

Predicting Performance with fMRI

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NIH fMRI Summer Course

7/23/18

Outline

- Why Predict Performance?
- How Can We Predict Performance?
- Performance as a Trait (Ability)
- Performance as a State (Mind-Wandering)
- Intervening to Improve Performance
- Case Study: Predicting Reading Recall
- Confounds and Conclusions
- Linking to Past Lectures:
 - Individual Differences
 - Machine Learning

Why Predict Performance?

What is Performance?

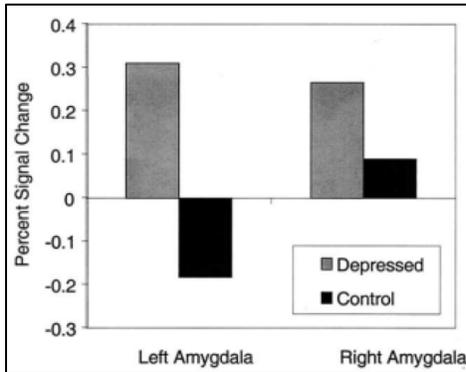
- *Dictionary Definition: the action or process of carrying out or accomplishing an action, task, or function*
- Our definition: An individual's score on a test of:
 - Cognitive abilities
 - Symptom severity
 - Educational achievement
- Often central to a patient's mental health complaint

Neuroimaging's Path to Prediction

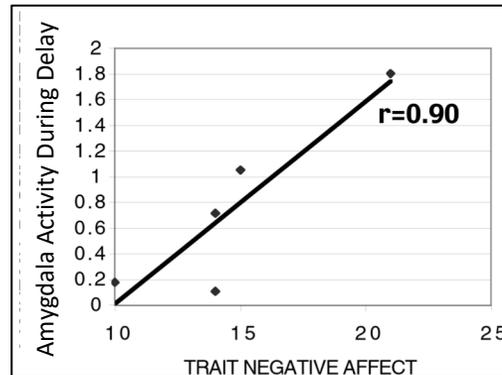
Find Group Differences

Find Performance Differences

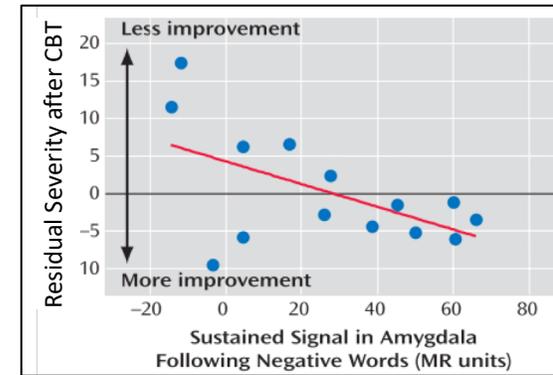
Predict Individual Outcomes



Sheline, Biol Psych 2001



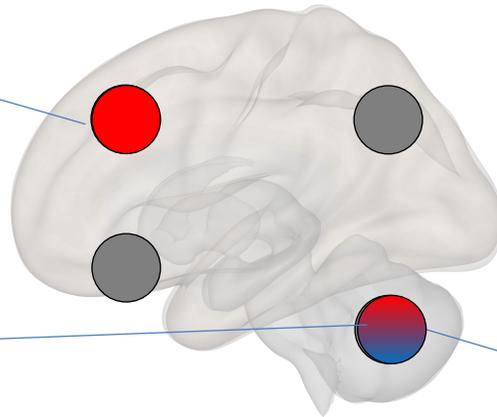
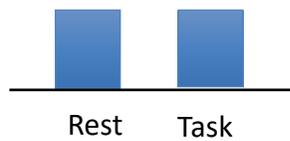
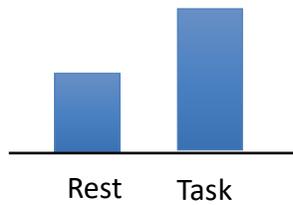
Schaefer, J Cog Neu 2002



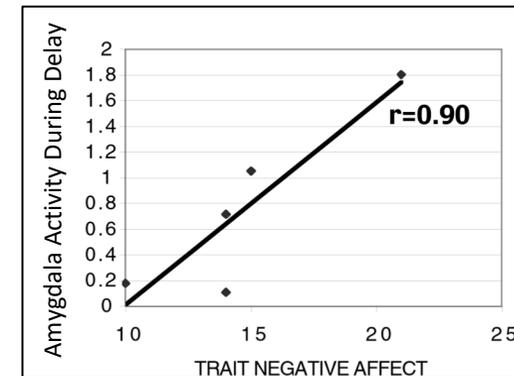
Siegle, Am J Psych 2006

Shed New Light on Neural Processes

Block-Design Analysis

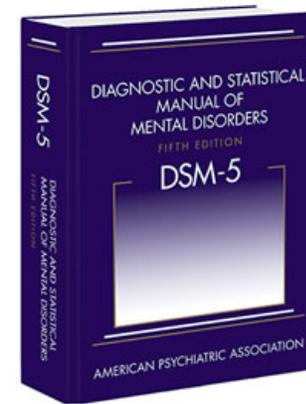
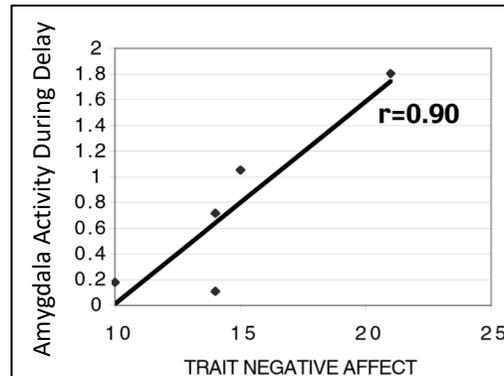
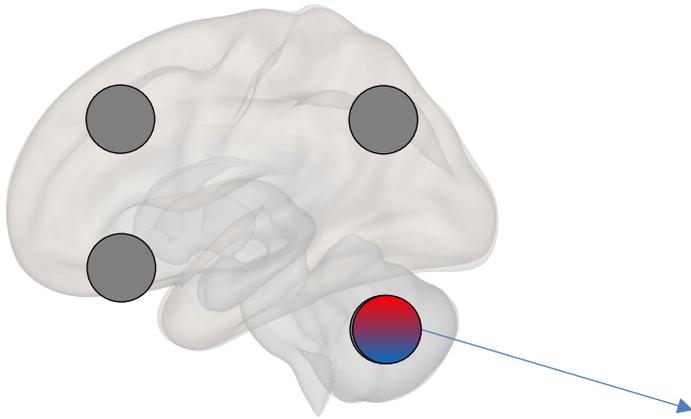


Predicting Performance

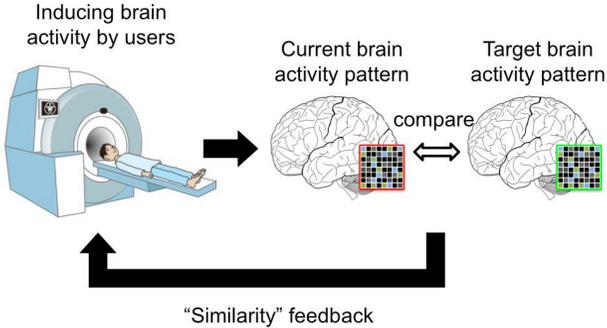
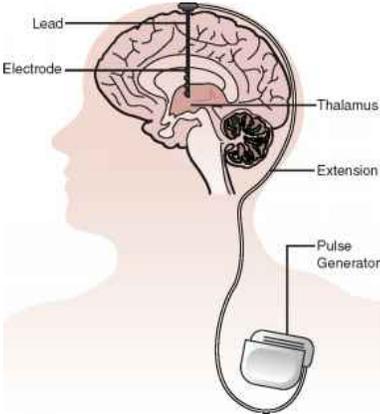
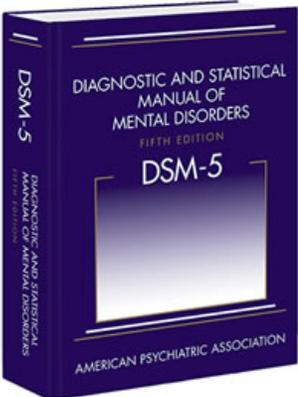


Make Brain-Based Diagnoses and Classifications

Predicting Performance

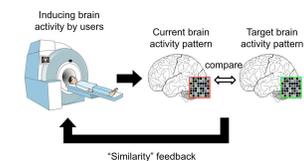
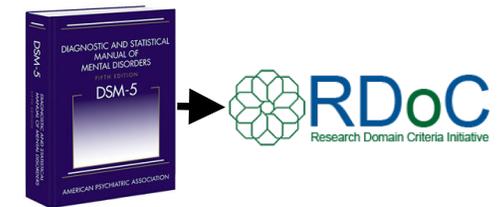
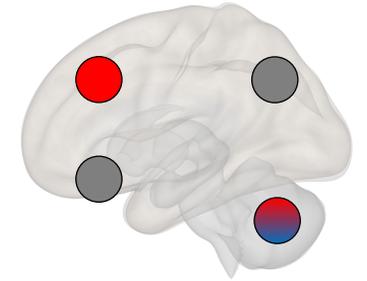


Suggest Targeted Interventions



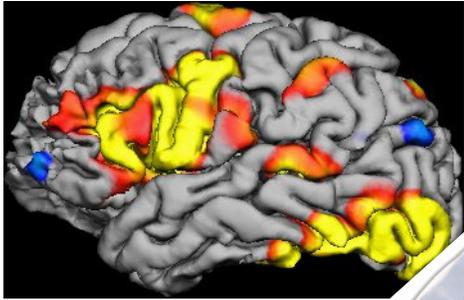
Why Predict Performance?

- Shed light on neural processes and individual differences
- Make brain-based diagnoses and classifications
- Suggest targeted interventions
 - Drugs
 - Therapy
 - Brain stimulation
 - Neurofeedback



How Can We Predict
Performance?

Machine Learning!



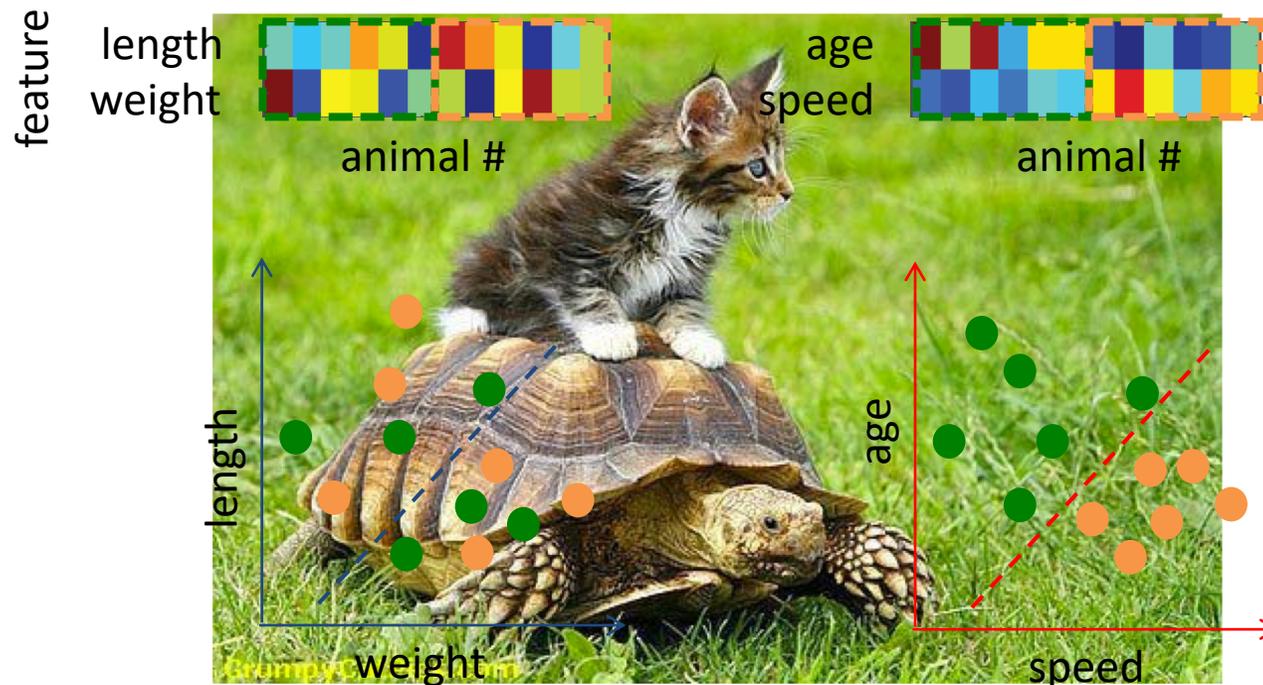
**Machine
Learning**



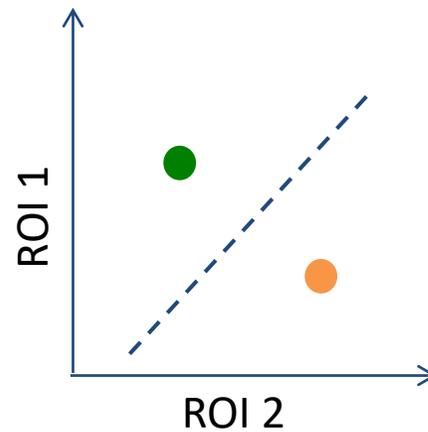
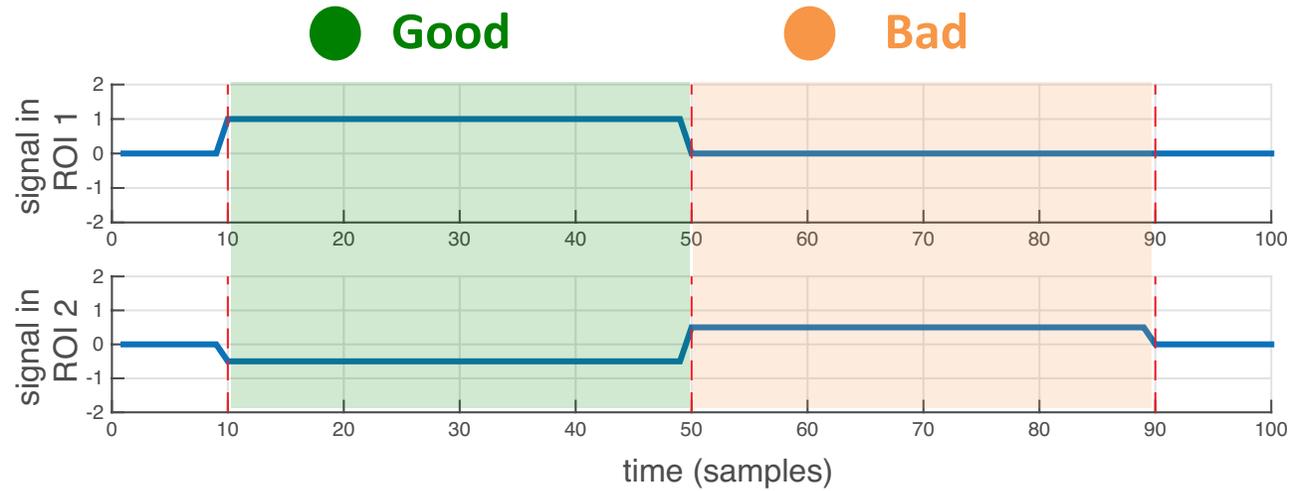
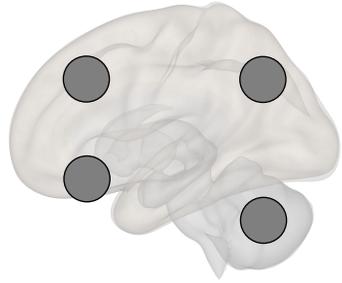
Machine Learning Features

In machine learning and pattern recognition, a **feature** is an individual measurable property of a phenomenon being observed. (Bishop, 2006)

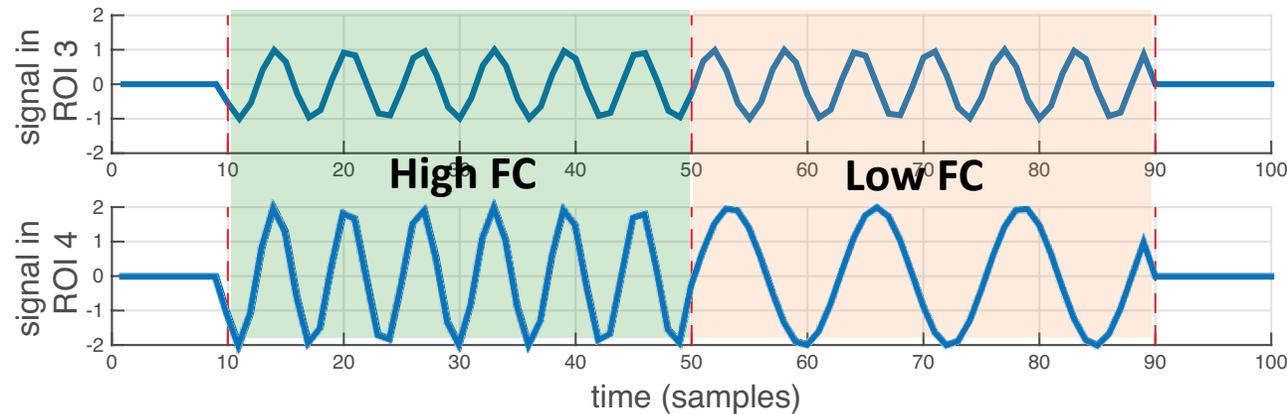
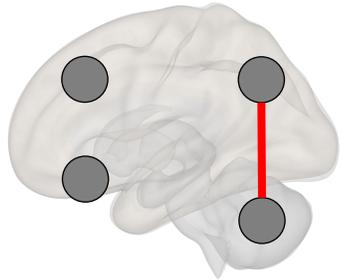
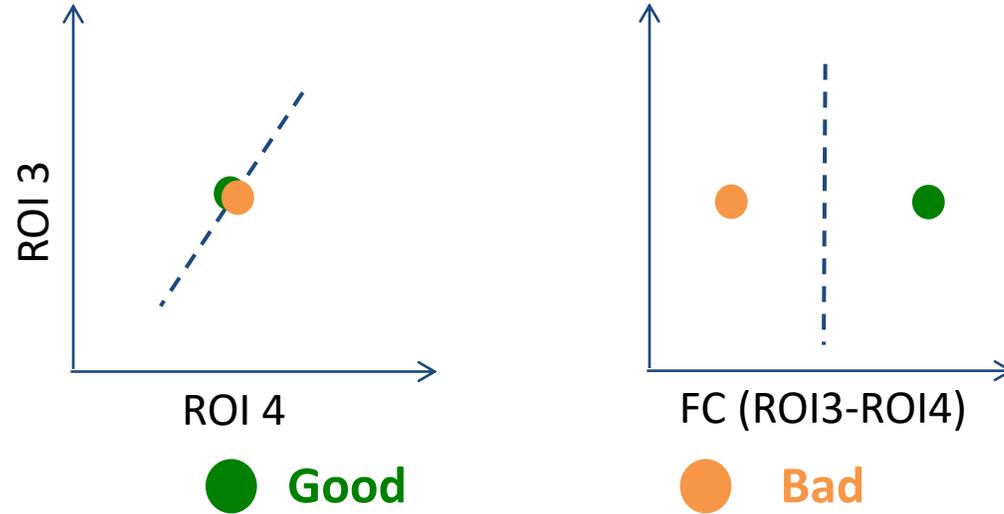
● Turtles Vs. ● Cats



