Using MRI protocols from the Human Connectome Project for precision imaging of the multiple demand system

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Cognitive control/ executive function

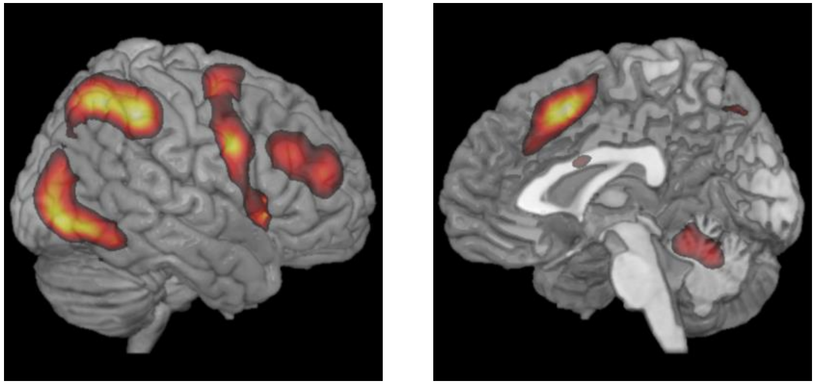
Wisconsin card-sorting: attentional shifting

Go/no-go: inhibition

Verbal fluency: self-generated strategy

Weaknesses in this way of thinking

A common element to different aspects of control:
The multiple-demand (MD) system



Fedorenko et al., 2013, PNAS

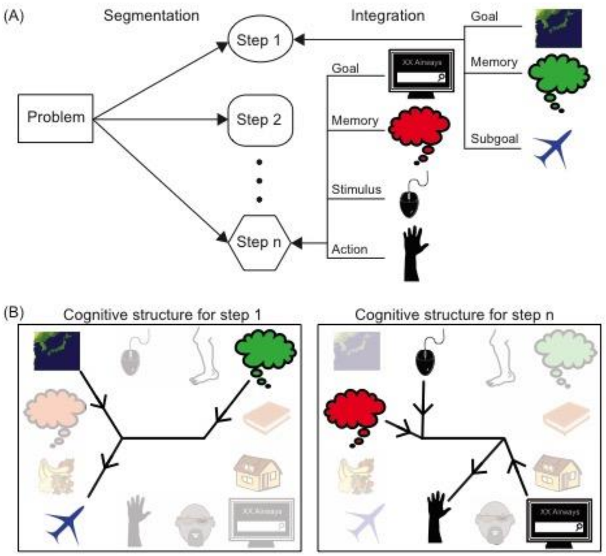
travel to Japan

fly

buy ticket

access web

mouse



“attentional integration” – the core of cognitive control

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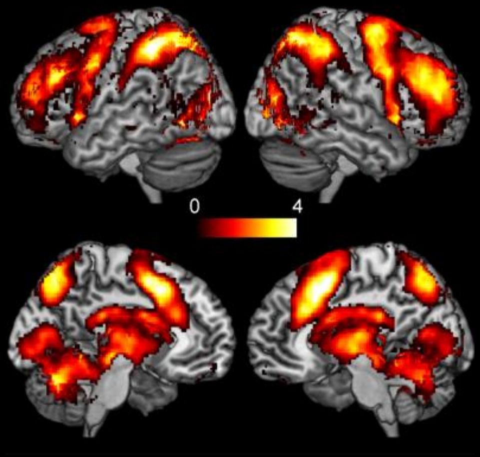
1000s of studies show similar activations – but are these truly overlapping?

with traditional methods, precision is too low to tell

what happens when precision increases?

Multiple-demand system



Yet no consensus on:

- Functional preferences
- Precise location
- Connectivity profile

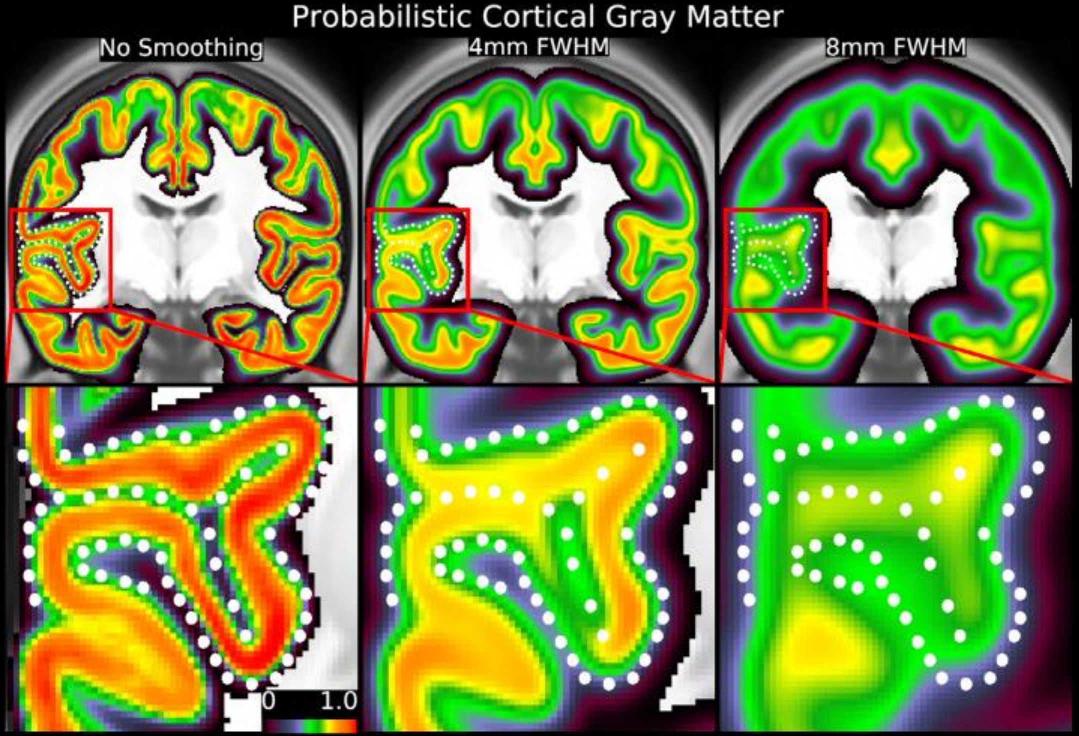
Human Connectome Project neuroimaging approach

Three main methodological advances:

1. Respect cortical geometry = surface based approach
2. Align cortices using multimodal criteria
3. Interpret results against a neurobiologically motivated parcellation

Volumetric-based approaches

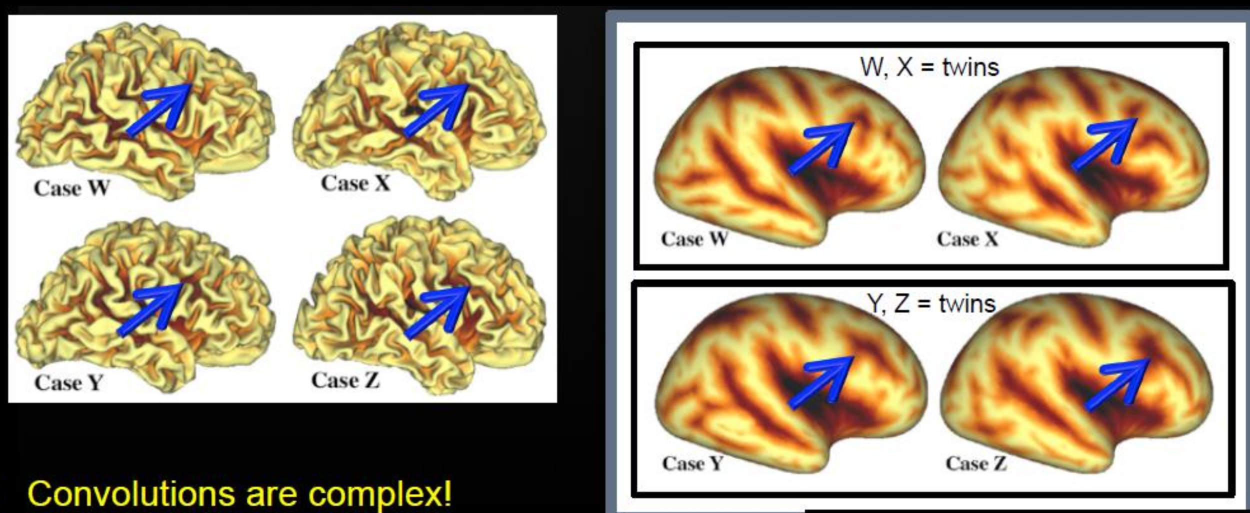
- Unconstrained spatial smoothing



Supp figure from Coalson et al (2018) *PNAS*

Volumetric-based approaches

- Heavily rely on cortical folding patterns for inter-subject alignment



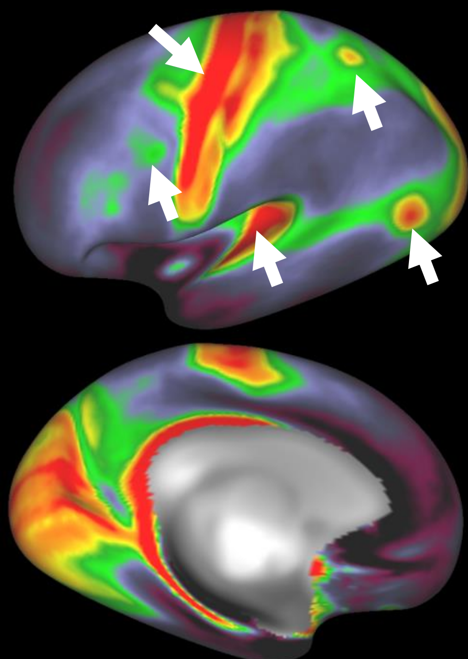
Botteron, Dierker, Todd et al. (OHBM 2008)

- Convolutions are complex!
- Highly variable across individuals
- More variable in ‘higher cognitive’ regions
- Variable even in identical twins, but some heritability

