An fMRI investigation of functional network connectivity during abstract reasoning

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Background

The Raven's Progressive Matrices (RPM) task is widely used by psychologists as a test of non-verbal abstract reasoning ability[1,2].

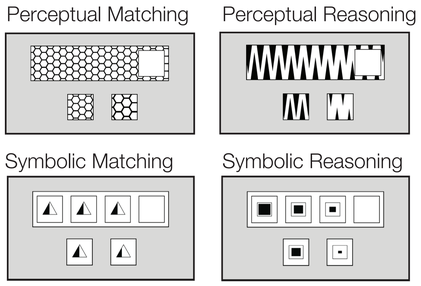
We designed a simplified RPM paradigm to study functional connectivity during two types of abstract reasoning: symbolic reasoning and perceptual reasoning.

Research Goals:

1. Use univariate functional connectivity methods to examine networks critical for symbolic and perceptual reasoning.
2. Determine task specific community structure of functional brain networks supporting reasoning.

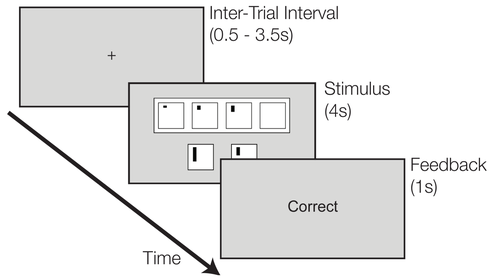
One-Dimensional Raven's Progressive Matrices Task

Conditions



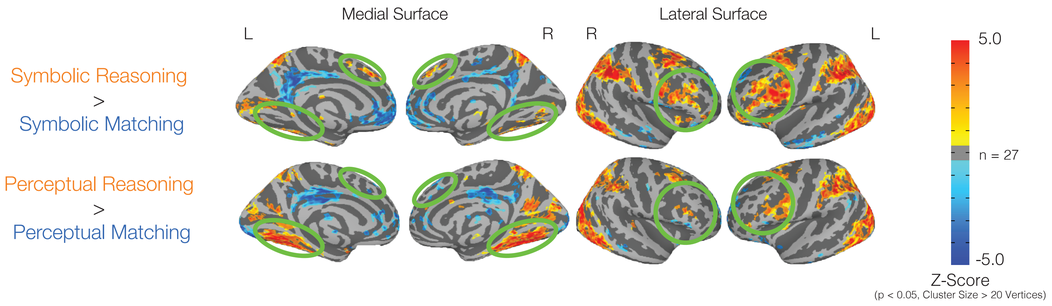
Participants were presented with a pattern at the top of the screen and asked to decide which of two answer choices best fit into the blank white square. Stimuli consisted of either continuous textures or discrete symbols. In the reasoning conditions, stimuli progressed from the left to the right side of the pattern according to a rule. In the matching conditions, stimuli were uniform throughout the pattern.

Trial Structure



During a single trial, participants first viewed a fixation cross (0.5 – 3.5s jitter). Next they viewed the problem and selected an answer choice with a button box (4s). Finally, they were presented with feedback ("Correct," "Wrong," or "No Response") (1s). Participants completed 384 trials over the course of a 1-hour fMRI scanning session.

Results: Univariate Activity Maps



Shaded regions showed significantly greater BOLD signal for the reasoning conditions (warm colors) compared to the matching conditions (cool colors). The reasoning > matching contrast is shown for the symbolic conditions in the top row and for the perceptual conditions in the bottom row. Large portions of the frontoparietal control network were activated in both contrasts. Green circles highlight regions that were activated in either, but not both, symbolic or perceptual conditions. Activation maps are thresholded for significance ($p < 0.05$) and cluster size (> 20 vertices).

Key Result: Anterior prefrontal cortex is activated during symbolic reasoning. Inferior temporal cortex is activated during perceptual reasoning.

1. Raven, JC. British Journal of Medical Psychology. (1941)
2. Raven, J. Cognitive Psychology. (2000)
3. Kent, JD. & Herholz, P. JOSS. (2019) (NiBetaSeries)
4. Power, et al. Neuron. (2011)
5. Hearne, et al. J. Neurosci. (2017)
6. D. Edler, A. Eriksson and M. Rosvall. (2010) (mapequation.org)
7. Xia M, Wang J, & He Y PLoS ONE. (2013) (BrainNetViewer)
8. Rubinov M. & Sporns O. NeuroImage. (2010) (Brain Connectivity Toolbox)