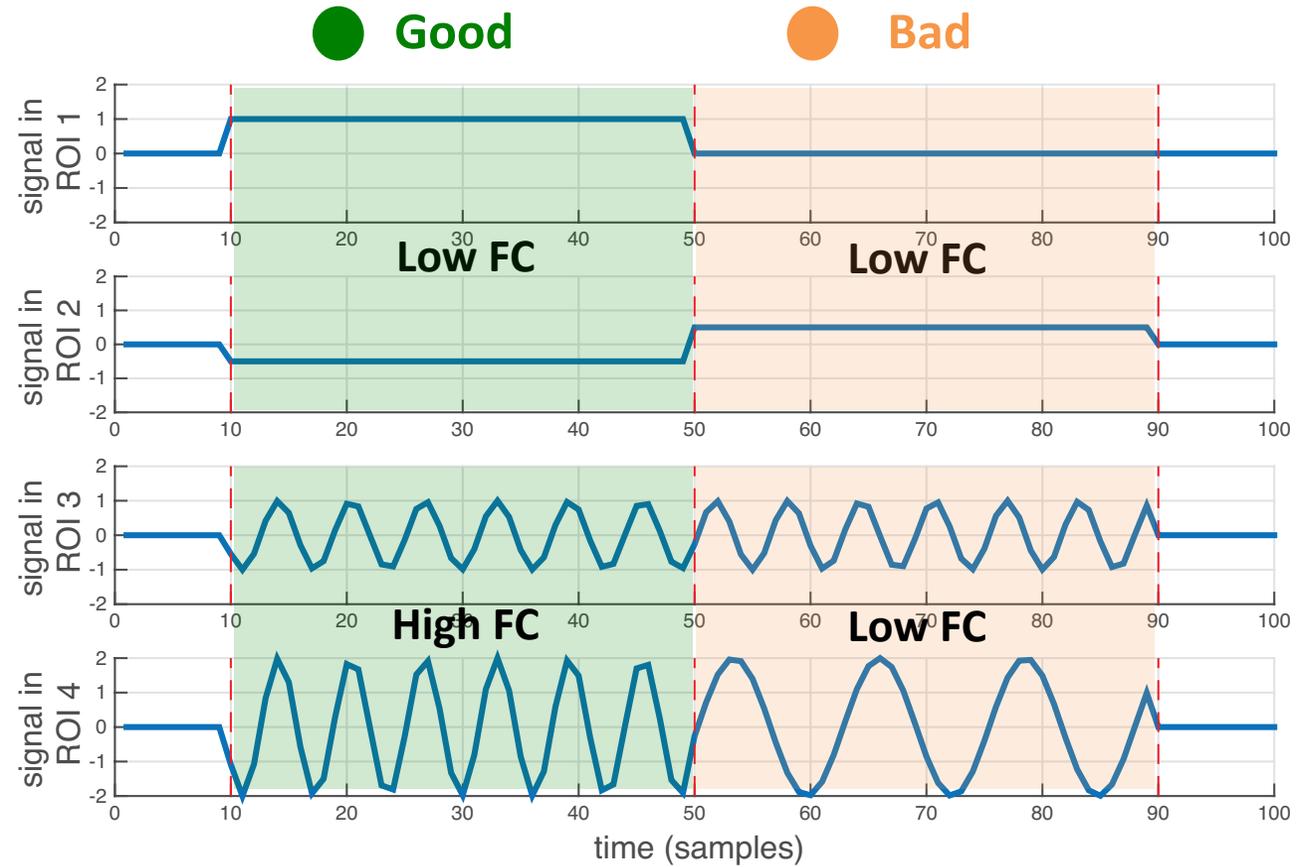
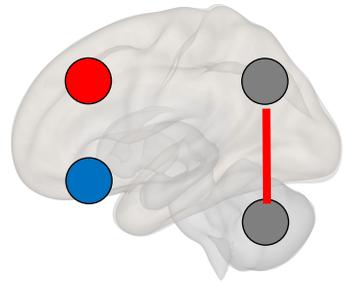
fMRI Magnitude for Prediction



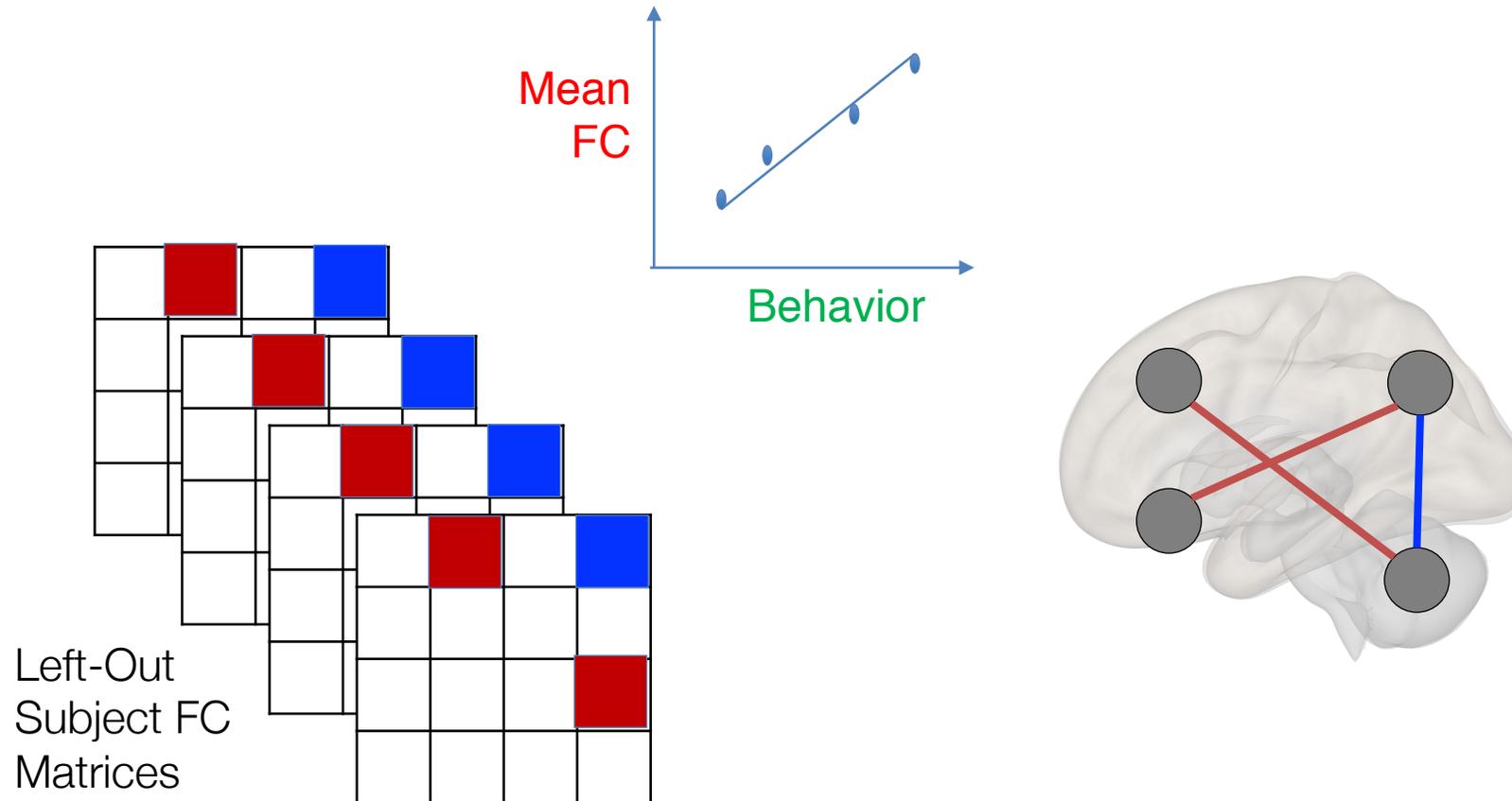
Functional Connectivity for Prediction



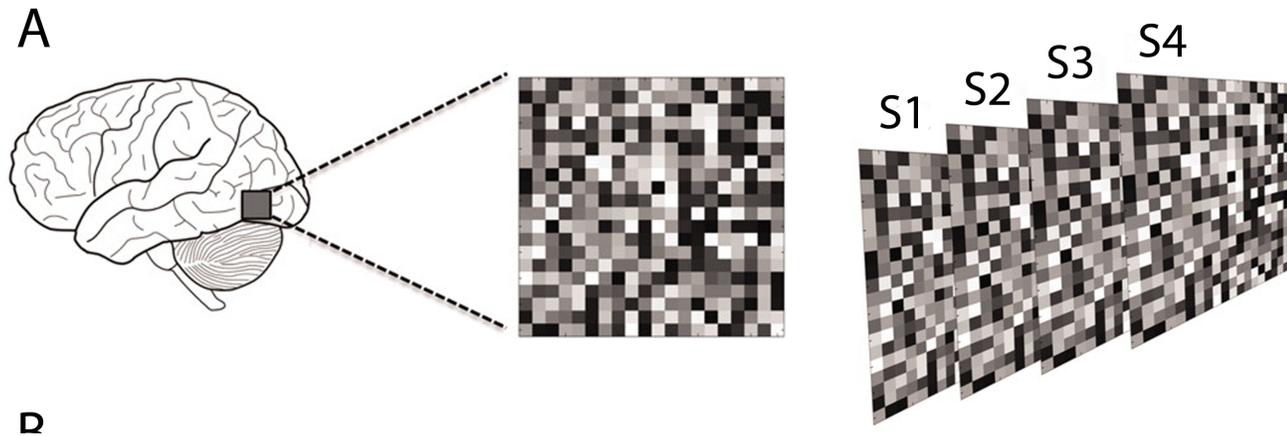
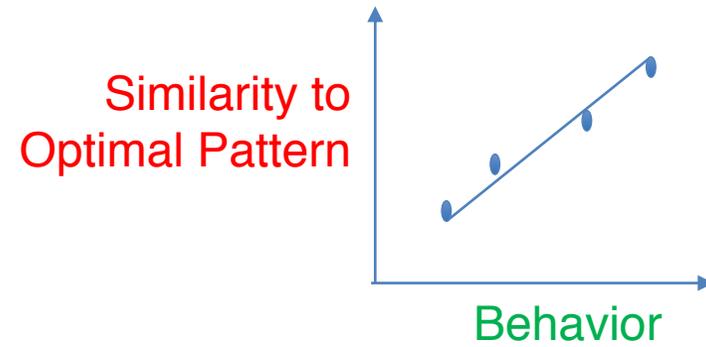
Dynamic Functional Connectivity



Whole-Brain FC Predicts Participant's Behavior



MVPA Predicts Participant's Behavior



Performance as a Trait

“Inherent Ability”

DMN and WM networks have stronger negative FC in good n-back (WM) performers

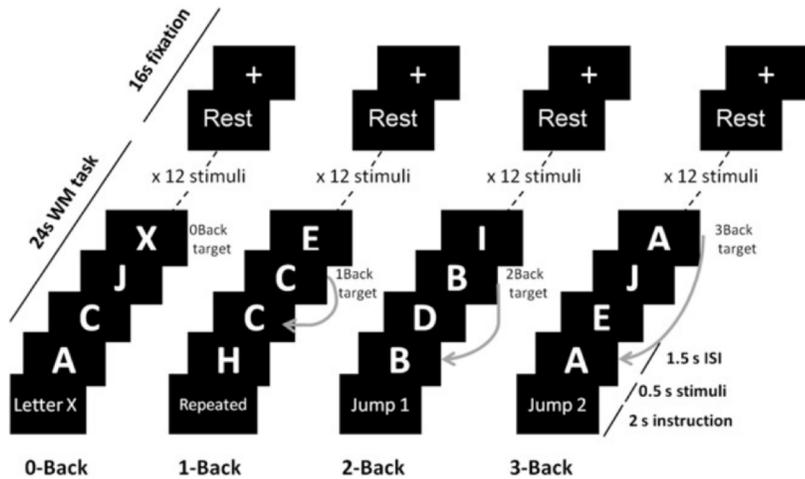


Fig. 1 – Design of the fMRI n-back task.

