Retrospective vs. Prospective Coding in Object Working Memory

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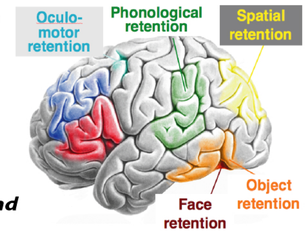
Introduction

- Working memory refers to the ability to maintain information in an active state when it is no longer present in the environment.
- Framework : **Working Memory as an Emergent Property**

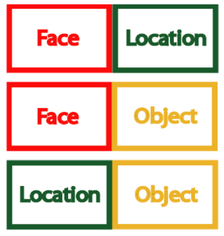
  Working memory arises through coordinated recruitment, via attention, of brain systems that have evolved to accomplish sensory, representational, and action-related functions. (Postle, 2006)
- Previous non-human primate research using extracellular recording has demonstrated that both prefrontal cortex (Rainer et al., 1999) and inferior temporal cortex (Takeda et al., 2005) can represent both retrospective and prospective coding of objects in working memory.

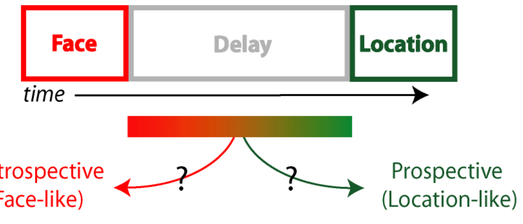


- ***Can human object working memory also be supported by retrospective and prospective codes?***
  - If we find evidence for prospective coding, this will imply that *object working memory is supported by activated LTM*.

Our Approach

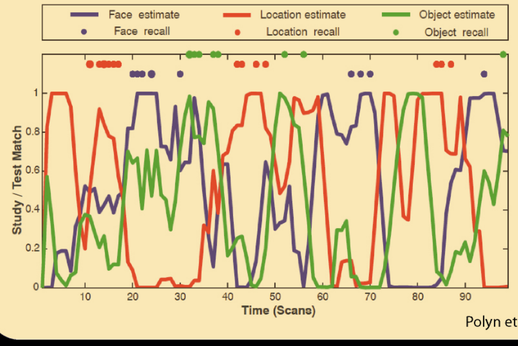
1. Subjects learn arbitrary stimulus pairings
   - i.e., commit them to LTM
2. **Delayed Paired-Associate Recognition**
   - working memory task
   - evaluate delay-period activity





Methodology

- Use whole-brain, multivariate pattern classification of fMRI data
  - Princeton Multi-Voxel Pattern Analysis toolbox (MVPA)
- This method was introduced by Polyn, Natu, Cohen, & Norman (2005) to test the theory of **Contextual Reinstatement** : the context in which an item is learned is re-instated during retrieval from memory.



- Cortical activity at recall **matches** pattern evoked from perceptual processing
- Patterns of activity reappear seconds before verbal recall

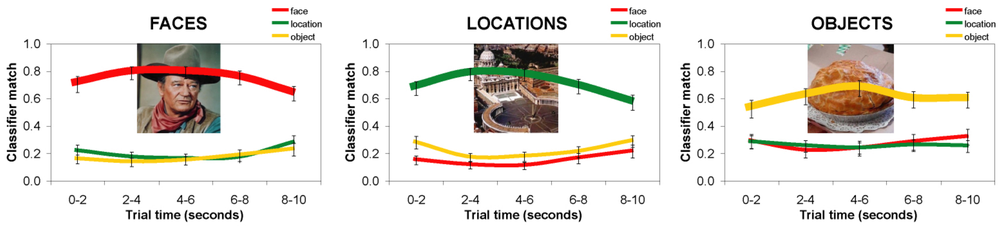
Polyn et al. (2005). Science 310, 1963-66.

