Individual Differences in Brain Networks during Pain Processing: New Methodology for Assessing Brain Modularity

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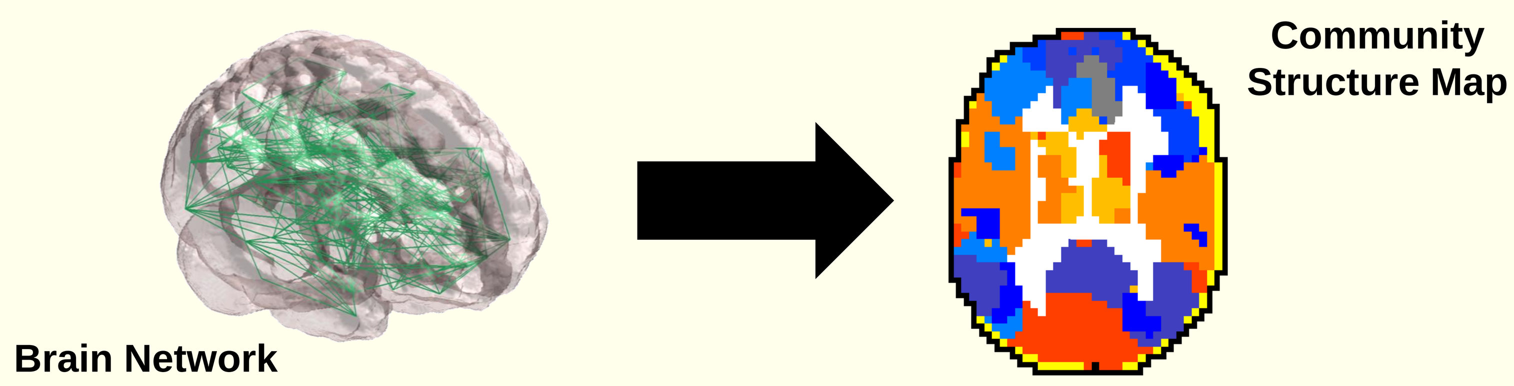
Introduction

Network science offers a unique opportunity to capture the complexity of human brain function by studying the interactions between different brain regions. One emerging aspect of network science research is modularity, which seeks to determine the community structure of complex networks. As modularity methods are constantly being improved, attempts have been made to compare the structure of different networks. However, most current methods are focused on evaluating a single consistent network at different time points where individual communities are clearly identifiable at multiple time steps. In brain networks, this is frequently not the case. The goal of this research is to develop a quantitative method for evaluating the consistency of community structure of complex networks with greater variability.

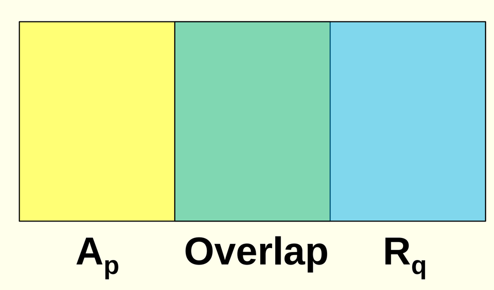
Methods: Scaled Inclusivity

1: Detect community structure of each brain network.



