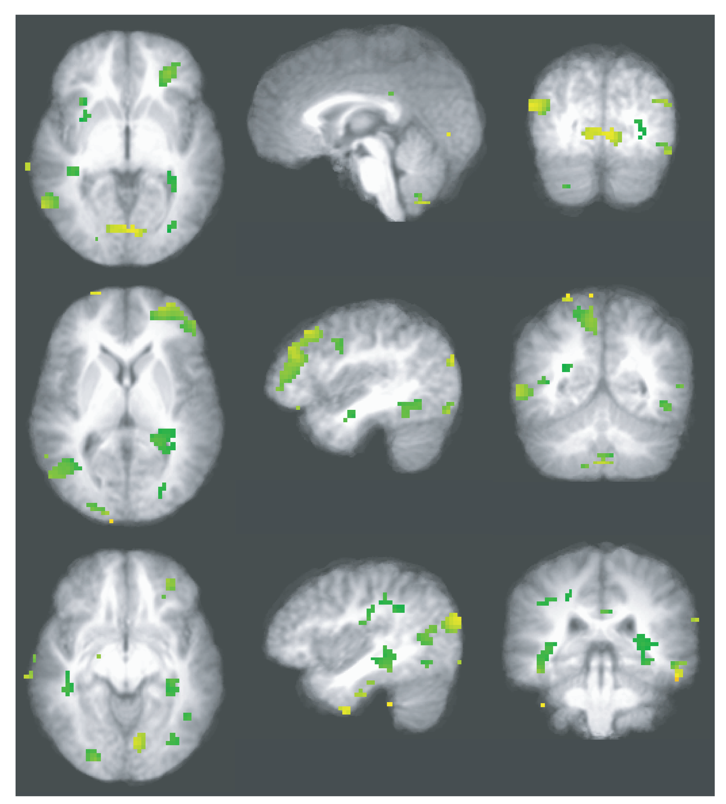
3T Siemens Allegra, 3x3mm voxels (1mm inter-slice gap), 64x64 matrix with 34 slices, TR=2000 ms. Anatomical MPRAGE after functional scanning.

5s per item
24 items per list
= 120s per list
20s arithmetic
100s free recall
10 study lists

Group analysis:

contrasting 3 contexts at study

Volume-registered, despiked, 8mm FWHM gaussian smoothing, each run normalized to percent signal change. GLM on individual subjects modelling the 3 study contexts, convolved using the default gamma variate HRF, modelling baseline, linear and quadratic trends in each run as regressors of no interest. 2-way ANOVA (study context = fixed effect, subject = random effect), showing main effect of study, $p<0.05$. Intra-cranial mask applied, only showing clusters of >100 microliters.



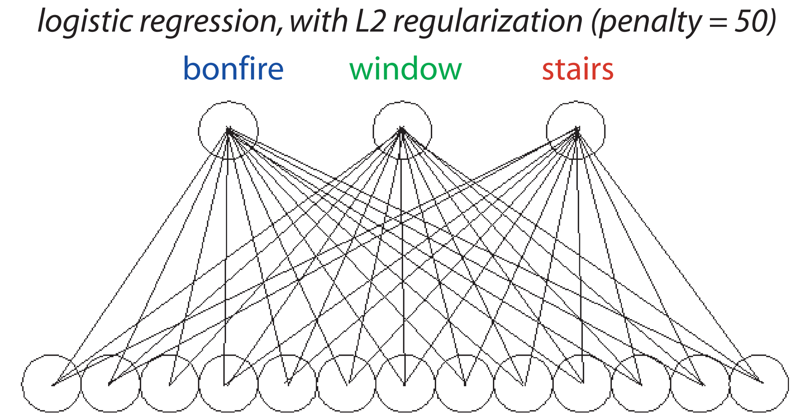
Classification methods

Volume-registered, despiked, detrended (linear and quadratic), 4mm FWHM gaussian smoothing, z-scored in time within run.

Study-study classification: 3 categories, train on 9 study periods, generalize to 10th study period, n-1 cross-validation, using 1000 best voxels from n-1 GLM contrast on training data, entirely within subject. Temporal smoothing on classifier output timecourse.

