Assessing individual differences with fMRI

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NIH Summer Neuroimaging Course
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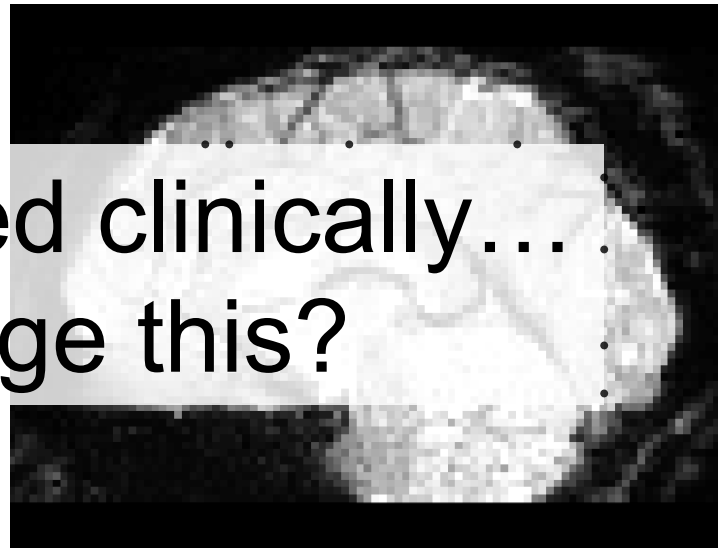
Structural MRI

Functional MRI)



fMRI is barely used clinically…
can we change this?

Outline

1. **What** do we mean by individual differences?
2. **Why** should we care about individual differences?
3. **How** can we study individual differences?
   (some practical guidelines)
4. **Where** are we going next?

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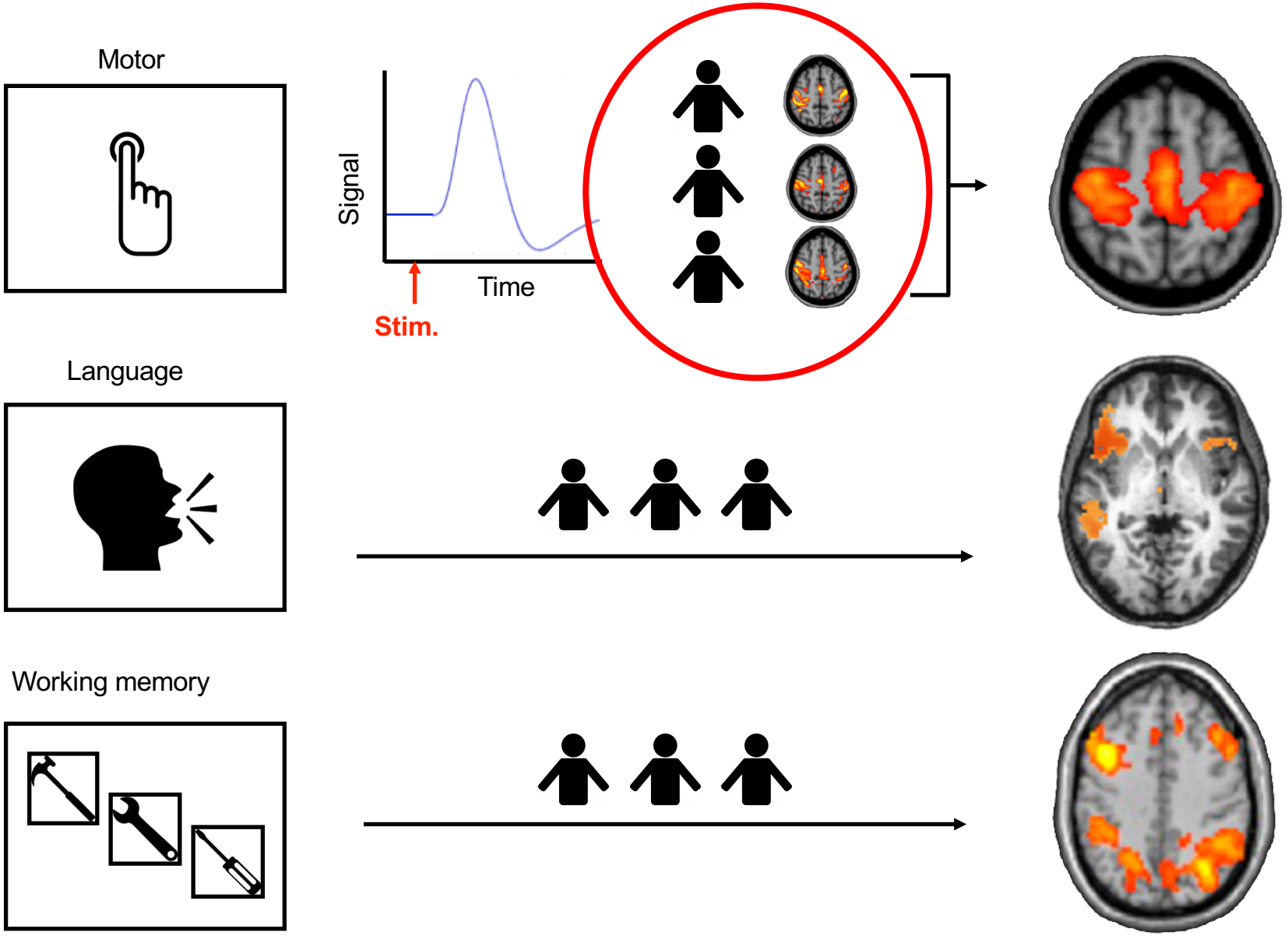
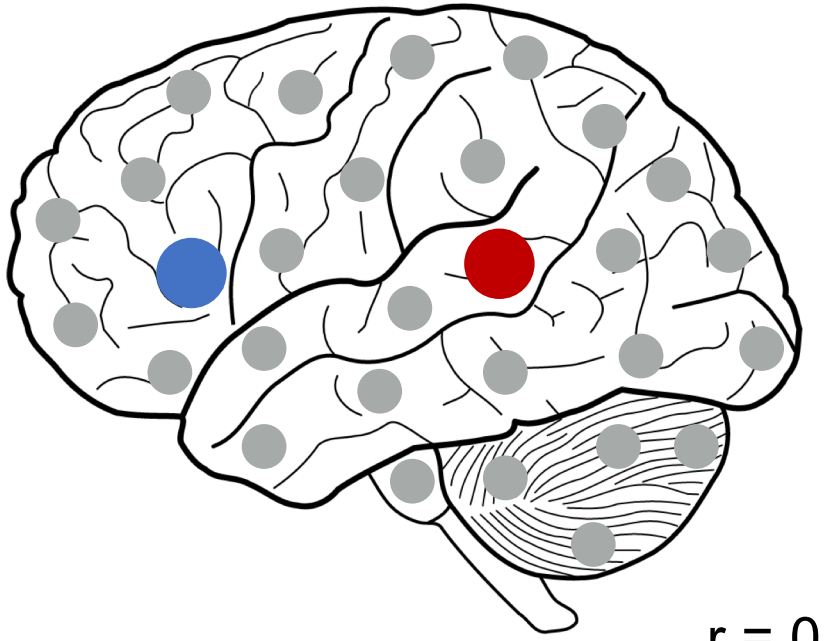
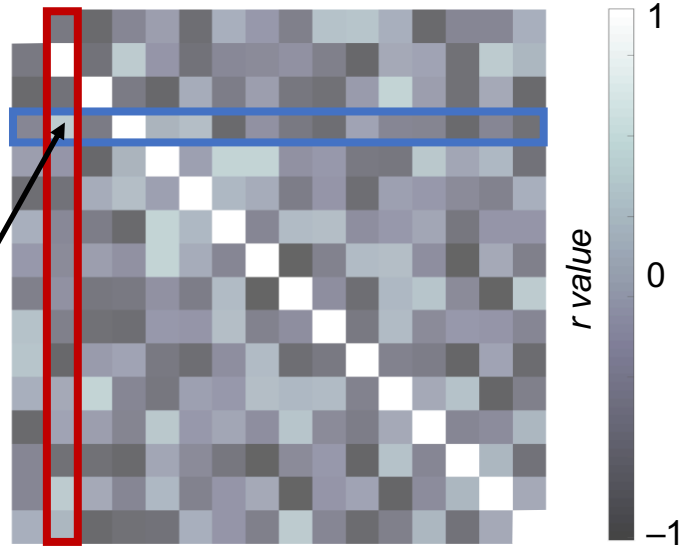
Traditional fMRI analyses

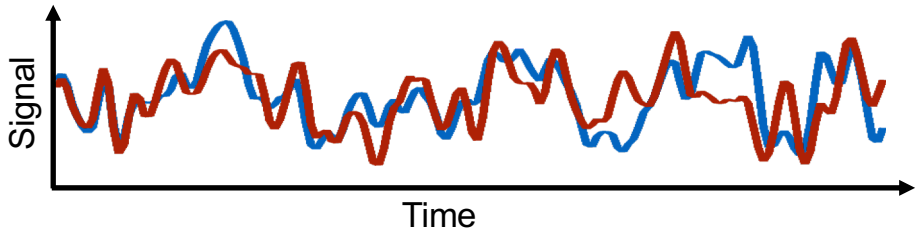


Functional connectivity



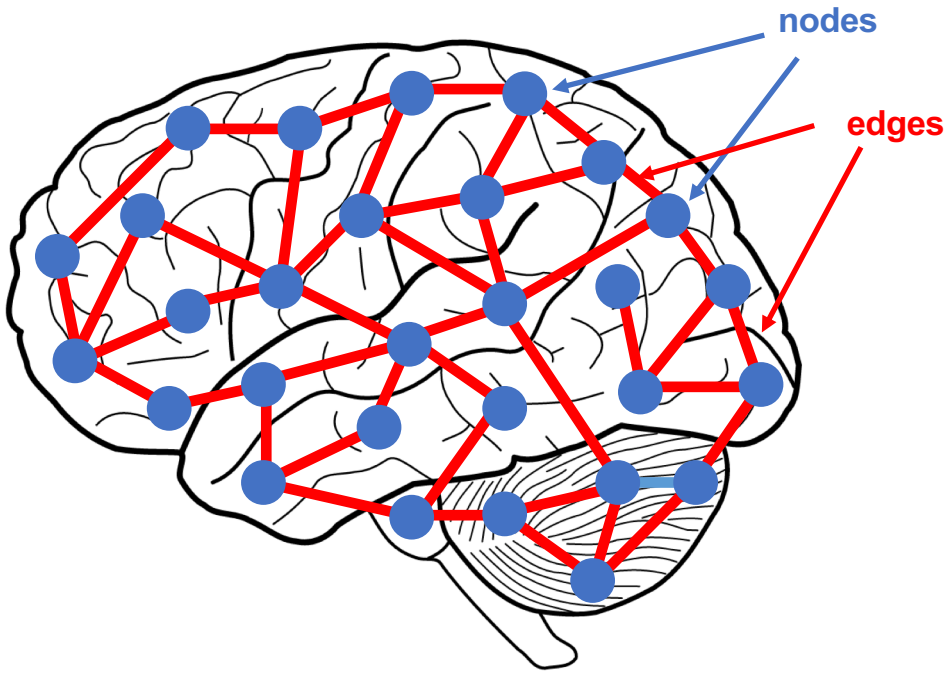


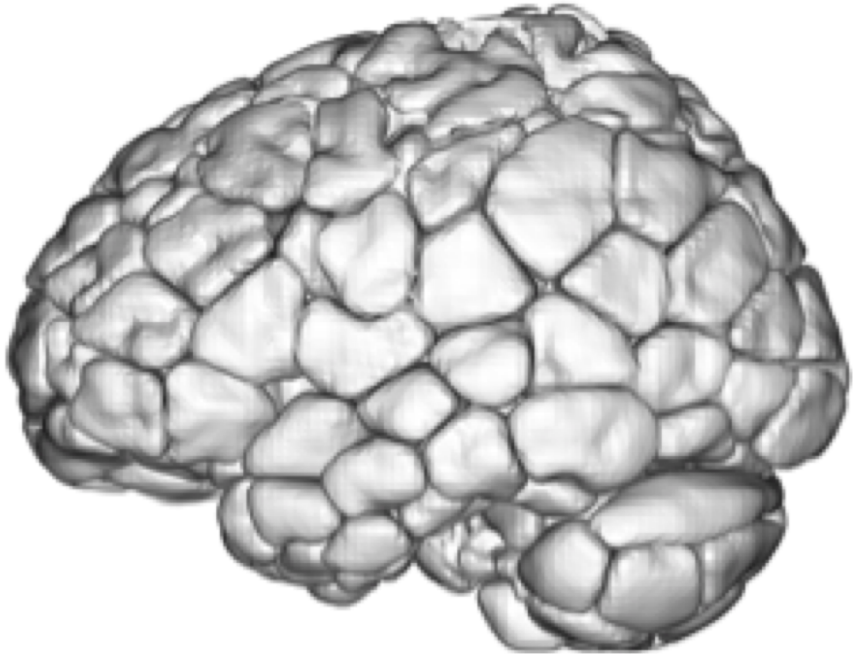
r = 0.63



- Whole-brain organization
- Can use resting-state data

Brain networks

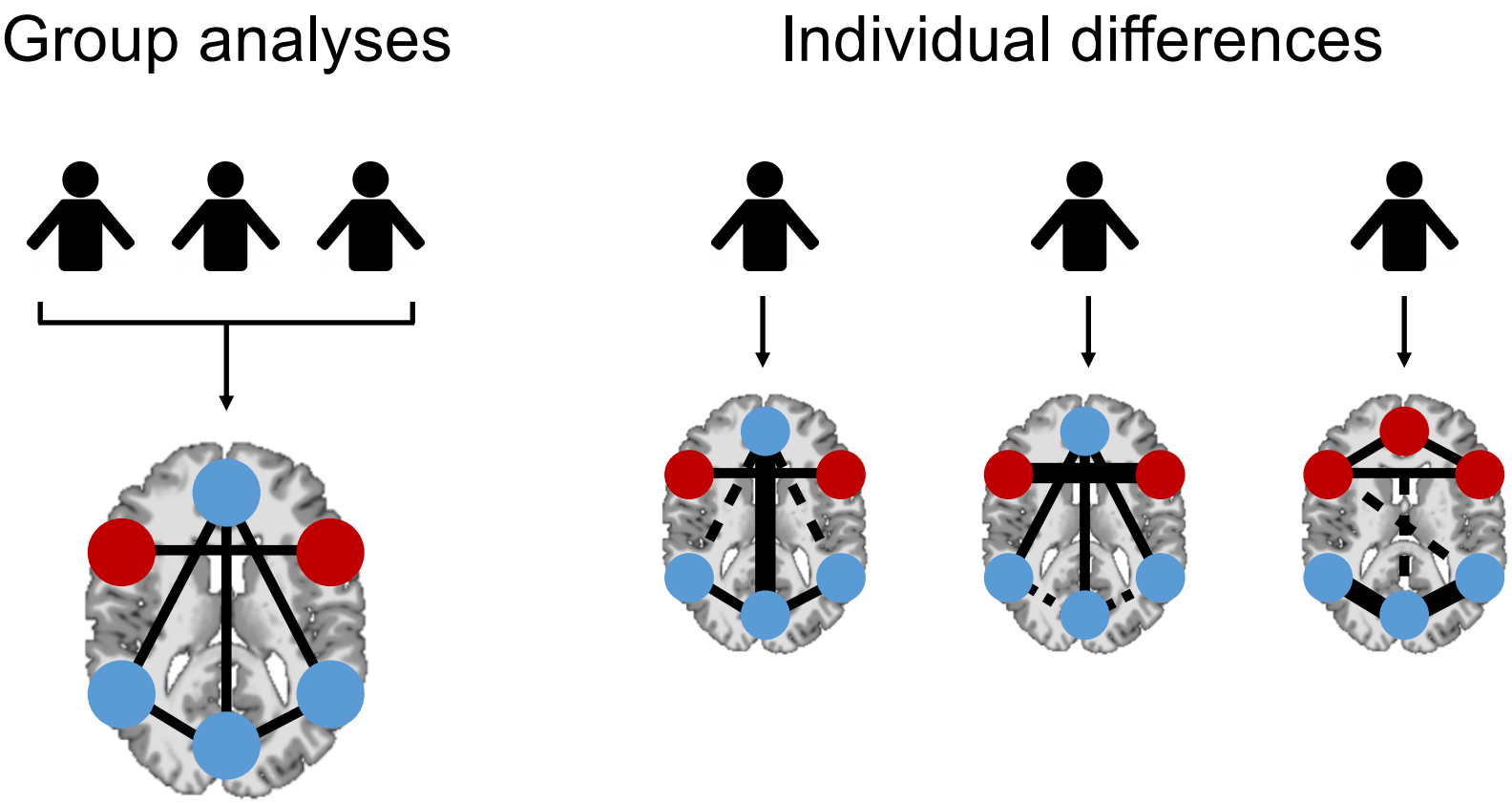




Shen et al., *NeuroImage* (2013)