From 2017 HCP course

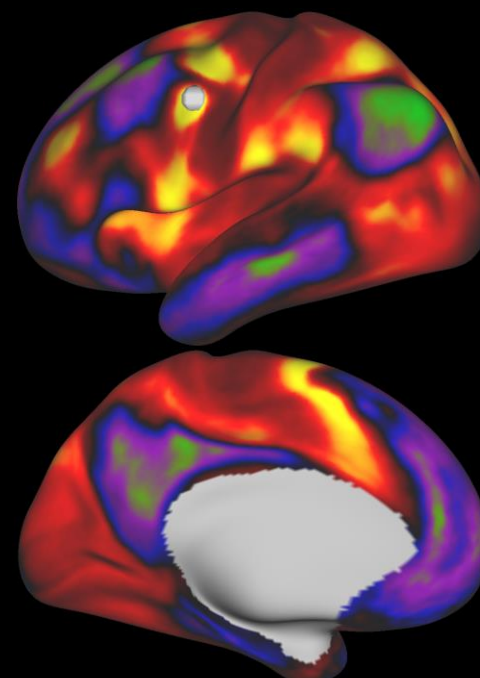
Areal feature-based surface registration

Myelin Map
T1w/T2w

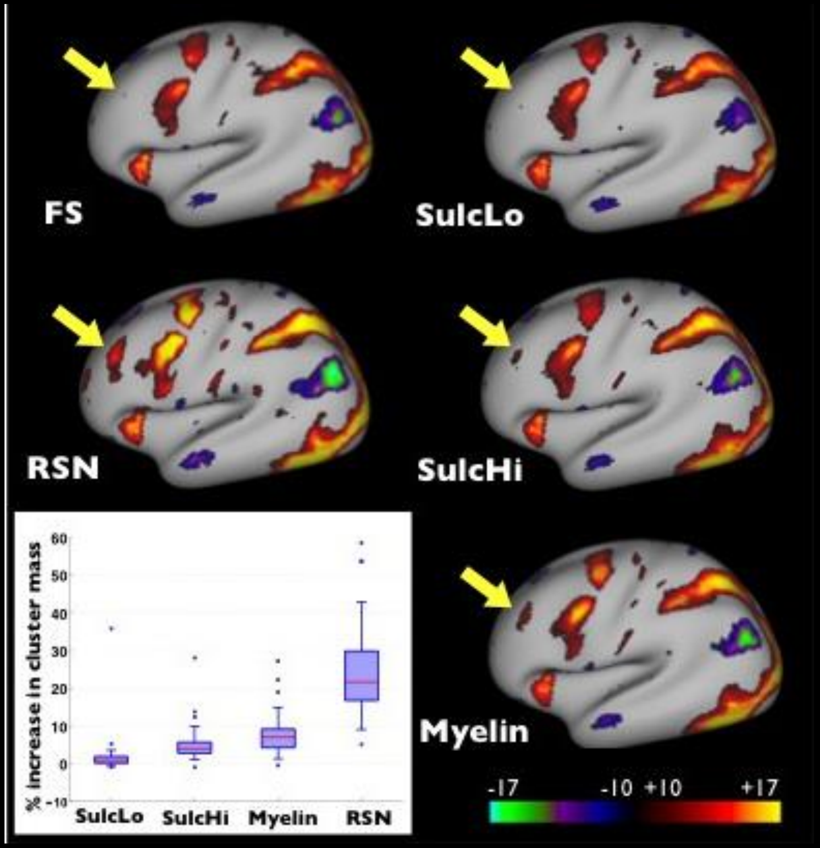


Glasser & Van Essen (2011)

fMRI connectivity maps

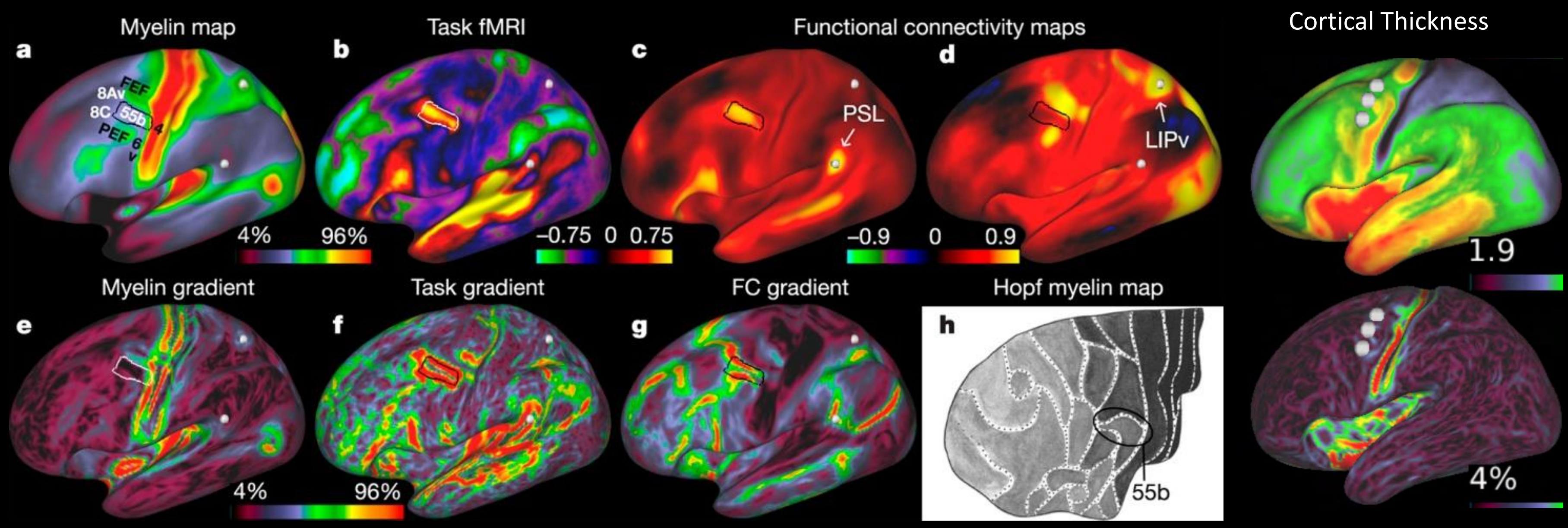


Multimodal Surface Matching (MSM)



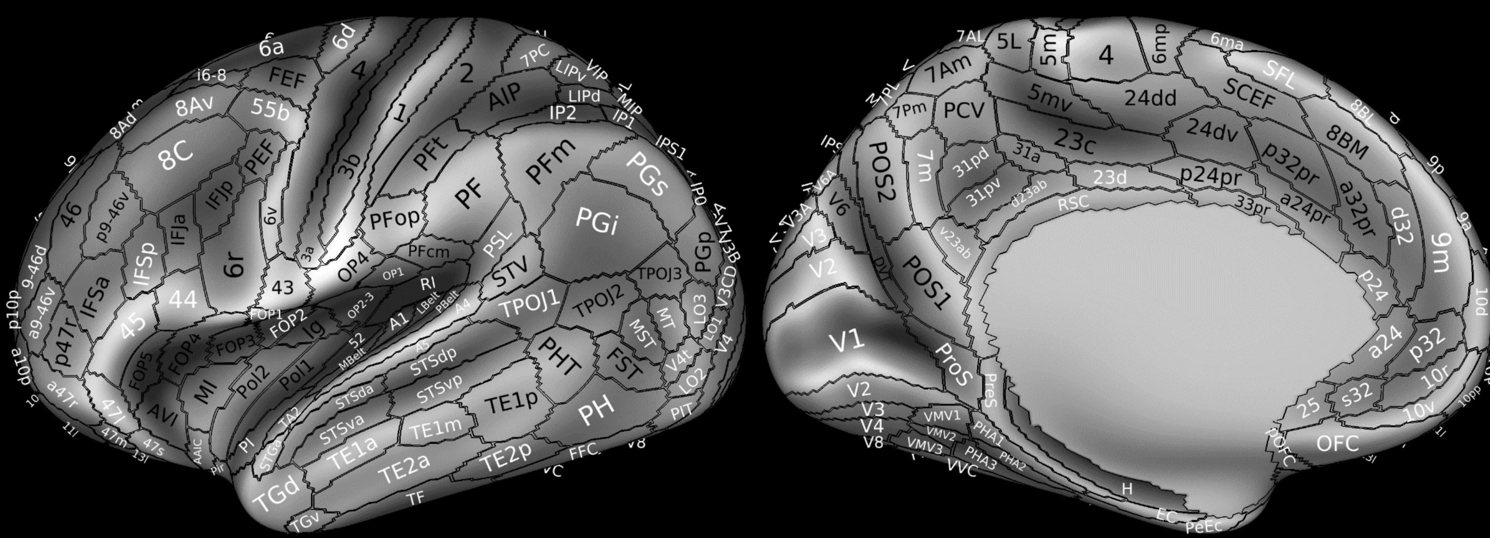
Robinson et al (2014 & 2018) *NeuroImage*

