Dynamic Functional Connectivity During Context-Dependent Rule Learning

#821

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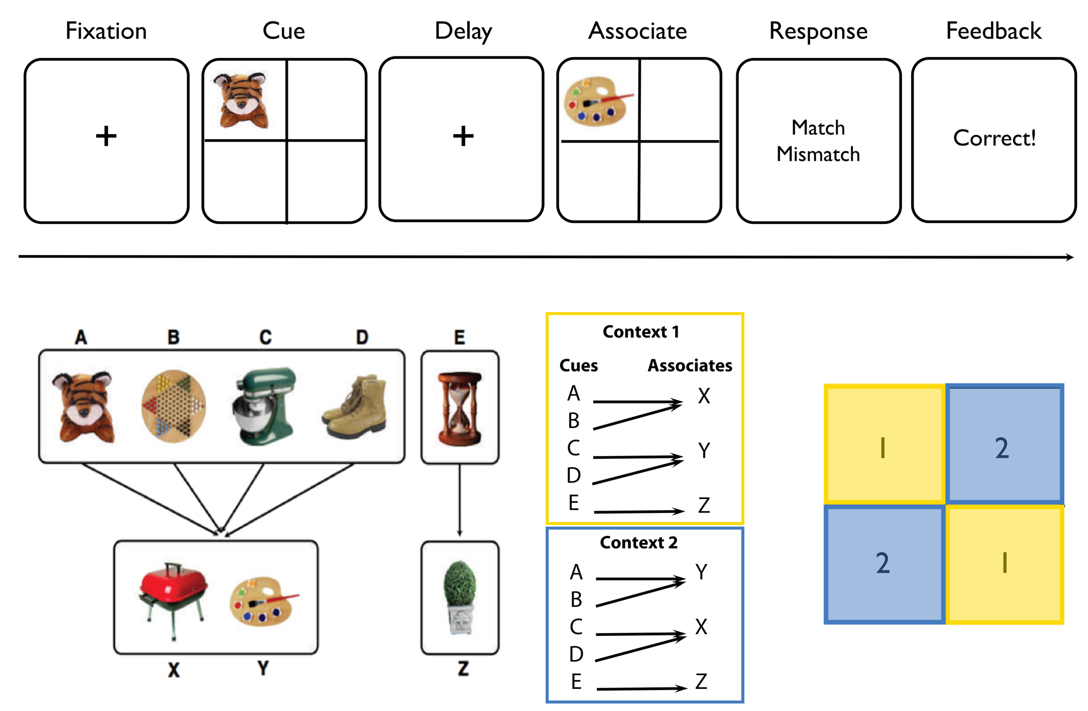
Project Summary

The functional connectivity of brain networks dynamically changes during learning and can be measured with fMRI.[1]

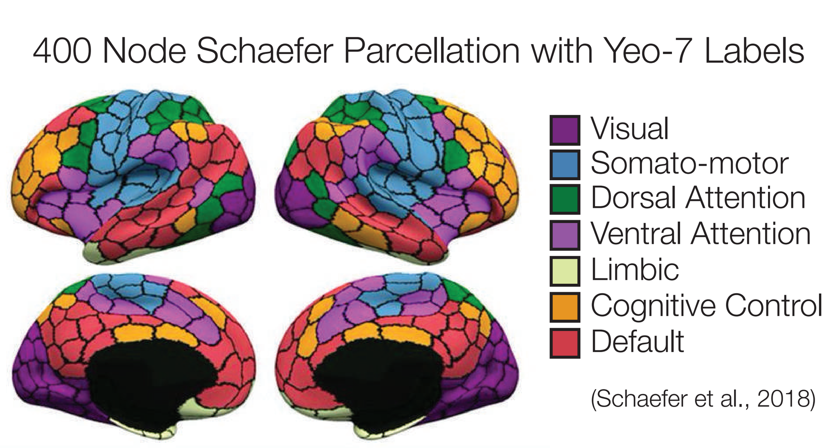
Previously, our lab scanned a cohort of 30 naive subjects while they learned a set of context-dependent paired associates.[2]

