Global and Regional Shifts in Module Properties with Increasing Working Memory Load

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Introduction

- Working memory (WM) load refers to the quantity of information that must be held "on line" in order to effectively engage in certain tasks.
- While univariate and bivariate analyses of neuroimaging data have produced important insights into working memory processes, it is likely that the neural components of working memory are instantiated in a complex, interdependent manner.
- Complex network analysis using graph theory allows for the investigation of working memory processes by approaching the study of the brain as an interdependent network with various interacting components that produce complex behaviors.

Purpose: To investigate whole-brain and regional changes in default mode (DM) and WM circuits in both modularity and modular hub properties of functional brain networks as the demands on working memory increase from n = 1 to n = 2 on the standard n-back task.

Method

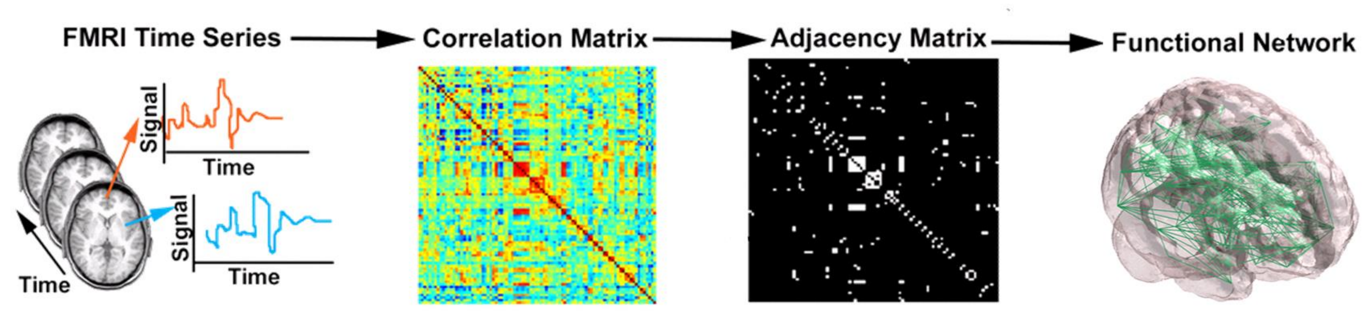


Figure 1. Overview of Network Construction

- fMRI data from 14 young adults collected over separate blocks of 1-back and 2-back.
- Time course of BOLD signal for each gray matter voxel extracted for each block of n-back to generate voxel-wise functional brain networks.
- Correlation matrix constructed from correlations between all voxels.
- Thresholding to remove weak correlations for generation of adjacency matrix.
- Adjacency matrix represented as a graph in standardized brain space.

Results

Modularity

Modularity analysis identifies sets of nodes that are more interconnected with each other than with the rest of the network, defined as:

$$Q = \sum_{i=1}^{K}\left[\frac{e_{ij}}{M} - \left(\frac{a_i}{M}\right)^2\right]$$

e_{ij} = within module connections in module i,
a_i= total degree of module i,
M = degree of the entire network.

Scaled inclusivity (SI)

SI then identifies the consistency of modular organization across all participant brain networks, defined as:

$$SI = \frac{|S_A \cap S_B|}{|S_A|}\frac{|S_A \cap S_B|}{|S_B|}$$

S_A and S_B denote sets of nodes in modules A and B, respectively.