Multi-modal parcellation

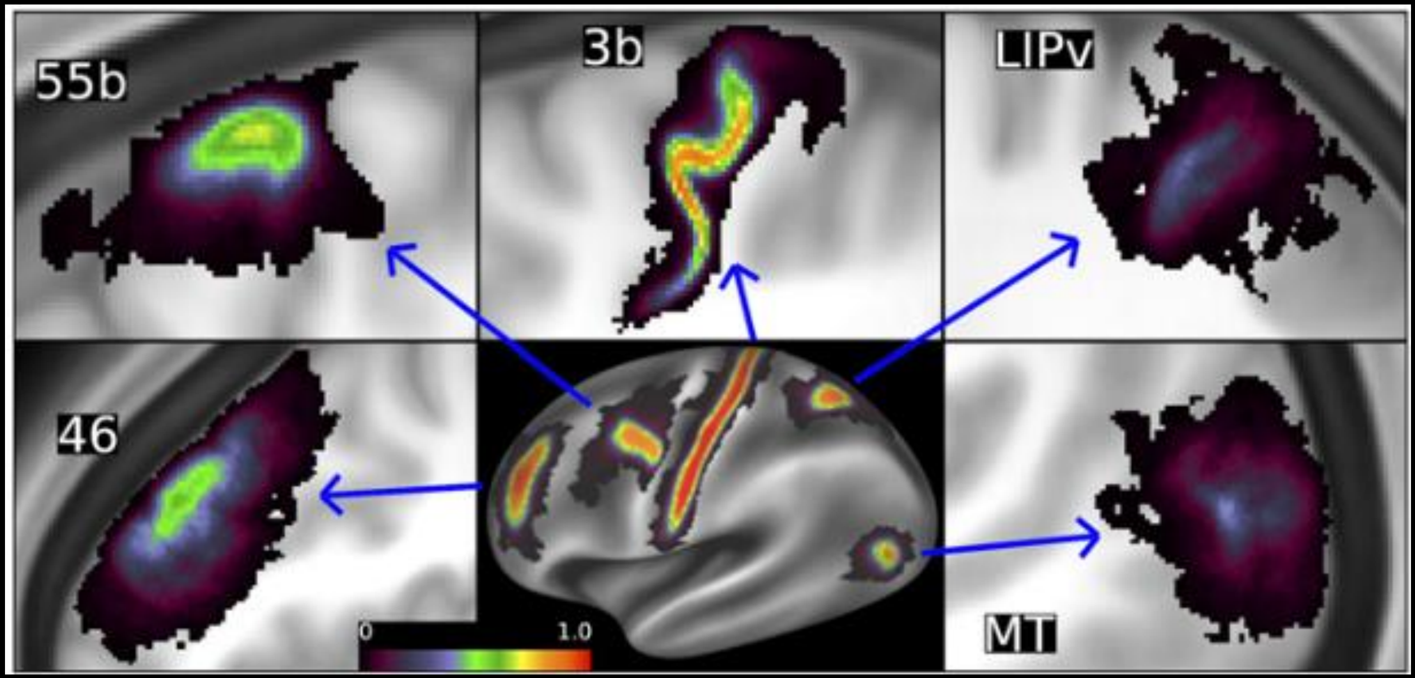


Glasser et al. (2016) *Nature*

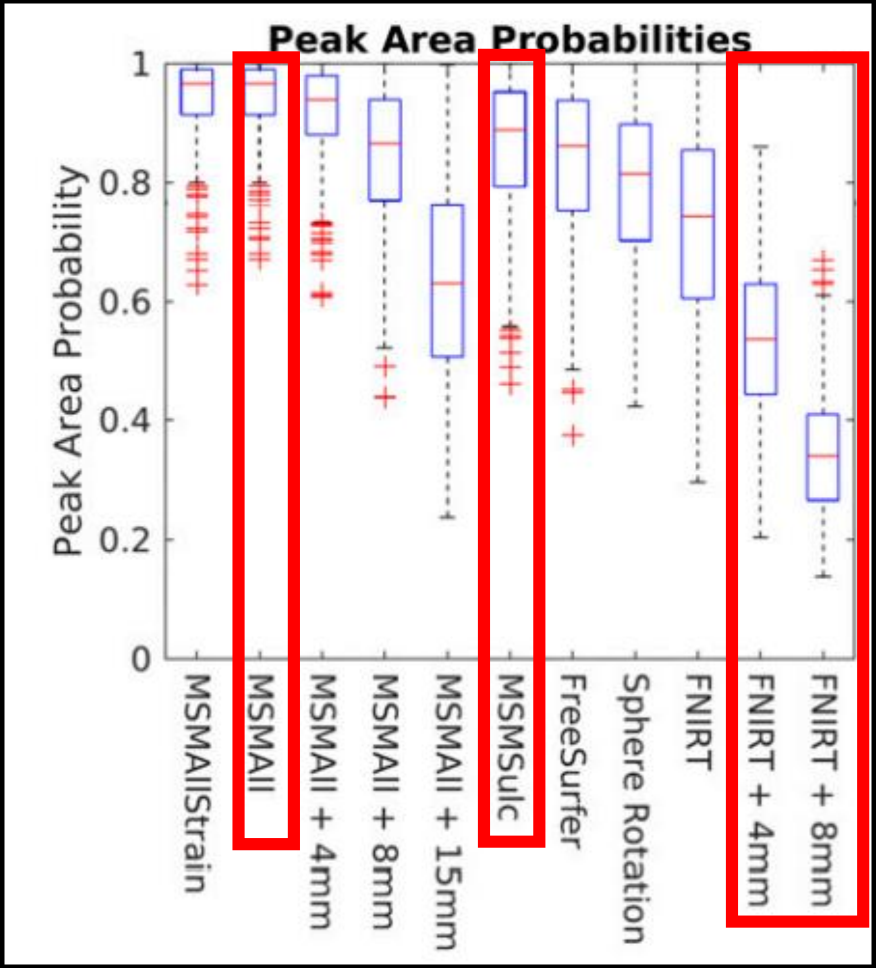
HCP MMP 1.0



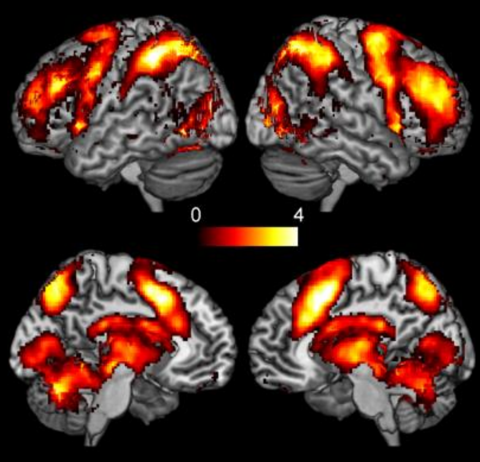
Glasser et al. (2016) *Nature*

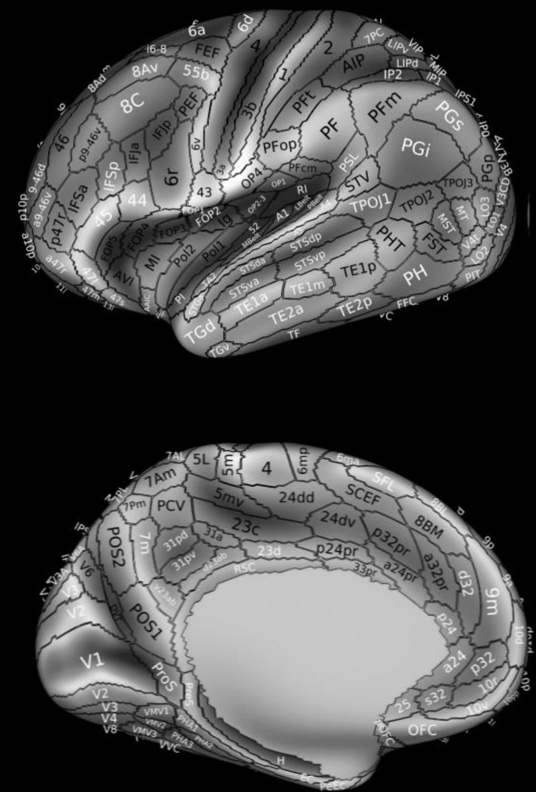


“the most common version of the traditional approach has spatial localization that is only 35% as good as the best surface-based method” Coalson et al (2018) PNAS



Coalson et al (2018) *PNAS*

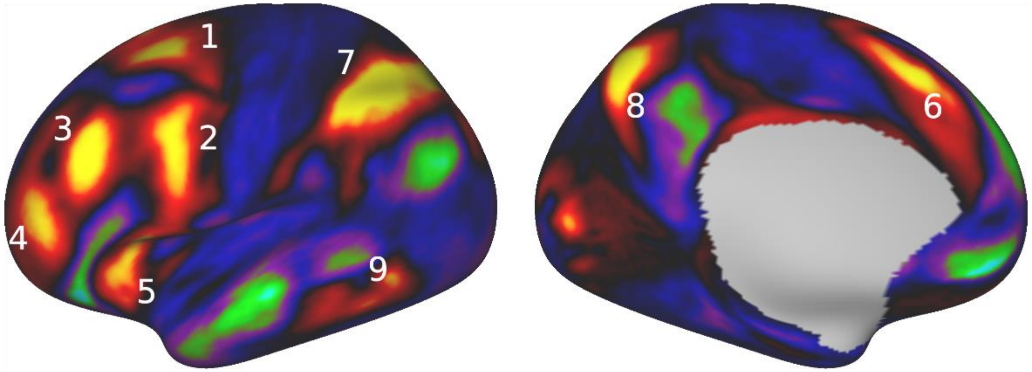

0
4


6a
6d
FEF
55b
8Av
8C
PEF
IFJp
IFJa
46
IFSp
IFSa
44
45
6r
43
OP4
PFop
PF
PFt
PFm
PGs
PGi
AIP
STV
TPOJ1
TPOJ2
TPOJ3
PHT
FST
PH
TE1p
TE1a
TE1m
TE2a
TE2p
TGd
STSdp
STSvp
STSva
MI
AVI
Pol2
Pol1
A1
3b
1
2
4
PSL
5L
5m
7Am
7Pm
PCV
5mv
24dd
24dv
23c
23d
SCEF
SFL
8BM
p32pr
a32pr
p24pr
a24pr
d32
9m
POS2
POS1
7m
31pd
31pv
31a
RSC
V1
V2
V3
V4
V6
V8
ProS
p24
a24
p32
10r
s32
25
OFC
H