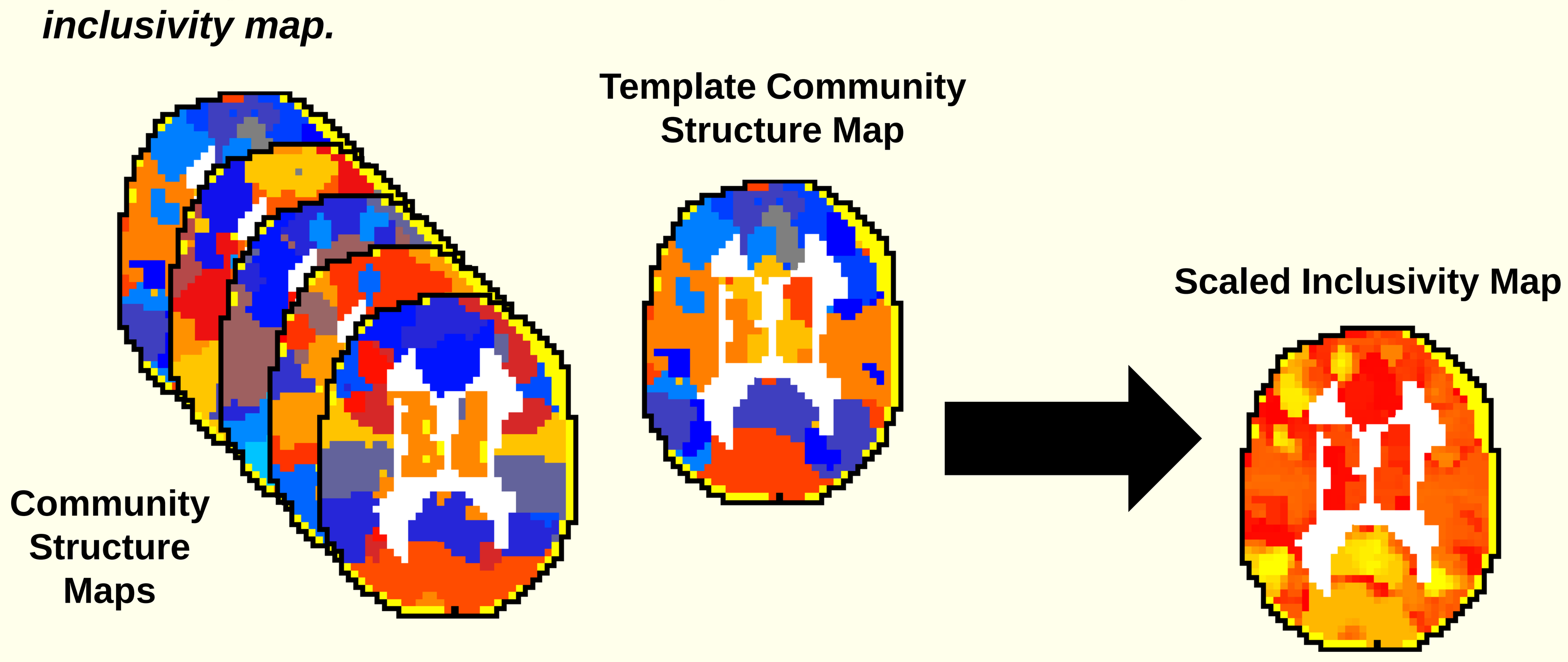
2: Compare each community in one community structure map to each community in the template (where A_p is one community in the current subject and R_q is one community in the template):

