Decoding cognitive task-sets from rostral prefrontal cortex functional connectivity patterns

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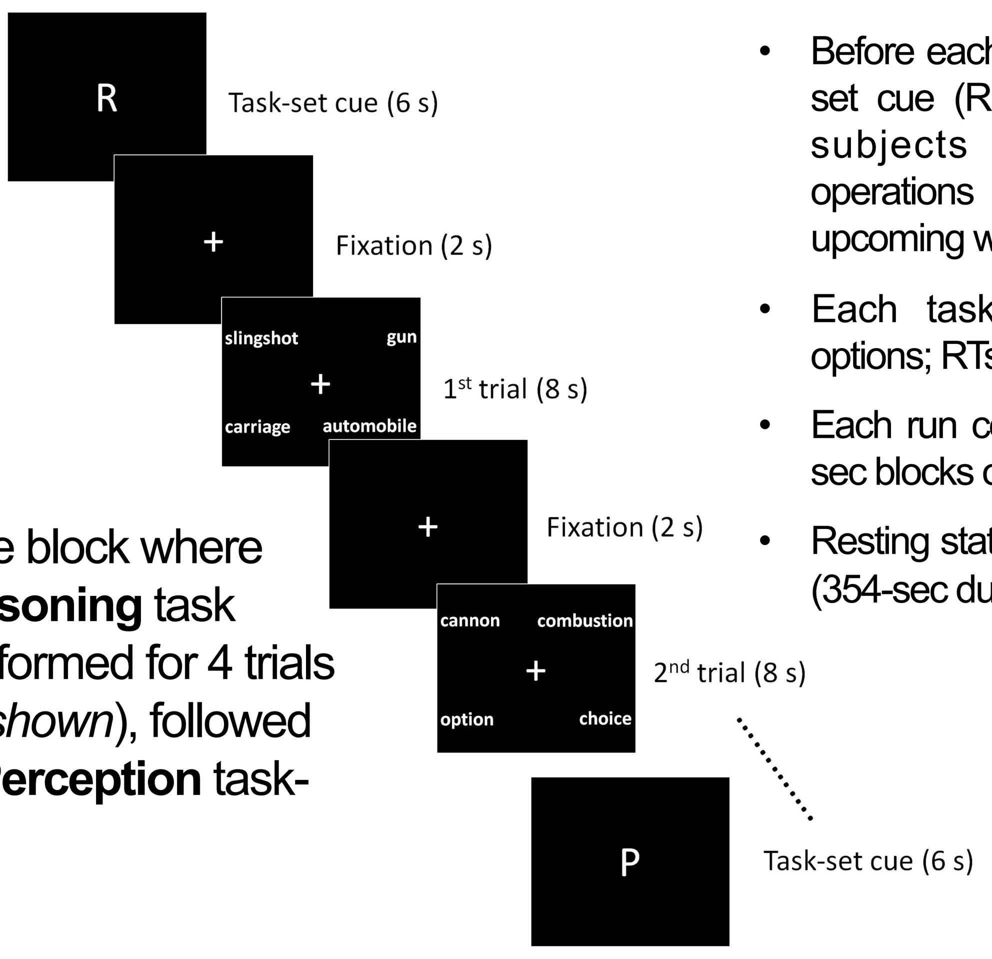
Background

- Distinct neural networks can be well characterized by assessment of intrinsically correlated fluctuations in fMRI BOLD timeseries data from the resting state[1].
- To support goal-directed cognition, one such network – the "Fronto-Parietal Task Control Network" (FPTCN) – may flexibly adjust its coupling with distinct processing networks depending on the information required to accomplish a given task[2].
- We have recently shown that FPTCN regions, particularly in rostral prefrontal cortex (RPFC), are commonly recruited during both memory and reasoning tasks and show distinct profiles of functional connectivity[3].
- Using fMRI data from rest and three distinct tasks matched for their perceptual attributes and response demands – episodic memory retrieval, analogical reasoning, and visuospatial perception – we examine whether it is possible to decode a person's cognitive task set from the underlying pattern of inter-regional connectivity across networks, with an emphasis on RPFC.