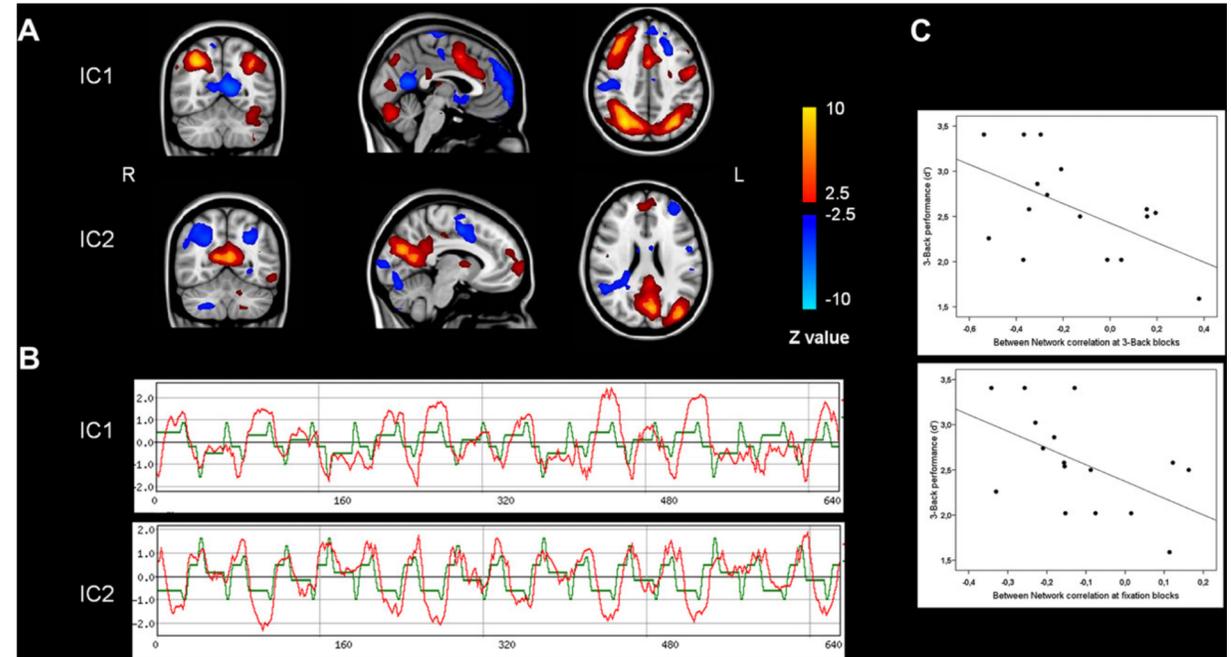
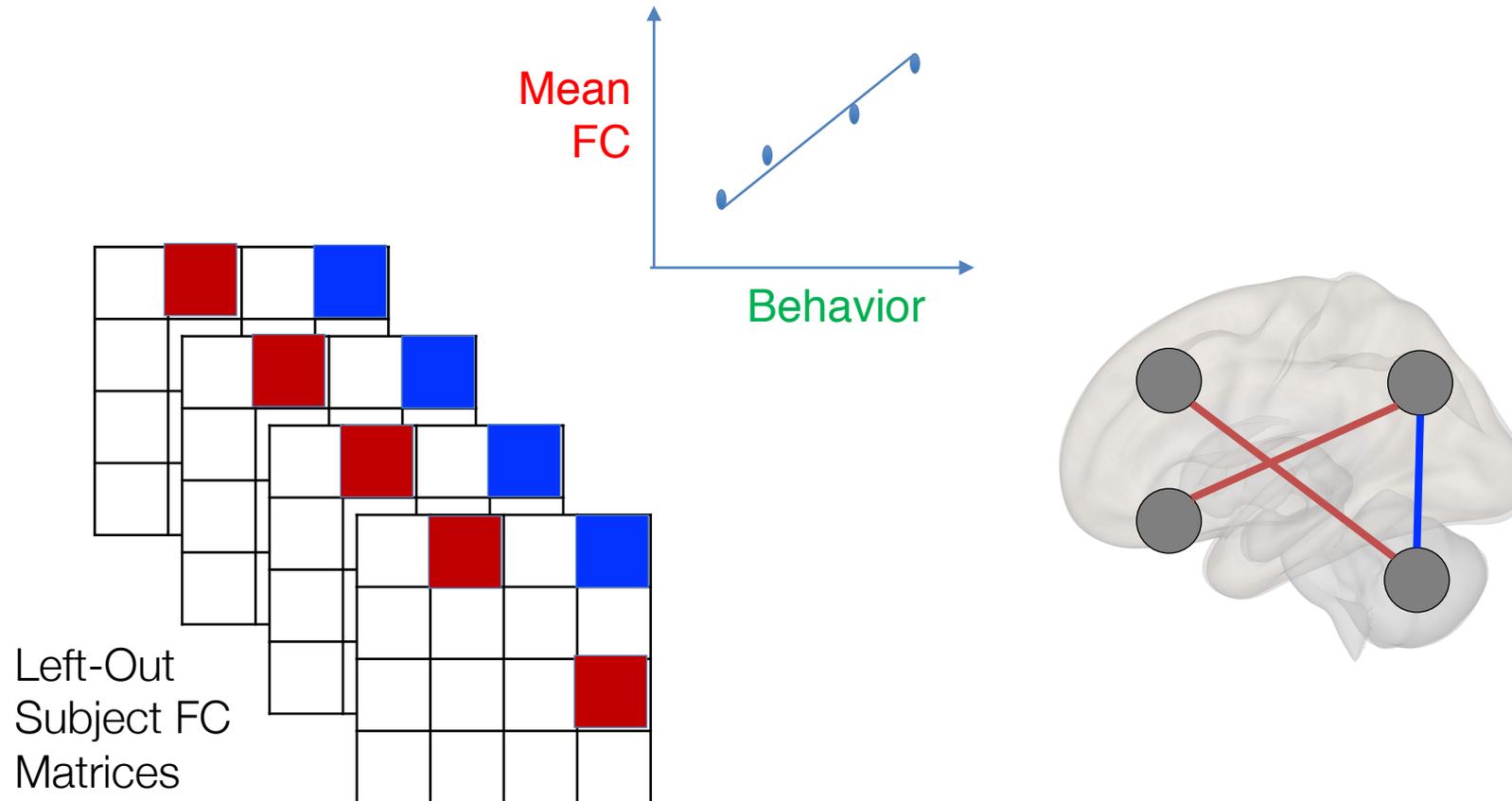
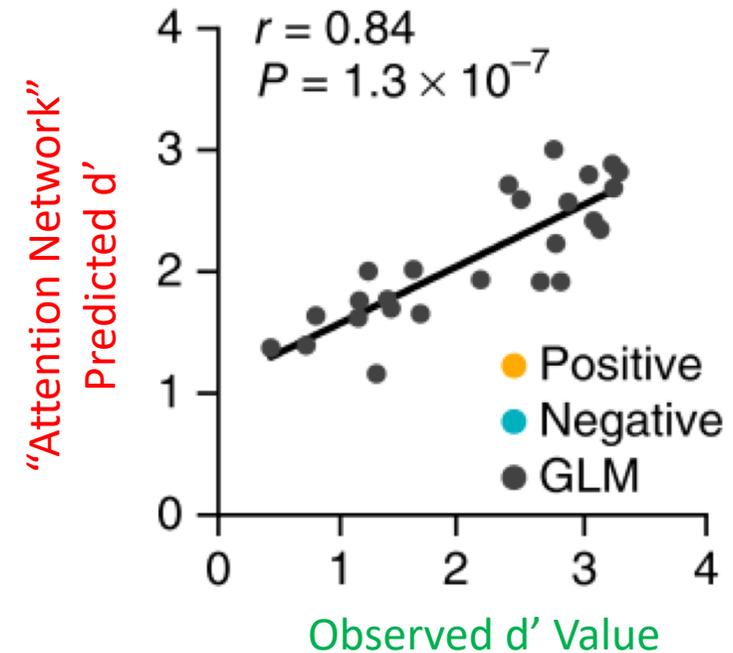
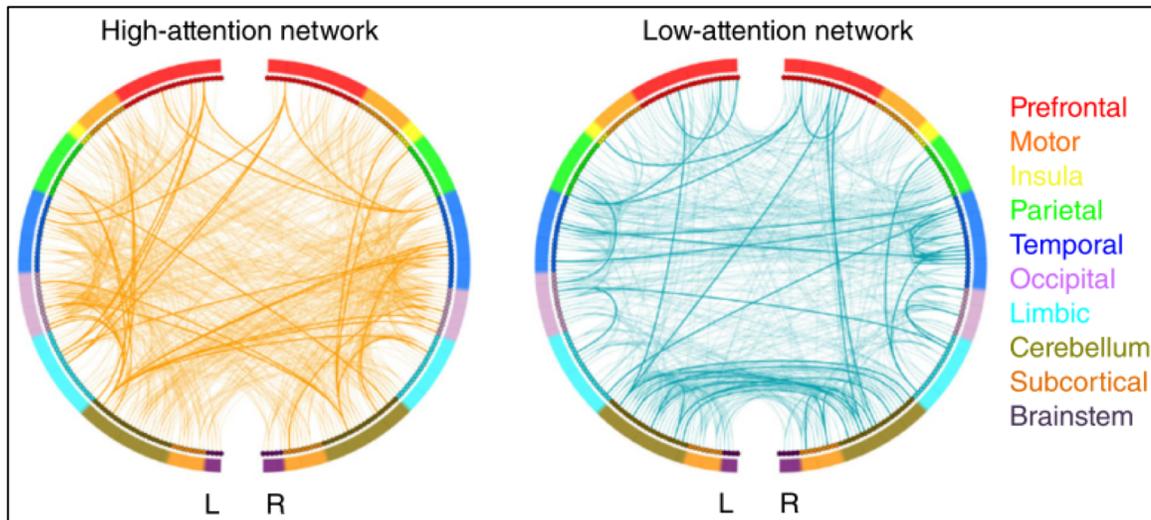


Fig. 4 – (A) Spatial maps of the two selected components: IC1 corresponds to the WMN and IC2 to the DMN. Hot colours represent brain activations and cold colours represent deactivations. (B) Time series of the two components: red lines are the component-related mean responses, while green lines show the fit with the task. (C) Scatter plots showing the relationship between the between-network correlations in the 3-back and fixation blocks and individual performance scores for the 3-back WM task.

Whole-Brain FC Predicts Participant's Behavior



High and Low-Attention Networks Learned from Grad-CPT Task Data

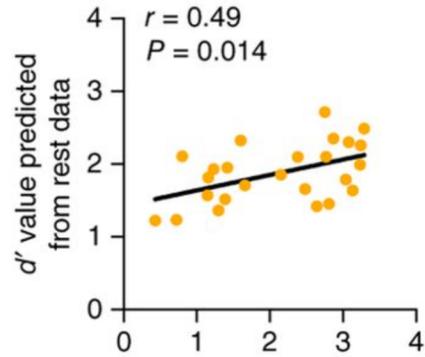


Rosenberg, Monica D., et al. "A neuromarker of sustained attention from whole-brain functional connectivity." *Nature neuroscience* (2015).

Predicting Other Behaviors

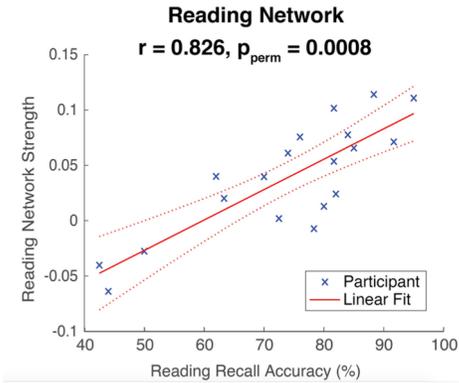
(slide courtesy of Emily Finn, Lecture 9)

Sustained attention



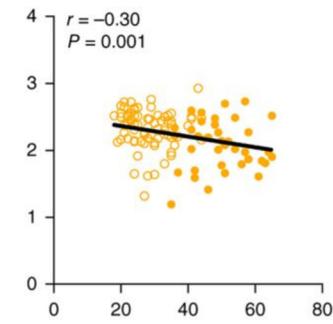
Rosenberg, Finn et al., *Nat Neurosci* (2016)

Reading ability

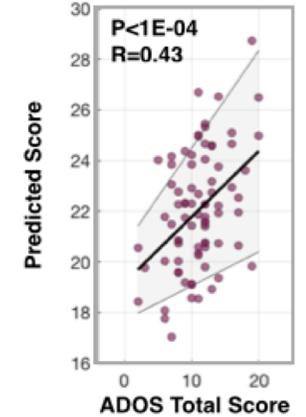


Jangraw et al., *NeuroImage* (2017)

ADHD, autism symptom severity

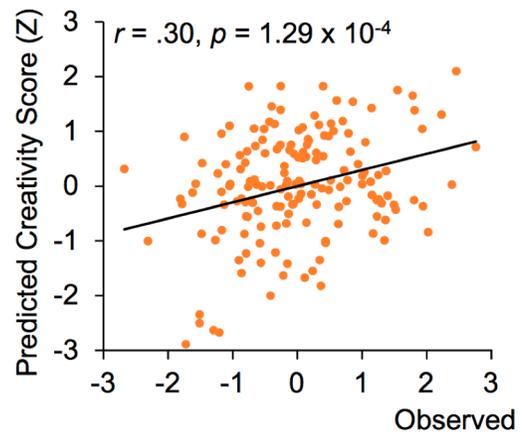


Rosenberg, Finn et al., *Nat Neurosci* (2016)



Lake et al., submitted

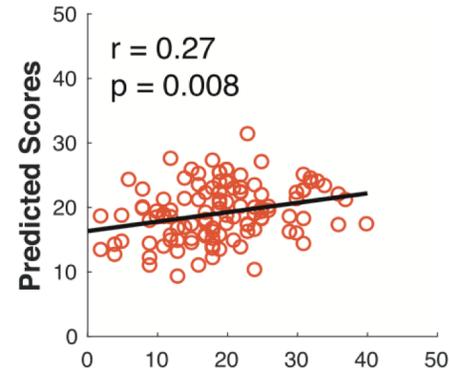
Creativity



Beaty et al., *PNAS* (2018)

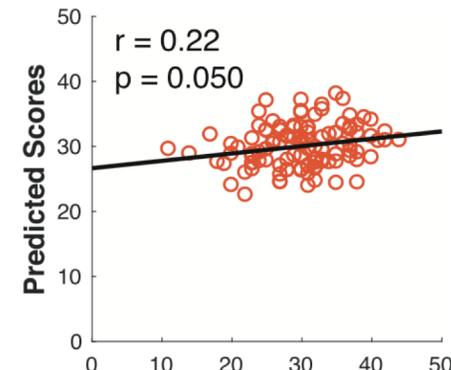
Personality traits

Neuroticism

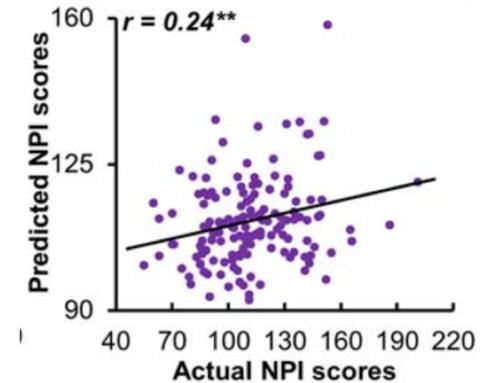


Hsu et al., *Soc Cogn Aff Neurosci* (2018)

Extraversion

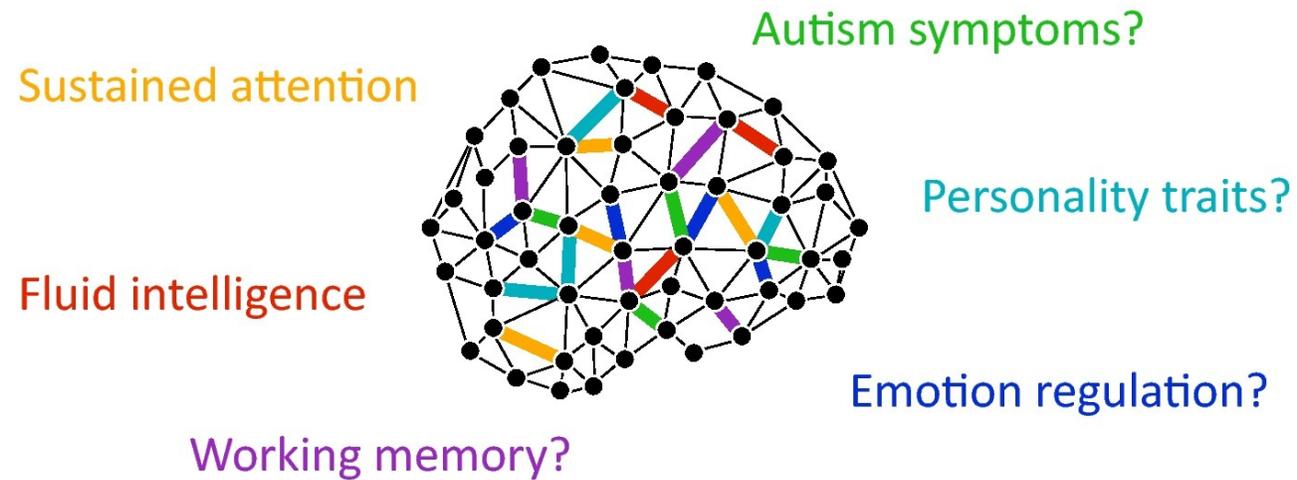


Narcissism



Feng et al., *Hum Brain Mapp* (2018)

Uncovering a Suite of Networks for a Suite of Abilities

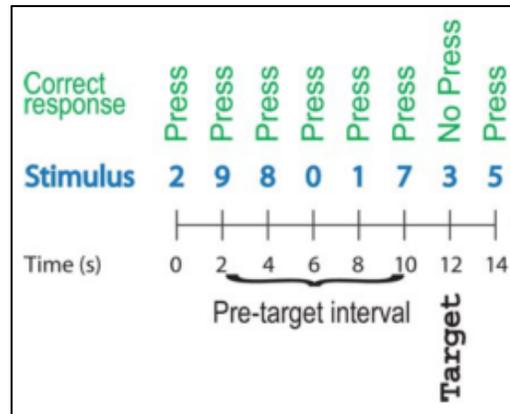


Performance as a State

“Mind-Wandering”

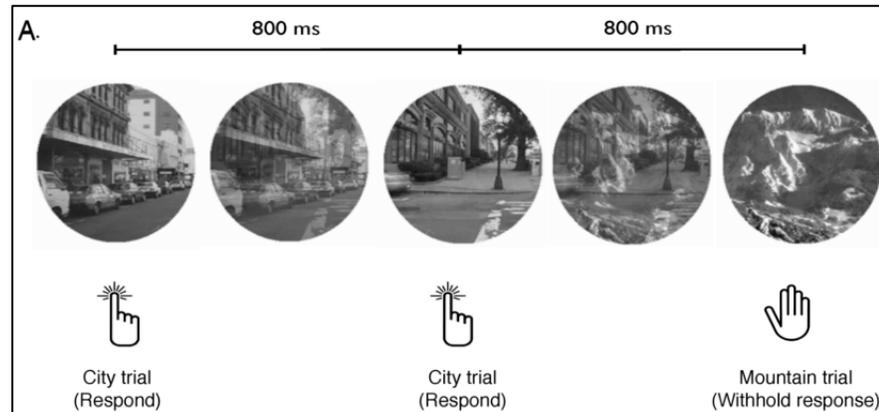
Sustained Attention Tasks

SART



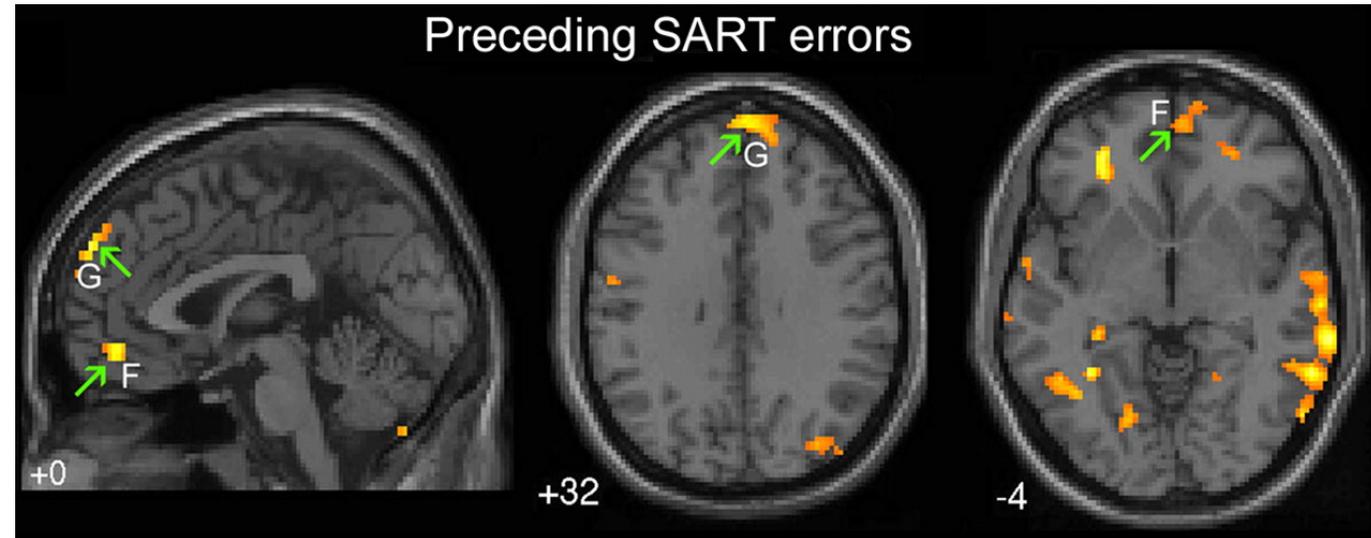
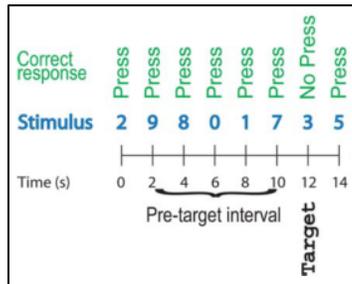
Christoff, 2009 PNAS