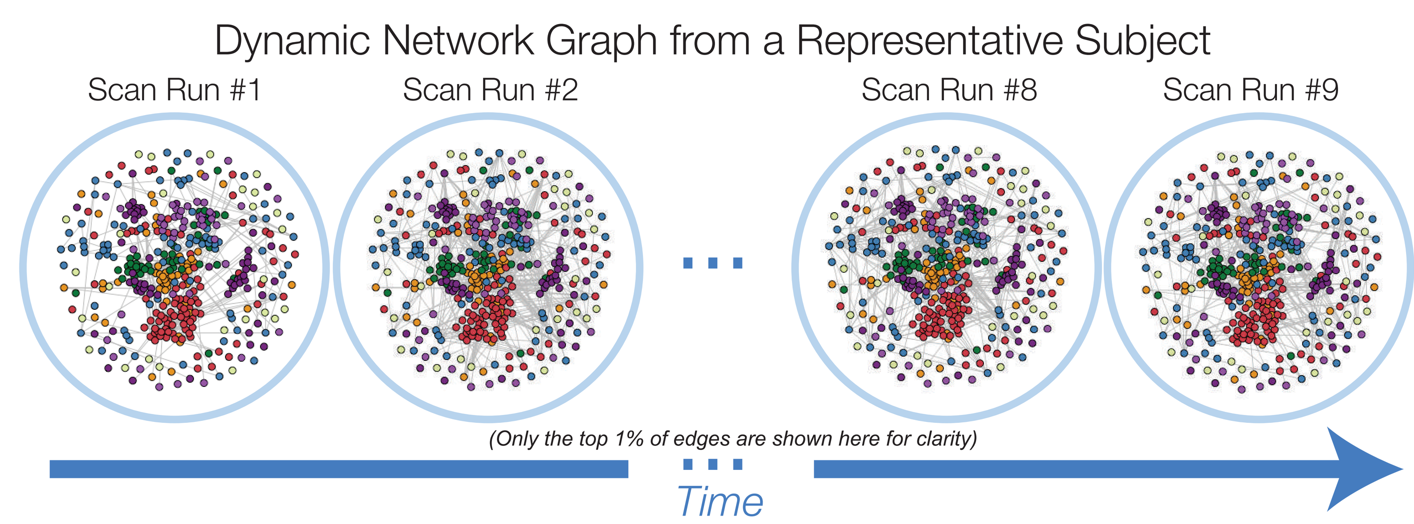
We found that successful learners developed stable networks faster, as they quickly adopted a successful cognitive strategy. Additionally, we found that for successful learners, the cognitive control network (CCN) plays a central role during the early stages of learning and becomes less central as the task becomes more automatic.



Context-dependent rule learning task[2].