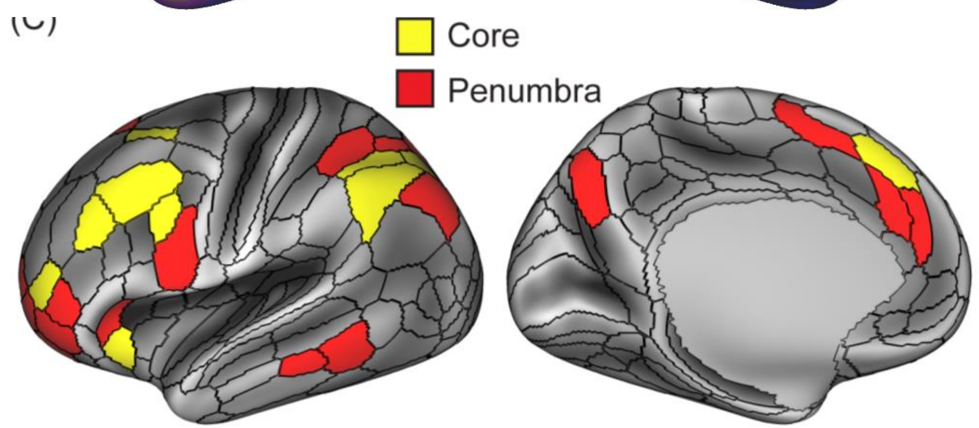
Extended MD system

Average of 3 HCP contrasts (n=449)

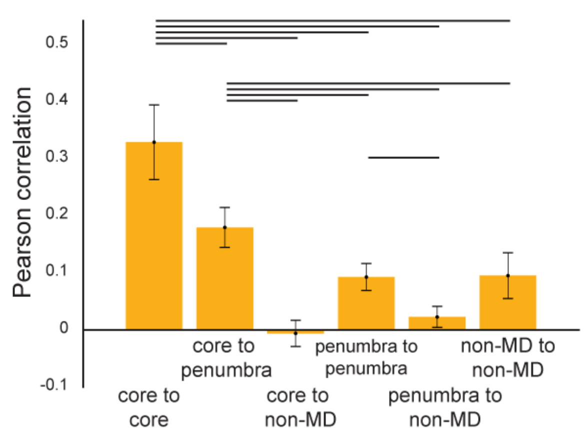
- Hard>easy working memory
- Hard>easy reasoning
- Math>story