GradCPT

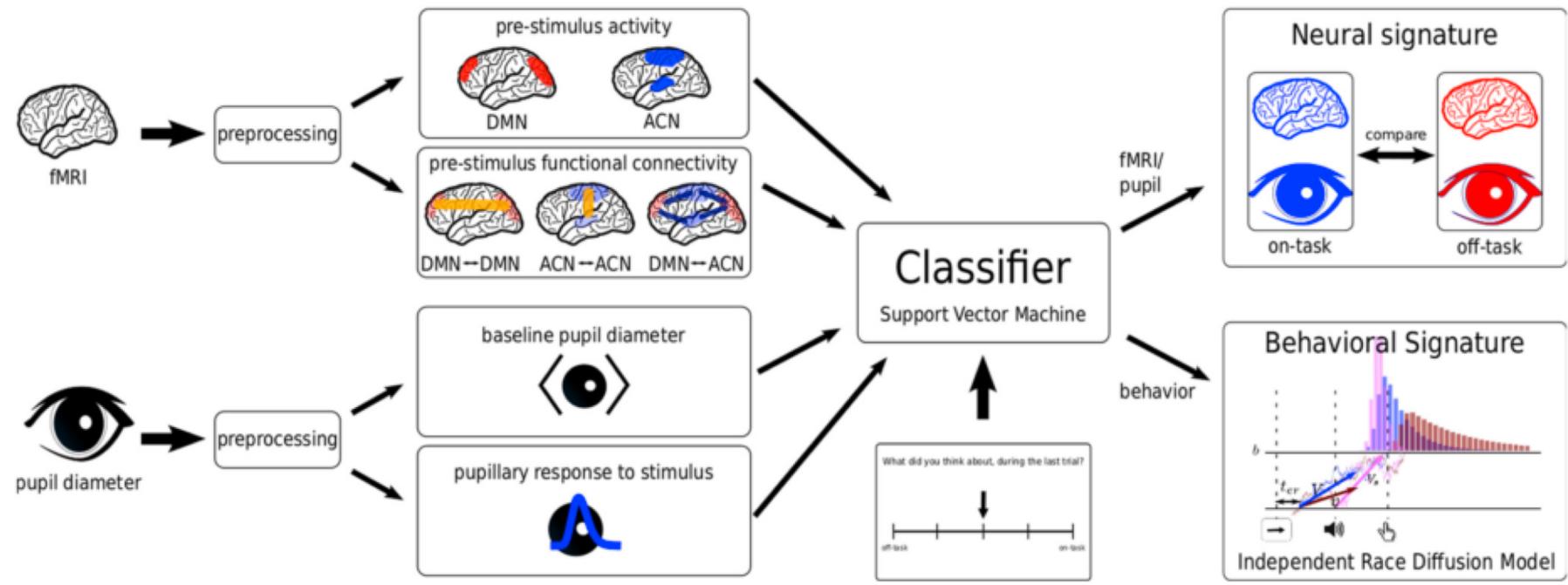
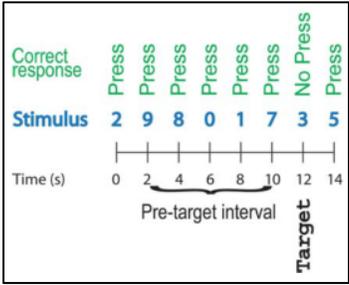


Esterman, 2013 Cer Cor

Activation-Based Mind-Wandering Prediction

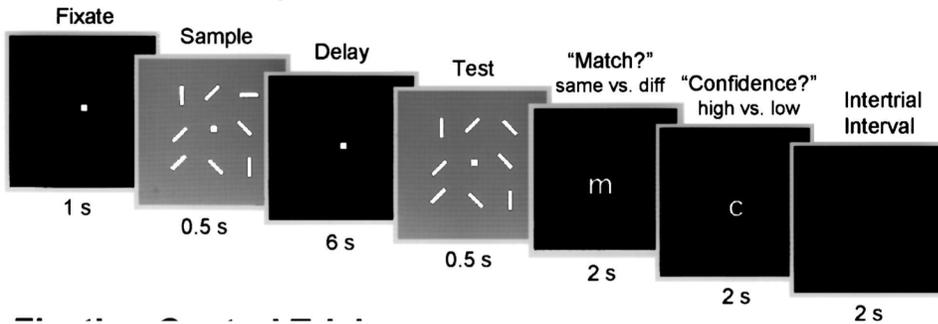


Multi-Feature Mind-Wandering Prediction



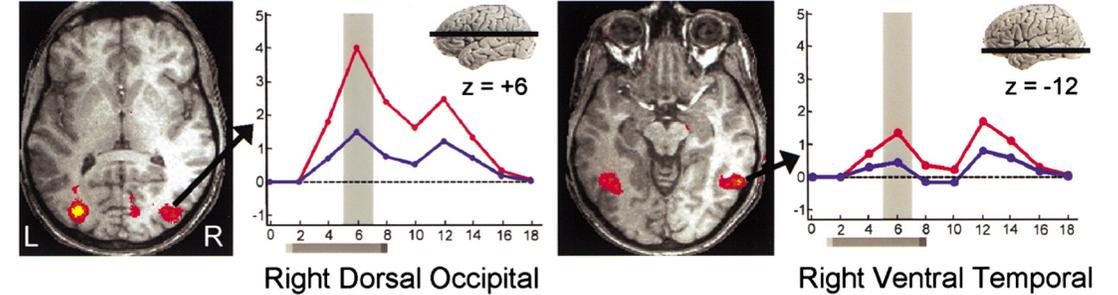
Activation Predicts Visual Working Memory Performance

Working Memory Trials

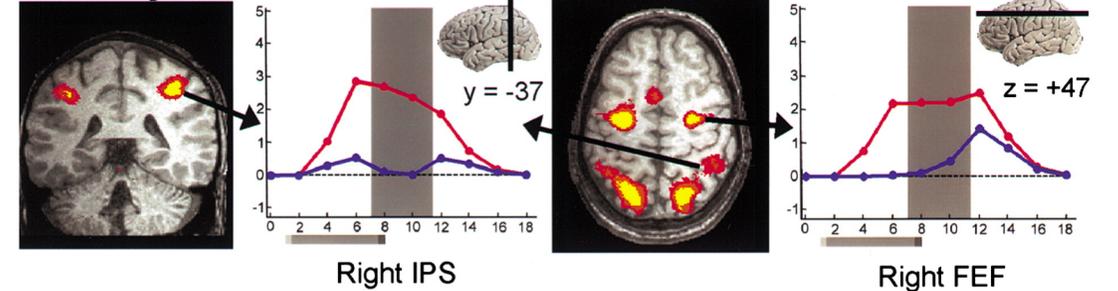


 Correct trials
 Incorrect trials

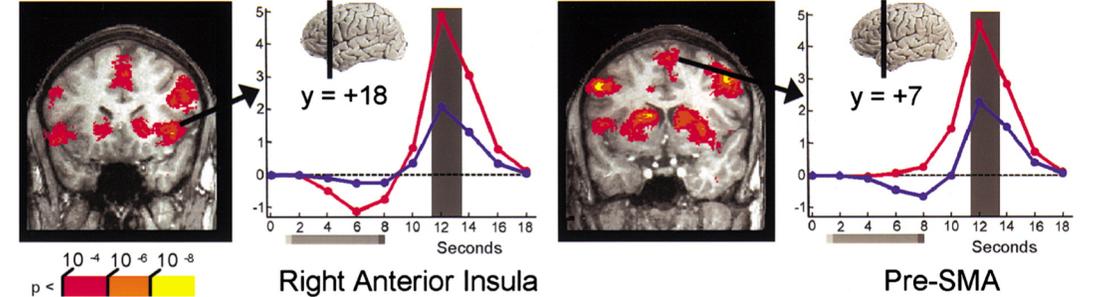
A. Encoding



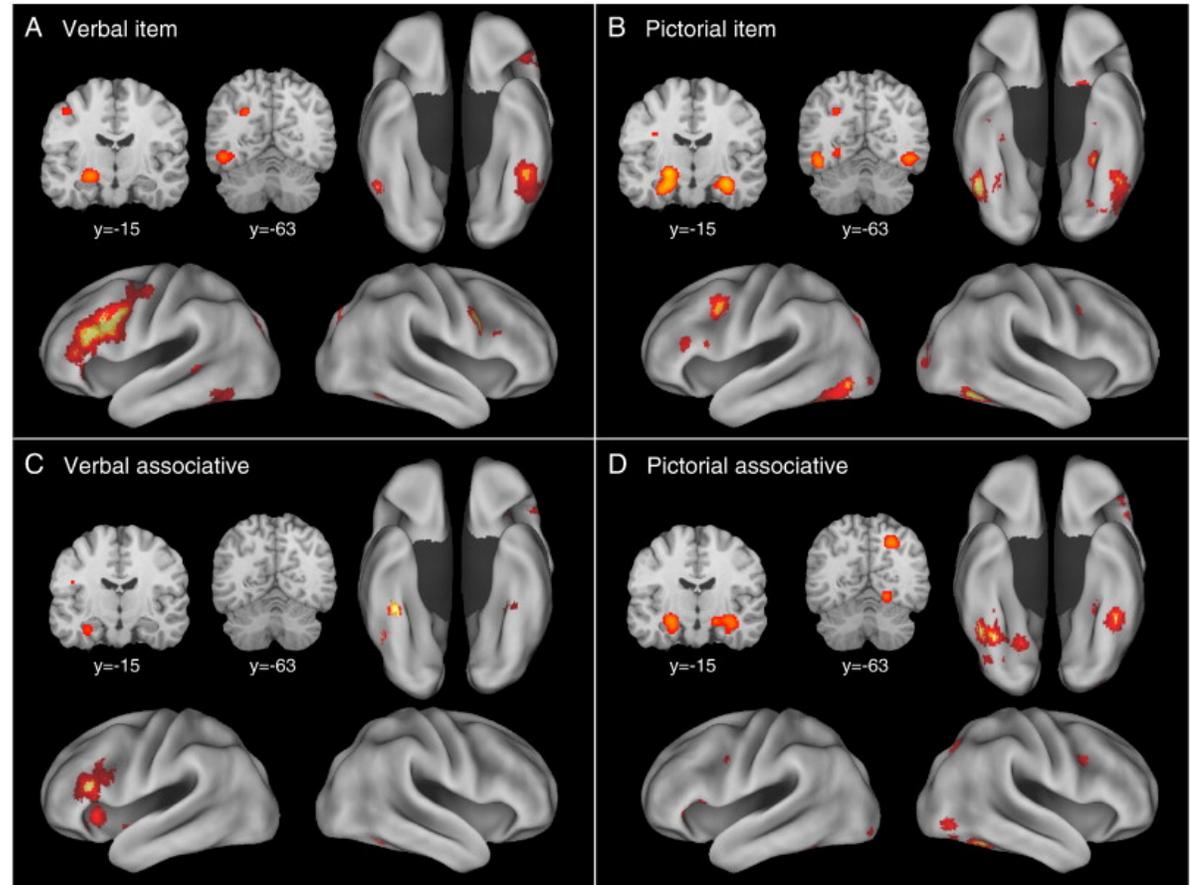
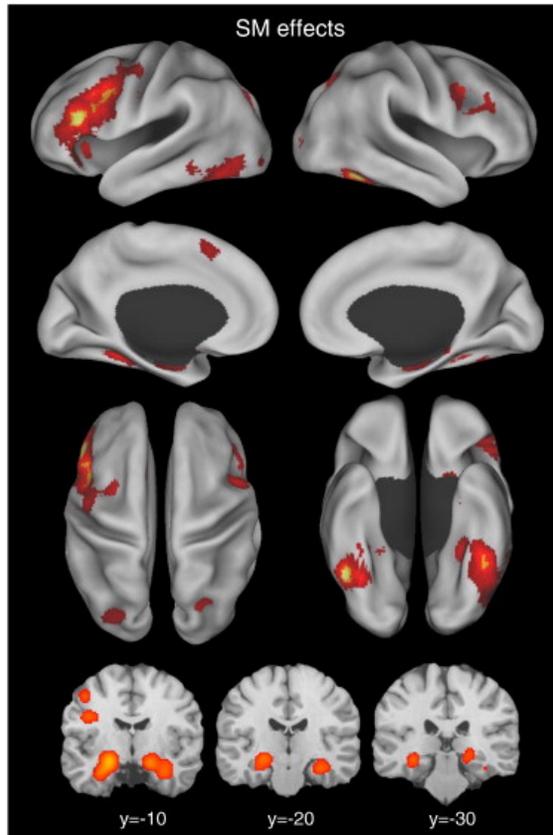
B. Delay



C. Test



Meta-Analysis of Subsequent Memory (SM)

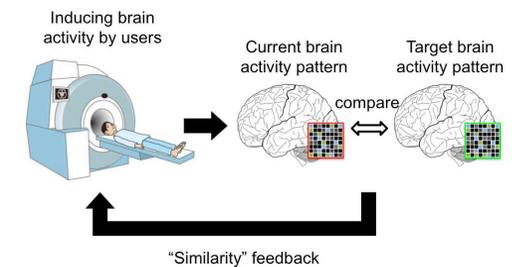
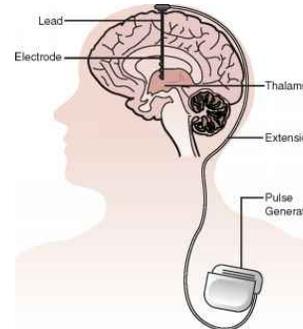


Kim, Hongkeun. "Neural activity that predicts subsequent memory and forgetting: a meta-analysis of 74 fMRI studies." *Neuroimage* 54.3 (2011): 2446-2461.

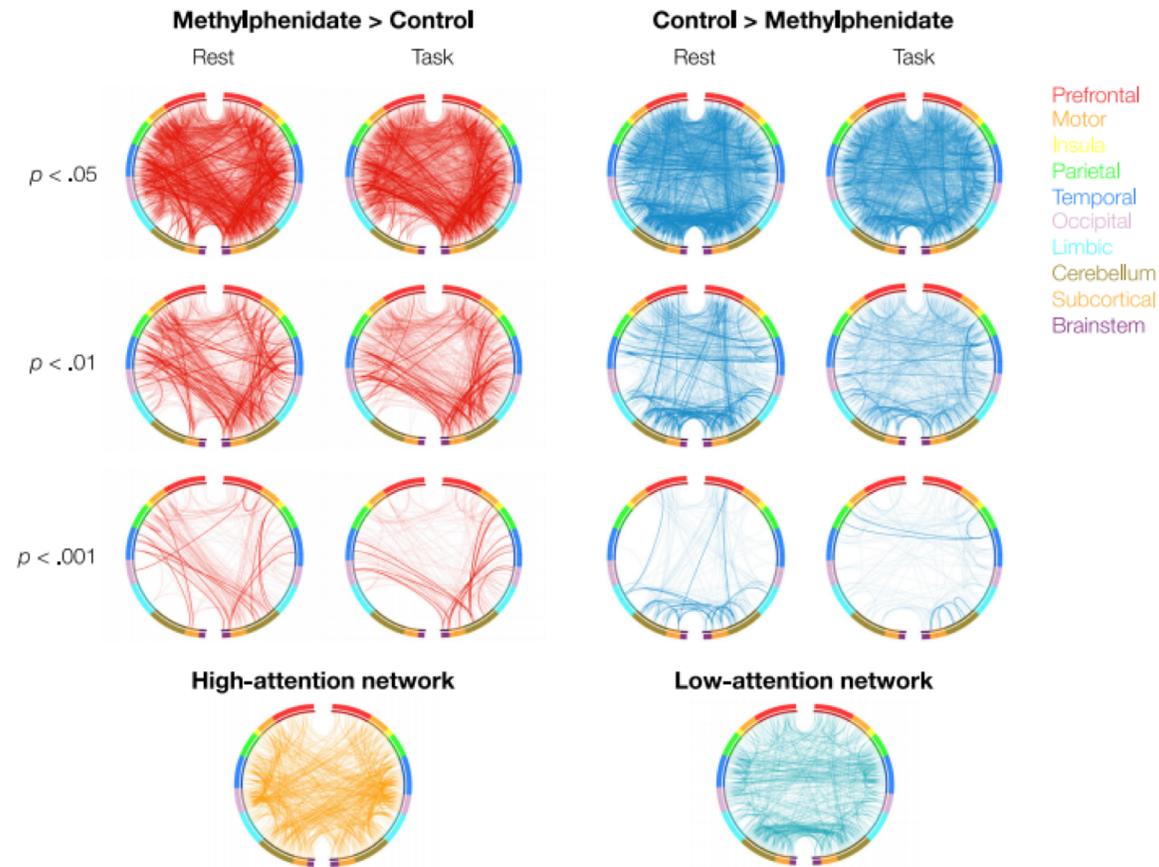
Intervening to Improve Performance

Targeted Interventions to Improve Performance

- Drugs
- Therapy
- Brain stimulation
- Neurofeedback



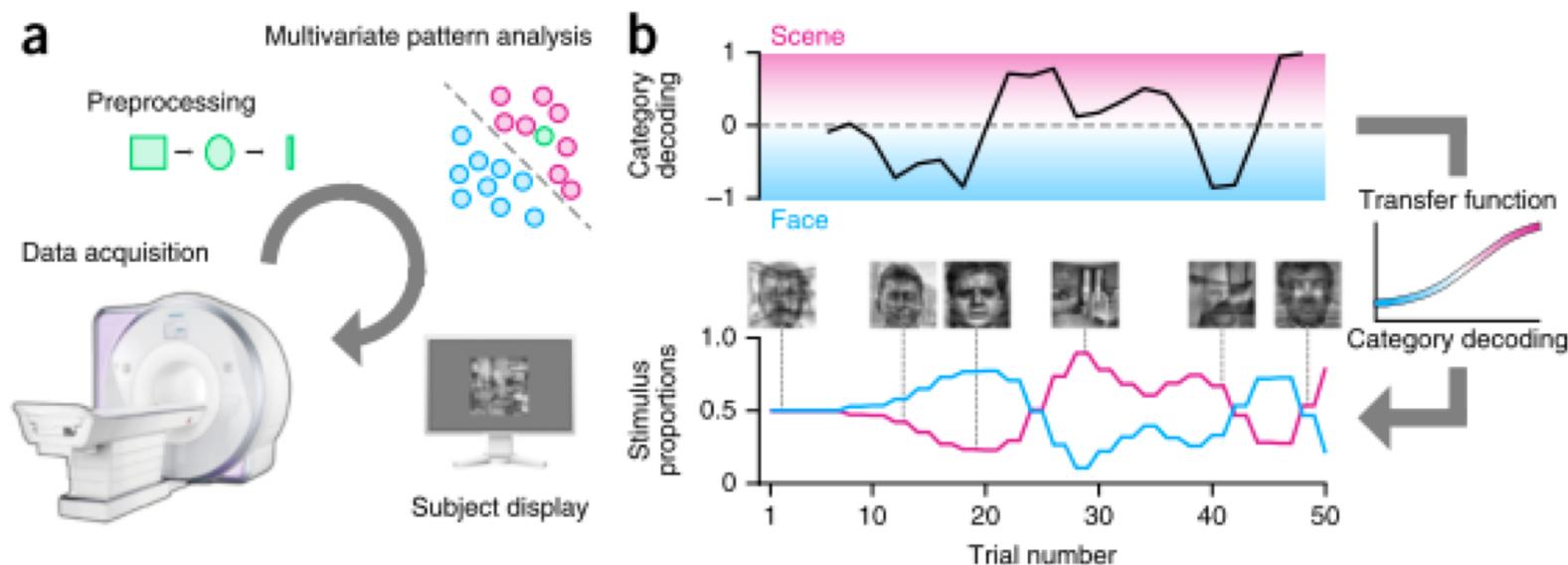
“Attention Network” Functional Connectivity Influenced by Methylphenidate (Ritalin)



Rosenberg, Monica D., et al. "Methylphenidate Modulates Functional Network Connectivity to Enhance Attention." *Journal of Neuroscience* 36.37 (2016): 9547-9557.