Experimental Design

- 20 subjects underwent fMRI scanning (3.0T Siemens, TR=2s, TE=30ms; voxel size=3x3x3.7mm) as they alternated between performing blocks of three cognitive tasks across eight 8-min runs.
- **Reasoning (R)**: judge whether the top and bottom word pairs shared the same abstract relationship or specify whether any non-analogous relationships were present
- **Memory (M)**: identify which, if any, of the 4 words had been encountered during a pre-scan study session (one day prior) and indicate the contextual source of the memory, if possible
- **Perception (P)**: identify which of the 4 words contained the greatest number of straight lines

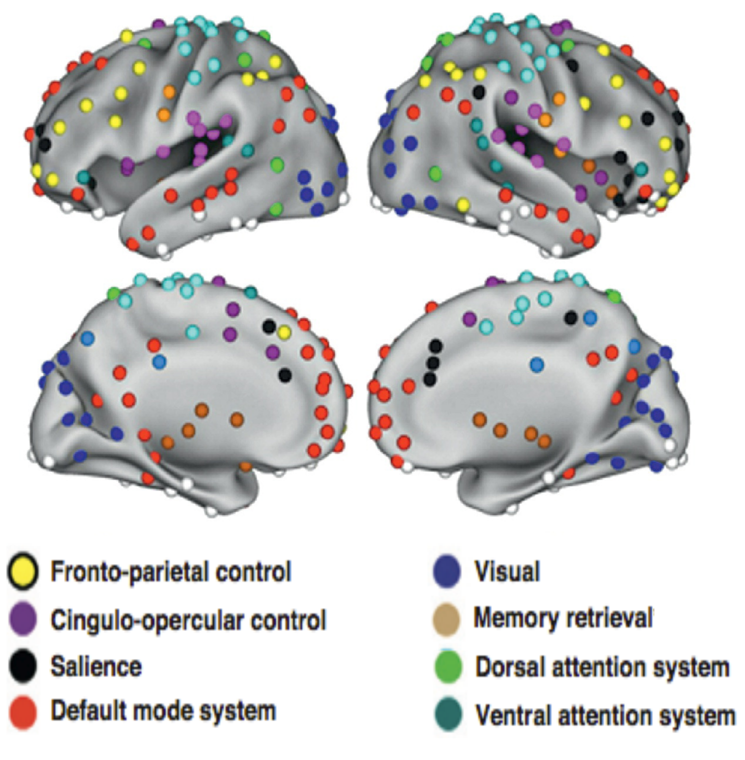


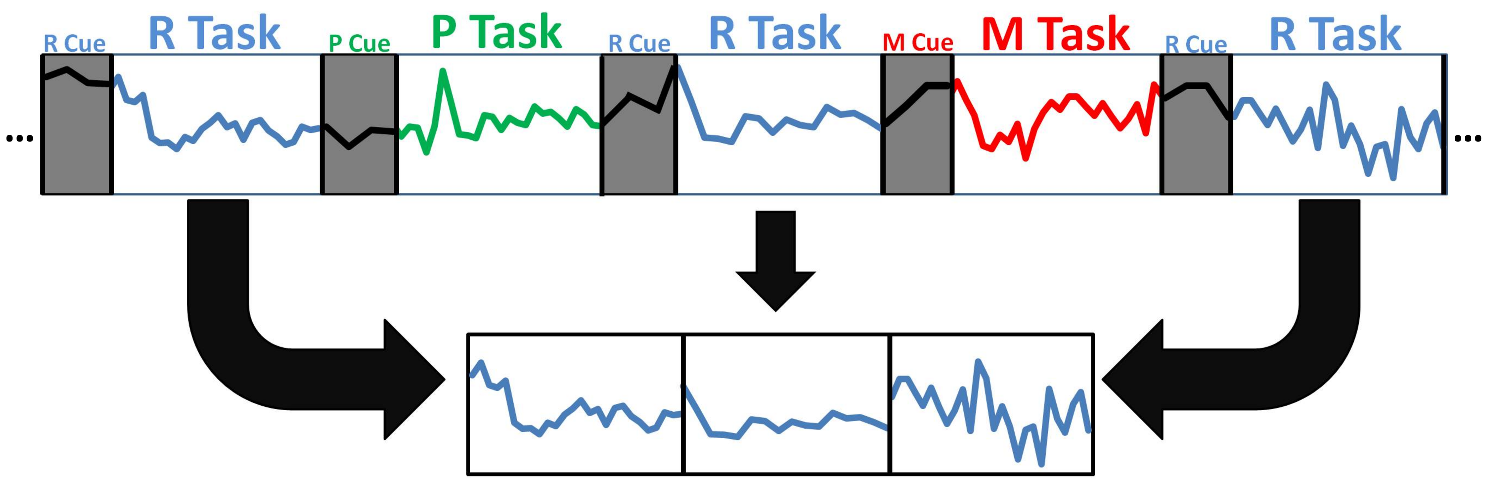
Example block where the **Reasoning** task was performed for 4 trials (*only 2 shown*), followed by the **Perception** task-set cue