Conjunction of 3 HCP contrasts



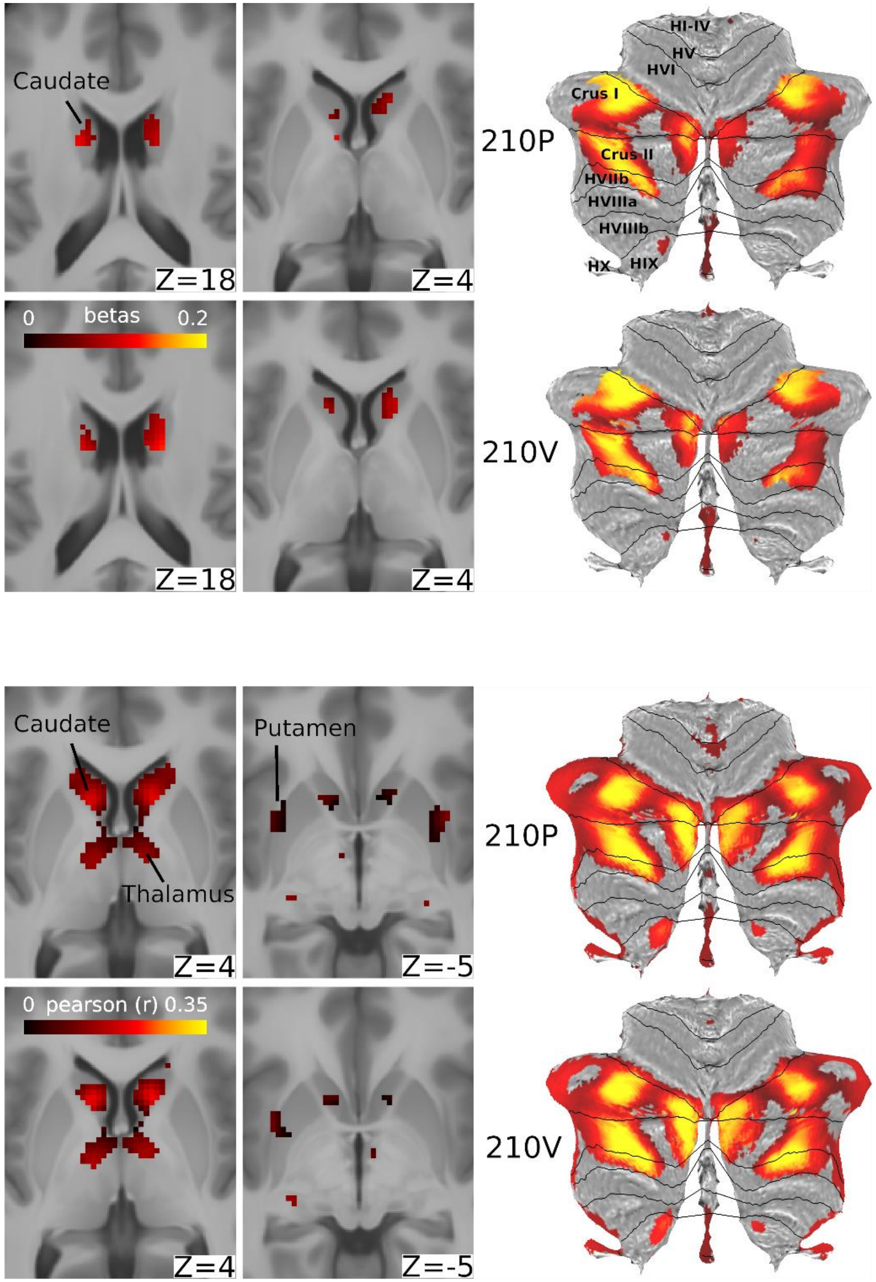
rfMRI connectivity



Assem et al (2020) Cerebral Cortex

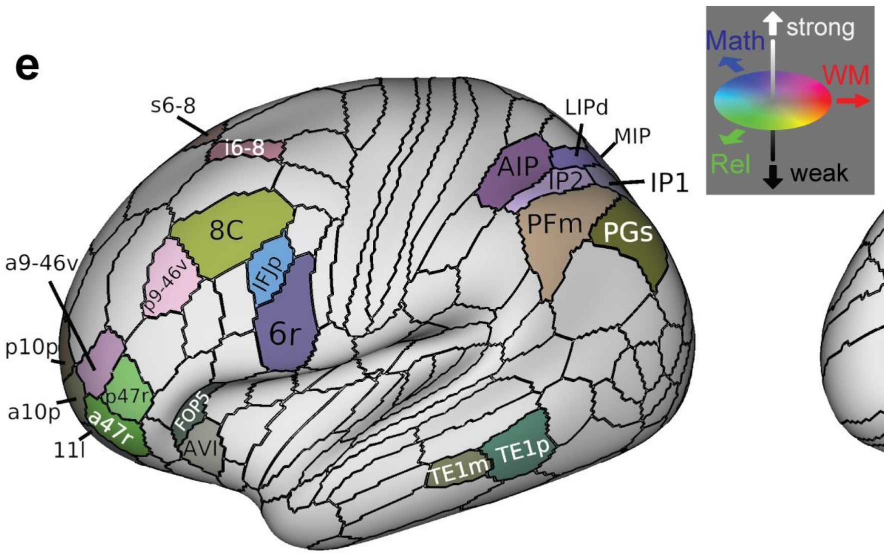
Conjunction of 3 HCP task contrasts

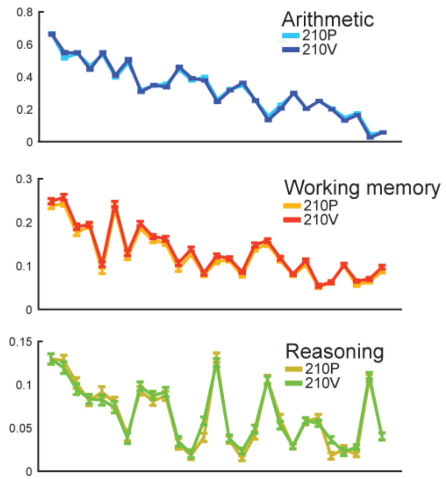
rfMRI connectivity with core MD

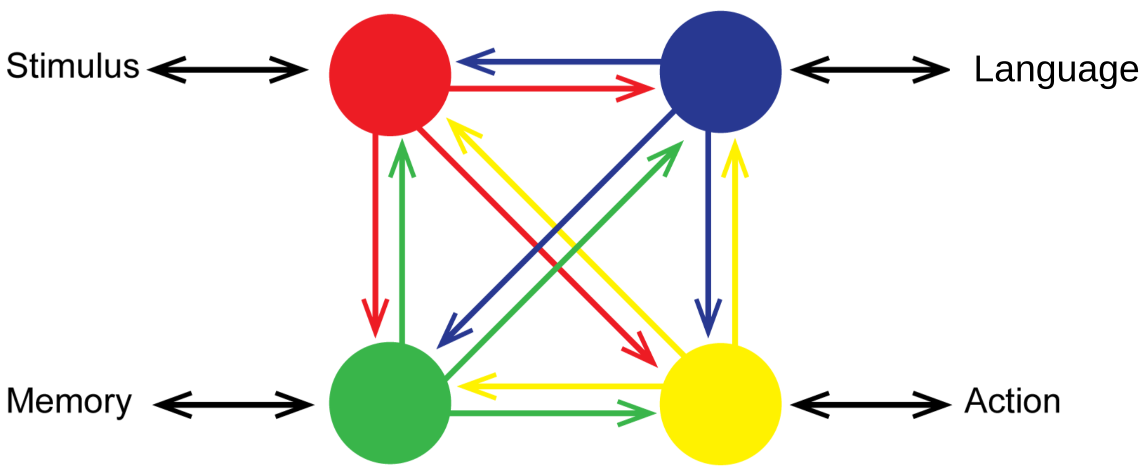


Assem et al (2020) Cerebral Cortex

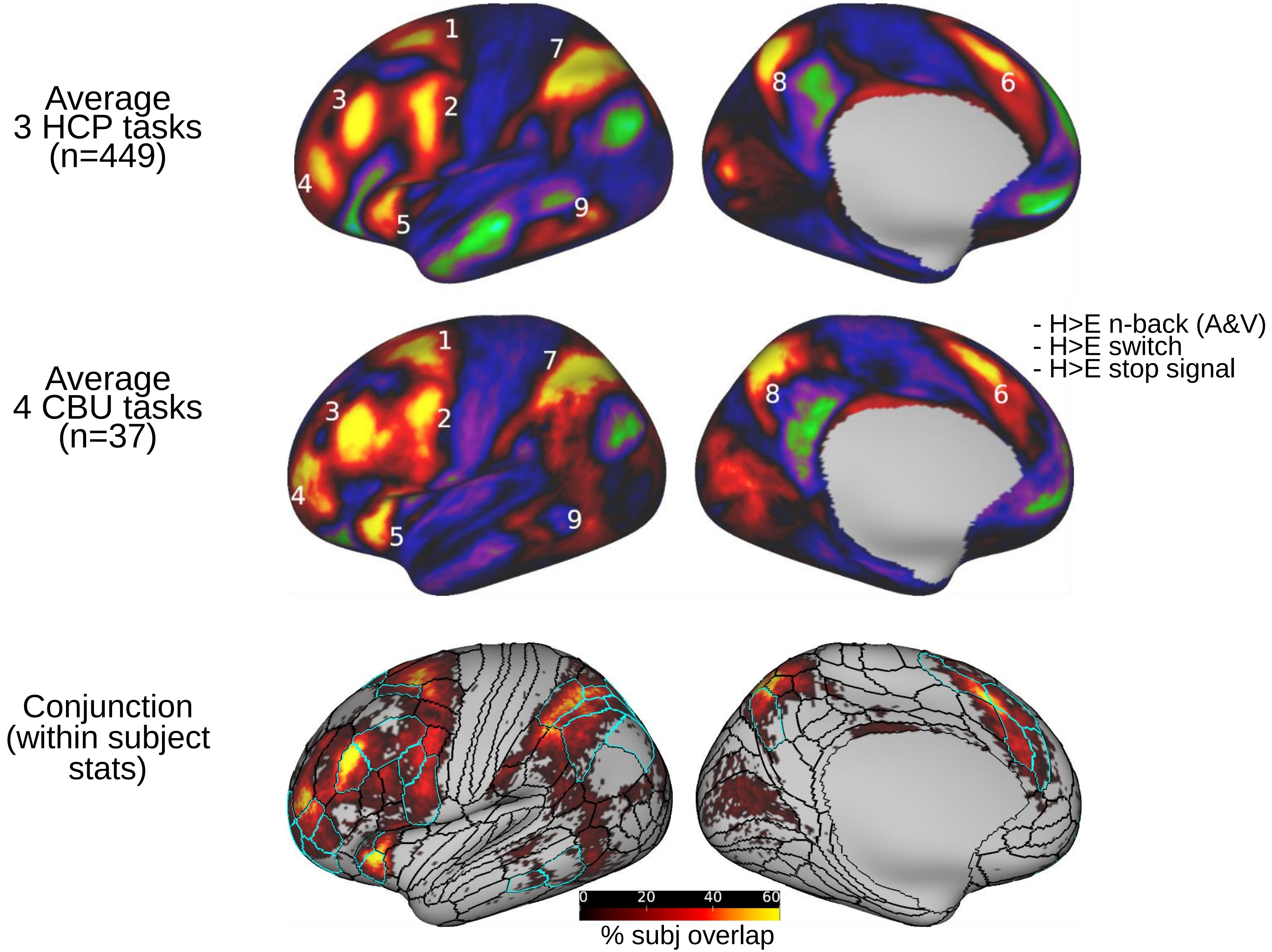