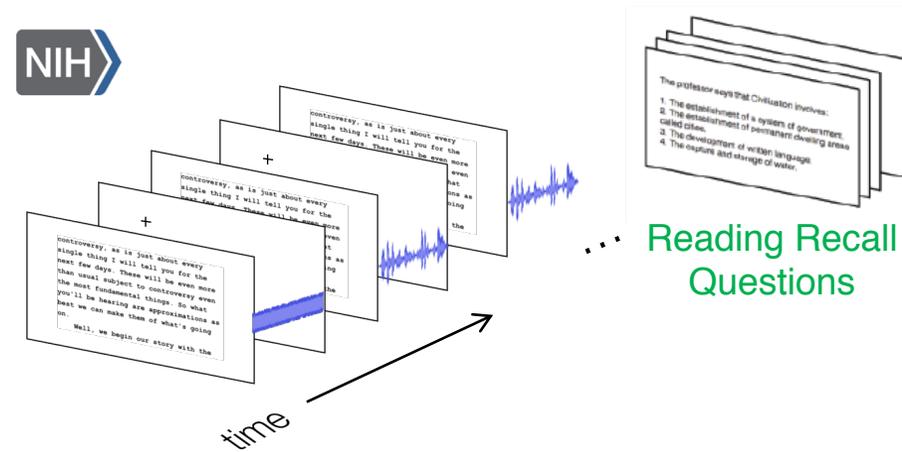
Face/Scene MVPA Pattern and Neurofeedback

- Visual discrimination task on blended face & scene
 - Real-time decoding of focus on face or scene
- Neurofeedback based on decoding improved focus

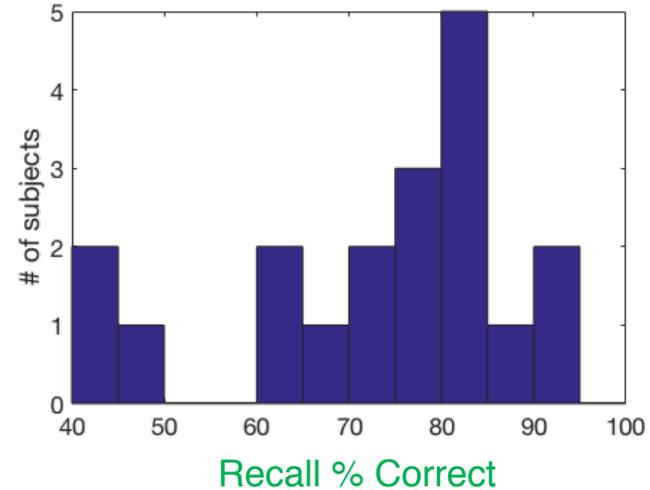


Case Study: Predicting Reading Recall

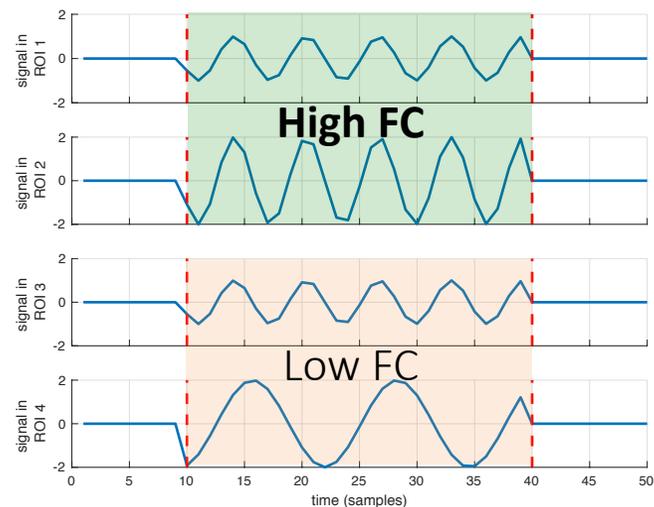
Predicting Recall Behavior from a Naturalistic Reading Task



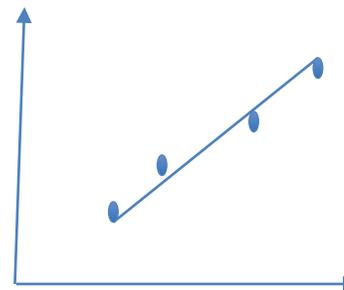
Reading Recall Behavior



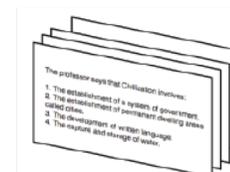
Functional Connectivity (FC): Patterns of Correlating Activity



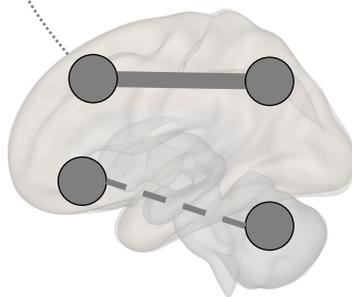
Mean FC
in network



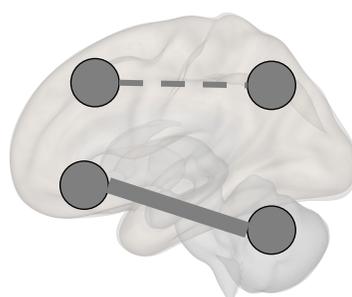
Reading recall



Good Readers

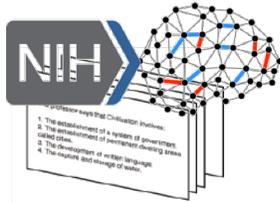


Bad Readers

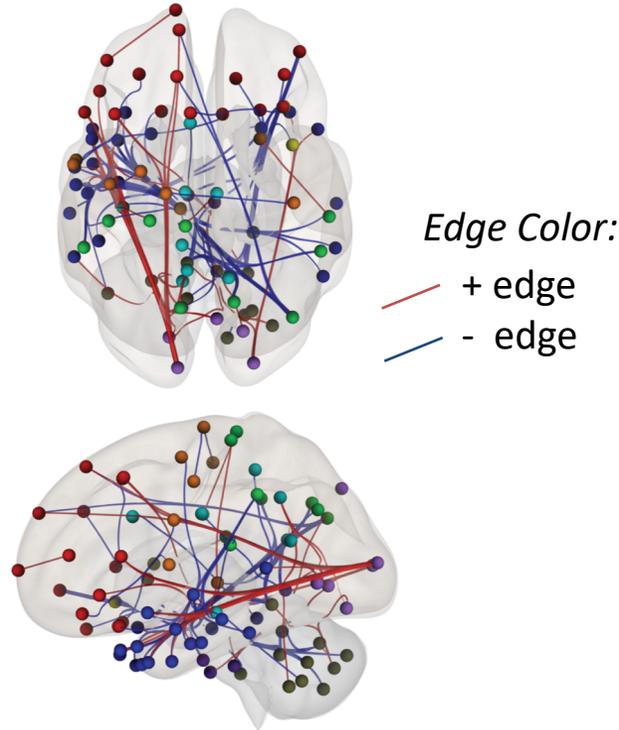


+ edge
- edge

Found "Reading Network" Whose FC Predicts Reading Recall

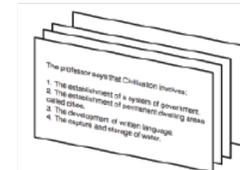
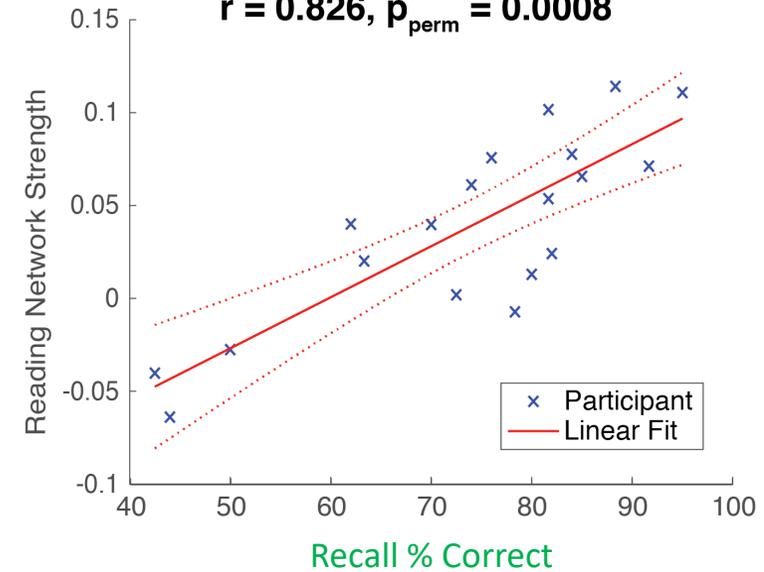


Reading Network

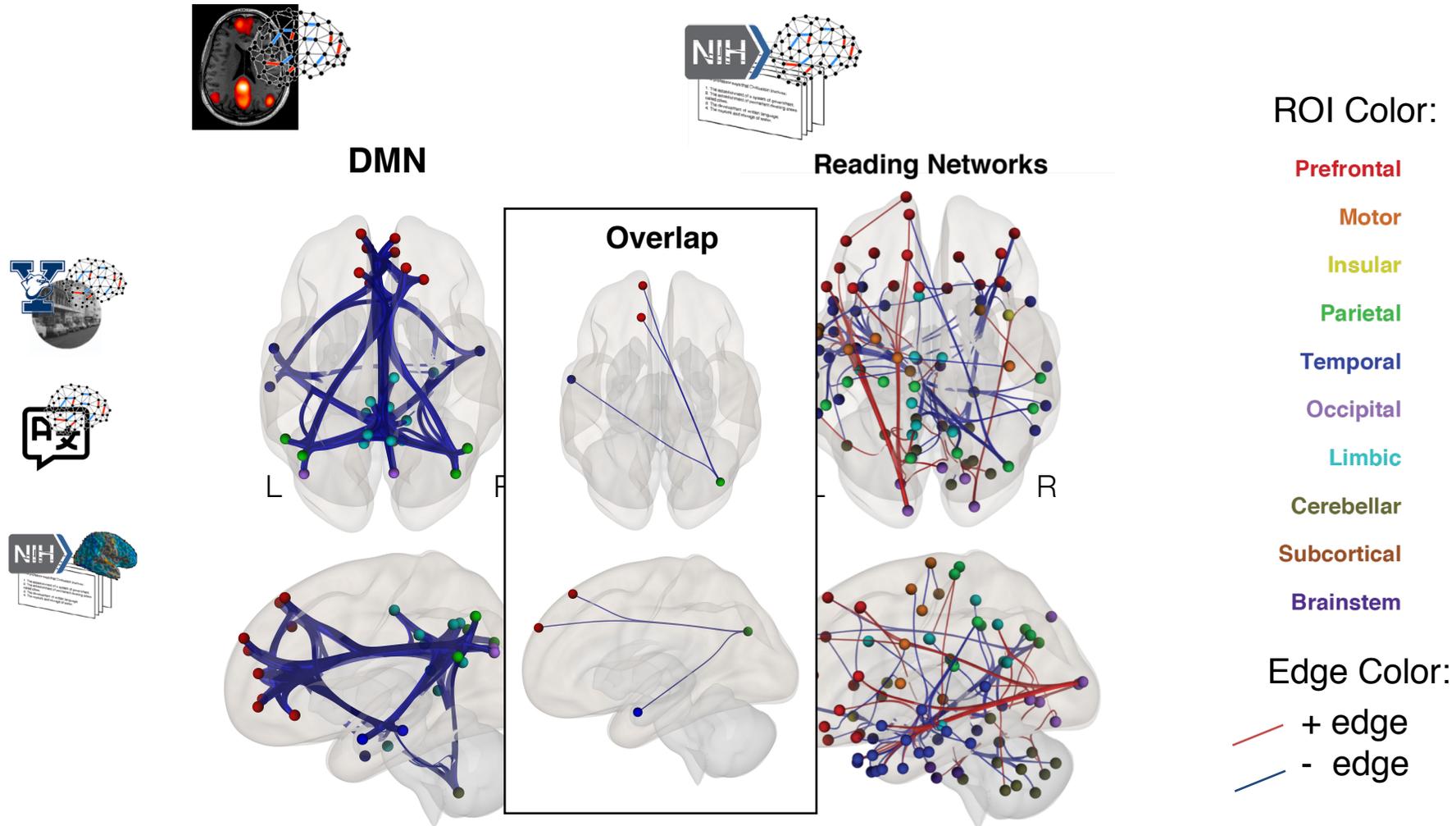


FC in Reading Network Predicts Subject's Recall (LOO Cross-Validated)

$r = 0.826$, $p_{\text{perm}} = 0.0008$

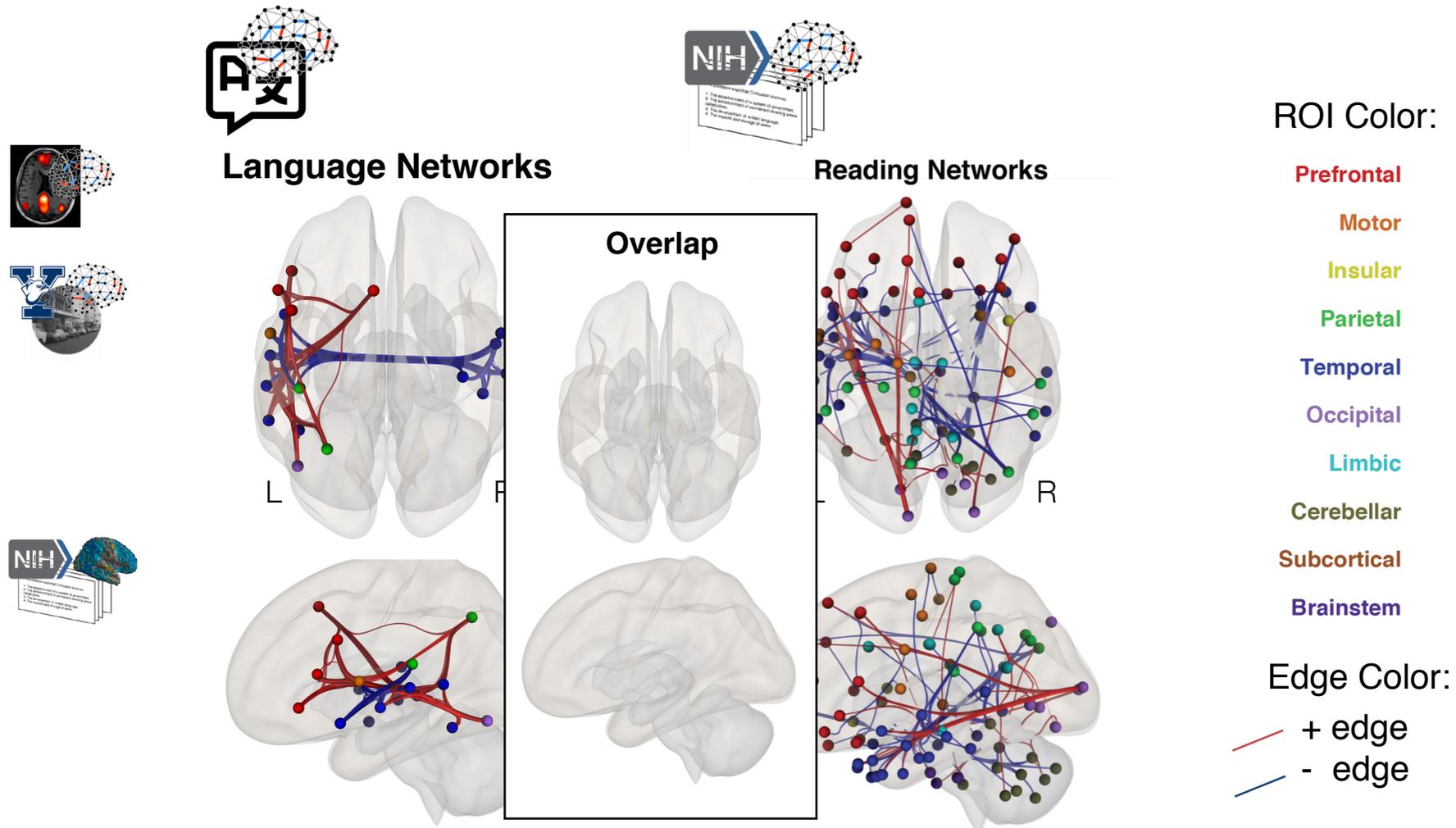


Spatial Distribution of Reading Network is Distinct from Default Mode Network



Derived from NeuroSynth (Yarkoni, 2011)