- Before each 4-trial block, a task-set cue (R, M, or P) informed subjects of the cognitive operations to perform on the upcoming word array stimuli.
- Each task had 4 response options; RTs were well-matched.
- Each run consisted of three 44-sec blocks of each task.
- Resting state scan also acquired (354-sec duration).

Methods: Creating Condition-Specific Correlation Matrices

- After preprocessing, BOLD time-courses were extracted from 264 nodes of interest (5-mm spheres from a recent study[1] that parcellated the brain into a series of networks based on meta-analysis and resting state data).
- Condition-specific time-courses were created by excluding cue-periods and concatenating task blocks.

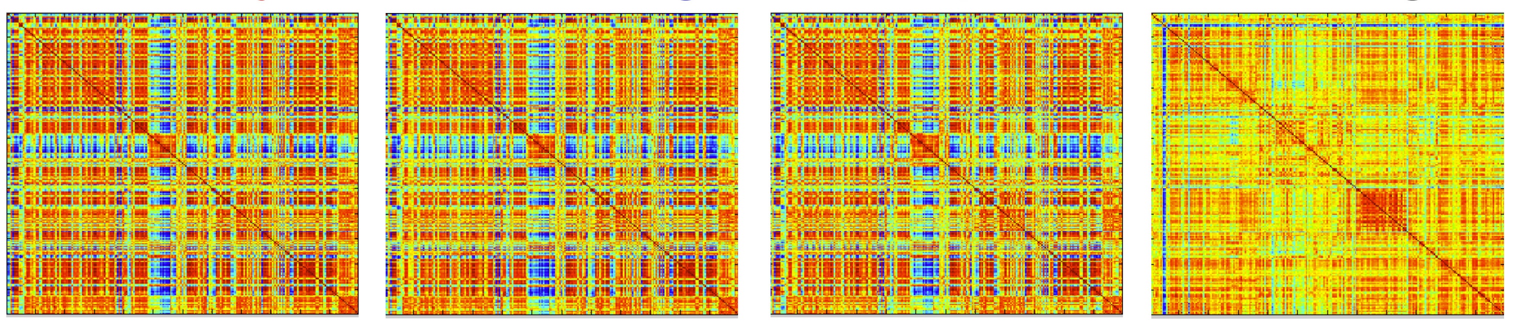




Concatenated Time-course for Reasoning Task

- These condition-specific time-courses were then correlated across all pairs of nodes to create correlation matrices for all 4 conditions.

Memory ***Reasoning*** ***Perception*** ***Resting***



Methods: Pattern Classification

- Using pairwise correlation values ("edges") as features, pattern classification was performed using regularized logistic regression with a leave-one-subject-out cross-validation procedure.
- Assessment of the testing set data was constrained by a forced-choice algorithm using the condition-specific classification evidence estimates. Our classification accuracy metric thus reflects the percentage of subjects for whom the classifier correctly assigned all condition-specific connectivity patterns to their true conditions.
- For all analyses, we confirmed that classification with scrambled class labels yielded the expected chance-level decoding accuracy.

