Phasic recruitment of basal ganglia and cerebellum in shifts of cortical modularity

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INTRODUCTION

A graphical analysis of the brain, denotes regions as nodes while connections between regions as edges [6,7]. Node activation is dependent on the external environment, resulting in conformational changes: can be task and state dependent, though are largely individualistic [2,6]. An integrated network is such that there are connections between nodes across multiple regions. A modular network predominantly has nodal connections within specialized regions e.g. limbic. Shine [4] hypothesizes the brain is akin to

Hypotheses:

1. Congruent (easier) task blocks will have higher cortical modularity than incongruent (harder).
2. The Bg will have greater influence during the incongruent task blocks, alternately the Cb in the congruent.

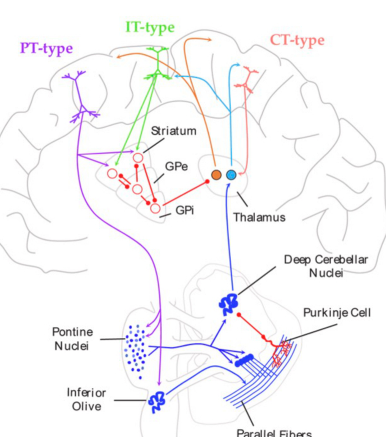


Figure 1. Subcortical regions basal ganglia and cerebellum are connected to cortex through gating of the matrix and core thalamus respectively. Image taken from Shine (2021).

METHODS

Color-word Stroop Task

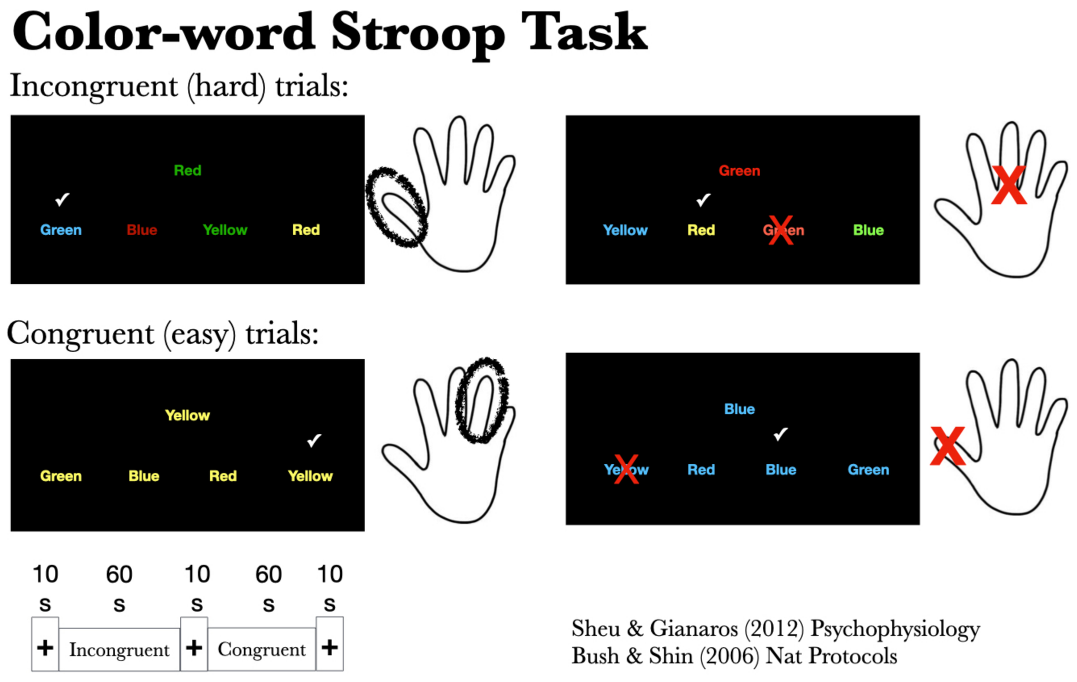
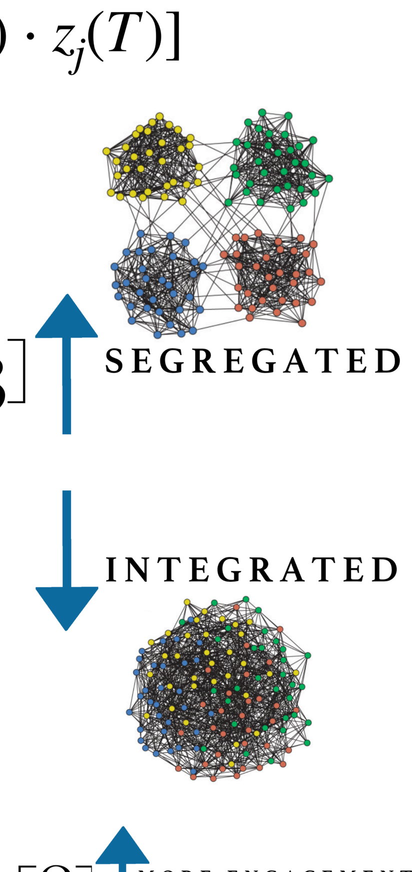


