# Neural evidence for the flexible use of working memory & episodic memory in prospective remembering

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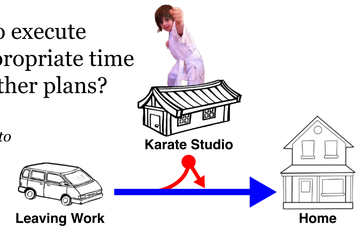
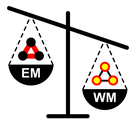
## 1 Introduction: *Prospective memory*

How do we remember to execute a specific goal at the appropriate time despite busily pursing other plans?




*e.g., How will I remember to pick up my son from his karate lesson on my way home from work tonight?*

Theories of cognitive control (e.g., by Braver and colleagues) and of prospective memory (e.g., by McDaniel and colleagues) suggest that I can either use **proactive control** (to actively maintain the goal information in working memory -- e.g., to mentally rehearse "stop at the karate studio"), or I could use **reactive control** (to rely on cue-based retrieval of goal information from episodic memory -- e.g., seeing the karate studio on the drive home reminds me to stop).

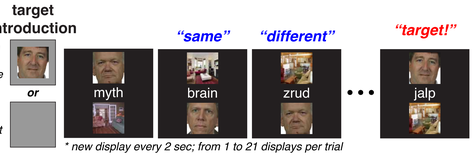



The flexible choice of strategy for a particular goal involves effort/performance trade-offs that depend on the *availability of cognitive resources* and the *likelihood of goal retrieval*.

Question: ***Can we use fMRI brain activations to track the flexible deployment of working memory and episodic memory to achieve a delayed goal?***

## 2 Task design and behavioral results

We developed a prospective memory paradigm for fMRI consisting of a picture target detection task (faces & scenes) embedded in an ongoing n-back task (lexical judgments).




* new display every 2 sec; from 1 to 21 displays per trial

**Two tasks are performed simultaneously:**

**a) A target detection task:**
Press a button with your pinky when the target picture reappears.
*[The target will reappear exactly once, on either the top or bottom of the screen, unpredictably between 2 and 42 secs after its introduction.]*

**b) A n-back lexical decision task:**
Press a button with your index finger (**same**) or middle finger (**different**) based on a comparison between the lexical status (i.e., word or nonword) of the current vs. the previous (n-back) letter string.
*[A response is made every 2 secs, and the correct responses are balanced across the experiment.]*

**In two different trial conditions:**

**EMbias**

a) A large set of heterogeneous pictures are trial-unique.
*[Low proactive interference]*

b) 2-back lexical judgments
*[High working memory load]*

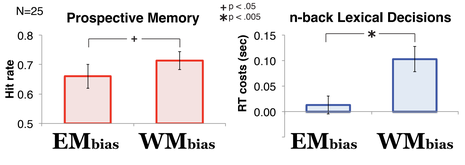
Low proactive interference and higher working memory load (2-back) should bias participants to rely on retrieval from episodic memory to identify the target at the moment that it reappears.

**WMbias**

a) A small set of homogenous pictures are repeated within and across trials.
*[High proactive interference]*

b) 1-back lexical judgments
*[Low working memory load]*

High proactive interference should interfere with episodic memory retrieval, and low working memory load (1-back) should bias participants to maintain the target throughout the trial.




***Results***: More targets were detected in WMbias trials, but the target detection task produced higher RT costs for lexical decisions in these trials.

## 3 Hypothesis and experimental approach

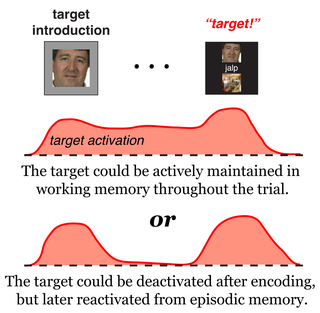
Both working memory and episodic memory strategies predict that target activation *at the point of target appearance* will predict prospective memory accuracy.

