# Task demand alters cortical network states ensuing integration and modularization

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## INTRODUCTION

In graph theory network analysis of the brain, regions are denoted as nodes while connections between these regions are identified as edges [5,6]. Node activation is dependent on the external environment a person is subject to, resulting in conformational changes in the network. These changes can be task and state dependent, though they are largely individualistic [2,4]. An integrated network is such that there are predominant connections between nodes across multiple regions regardless of specialization. Conversely, a modular network is one where there are predominant nodal connections within specialized regions e.g. limbic. Shine [3] hypothesizes the brain is akin to an attractor landscape, where wells indicate stores of energy. In this domain a modular network indicates stores of energy within specialized regions while an integrated network has shallow wells with distributed energy stores. In this context the cerebellum would drive network change to a modular pattern, while the basal ganglia integration, through thalamic connections [3]. Integration is said to aid in accomplishing harder tasks while modularization easier [5,6].

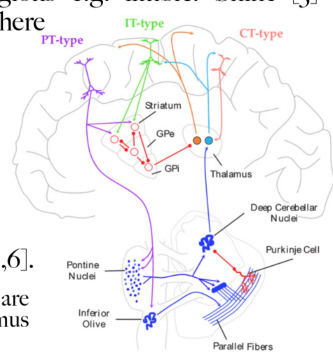


Figure 1. Subcortical regions basal ganglia and cerebellum are connected to cortex through gating of the matrix and core thalamus respectively. Image taken from Shine (2021).

## METHODS

### Color-word Stroop Task

Incongruent (hard) trials:

Congruent (easy) trials:

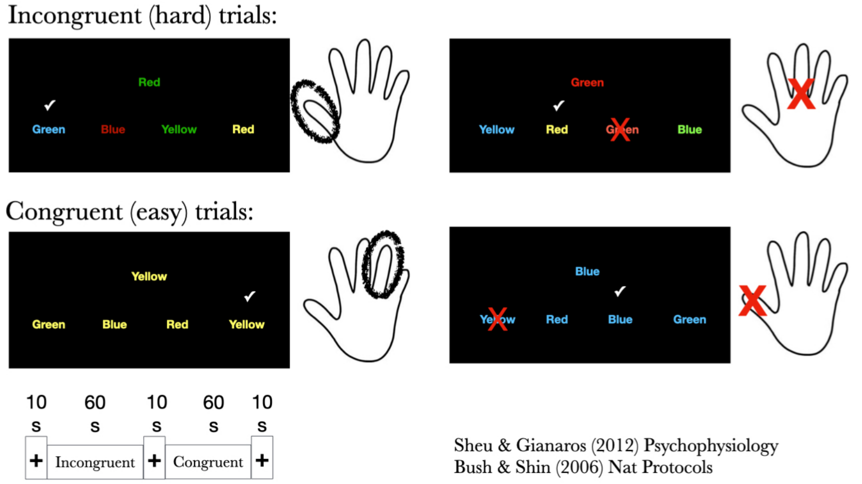


Figure 2. An adaptive Stroop task - to prevent habituation - was performed by participants during functional Magnetic Resonance Imaging (fMRI). Alternating task blocks (60s) were interleaved with crosshair fixation (10s) [8]. Image taken from Rasero et al. (2021).

Edge time series [1]:

$$Let\ c_{ij} = [z_i(1) \cdot z_j(1), \ldots, z_i(T) \cdot z_j(T)]$$

Eigenvector centrality [7]:

$$x_i = K_1^{-1} \sum_j A_{ij} x_j$$

Modularity index [9]:

$$B = A - P$$

$$Q^{signed} = \sum_{ij} \left[B_{ij}^{+} - B_{ij}^{-}\right] \delta\left(\sigma_i, \sigma_j\right)$$