268 nodes = 35,778 edges

Individual differences



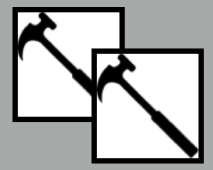
Identification experiments

Human Connectome Project
- 126 healthy subjects (50 sets of twins)
- Age 22-35 years old

Day 1

Resting
R1

Working memory
WM



Motor
Mt

Day 2

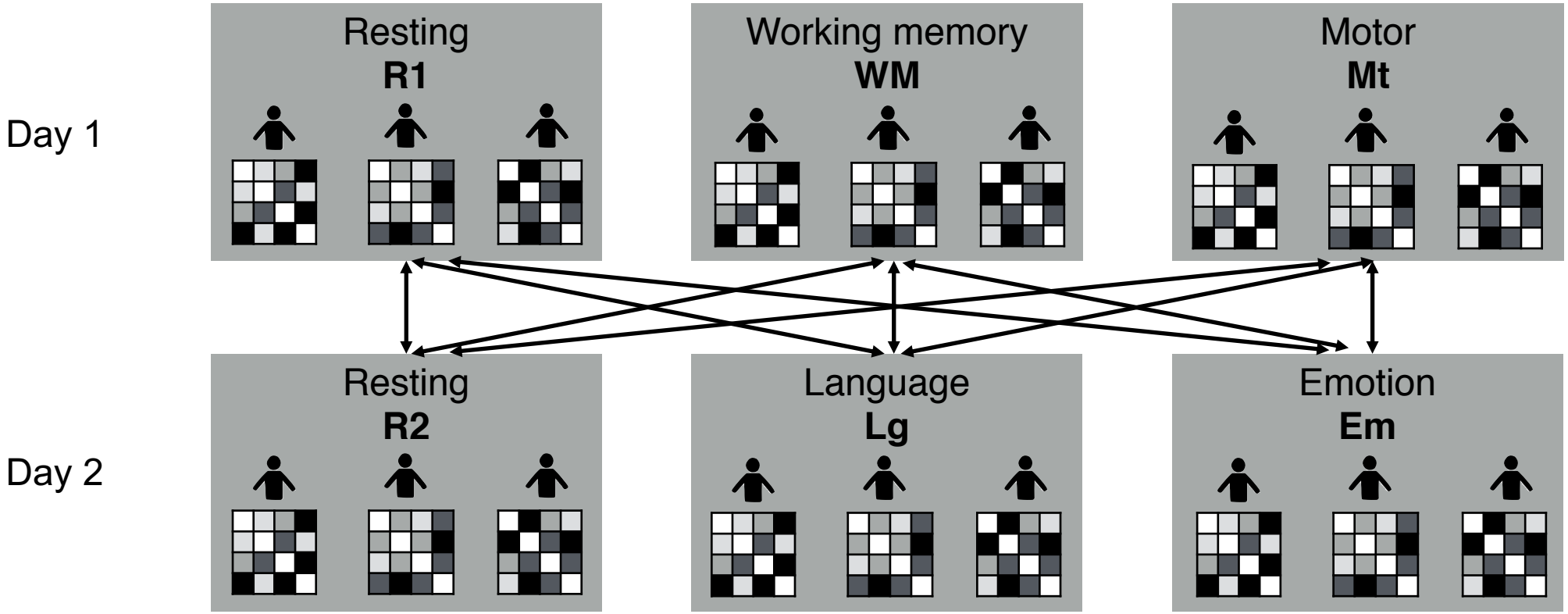
Resting
R2

Language
Lg

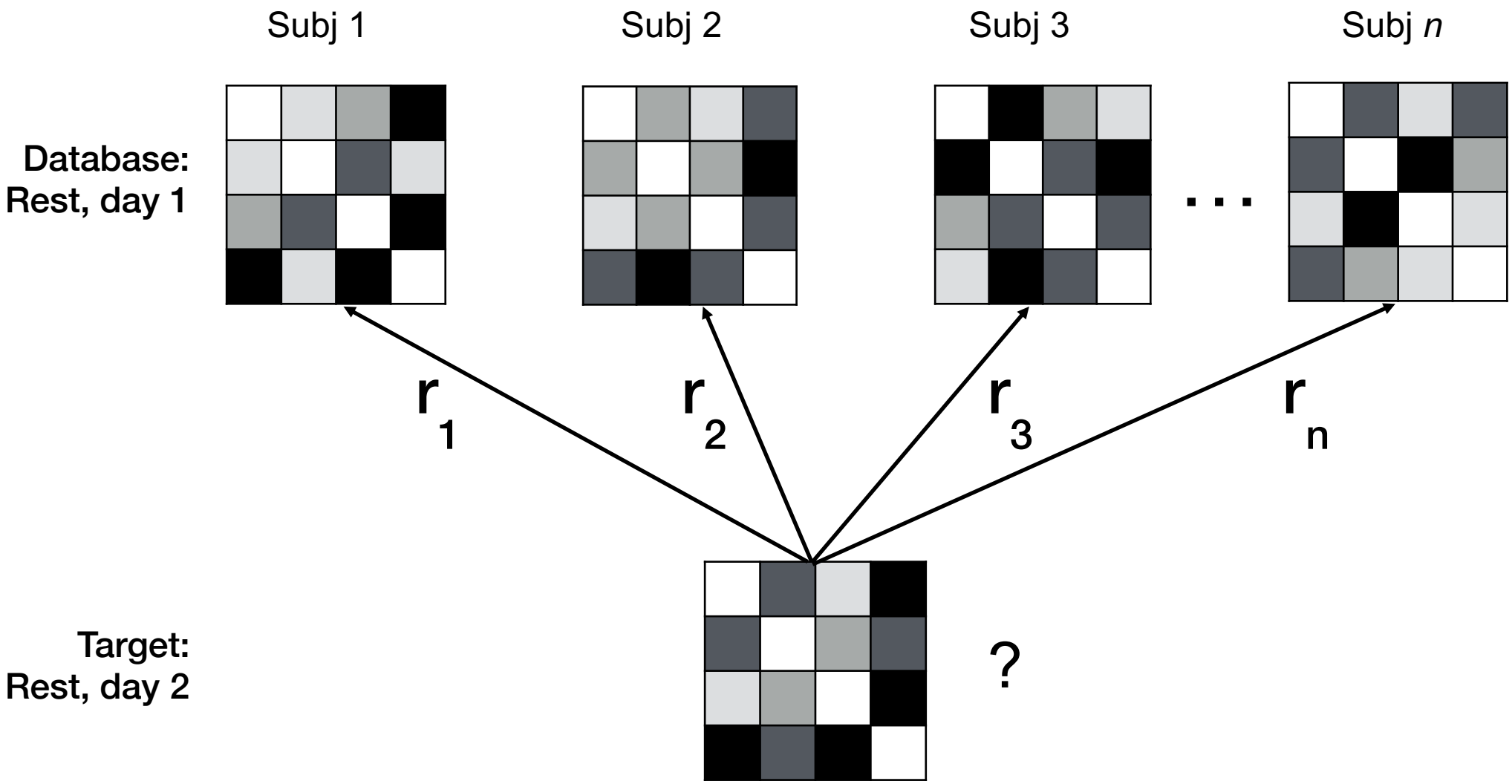
Emotion
Em

Identification experiments

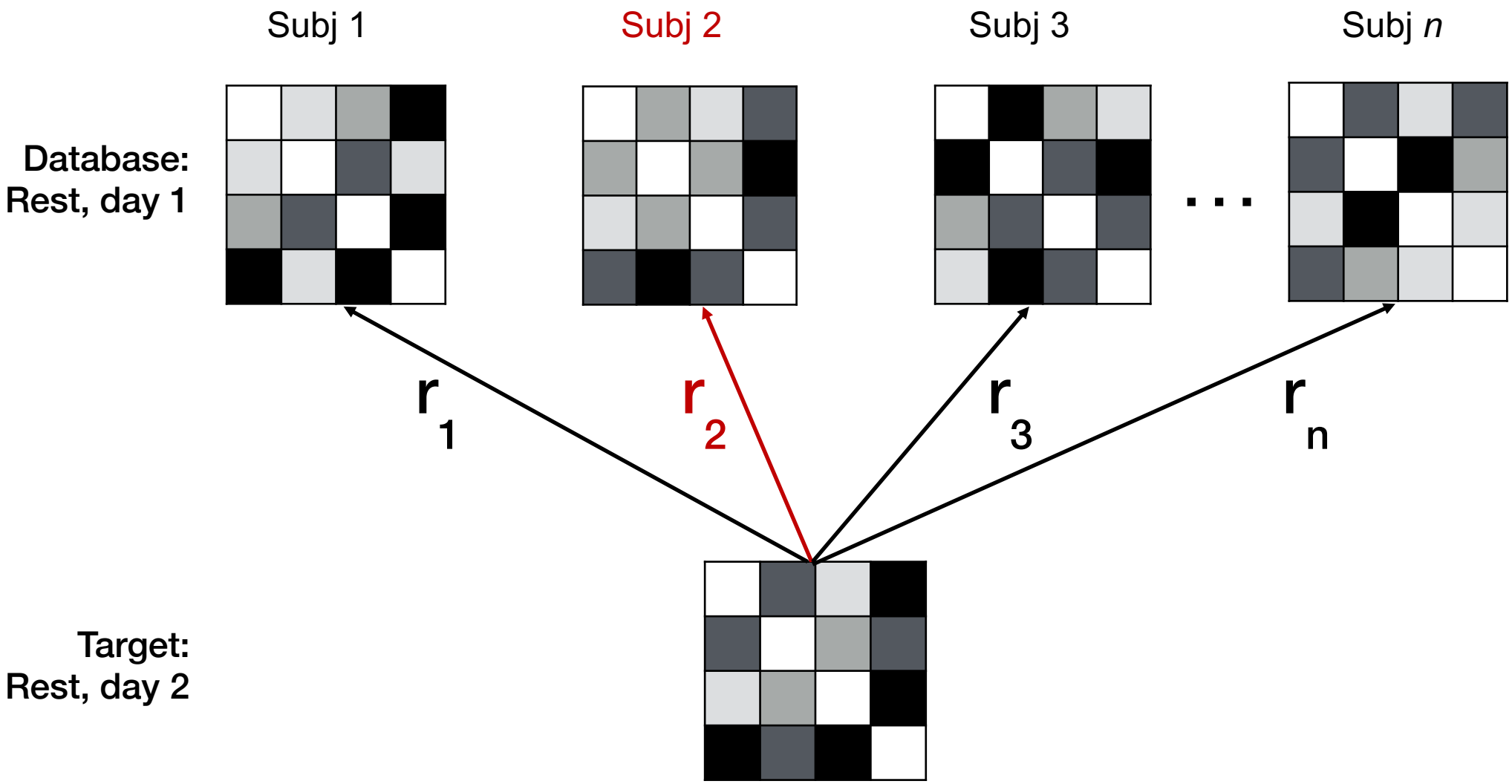
Human Connectome Project
- 126 healthy subjects (50 sets of twins)
- Age 22-35 years old



