Dynamic functional connectivity underlies general intelligence

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Introduction

- Humans exhibit general intelligence (*g*), the ability to solve the wide range of problems we face in life. A central question in cognitive neuroscience is: How does the brain support this general problem-solving capacity?
- Traditional theories have linked *g* to localized activity within the frontoparietal network[1].
- However, solving complex, real-world problems often requires shifting strategies, integrating information, and adapting to changing demands, suggesting *g* may depend on dynamic global brain processes rather than fixed regional activity.
- Network Neuroscience Theory (NNT) proposes that *g* arises from the brain's capacity to dynamically reconfigure its functional network architecture[2].
- That is, individuals with higher intelligence may be better able to access and transition between a diverse set of brain network states in response to changing task demands.
- To test this hypothesis, we used a set-shifting task in which cognitive demands vary across multiple dimensions on a trial-by-trial basis[3].
- We examined how the brain's functional connectome dynamically adapts to these varying demands using Leading Eigenvector Dynamics Analysis (LEiDA)[4] and Sample Entropy to characterize the richness and dynamics of network state transitions.

Is *g* associated with the dynamics of global, functional connectivity?

Does *g* depend on the ability to access a large repertoire of topological states?

Methods

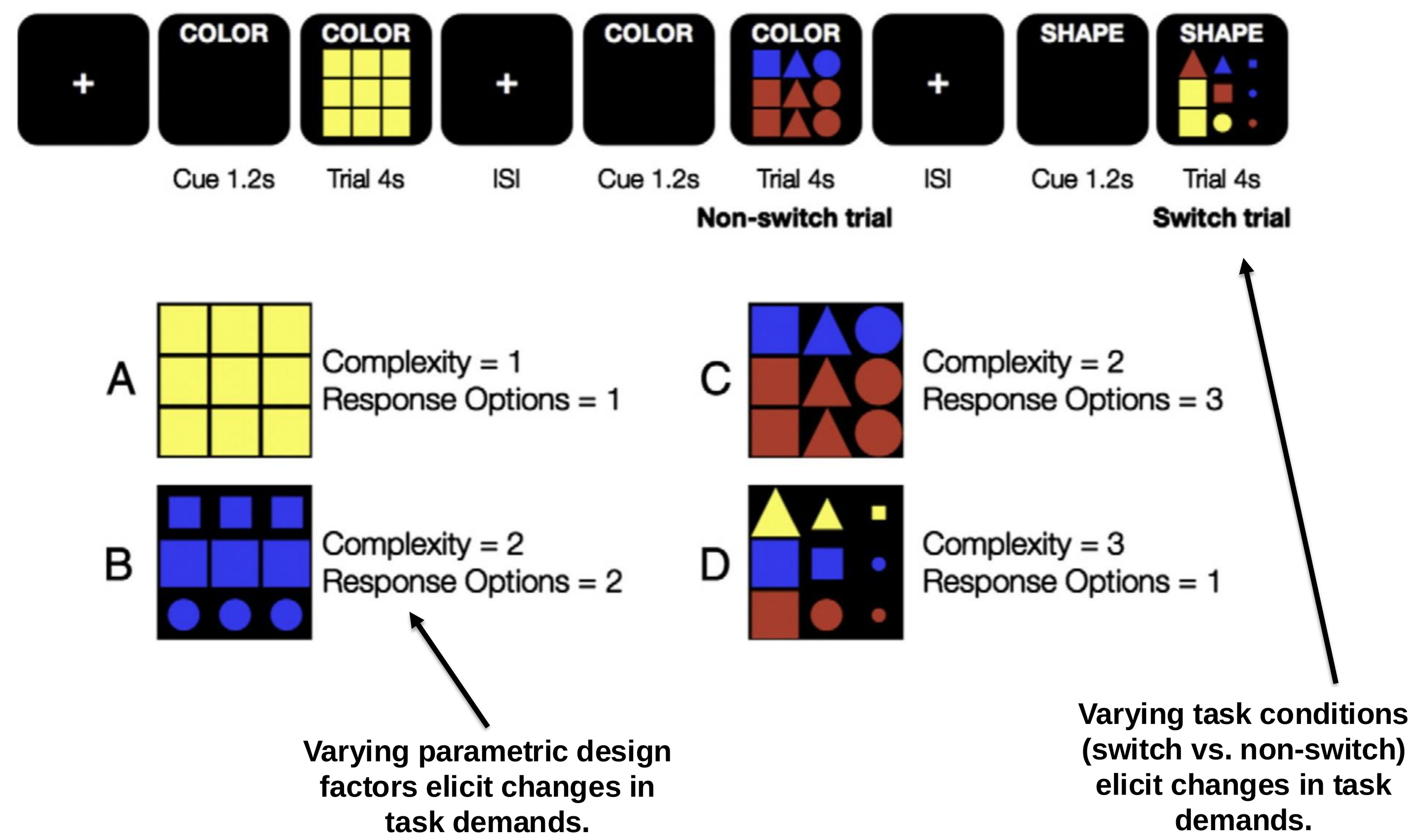
Participants
- Community sample of individuals from the Urbana-Champaign area
- N = 245
- Age = 18-43 [23.19, 4.9]; 51% female