However, if participants are using a working memory strategy, then:

(a) Target activation *before* the point of target appearance will also predict prospective memory accuracy.

(b) Suppression of lexical decision processing *before* the point of the target appearance should also predict prospective memory accuracy.

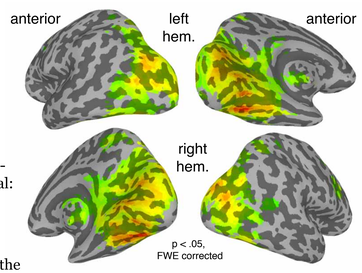
Analysis strategy: Use fMRI pattern classifiers to read out the activation of the target on a moment-to-moment basis. Use these neural measures to predict whether people will identify the target when it reappears at the end of each trial.




## 4 Relating target activations to prospective remembering

### Identify "target-sensitive" regions

Contrast: Target vs. No Target trials during the n-back lexical decision task. ***Note***: Sensory stimulation is identical during the lexical decision task in both trial types (a new face, scene, and letter string appear on the screen every 2 secs).



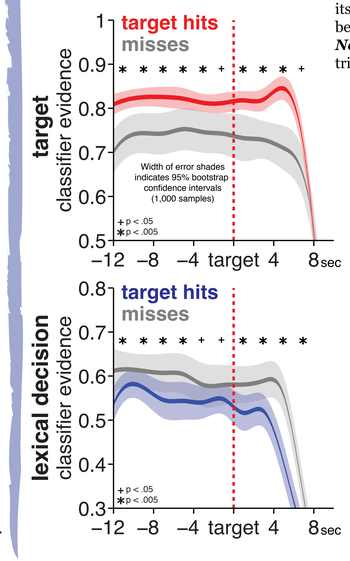

### fMRI pattern classification

**1.** Train a 4-way L2-penalized logistic regression classifier, using cross-validation, on data from the lexical decision and rest phases of each trial:

**1**-*face target trials* **3**-*no target trials (lexical decision only)*
**2**-*scene target trials* **4**-*rest (blank screen between trials)*

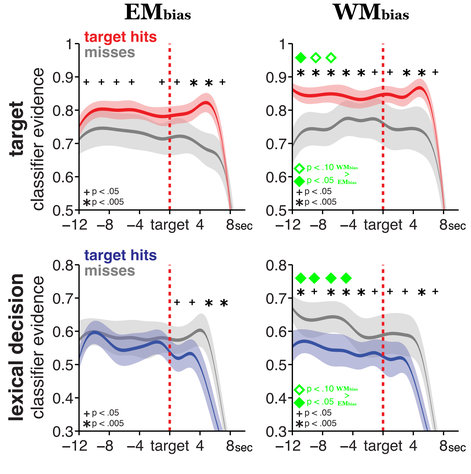
**2.** Use the trained classifier to decode the brain activation patterns at every time point in all trials. ***Note***: separate trials were always used in the training and testing sets to avoid circularity.

### All trials




***Results***: Stronger classifier readouts for the target item both *before* and *after* its reappearance were associated with better prospective memory accuracy.
***Note***: This was stronger in WMbias trials prior to target reappearance.

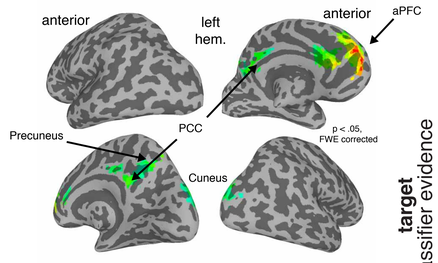
Also, *weaker* classifier readouts for lexical decision activity were associated with better prospective memory.
***Note***: Only WMbias trials showed this prior to target reappearance.