Figure 2. An adaptive Stroop task - to prevent habituation - was performed by participants during functional Magnetic Resonance Imaging (fMRI). Alternating task blocks (60s) were interleaved with crosshair fixation (10s) [9]. Image taken from Rasero et al. (2021).

Edge time series [1]:

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

Modularity index [10,3]



$$B = A - P$$

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

Eigenvector centrality [8]

MORE ENGAGEMENT

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

LESS ENGAGEMENT

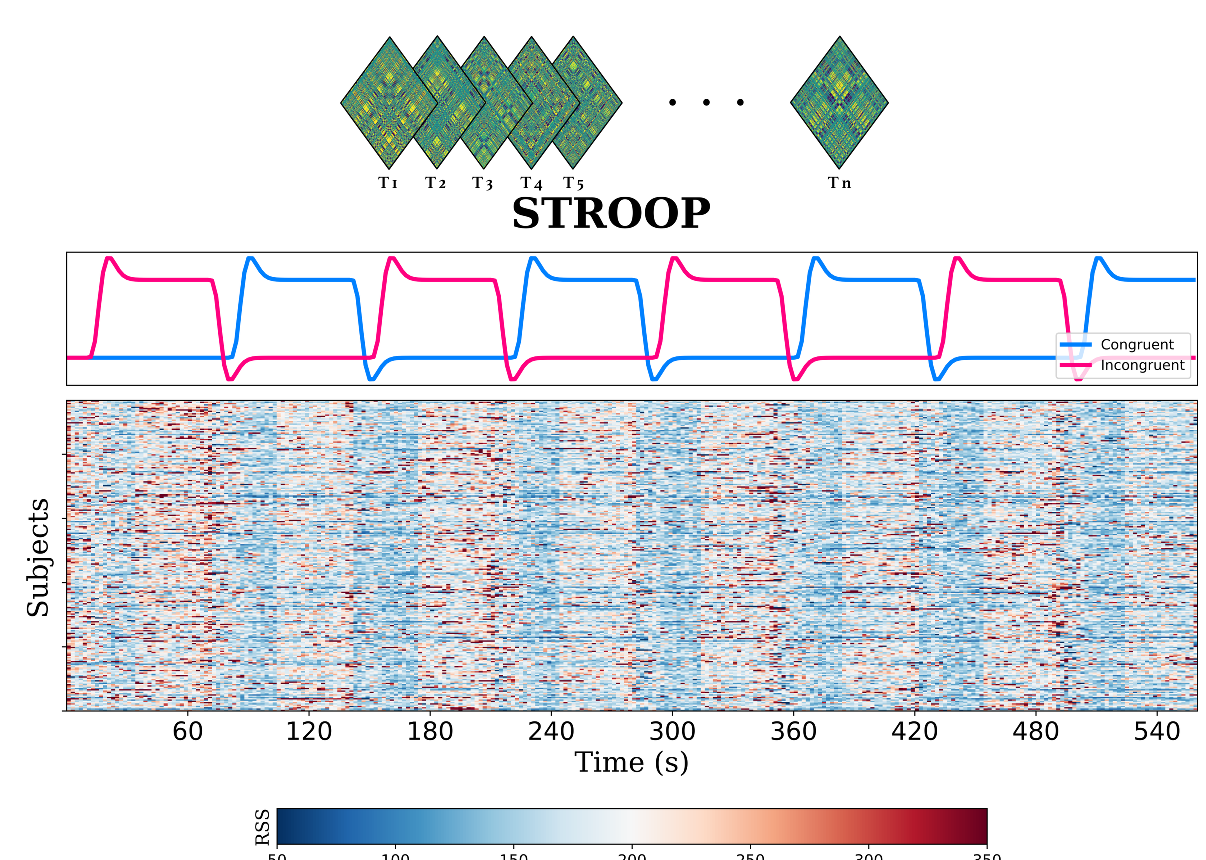


Figure 3. Stacked heat map of subjects (n=242) showing residual sum or squares (RSS) across the fMRI timescale (axis 2), with task paradigm (axis 1). Higher RSS indicates greater integration of networks, while lower RSS indicates less integration (modularization). Image adapted from Rasero et al. (2021).