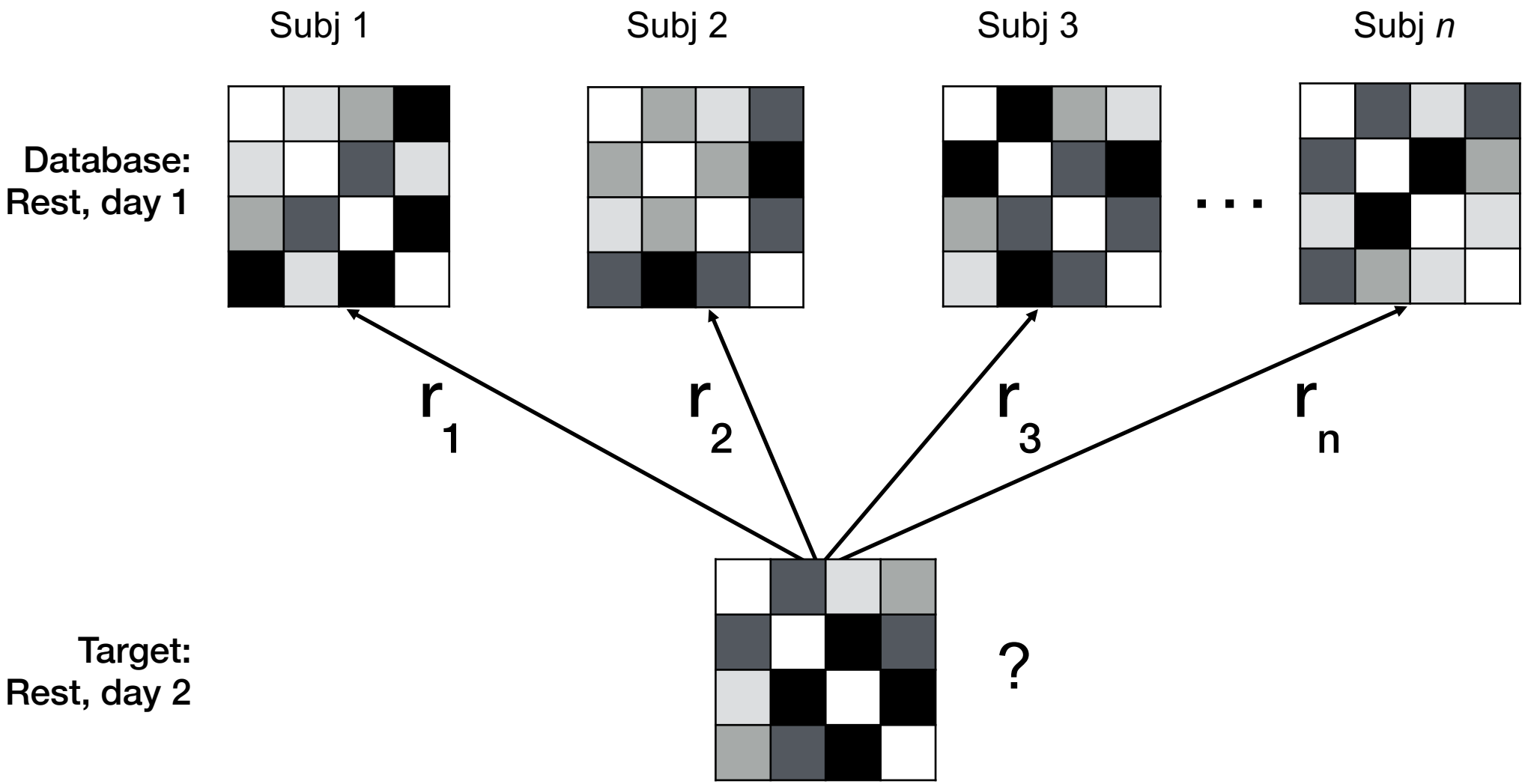
Identification experiments



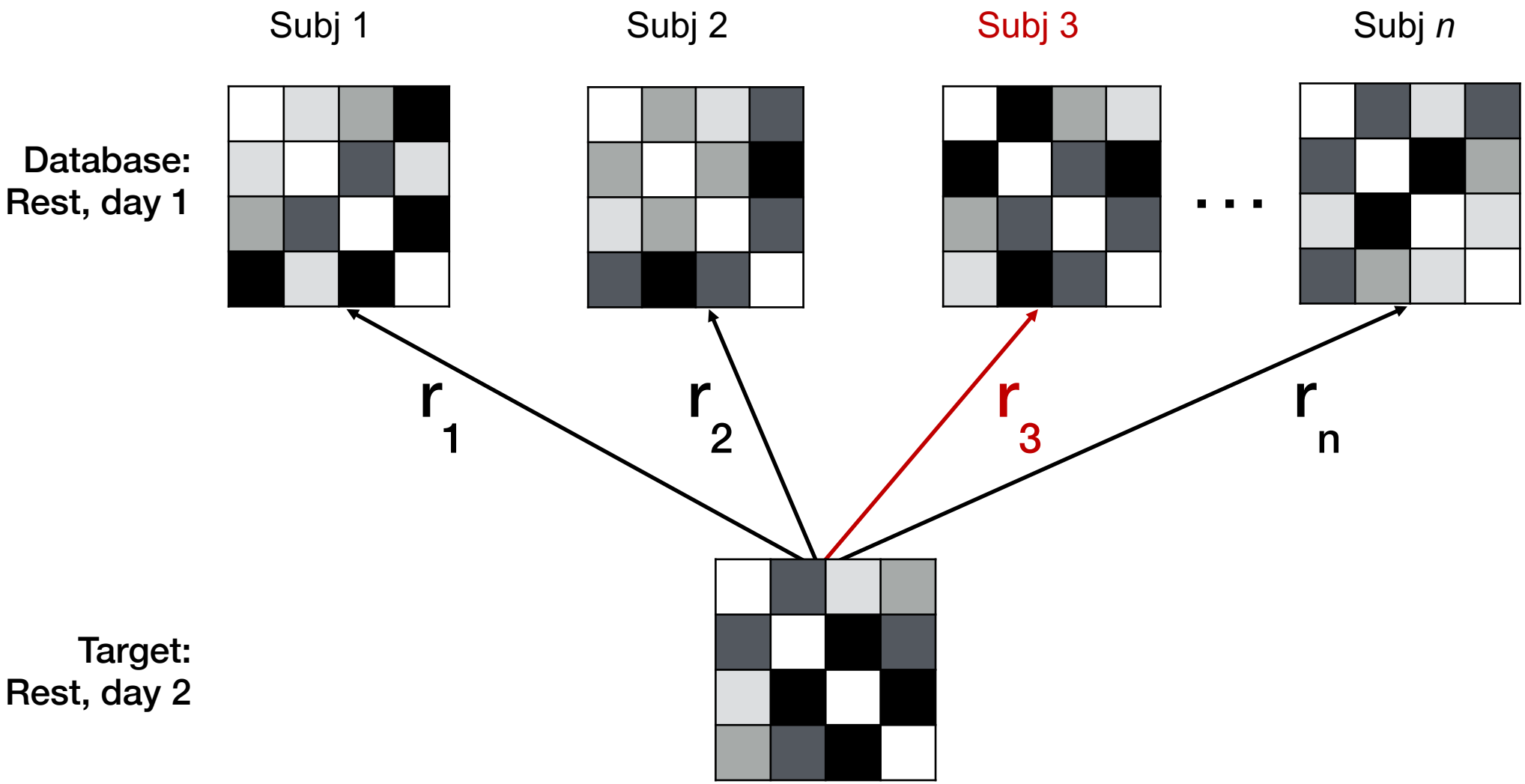
Identification experiments



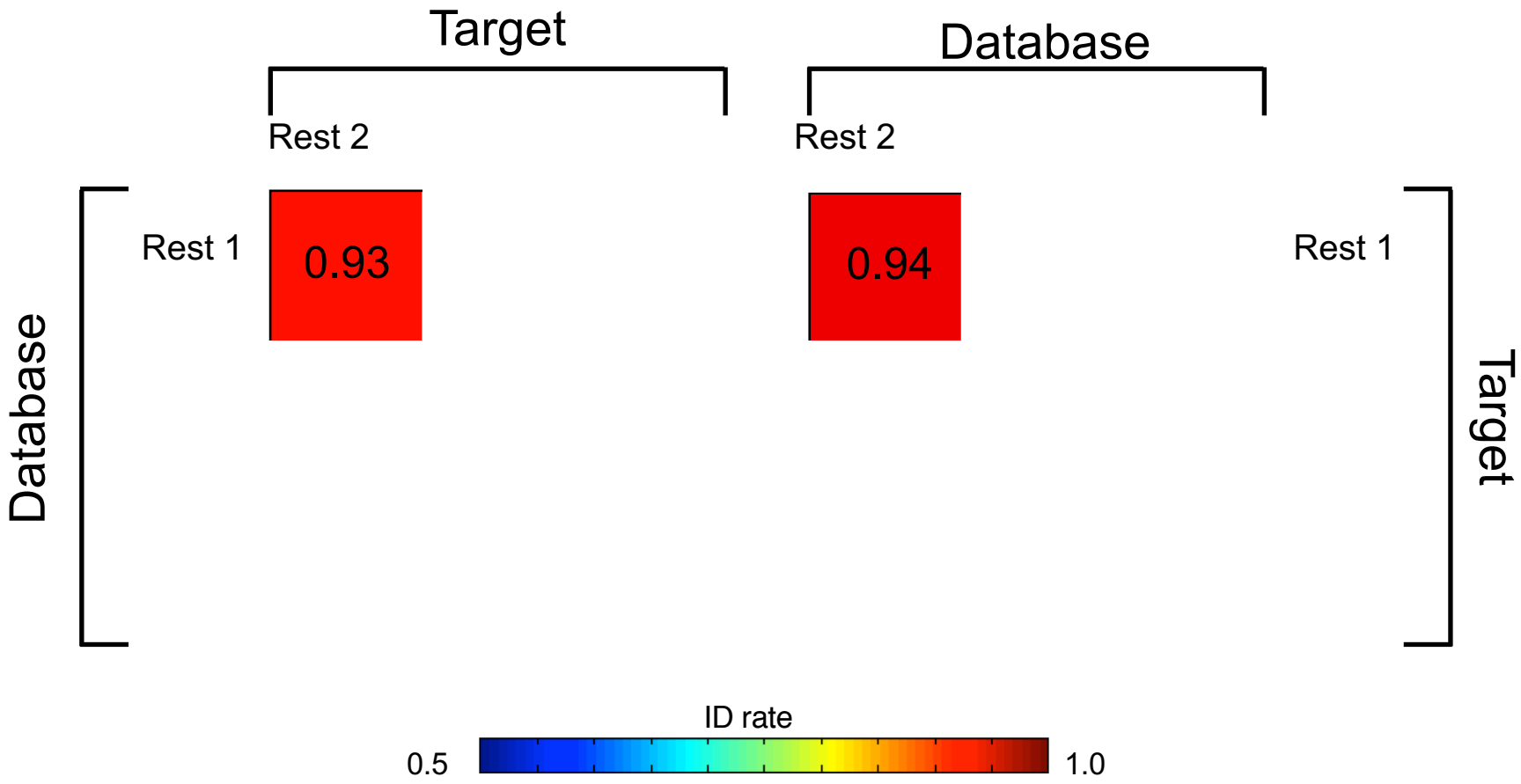
Identification experiments



Identification experiments



Identification results

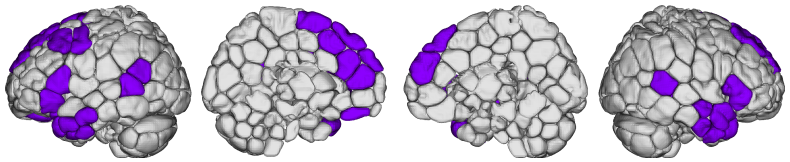


Chance: ~0.008

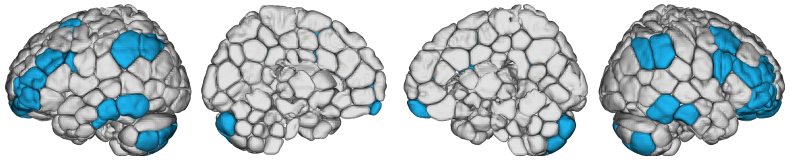
Finn, Shen et al., *Nat Neurosci* (2015)

Network-based identification

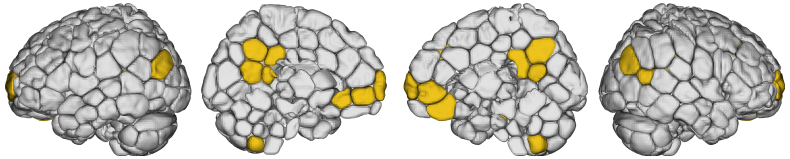
1. Medial frontal



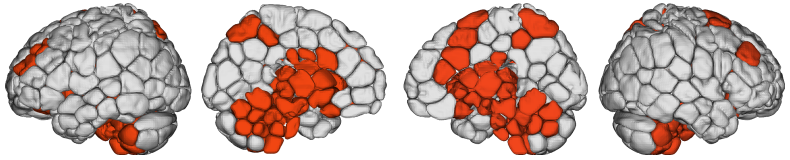
2. Frontoparietal



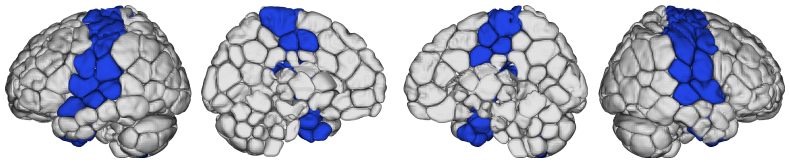
3. Default mode



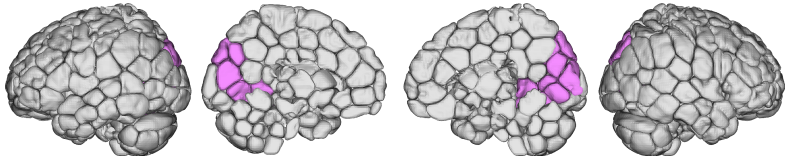
4. Subcortical/cerebellum



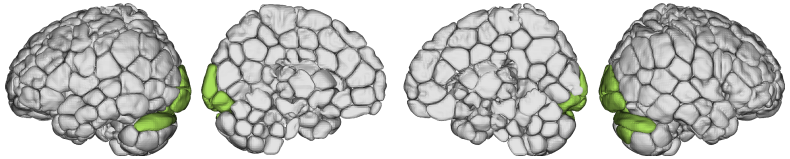
5. Somato-motor



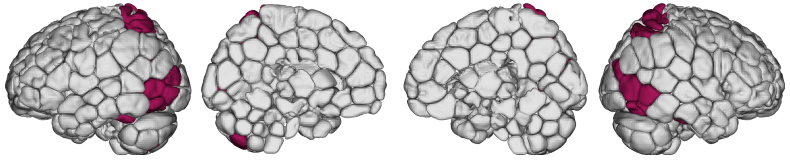
6. Visual I



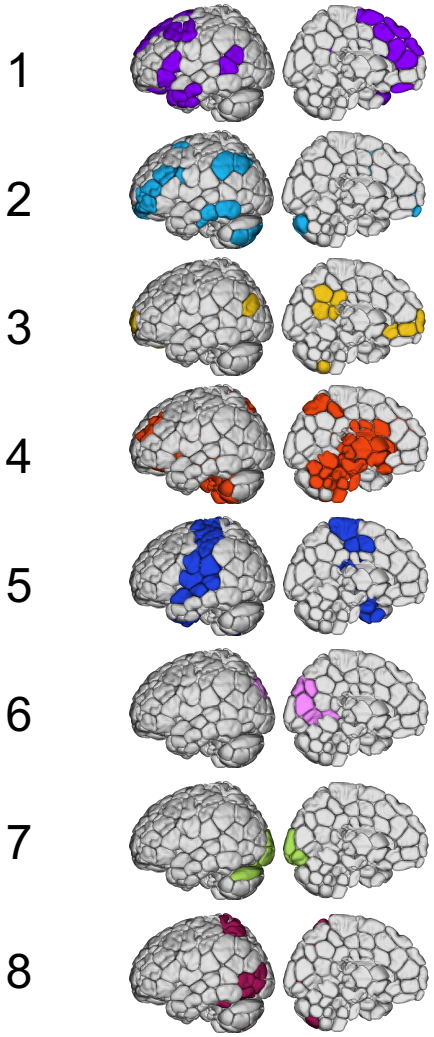
7. Visual II

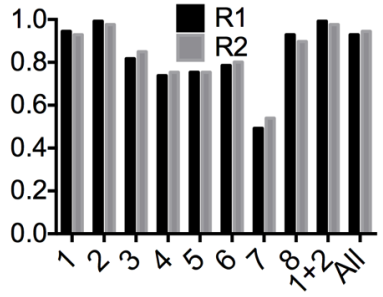


8. Visual association



Network-based identification





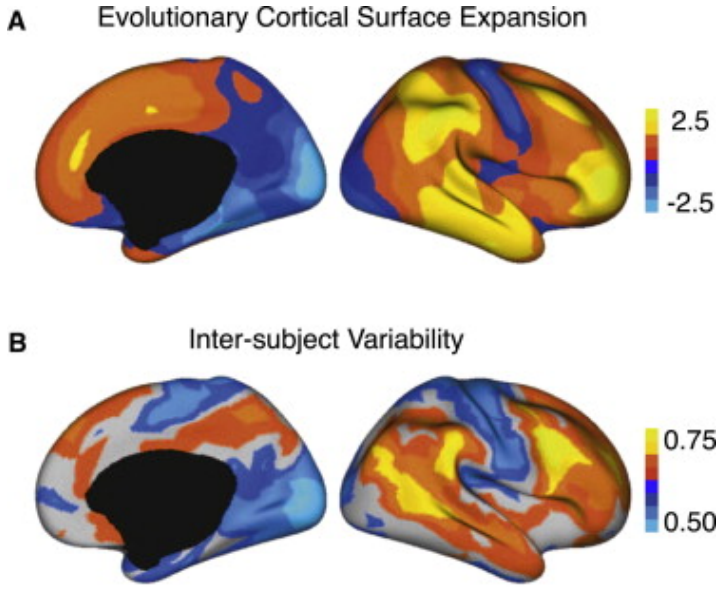
Identification rate

Network

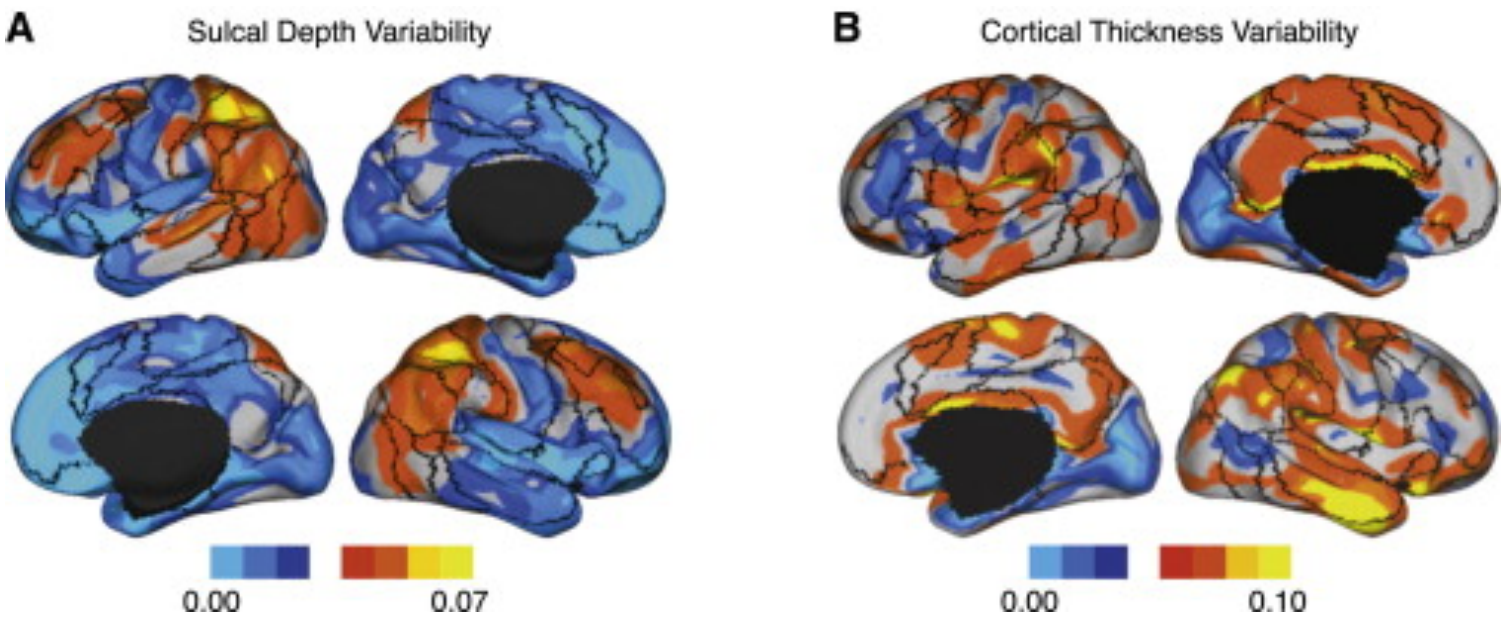
Finn, Shen et al., *Nat Neurosci* (2015)