$$X_{iR}^{pq} = \frac{|A_p \cap R_q|}{|A_p|}\frac{|A_p \cap R_q|}{|R_q|}$$

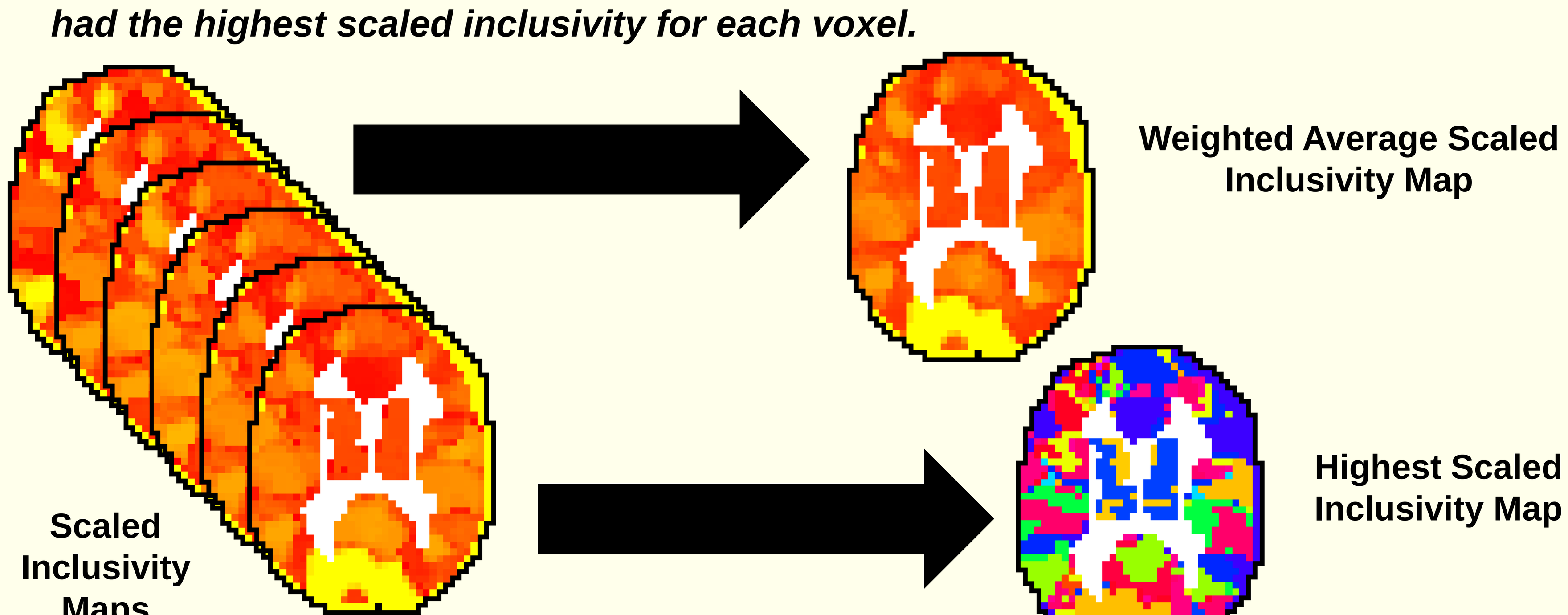


- Values range from 1 (for communities that perfectly overlap) to 0 (for communities that do not overlap at all.
- These values are assigned to all nodes in the overlap. The opposite of these values may be assigned to the nodes included in A_p that are not in the overlap.

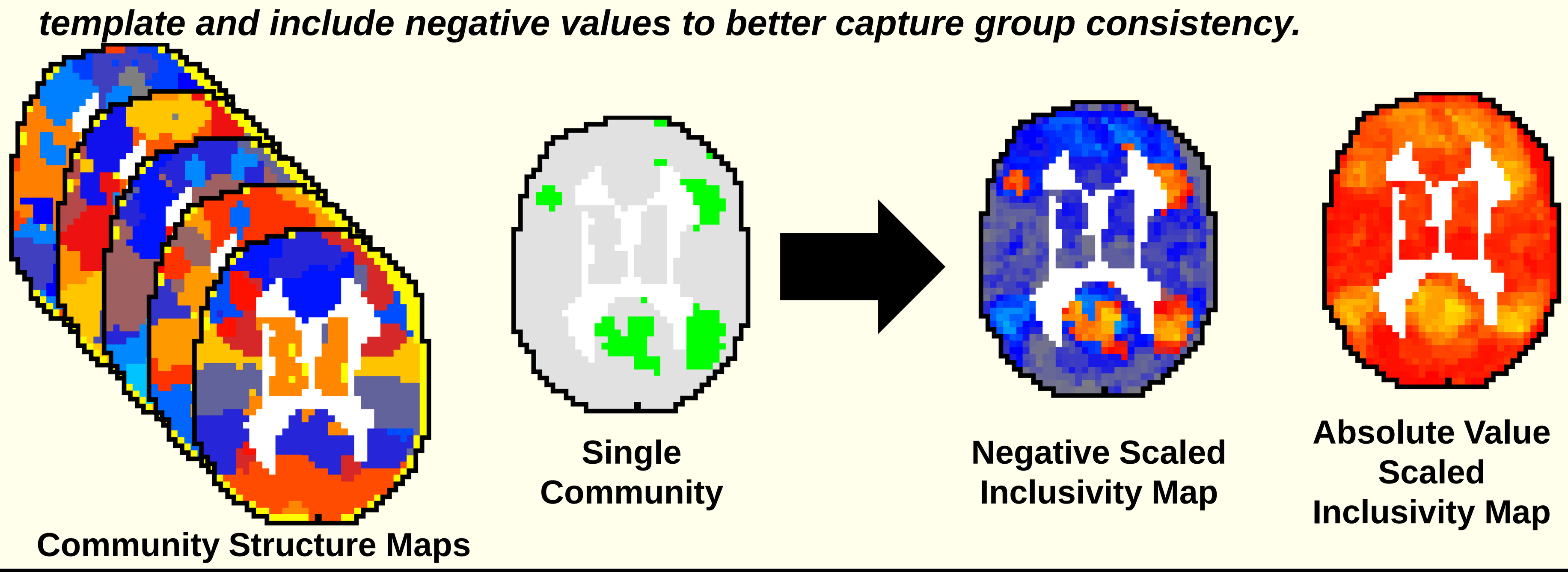
3: Compare each community in each community structure map with each community in the template separately and sum the results to yield a scaled inclusivity map.