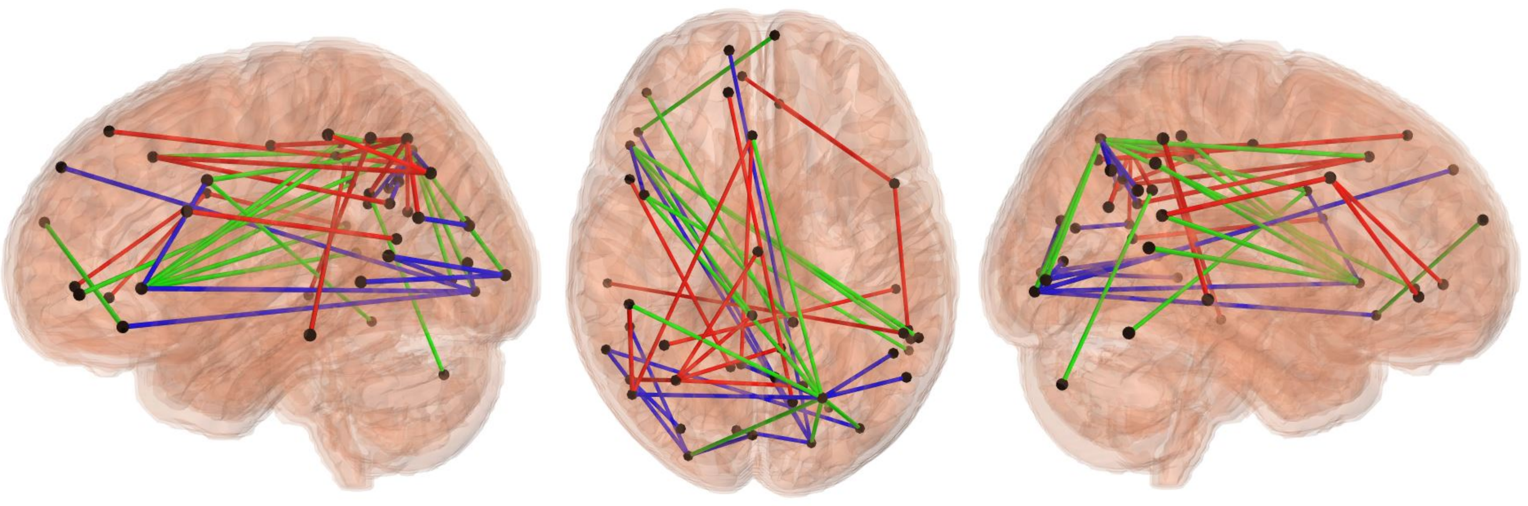
Results

- Using the correlations between all 264 nodes as features, **4-way** (Memory vs. Reasoning vs. Perception vs. Resting), **3-way** (Memory vs. Reasoning vs. Perception), and **2-way** (Memory vs. Reasoning) classifications all achieved ***100% accuracy***.

Classifier Importance Map

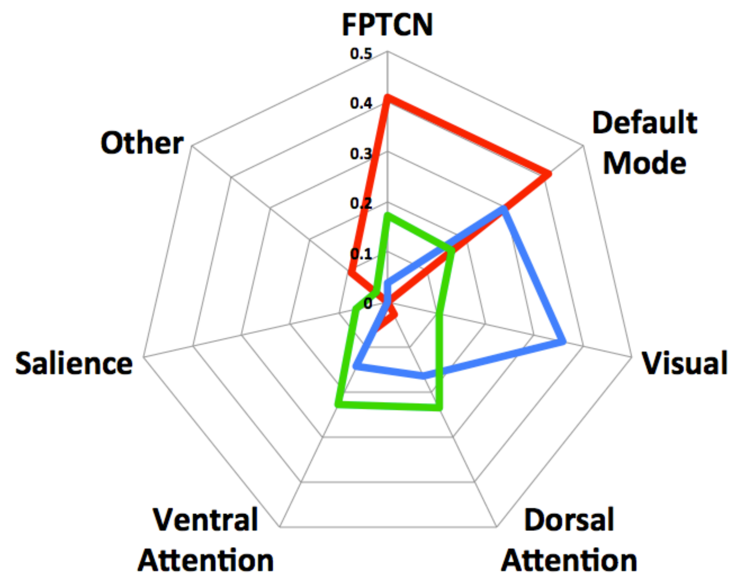
Top 15 edges for 264-node set

Memory vs. **Reasoning** vs. **Perception**



- These renderings illustrate that the functional connections of many prefrontal nodes were informative to our classifier. However, edges between posterior regions also carried substantial predictive value.

