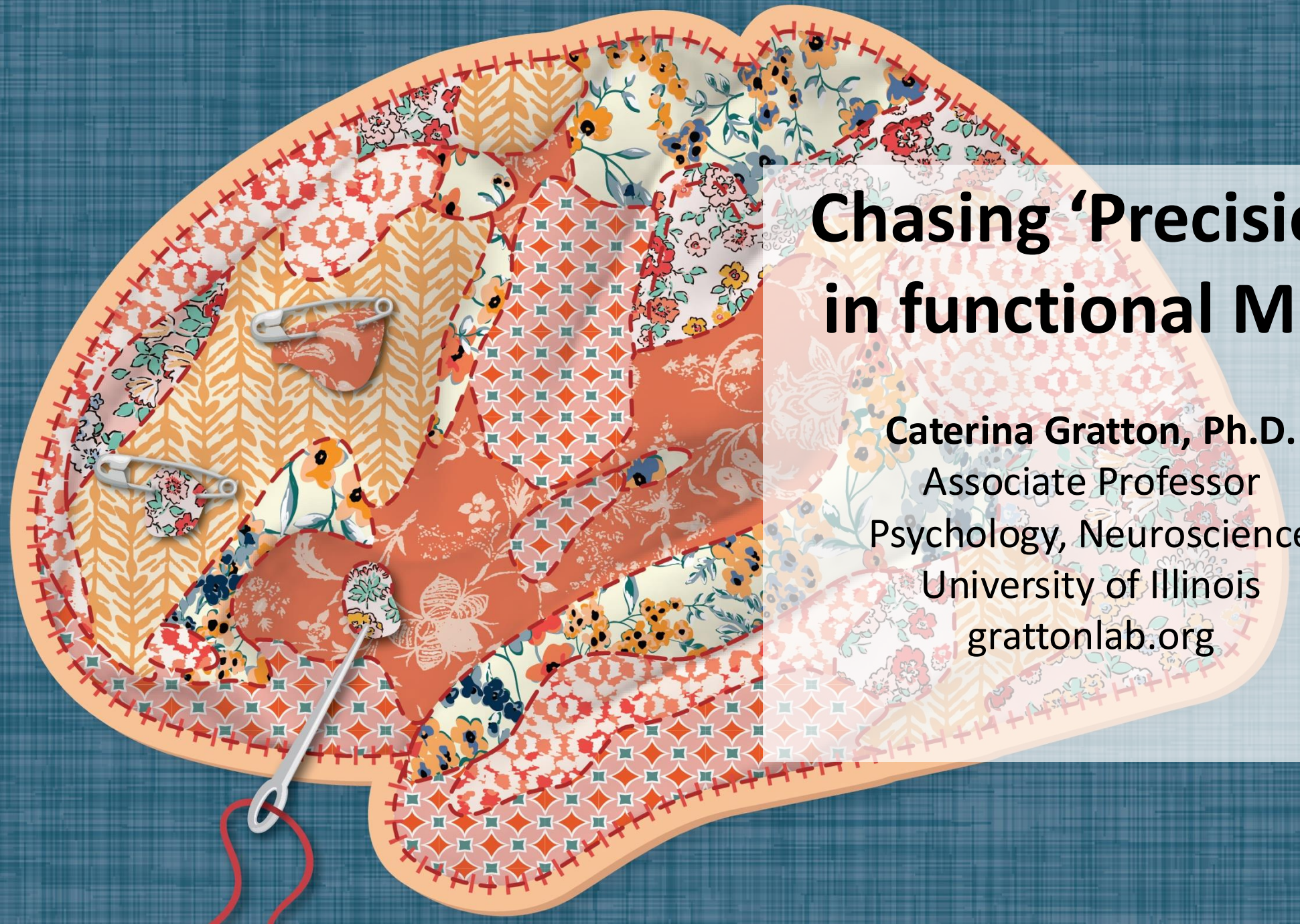
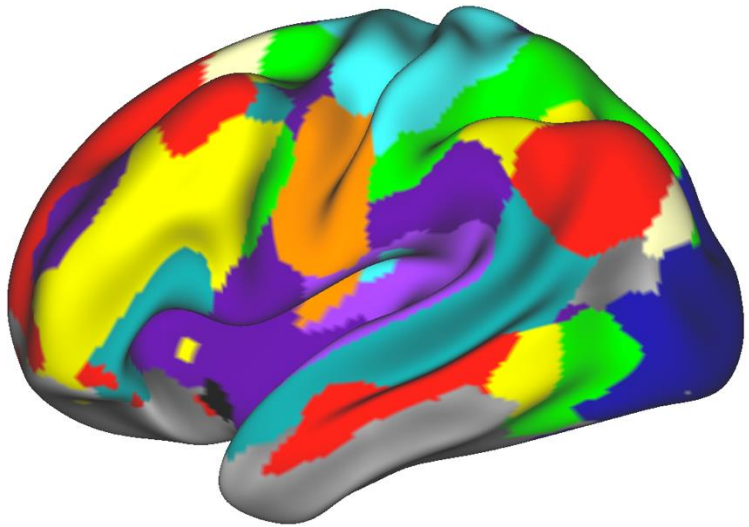
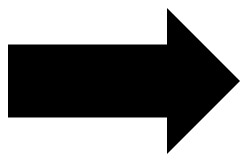


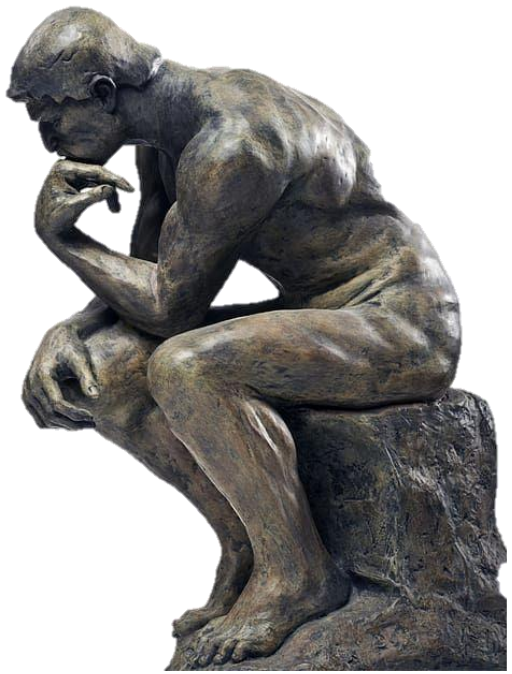
Chasing ‘Precision’ in functional MRI

Caterina Gratton, Ph.D.
Associate Professor
Psychology, Neuroscience
University of Illinois
grattonlab.org

brain & cognition

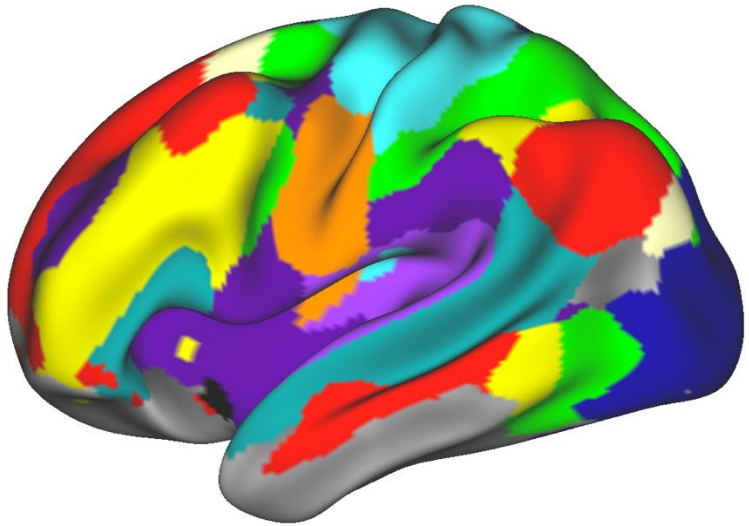






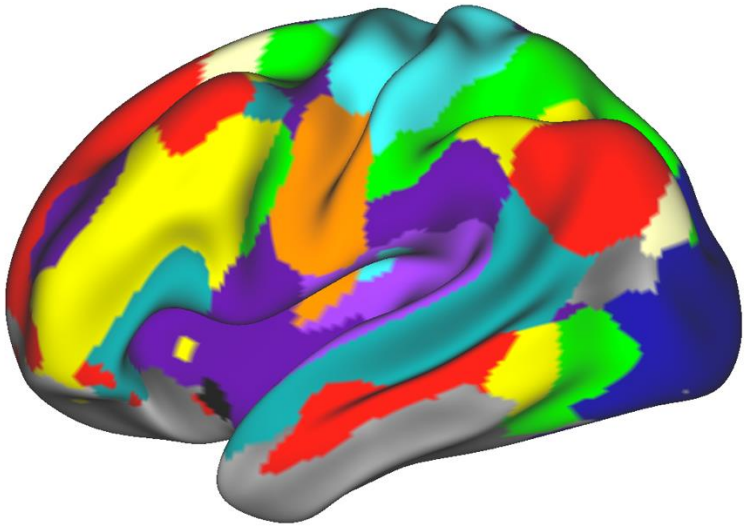
brain & cognition

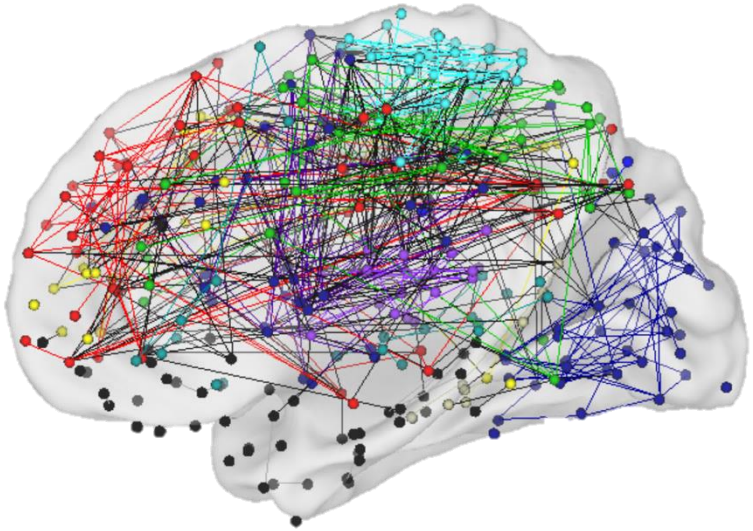
Gratton Lab

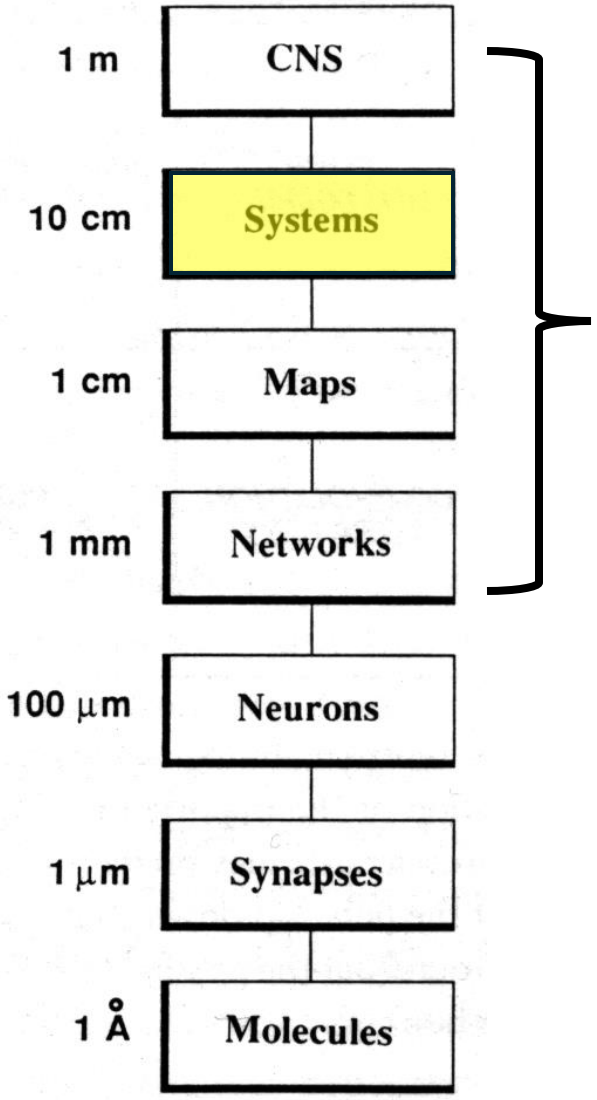


'control' or
'executive function'