Localizing individual differences

Biggest differences found in most evolutionarily recent regions:

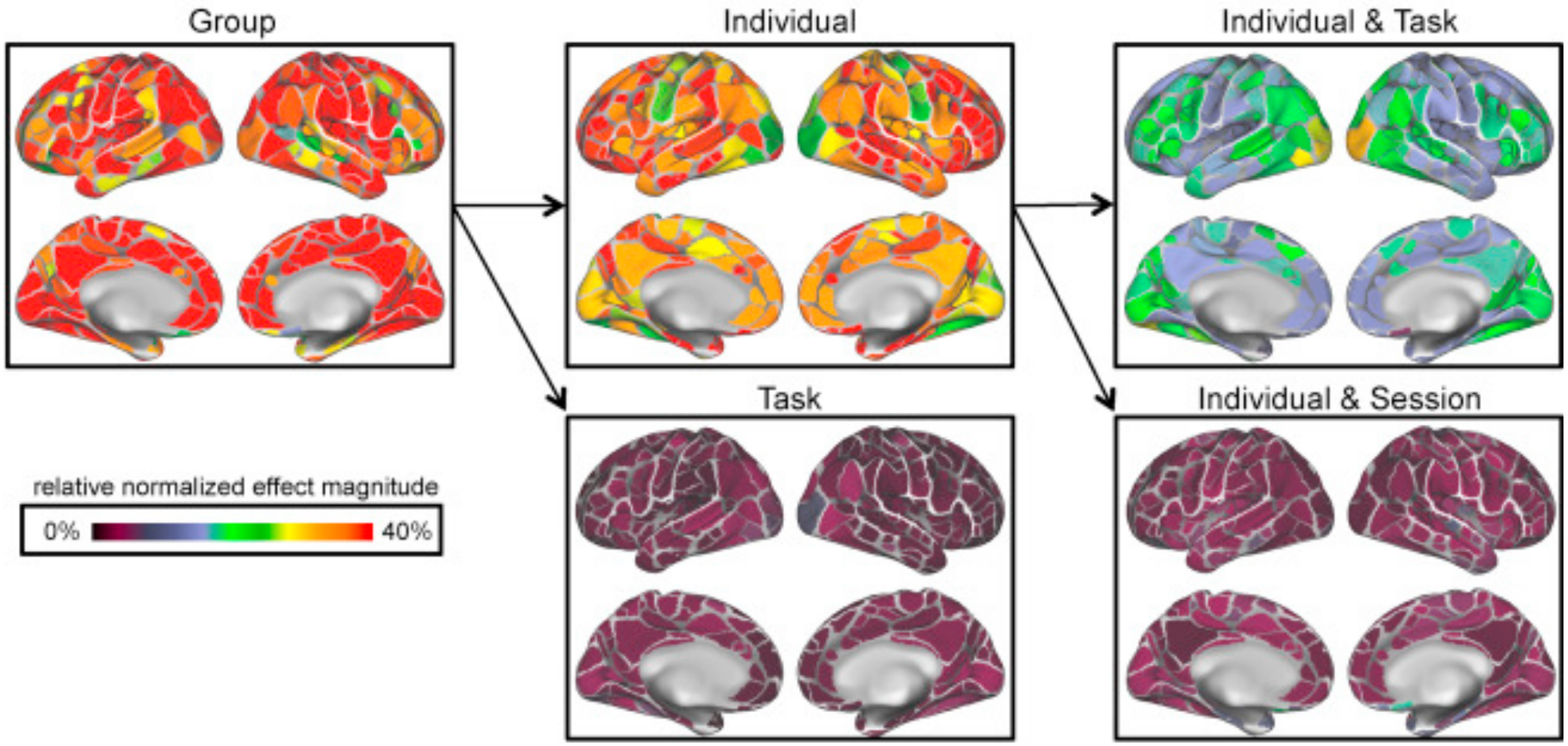


Anatomical differences also play a (large) role:



Mueller et al., *Neuron* (2013)

Individuals account for the most variance!



Gratton et al., *Neuron* (2018)

Outline

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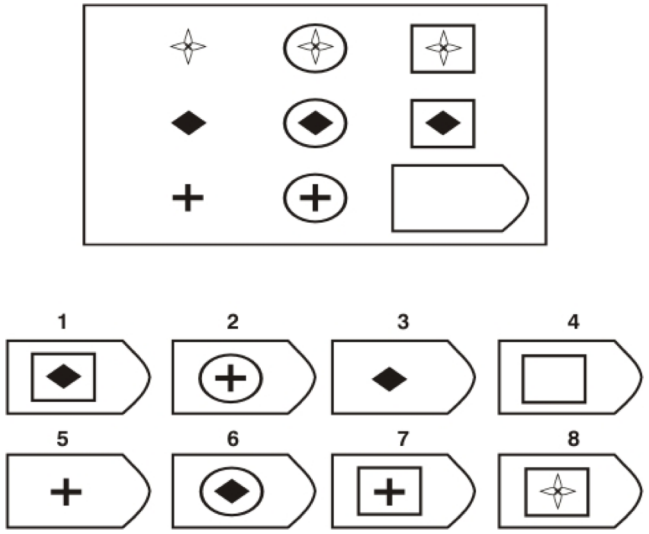
Why is this important?

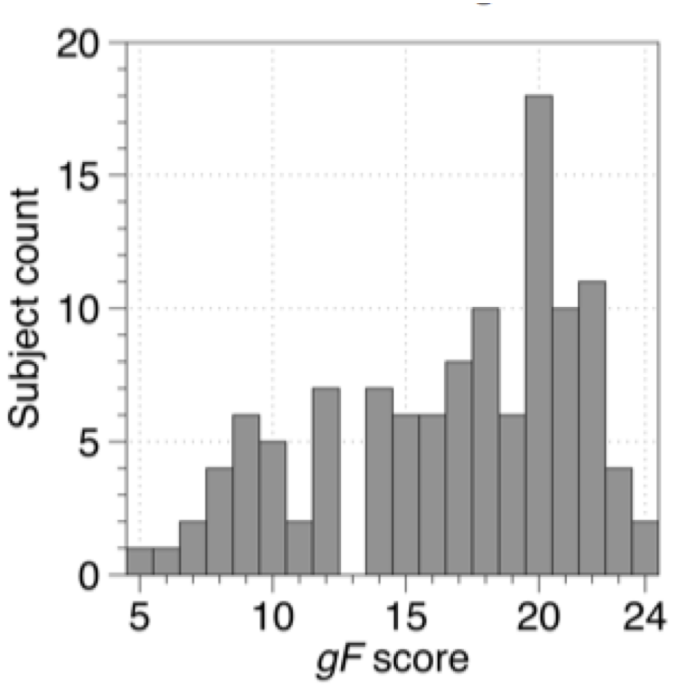
- It’s trivial to ID someone based on a structural scan
- Could just be anatomy, other confounds
- How can we prove these differences are meaningful?

BEHAVIOR!

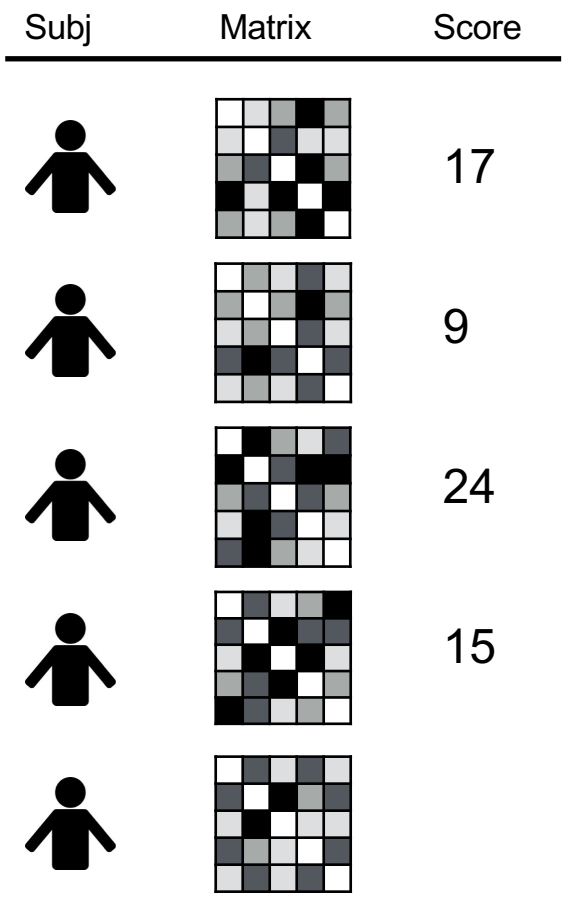
Predicting fluid intelligence

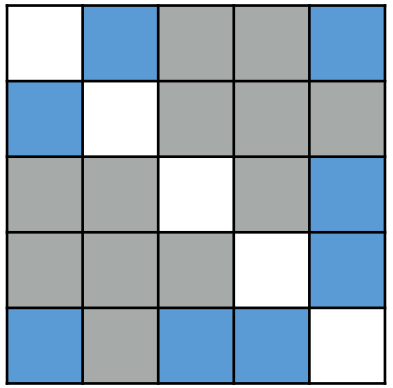
- ability to discern patterns
- independent of learned knowledge

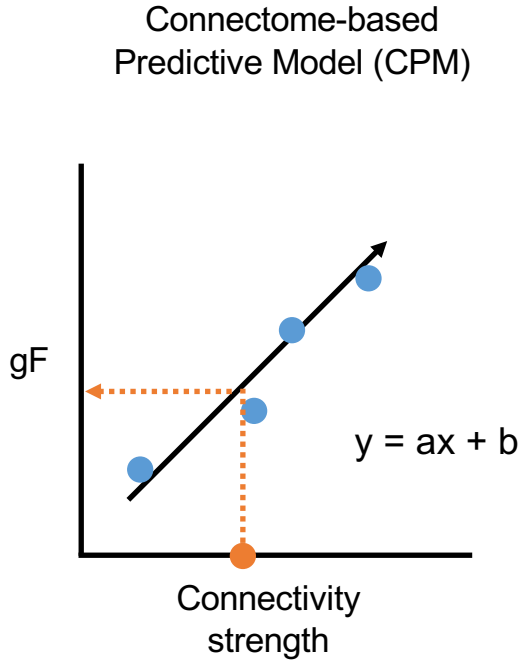




Predicting fluid intelligence







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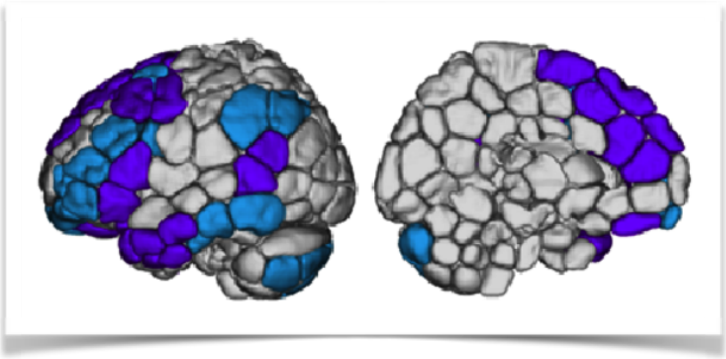
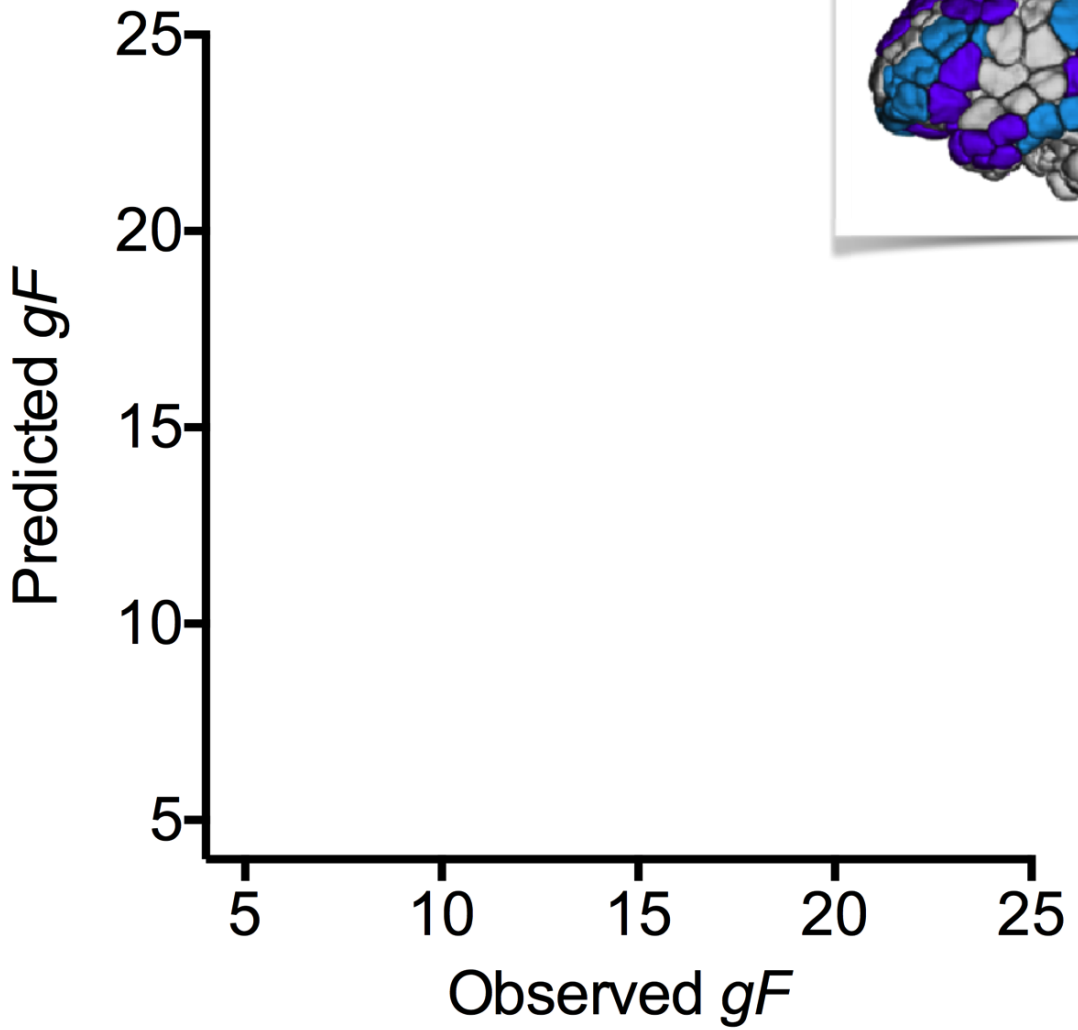
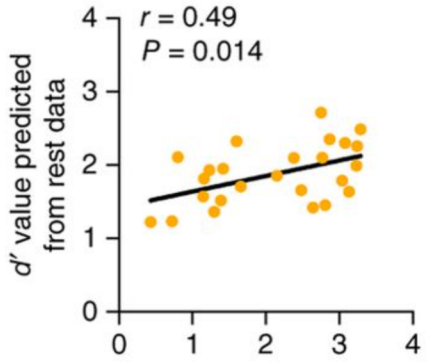