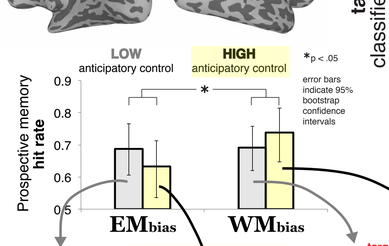



## 5 Anticipatory control and prospective memory strategies

### Identify regions associated with prospective memory success

Contrast: Hits vs. Misses at time of target reappearance



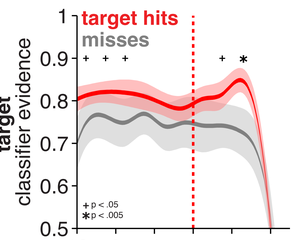



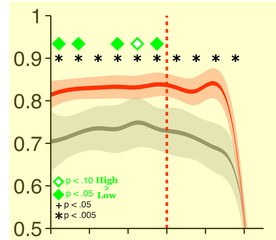

**LOW** anticipatory control

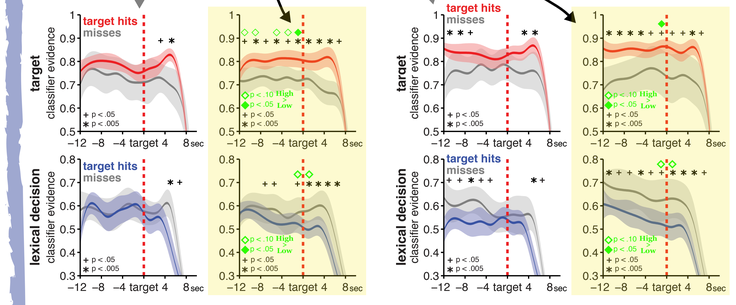
**HIGH** anticipatory control

*48.6% WMbias* — n.s. — *51.4% WMbias*

*68.7% Hits* — n.s. — *68.7% Hits*




***Result***: The anticipatory activation of control regions (including anterior PFC, a region implicated in prospective remembering, e.g., Koechlin and Hyafil, 2007; Gilbert, 2011) led to a tighter coupling between working memory activations and performance: stronger target activations and weaker lexical decision activity were associated with better prospective memory.

However, memory performance did not suffer under low anticipatory control; stronger target activations in response to the target appearance on hits suggests the use of reactive control, i.e., retrieval of the target from episodic memory.

* Our neural diagnosis of proactive control led to *better* performance in **WMbias** trials, and *worse* performance in **EMbias** trials, which suggests a memory performance cost associated with non-optimal strategy use.

## 6 Future directions: Modeling & training

We are developing **normative computational models** that formally specify the costs benefits associated with different memory strategies. These models will generate fine-grained predictions about how people should deploy working memory and episodic memory resources in order to optimize performance.

When a participant's performance deviates from the model's predictions regarding optimal strategy choice, there are two possible explanations:

1. Our model of optimal performance is wrong and needs to be updated
2. The person is behaving suboptimally (i.e., they could do better by adjusting strategy)

To arbitrate between these possibilities, we will use **real-time fMRI neurofeedback** to train people to use the strategy that the model predicts is optimal.

Using methods that were recently developed at Princeton, we will apply fMRI decoding in real time to derive a readout of how much the person is relying on working memory vs. episodic memory, and the person will be encouraged to adjust their strategy use to bring it in line with the model; if the model's predictions about optimal strategy use are correct, following this feedback will lead to an improvement in memory performance.

## 7 Take home points

1. We used fMRI pattern classifiers to read out the memory activation strength of a picture target and the processing of an ongoing lexical decision task, on a moment-to-moment basis, and we used these neural measurements to predict whether people would identify the target when it reappeared during a test of prospective memory.
2. Stronger activation corresponding to the target picture (and *weaker* activity associated with the ongoing lexical decision task), both before and after the target reappeared, was associated with better prospective memory.
3. Anticipatory activity in cognitive control regions (e.g., anterior PFC) revealed a dissociation between proactive and reactive control strategies that were flexibly, and successfully, used in the service of prospective remembering.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