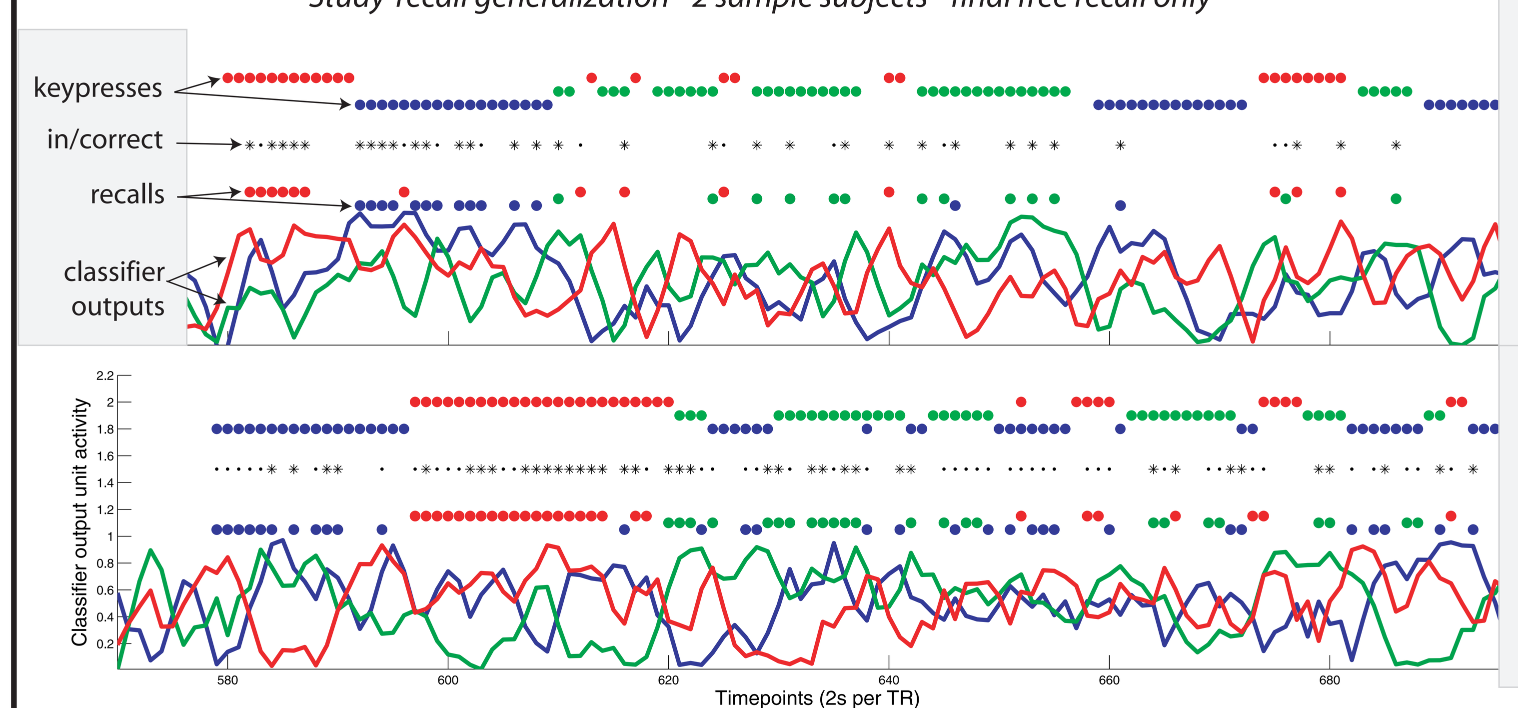
Study-recall classification: as above, but train on all 10 study periods, test on all recall periods, using 1000 voxels from GLM contrast on contexts using all study periods.

logistic regression, with L2 regularization (penalty = 50)