Methods: Dynamic Network Construction

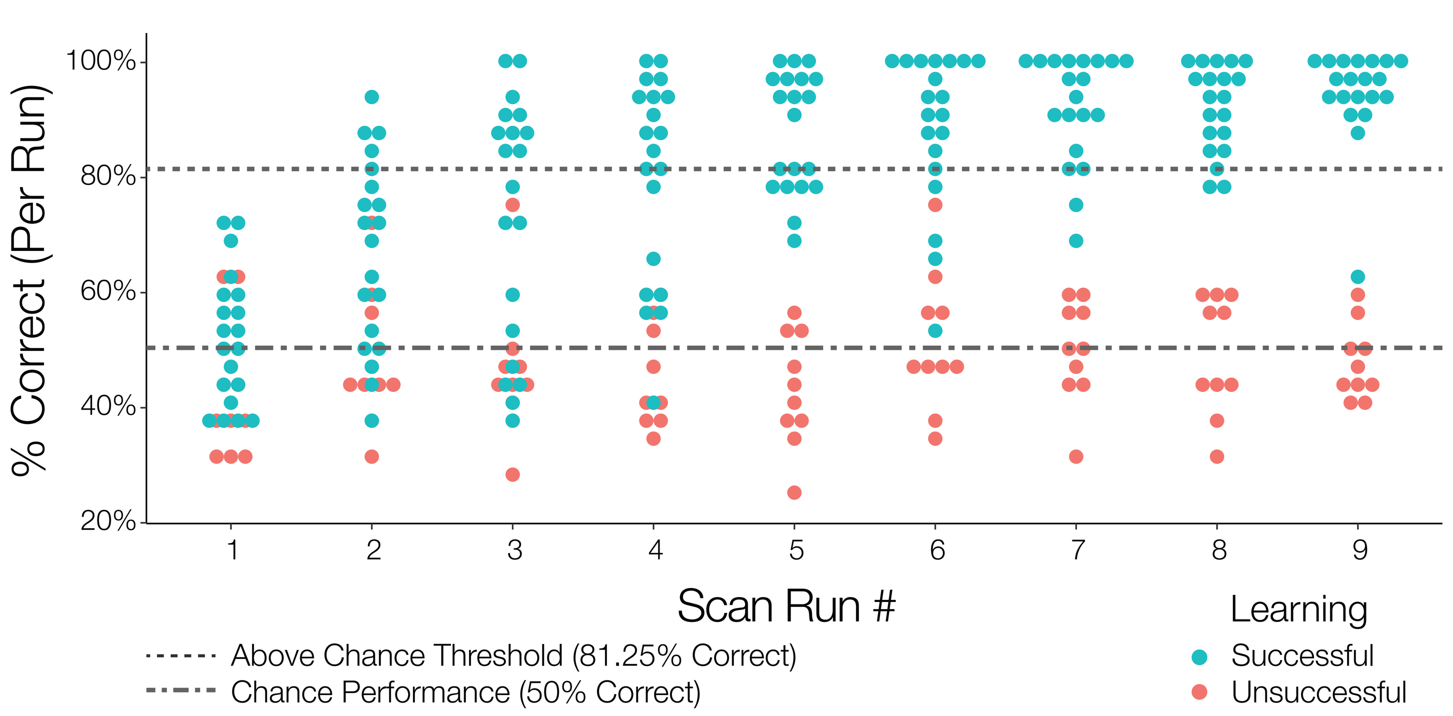




For each subject, we constructed a dynamic connectivity network consisting of 9 layers (one layer for each scanning run). **Nodes** of the network represent the mean time-series from each cortical region defined by the Schaefer-400 parcellation[3] (shown above). Each node is collored according to the corresponding canonical Yeo-7 resting state network[4] to which that node belongs.

Edges connecting nodes within a layer represent the Pearson correlation between the BOLD signal timecourses of a pair of nodes. Edges were only included if the Pearson correlation surpassed a statistical threshold (p < 0.05). Intra-layer edges connected a node across time and were assigned a weight of 0.5.

Results: Learning Ability Widely Varied Across Subjects

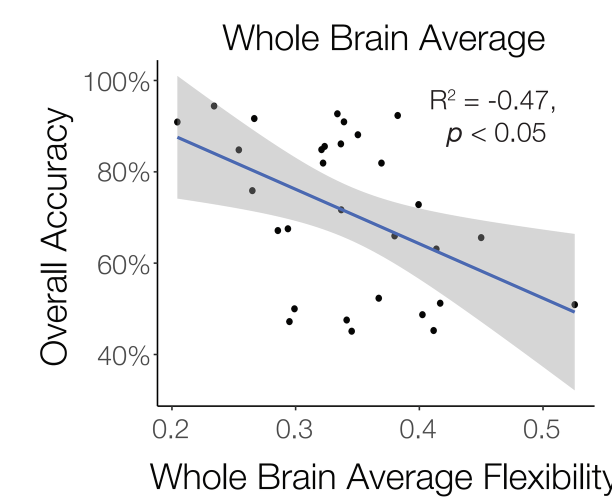


Individual subjects varied widely in their overall task performance. To the left, accuracy is plotted for each of the nine runs of the task. To qualify as a successful learner, a subject must have achieved an accuracy significantly above-chance for at least one run (defined as the 99.9th quantile of the binomial distribution: 81.25% correct for this task). Subjects are divided into two groups: successful learners (blue, n=20) and unsuccessful learners (red, n=10).