Relative functional preferences



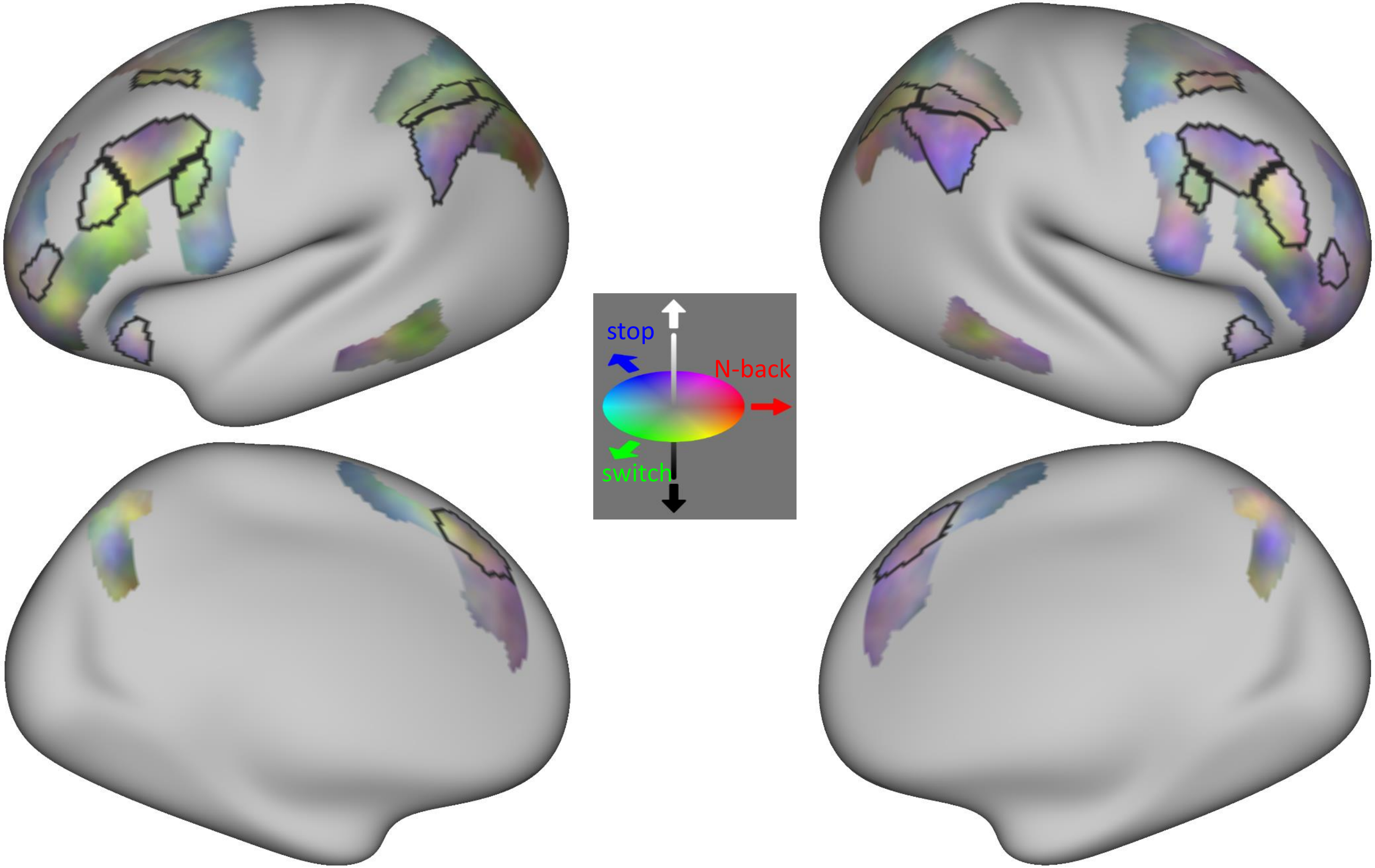


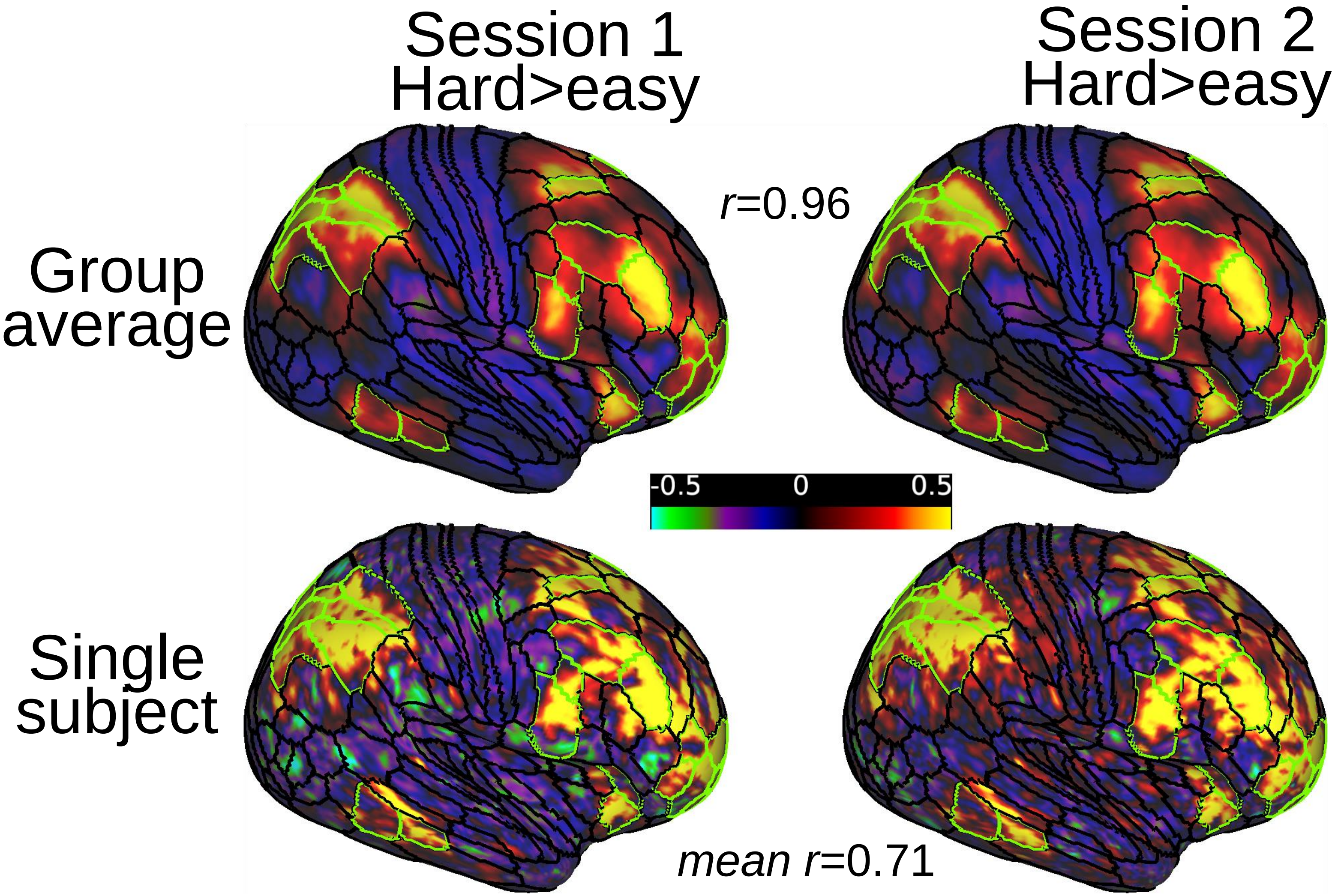


Assem et al (2020) Cerebral Cortex
Duncan et al. (2020) *TICS*



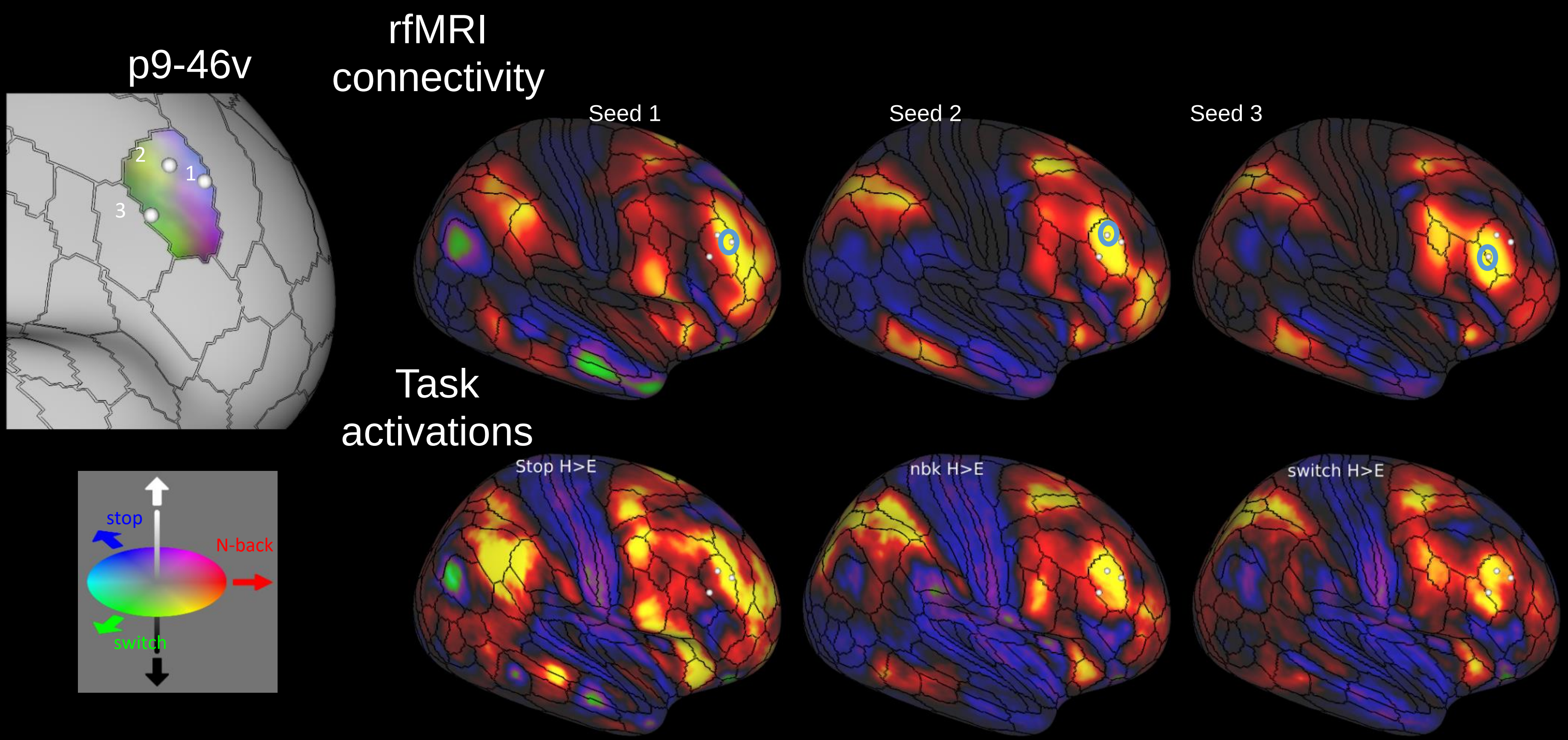
Average
3 HCP tasks
(n=449)
Average
4 CBU tasks
(n=37)
Conjunction
(within subject
stats)
1
2
3
4
5
6
7
8
9
- H>E n-back (A&V)
- H>E switch
- H>E stop signal
0
20
40
60
% subj overlap