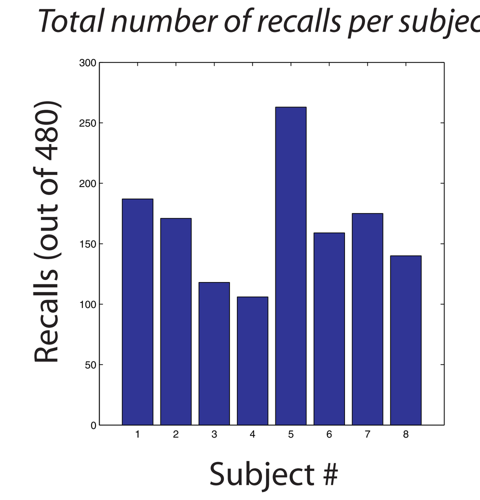


Classification results

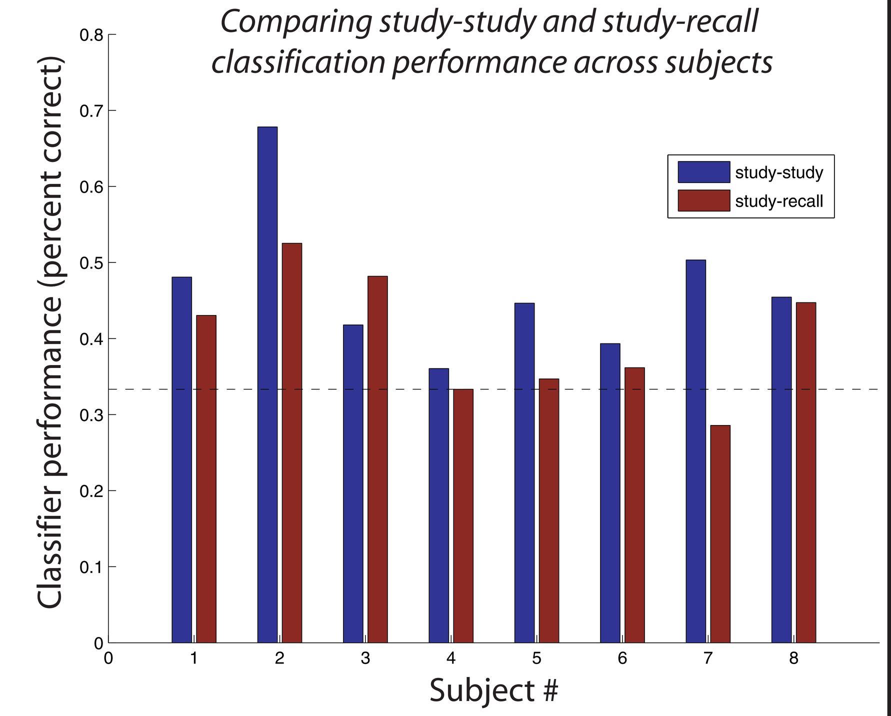
Study-recall generalization - 2 sample subjects - final free recall only



Total number of recalls per subject



Comparing study-study and study-recall classification performance across subjects



Mean classifier performance (across subjects)

- study-study 47%
- study-recall 40%

Why is study-recall generalization performance for some subjects so much higher than for others?

- Requires discriminable but stable patterns for each context, common to both study and recall - yet subjects might be thinking of different facets of the complex context scenes at different times

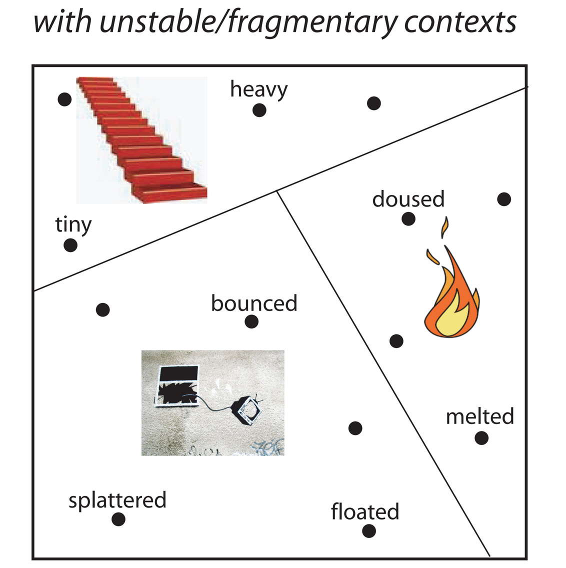
- Some subjects can reinstate context at recall in a discriminable, consistent, classifiable manner - a trainable skill?

- Contextual cue overloading - context representations that are too static may get overloaded as a retrieval cue. Good behavioral recall performance may require flexible cuing.

- Another experiment using task contexts (size, animacy, pleasantness) yielded better study-study generalization but still poor study-recall; in this case, it may be hard to reinstate a task context without actually being able to perform the task...

- A pilot experiment with a single highly-trained subject and 6 distinctive, personally-chosen physical locations for contexts yielded the best study-recall generalization so far (40% where chance = 16%).

Schematic depiction of mental space with unstable/fragmentary contexts



Conclusions

Some ability to predict behavior by tracking the reoccurrence of study contexts using a classifier

Considerable variability in classifier performance between subjects

MVPA analyses may provide a means of investigating subtle cuing and interference behavior, but this will probably require very careful consideration of subjects' recall strategies.

Future directions

To study memory cuing, we need to figure out a way to give the classifier a sufficient amount of training for that cue state, without overloading the cue during the experiment

Breaking down contexts into sub-contexts?

Can subjects be trained to form consistent yet discriminable mental cues?

Multi-Voxel Pattern Analysis (MVPA) toolbox

All of the analyses described were implemented using the Princeton Multi-Voxel Pattern Analysis (MVPA) toolbox in Matlab (Detre et al., 2006), which is freely available online at **http://www.csbmb.princeton.edu/mvpa**. It provides a framework for import/export of neuroimaging data into Matlab, pre-processing, and cross-validated feature selection and classification.

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