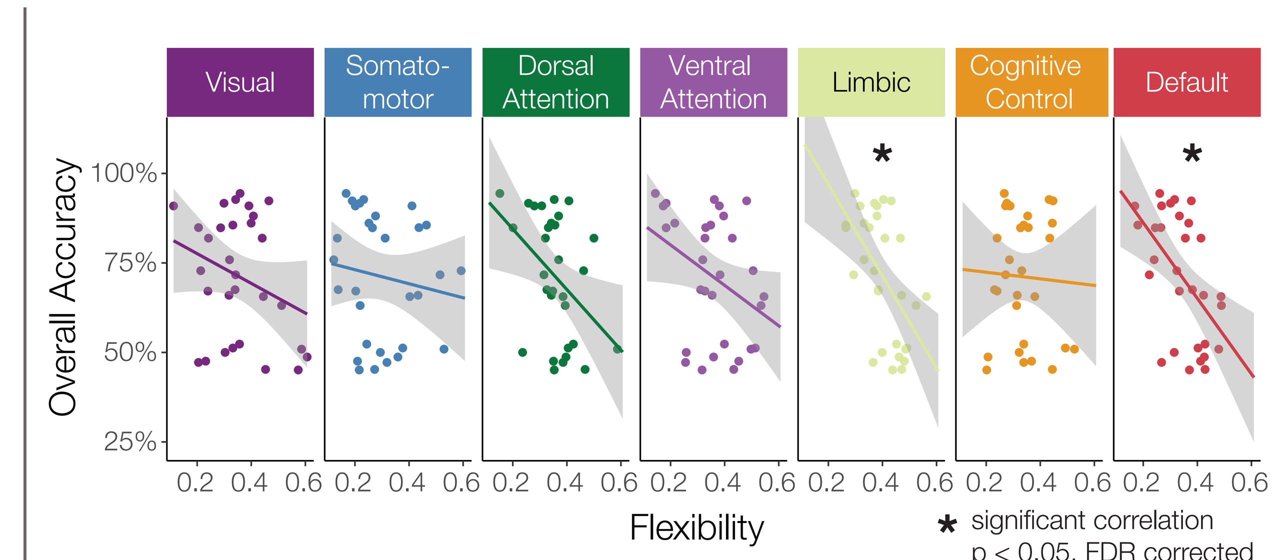
Results: Successful Learning is Associated with Lower Network Flexibility

For each subject's layered network, we used a Louvain community detection algorithm each subject's mulit-layer network[5] to assign the 400 nodes to communities. Crucially, the community membership of each node was allowed to change over time. The flexibility of each node was calculated according to Equation 1. To determine whether successful and unsuccessful learners exhibited differences in network flexibility, we calculated the correlation between node flexibility and overall accuracy on the task. This was repeated for the whole brain average flexibility, the average flexibility of each Yeo-7 canconical network, and for each node individually.

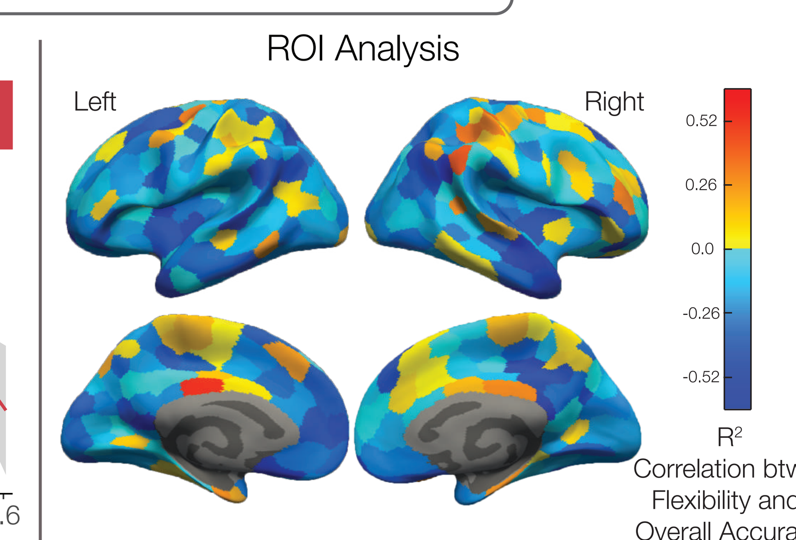
$$\textbf{Equation 1:} \text{Flexibility} = \frac{\#\text{ Community Switches}}{\#\text{ PossibleSwitches}}$$



Decreased mean whole brain flexibility (averaged across all 400 regions of cortex) is associated with increased overall accuracy on the task (R^2 = -0.47, p < 0.05).