Spatial Distribution of Reading Network is Distinct from Language Network

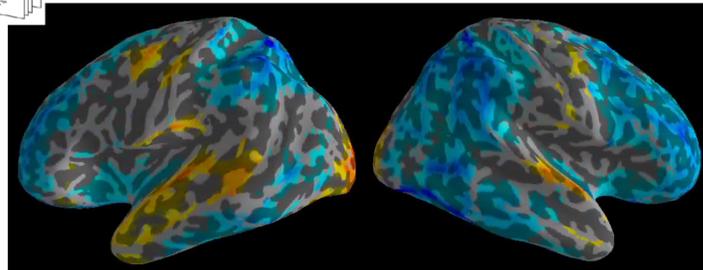


Derived from NeuroSynth (Yarkoni, 2011)

Regions Informing Reading Recall Performance are Distinct from Typical Activation Maps

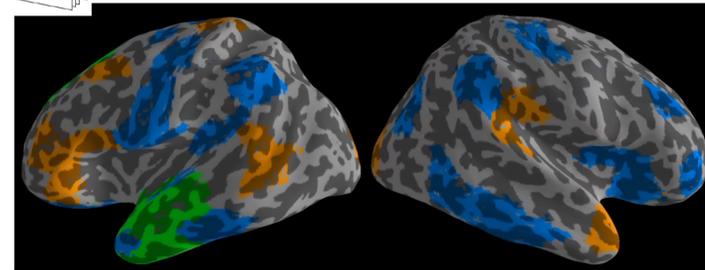


NIH **GLM of Reading vs. Fixation**



-3 Group β Value 3

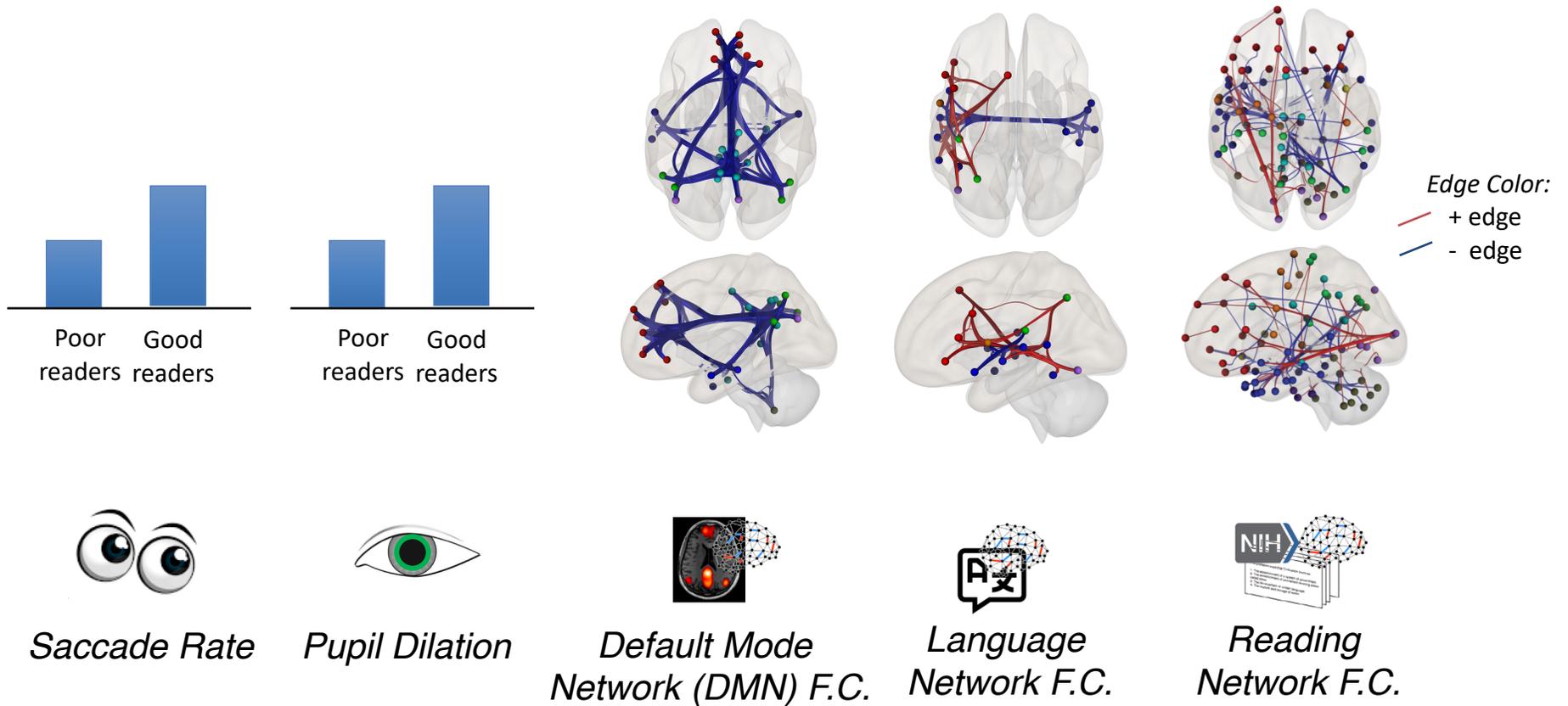
NIH **Reading FC Network**



Orange Positive Network
Blue Negative Network
Green Both

Reading Network

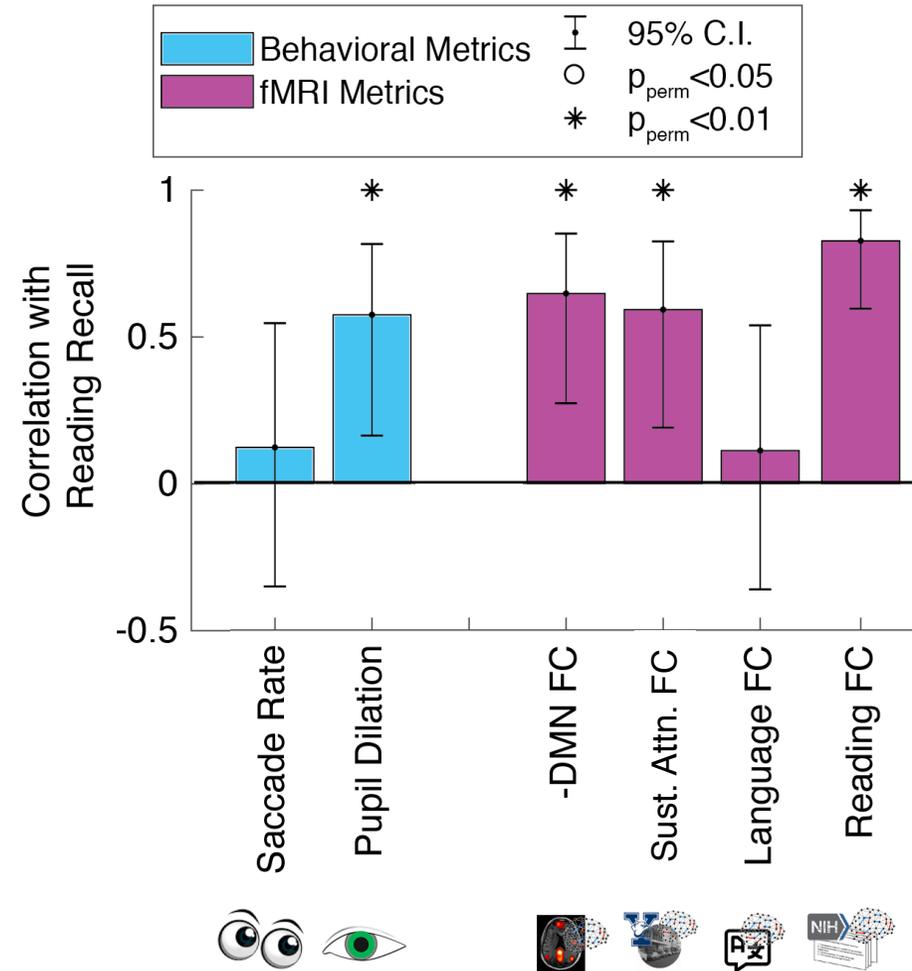
Uses Different Brain Areas



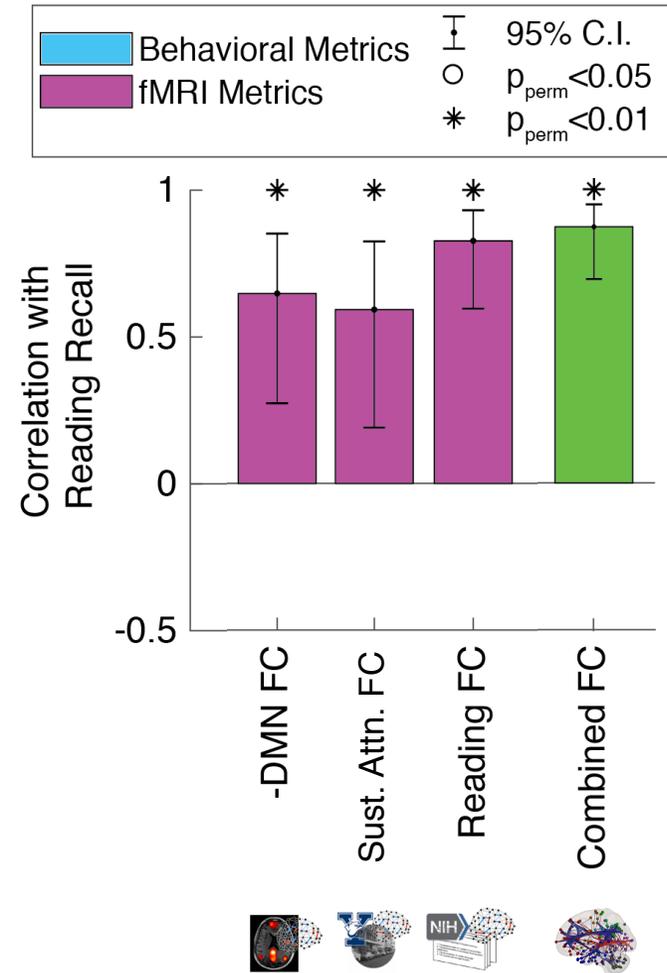
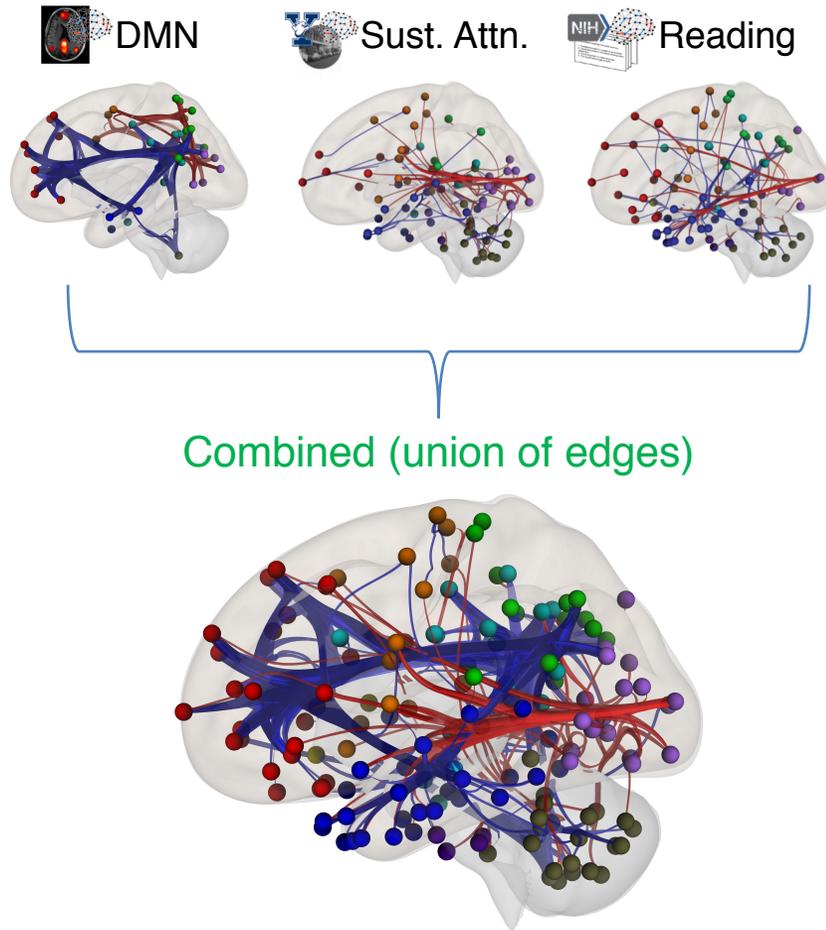
Eye-Based Predictors

Brain-Based Predictors

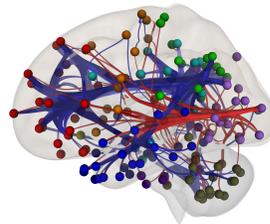
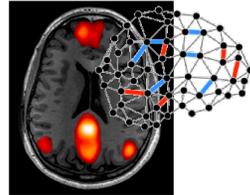
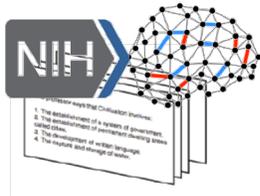
Reading Network Outperforms Other Metrics



Combining Reading Edges with Attention Edges Can Improve Prediction



Reading Recall Prediction: Outcomes

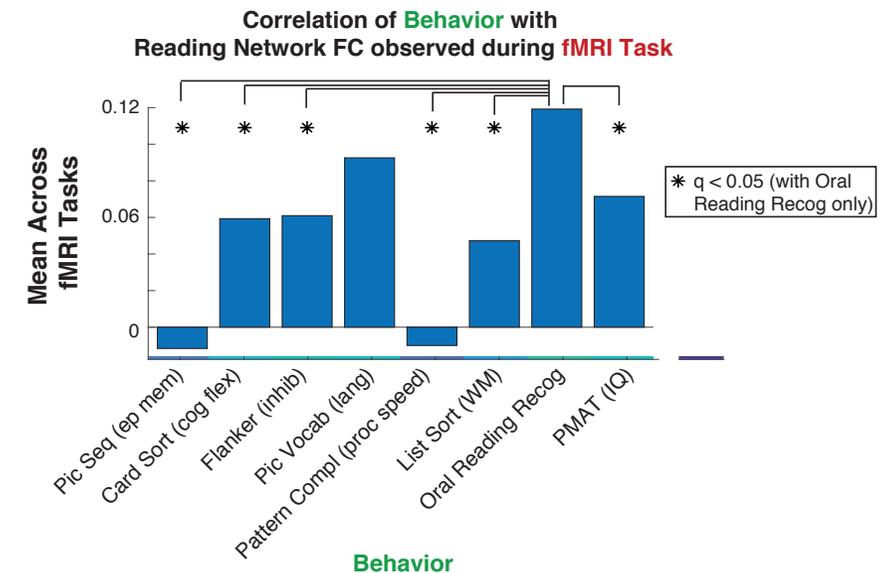


- Identified **Reading-Recall-Specific Brain Network**
- It uses **Different Brain Areas** from attention/language metrics
- It has **Predictive Information** beyond other metrics
- Its information is **Not Redundant** with other metrics
 - Using them together could boost prediction

Confounds and Conclusions

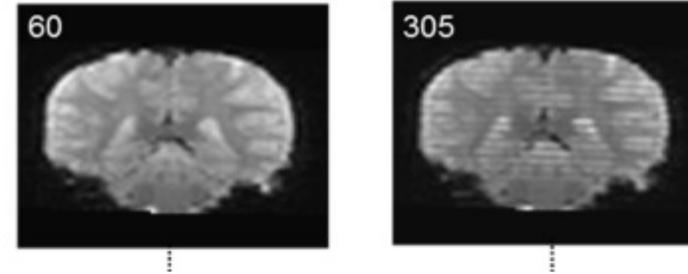
Performance Confounds: IQ & Compliance

- Reliability of MRI signature depends on reliability of performance measure
- Often covaries with conditions
- Collect multiple performance measures
 - Remove effect with projection, partial correlation
- Decide whether you care!