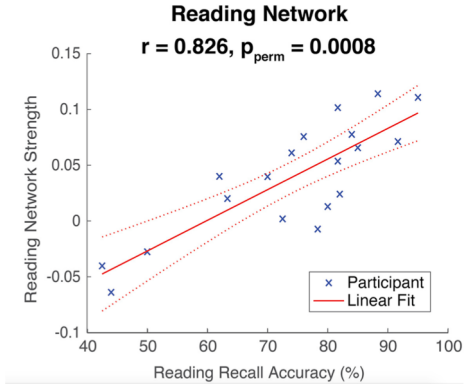
Predicting other behaviors

Sustained attention



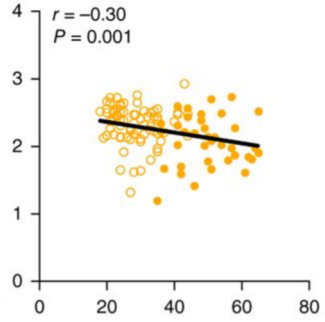
Rosenberg, Finn et al., *Nat Neurosci* (2016)

Reading ability

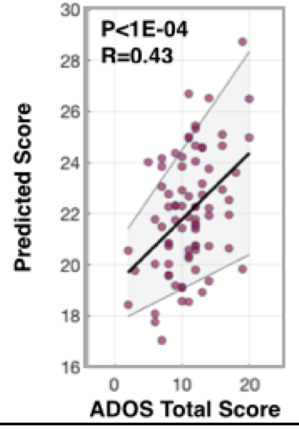


Jangraw et al., *NeuroImage* (2017)

ADHD, autism symptom severity

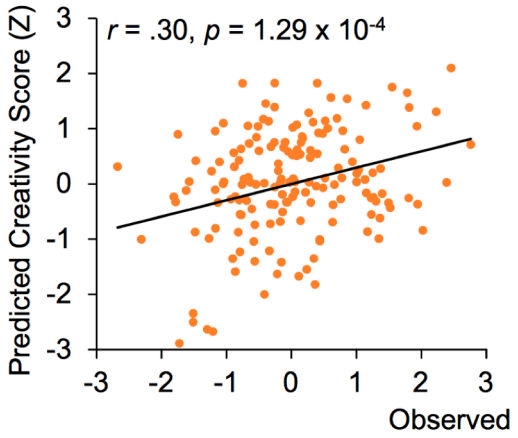


Rosenberg, Finn et al., *Nat Neurosci* (2016)



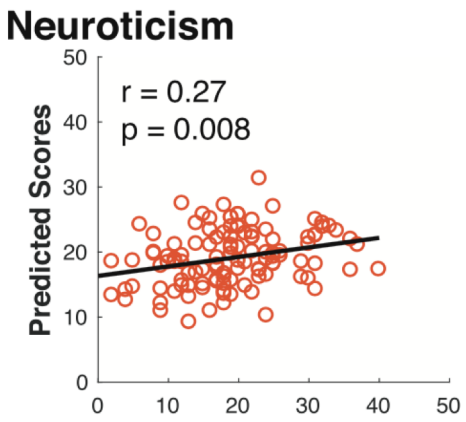
Lake et al., submitted

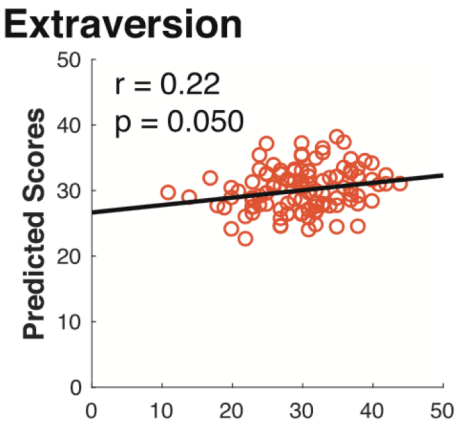
Creativity



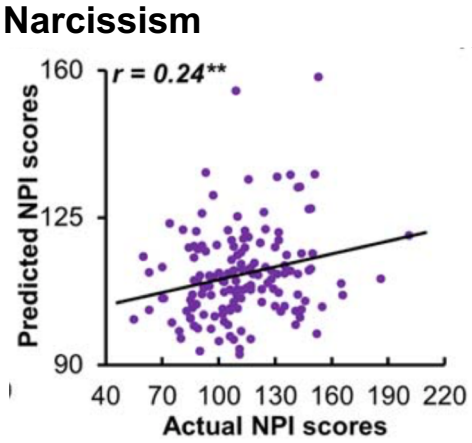
Beaty et al., *PNAS* (2018)

Personality traits



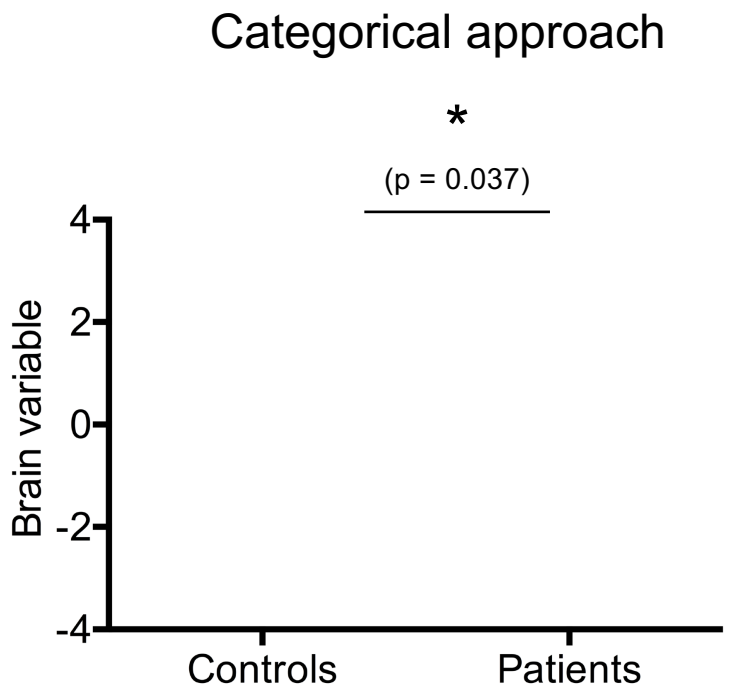


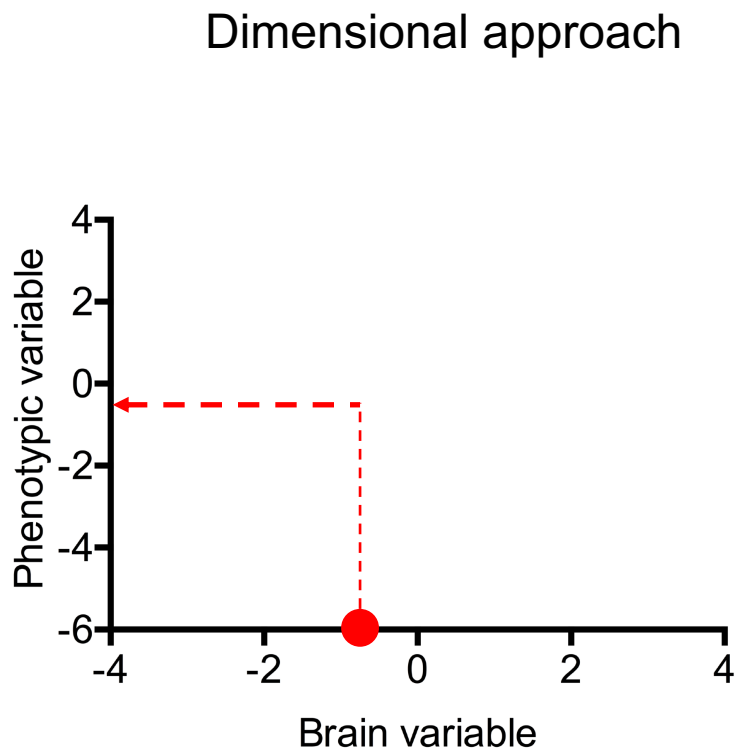
Hsu et al., *Soc Cogn Aff Neurosci* (2018)



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

Translational applications





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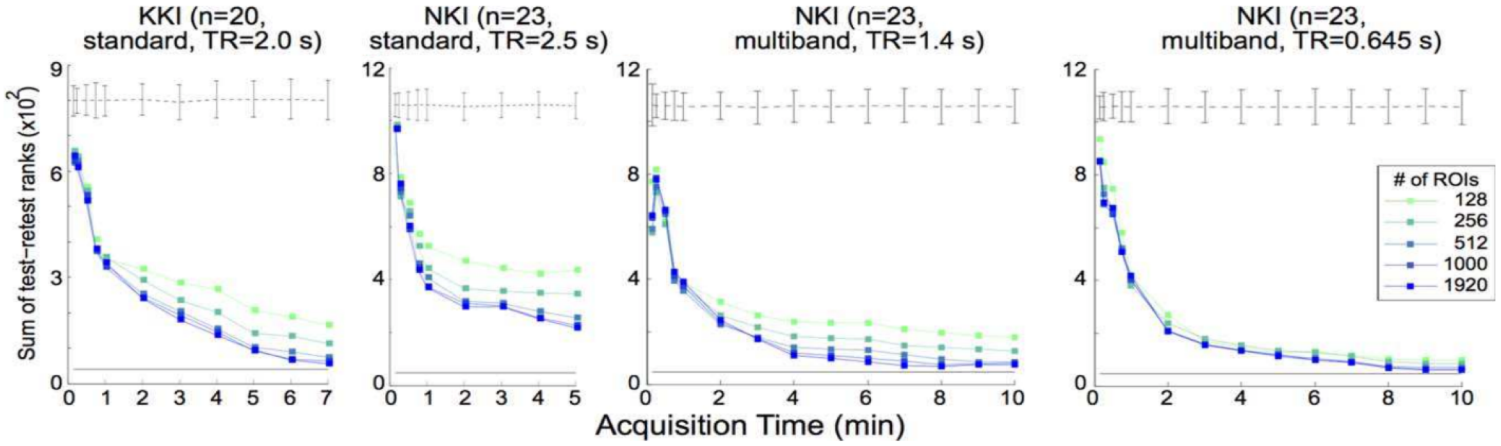
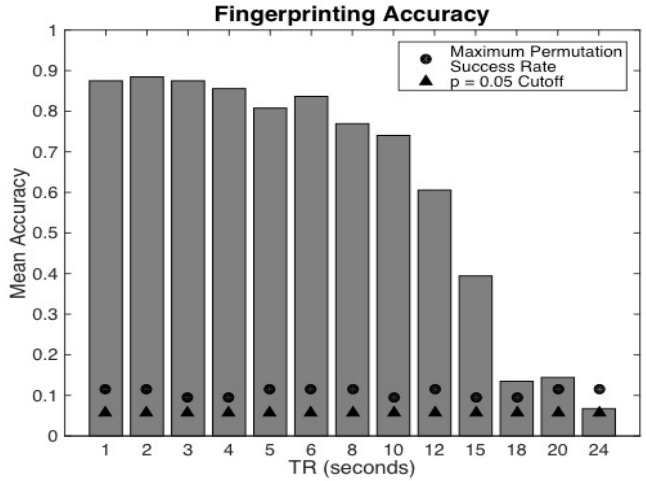
Q. Do you need HCP-quality data?
A. Not really

ID is fairly robust even at more standard spatial & temporal resolutions:



Airan et al., Hum Brain Mapp (2016)



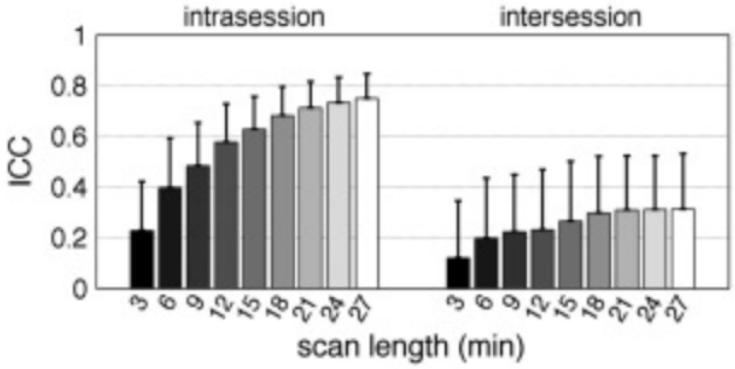
Courtesy of Jason Druzgal

- More nodes → higher identification rate
  - Parcellation method (random vs. functional) did not matter
  - *Caution:* Higher resolution may amplify effects of anatomical diffs/registration error
  - Parcellations in the 200-300 node range seem like a good compromise

Q. What about amount of data?
A. Scan duration matters!

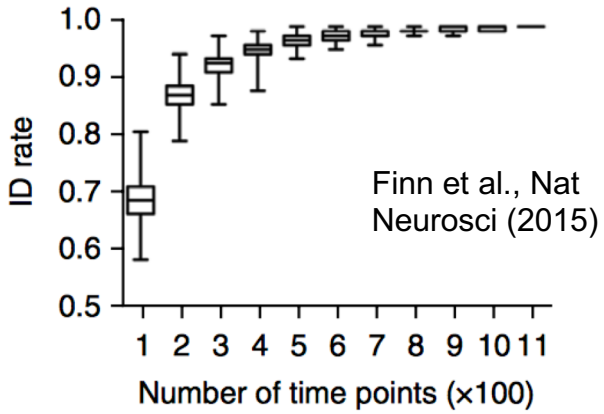
Longer acquisitions are better:

- higher reliability within subjects



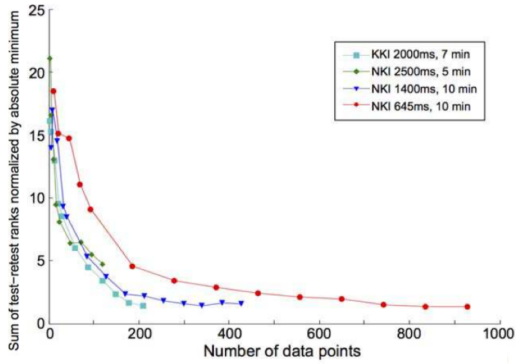
Birn et al., NeuroImage (2013)