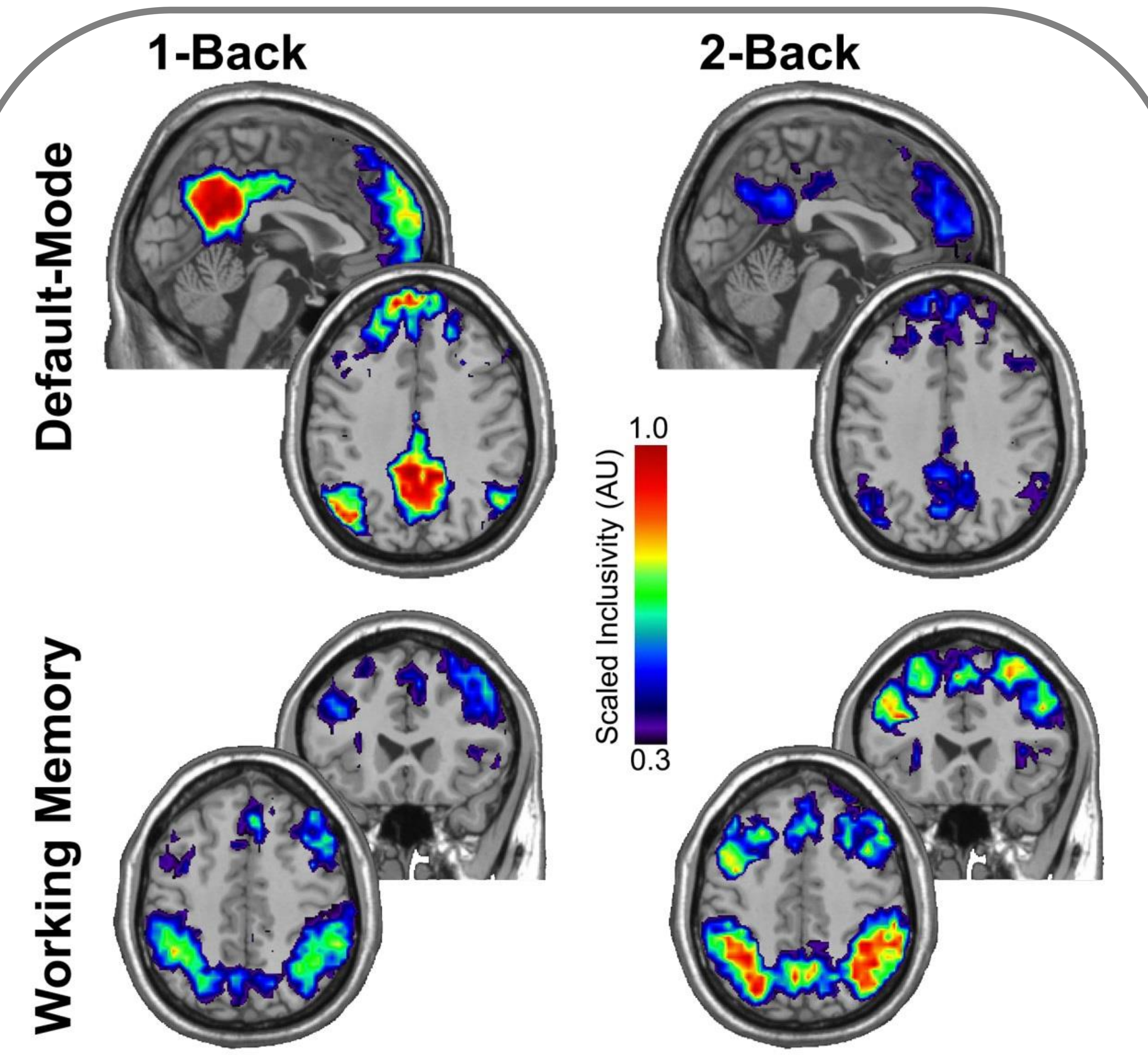


Figure 2. Consistency of modular structure during 1-back and 2-back.

- The modular structure within the DM circuit is highly consistent across participants during 1-back, but this consistency significantly diminishes during the more demanding 2-back task.
- The consistency of modular structure across participants exhibited the opposite pattern within the WM circuit showing significantly higher consistency in modular structure across participants during 2-back than 1-back.