Functional network membership status of most informative edges

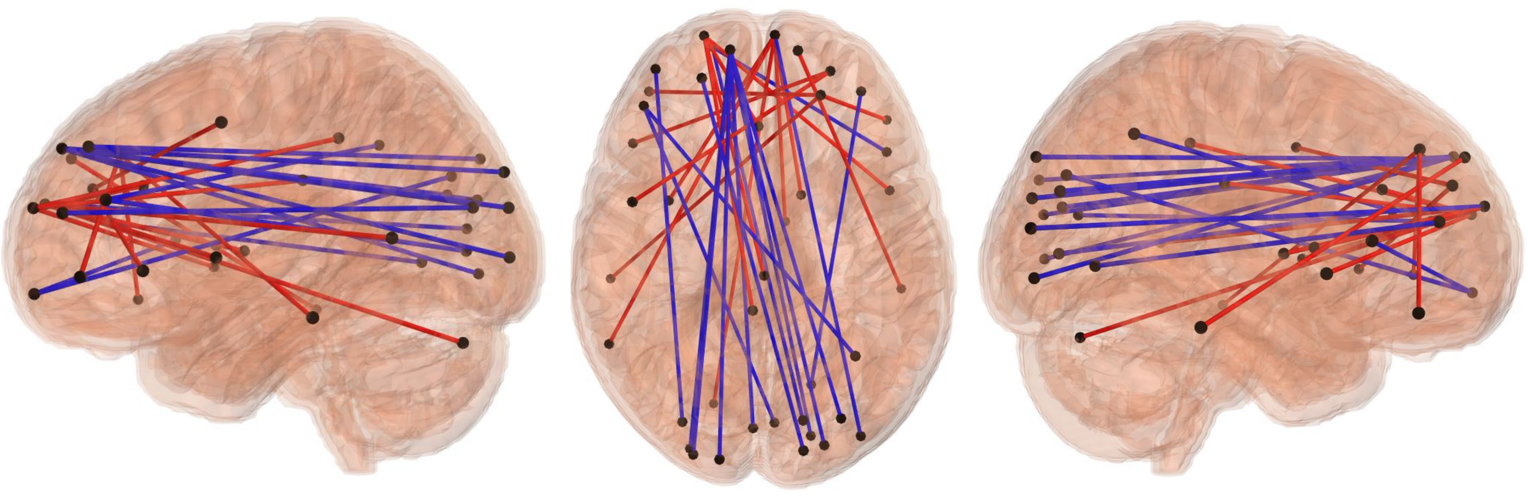


The connectivity "fingerprint" of the **Memory** task predominately involved connections with FPTCN and Default Mode Network nodes, whereas decoding of **Reasoning** and **Perception** involved nodes in a more diverse set of networks.

Classifier Importance Map

Top 15 edges for RPFC to 264-node set

Memory vs. **Reasoning**



- Classification restricted to RPFC connections also achieved 100% accuracy. Edges from medial RPFC to visual regions for Reasoning and to midline Default Mode Network structures for Memory were particularly diagnostic for distinguishing between tasks.

Summary and Conclusions

- Using a classifier trained on functional connectivity patterns measured in the brains of other subjects, we can predict with 100% accuracy whether an individual subject is performing an episodic memory retrieval task, an analogical reasoning task, a visuospatial perception task, or just resting in the scanner.
- Since our cognitive tasks were matched for their stimulus presentation and response characteristics, our classifier must capitalize on functional connectivity differences linked to the particular mental operations being performed on the stimuli.
- We found that classification of the Memory task was particularly dependent on connections involving FPTCN and default mode network nodes, while classification of the other tasks received contributions from a more diverse set of networks.
- Rostral PFC nodes strongly contributed to task-set decoding. Constraining our analysis to edges between RPFC and posterior nodes yielded robust memory vs. reasoning decoding.

References

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