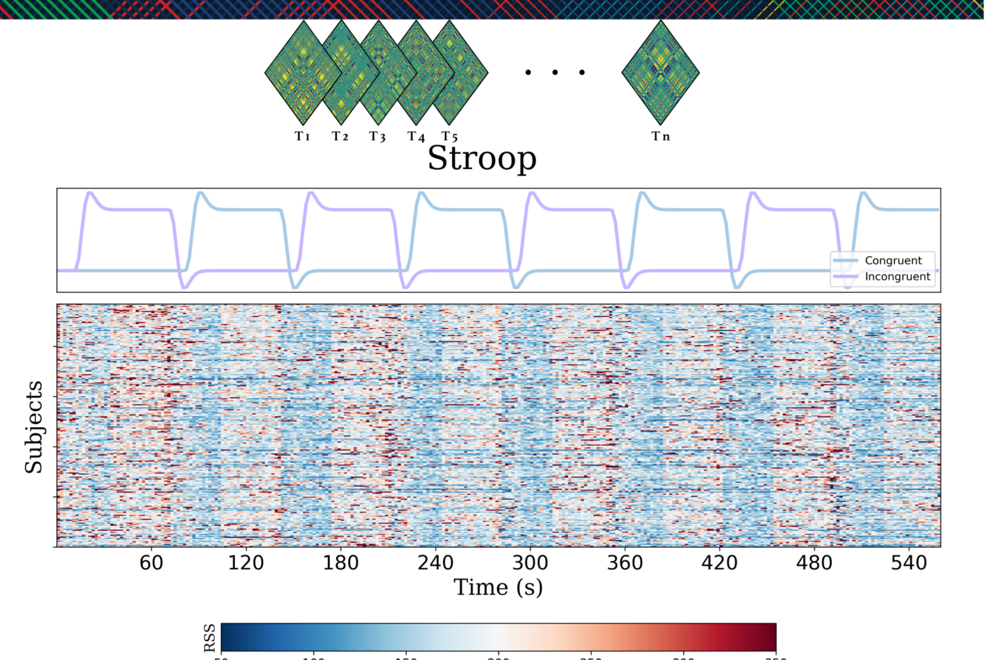


Figure 3. Stacked heat map of subjects (n=242) showing residual sum or squares (RSS) across the fMRI timescale (axis 2), with task paradigm (axis 1). Higher RSS indicates greater integration of networks, while lower RSS indicates less integration (modularization). Image adapted from Rasero et al. (2021).

- A total of 242 subjects performed an adaptive Stroop task while being scanned for fMRI (female=119, male=123; mean age=40 ± 6; min age=30, max age=51).
- The scanner used was a 3 Tesla Trio with 12-channel head coil. fMRI obtained was T2*weighted with 3mm isotropic resolution (TR=2s, ET=28ms, Flip=90°).
- For data analysis we used the Shen atlas for region segmentation and performed edge time series analysis [1]. Modularity index [9] was obtained for cortical regions and eigenvector centrality [7] for basal ganglia and cerebellum (cortical connected nodes only).

## RESULTS

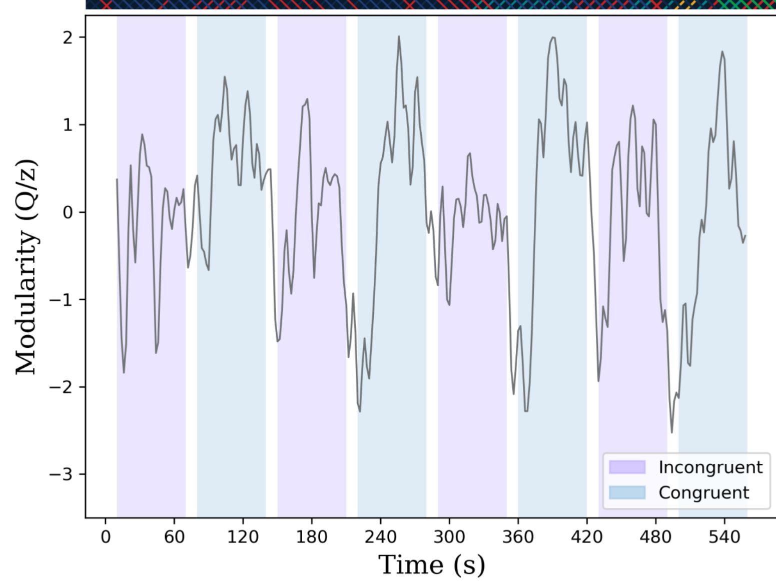


Figure 4. (left) Gaussian smoothed z-scored cortical modularity index, averaged across subjects. There is increased modularity during congruent (easier) task blocks ($\beta$=0.128; 95% CI=0.081, 0.175), compared to incongruent (harder) task blocks ($\beta$=0.072; 95% CI=0.028, 0.116).