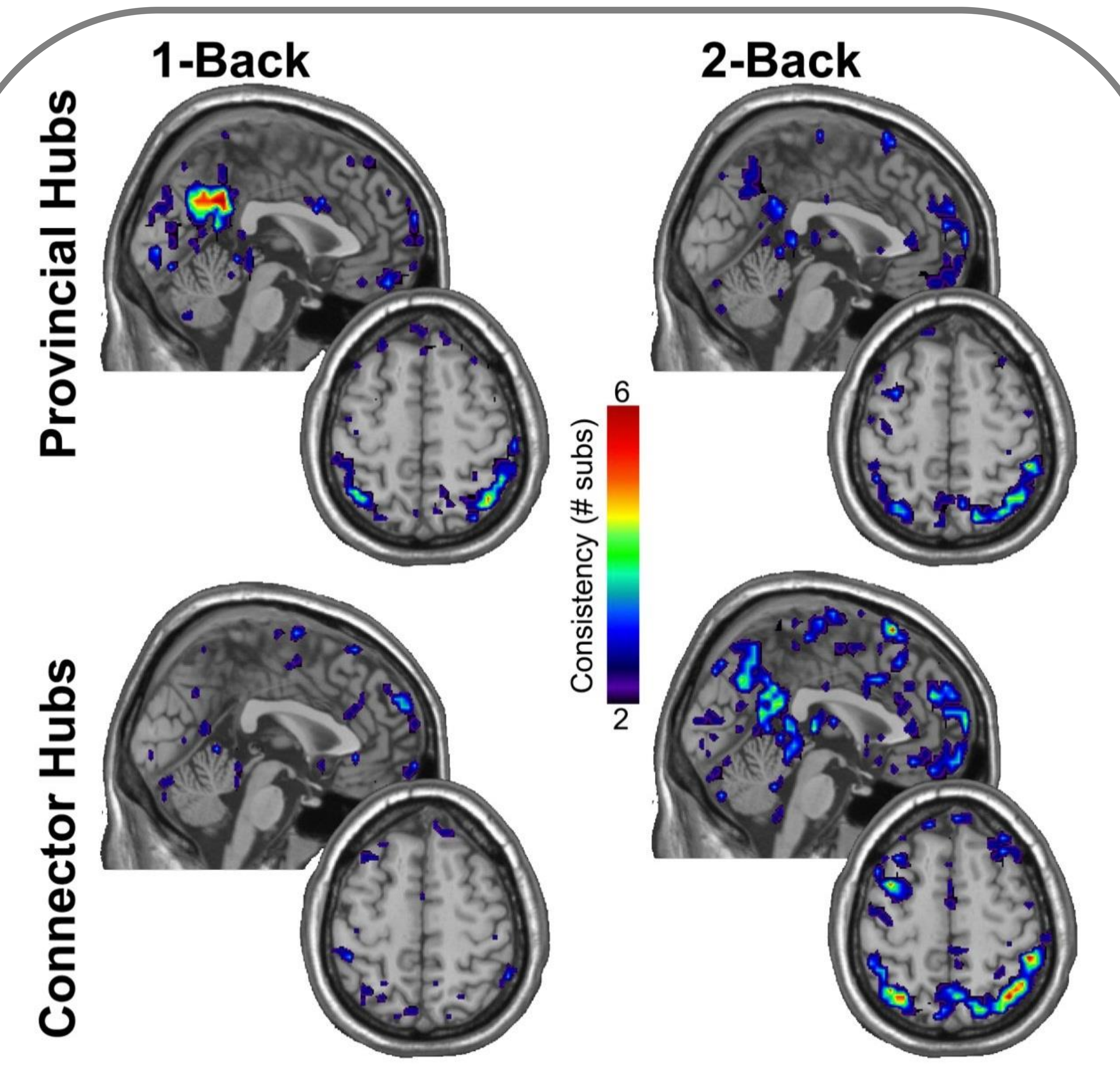
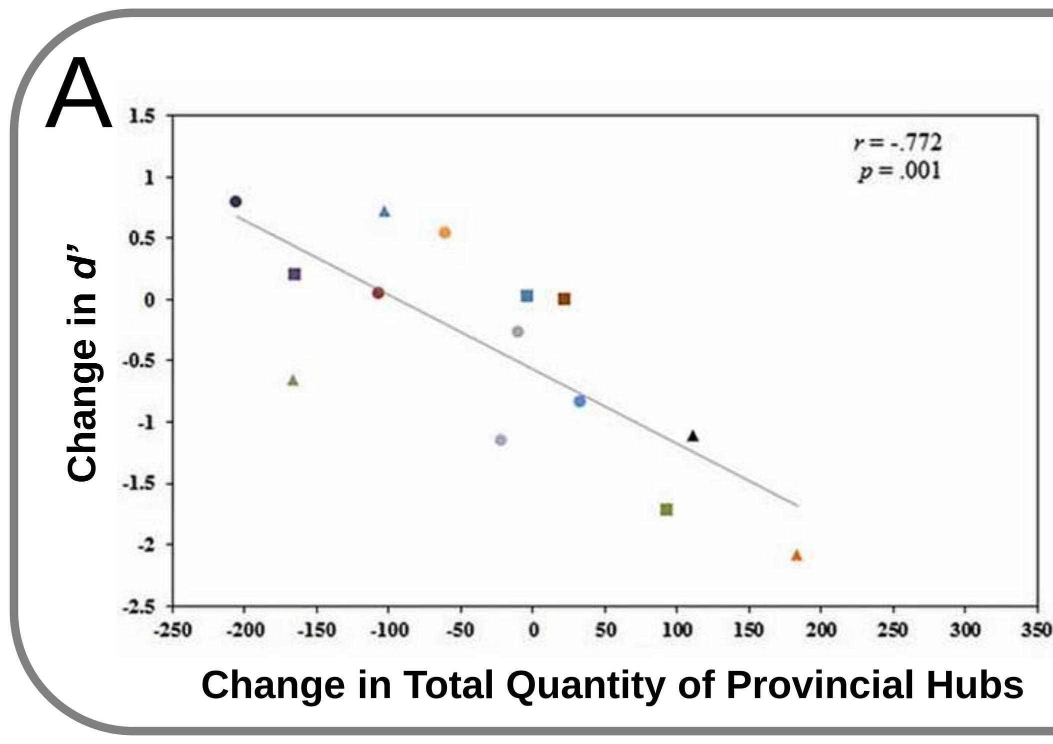
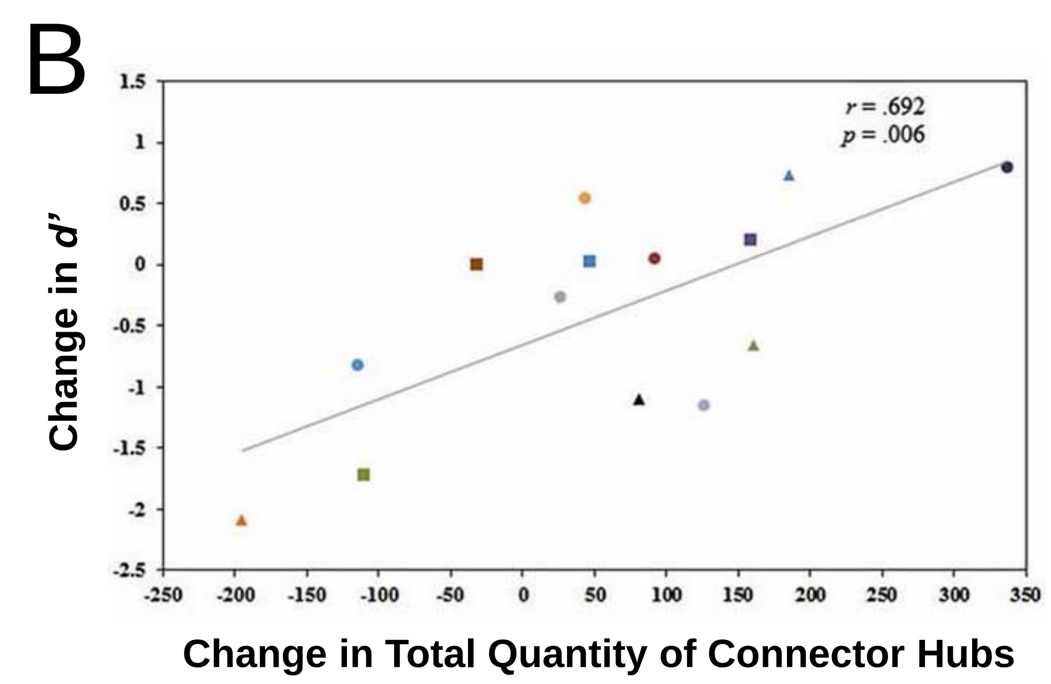