- higher identifiability across subjects

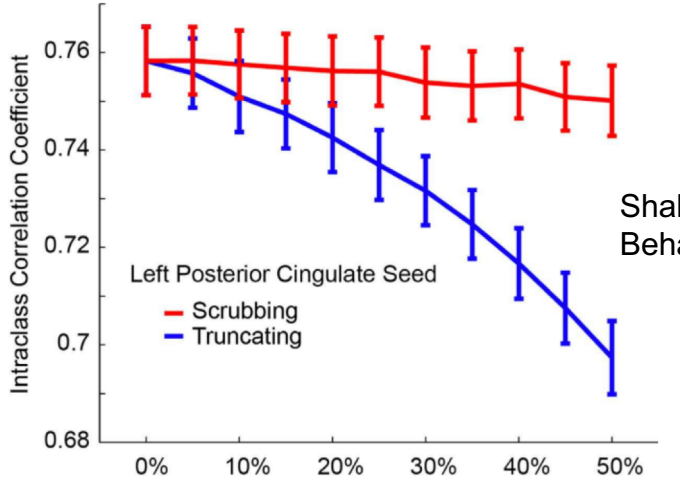


Finn et al., Nat Neurosci (2015)

- higher sampling rate (shorter TR) cannot make up for shorter scan duration

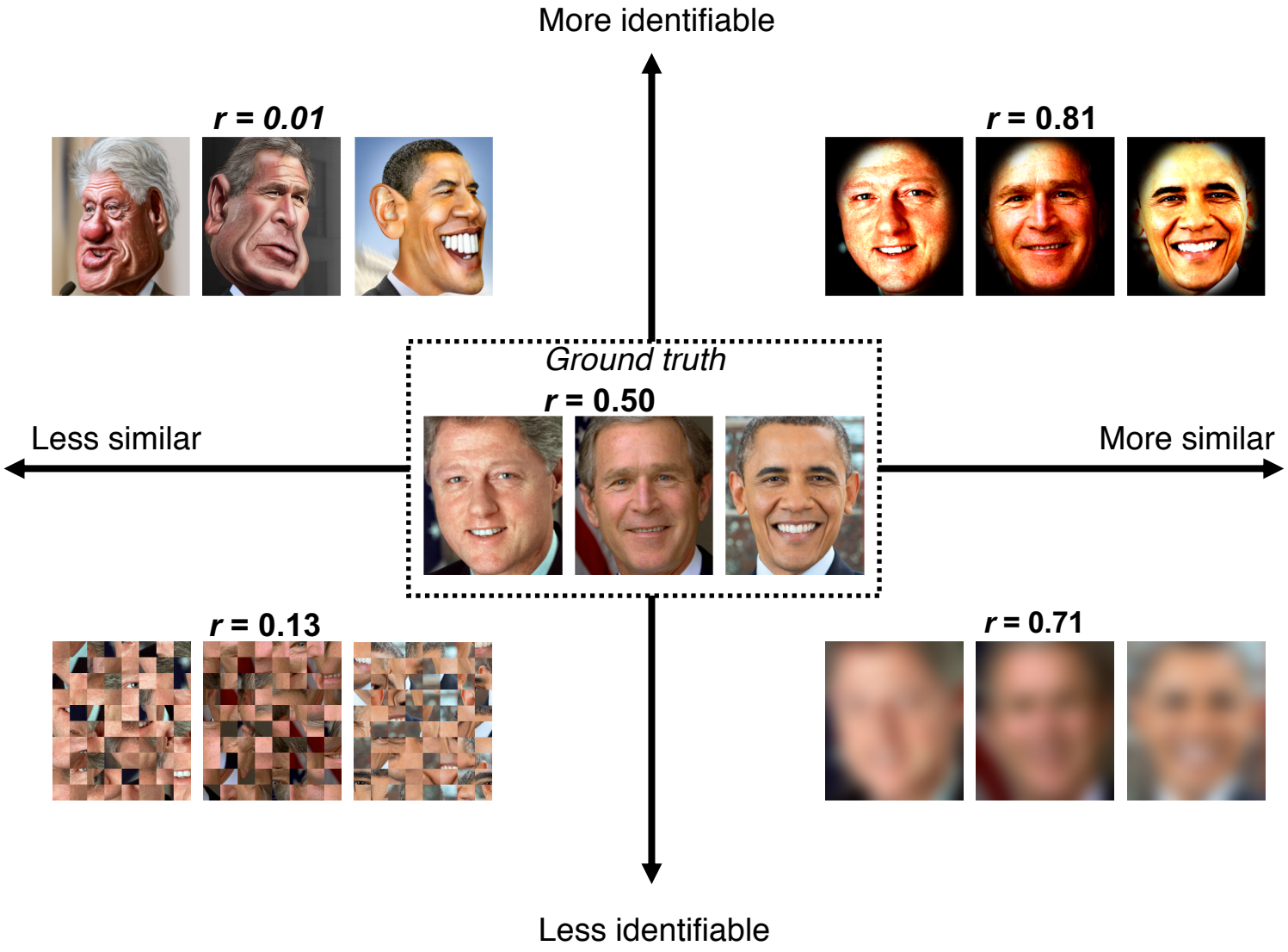


Airan et al., Hum Brain Mapp (2016)



Shah et al., Brain & Behav (2016)

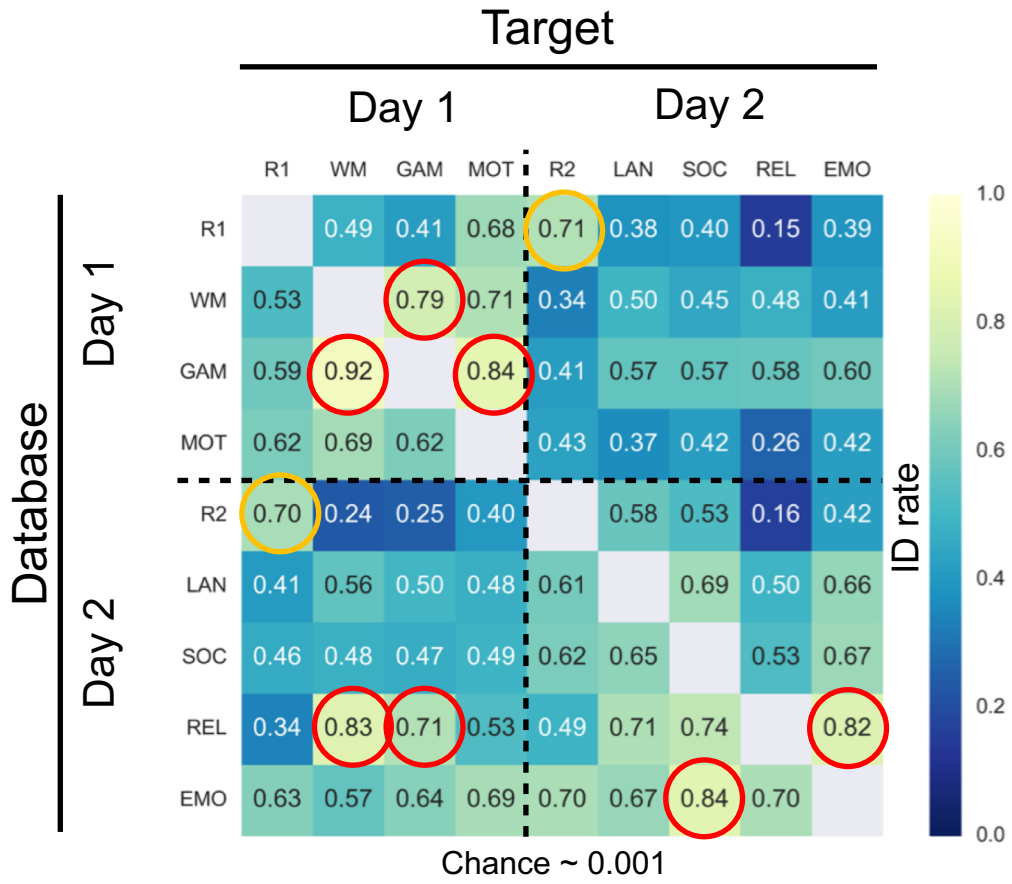
Q. Does scan condition matter?
A. Yes!



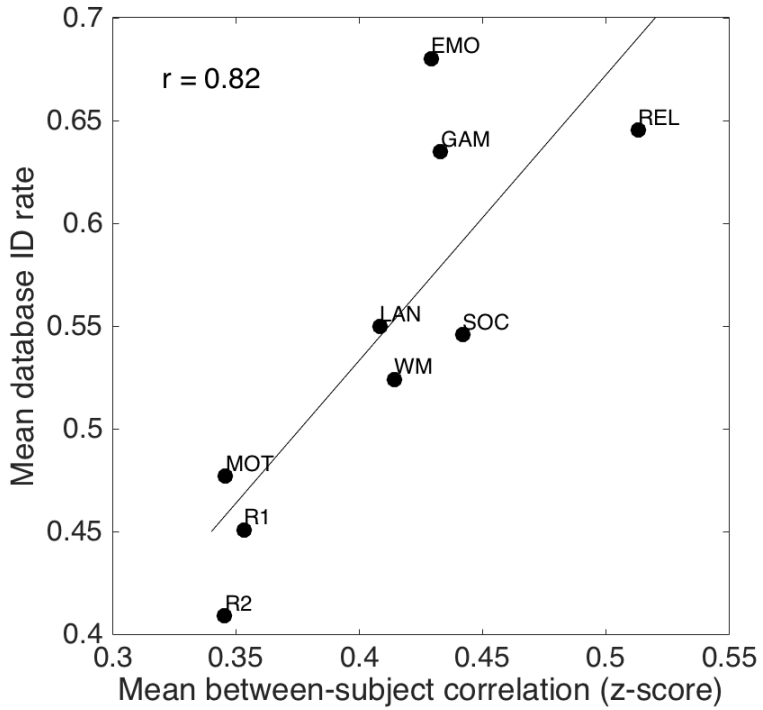
Q. Does scan condition matter?
A. Yes!

Rest has become the default condition for FC & individual differences, but tasks may increase signal-to-noise

Replicating identification experiments:

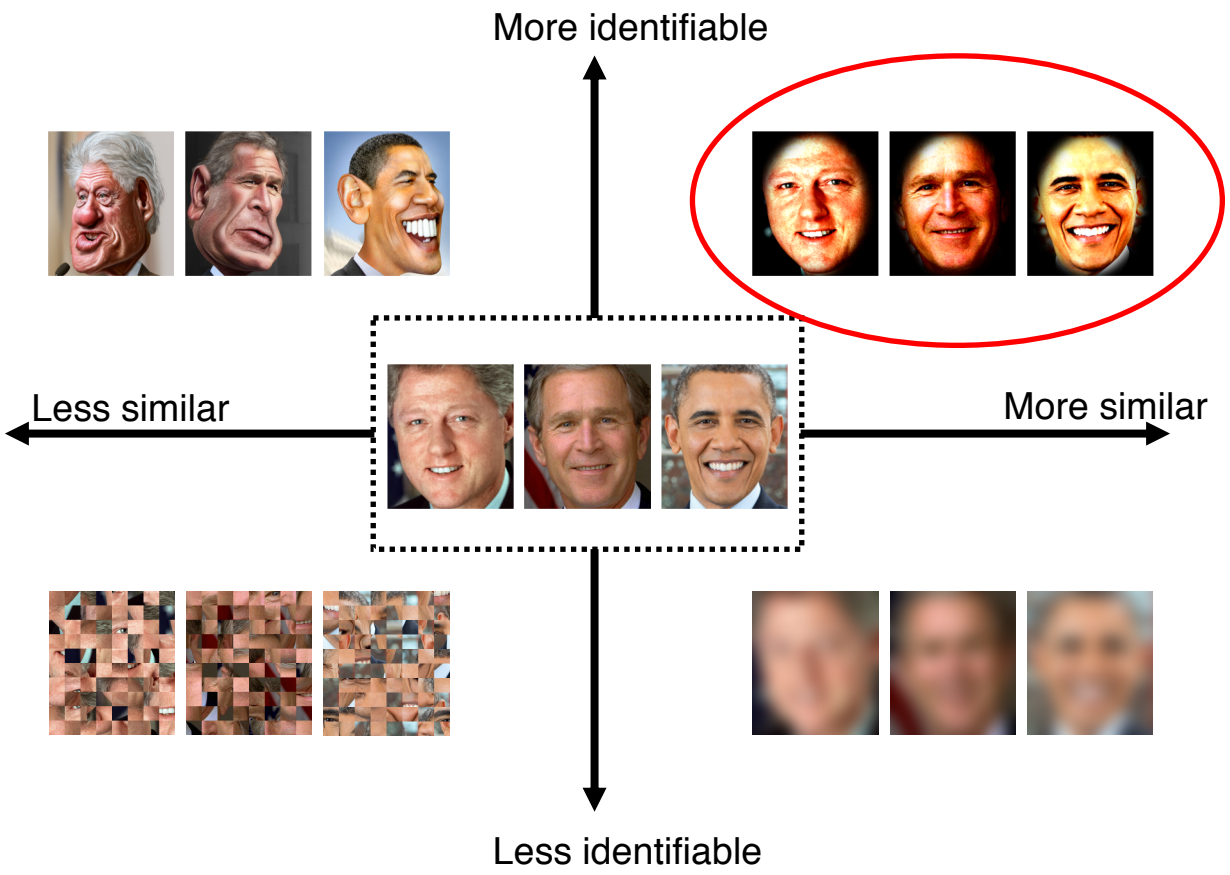


Conditions that make subjects look **more similar** to one another actually make **better databases** for identification:

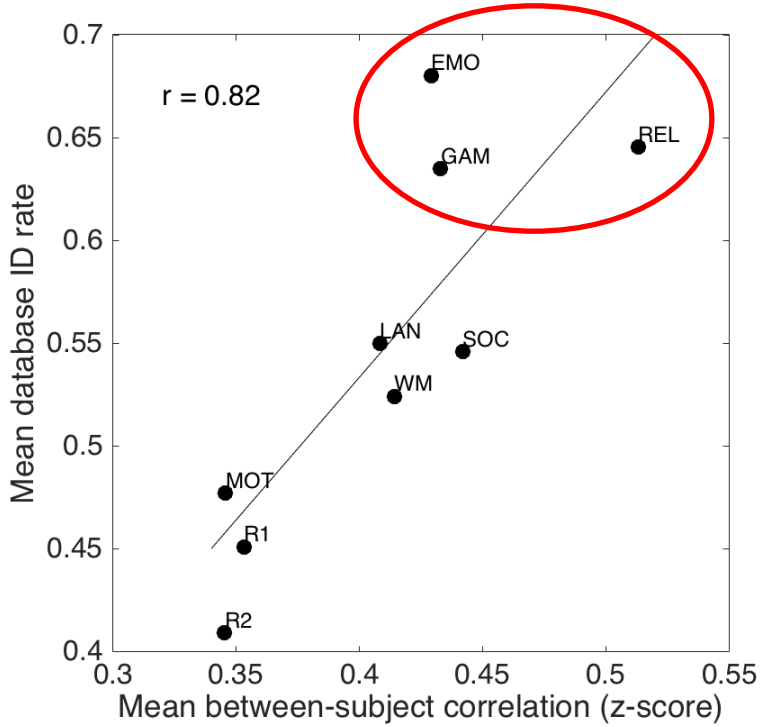


Q. Does scan condition matter?
A. Yes!

Rest has become the default condition for FC & individual differences, but tasks may increase signal-to-noise