Cognitive Measures
- Law School Admissions Test Logical Reasoning Battery (Fluid & Crystallized Intelligence)
- Figure-series (Fluid Intelligence)
- Shipley-vocab (Crystallized Intelligence)
- Adult Decision-Making Competence Battery

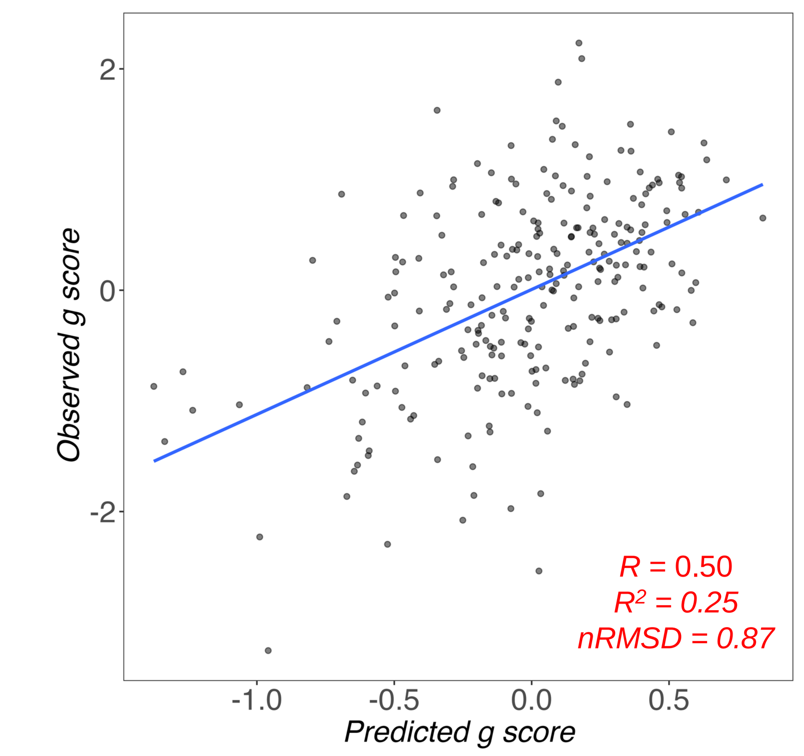
Neuroimaging
- T1w imaging (Anatomy)
- Task-based fMRI (Functional Topology)