4: Create scaled inclusivity maps with each map as the template. Use these maps to create a weighted average of scaled inclusivity and a map showing which subject had the highest scaled inclusivity for each voxel.



5: Find a region of interest in the highest scaled inclusivity map. The subject with the highest values in that region is the most representative of the group there, so compare all community structure maps with each individual community from the template and include negative values to better capture group consistency.



Methods: Study Design

Participants: 4 healthy normal young adults

Methods: Functional MRI data was collected from each subject over three or four days. In each series, a noxious stimulus consisting of a thermal probe was applied to the leg in block design, alternating between 35C (neutral) and 49C (noxious). At least 20 series were collected for each subject. Voxel-based whole-brain functional networks were generated for each time series. The community structure was evaluated using the QCut algorithm.

Results

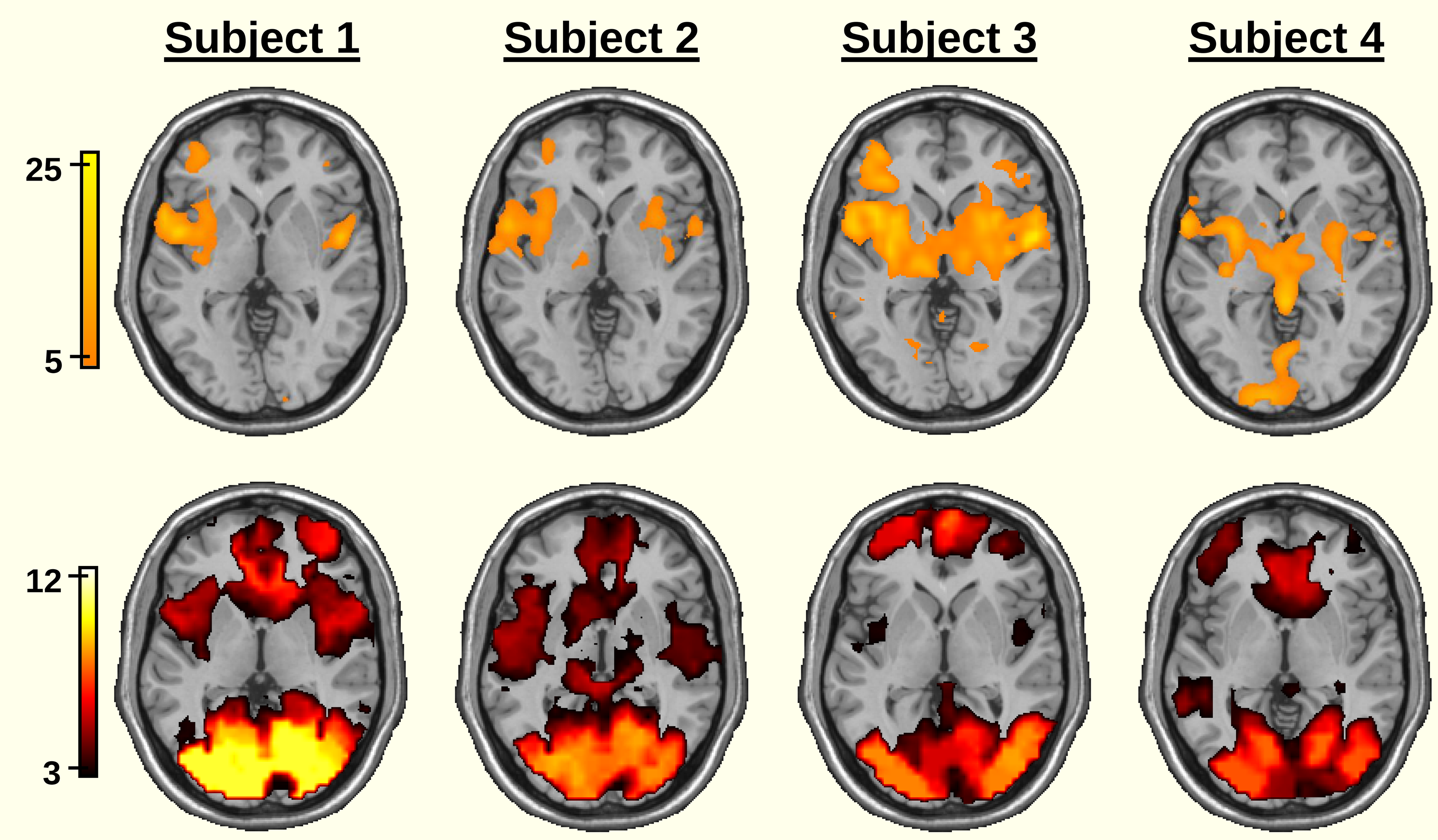


Figure 1

Preliminary results suggest that in some cases, consistency of activation and consistency of community structure are inversely related.

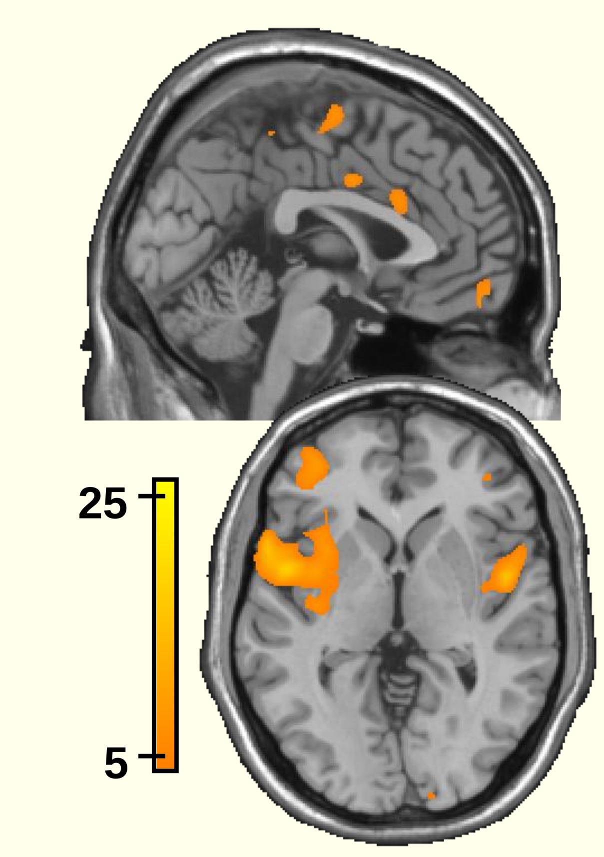


Figure 2

Subject 1 had no significant activation in the visual cortex, but the community structure in that region was highly consistent. Subjects were instructed to keep their eyes closed during all scans.