Large-scale systems of the human brain

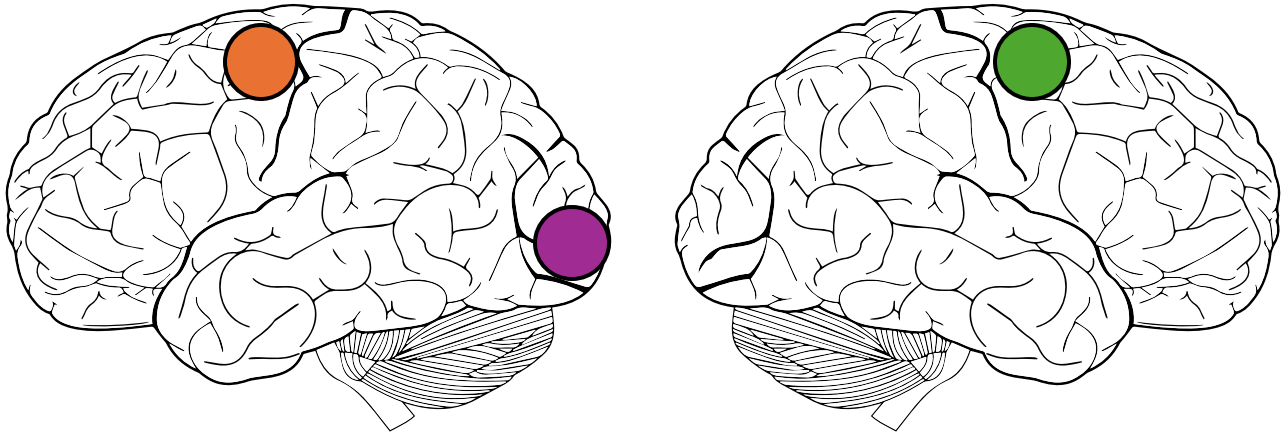


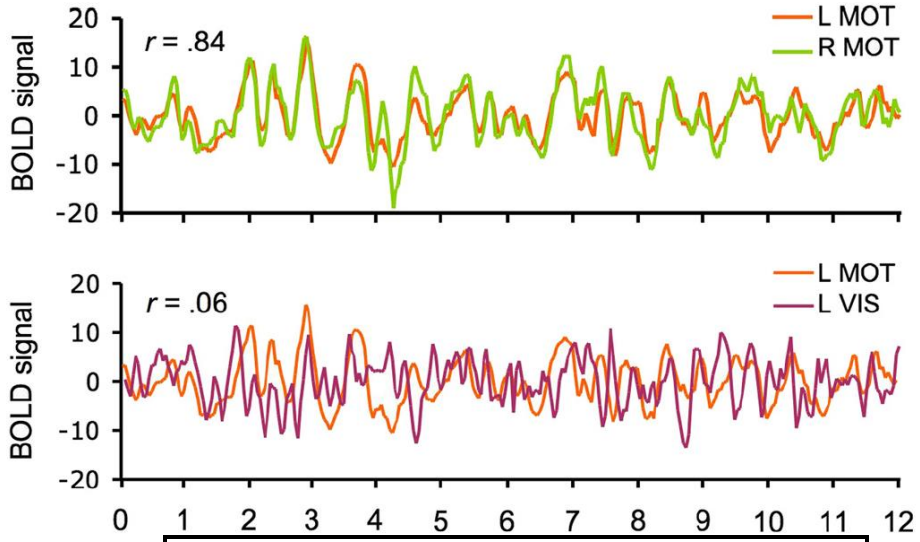




Churchland & Sejnowski, 1992

Functional Connectivity (FC): measuring relationships across brain regions

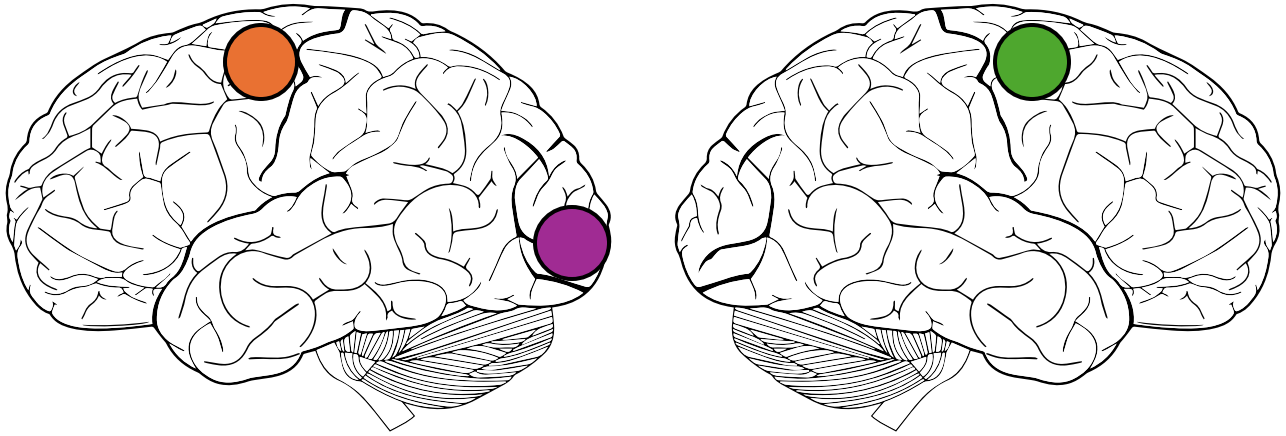




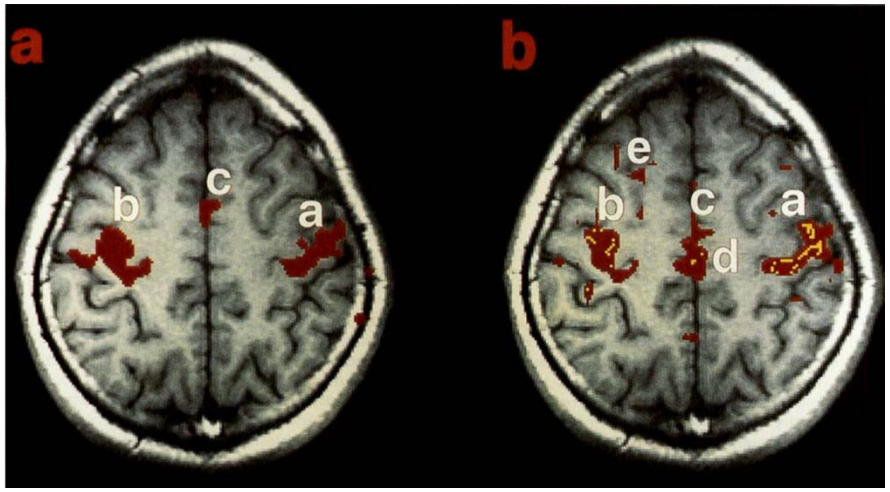
during a **resting state**

Van Dijk et al., 2010, J Neurophysiol

Functional Connectivity (FC): measuring relationships across brain regions



finger movement

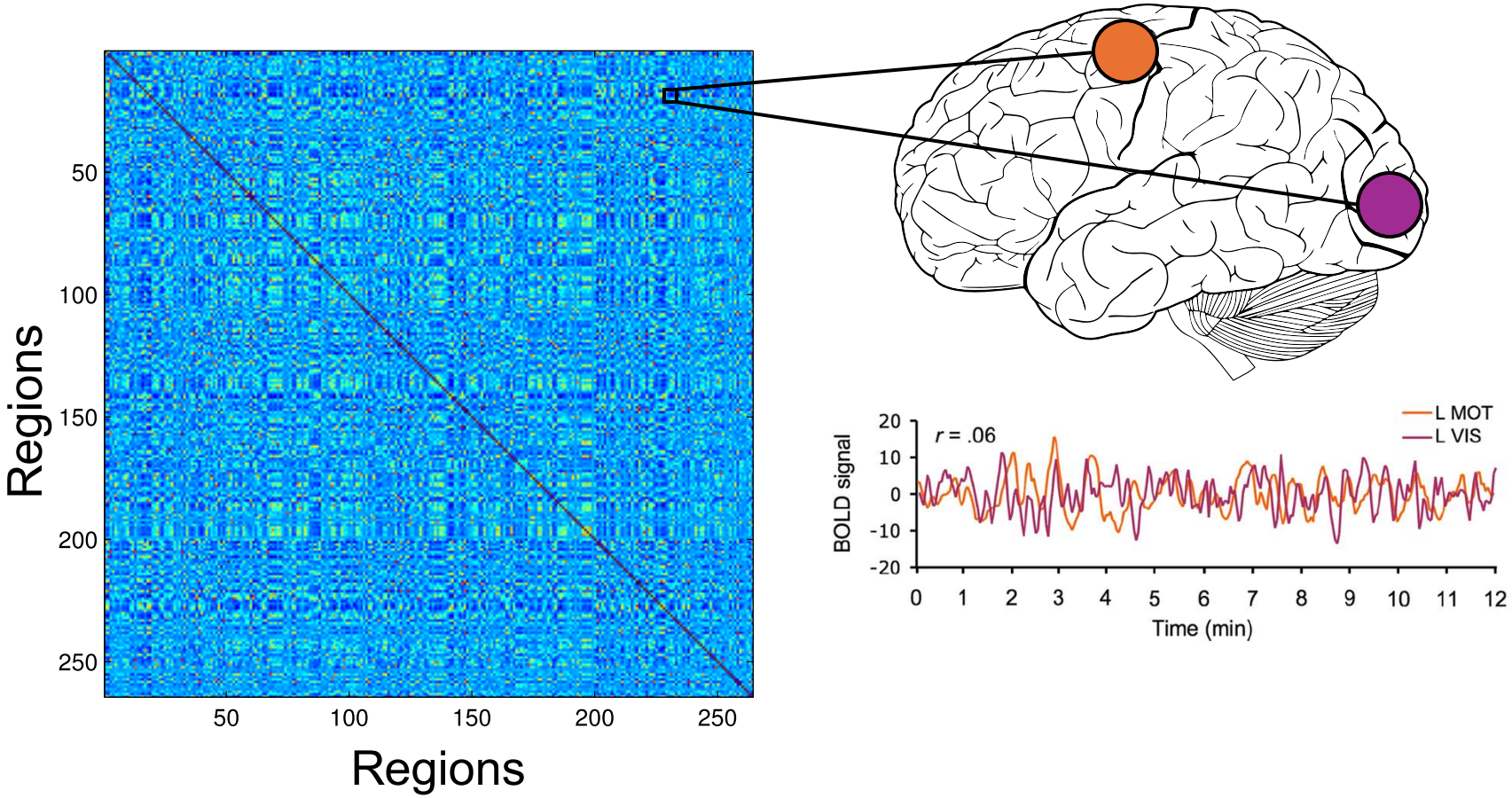


spontaneous correlations

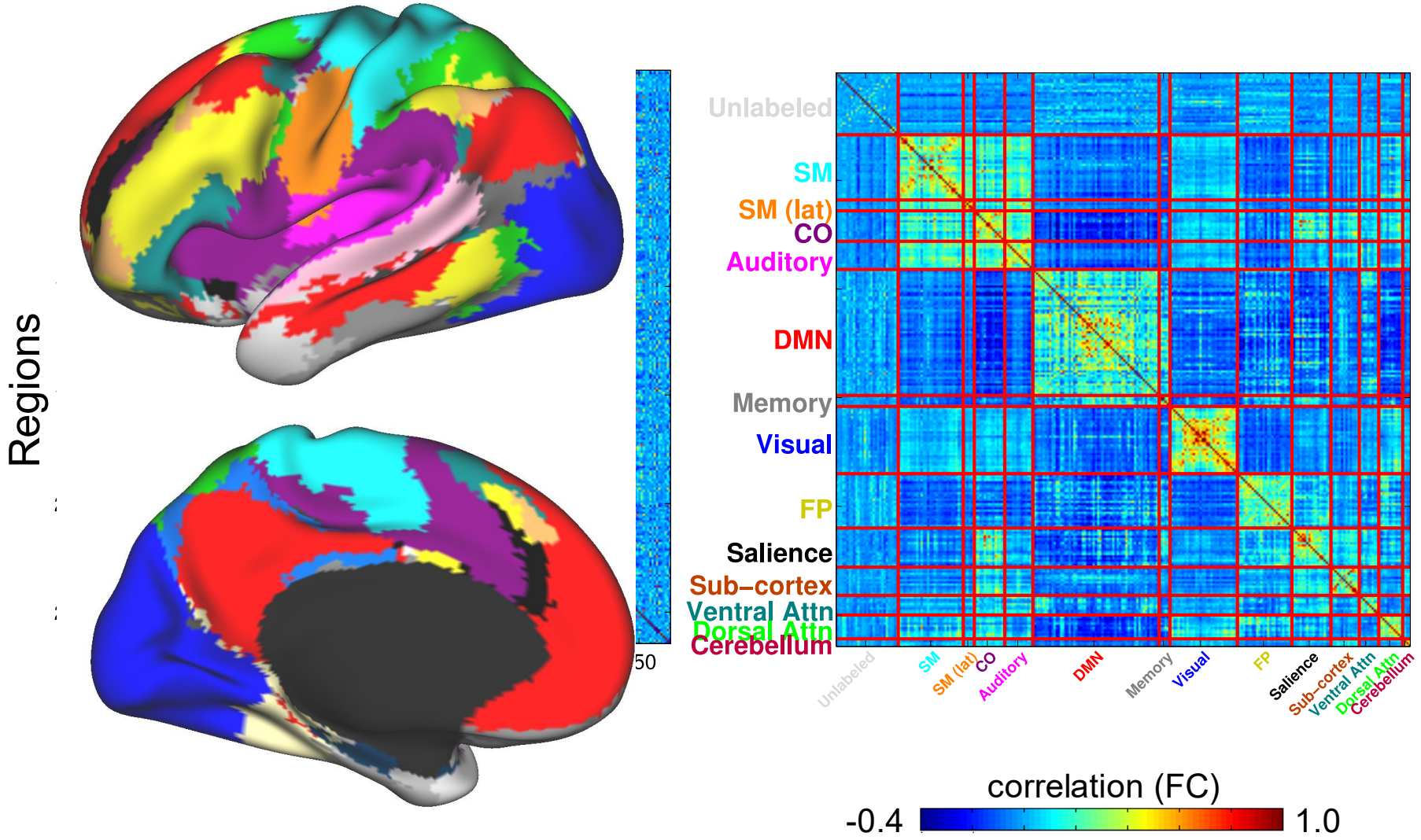
Biswal et al., 1995, MRM

during a **resting state**

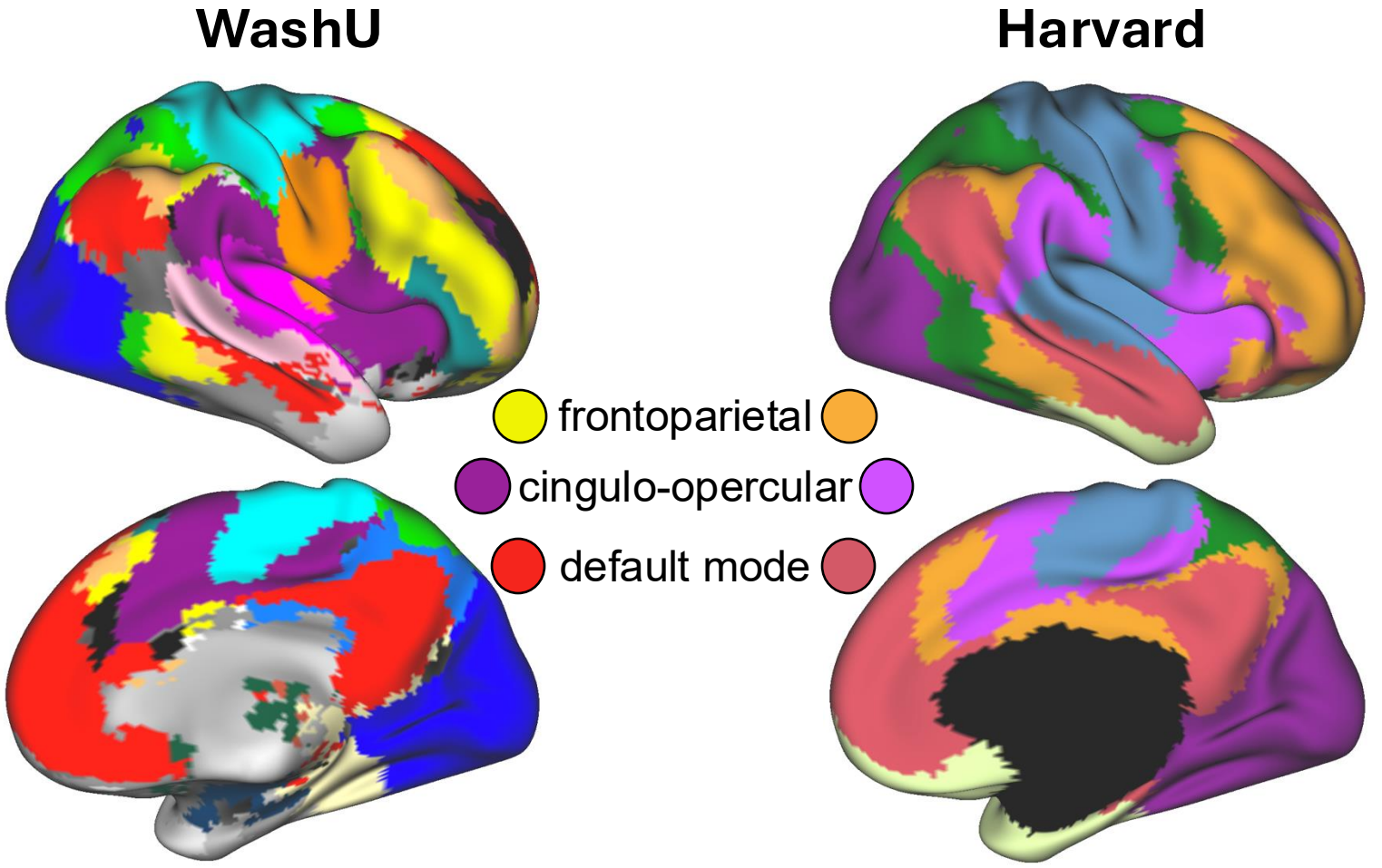
FC: A way to map brain organization



FC: A way to map brain organization



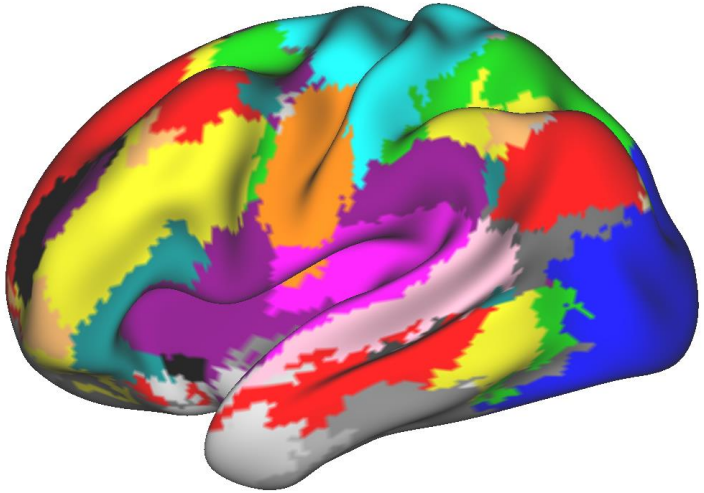
Typical “group-average” systems

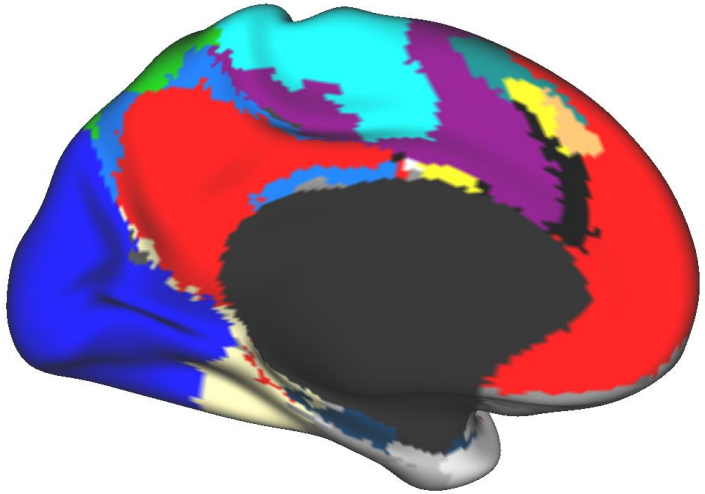


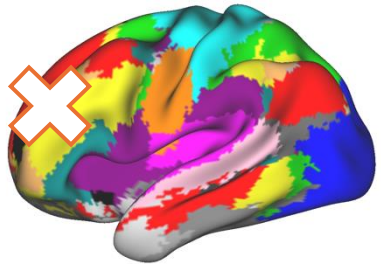
Power et al., 2011

Yeo et al., 2011

The promise of functional connectivity

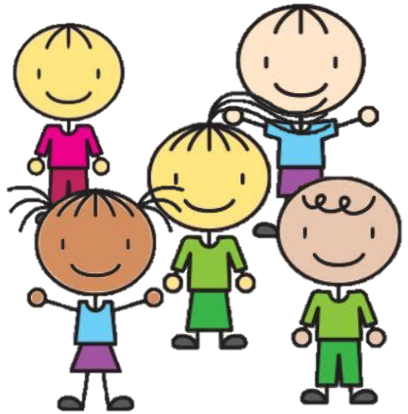




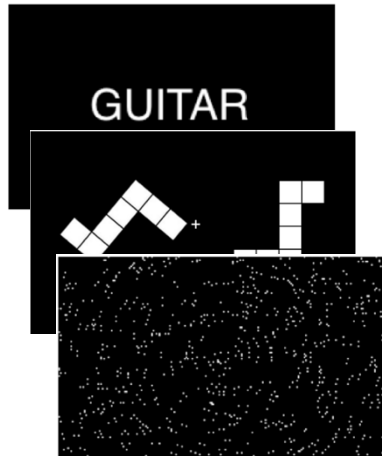


Brain damage
and disease

Individual
differences



Development
and aging



Cognitive demands

The problem

OXFORD

Cerebral Cortex, November 2017;27: 5415–5429

doi: 10.1093/cercor/bhx230
Advance Access Publication Date: 12 September 2017
Original Article

ORIGINAL ARTICLE

Influences on the Test–Retest Reliability of Functional Connectivity MRI and its Relations Utility

Stephanie Noble[1], Marisa N. Spann[2], Fuyuze To
R. Todd Constable[1,3,4] and Dustin Scheinost[3]

Psychological Science
Volume 31, Issue 7, July 2020, Pages 792-806
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https://doi.org/10.1177/0956797620916786

SAGE journals

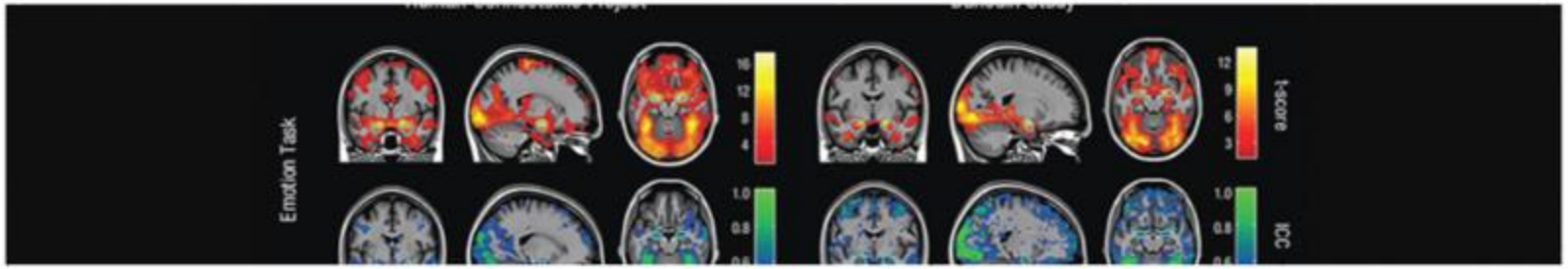
General Article - Research Article

What Is the Test-Retest Reliability of Common Task-Functional MRI Measures? New Empirical Evidence and a Meta-Analysis

PUBLISHED JUNE 3, 2020 IN RESEARCH, MEDICINE

STUDIES OF BRAIN ACTIVITY AREN'T AS USEFUL AS SCIENTISTS THOUGHT

Duke researcher questions 15 years of his own work with a reexamination of functional MRI data



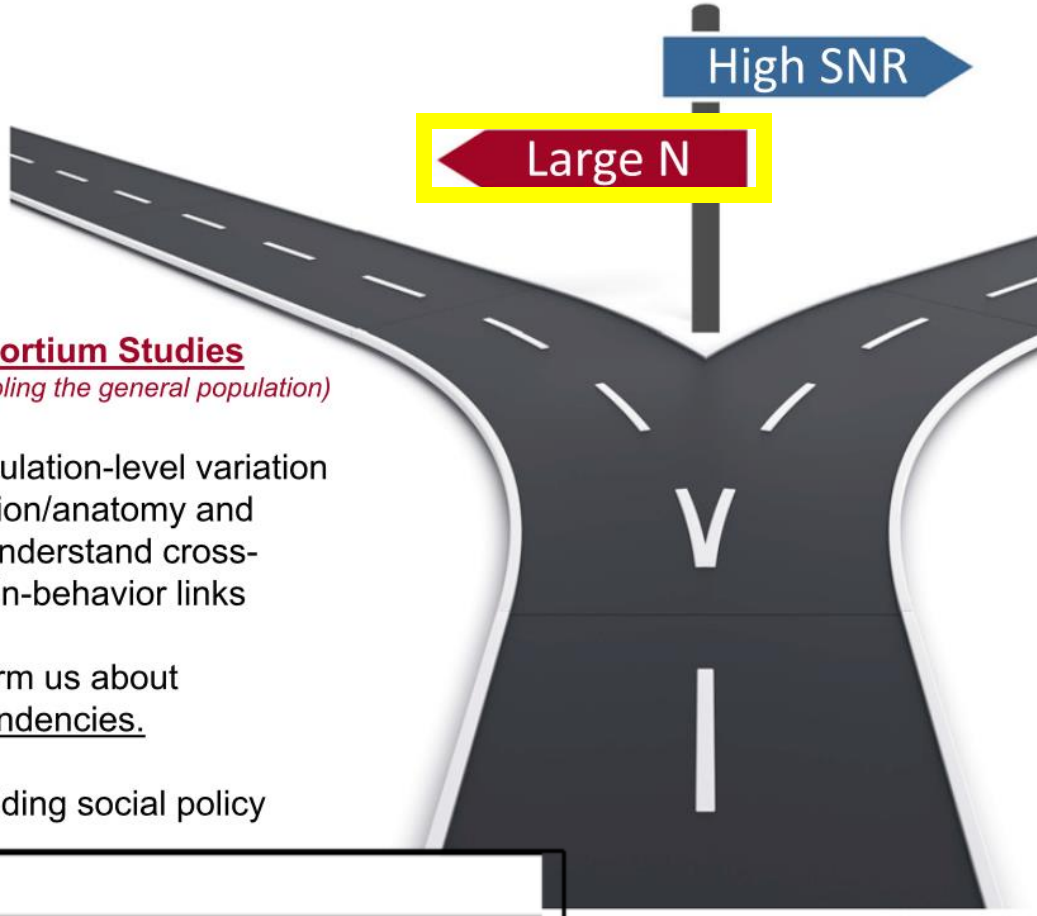
Article

Reproducible brain-wide ass require thousands of individ

https://doi.org/10.1038/s41586-022-04492-9
Received: 19 May 2021
Accepted: 31 January 2022

Scott Marek[1,2✉], Brenden Tervo-Clemm
Benjamin P. Kay[1], Alexander S. Hatoum[1],
Ryland L. Miller[1,3], Timothy J. Hendricks
Eric Feczko[4,10], Oscar Miranda-Dominguez

Solution: Evolving study designs for cognitive neuroscience



Consortium Studies
(N>1000 sampling the general population)

Measure population-level variation in brain function/anatomy and behavior to understand cross-sectional brain-behavior links

Findings inform us about population tendencies.

Useful for guiding social policy

Focused Studies
(Small N, maximize signal and minimize noise)

Deeply characterize brain function/anatomy and behavior to understand brain-behavior links within people

Findings inform us about effects in individuals.

Useful for guiding clinical care

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Reproducible brain-wide association studies require thousands of individuals

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Scott Marek[1,2,3,11], Brenden Tervo-Clemmens[1,2,3,11], Finnegan J. Calabro[4,11], David F. Montez[5], Benjamin P. Kay[5], Alexander S. Hatoum[1], Meghan Rose Donohue[1], William Foran[4], Ryland L. Miller[1,10], Timothy J. Hendrickson[1], Stephen M. Malone[6], Sridhar Kandala[1], Eric Feczko[3,10], Oscar Miranda-Dominguez[3,10], Alice M. Graham[3,7], Eric A. Earl[3,10], Andrew J. Perrone[3,7], Michaela Cordova[3], Olivia Doyle[3], Lucille A. Moore[3]

Marek, Tervo-Clemmens, et al., 2022, *Nature*

Gratton, Nelson, Gordon, 2022, *Neuron*

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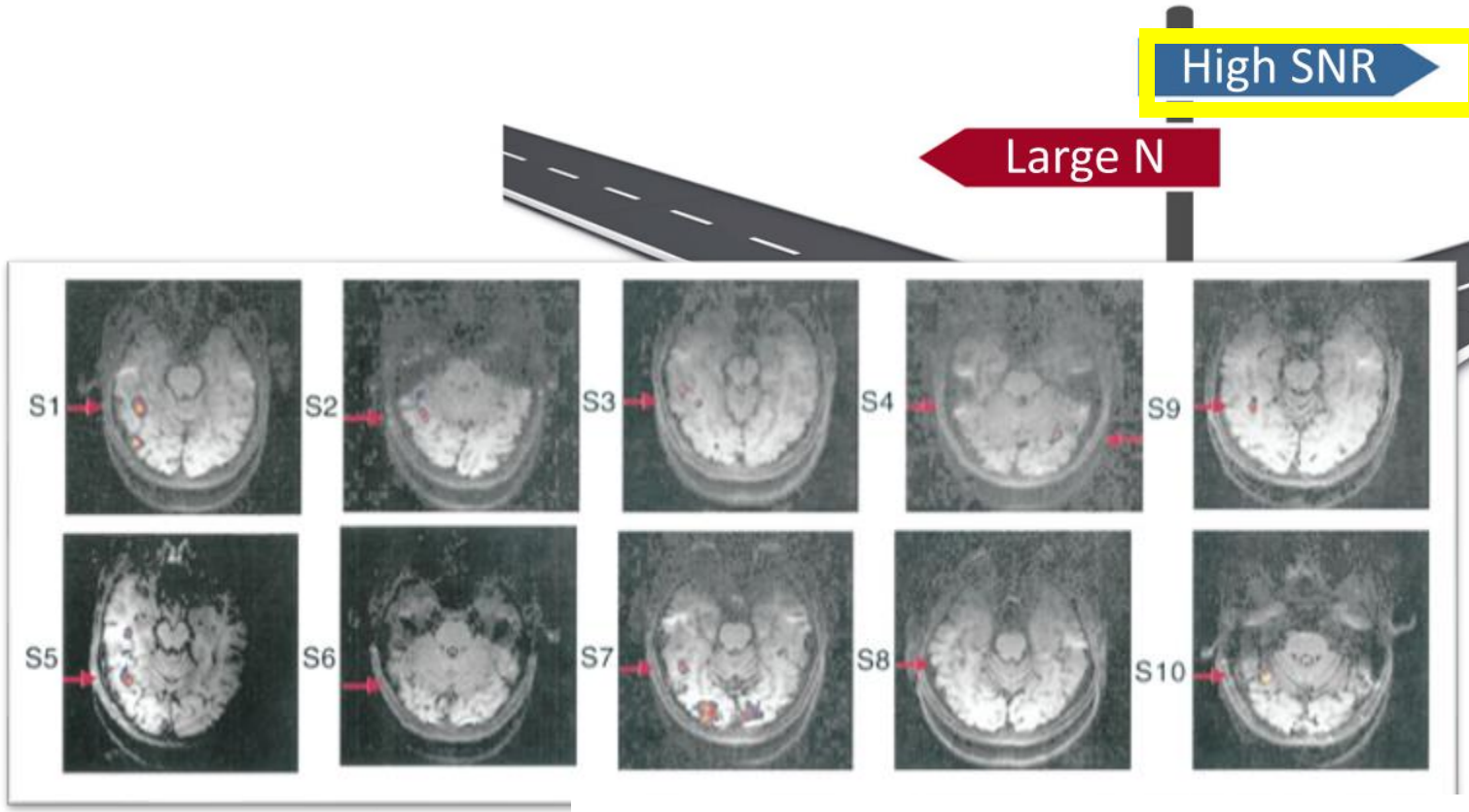

Kanwisher, McDermott, & Chun, 1997, J Neuro

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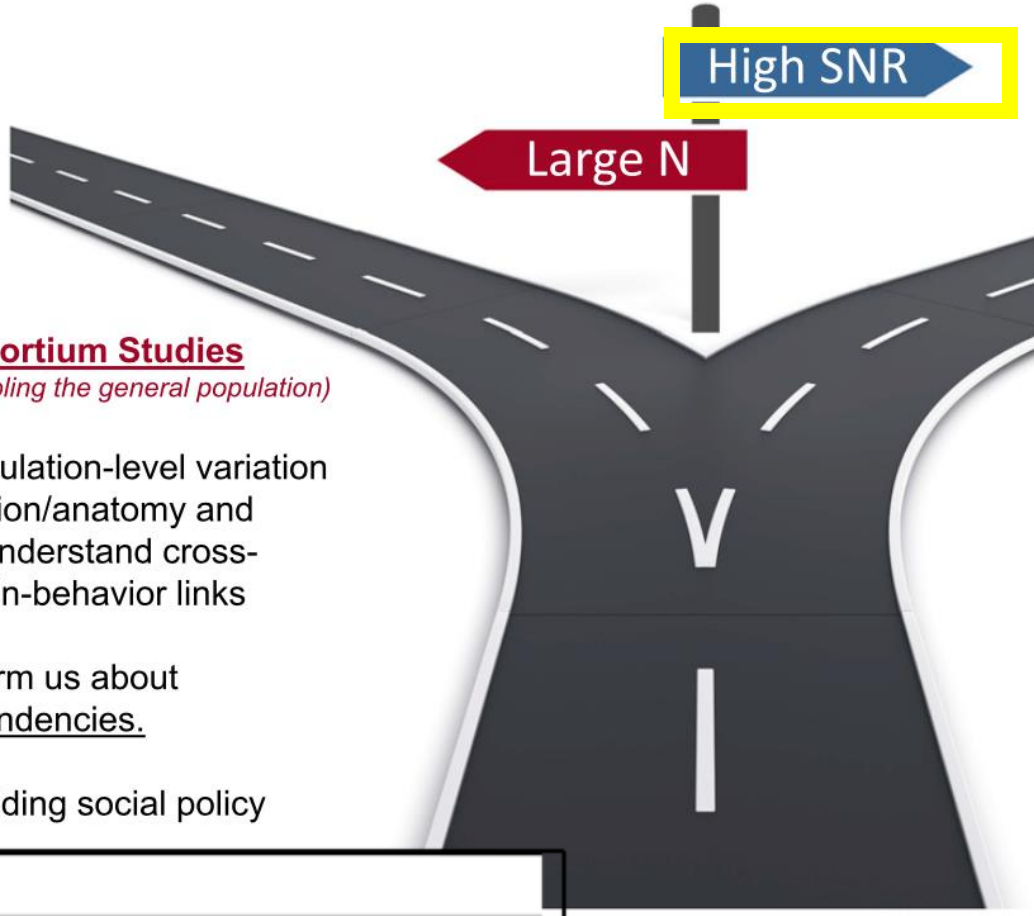

Precision fMRI

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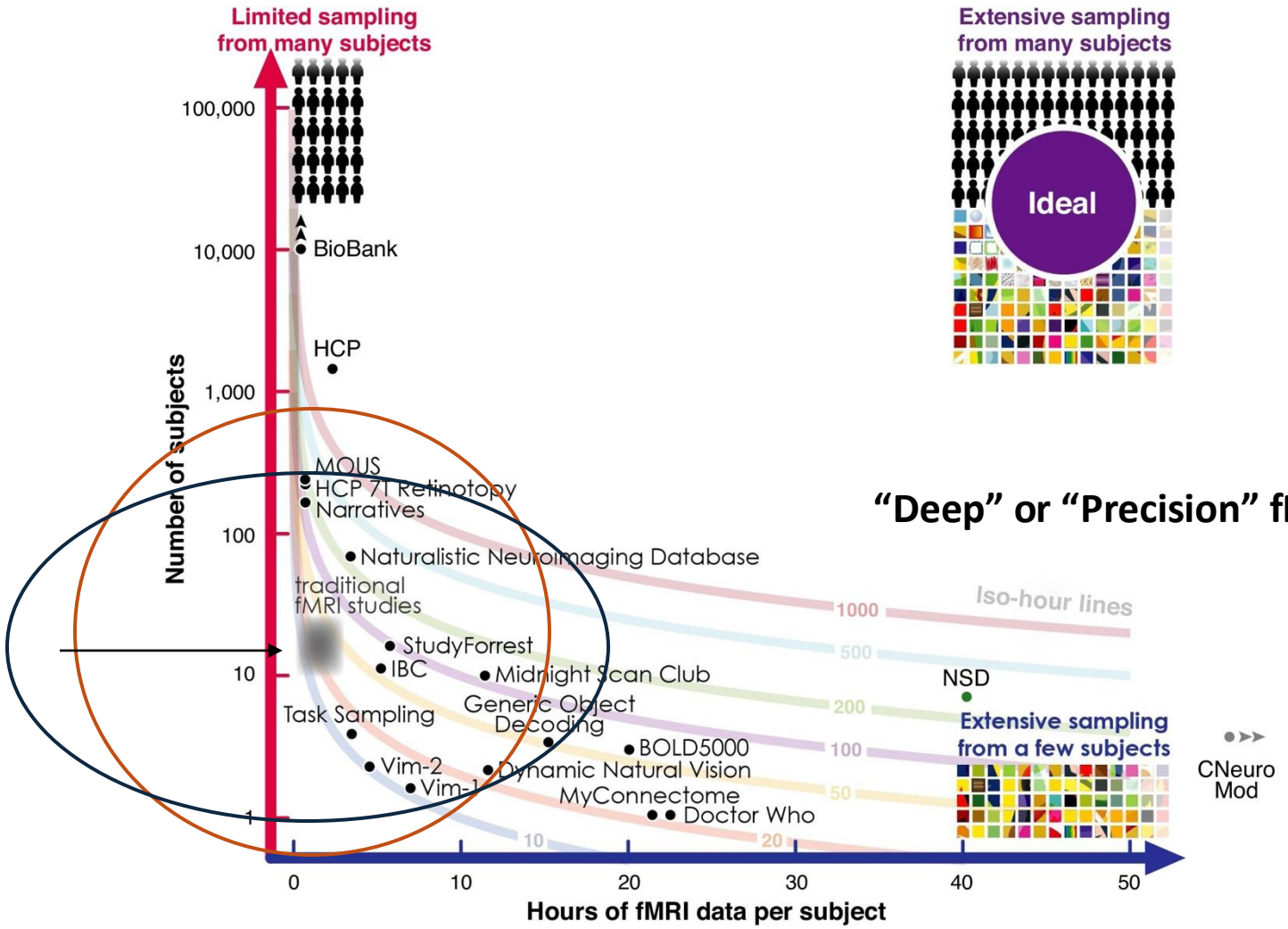


"Deep" or "Precision" fMRI

Naselaris et al., 2021, *Curr Op in Beh Sciences*

Solution: Evolving study designs for cognitive neuroscience

Table 1. Principles, considerations, and practical examples for creating intensive fMRI data sets that provide extensive and high-quality sampling of specific cognitive phenomena

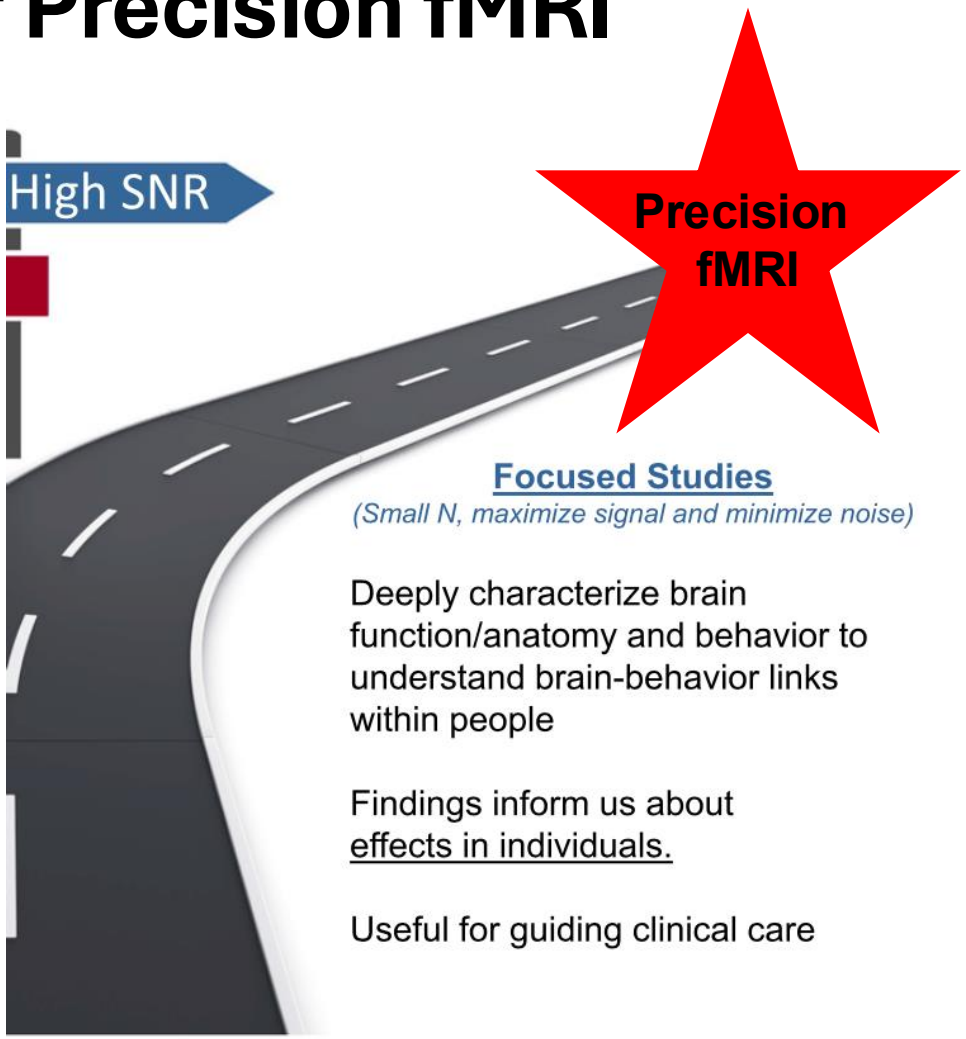
Principles	Considerations	Practical examples
Design well	Elicit rich cognitive phenomena	Sample many distinct experimental conditions Cover a large hypothesis space
Scan more	Have a 'data-hungry' mindset	Collect large amounts of data per participant Acquire auxiliary measures (e.g., venograms or quantitative MRI) Acquire physiological data (e.g., heart rate or breathing)
Optimize quality	Optimize data acquisition	Screen, select, and train participants Optimize trial and experimental design Maximize signal-to-noise ratio in single voxels
	Optimize data preparation	Perform frequent and extensive data inspection Tailor preprocessing and analysis steps if needed Develop new analysis techniques to improve data quality
Share better	Create a community-oriented data set	Solicit feedback from community before data collection Release multiple versions of the data to allow for different use cases Include comprehensive documentation

For resting state:
- Scan parameters
- Alignment
- Denoising
- Network definition

Tutorial:
4 ways to look at FC data

The Promise of Precision fMRI

1. Improve measurement of brain networks
2. Identify basic properties of brain function & organization
3. Identify new brain-behavior relationships
4. Characterize individual differences



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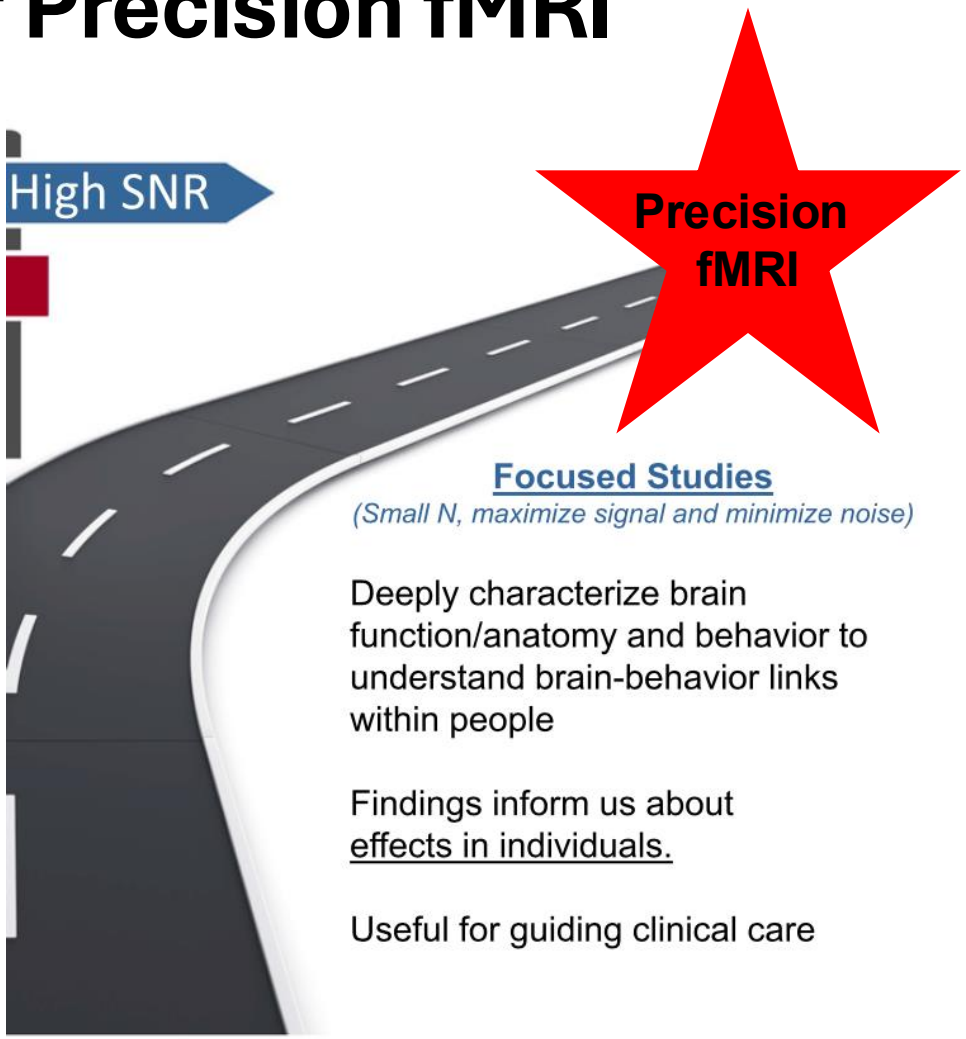


Precision fMRI Datasets

My Connectome

1 subject
x 80+ rs-fMRI sessions
+ surveys, blood draws, etc.