Figure 3. Functional cartography analysis identifying those network hubs that (1) are highly interconnected with immediate community and provide modular specificity (***provincial hubs***) or (2) interconnect different modules allowing for global integration of information (***connector hubs***).

- High consistency of provincial hubs within the ventral PC and PCC of DM circuit during 1-back, but no consistency during 2-back.
- Sizeable increase in both total quantity and spatial consistency of connector hubs within WM circuits with increased load.



(A) The change in the total quantity of provincial hubs in the entire brain network from 1-back to 2-back (quantity at 2-back minus quantity at 1-back) is significantly and negatively related to the change in WM performance from 1-back to 2-back (2-back d' minus 1-back d').



(B) The change in the total quantity of connector hubs in the entire brain network from 1-back to 2-back (quantity at 2-back minus quantity at 1-back) is significantly and positively related to the change in WM performance from 1-back to 2-back (2-back d' minus 1-back d').

Conclusions

- Using graph theory measures common to complex network analyses of neuroimaging data, we observed significant regional shifts in modular consistency, the quantity of provincial hubs, and the quantity of connector hubs within DM and WM circuits from 1-back to 2-back on the standard n-back task. No global shifts in modularity or modular hub properties were observed between load conditions.
- However, only the change in the quantity of provincial and connector hubs in the *entire* brain was correlated with behavioral performance on the n-back task. No regional shifts in modularity or modular hub properties were associated with behavioral performance.

Questions or Comments? Email Matthew Stanley: stanleymattl9@gmail.com