Predictive Model
- 10-fold cross validation with elastic net

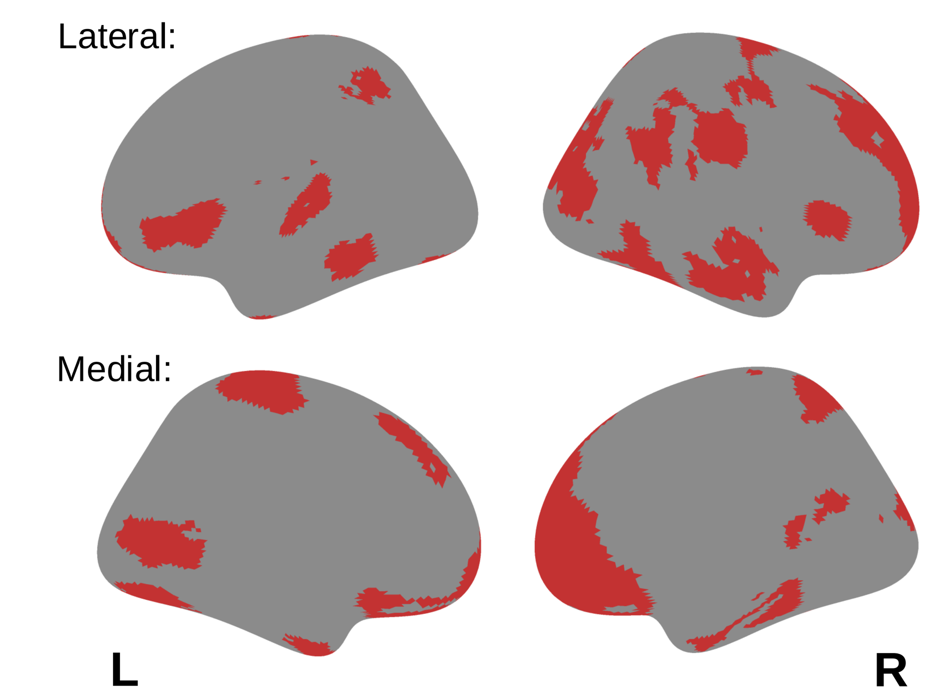
Mental Set Shifting Task (SST)



The Dynamics of the Functional Connectome Predict *g*



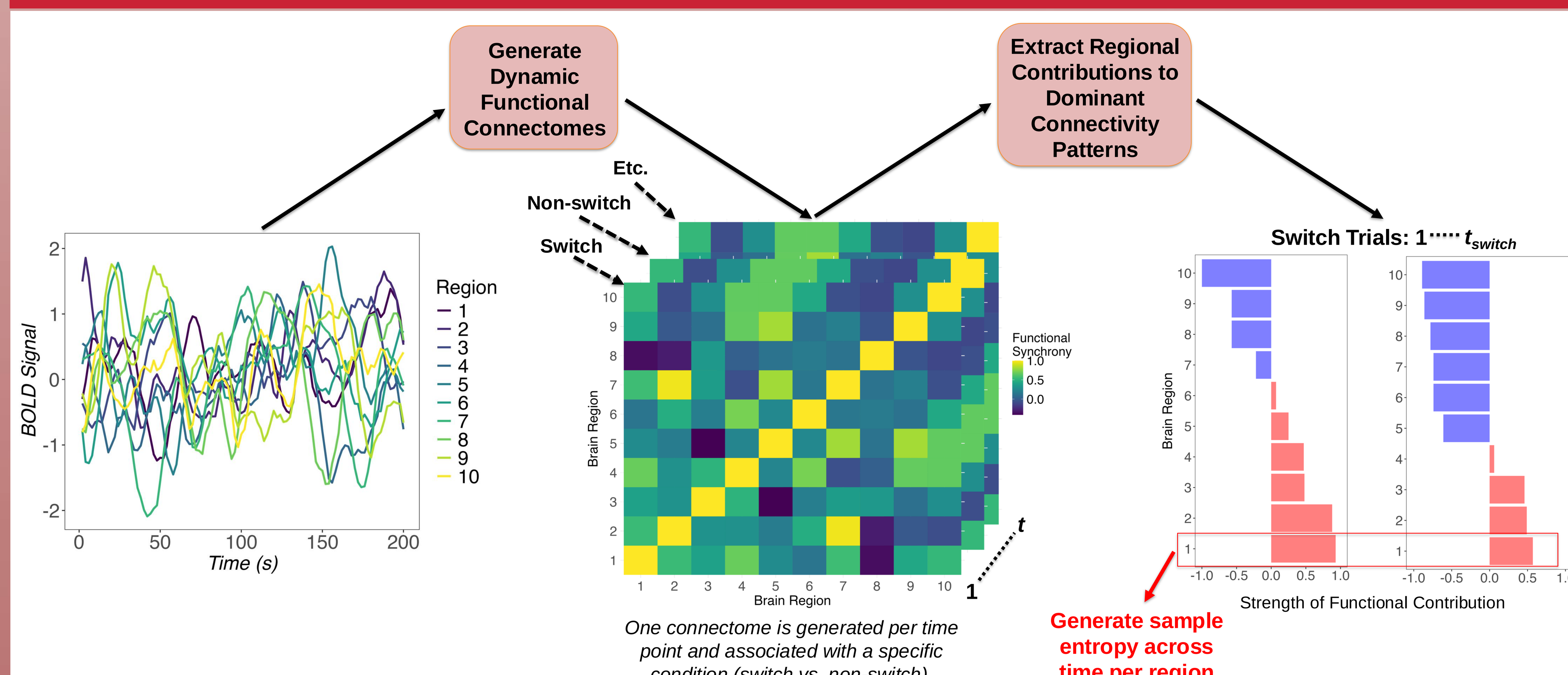
Results from the predictive model fit on region-wise sample entropy values generated from dominant connectivity patterns across switch trials.