Poldrack et al., 2015, *Nat Comm*

https://openneuro.org/datasets/ds000031/versions/2.0.2

Midnight Scan Club

10 subjects
x 10 fMRI sessions
x 3 tasks + rest

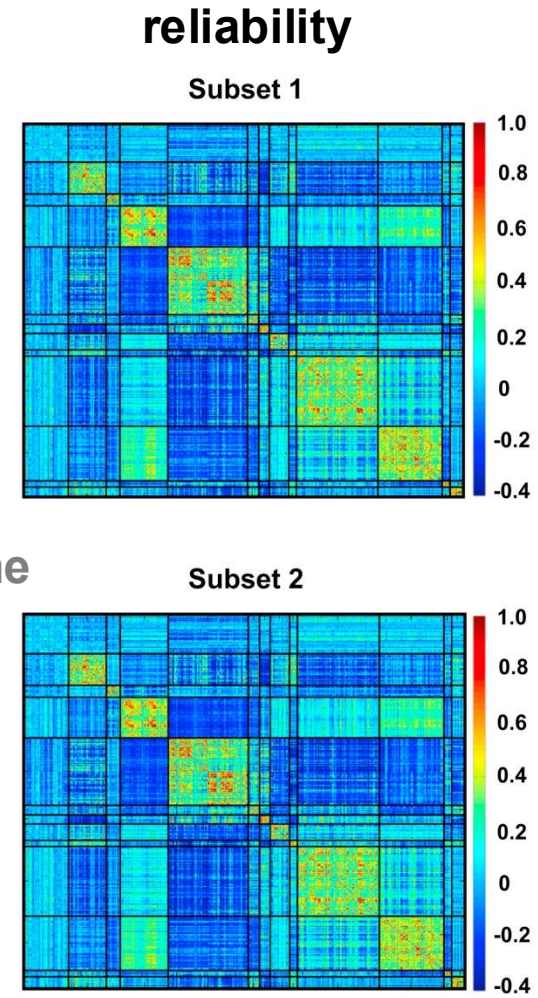
Gordon et al., 2017, *Neuron*

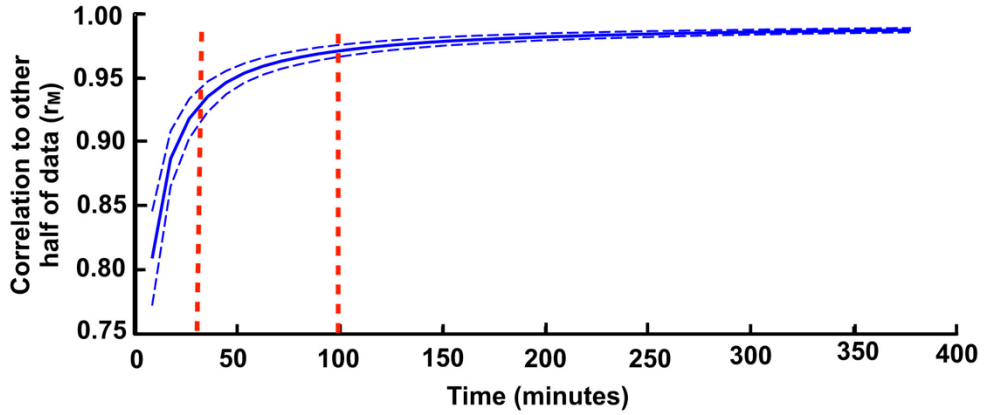
https://openneuro.org/datasets/ds000224/versions/1.0.4

What can you do with precision fMRI?

1. Improve measurement of brain networks

My Connectome





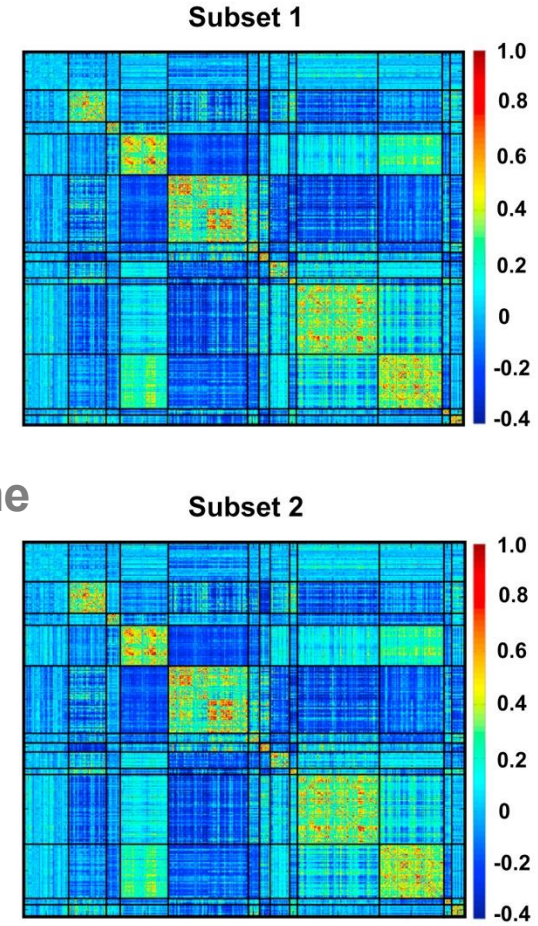
Laumann et al., 2015, *Neuron*

What can you do with precision fMRI?

1. Improve measurement of brain networks

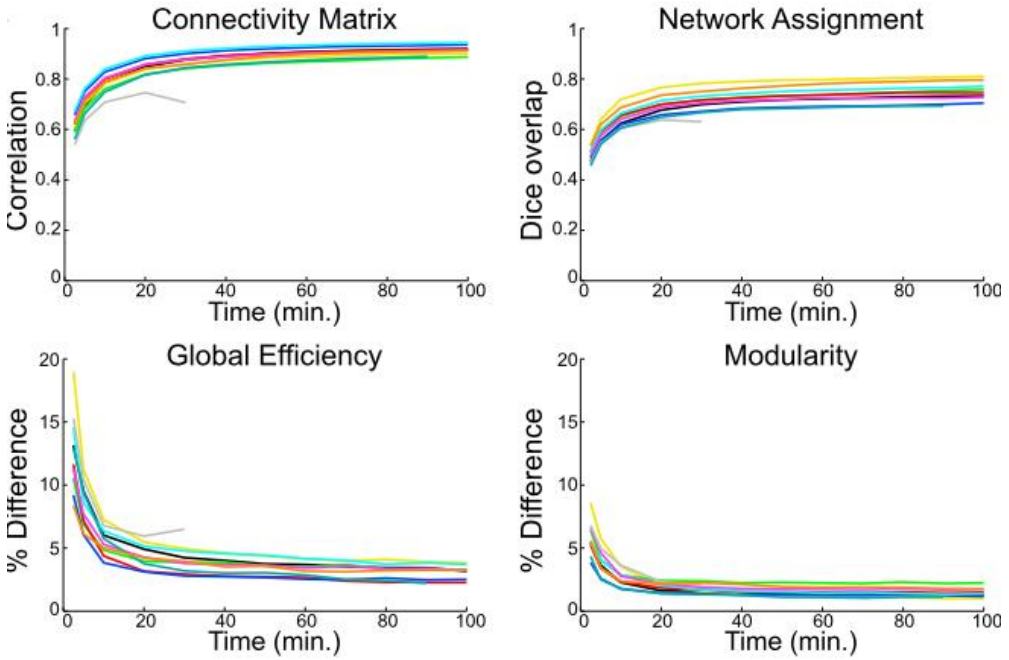
reliability

My Connectome



Laumann et al., 2015, *Neuron*

Midnight Scan Club

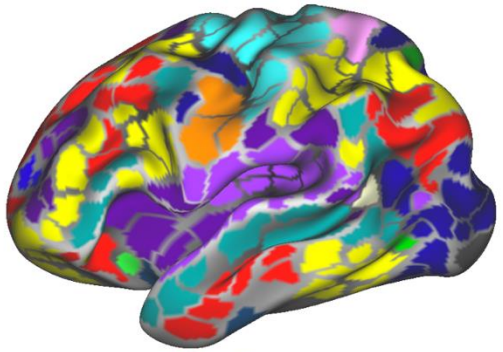


Gordon et al., 2016, *Neuron*

What can you do with precision fMRI?

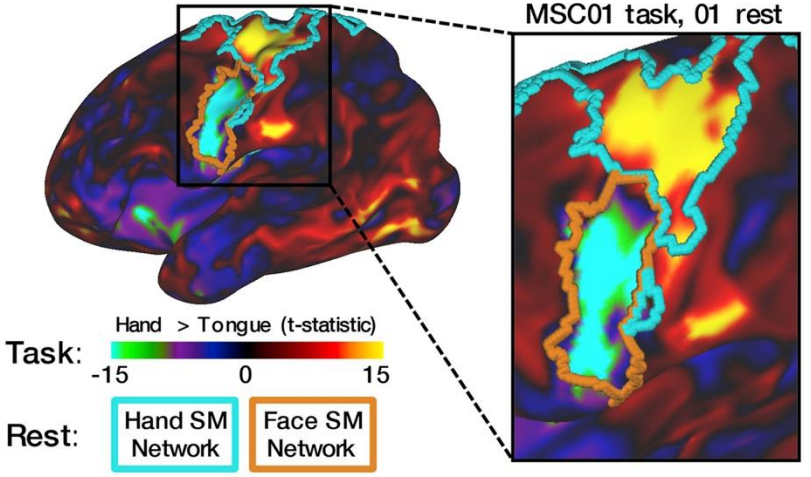
1. Improve measurement of brain networks

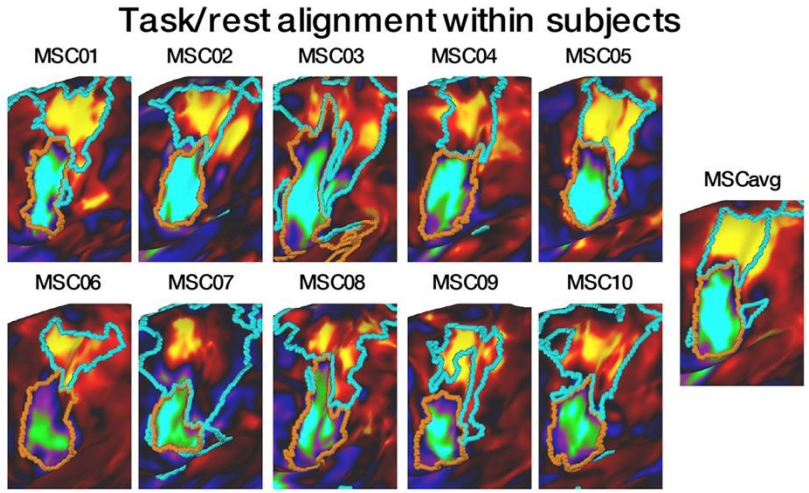
validity



MSC01

Gordon et al., 2017, *Neuron*

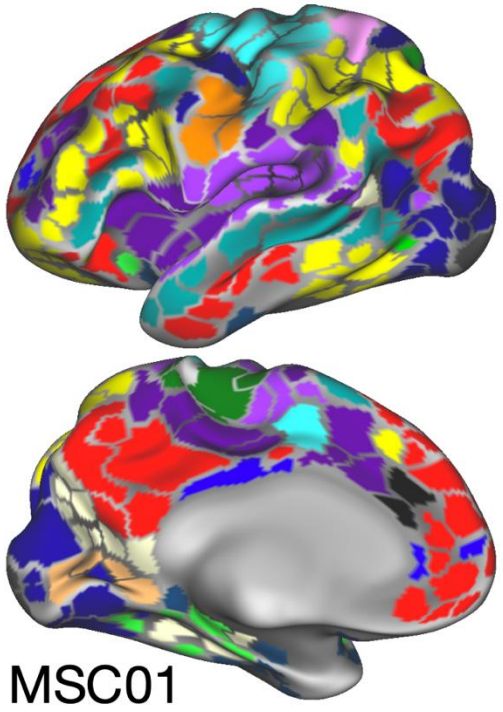


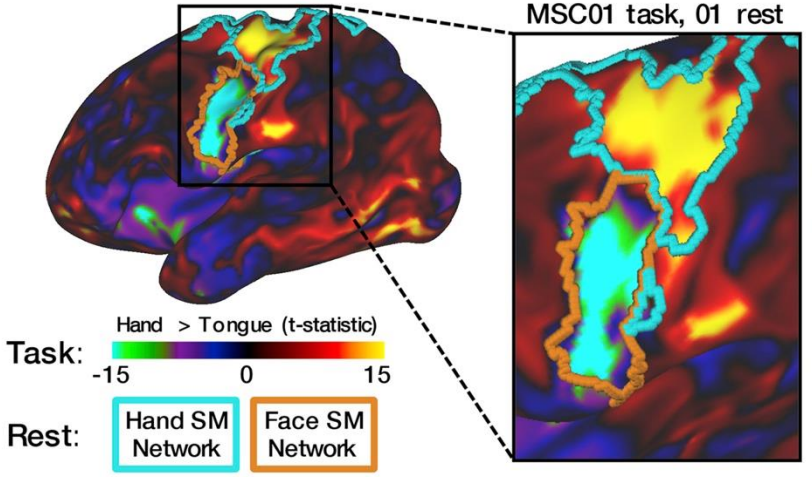


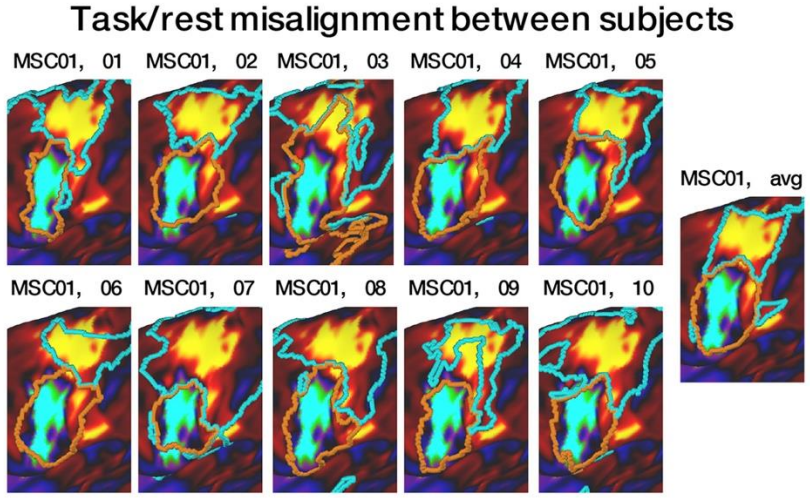
What can you do with precision fMRI?

1. Improve measurement of brain networks

validity





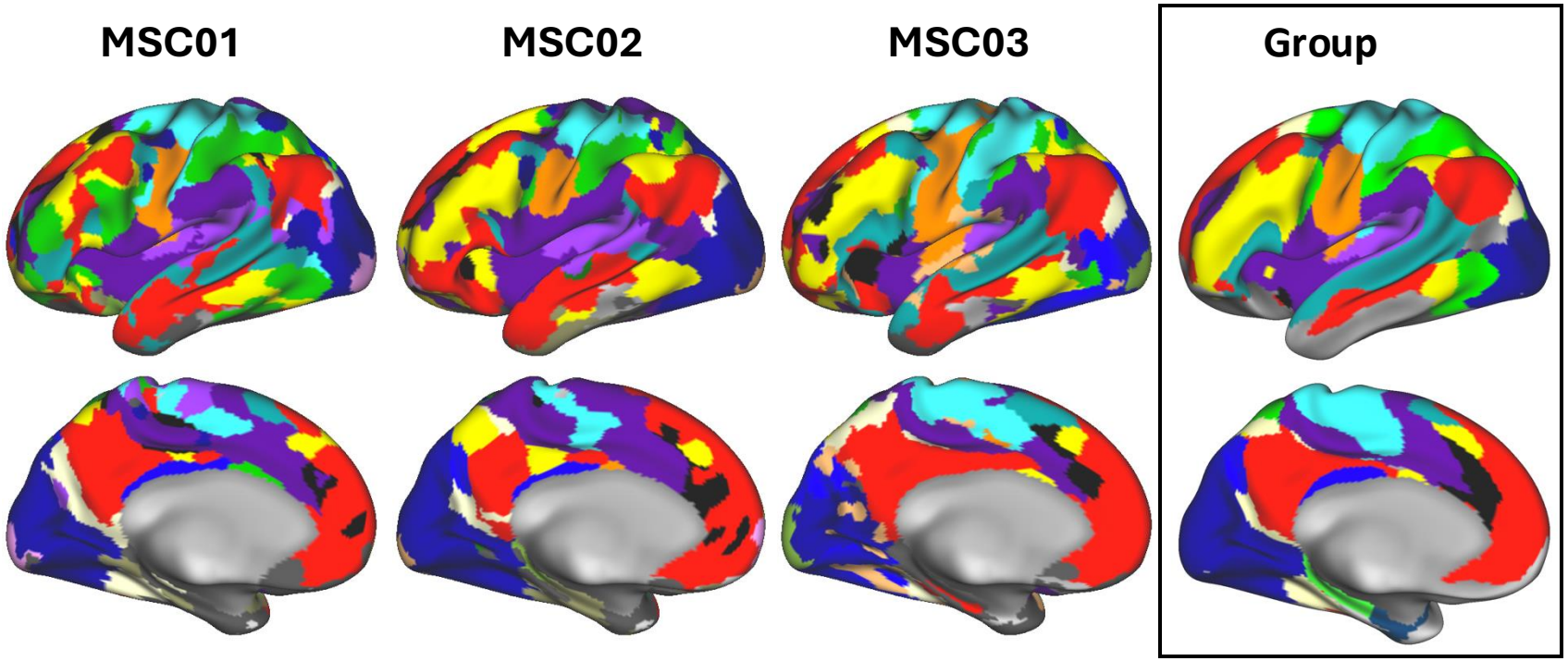


Gordon et al., 2017, *Neuron*

What can you do with precision fMRI?

1. Characterize individual differences

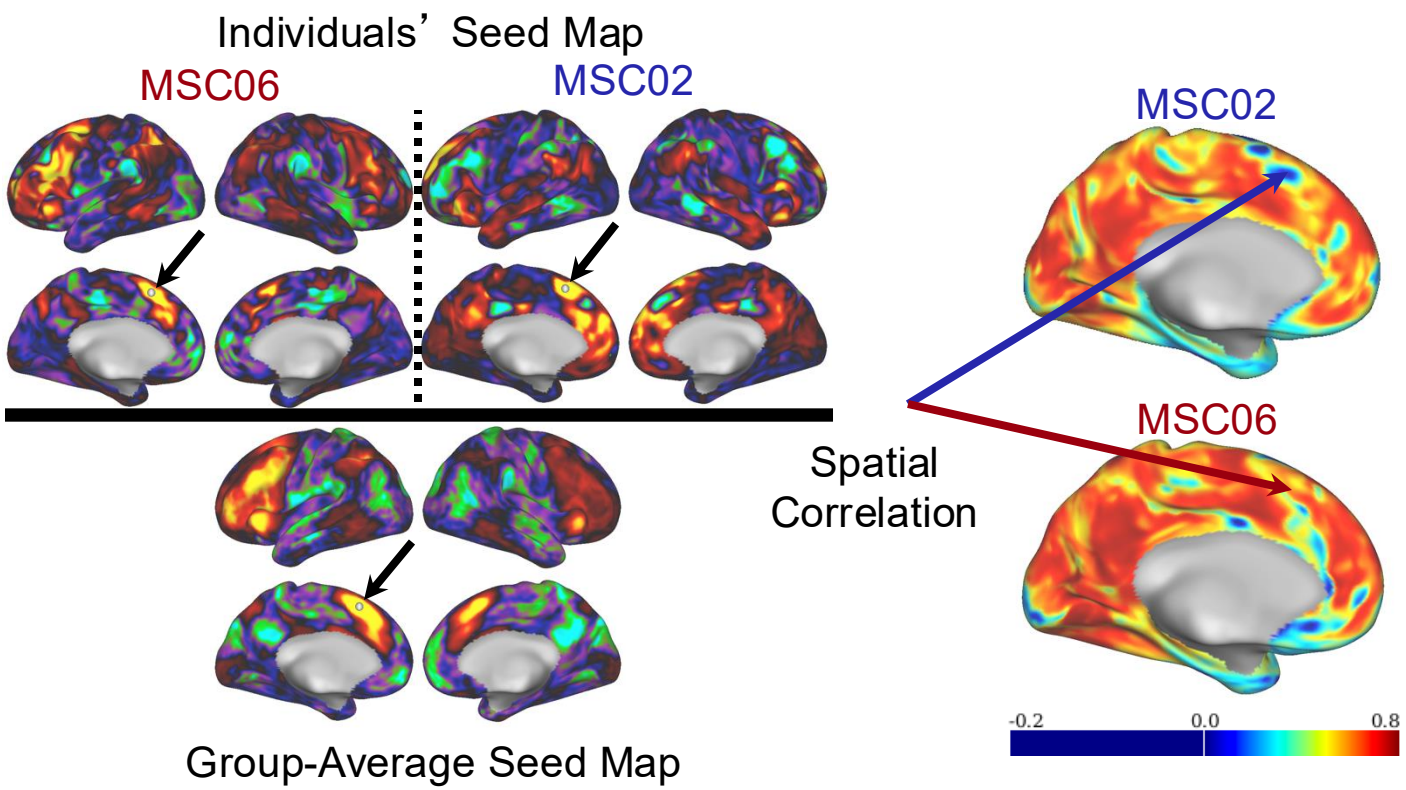
Midnight Scan Club

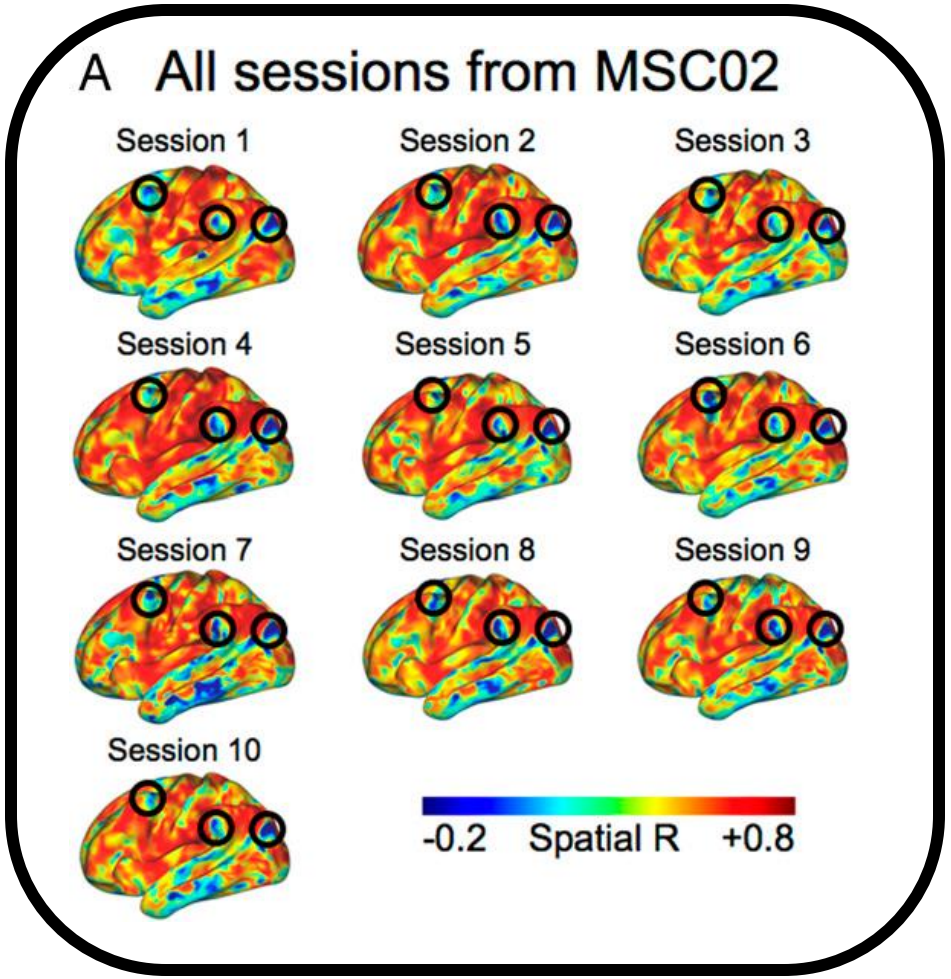


Gordon et al., 2017, *Neuron*

See also: Braga et al., 2017, Neuron; Du et al., 2024, J Neurophys

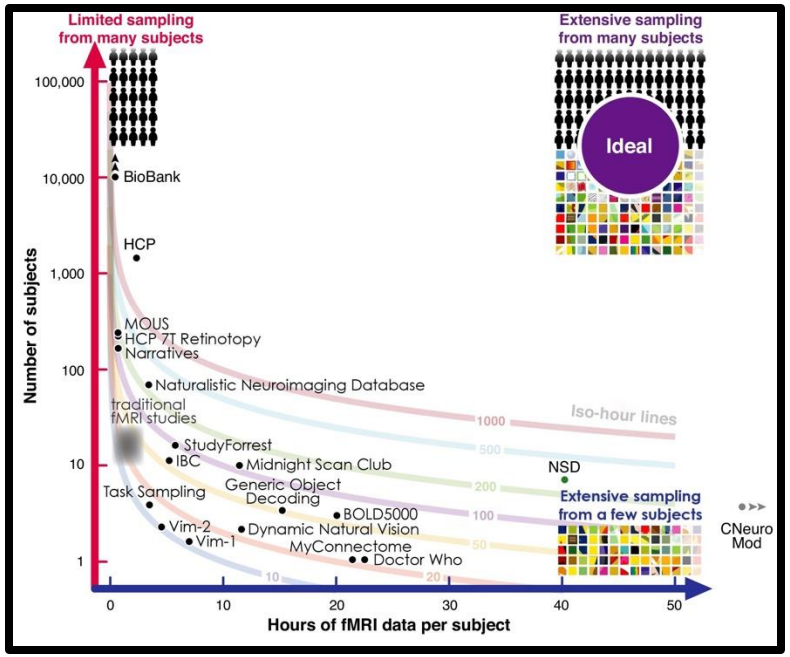
Precision fMRI can be used to **characterize individual differences**



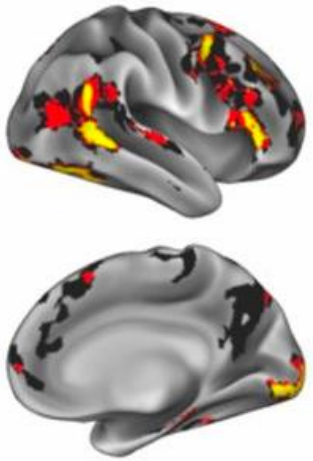


Seitzman*, Gratton*, et al., 2019, *PNAS*

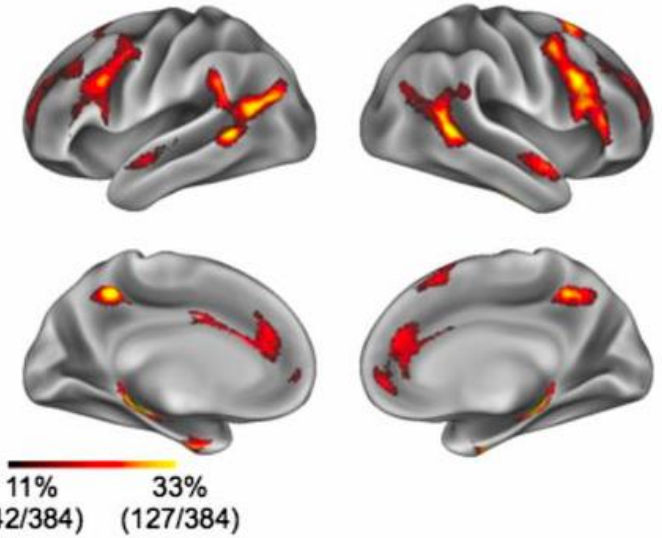
Network variants are frequently found in association systems of the brain



Midnight Scan Club
(9 Individuals)



Human Connectome
Project (384 Individuals)

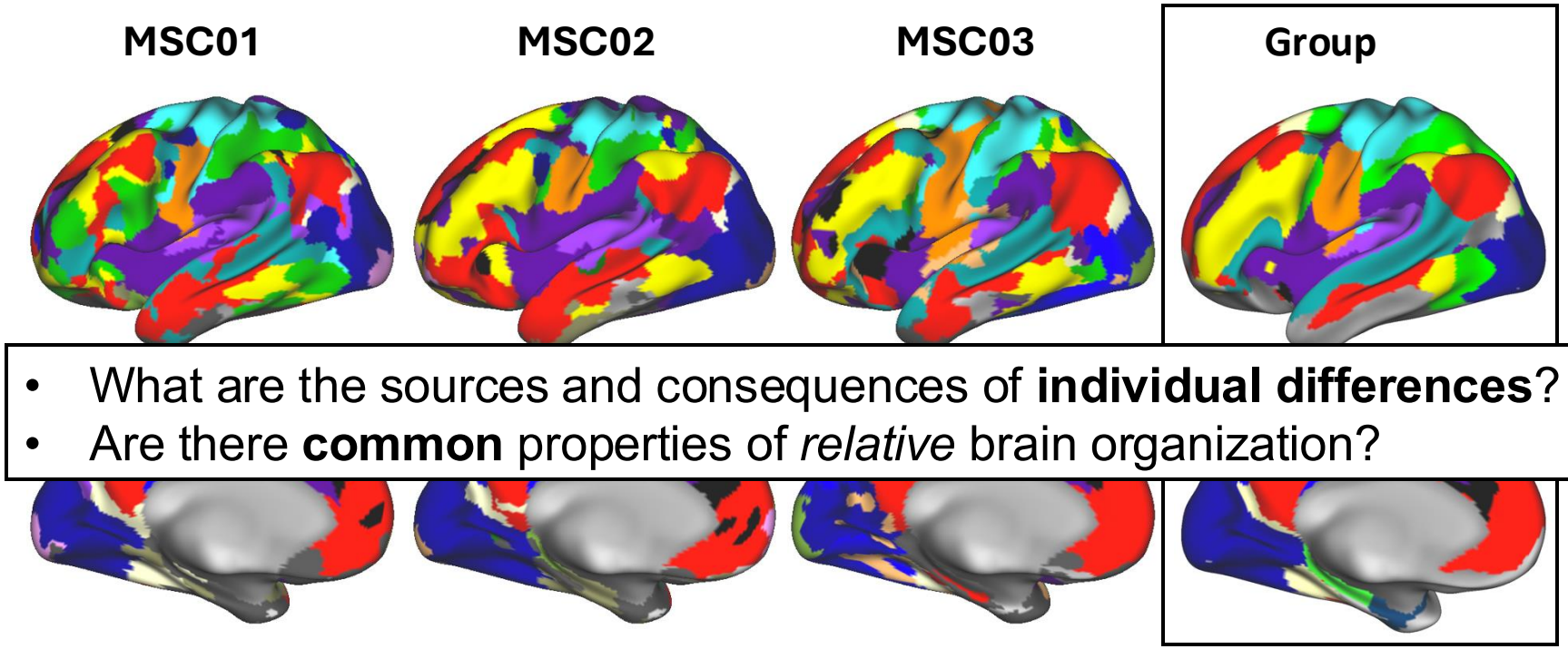


Seitzman*, Gratton*, et al., 2019, PNAS
For hemispheric asymmetries: Perez et al… Gratton, 2023, JoCN

What can you do with precision fMRI?