Train classifier

Cue	Stimulus	Judge	ITI (Math)
2s	5s	3s	16s

For classification : initial 10s of each trial
90 total trials (30 of each category)

- Train neural network classifier
  - pre-processed fMRI data
  - backpropagation algorithm
- Below is classifier training data for 1 subject (all subjects show similar results)



Learn stimulus pairs

- Offline, learn 6 pairs of stimuli to criterion (24 consecutive correct responses)
  - Randomly select 4 exemplars from each of the 3 categories
  - With these 12 pictures, create 6 unique pairs
  - Practice recognizing pairs (forward and reverse directions) using 3-alternative forced choice
  - Once criterion reached, assumed pairs committed to LTM

(3) between-category



(3) within-category



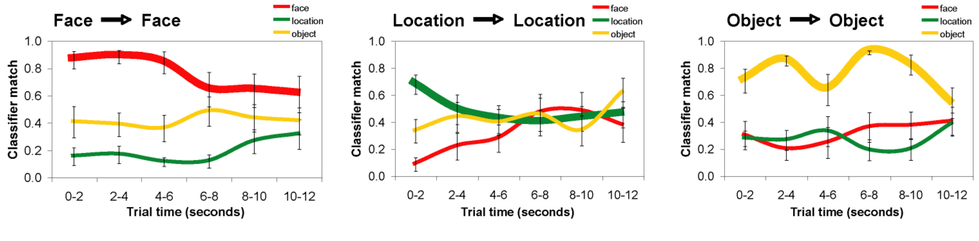
Within-category memory trials

- There are 36 between-category, 36 within-category, and 24 no-memory trials (= 96 total)



Target	Delay	Probe	Response	ITI
1s	11s	1s	5s	13s

- The within-category trials are for validation; we expect to see delay-period activity consistent with both the retrospective & prospective item (they are the same category)
  - Below is data averaged across 1 subject's within-category trials. Note the 'Face-->Face' and 'Object-->Object' trials display the hypothesized pattern of activity.



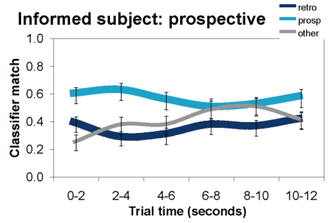
Between-category

- The between-category trails are the experimental trials which investigate the transition of neural activity from the retrospective to the prospective item.



Target	Delay	Probe	Response	ITI
1s	11s	1s	5s	13s

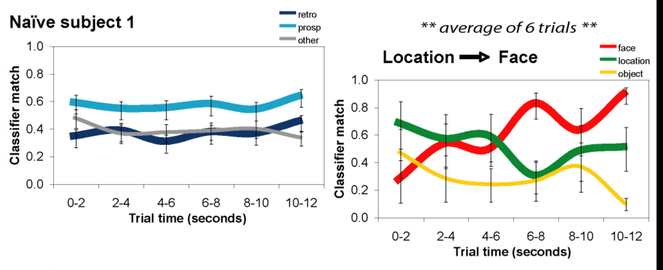
*** These graphs show data collapsed across all 36 between-category trials. ***



One subject was asked to use *prospective* coding.

The prospective pattern (prosp) is more highly matched throughout the delay period than the retrospective (retro).

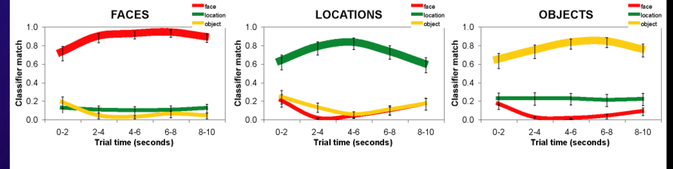
- One subject was not informed how to complete the task.



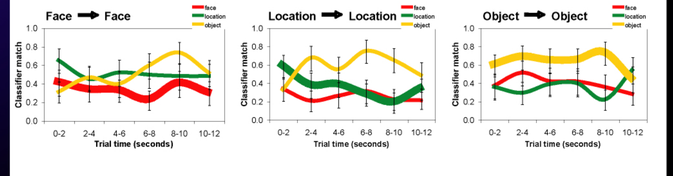
- *Overall, this subject demostrated evidence of prospective coding during the delay period.*

Individual differences

- It is possible that individuals may vary in the extent to which they represent information in WM via sustained activity in perceptual cortex vs. some other mechanism.
  - e.g., if the distribution of cortical activity is substantially different between training (perceptual/semantic) and the working memory task (reactivation from LTM).
- For example, **naive subject 2** shows successful classification of training data:



- *But* classifier fails on within-category delayed-recognition:



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