MRI Confounds: Motion & Breathing

- Can lead to fMRI signal change not coming from brain activity
- Often covaries with conditions
- Preprocessing and Censoring
 - See previous lectures
- Motion-matched participants
- Careful examination of data & results

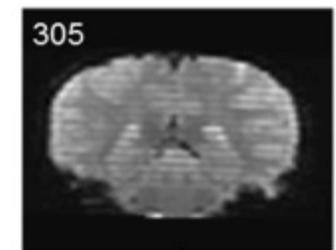
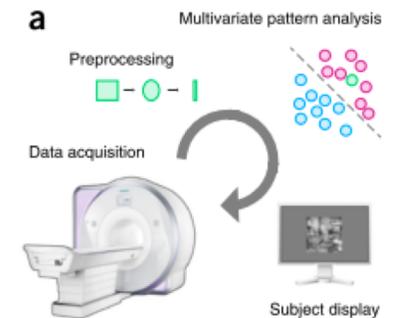
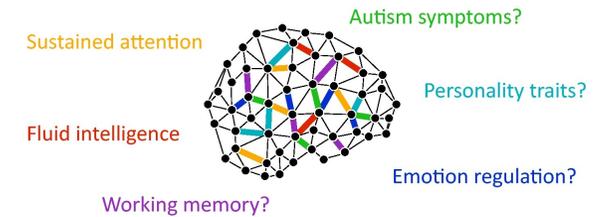


	ADHD		Normal controls		t-test values
	Mean	(S.D.)	Mean	(S.D.)	
Youths					
Mock scanner motion	5.0	(7.6)	3.0	(4.1)	0.76
Actual scanner motion	0.10	(0.06)	0.07	(0.04)	1.50
Parents					
Mock scanner motion	3.1	(3.7)	1.4	(1.6)	1.38
Actual scanner motion	0.08	(0.03)	0.07	(0.04)	0.49

Note: Mock scanner motion measured as the number of **head movements** greater than 2 mm; actual scanner motion measured as mean motion (in mm) per image acquisition (i.e., 2.5 s).

Conclusions

- Performance is central to quality of life
- Prediction can be based on many features
 - Combination of literature and “data-driven” selection
- Performance can be State-Based (Innate Ability)
 - Stable, present regardless of Task
- Performance can be Trait-Based (Mind-Wandering)
 - Based on time-limited signals observed during task
- Performance Prediction with fMRI can:
 - Shed light on neural processes and individual differences
 - Suggest targeted interventions (drugs, neurofeedback)
- Confounds can affect results & interpretation
 - Be proactive!



Thanks To:

SFIM

- **Emily Finn**
- **Javier Gonzalez-Castillo**
- **Daniel Handwerker**
- **Puja Panwar**
- **Peter Bandettini**
- Pete Molfese
- Laurentius Huber
- Yuhui Chai
- Sara Kimmich
- Benjamin Gutierrez
- Natasha Topolski
- Harry Hall

LBC & AFNI

- **Merage Ghane**
- Paul Taylor
- Daniel Glen

NIMH

- Danny Pine
- Ellen Leibenluft
- Argyris Stringaris
- The Emotion & Development Branch
- Analyses used the High-Performance Computing Biowulf Cluster

Yale

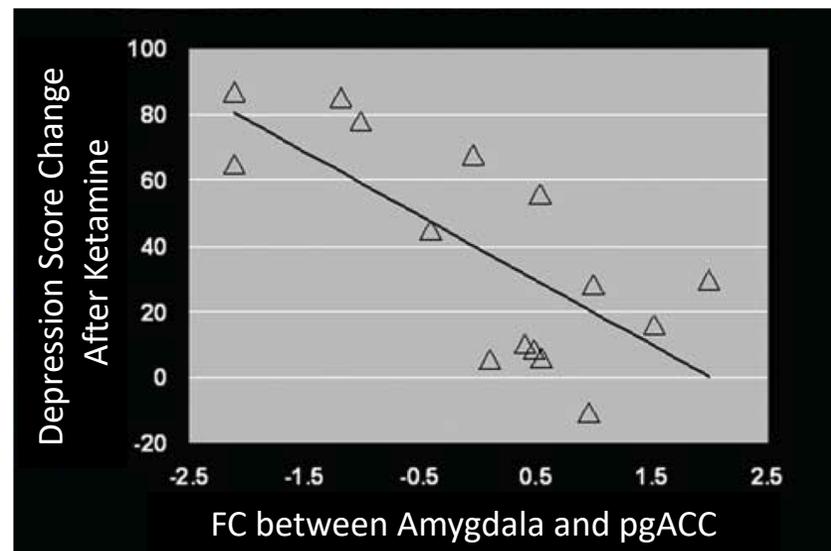
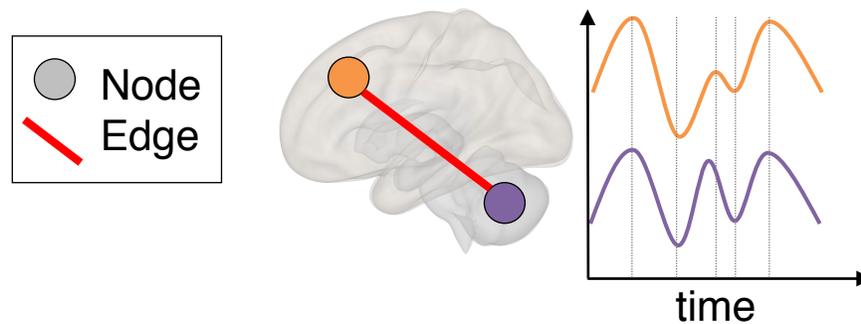
- **Monica Rosenberg**

*Co-authors in **Bold***



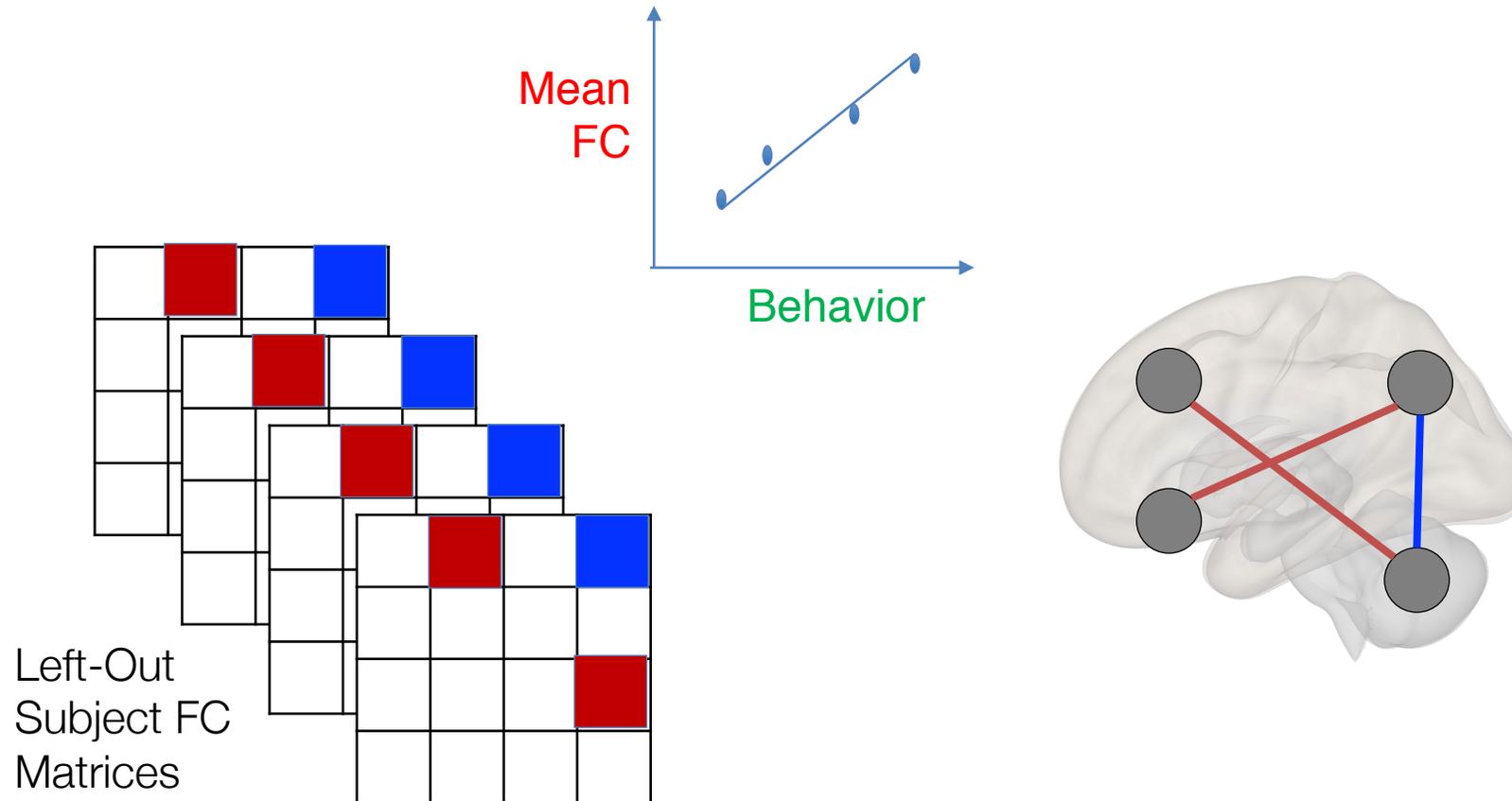
Extra Slides

Better Predictions with Functional Connectivity (FC)

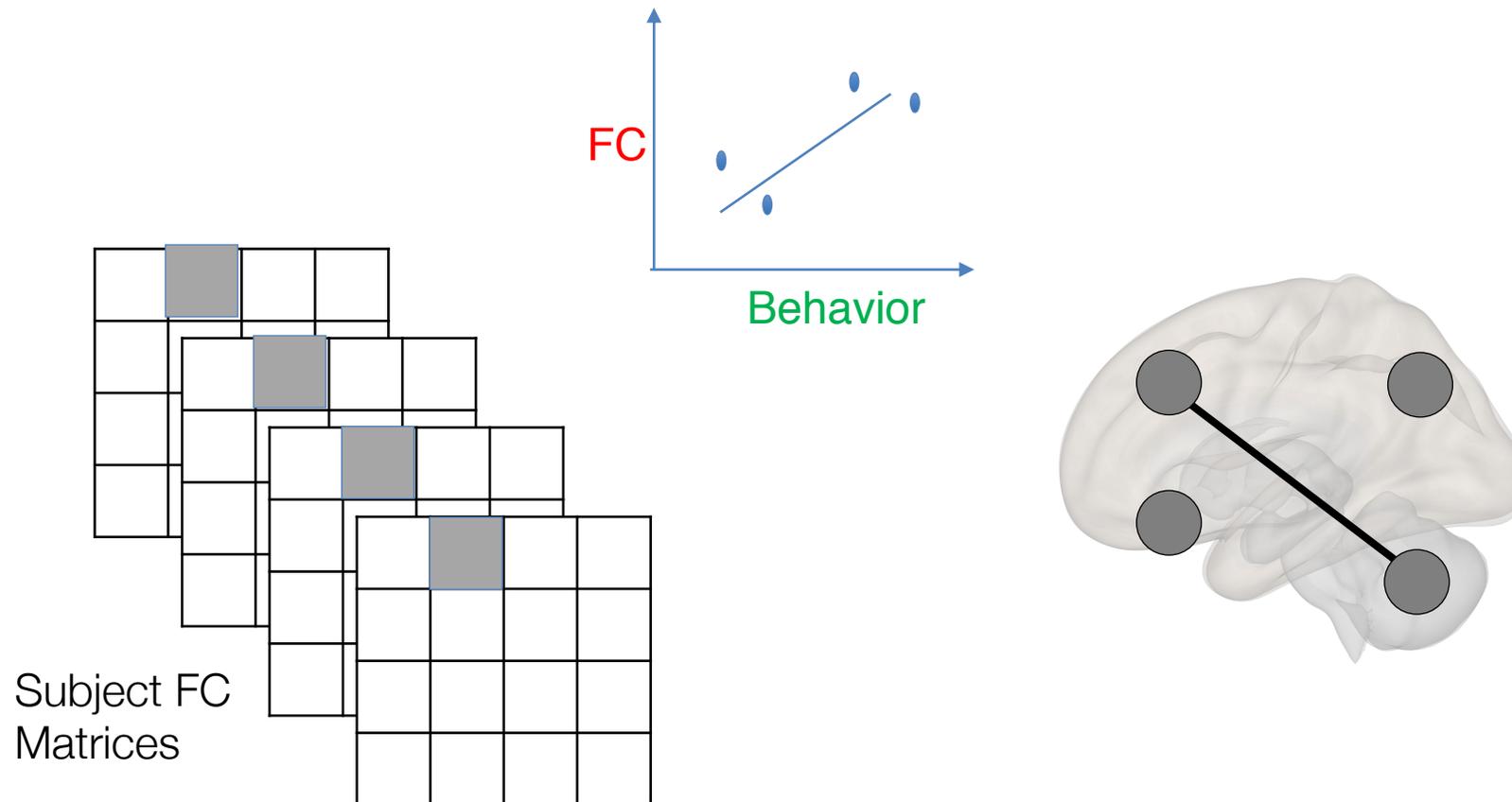


Salvadore, Neuropsychopharmacology 2010

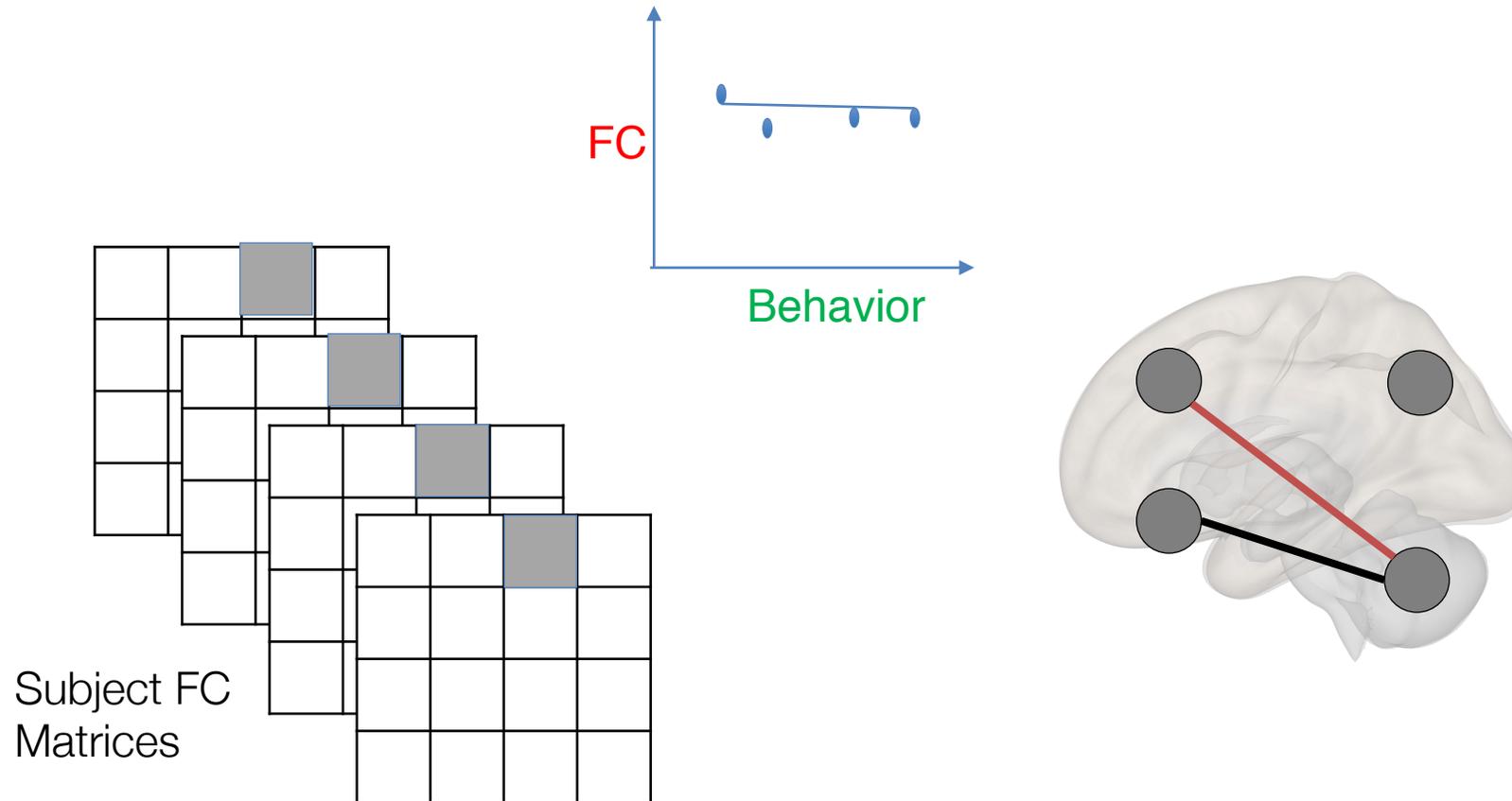
Better Predictions with Whole-Brain FC



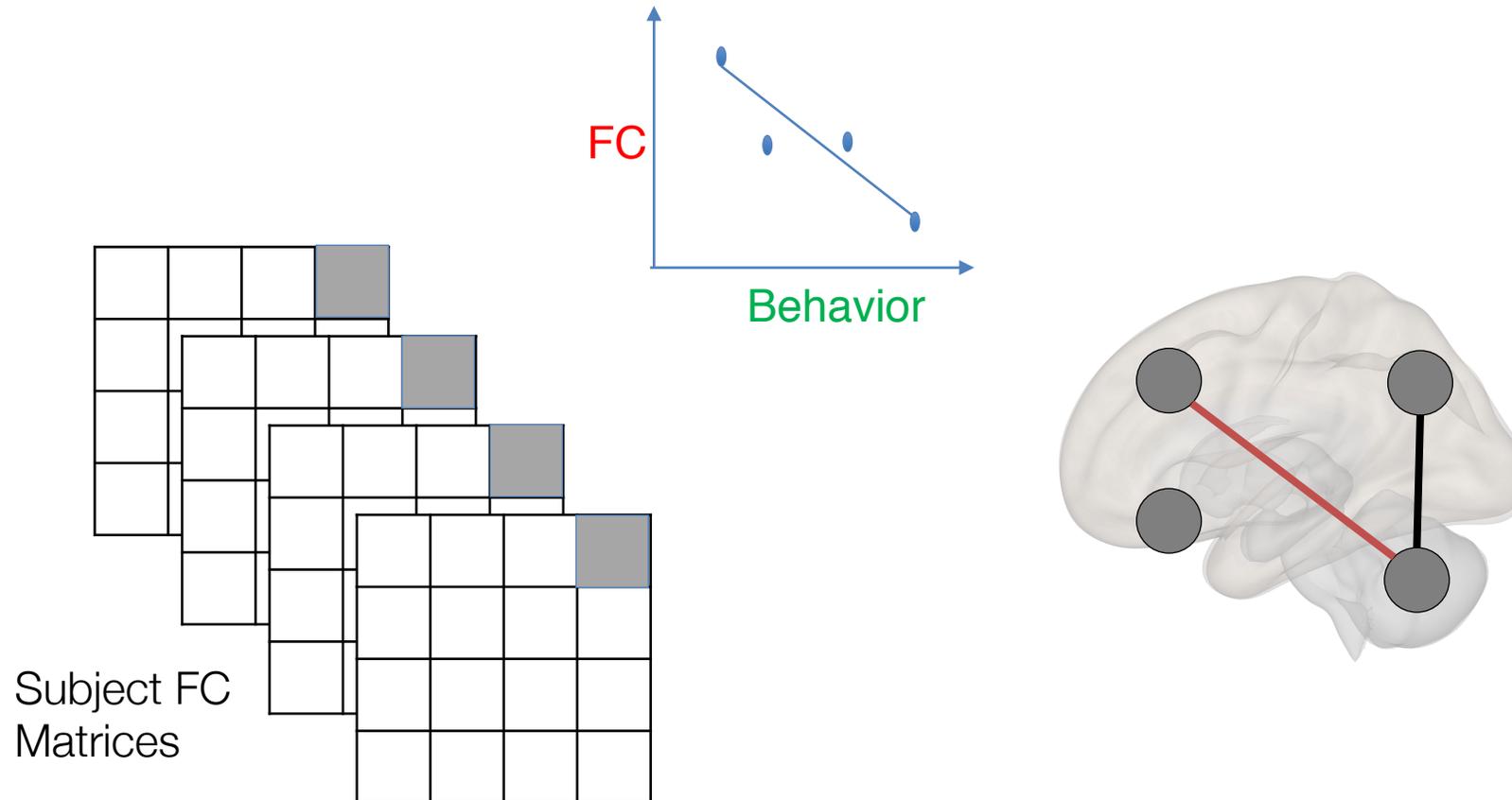
Connectome-based Predictive Modeling: Whole-Brain FC Predicts Participant's Behavior