1. Characterize individual differences

Midnight Scan Club



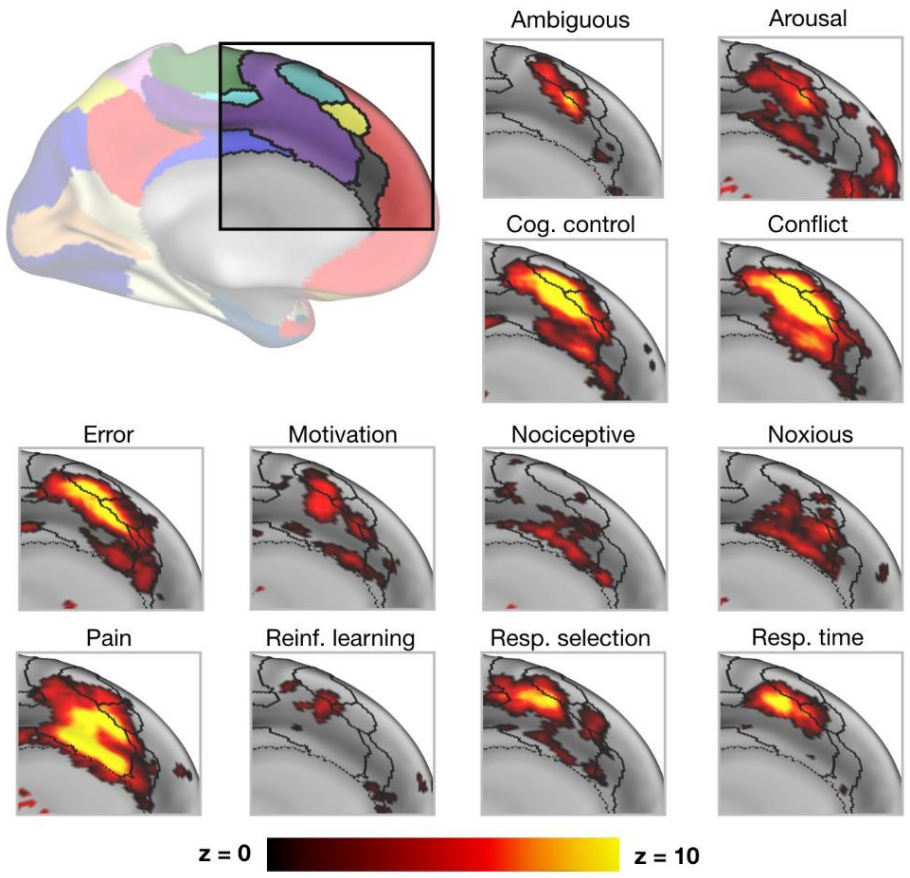
- What are the sources and consequences of **individual differences**?
- Are there **common** properties of *relative* brain organization?

Gordon et al., 2017, *Neuron*

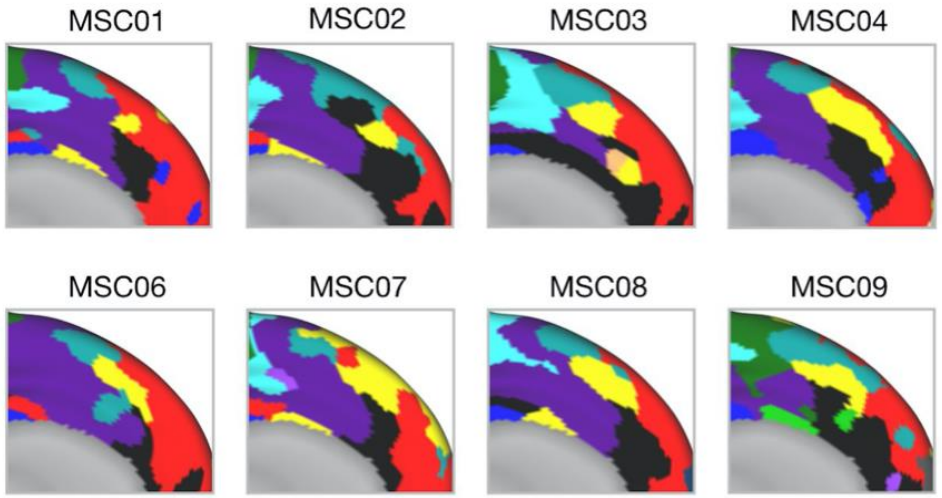
See also: Braga et al., 2017, Neuron; Du et al., 2024, J Neurophys

Consequences of individual differences for studies of control

Neurosynth



MSC: individual networks



Derek Smith

Smith… Gratton, 2021, *Curr Op in Beh Sciences*

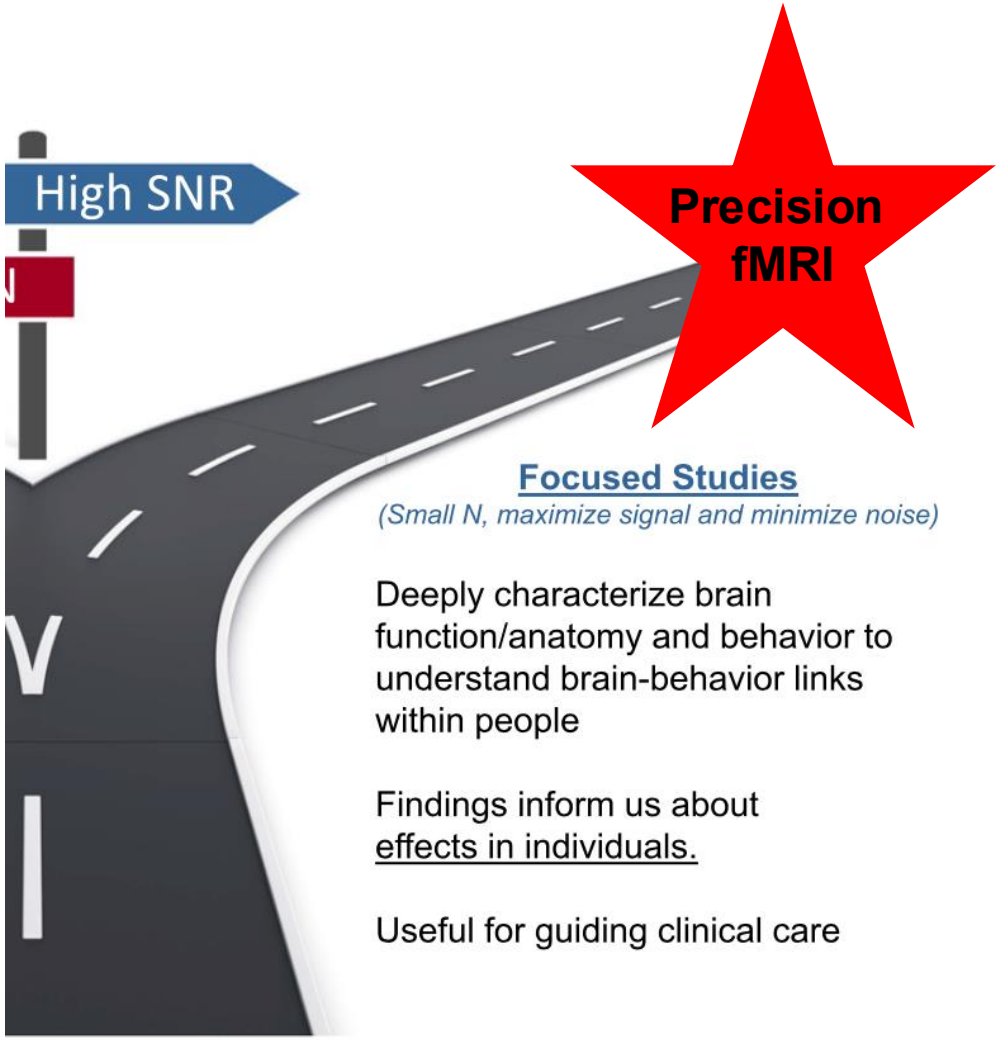
The Promise of Precision fMRI

1. Improve measurement of brain networks

2. **Identify basic properties of brain function & organization**
   Ladwig et al., submitted

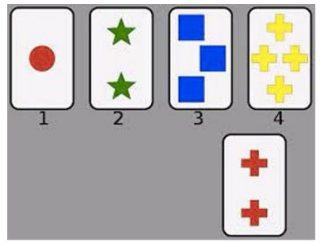
3. Identify new brain-behavior relationships

4. Characterize individual differences

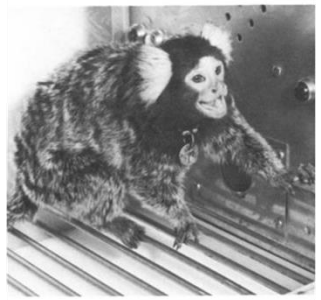


The lateral prefrontal cortex is difficult to study

The LPFC is critical for goal-directed behavior



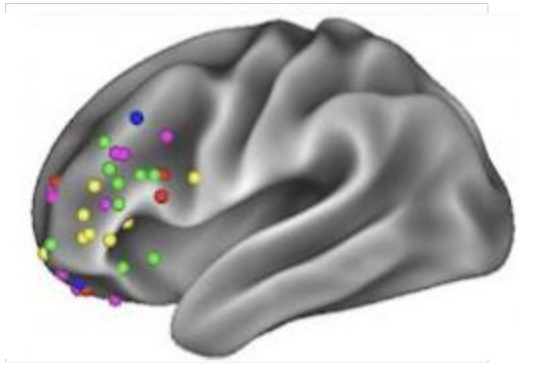
Milner et al 1963



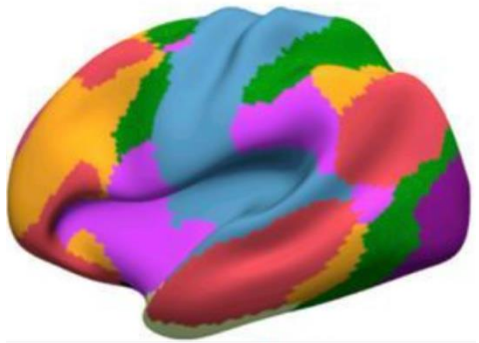
Jacobsen et al 1935

Lhermitte et al 1986

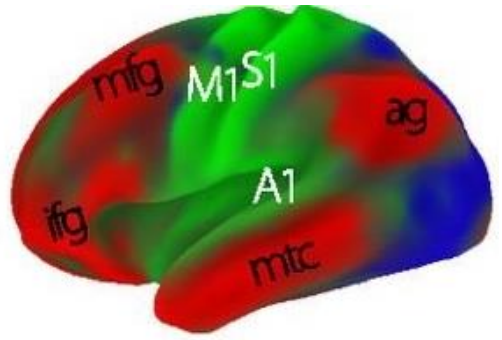
… but organizational principles have been hard to identify



Duncan & Owen 2000

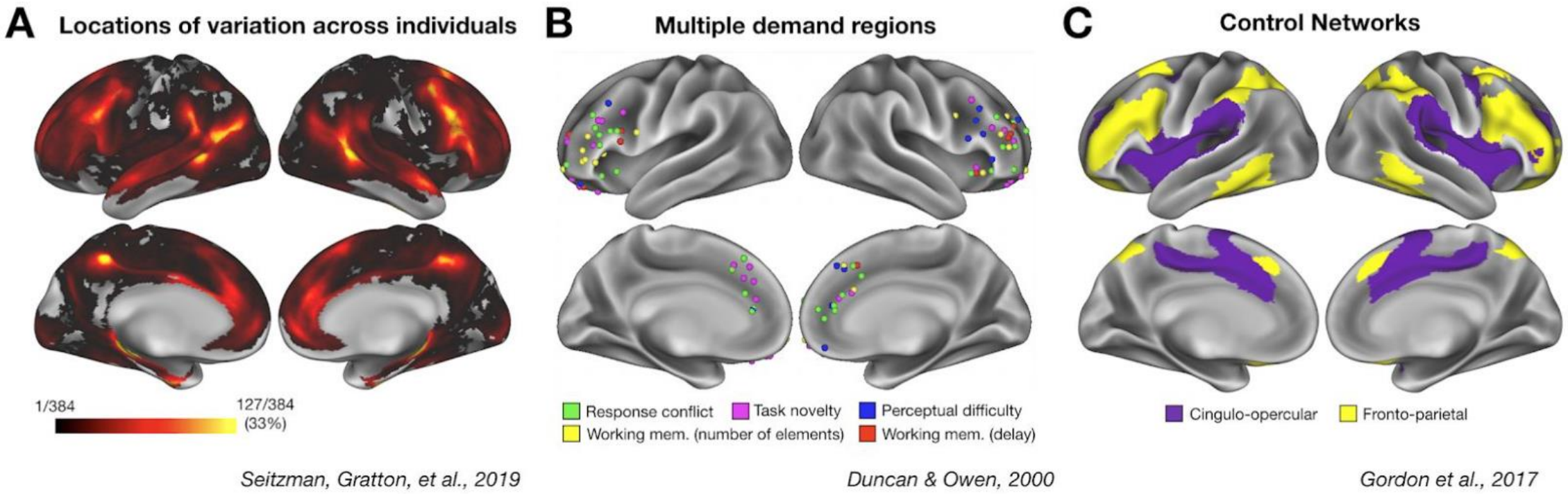


Yeo 2011



Margulies et al., 2016

Importance of Individual Differences to Control



Seitzman, Gratton, et al., 2019

Duncan & Owen, 2000

Gordon et al., 2017

Individual differences need to be addressed to assess **common** and **distinct** properties of how frontal and parietal regions support control

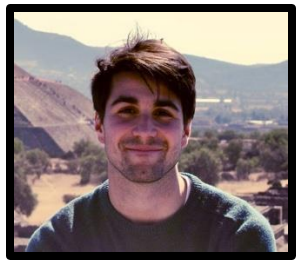
Smith… Gratton, 2021, *Curr Op in Beh Sciences*

Using Precision fMRI to study the LPFC

PAN Dataset

10 subjects
x 7-10 fMRI sessions
x 13 tasks + rest

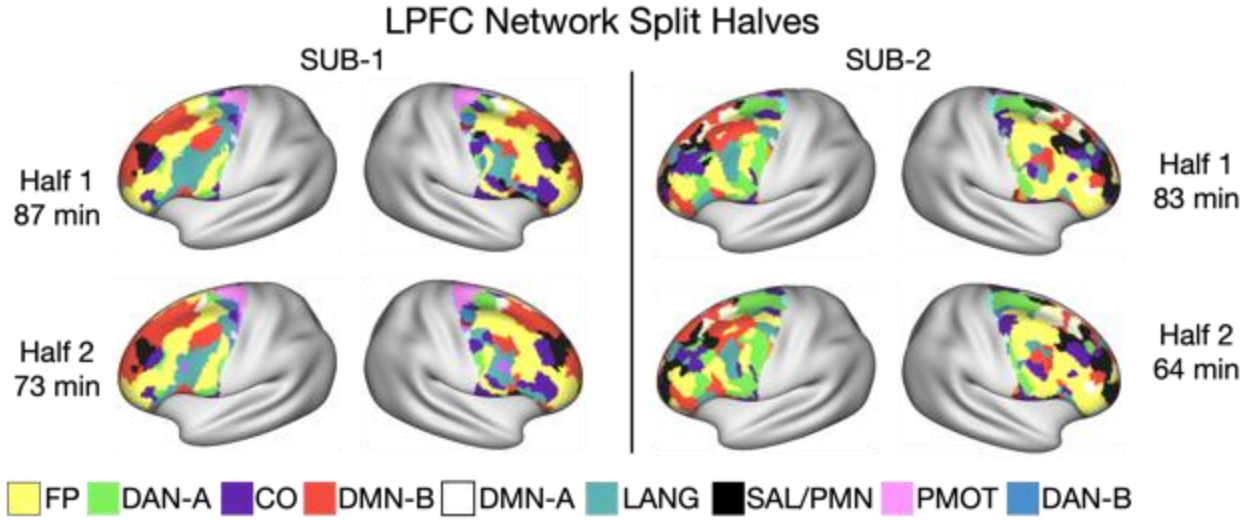
- visual working memory 2-back
- auditory 2-back
- visual sustained attention
- auditory sustained attention
- numeric multi-source interference
- verbal multi-source interference
- spatial memory span
- verbal memory span
- visual language task
- auditory language task
- episodic projection
- theory of mind
- movie (*Social Network*)
- resting-state

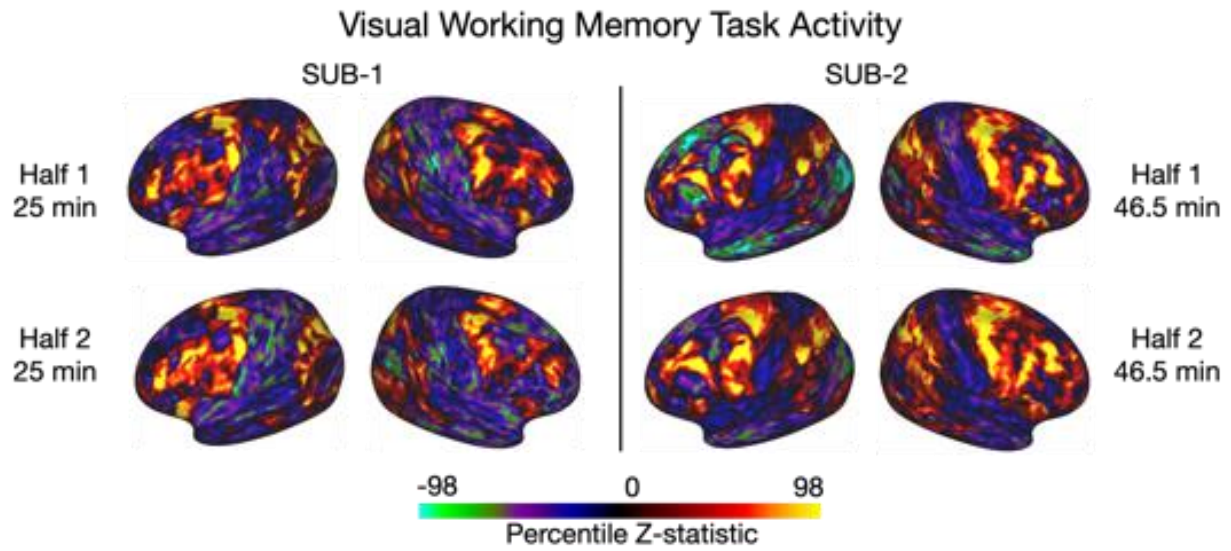


Nathan Labora

Ladwig et al., submitted

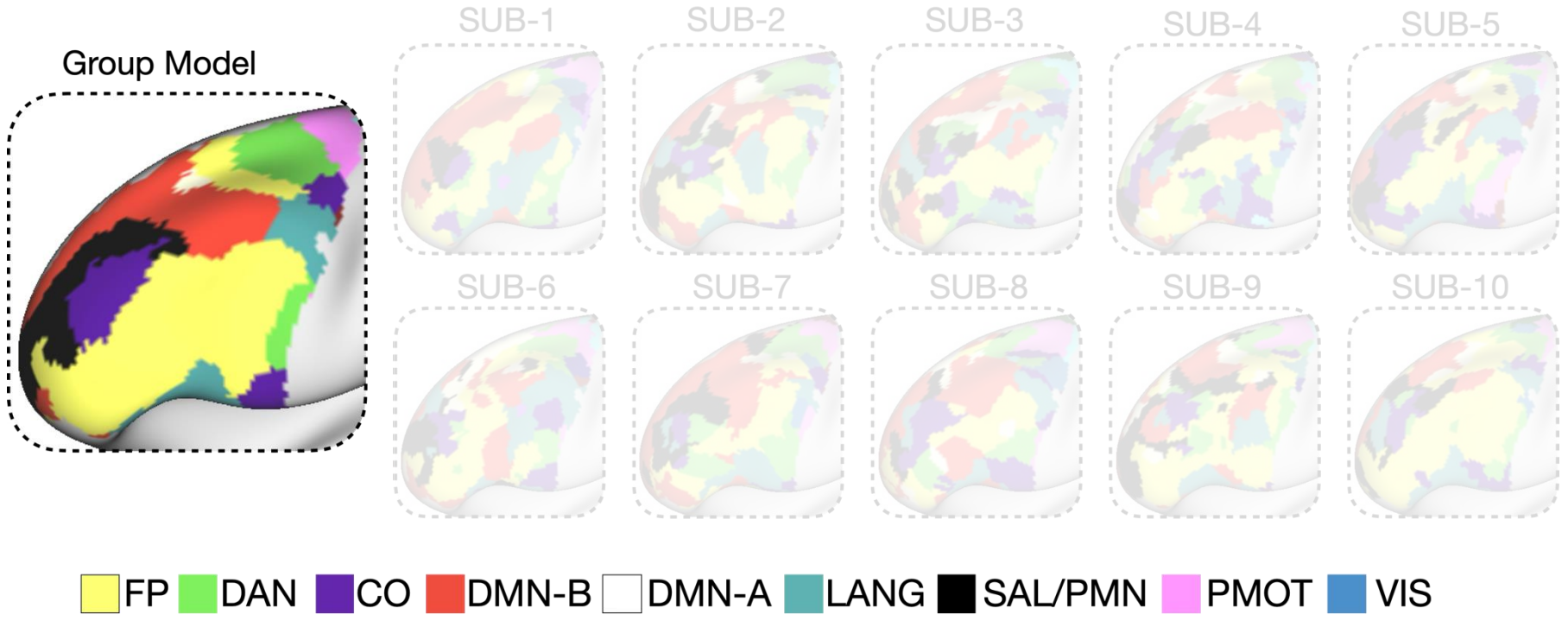
Using Precision fMRI to study the LPFC



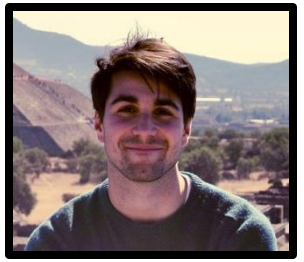


Ladwig et al., submitted

The individual lateral prefrontal cortex is patchy



Ladwig et al., submitted



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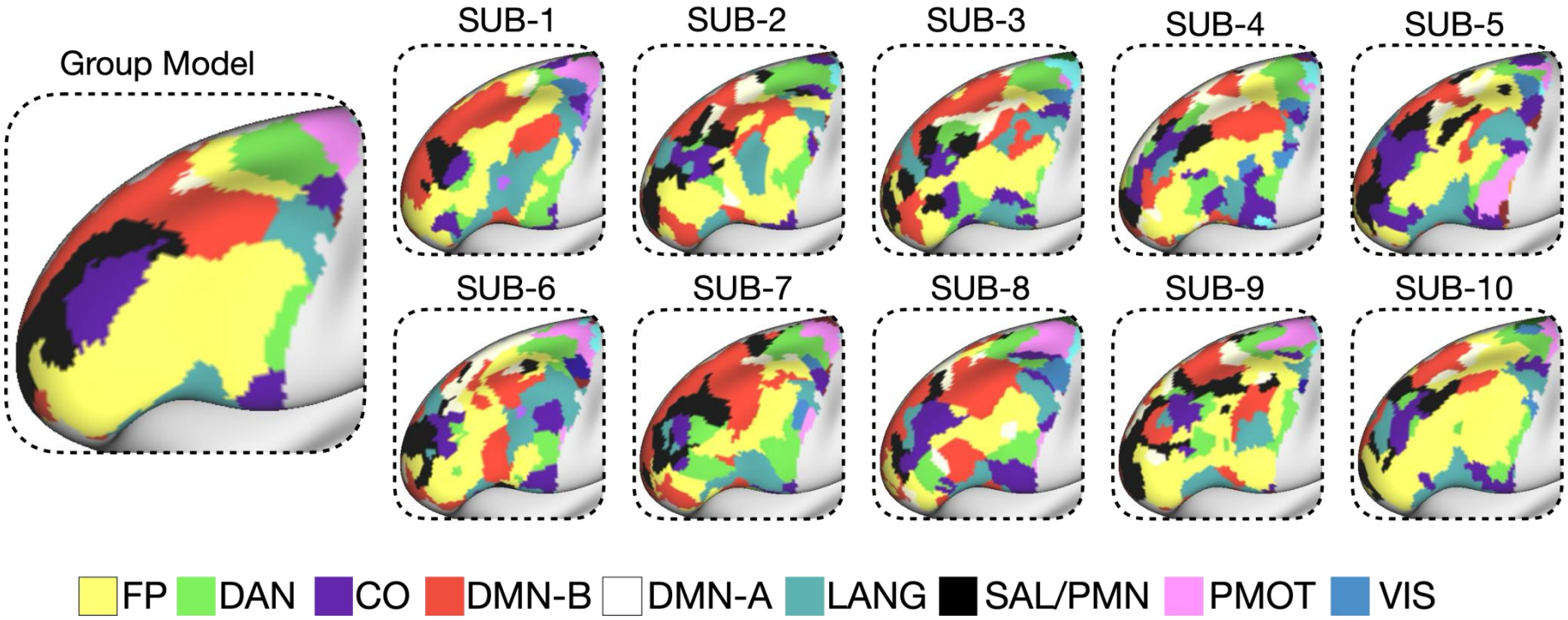
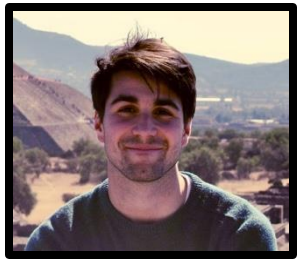
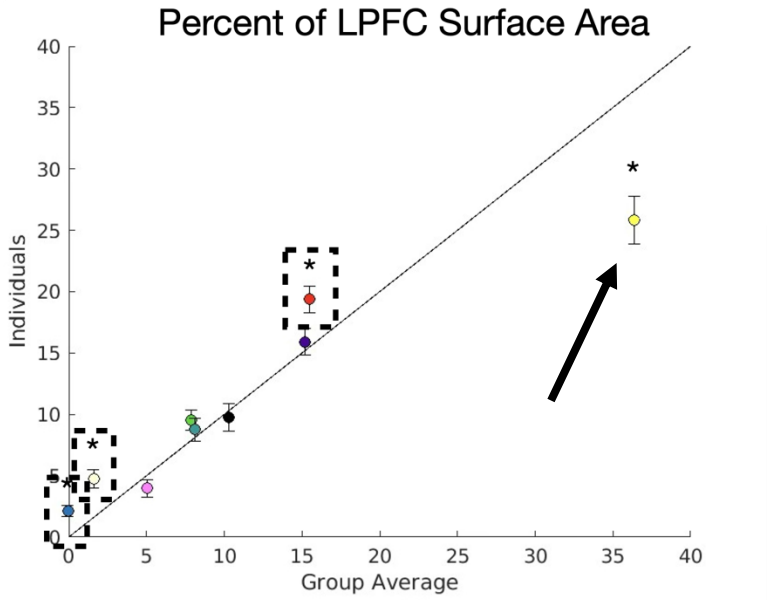


Ladwig et al., submitted

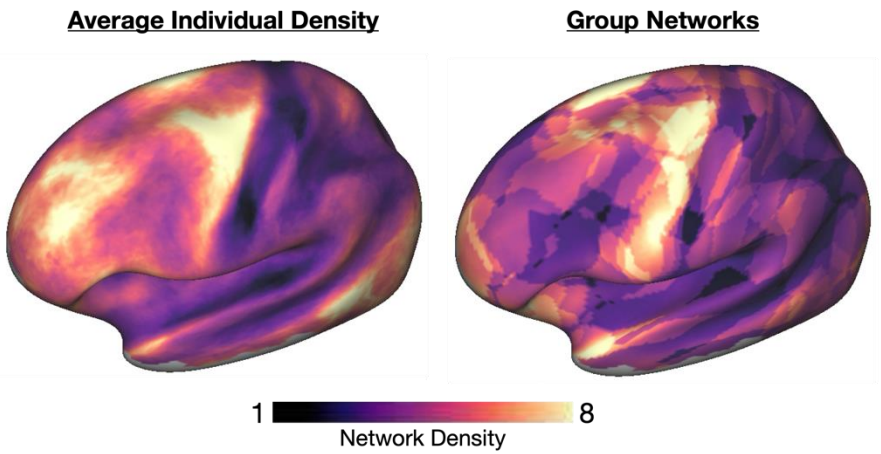


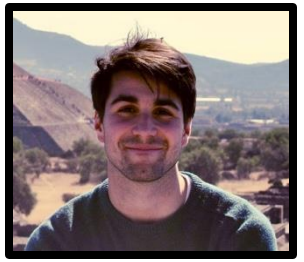
The individual lateral prefrontal cortex differs in basic organizational principles from the group average