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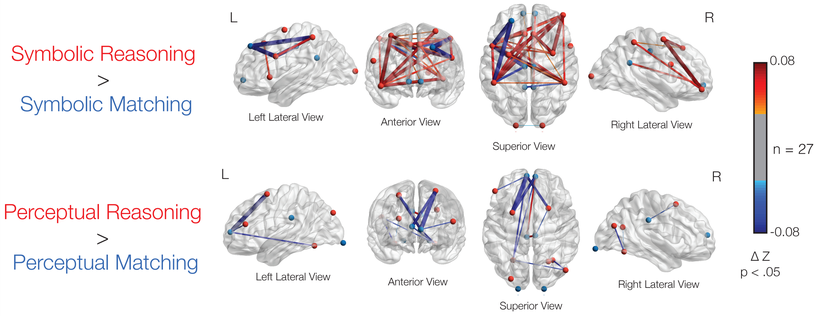
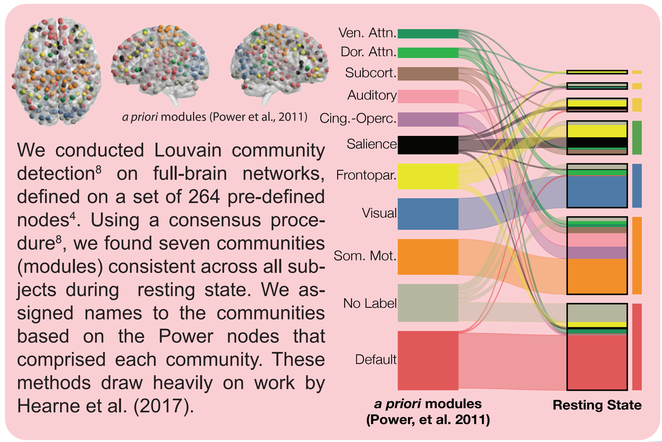
Results: Functional Connectivity Between Task Positive and Task Negative Nodes



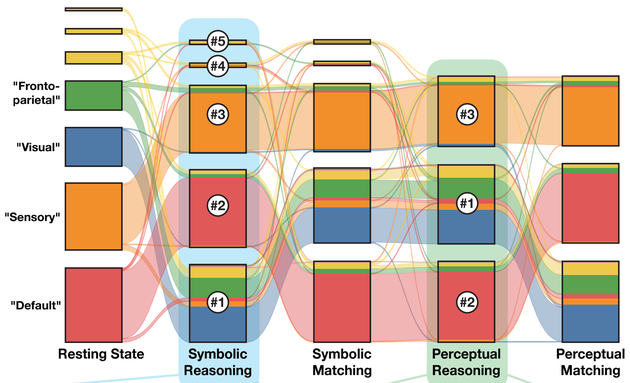
Beta series regression was employed to calculate pairwise functional connectivity differences across task conditions[3]. Nodes represent spherical seeds (radius = 4mm) placed at locations of activation maxima (red) and minima (blue) derived from the univariate activity maps. Edges represent Z-transformed correlation difference between task conditions. A thicker edge indicates a larger correlation difference between conditions. Maps were made in BrainNetViewer[7].

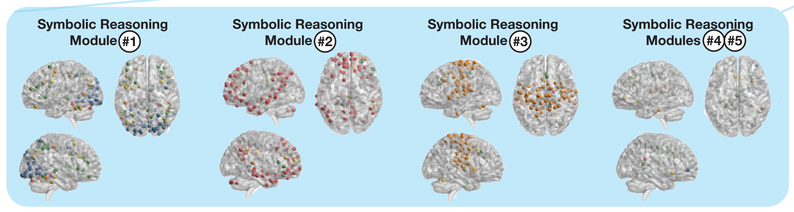
Key Result: Functional connectivity between anterior prefrontal cortex and the frontoparietal control network increases during symbolic reasoning.

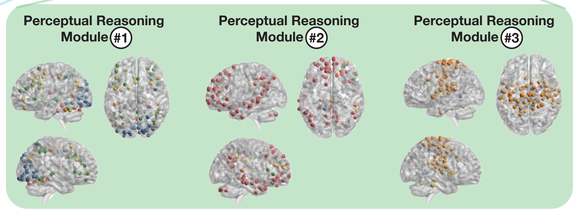
Results: Functional Network Reconfigurations During Reasoning



We conducted Louvain community detection[5] on full-brain networks, defined on a set of 264 pre-defined nodes[4]. Using a consensus procedure[8], we found seven communities (modules) consistent across all subjects during resting state. We assigned names to the communities based on the Power nodes that comprised each community. These methods draw heavily on work by Hearne et al. (2017).







Using a Louvain community-detection and consensus procedure (analysis methods follow those reported by Hearne et al., 2017), we defined communities (modules) for each of the four task conditions and during resting state. An alluvial flow plot[6] (top right) was constructed to follow the community membership of each node across task conditions. Below the flow plot, we show the nodes that comprise each community during the symbolic reasoning and perceptual reasoning conditions mapped onto the brain.

Key Results: During the reasoning task, nodes "team-up" to form a task-specific community structure. While seven communities are observed at rest, five communities are formed during symbolic conditions, and only three are formed during the perceptual conditions. The three perceptual communities are largely preserved during symbolic conditions, suggesting that nodes in communities 4 and 5 may form a specialized module for symbolic processing.

Summary & Conclusions

1. Increased functional connectivity between anterior prefrontal cortex and the frontoparietal control network supports symbolic processing during an abstract reasoning task.

2. In general, reconfiguration of the brain's functional community structure supports visuospatial processing. Nodes in lateral parietal and anterior prefrontal cortices may form a specialized module during symbolic conditions of the task.

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