The Representational Capacity of the Prefrontal Cortex: An fMRI Study

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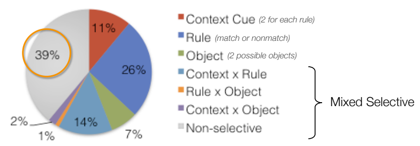
Introduction

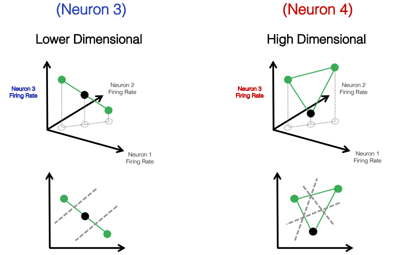
- Single neurons in monkey PFC appear to respond to a diversity of task aspects
- Many neurons show selectivity to key task conditions, but a large portion seem nonselective, consistently firing for non-linear combinations of task dimensions

Context-Cued Matched/Nonmatch-to Sample Task



(Data from Wallis et al., 2001)

- Computational models have shown that, at the population level, mixed selectivity allows classification of high number of dimensions.



(Adapted from Rigotti et al., 2013)

- Rigotti et al. (2013) demonstrated high dimensionality of task representations in monkey PFC using single-unit recording data from a complex working memory task (Warden et al., 2007; 2010).
- Representational capacity (d) of the neural population can be estimated by examining the number of possible binary classifications (N_c) that can be decoded from the network activity

$$\text{dimensionality } (d) = \log_2 N_c$$

- High dimensionality provides the system with great flexibility to read out many possible task combinations in support of complex behavior

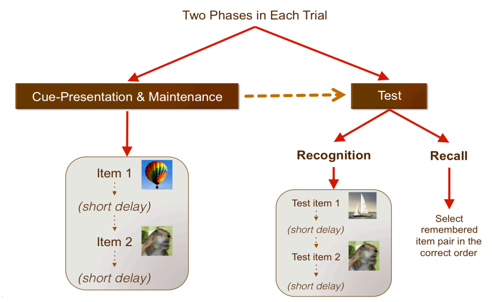
Open Questions

- Does the human PFC use high dimensional representations for performing complex tasks?
- Is high representational capacity a computational feature that is unique to the PFC for encoding task information?

Methods & Approach

- High resolution whole-brain fMRI (1.5 x 1.5 x 2mm voxels)
- Adapted the working memory task from Warden et al. (2010) to an event-related fMRI design
- This task provides a large number of possible task combinations that could be estimated from population-level activity

Two-Object Sequential Memory Task



- Representational capacity calculated by using MVPA to estimate the total number of implementable classifications
- Specifically, binary classification of activation patterns were performed for all possible combinations of task aspects

Cue + Delay Period 1

4 possible cues x 2 test types = 8 task dimensions

$N_c = 2^8 = 256$

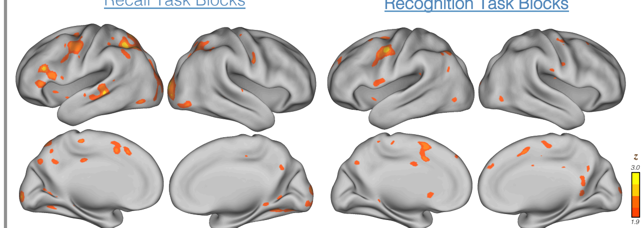
Cue + Delay Period 2

4 cues (period 1) x 3 cues (period 2) x 2 test types = 24 task dimensions

$N_c = 2^{24}$

Univariate Activation Maps

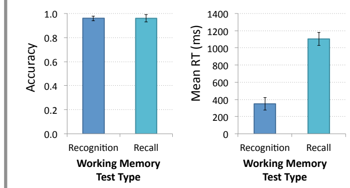
Maintenance Period Activation



- Main effects in expected areas associated with working memory maintenance (i.e., fronto-parietal and visual areas)
- Recall and recognition associated with overlapping, but differential network activity patterns

$N = 7$

Behavioral Results

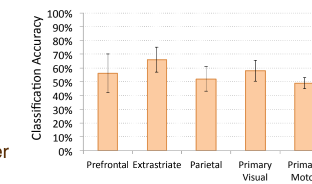


- Human participants performed well in both tasks
- In contrast, when tested with recall of the cues, monkeys performed more poorly, at around 65% accuracy (Warden et al., 2010)

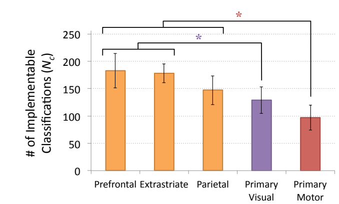
$N = 7$

Representational Capacity

- Classifications performed for five bilateral regions:
  - Lateral prefrontal, extrastriate, posterior parietal, primary visual, and primary motor cortices (defined using Freesurfer parcellations)
- Example performance for decoding specific cue vs. all other task aspects shown here for delay period 1 → (i.e., 4 of 127 *unique* binary comparisons)
- Chance levels for each classifier were determined by estimating bootstrapped null distributions



Representational capacity during first delay period suggests lower dimensionality of task representations in primary cortical areas and higher dimensionality in association areas



* $p < 0.01$

Summary & Conclusions

- Although fMRI is comparatively noisier to extracellular recording, using MVPA we observed indications of the capacity for high dimensional representations in the PFC, as well as in other association cortices
- Greater representational capacity may be a general feature of higher order association areas for supporting the computations that give rise to complex behaviors

References

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