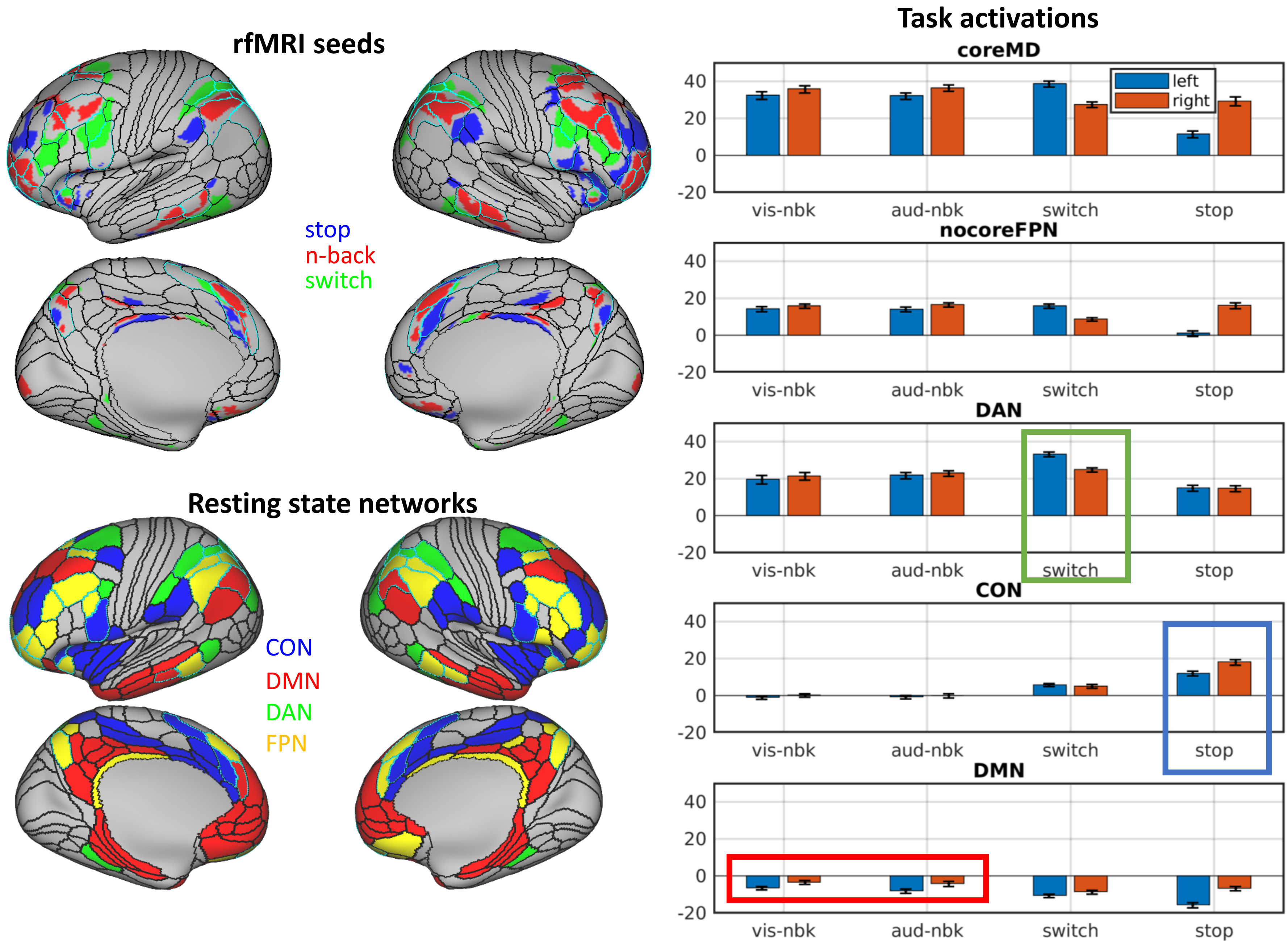

stop
N-back
switch



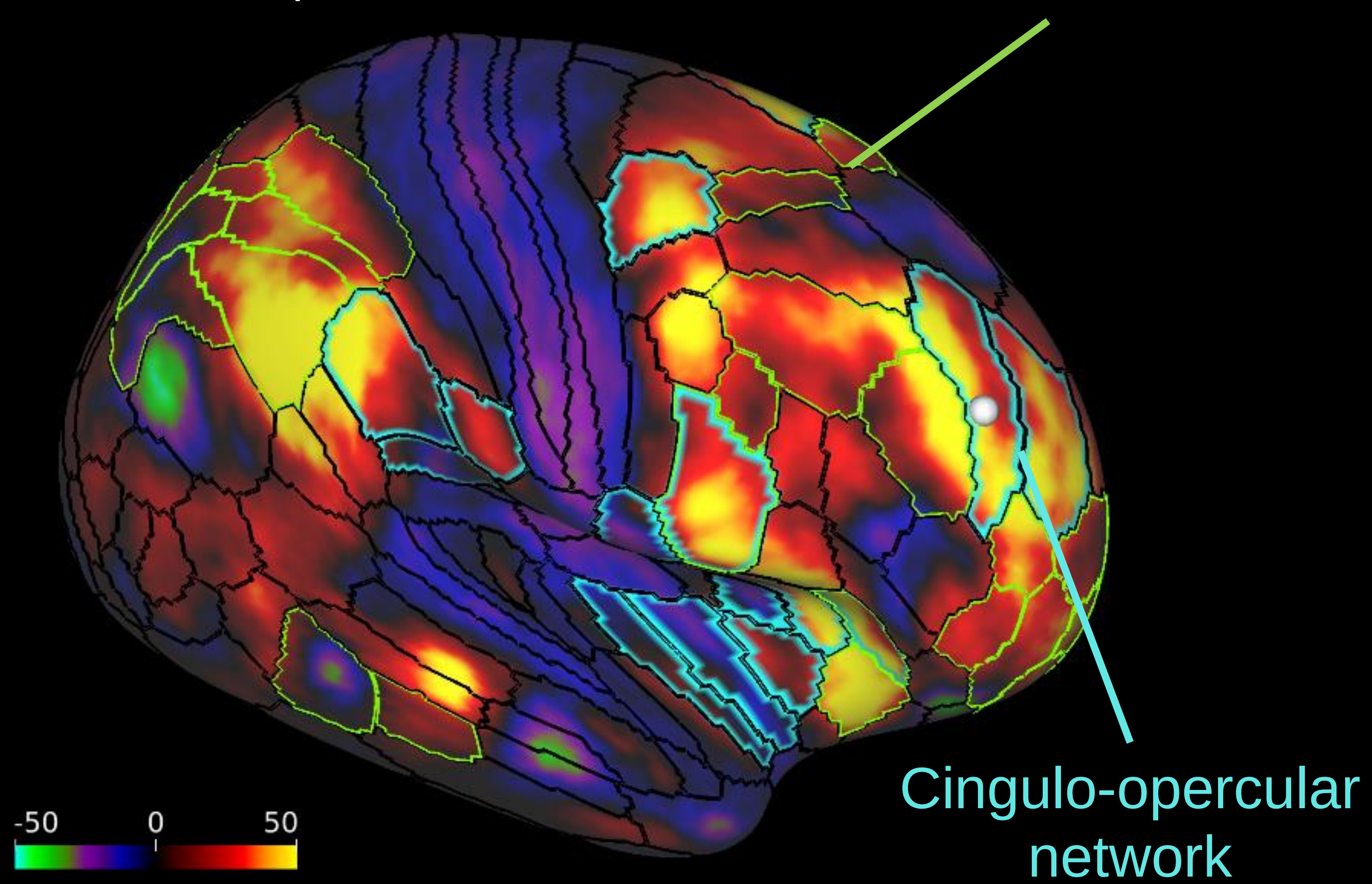
Assem et al (2022) cerebral cortex

Finer grained functional preferences

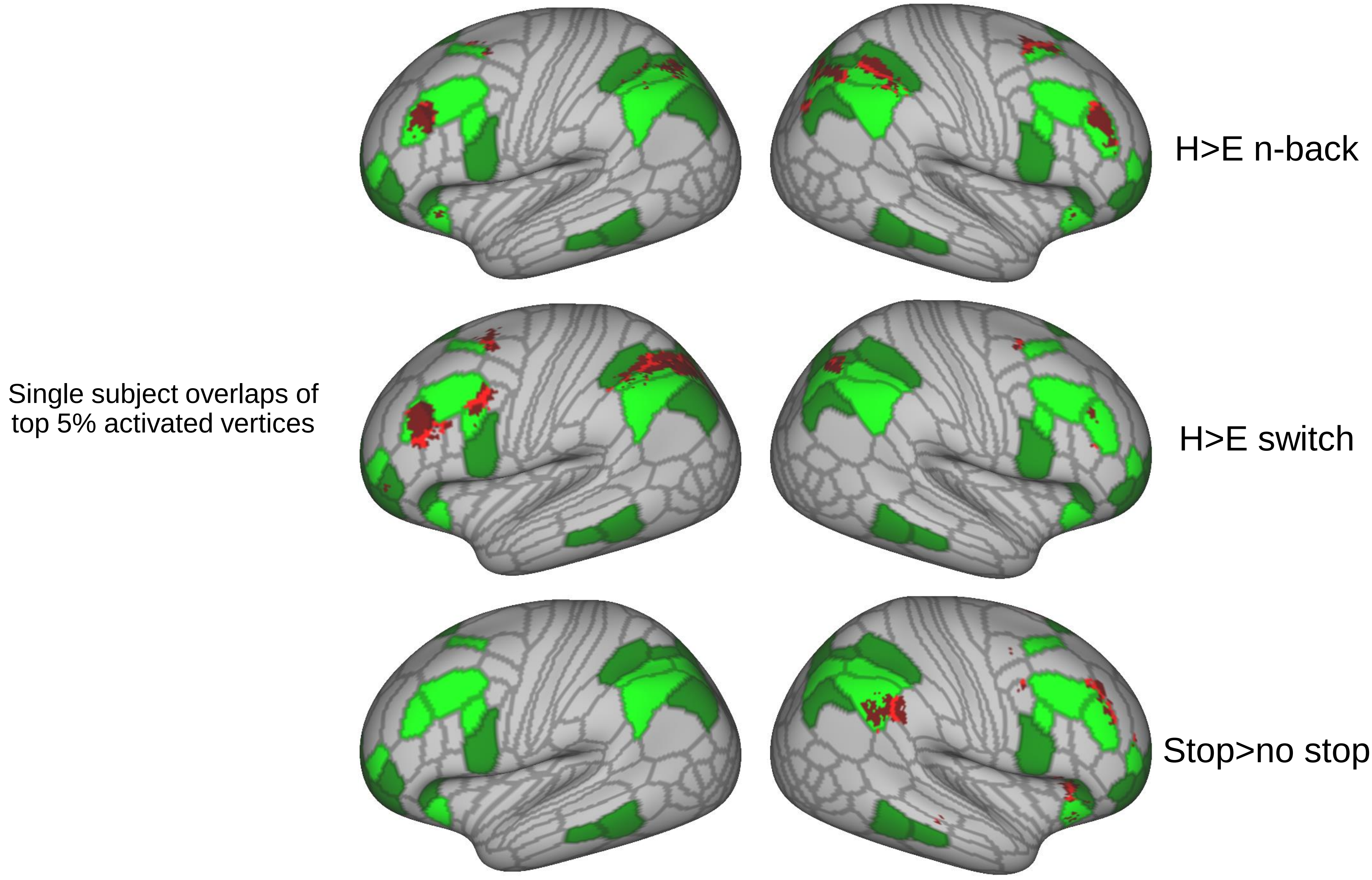


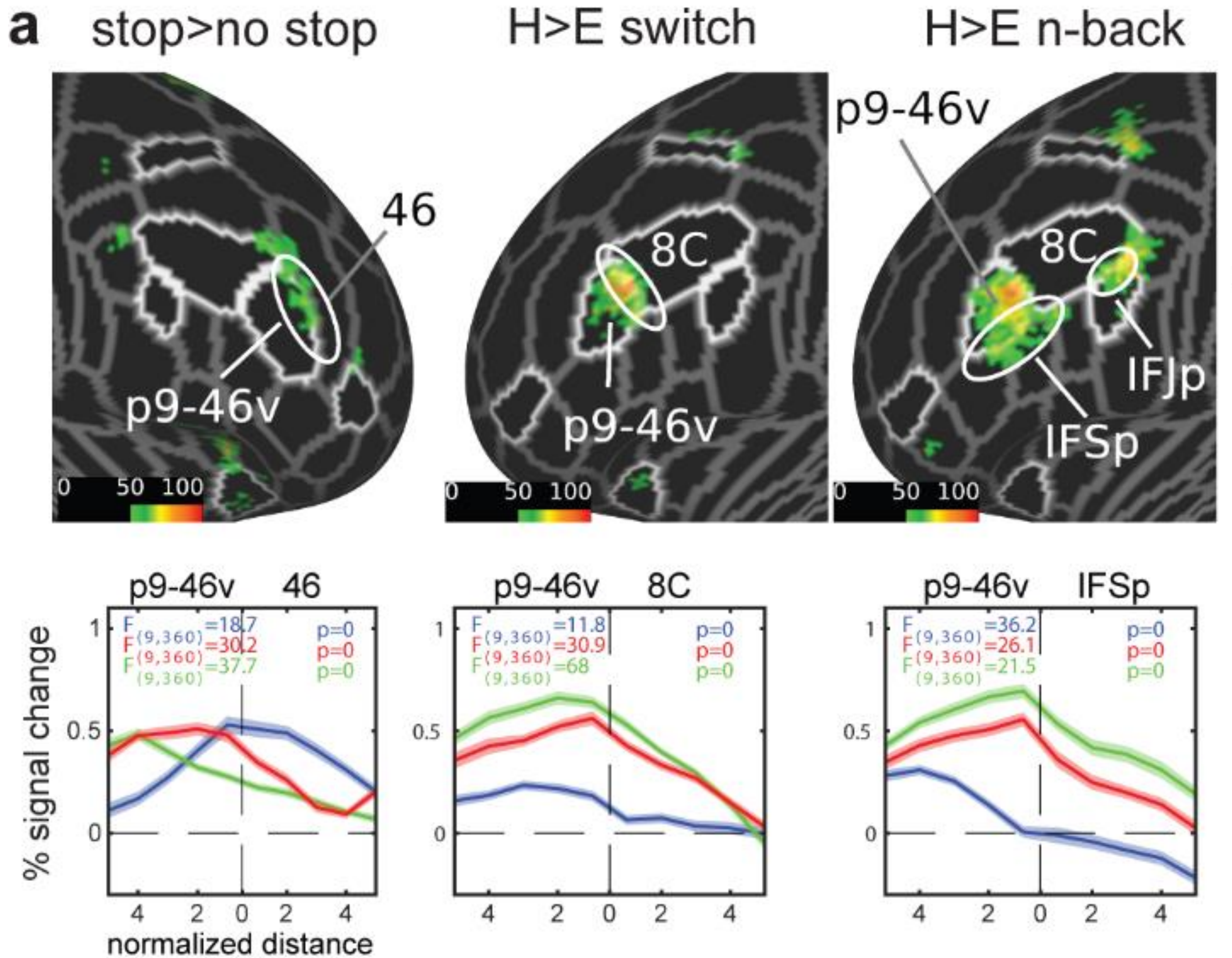

rfMRI seeds
stop
n-back
switch
Resting state networks
CON
DMN
DAN
FPN
Task activations
coreMD
left
right
nocoreFPN
DAN
CON
DMN
40
20
0
-20
vis-nbk
aud-nbk
switch
stop