The frontoparietal network is **overestimated** in group averages



The **density of networks** in the LPFC is particularly high





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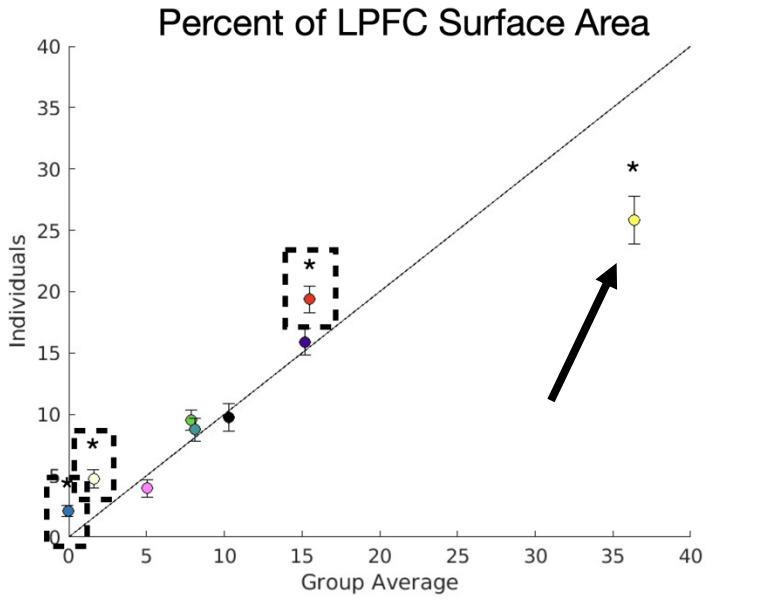

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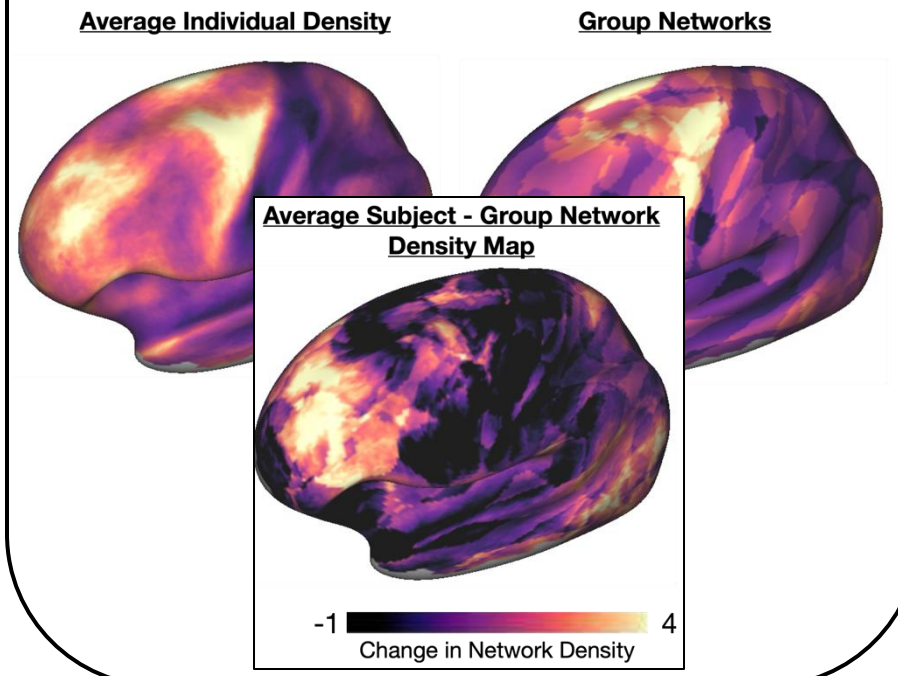
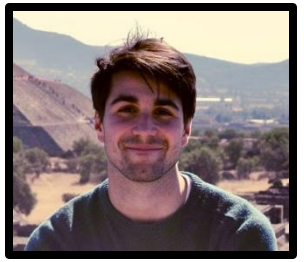
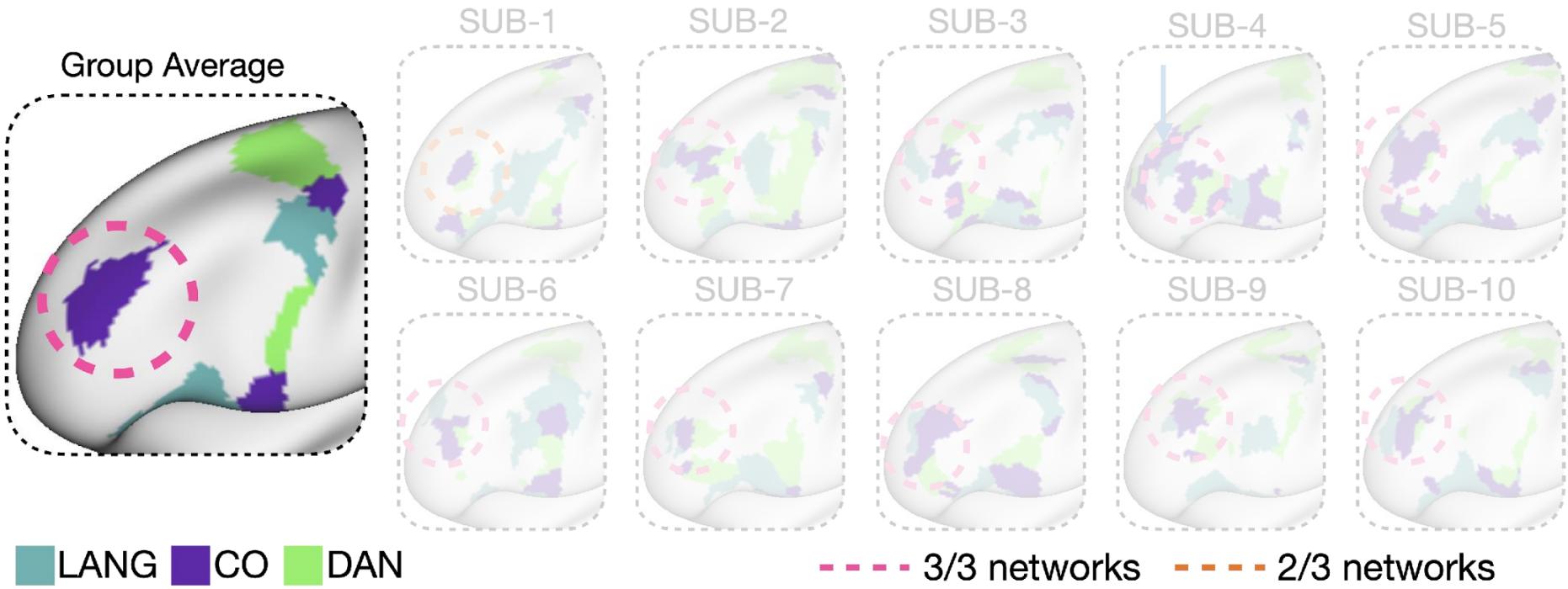


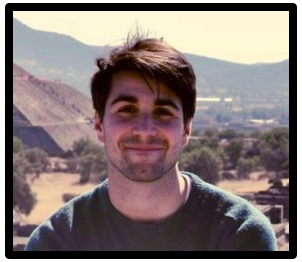
Ladwig et al., submitted



The individual lateral prefrontal cortex has conserved motifs



Ladwig et al., submitted



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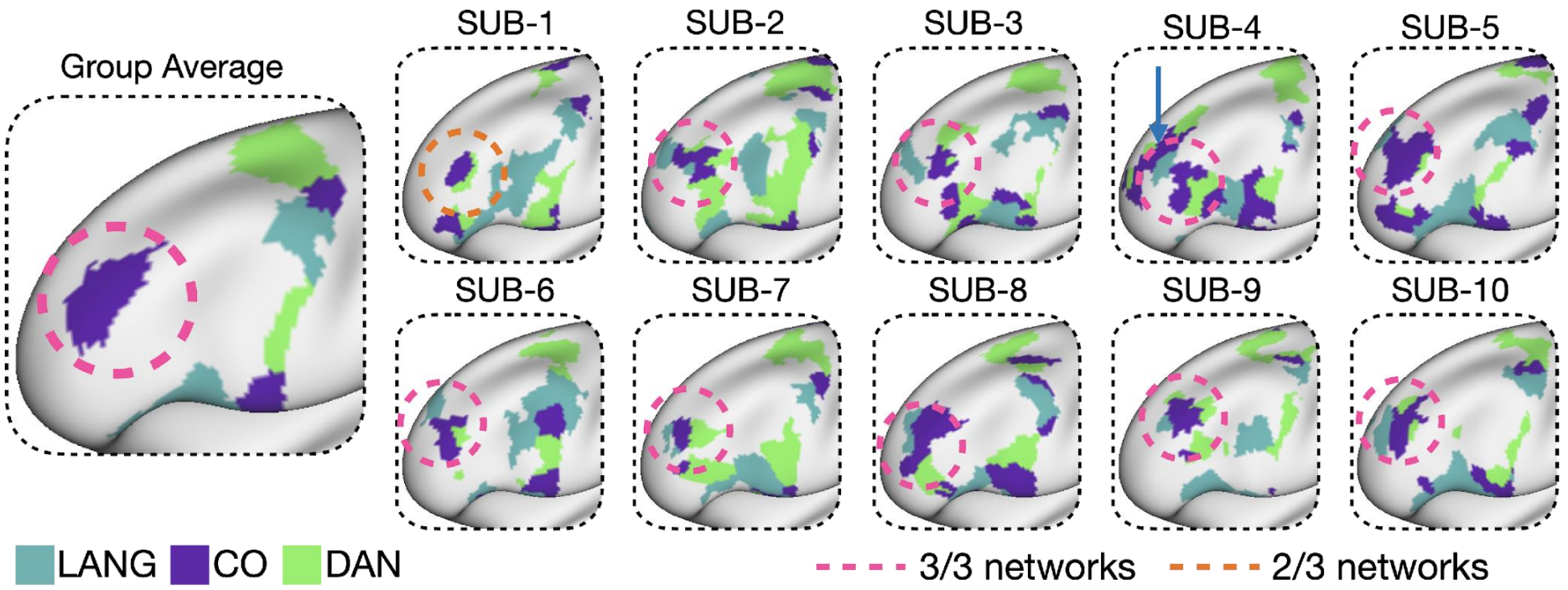
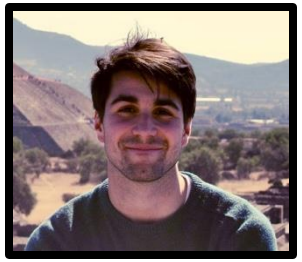


Ladwig et al., submitted



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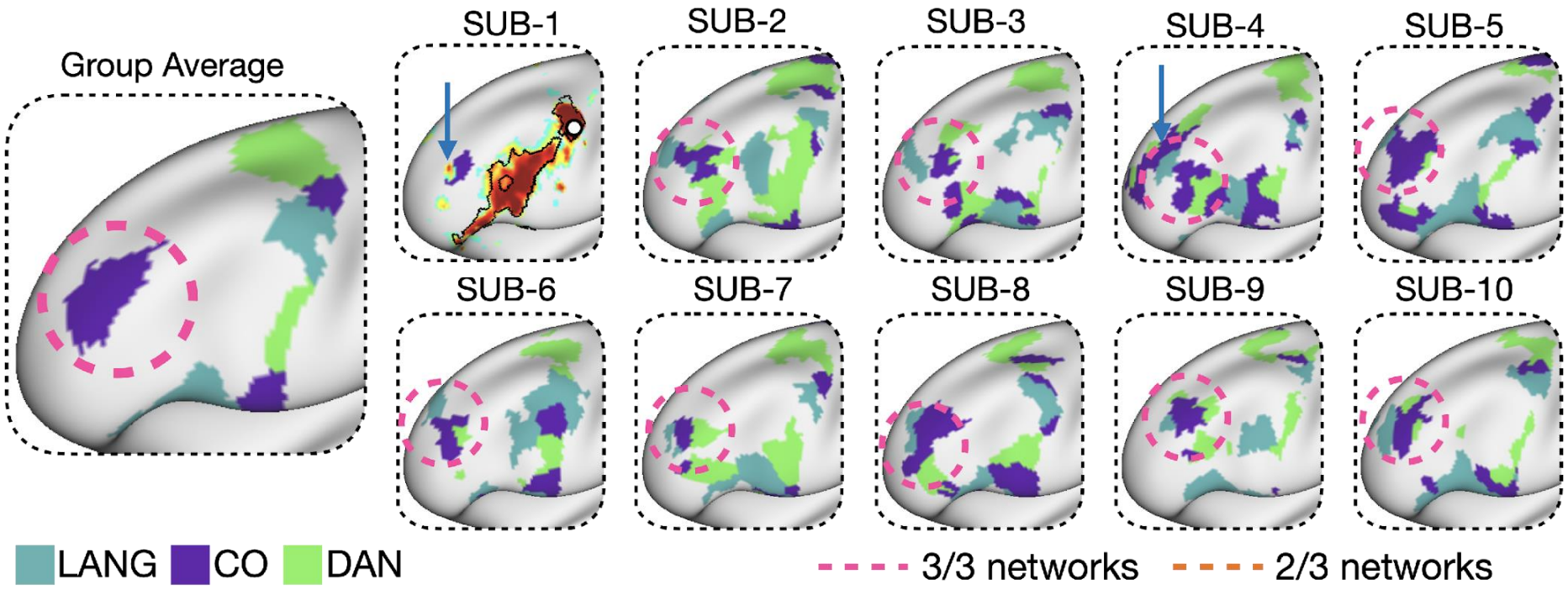
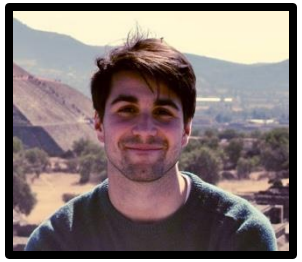


Ladwig et al., submitted



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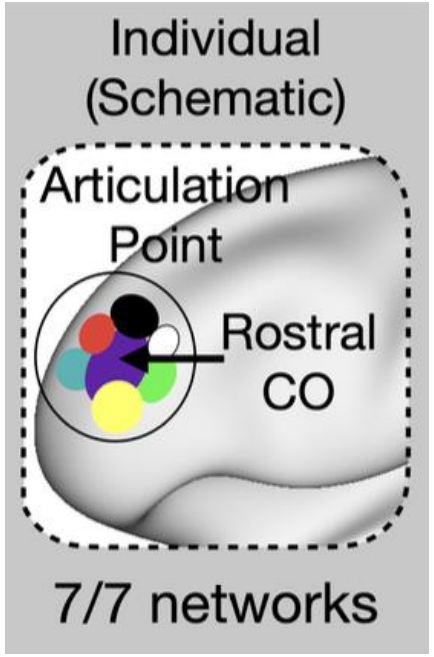
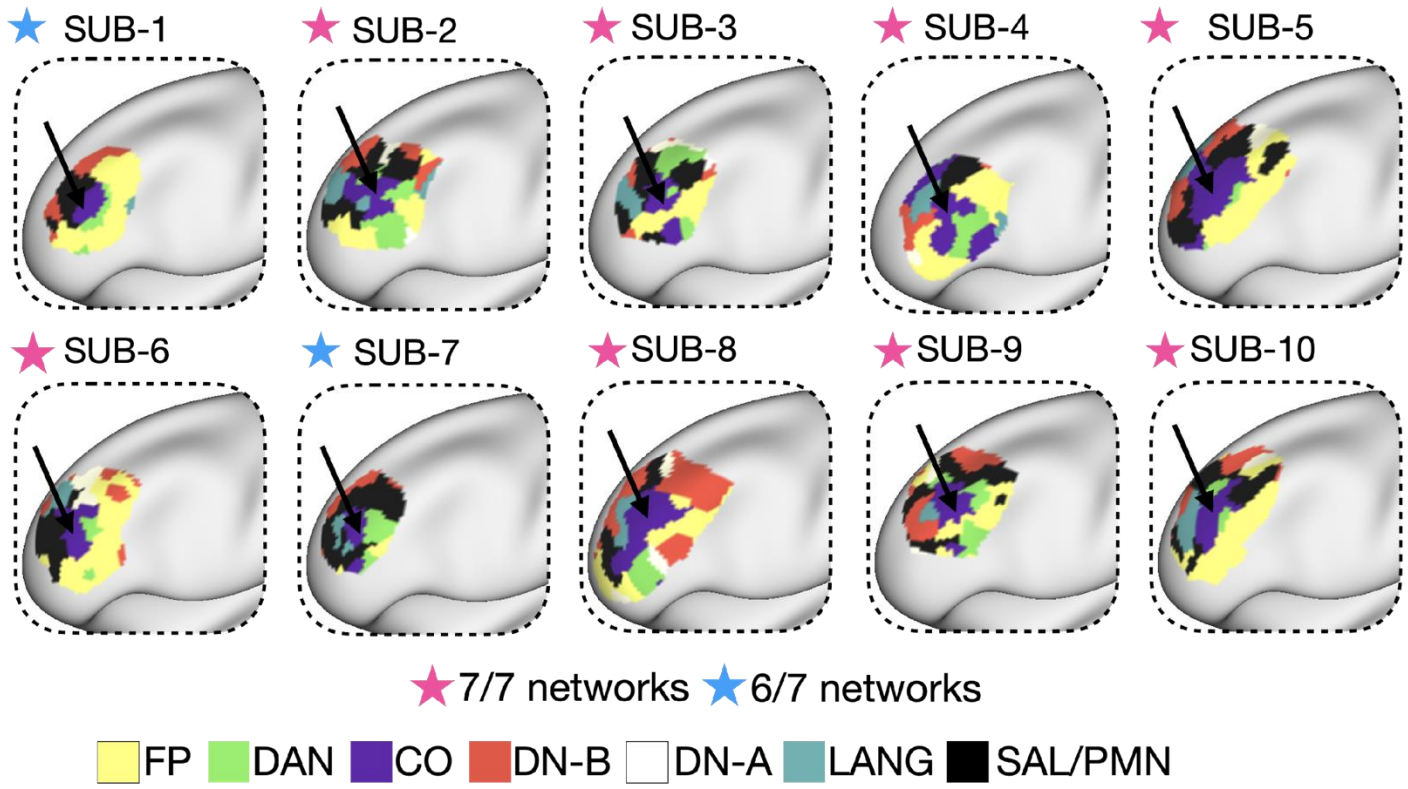
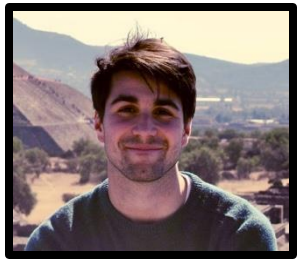
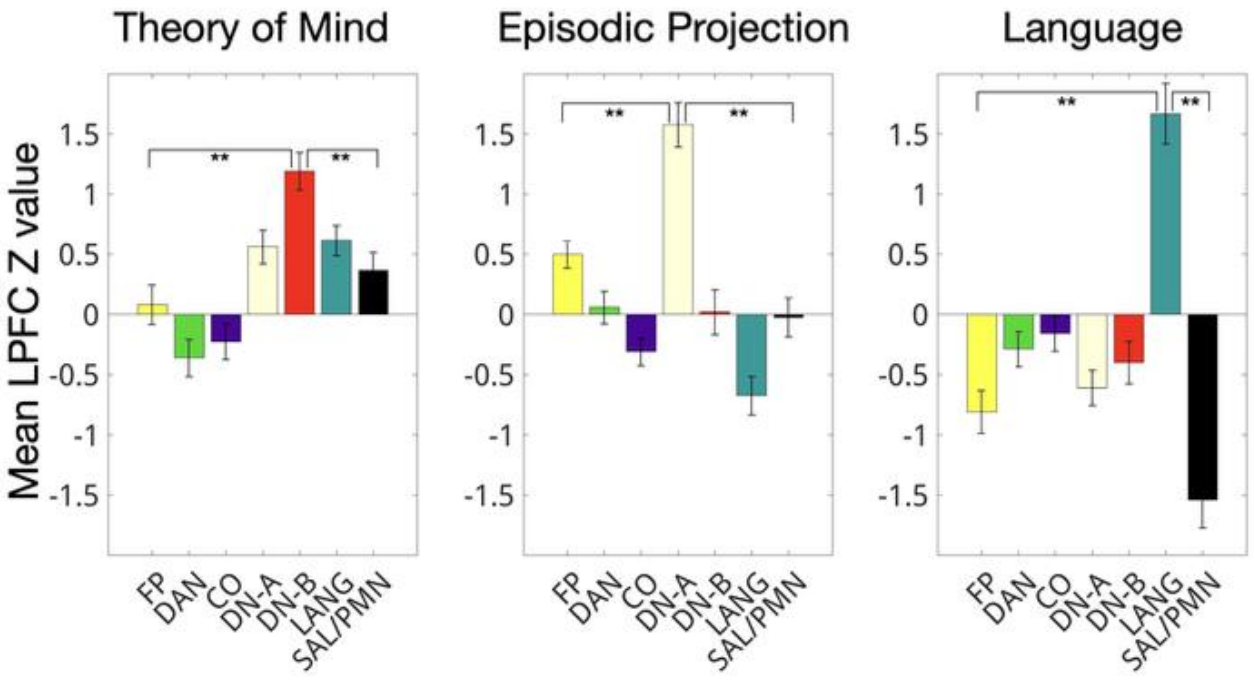




Ladwig et al., submitted

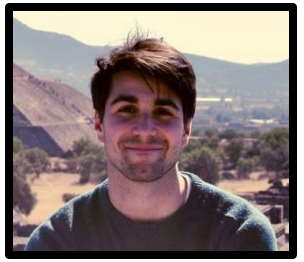


Function follows individual network definitions in the lateral PFC



See also: Di Nicola et al., 2020, 2023; Fedorenko et al., 2012,; Braga et al, 2020; Du et al., 2024

Ladwig et al., submitted



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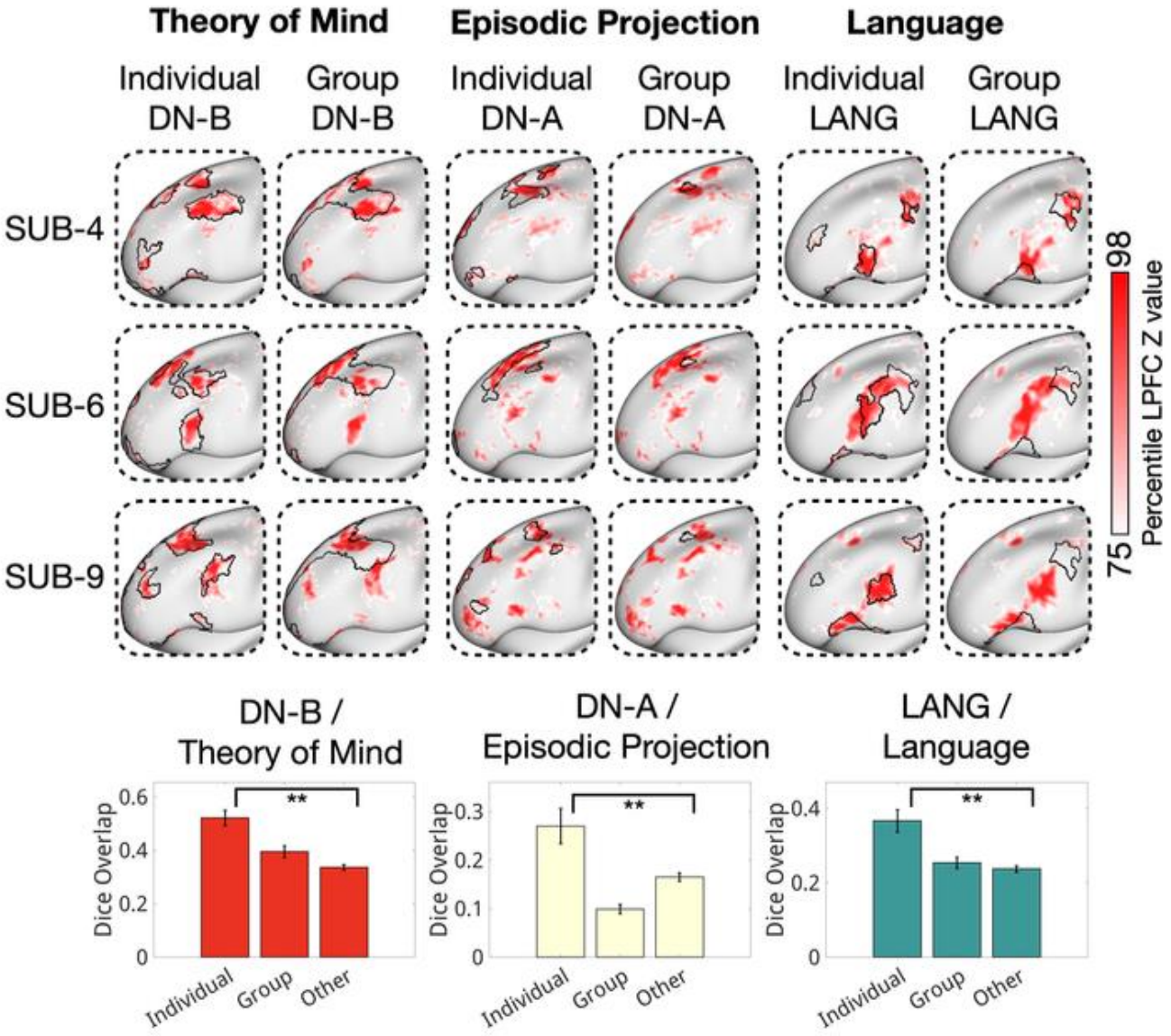
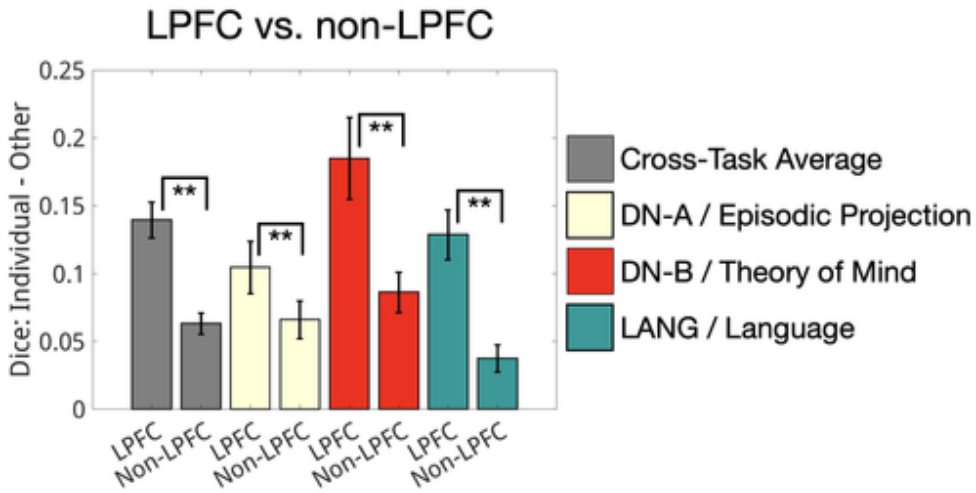
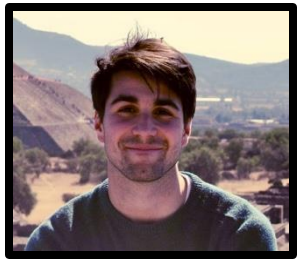
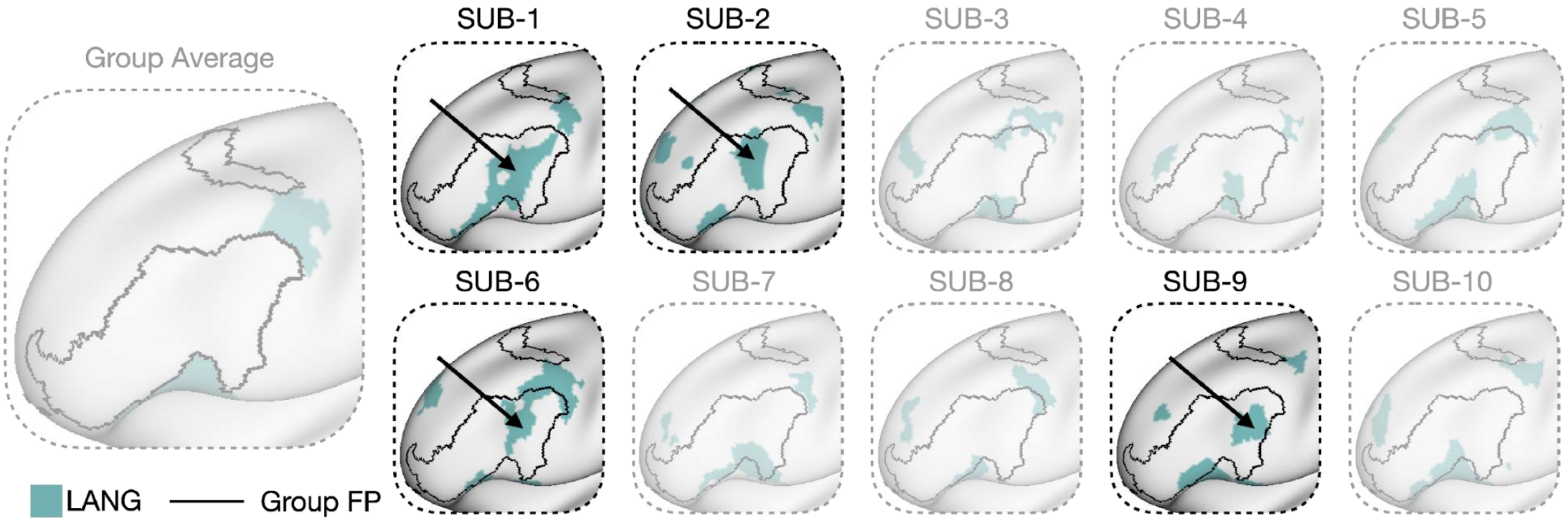