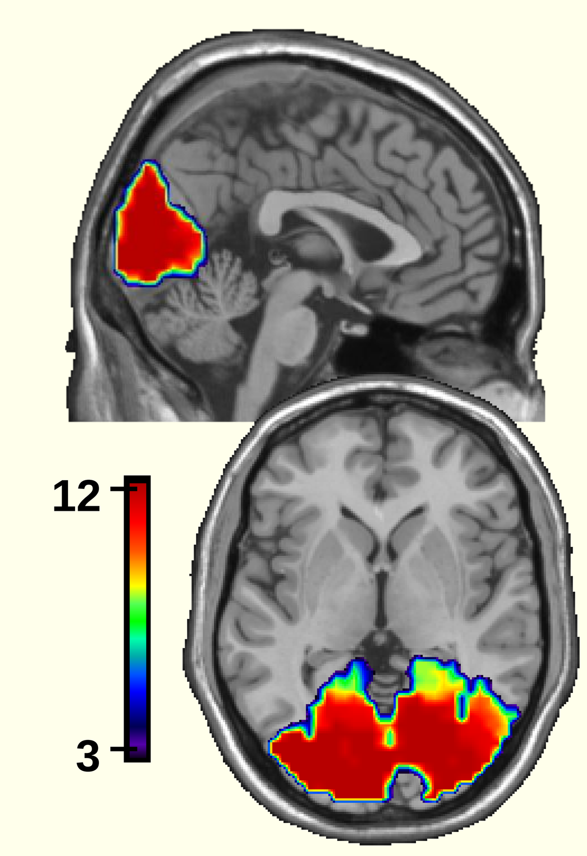
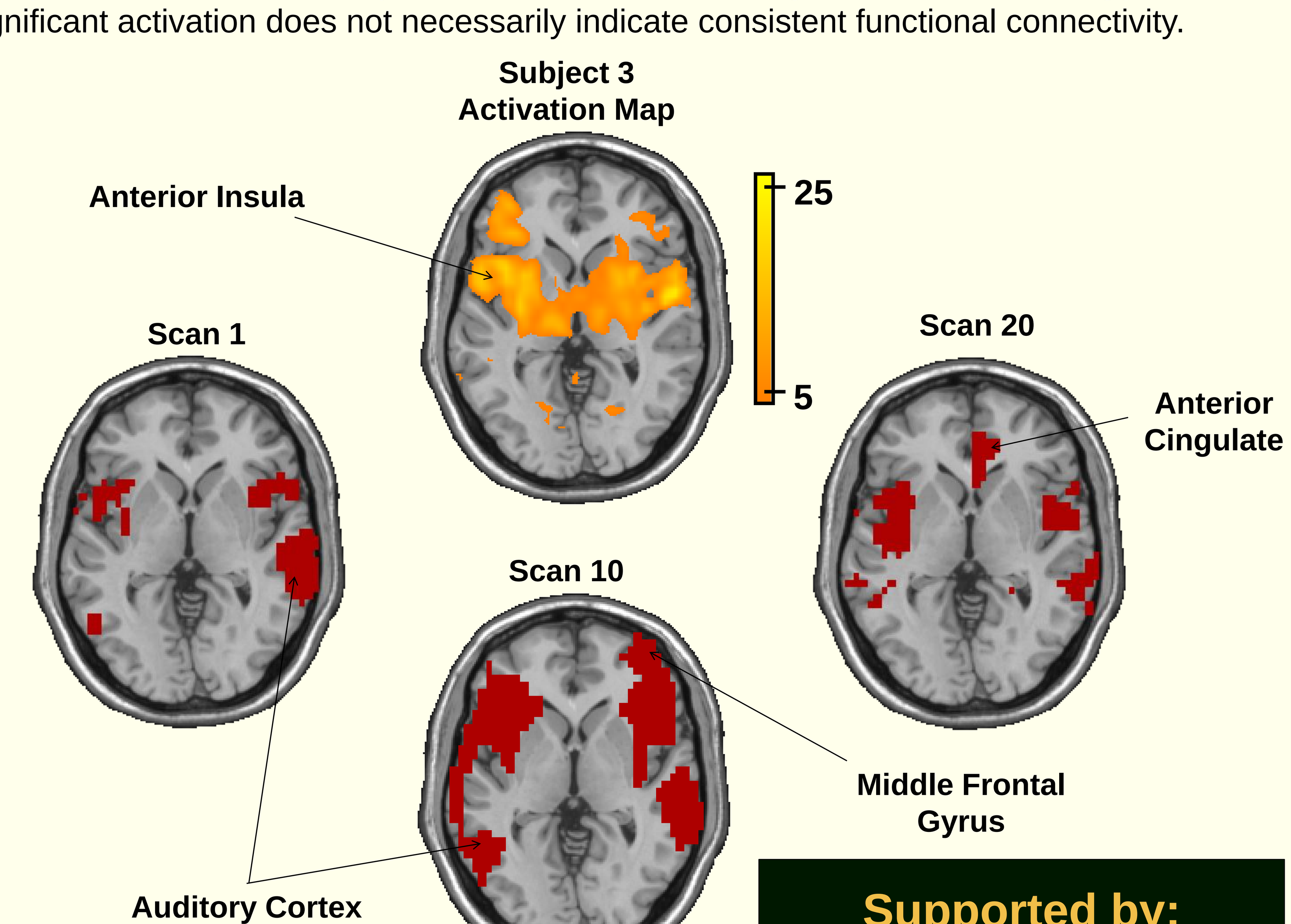


Figure 3

Subject 3 had significant activation in several regions including the anterior insula. However, that region had inconsistent community structure. In scan 1, that community included the right auditory cortex. In scan 10, the middle insula was included bilaterally, along with the right middle frontal gyrus and primary auditory cortex and left secondary auditory cortex. In scan 20, the community included some auditory cortex and the anterior cingulate cortex. This suggests that significant activation does not necessarily indicate consistent functional connectivity.



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