*Cortical map displaying the anatomical location of regions that contributed to predictive performance. Predictive regions are shown in **RED**.*

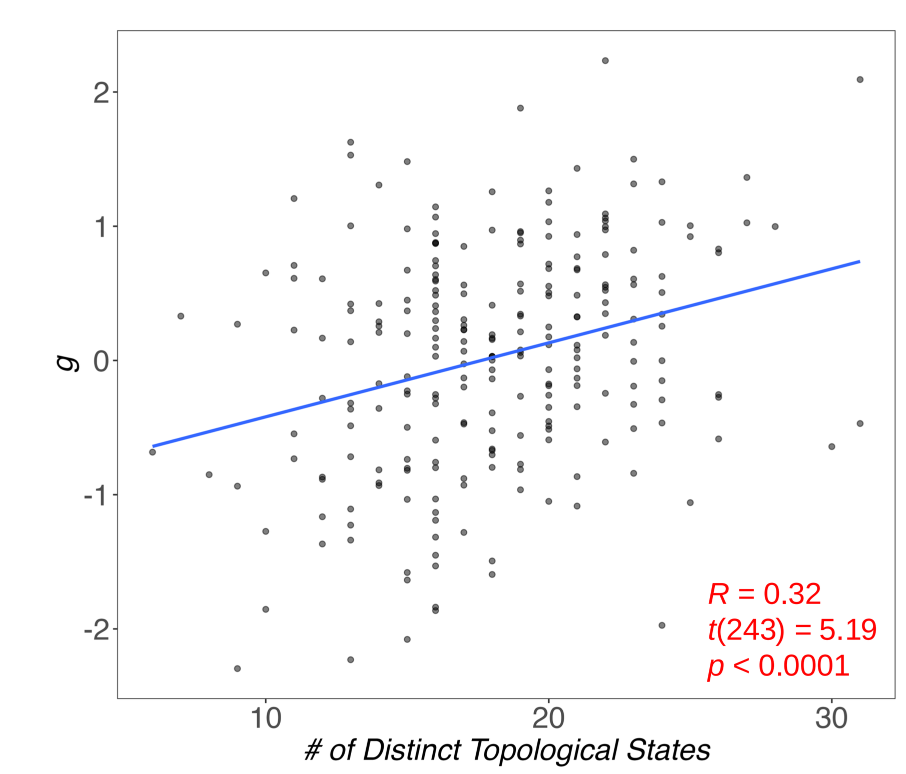
Predictive regions identified from all 10 folds of the cross-validation scheme are **distributed across the cortex**.

Leading Eigenvector Dynamics Analysis (LEiDA)



One connectome is generated per time point and associated with a specific condition (switch vs. non-switch).

Individuals that Engage More Distinct Topological States Have Greater *g* Scores



Results from correlating g with the # of distinct topological states engaged during task completion. Distinct topological states were determined by spectral clustering applied to dominant connectivity patterns across switch trials.