Ladwig et al., submitted



Idiosyncrasies in networks relate to idiosyncrasies in task responses



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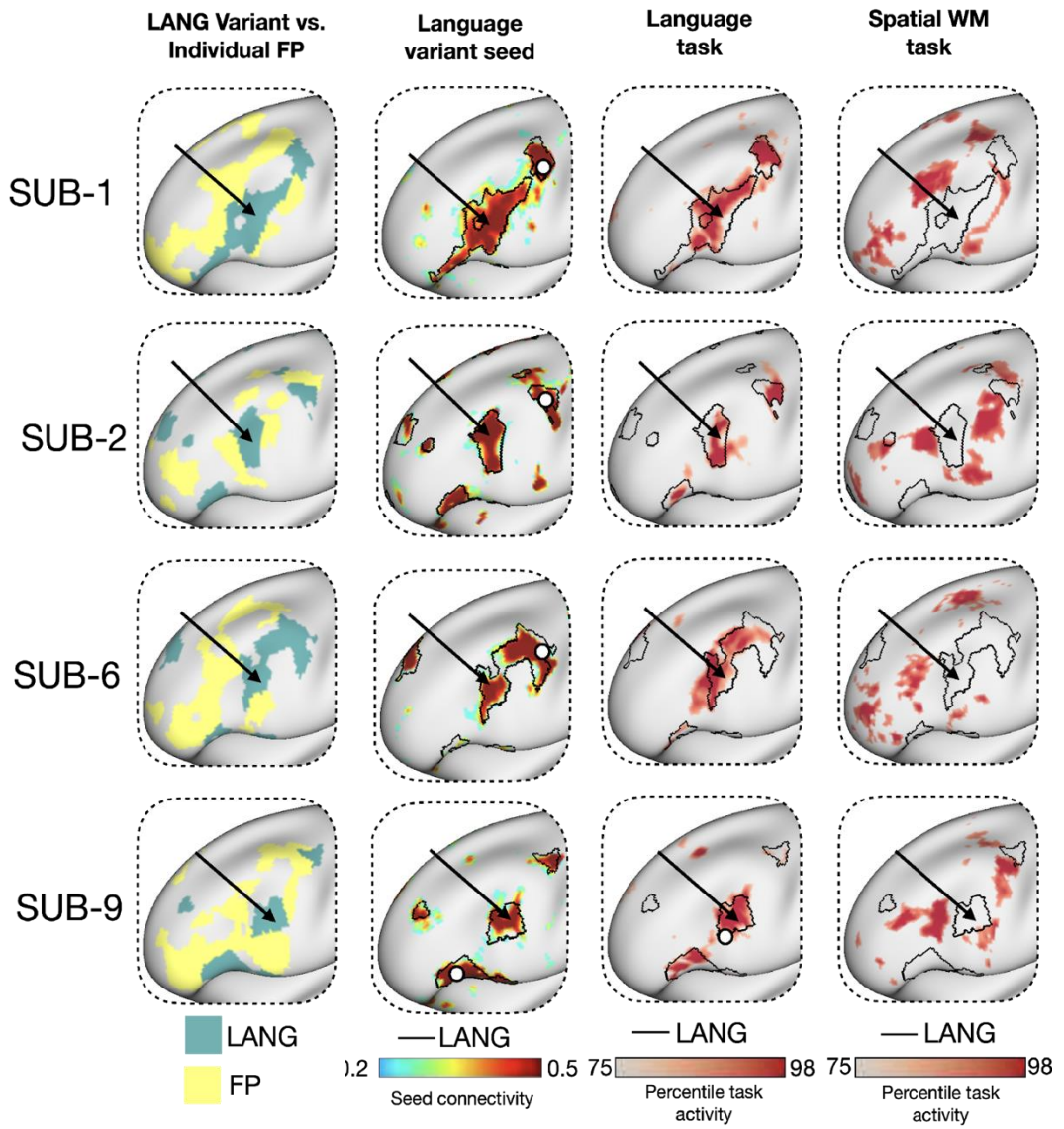
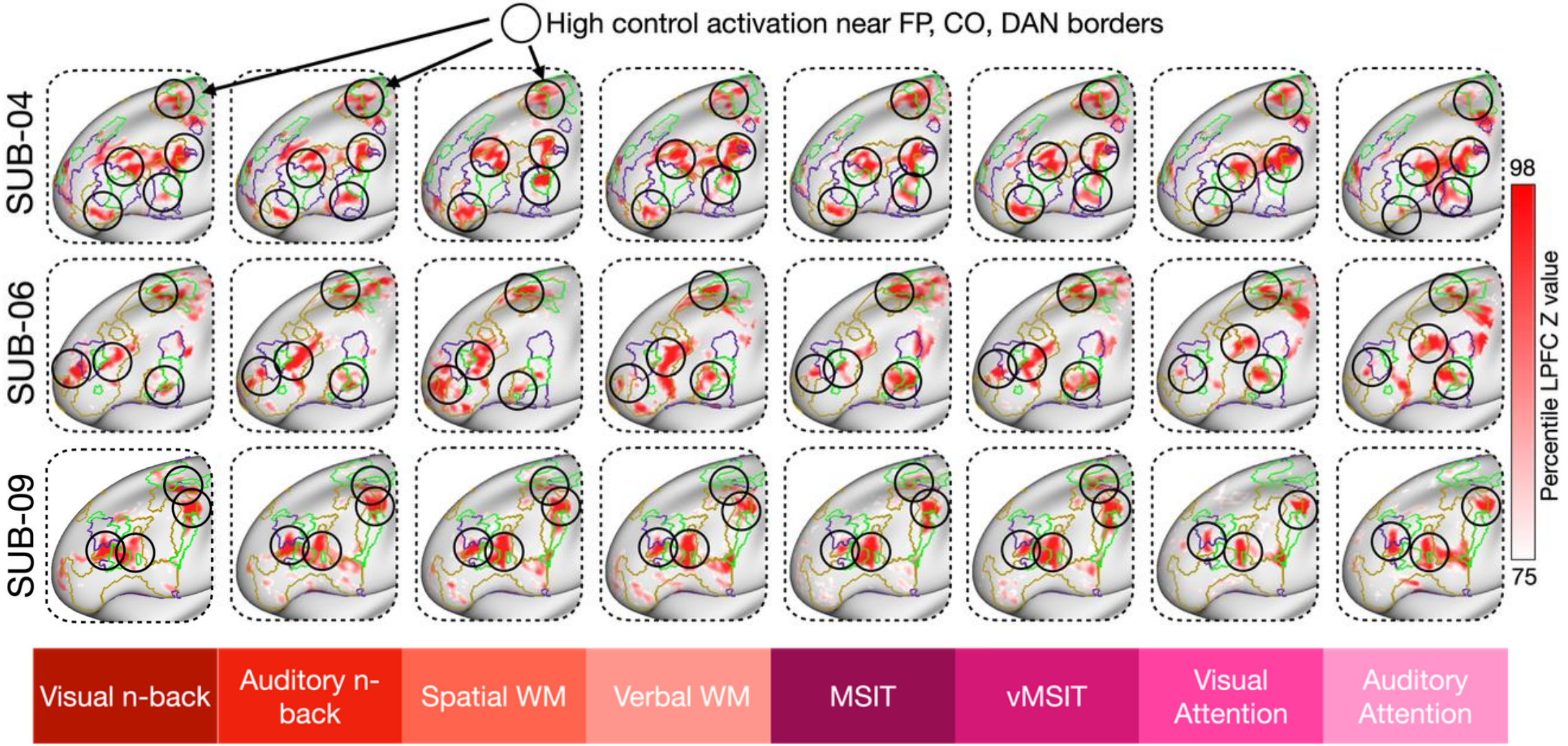
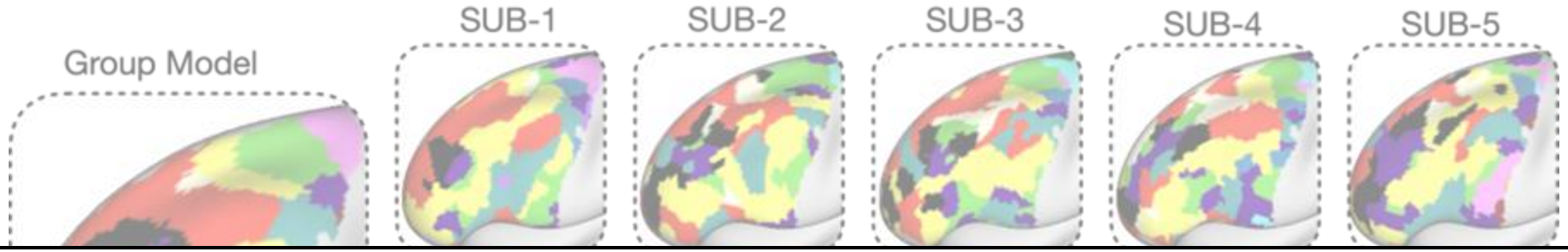


Control-related activations hug network borders



What can you do with precision fMRI?

2. Study basic properties of functional networks

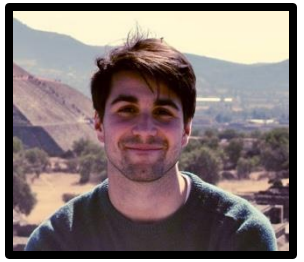


Take aways:

- The **individual lateral prefrontal cortex** is **patchy**, with lots of network **borders**
- The individual lateral PFC has a **smaller frontoparietal network** than you would expect
- **Task activations follow network patterns**, particularly in the lateral PFC
- **Control related task activations** occur near **network borders**

FP DAN CO DMN-B DMN-A LANG SAL/PMN PMOT VIS

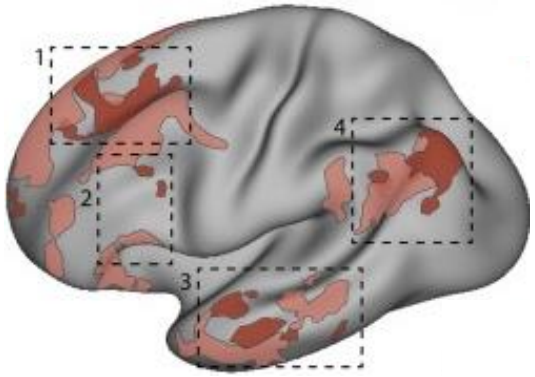
Ladwig et al., submitted



What can you do with precision fMRI?

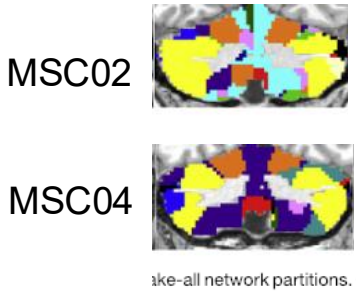
2. Study basic properties of brain networks

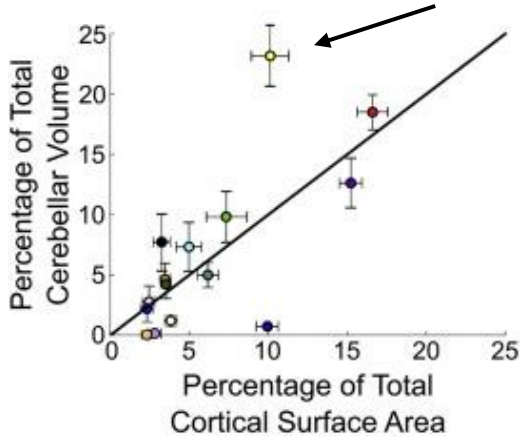
Two 'default' networks



Braga, et al., 2017, *Neuron*

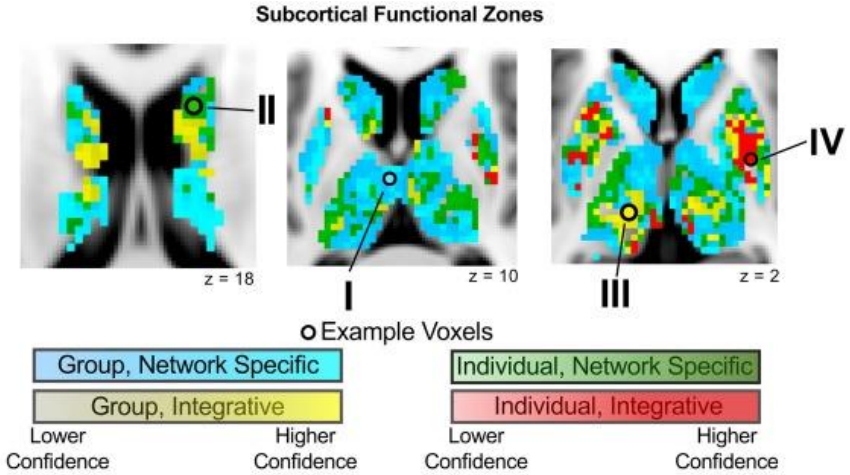
Expanded frontoparietal network in the cerebellum





Marek, et al., 2018, *Neuron*

Integrative and network specific subcortical zones



Greene, et al., 2020, *Neuron*

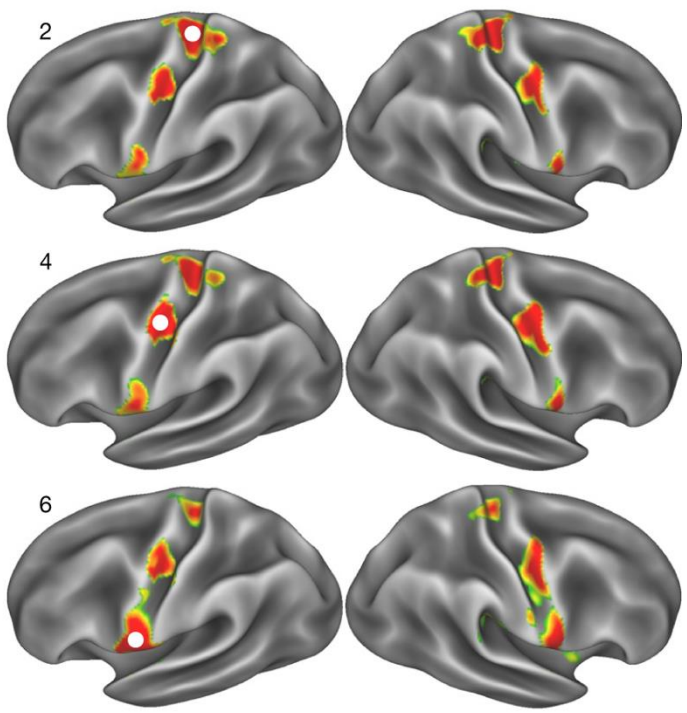
What can you do with precision fMRI?

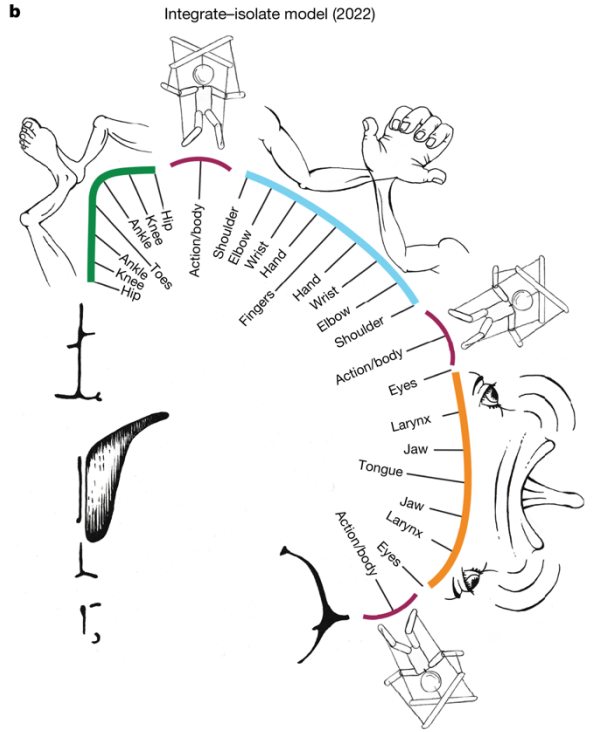
2. Study basic properties of brain networks

Two ‘default’ networks

Expanded frontoparietal network in the cerebellum

Somato—cognitive action network in the motor cortex

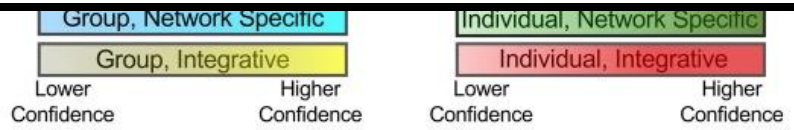




Gordon et al., 2022, *Nature*

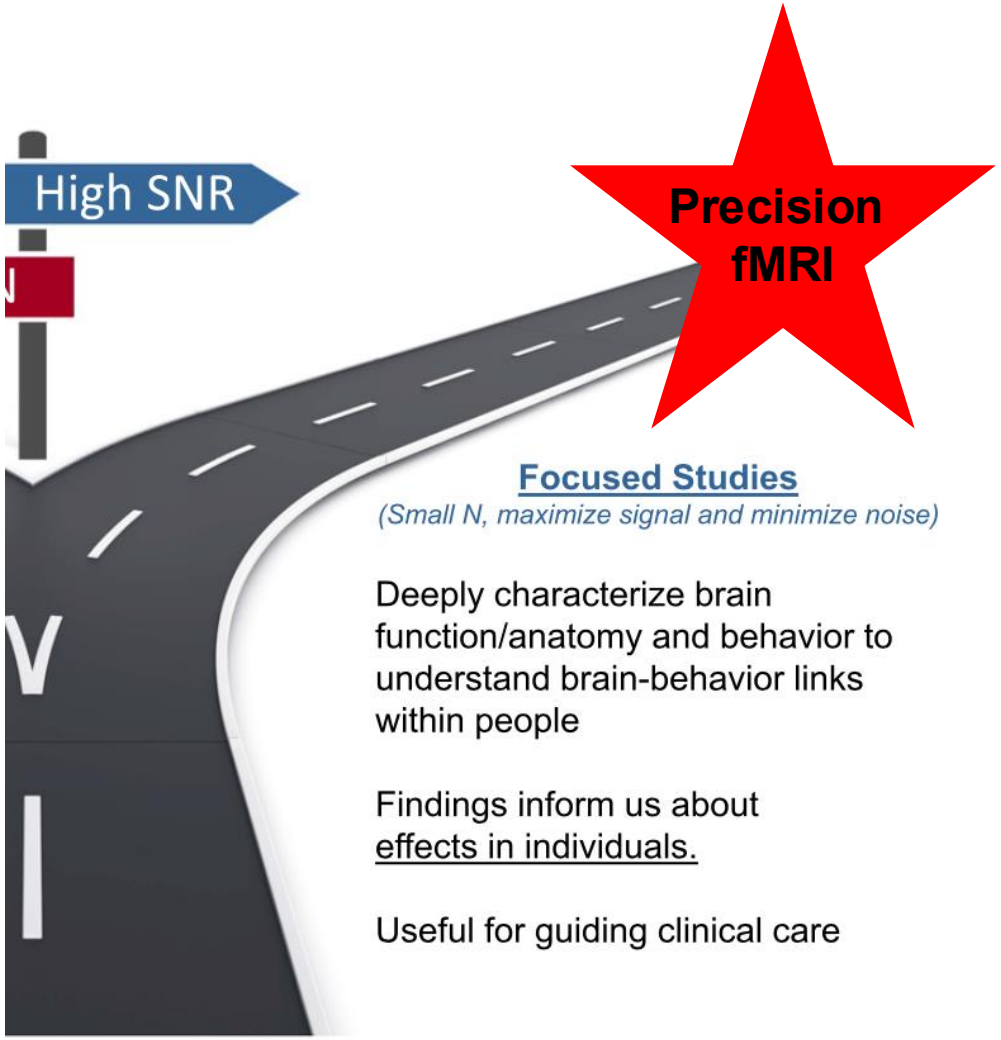
Braga

Greene, et al., 2020, *Neuron*



The Promise of Precision fMRI

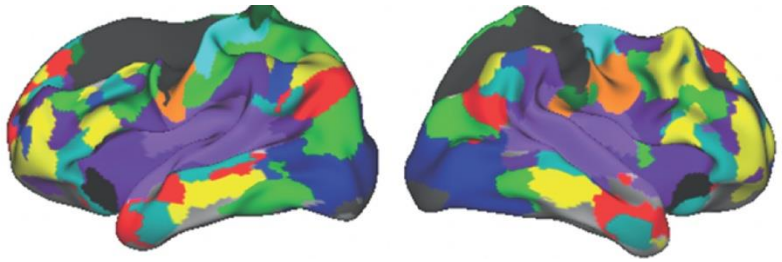
1. Improve measurement of brain networks
2. Identify basic properties of brain function & organization
3. **Identify new brain-behavior relationships**
4. Characterize individual differences



What can you do with precision fMRI?

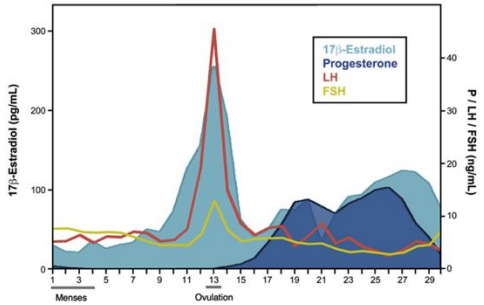
3. Study new brain-behavior relationships

response to injury



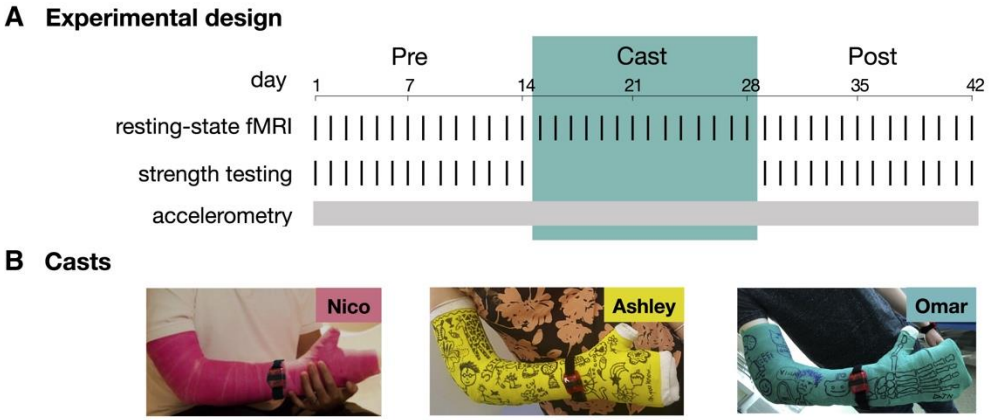
Laumann et al., 2021, *Lancet Neurology*

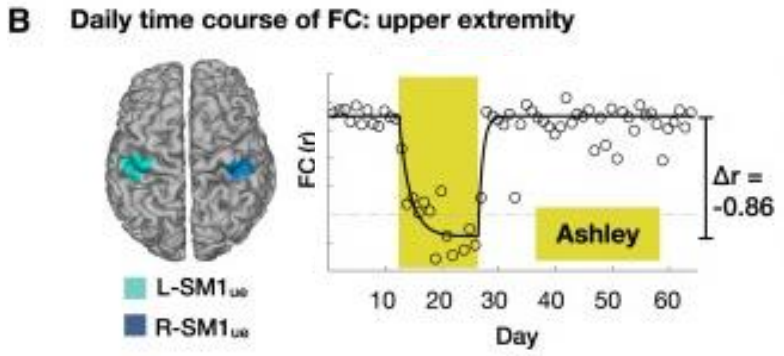
response to hormones



Pritschet et al., 2020, Neuroimage

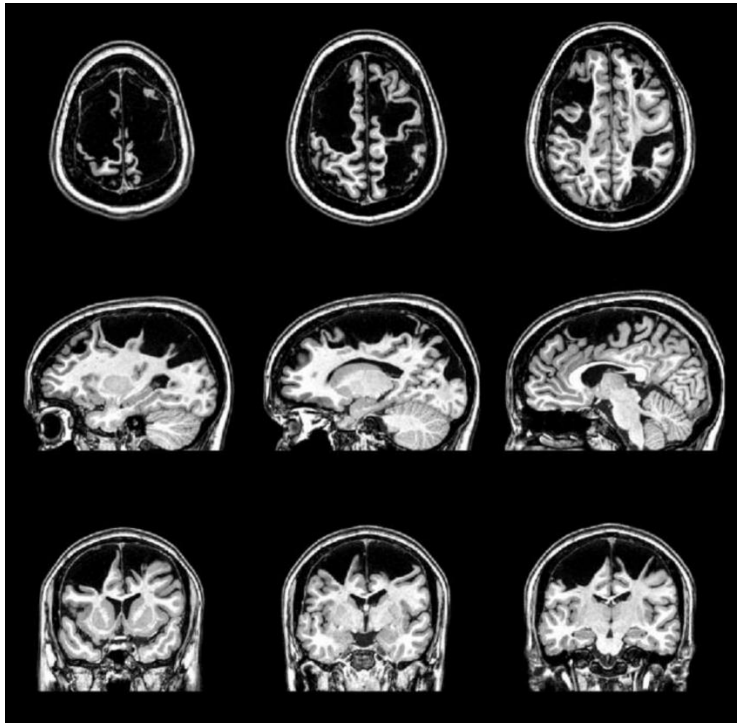
response to interventions





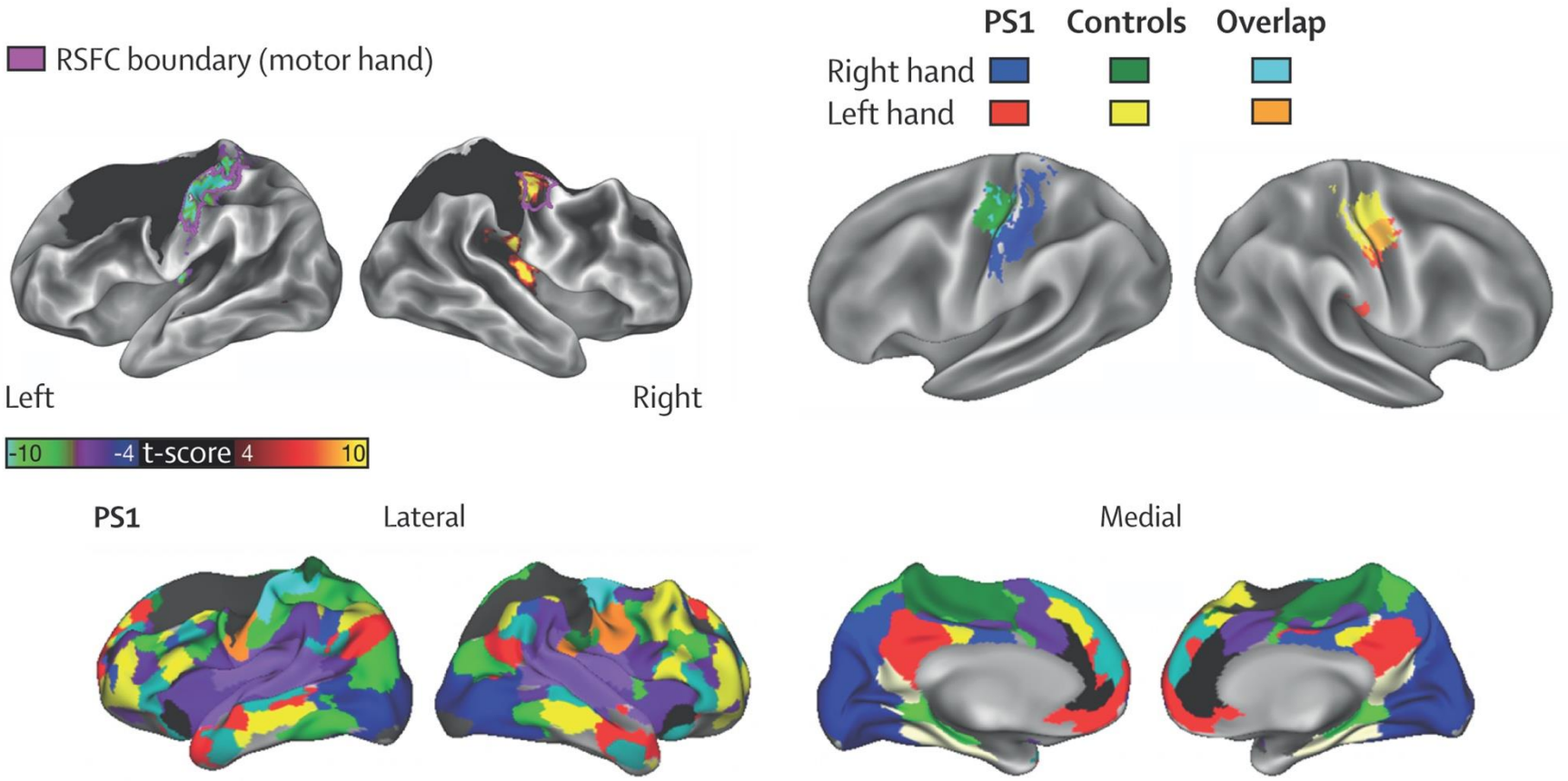
Newbold et al., 2020, *Neuron*

Precision fMRI:
functional remapping after brain damage



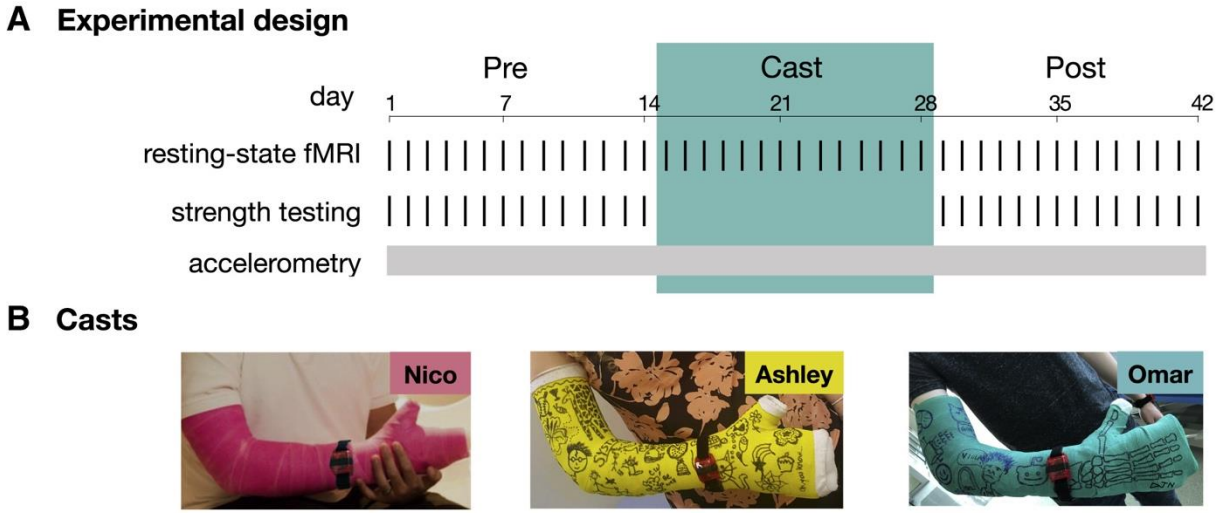
Laumann et al., 2021, *Lancet Neurology*