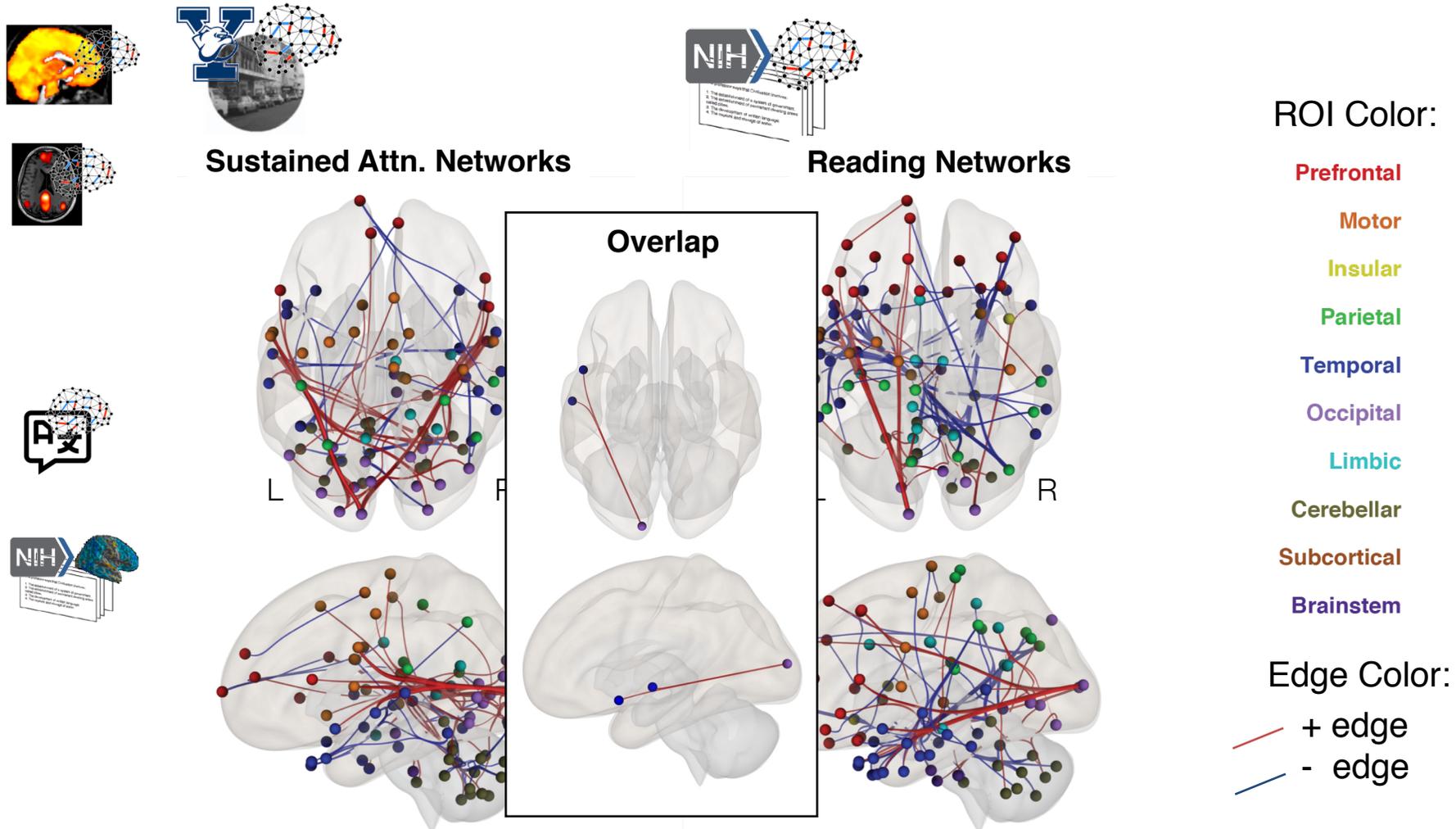
Connectome-based Predictive Modeling: Whole-Brain FC Predicts Participant's Behavior



Connectome-based Predictive Modeling: Whole-Brain FC Predicts Participant's Behavior

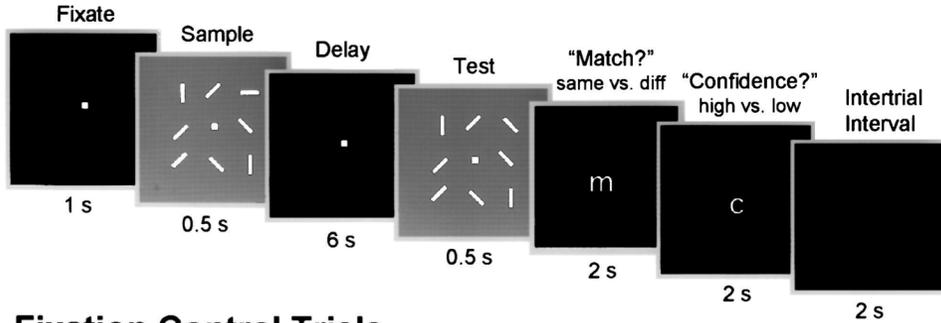


Spatial Distribution of Reading Network is Distinct from Sustained Attn. Network

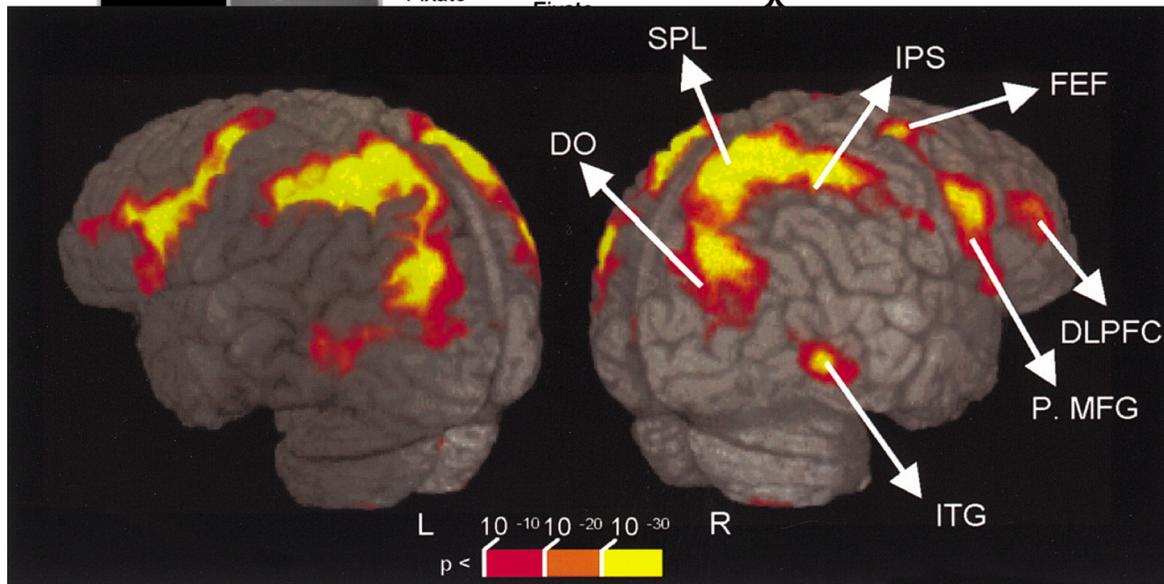


Activation Predicts Visual Working Memory Performance

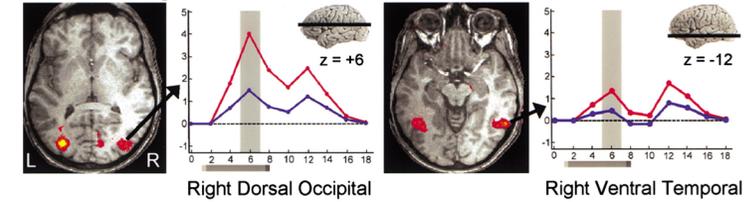
Working Memory Trials



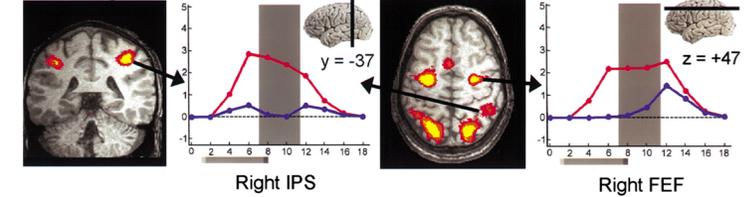
Fixation Control Trials



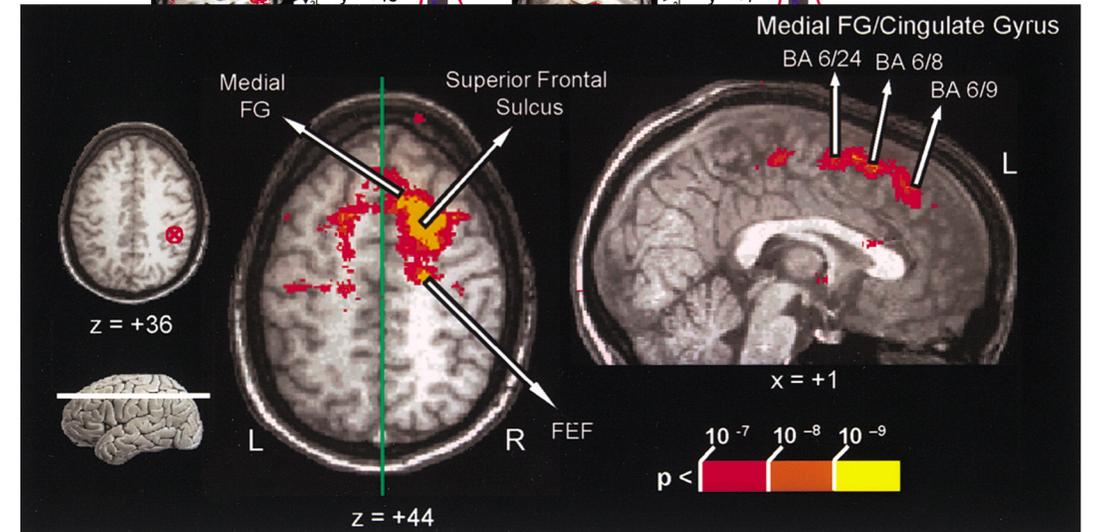
A. Encoding



B. Delay



C. Test



DMN and WM networks have stronger negative FC in good n-back (WM) performers

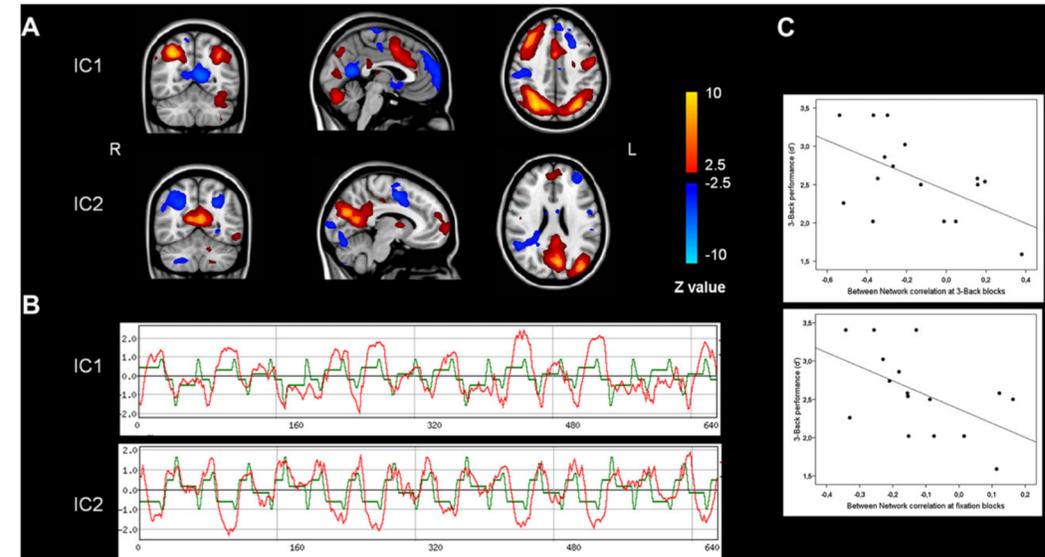
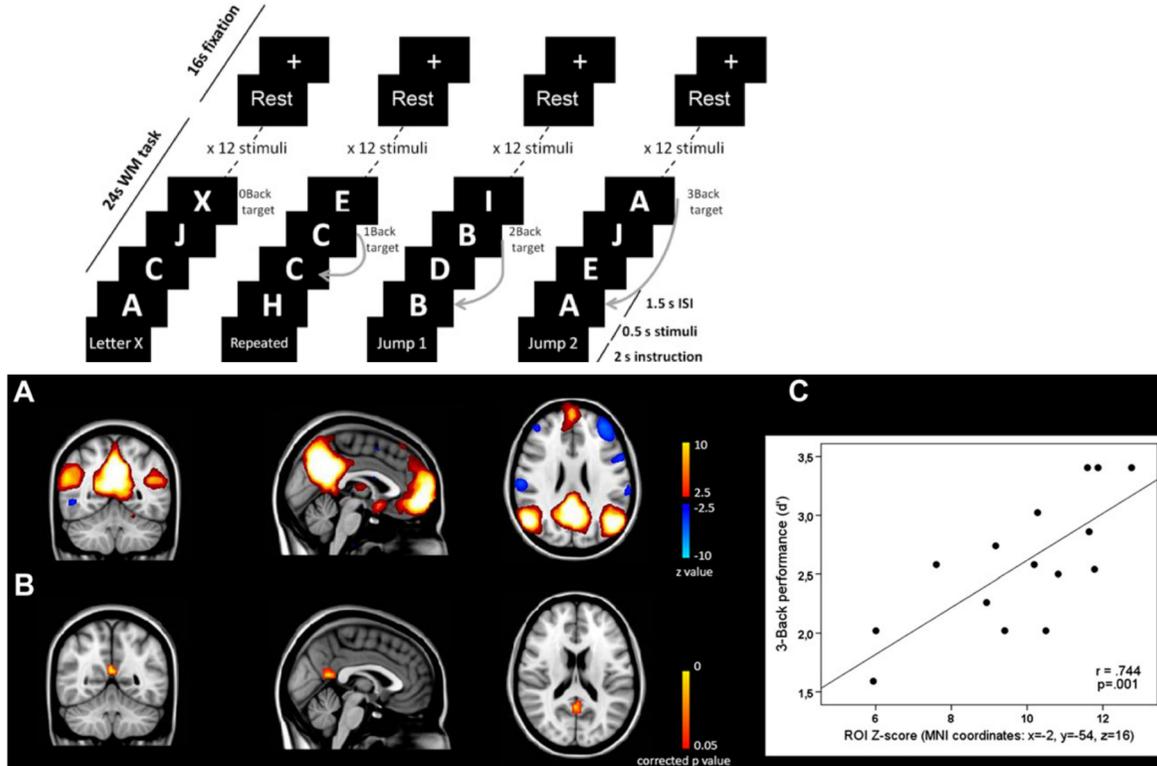


Fig. 4 – (A) Spatial maps of the two selected components: IC1 corresponds to the WMN and IC2 to the DMN. Hot colours represent brain activations and cold colours represent deactivations. (B) Time series of the two components: red lines are the component-related mean responses, while green lines show the fit with the task. (C) Scatter plots showing the relationship between the between-network correlations in the 3-back and fixation blocks and individual performance scores for the 3-back WM task.

Fig. 3 – (A) Spatial pattern of the DMN for all subjects during the resting acquisition. (B) Area within the DMN whose activity correlates with subsequent 3-back performance ($p < .05$, FWE corrected). (C) Scatter plot depicting a positive correlation between the DMN Z-values of the precuneus and WM performance.