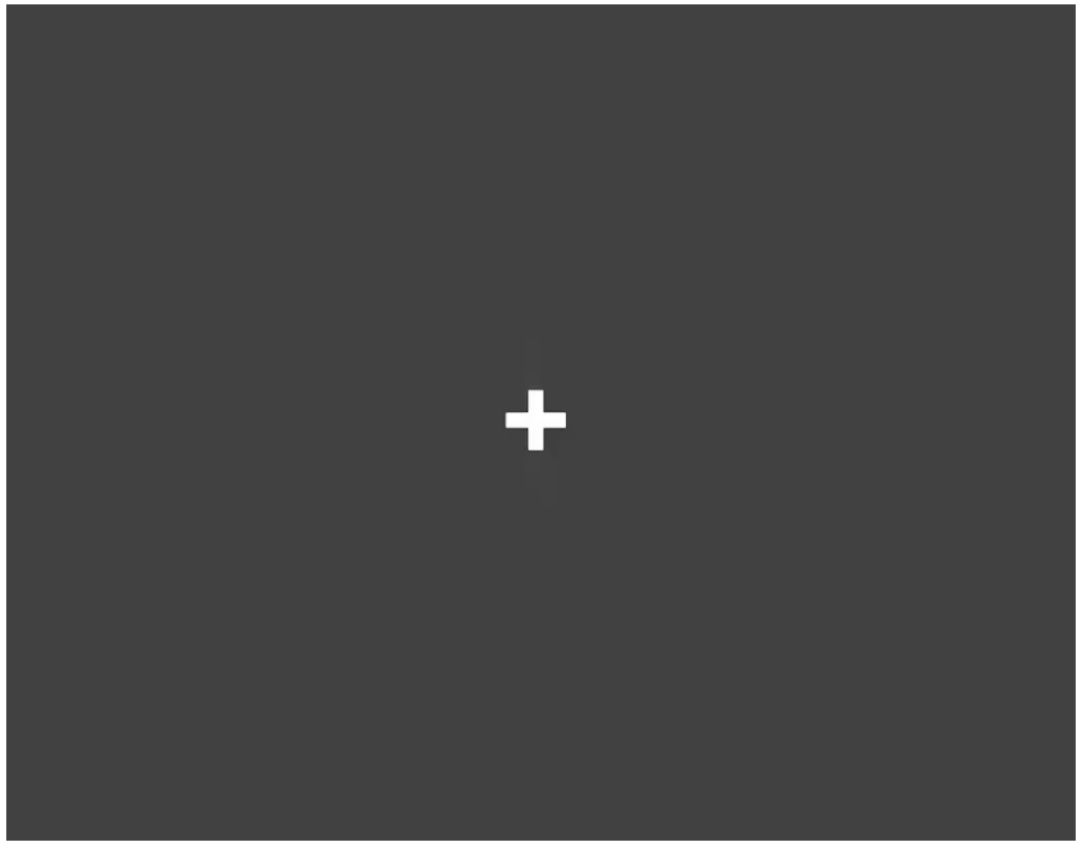


Conditions that make subjects look **more similar** to one another actually make **better databases** for identification:



Q. Is rest best?
A. Probably not

Consider naturalistic tasks:

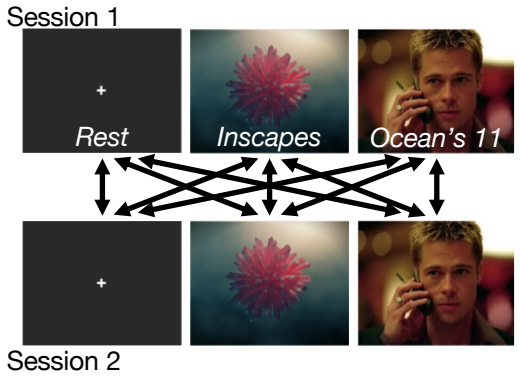


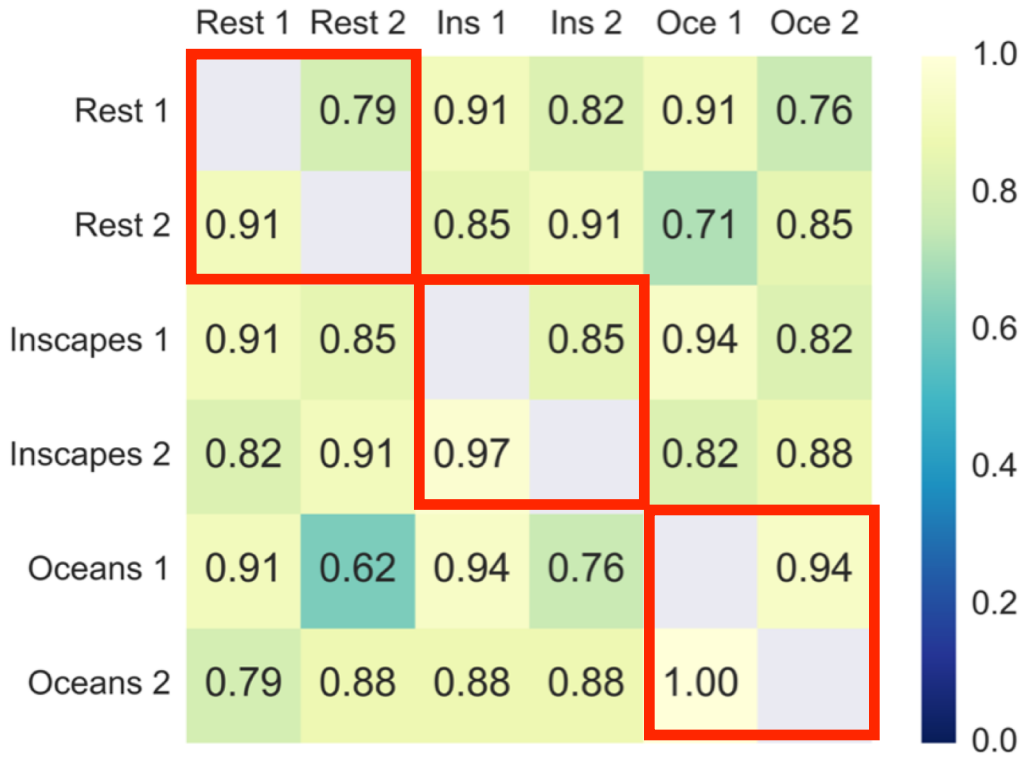
Inscapes: Vanderwal et al., *NeuroImage* 2015
headspacestudios.org

Q. Is rest best?
A. Probably not

Consider naturalistic tasks:

- ID rate is just as good as (if not better than) rest



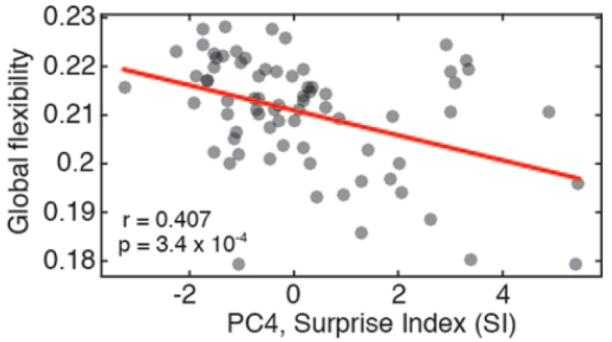


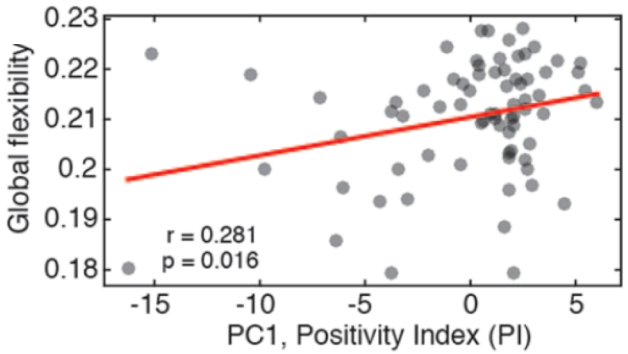
Vanderwal et al., NeuroImage (2017)

How to choose behavior

Is it stable?

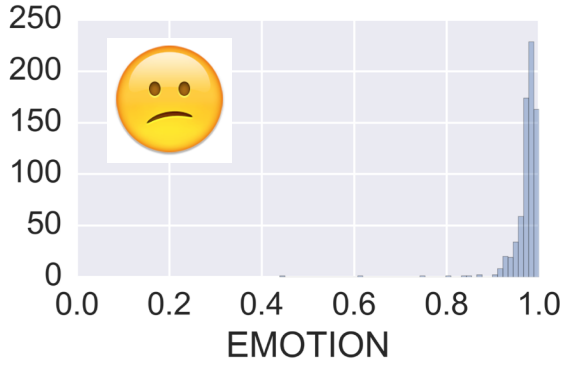
- Trait vs. state
- State variables may be better suited to within-subject analysis

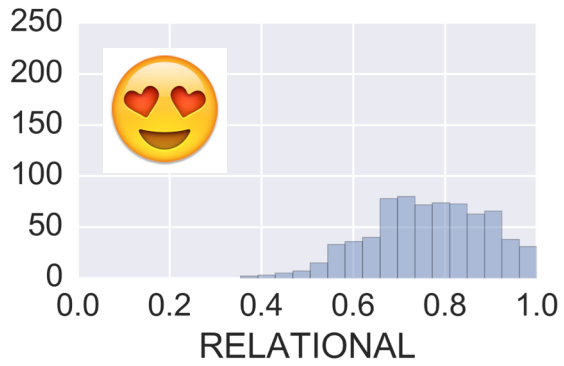




Betzel et al., Sci Rep (2017)

Does it show a good distribution in your population?





Behavior: Mitigating confounds

Many behaviors/phenotypes are correlated with head motion!

Negatively:

Subject measures	Pearson *r*
ReadEng (AgeAdj)	−0.23
ReadEng (Unadj)	−0.23
Vocabulary (AgeAdj)	−0.19
Dexterity (Unadj)	−0.18
CardSort (Unadj)	−0.18
Dexterity (AgeAdj)	−0.18
CardSort (AgeAdj)	−0.18
Education	−0.17
Fluid intelligence	−0.17
Spatial orientation	−0.17
Vocabulary (unadjj)	−0.17
Emotion recognition	−0.16

Positively:

DSM somatic problems (pct)	0.16
DSM antisocial (raw)	0.16
ASR externalizing (raw)	0.16
DSM somatic problems (raw)	0.16
Tobacco use 7 day	0.18
Diastolic blood pressure	0.18
ASR externalizing	0.18
Tobacco use today	0.2
Systolic blood pressure	0.23
Weight	0.52
Body mass index (BMI)	0.66

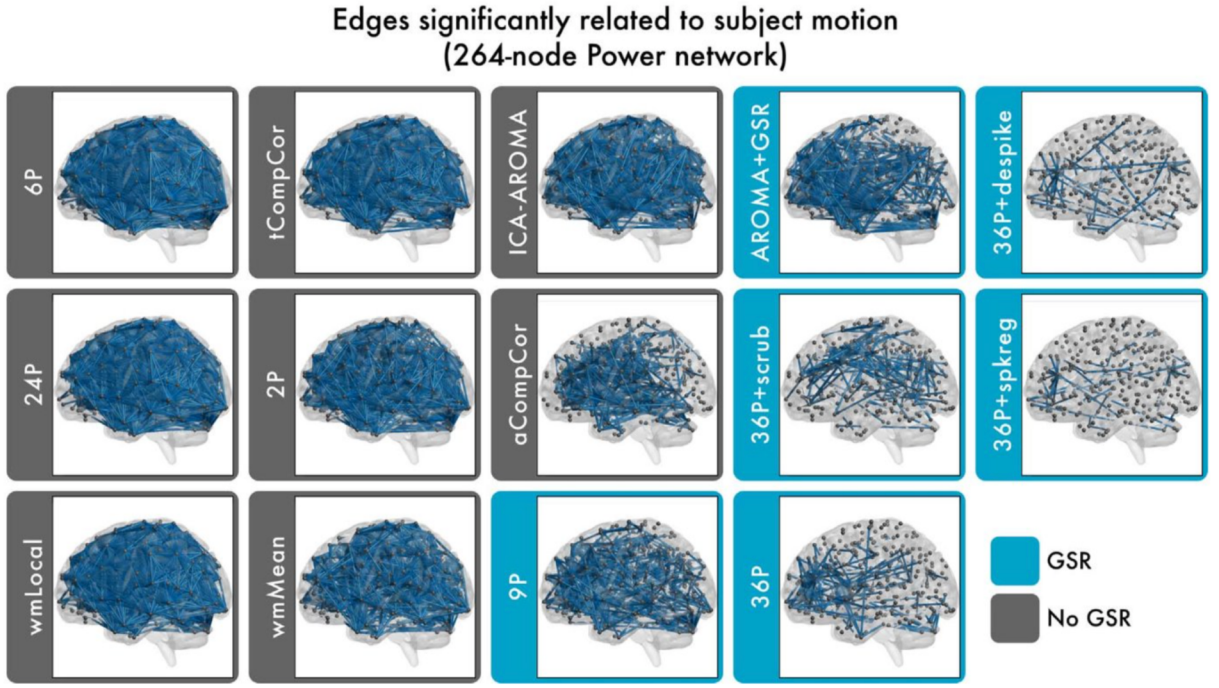
- Patients of any kind move more
- Children move more
- Older adults move more

Siegel et al., Cerebral Cortex (2016)

Behavior: Mitigating confounds

Many behaviors/phenotypes are correlated with head motion!

- Check correlation in your sample
- Consider excluding particularly high-motion subjects
- Choose appropriate preprocessing techniques
- Use motion as an explicit covariate

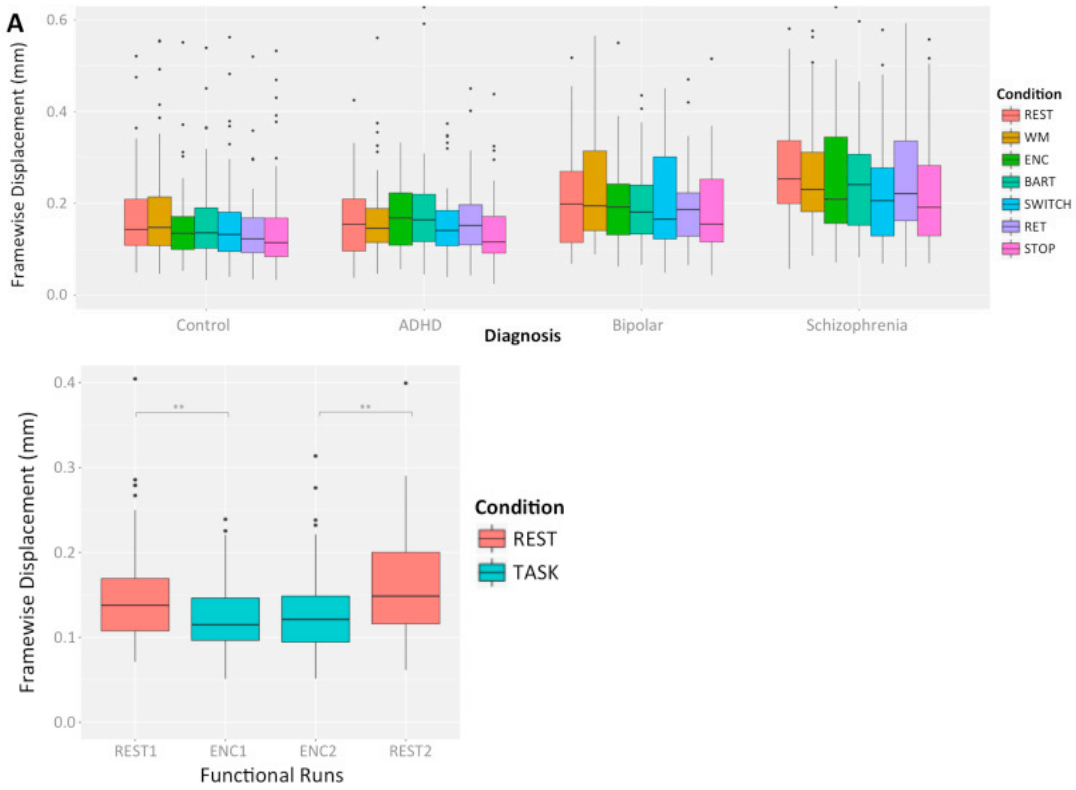


Ciric et al., NeuroImage (2017)