Precision fMRI:
functional remapping after brain damage

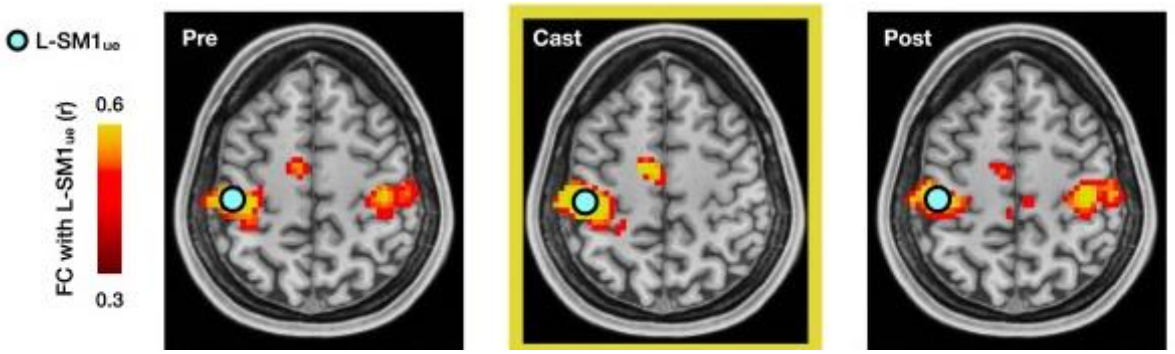


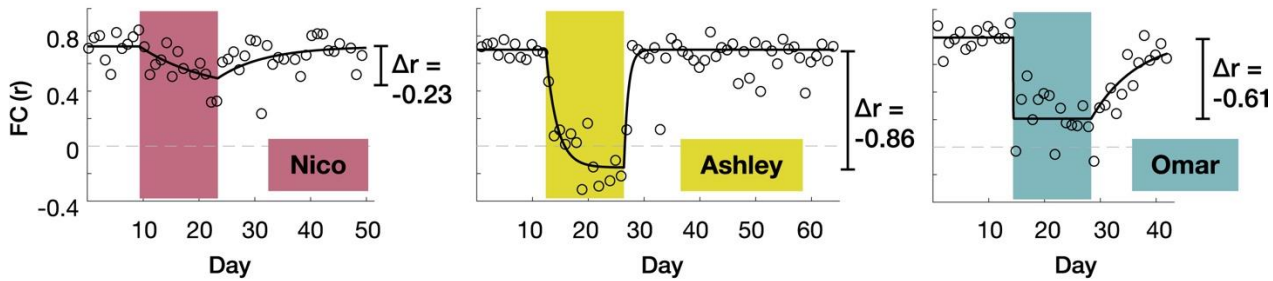
Laumann et al., 2021, *Lancet Neurology*

Precision fMRI:
shorter-term plasticity in functional connectivity



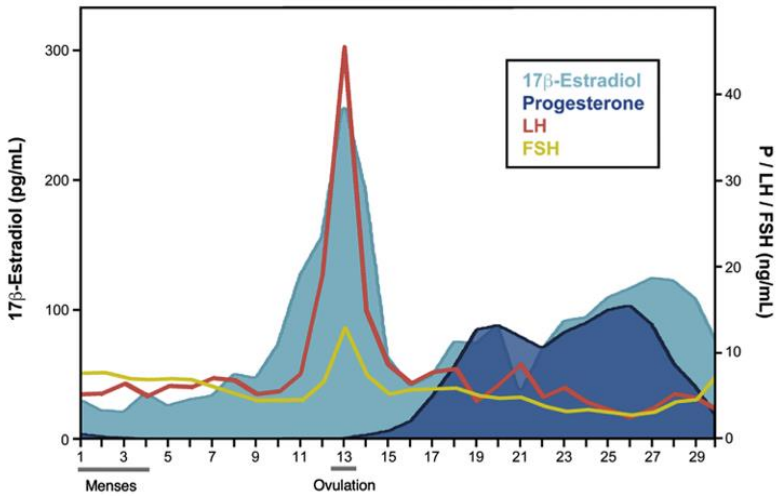
Newbold et al., 2020, *Neuron*



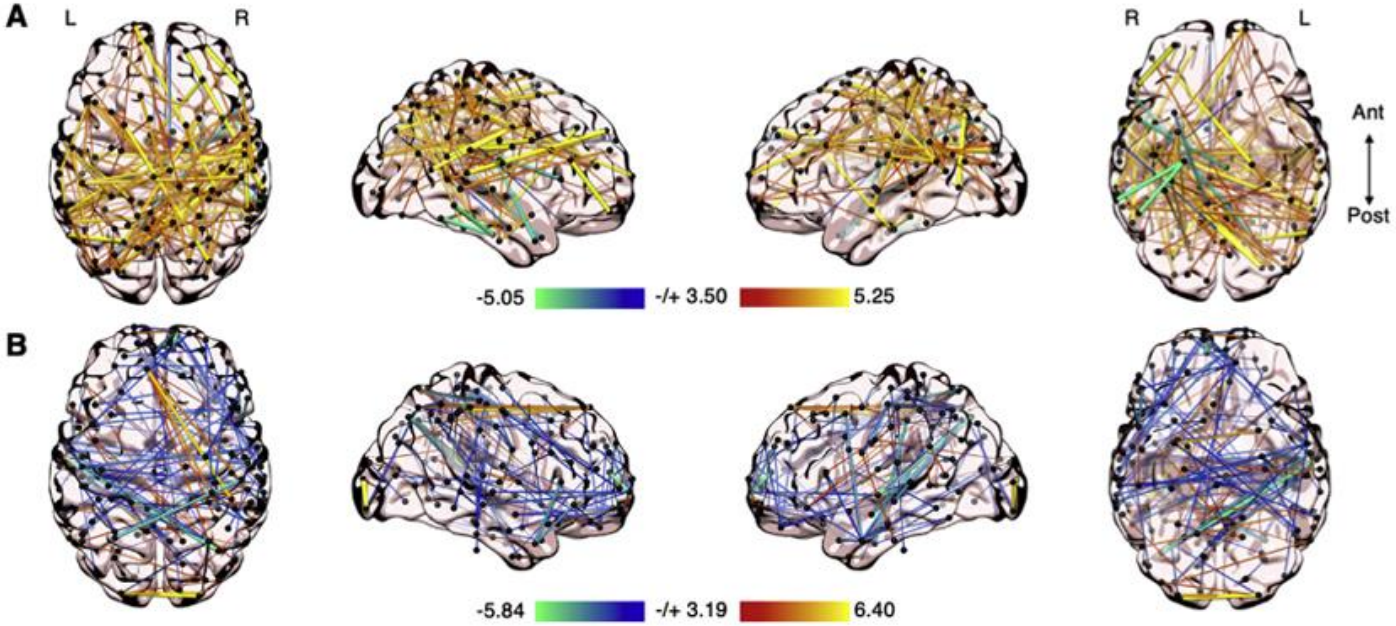


https://openneuro.org/datasets/ds002766/versions/3.0.0

Precision fMRI: Brain changes with hormones

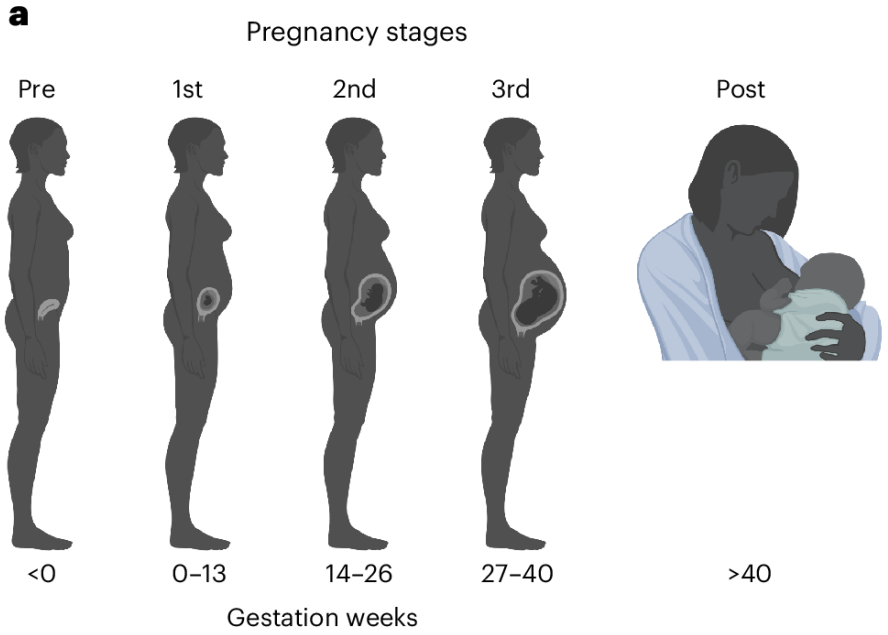


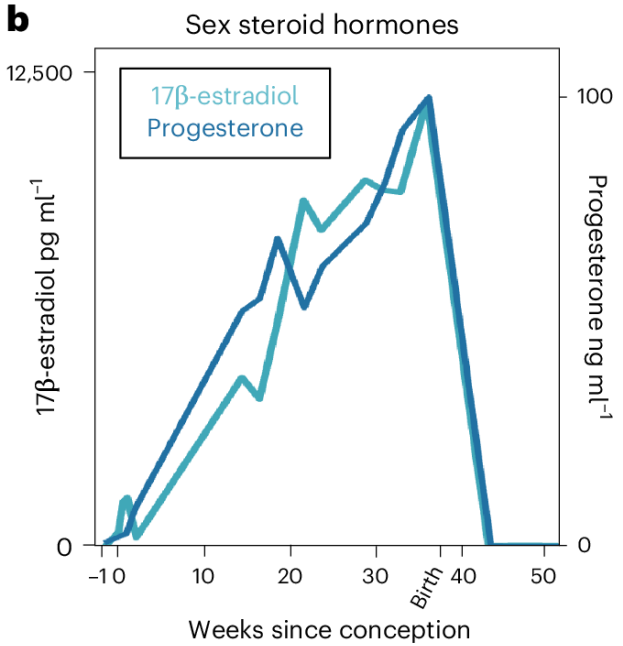
Pritschet et al., 2020, *Neuroimage*

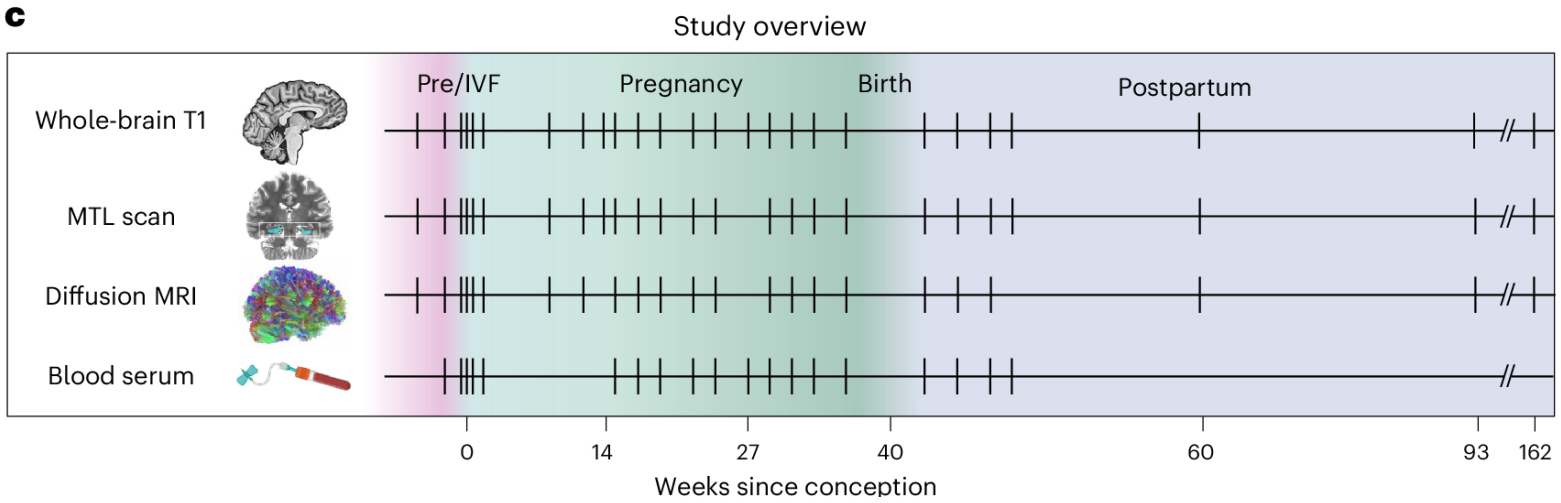


https://openneuro.org/datasets/ds002674/versions/1.0.6

Precision fMRI: Brain changes with hormones

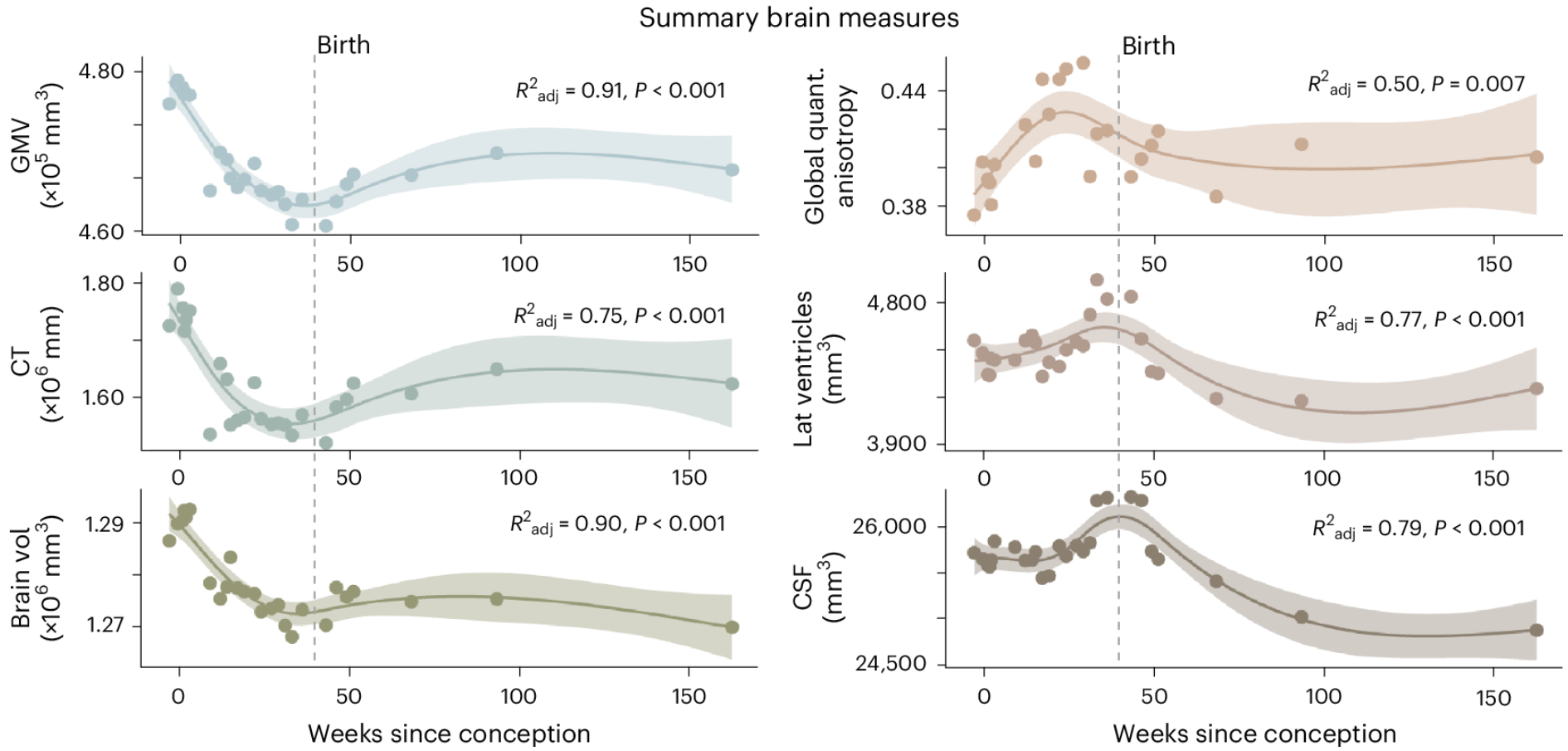






Pritschet et al., 2025, Nature Neurosci

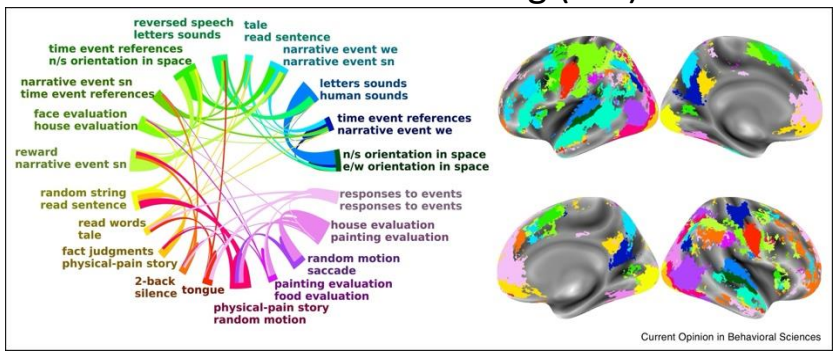
Precision fMRI: Brain changes with hormones

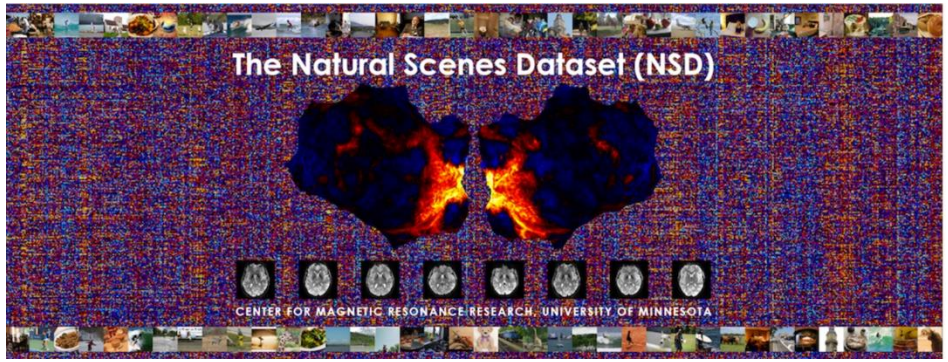


Pritschet et al., 2025, Nature Neurosci

Precision fMRI approaches: datasets to power individual prediction studies

Individual Brain Charting (IBC)





Open Access | Published: 12 June 2018

Individual Brain Charting, a high-resolution fMRI dataset for cognitive mapping

Ana Luísa Pinho, Alexis Amadon, Torsten Ruest, Murielle Fabre, Elvis Dohmatob, Isabelle Denghien, Chantal Ginisty, Séverine Becuwe-Desmidt, Séverine Roger, Laurence Laurier, Véronique Joly-Testault, Gaëlle Médiouni-Cloarec, Christine Doublé, Bernadette Martins, Philippe Pinel, Evelyn Eger, Gaël Varoquaux, Christophe Pallier, Stanislas Dehaene, Lucie Hertz-Pannier & Bertrand Thirion

Scientific Data 5, Article number: 180105 (2018) | Cite this article

8254 Accesses | 30 Citations | 79 Altmetric | Metrics

Abstract

Functional Magnetic Resonance Imaging (fMRI) has furthered brain mapping on perceptual, motor, as well as higher-level cognitive functions. However, to date, no data collection has

RESOURCE

https://doi.org/10.1038/s41593-021-00962-x

nature neuroscience

Check for updates

A massive 7T fMRI dataset to bridge cognitive neuroscience and artificial intelligence

Emily J. Allen[1,2], Ghislain St-Yves[3,17], Yihan Wu[4], Jesse L. Breedlove[3,18], Jacob S. Prince[5,19], Logan T. Dowdle[6,7], Matthias Nau[8], Brad Caron[9,10], Franco Pestilli[11,12,13], Ian Charest[14,15], J. Benjamin Hutchinson[16], Thomas Naselaris[3,17,20] and Kendrick Kay[1,20]

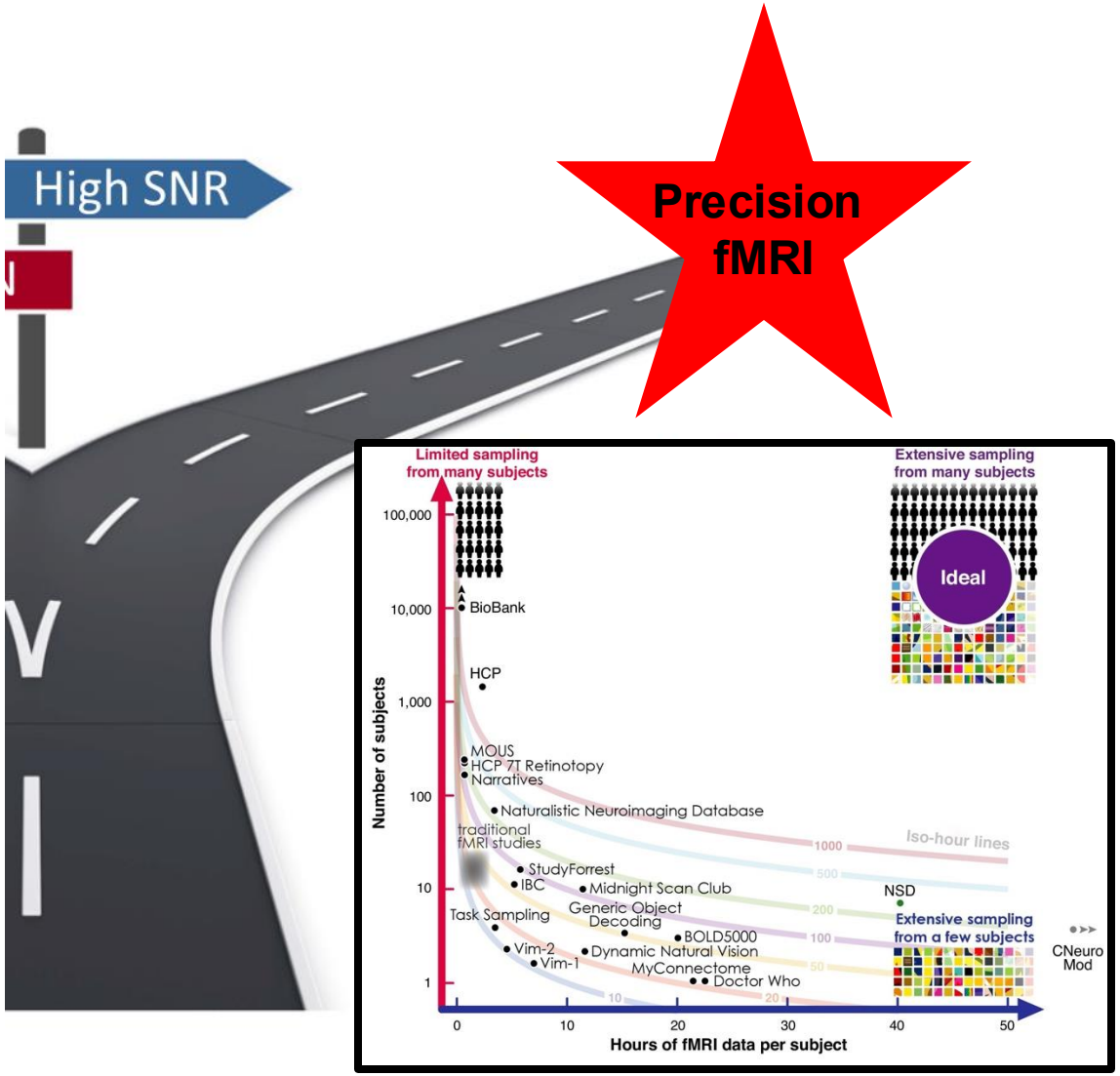
Extensive sampling of neural activity during rich cognitive phenomena is critical for robust understanding of brain function. Here we present the Natural Scenes Dataset (NSD), in which high-resolution functional magnetic resonance imaging responses to tens of thousands of richly annotated natural scenes were measured while participants performed a continuous recognition task. To optimize data quality, we developed and applied novel estimation and denoising techniques. Simple visual inspections of the NSD data reveal clear representational transformations along the ventral visual pathway. Further exemplifying the inferential power of the dataset, we used NSD to build and train deep neural network models that predict brain activity more

Pinho et al., 2018, *Scientific Data*
Thirion et al., 2021, *Curr Op Beh Sci*

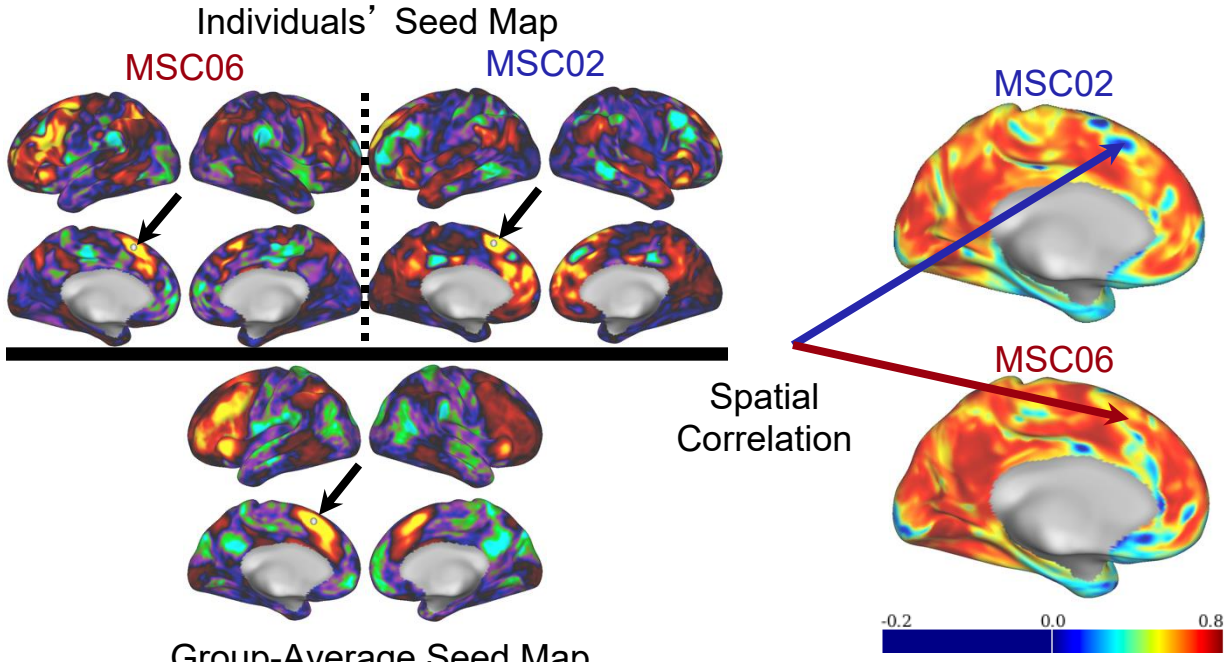
Allen et al., 2022, *Nature Neuroscience*
Naselaris et al., 2021, *Curr Op Beh Sci*

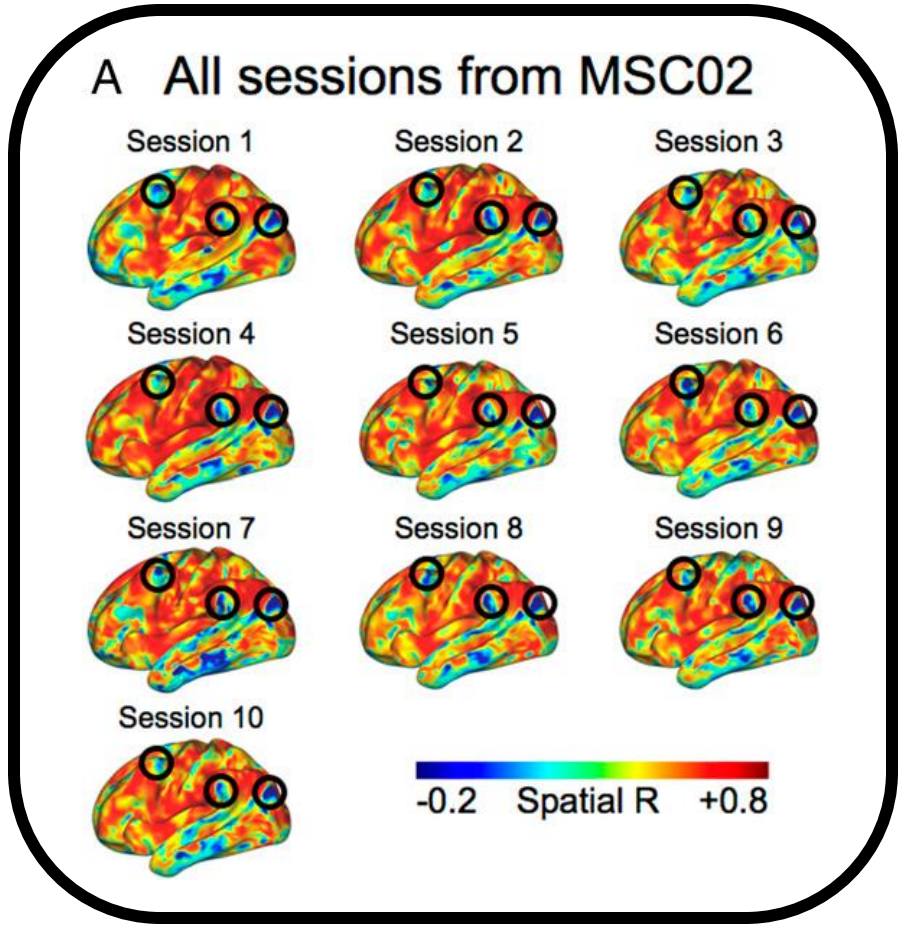
The Promise of Precision fMRI

1. Improve measurement of brain networks
2. Identify basic properties of brain function & organization
3. Identify new brain-behavior relationships
4. **Characterize individual differences (*in combination with big data*)**