- 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 [10] was obtained for cortical regions and eigenvector centrality [8] for basal ganglia and cerebellum (cortical connected nodes only).

RESULTS

Figure 4. Gaussian smoothed z-scored basal ganglia (Bg) and cerebellum (Cb) eigenvector centrality values, averaged across subjects and task blocks. The Bg was more engaged in the beginning of the task and declined towards the end. The Cb peaked in engagement at the end of the task, decreased over the fixation and was lowest at the beginning of the subsequent task block.

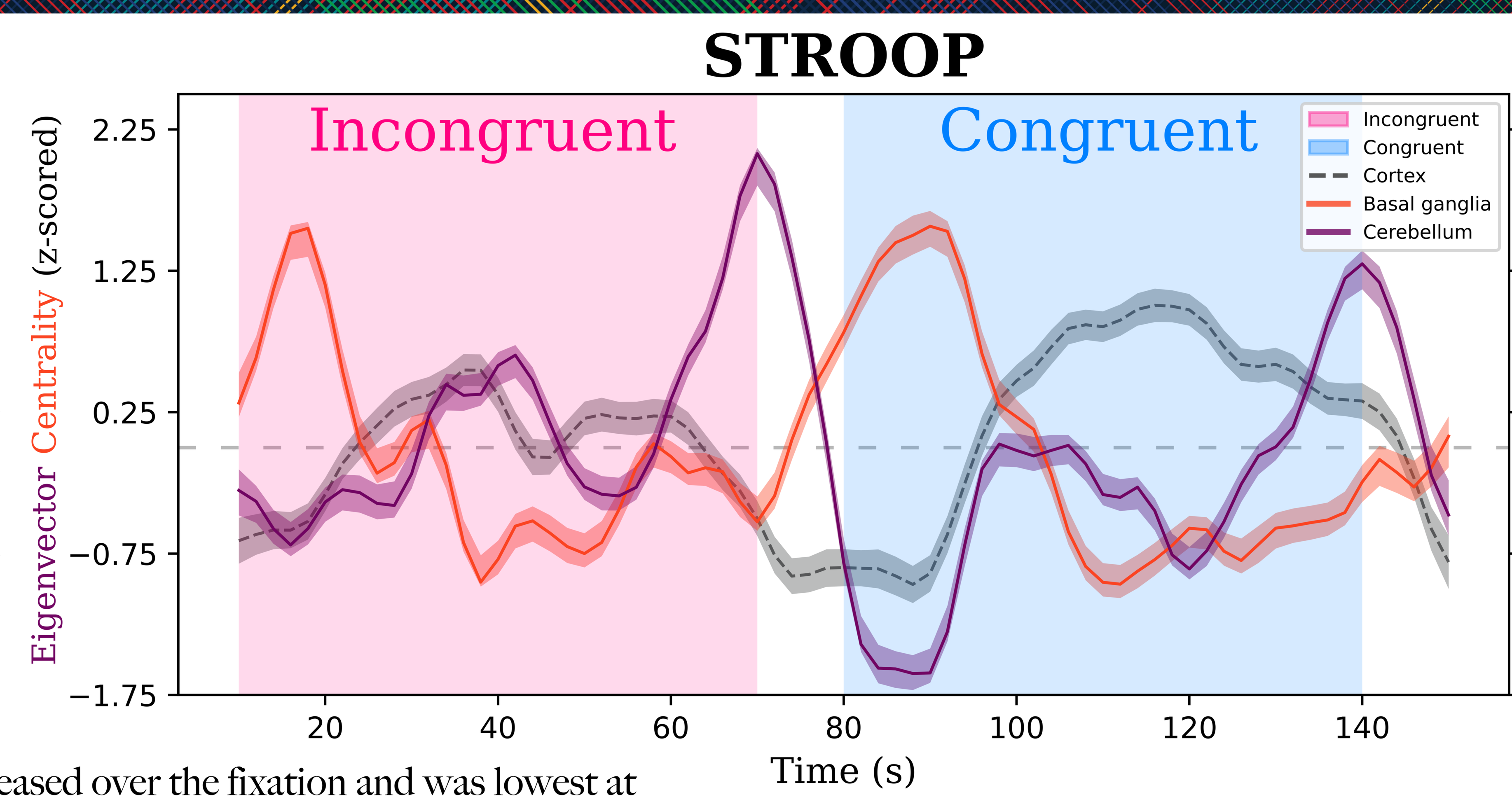
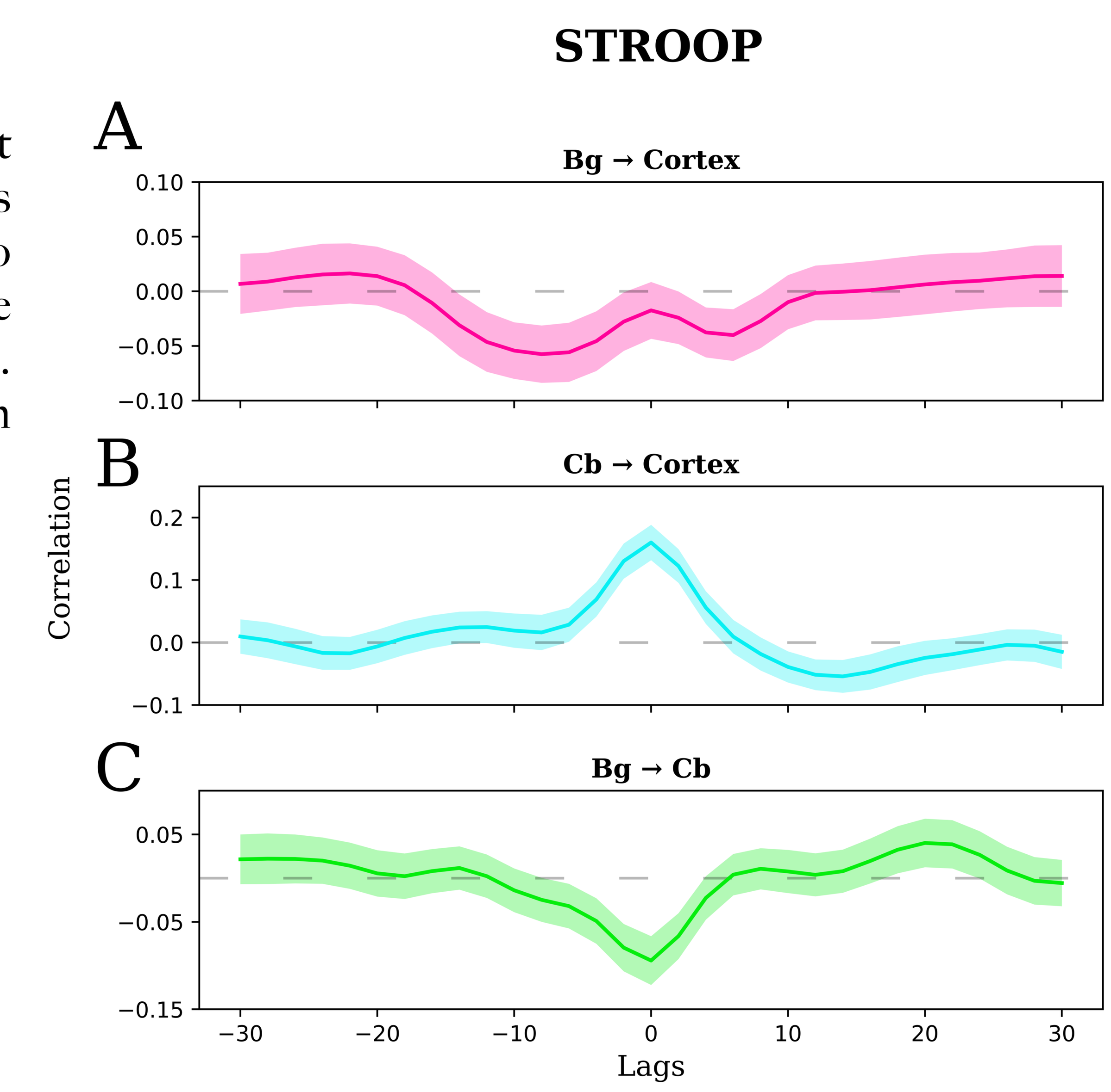


Figure 5. Pair-wise cross correlation of our regions of interest with forward and backward lags, indicated the basal ganglia has a controlling influence on the cortex. Conversely, there was no controlling influence of the cerebellum on the cortex, but the inverse with the cortex exhibiting a control on the cerebellum. The subcortical regions exhibited no controlling influence on each other.



CONCLUSION

1. We obtained patterns of modularity in the cortex consistent with prior studies i.e. more integration in harder portions of the task (incongruent) [5,6].
2. The Bg and Cb have opposite phase engagement during trials, with the Bg beginning a control mechanism for the cortex. The Shine [4] model may be more complex than initially hypothesized.

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