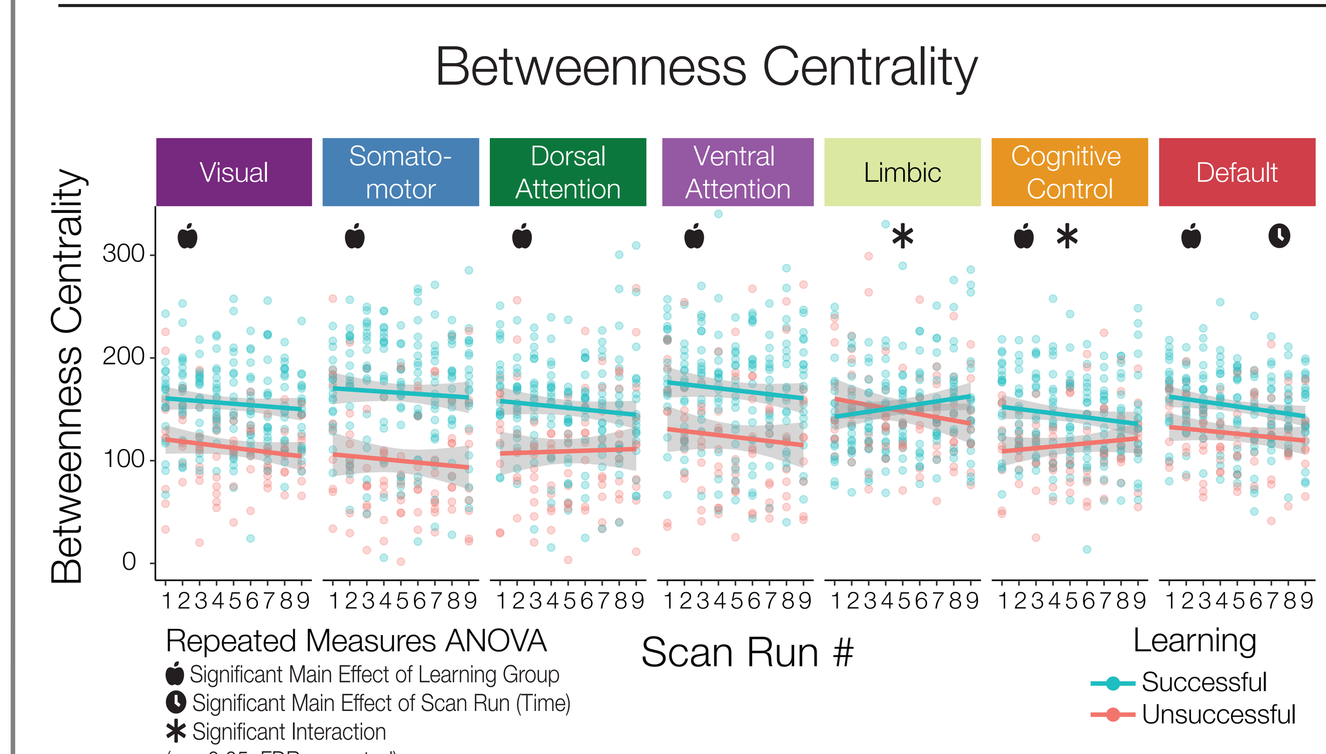


There was a significant negative correlation between flexibility and overall accuracy in the Limbic (R^2 = -0.56, p < 0.05), and Default Networks (R^2 = -0.54 , p < 0.05, FDR corrected for multiple comparisons).