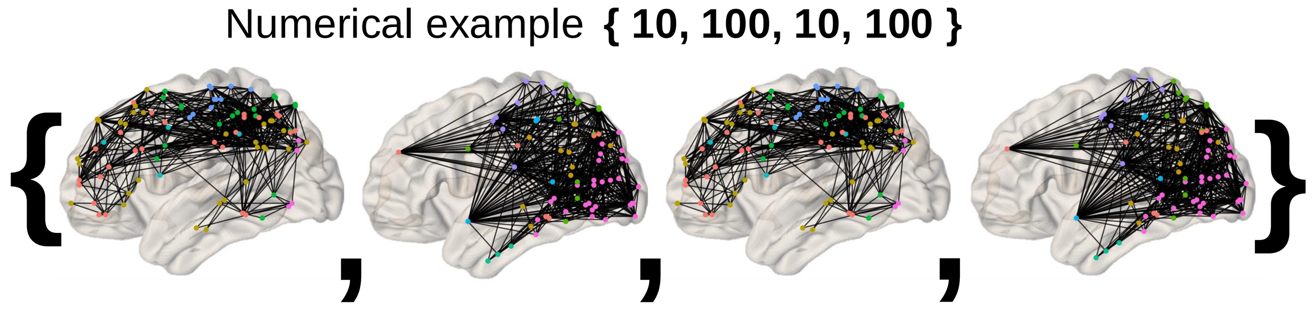
The engagement of a **larger number of distinct topological states** during successful task completion is associated with **higher *g* scores**.

Sample Entropy Example

Low Entropy

Numerical example **{ 10, 100, 10, 100 }**

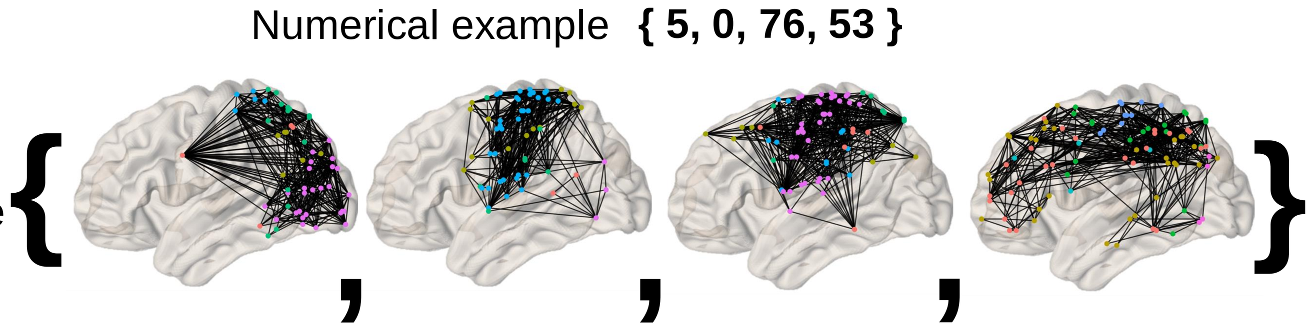
Neural example



High Entropy

Numerical example **{ 5, 0, 76, 53 }**

Neural example



Conclusions & Future Directions

- Dynamic modeling shows how adaptive functional connectivity supports general intelligence in a way that is inconsistent with localized models of *g*.
- This dynamic topology is distributed across the cortex.
- Spectral clustering suggests that this dynamic topology contributes to *g* via access to a wider variety of diverse brain states.
- Our findings support a dynamic, global view of intelligence, suggesting that *g* emerges from the dynamics of a distributed system in response to changing environmental demands, rather than from localized features.
- An important question for future work to answer is: How do neural mechanisms underlying functional connectome dynamics contribute to individual differences in *g*?
- Structural control theory[5] offers an appealing framework, describing structural mechanisms (e.g., modal controllability) capable of driving the brain through various transitions between functional states that support effortful cognition.
- Investigating the relationship between modal control regions and measures of functional dynamics (e.g., sample entropy), and how this relationship contributes to *g* would help elucidate the neurobiology of general intelligence.

References

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Funding Acknowledgement

This research was supported by funds form the Office of the Director of National Intelligence (ODNI), Intelligence Advanced Research Projects Activity (IARPA), via Contract 2014-13121700004 to the University of Illinois at Urbana-Champaign (PI: Barbey)

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