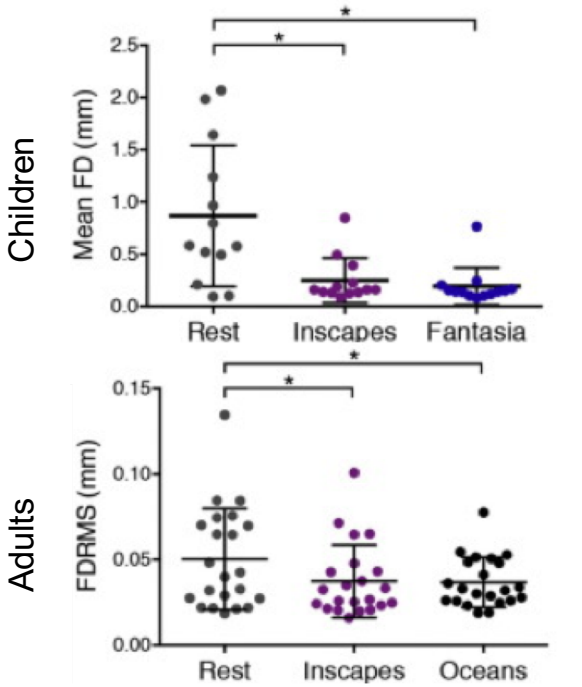
Q. Is rest best?
A. Probably not

Tasks also have purely practical advantages:

- increase subject compliance (i.e., decrease head motion), especially in certain populations



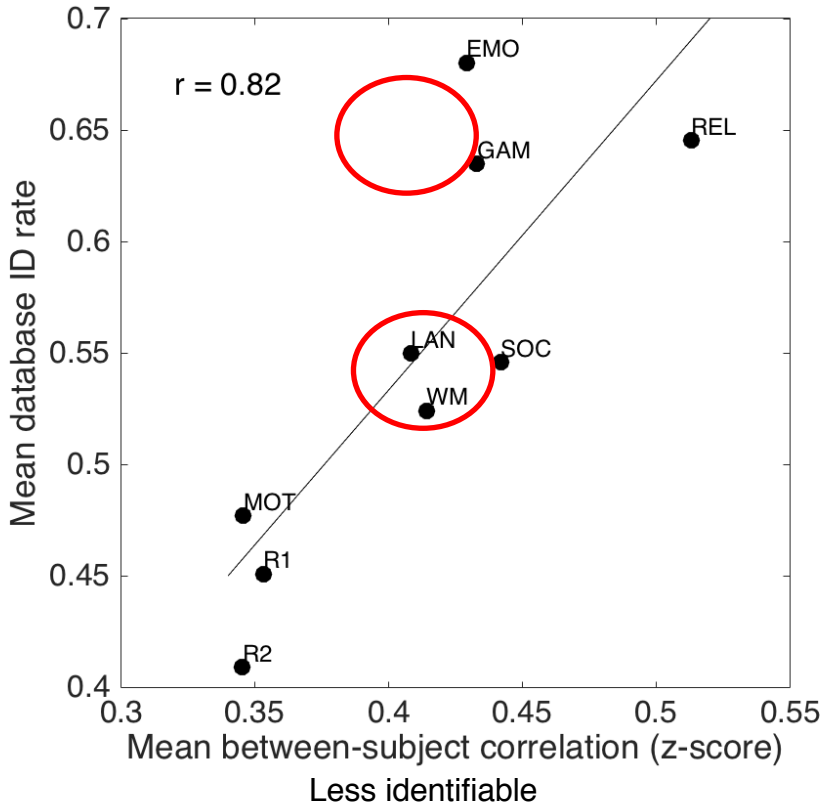
Huijbers et al., NeuroImage (2017)

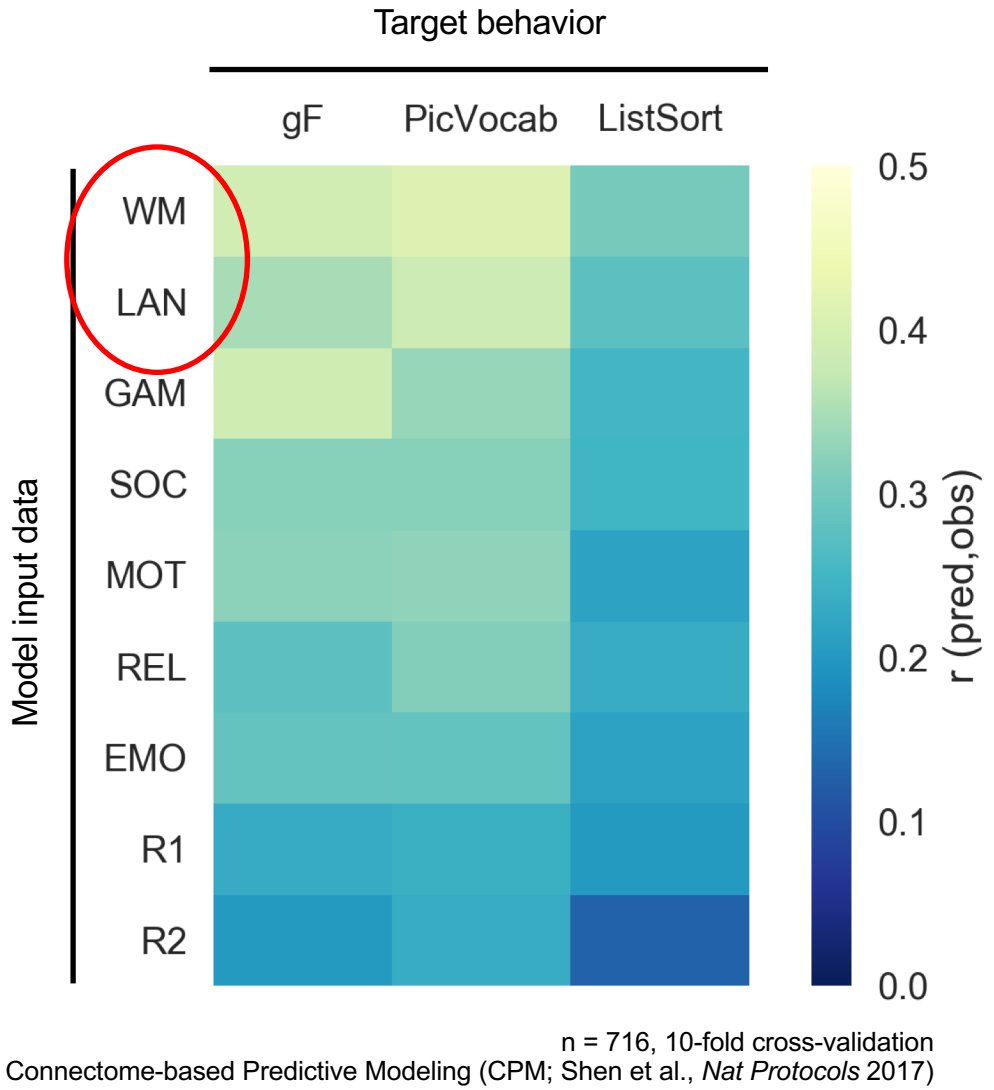


Vanderwal et al., NeuroImage (2015)

Q. What is the best brain state?
A. Maybe it depends on your behavior

Certain task conditions generate better predictions of behavior:





n = 716, 10-fold cross-validation
Connectome-based Predictive Modeling (CPM; Shen et al., *Nat Protocols* 2017)

Outline

1. **What** do we mean by individual differences?
2. **Why** should we care about individual differences?
3. **How** can we study individual differences?
   (some practical guidelines)
4. **Where** are we going next?

Outline

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   (some practical guidelines)
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Outstanding questions

Data acquisition

Populations
- Many individuals lightly sampled, or few individuals densely sampled?
- Patients, controls?
- Longitudinal studies?

Imaging
- Scan condition? “Stress test”?
- Function, anatomy, both?

Behavior
- Robust measures?
- *Inter-* vs *intra-*subject variability?

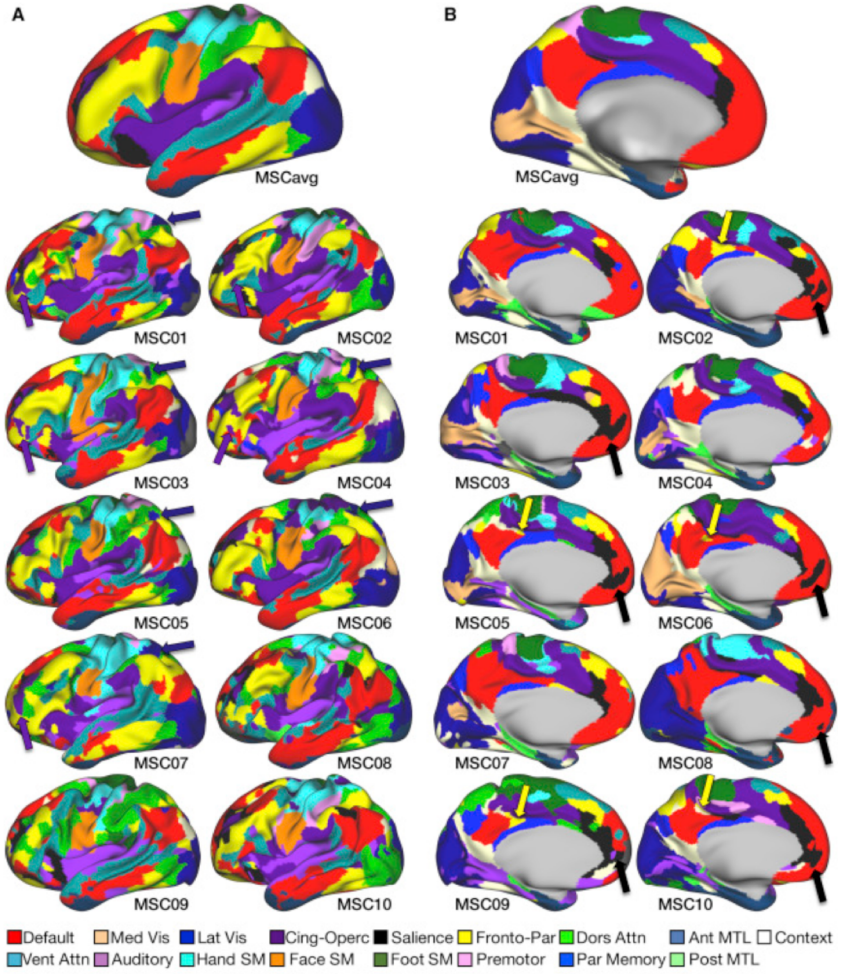
Data analysis

Strategy
- Functional connectivity?
- Activation?
- Combination?

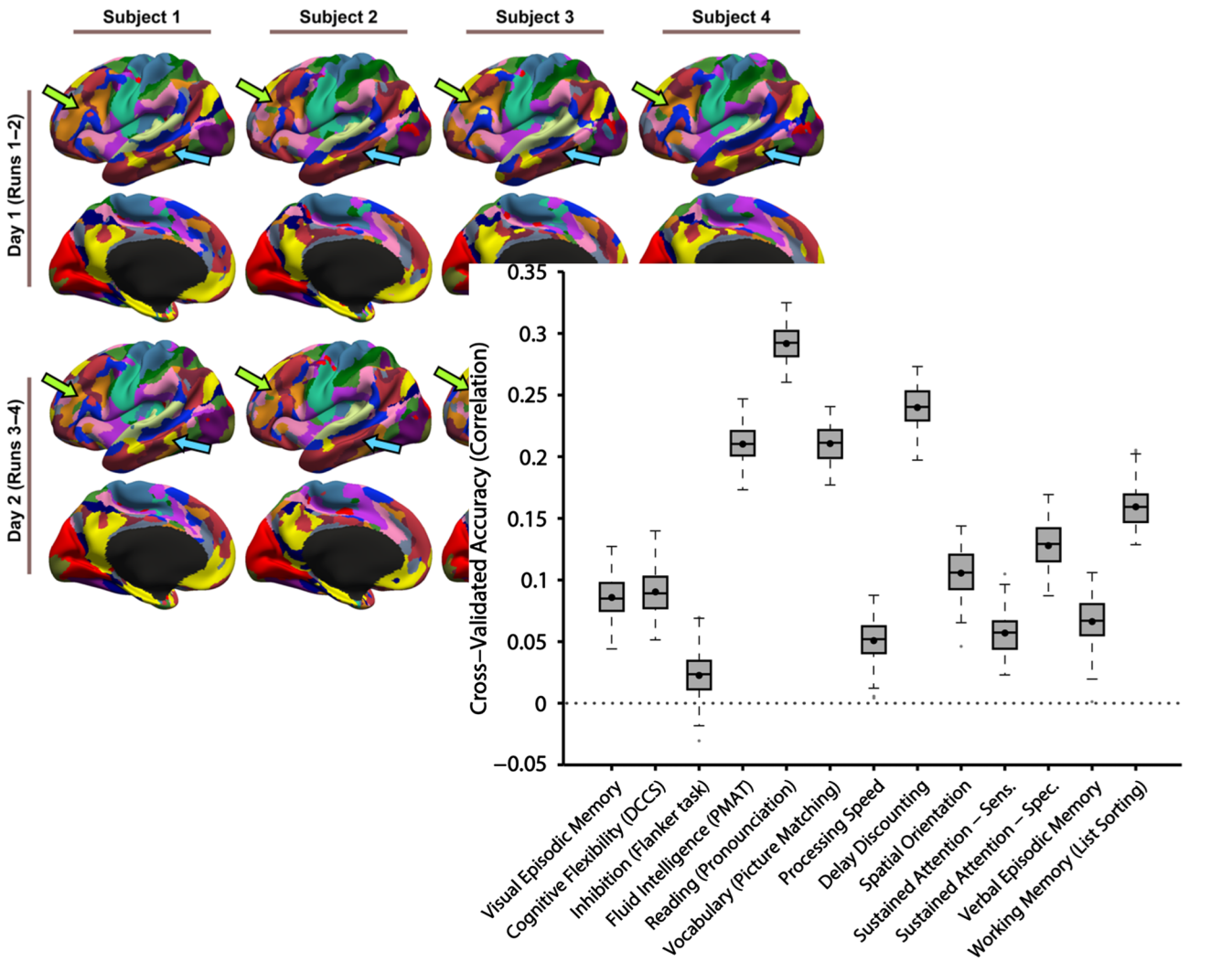
Specifics
- Parcel boundaries? Connections between parcels? Both?

Interpretations & applications

Individual-specific parcellations



Gordon et al., *Neuron* (2017)



Kong et al., *Cereb Cortex* (2018)

Outstanding questions

Data acquisition

Populations
- Many individuals lightly sampled, or few individuals densely sampled?
- Patients, controls?
- Longitudinal studies?

Imaging
- Multisite studies?
- Scan condition? “Stress test”?
- Function, anatomy, both?

Behavior
- Robust measures?
- *Inter-* vs *intra*-subject variability?

Data analysis

Strategy
- Functional connectivity?
- Activation?
- Combination?

Specifics
- Parcel boundaries? Connections between parcels? Both?

Applications & interpretations

Mutability
- Development?
- Disease progression?
- Plasticity/training?

Applications
- Translational utility?
- Ethics?

Further reading & open data sets

Selected reviews:

Prediction as a humanitarian and pragmatic contribution from human cognitive neuroscience
Gabrieli, Ghosh & Gabrieli, *Neuron* (2015)

Building a science of individual differences from fMRI
Dubois & Adolphs, *Trends in Cognitive Sciences* (2016)

From regions to connections and networks: new bridges between brain and behavior
Misic & Sporns, *Current Opinion in Neurobiology* (2016)

Can brain state be manipulated to emphasize individual differences in functional connectivity?
Finn et al., *NeuroImage* (2017)

Open data sets with brain and behavior:

Philadelphia
Neurodevelopmental
Cohort

CHILD MIND®
INSTITUTE
healthy brain network

Use these on their own or in combination with your own data to generate or test hypotheses, see if a finding generalizes, etc

Acknowledgements

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