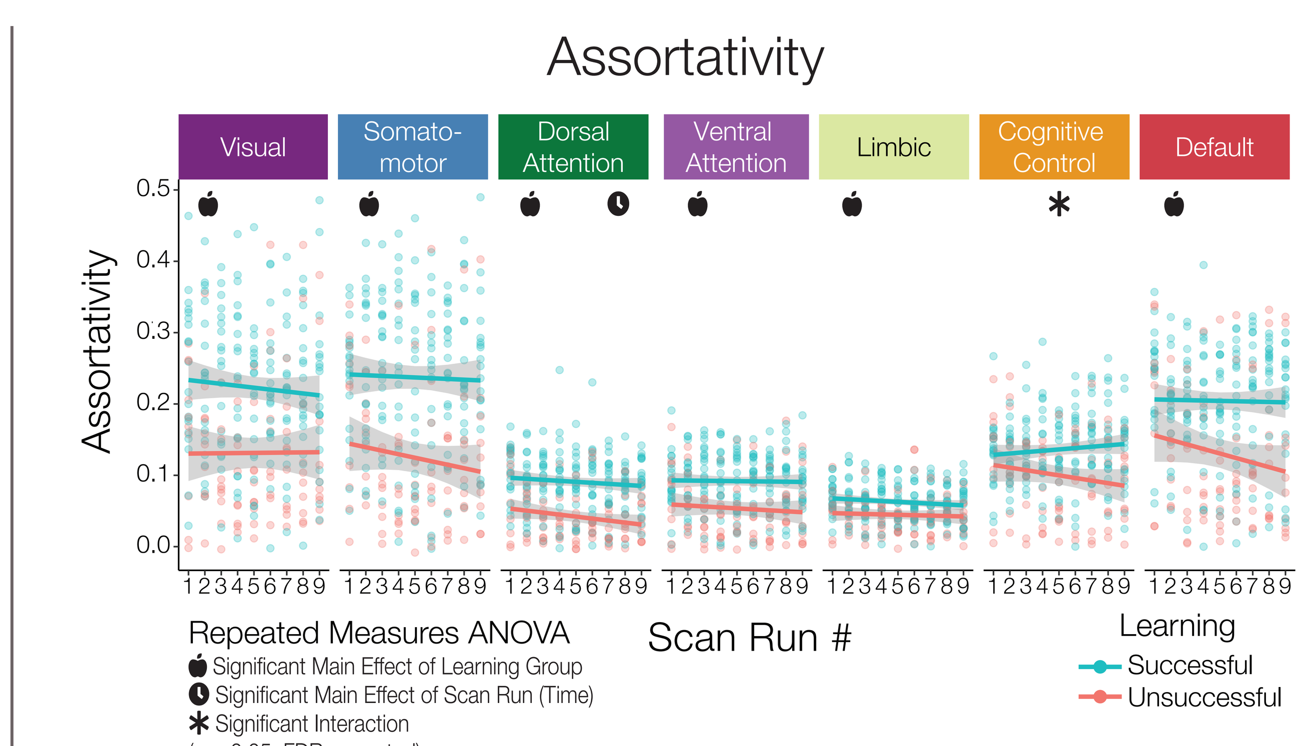


Correlation between flexbility and overall accuracy are mapped onto the Schaefer-400 cortical parcellation[3]. Warm-colored regions show a positive correlation between flexibility and accuracy. Cool-colored regions show a negative correlation.

Results: In Some Networks, Changes in Centrality & Assortativity are Associated with Learning



A single shortest path connects any two nodes on a graph. The **betweenness centrality**[6] of a particular node is the sum of all such shortest paths that pass through said node. High values indicate that a region is centrally located in the brain-wide network. We calculated the mean betweenness centrality across all the nodes contained in each canonical Yeo-7 network. The Limbic and Cognitive Control networks showed a significant interaction between learning ability and scan run on betweenness centrality measures (p < 0.05, FDR corrected).



Assortativity[7] measures the preference for nodes to connect to other nodes that are assigned to the same canonical Yeo-7 network. Higher values of assortativity indicate that a Yeo-7 network is more highly interconnected than it is connected to other networks. As expected, primary sensory networks (e.g. Visual, Somato-motor) showed higher overall values of assortativity. The Cognitive Control network showed a significant interaction between learning and scan run on assortativity measures (p < 0.05, FDR corrected).

Discussion & Conclusions

- Successful learners formed stable brain network representations, as they more quickly adopted a successful strategy to solve the context-dependent rule-learning task.
- The Cognitive Control network was more centrally located in the brain networks of successful learners, but only during the early stages of learning.
- Together, the results suggest that the Cognitive Control network is important for forming a strategy early on in learning. This was a key difference observed between successful and unsuccessful learners.

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