Precision fMRI can be used to identify and characterize individual differences

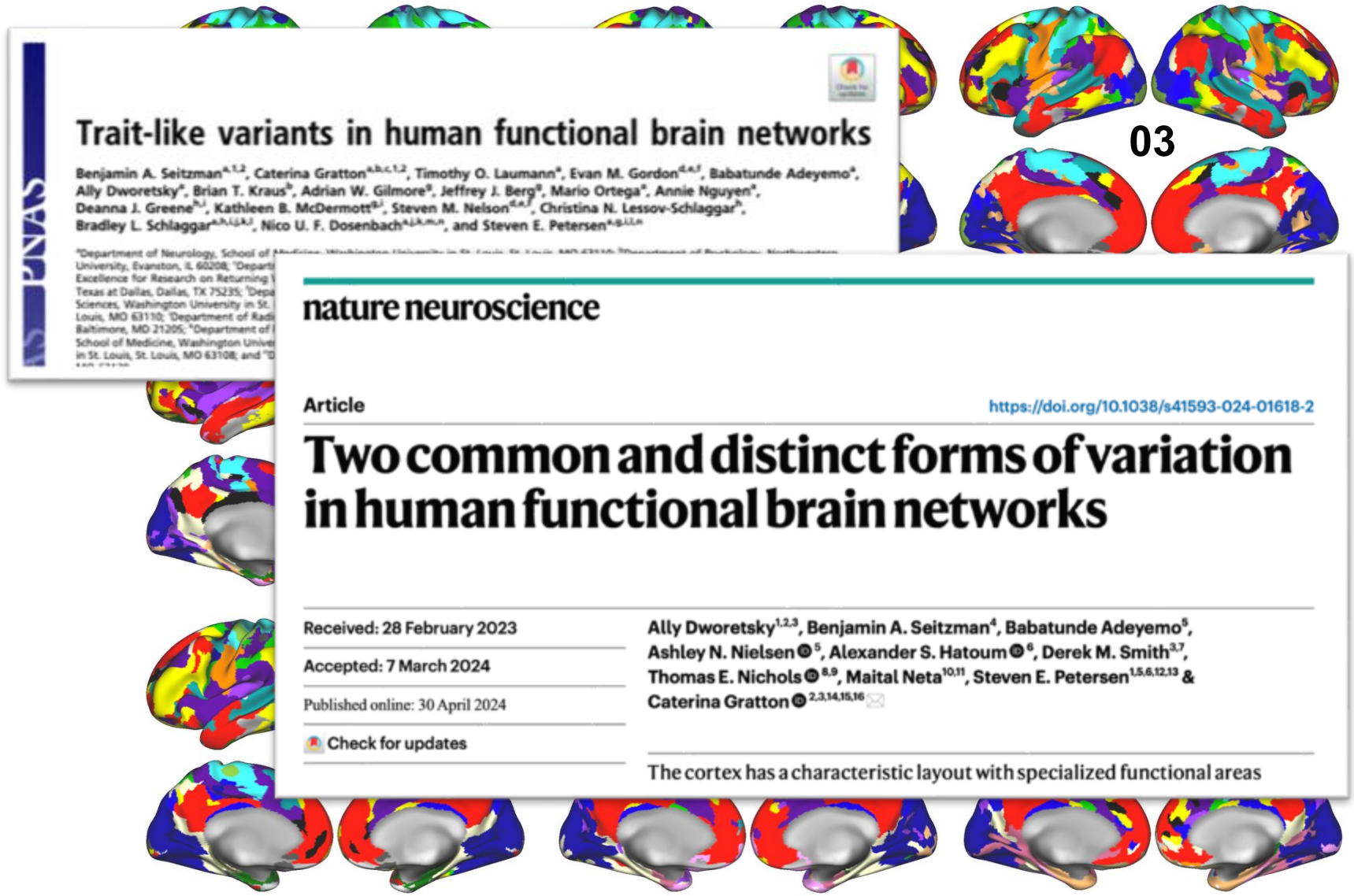




Seitzman*, Gratton*, et al., 2019, *PNAS*

https://github.com/GrattonLab/SeitzmanGratton-2019-PNAS

Precision fMRI can be used to identify and characterize individual differences



PNAS

Trait-like variants in human functional brain networks

Benjamin A. Seitzman[a,1,2], Caterina Gratton[a,b,c,1,2], Timothy O. Laumann[a], Evan M. Gordon[d,e,f], Babatunde Adeyemo[a], Ally Dworetsky[a], Brian T. Kraus[b], Adrian W. Gilmore[g], Jeffrey J. Berg[g], Mario Ortega[a], Annie Nguyen[a], Deanna J. Greene[h,i], Kathleen B. McDermott[g,j], Steven M. Nelson[d,e,f], Christina N. Lessov-Schlaggar[b], Bradley L. Schlaggar[a,b,h,i,j,k,l], Nico U. F. Dosenbach[a,j,k,m,n], and Steven E. Petersen[a,g,i,l,n]

nature neuroscience

Article

https://doi.org/10.1038/s41593-024-01618-2

Two common and distinct forms of variation in human functional brain networks

Received: 28 February 2023

Accepted: 7 March 2024

Published online: 30 April 2024

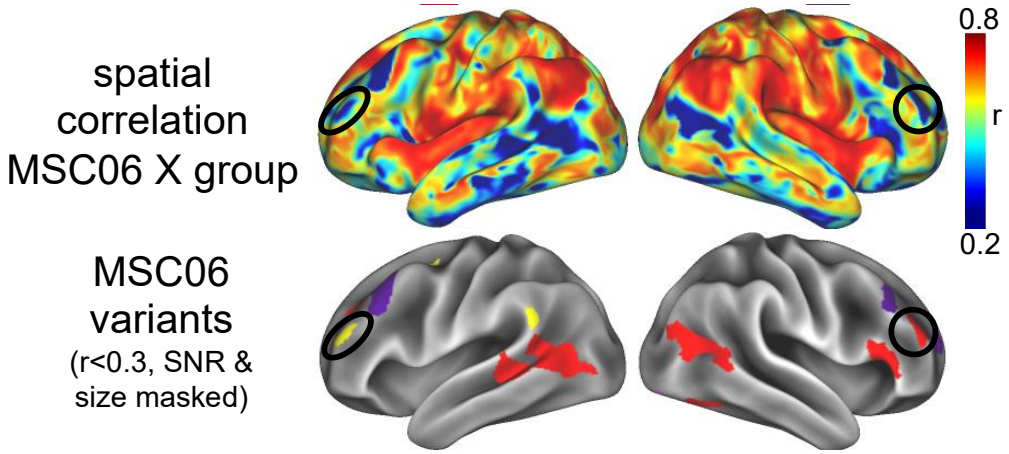
Check for updates

Ally Dworetsky[1,2,3], Benjamin A. Seitzman[4], Babatunde Adeyemo[5], Ashley N. Nielsen[5], Alexander S. Hatoum[6], Derek M. Smith[3,7], Thomas E. Nichols[8,9], Maital Neta[10,11], Steven E. Petersen[1,5,6,12,13] & Caterina Gratton[2,3,14,15,16]

The cortex has a characteristic layout with specialized functional areas

Are there different forms of network variants?

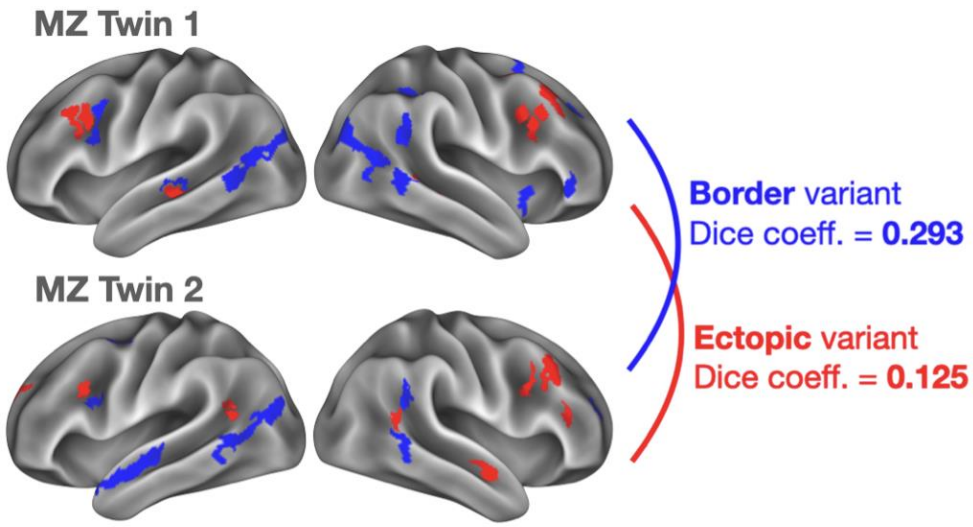
Ally Dworetsky

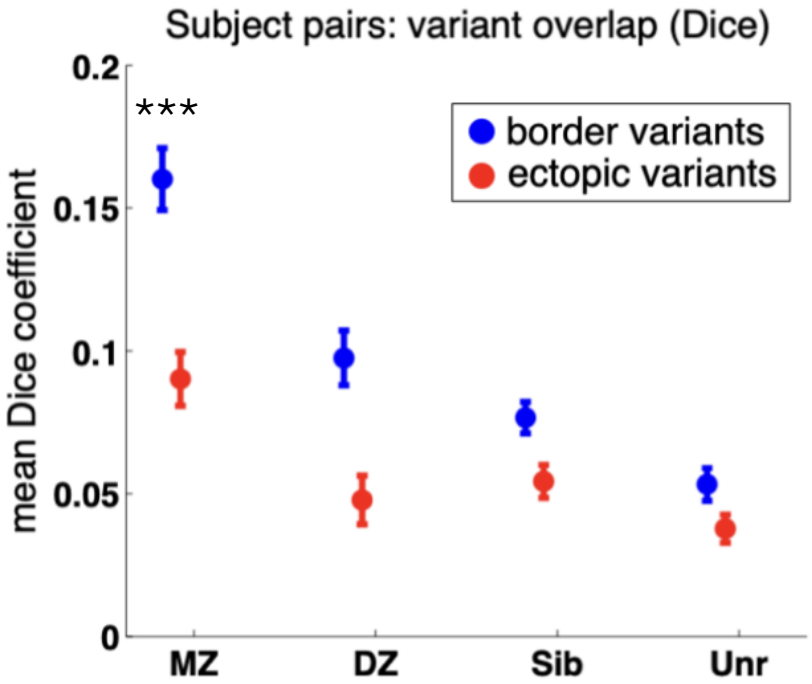


Dworetsky et al…. Gratton, 2024, *Nature Neurosci*

Border and ectopic variants differ in the extent that they track with genetics

Ally Dworetsky



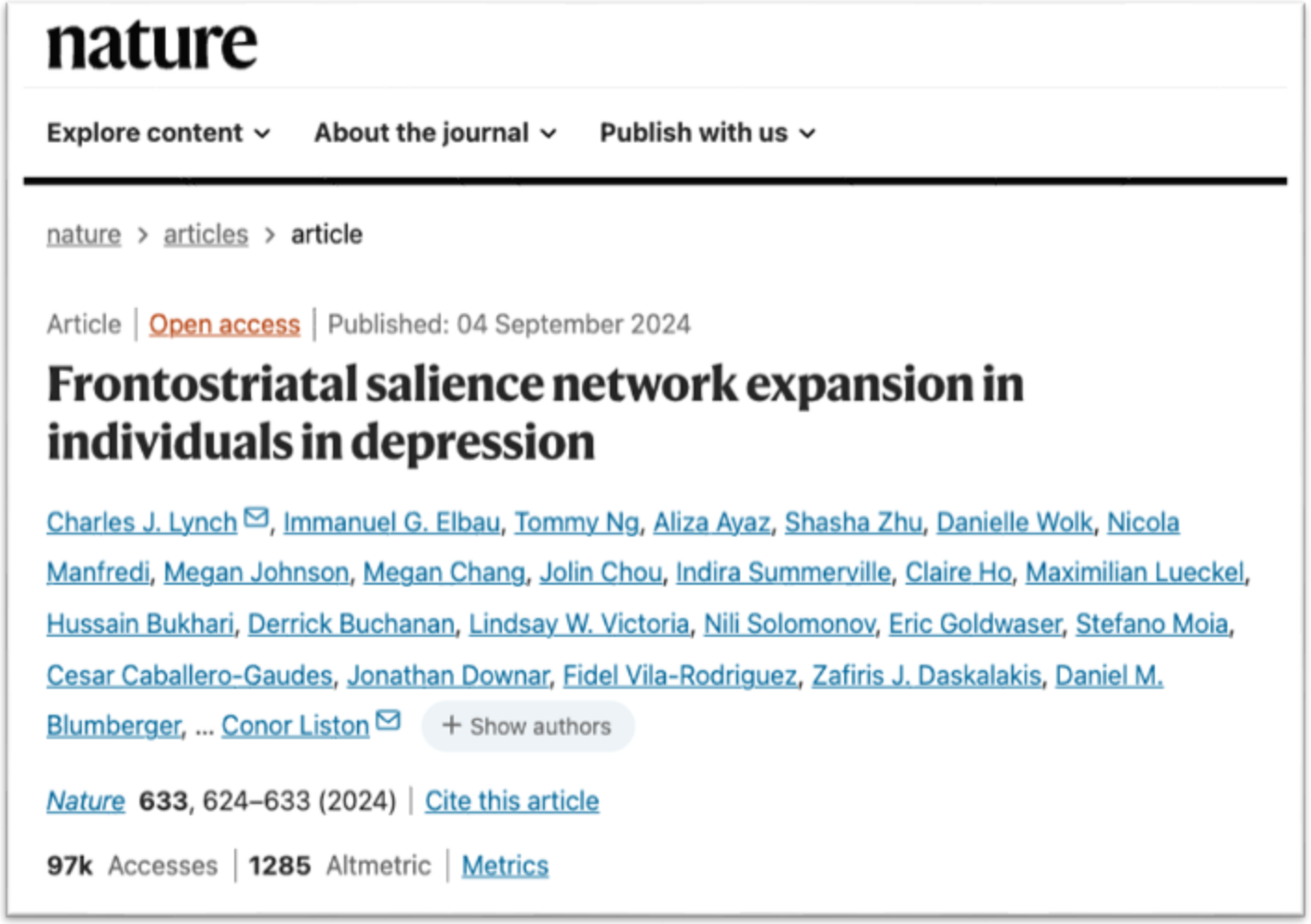


Falconer's Formula
Border: $p < 0.001$
Ectopic: $p < 0.002$

HCP, N = 823 full sample, low motion

Dworetsky et al.… Gratton, 2024, *Nature Neurosci*

Precision fMRI in Depression



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Article | Open access | Published: 04 September 2024

Frontostriatal salience network expansion in individuals in depression

Charles J. Lynch ✉, Immanuel G. Elbau, Tommy Ng, Aliza Ayaz, Shasha Zhu, Danielle Wolk, Nicola Manfredi, Megan Johnson, Megan Chang, Jolin Chou, Indira Summerville, Claire Ho, Maximilian Lueckel, Hussain Bukhari, Derrick Buchanan, Lindsay W. Victoria, Nili Solomonov, Eric Goldwaser, Stefano Moia, Cesar Caballero-Gaudes, Jonathan Downar, Fidel Vila-Rodriguez, Zafiris J. Daskalakis, Daniel M. Blumberger, … Conor Liston ✉ + Show authors

Nature **633**, 624–633 (2024) | Cite this article

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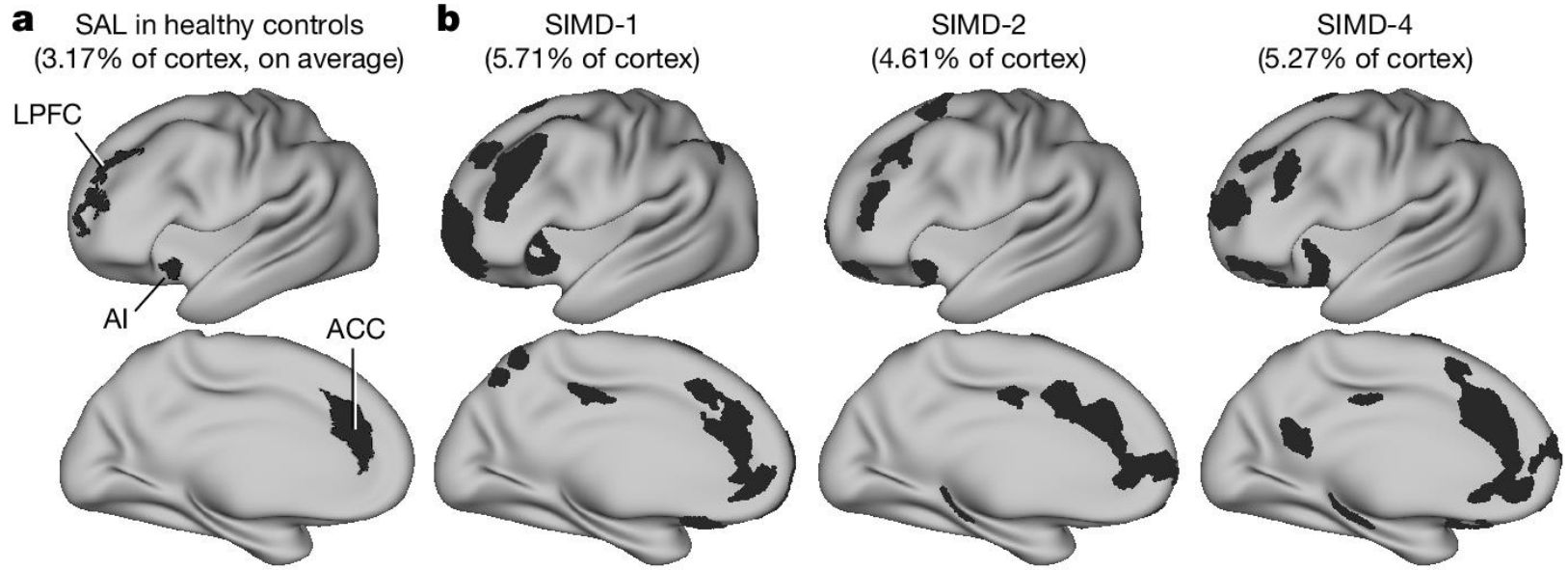
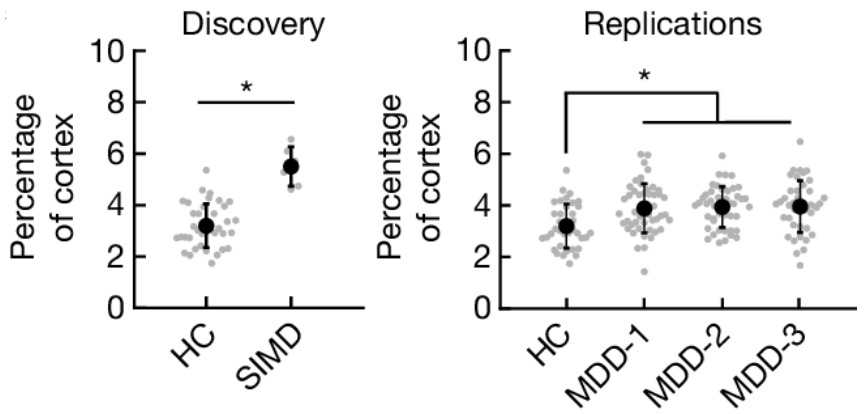
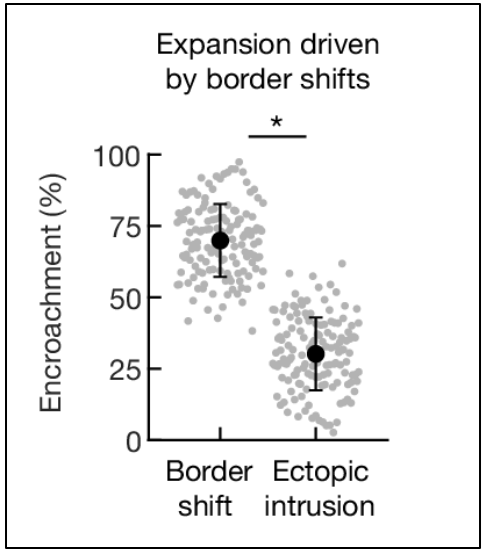
Precision fMRI in Depression







Lynch et al., 2024, Nature

Current Directions:
Brain networks across the adult lifespan

How do individual differences vary over the adult lifespan?

Extend data collection to ages: 35 - 75

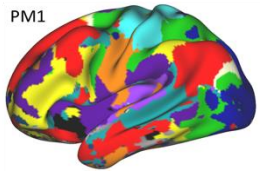
R01 Supplement, PI: Gratton

Diana Perez

Mackenzie Mitchell

Ashley Jaimes

Can individual network measures track differences in **neurodegeneration (PD)**?



N = 70 PD
N = 50 HC
4 days of fMRI

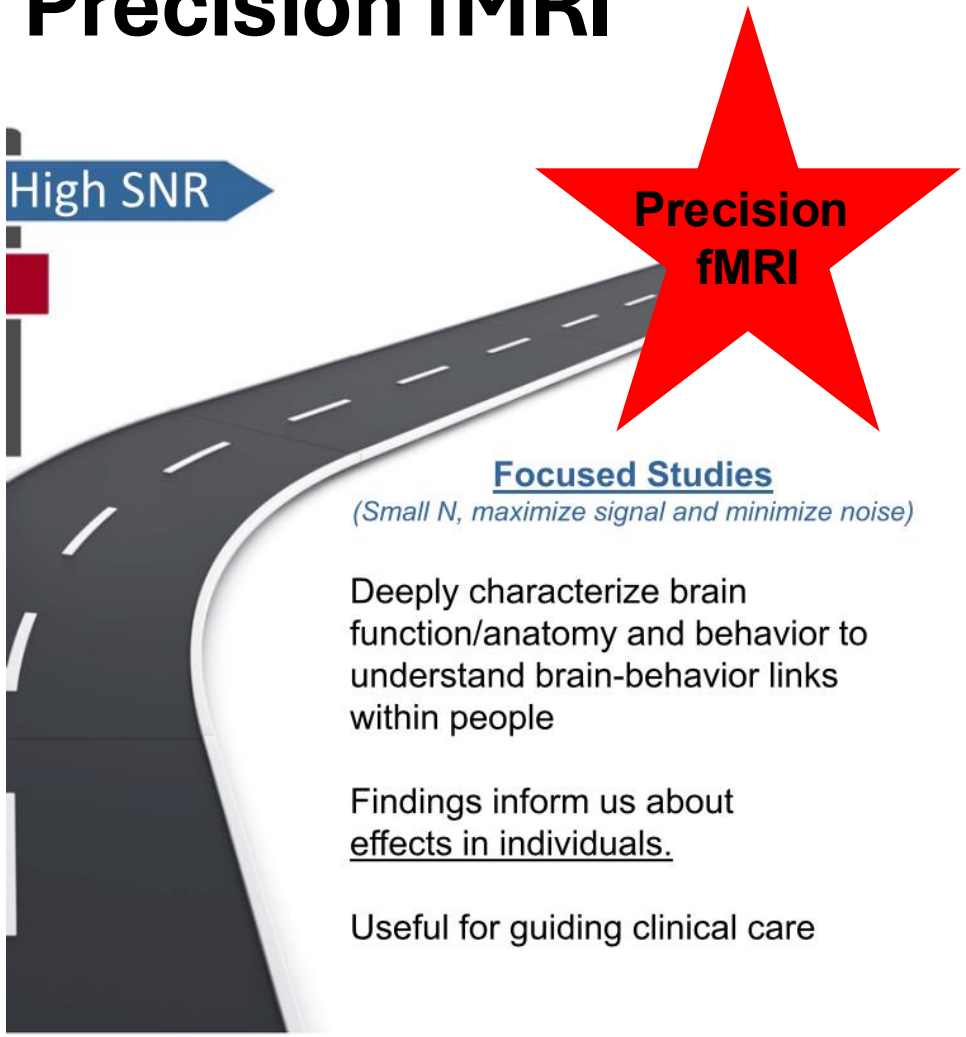
R01NS124738
PIs: Campbell & Gratton

Jake Chernicky

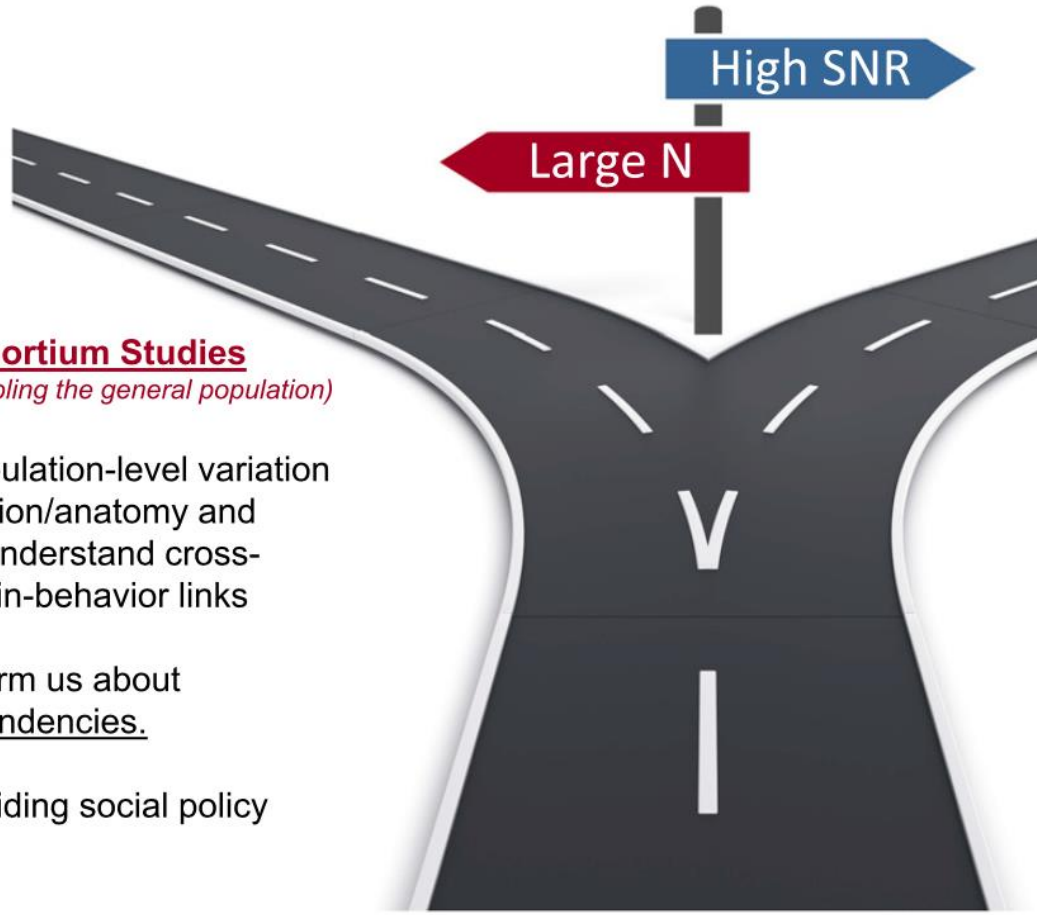
Meghan Campbell
Prof, WUSTL

The Promise of Precision fMRI

1. **Improve measurement of brain networks**
2. **Identify basic properties of brain function & organization**
3. **Identify new brain-behavior relationships**
4. **Characterize individual differences**



Precision + Big N fMRI



Precision fMRI

Consortium Studies
(N>1000 sampling the general population)

Measure population-level variation in brain function/anatomy and behavior to understand cross-sectional brain-behavior links

Findings inform us about population tendencies.

Useful for guiding social policy

Focused Studies
(Small N, maximize signal and minimize noise)

Deeply characterize brain function/anatomy and behavior to understand brain-behavior links within people

Findings inform us about effects in individuals.

Useful for guiding clinical care

Naselaris T, Allen E, Kay K: **Extensive sampling for complete models of individual brains**. *Curr Opin Behav Sci* 2021, **40**:45-51.

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Bandettini PA, Huber L, Finn ES: **Challenges and opportunities of mesoscopic brain mapping with fMRI**. *Curr Opin Behav Sci* 2021, **40**:189-200.

etc…

Acknowledgments

Gratton Lab

Jake Chernicky
Elena Housteau
Zach Ladwig
Hyejin Lee
Mackenzie Mitchell
Diana Perez
Ana Triana Hoyos
Kian Zendehrouh Kermani

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Scott Marek
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Adrian Gilmore
Haoxin Sun
Damien Fair
Gagan Wig
Kartik Sreenivasan
Emi Nomura
Fernando Perez
Taraz Lee
Jess Cohen
Yuhua Yu
Ellyn Butler
Zach Anderson
Brad Sutton
Monica Fabiani
Gabriele Gratton
Adam Steel

Funding

NIH National Institute of Mental Health

NIH National Institute on Aging

NIH National Institute of Neurological Disorders and Stroke

NSF CAREER Award