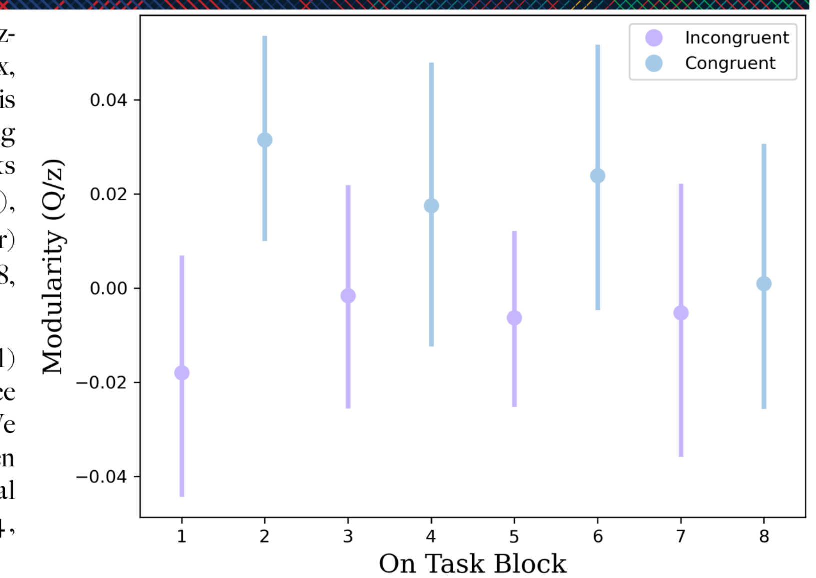


Figure 5. (right) Mean (ball) modularity index with confidence interval (stick) across trial blocks. We found a significant difference between incongruent and congruent trial blocks (uncorrected p=0.014, std=-0.056, corrected p=0.028).

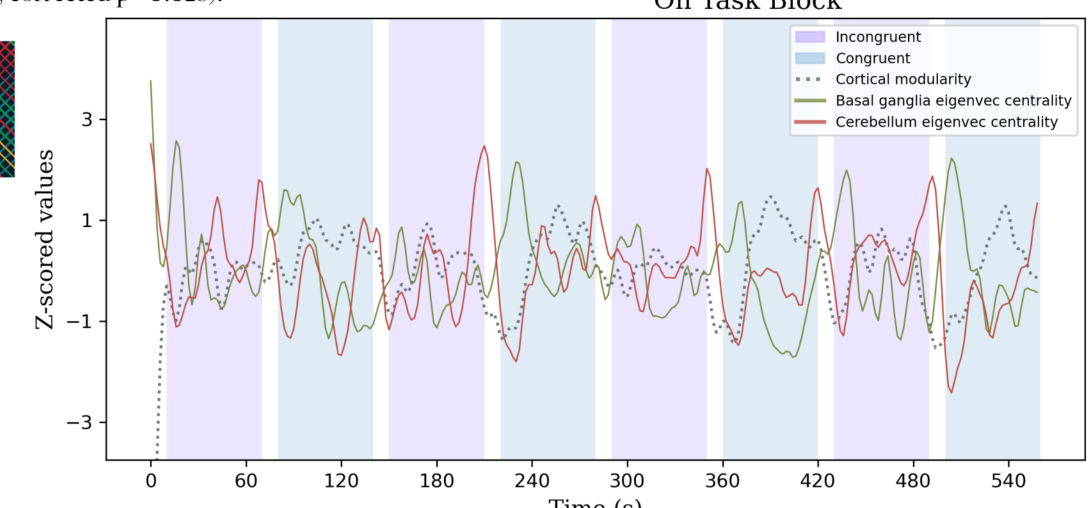


Figure 6. Gaussian smoothed z-scored basal ganglia (bg) and cerebellum (cb) eigenvector centrality values, averaged across subjects. The bg and cb exhibit an anti-correlated pattern across the timescale with bg exhibiting more influence in the beginning of a task while cb at the end.

## CONCLUSION

We examined the influence of basal ganglia (bg) and cerebellum (cb) on cortical gating activity during easier and harder tasks. We determined the bg is more influential to the network in the beginning of a task while the cb at the end. These preliminary results may indicate the Shine [3] model is more complex than bg driving integration and cb modularization.

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