Stop > no stop

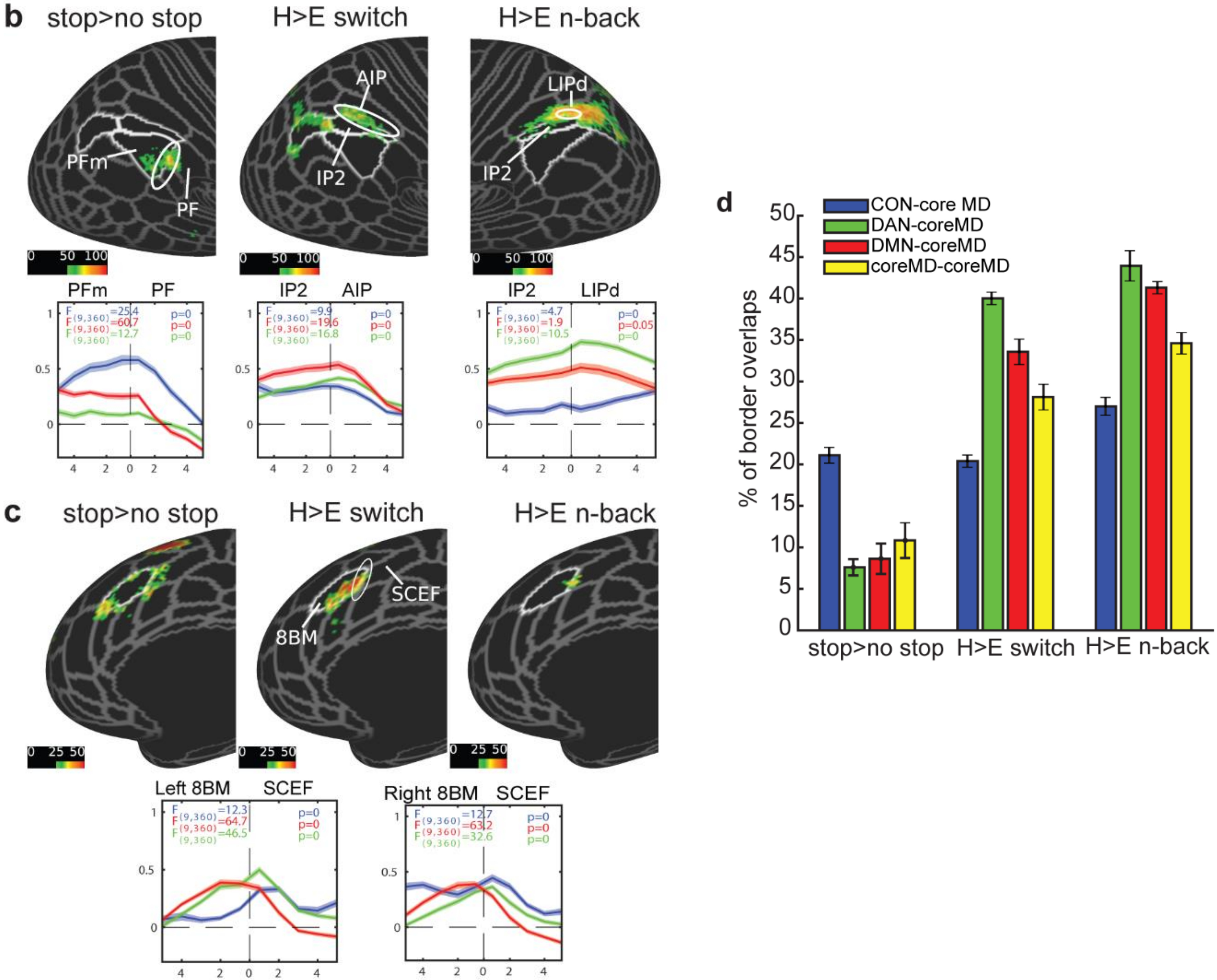


Task activations peak at core MD borders

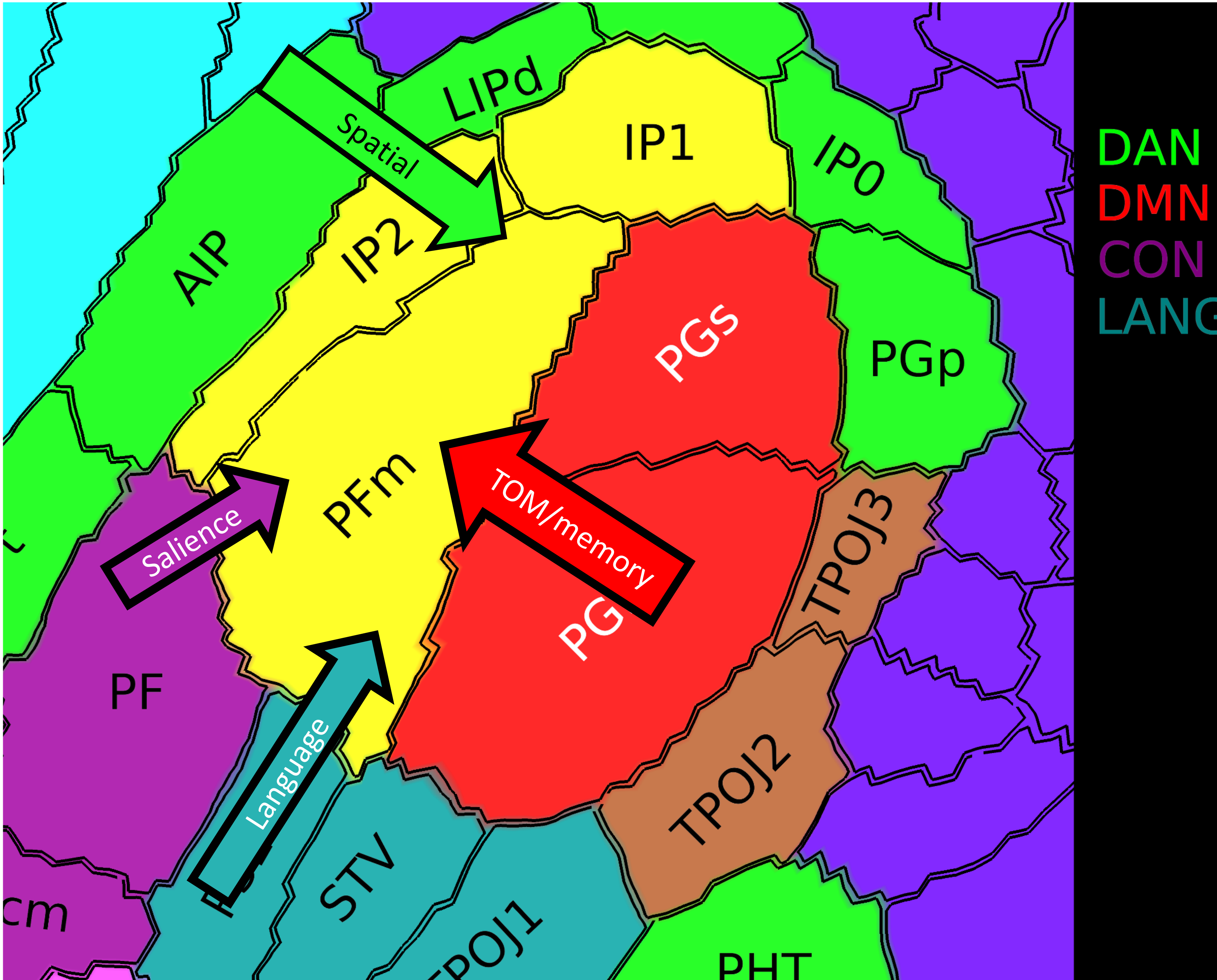




a
stop>no stop
H>E switch
H>E n-back
46
p9-46v
8C
p9-46v
p9-46v
8C
IFJp
IFSp
0 50 100
0 50 100
0 50 100
p9-46v 46
p9-46v 8C
p9-46v IFSp
$F_{(9,360)}$=18.7 p=0
$F_{(9,360)}$=30.2 p=0
$F_{(9,360)}$=37.7 p=0
$F_{(9,360)}$=11.8 p=0
$F_{(9,360)}$=30.9 p=0
$F_{(9,360)}$=68 p=0
$F_{(9,360)}$=36.2 p=0
$F_{(9,360)}$=26.1 p=0
$F_{(9,360)}$=21.5 p=0
% signal change
normalized distance



b
stop>no stop
H>E switch
H>E n-back
PFm
PF
AIP
IP2
LIPd
IP2
c
stop>no stop
H>E switch
H>E n-back
SCEF
8BM
Left 8BM
SCEF
Right 8BM
SCEF
d
CON-core MD
DAN-coreMD
DMN-coreMD
coreMD-coreMD
% of border overlaps
stop>no stop
H>E switch
H>E n-back


LIPd
IP1
IP0
AIP
IP2
Spatial
PGs
PGp
PFm
TOM/memory
Salience
PG
TPOJ3
PF
Language
TPOJ2
STV
TPOJ1
PHT
DAN
DMN
CON
LANG

9 MD patches

3 HCP tasks
(n=449)

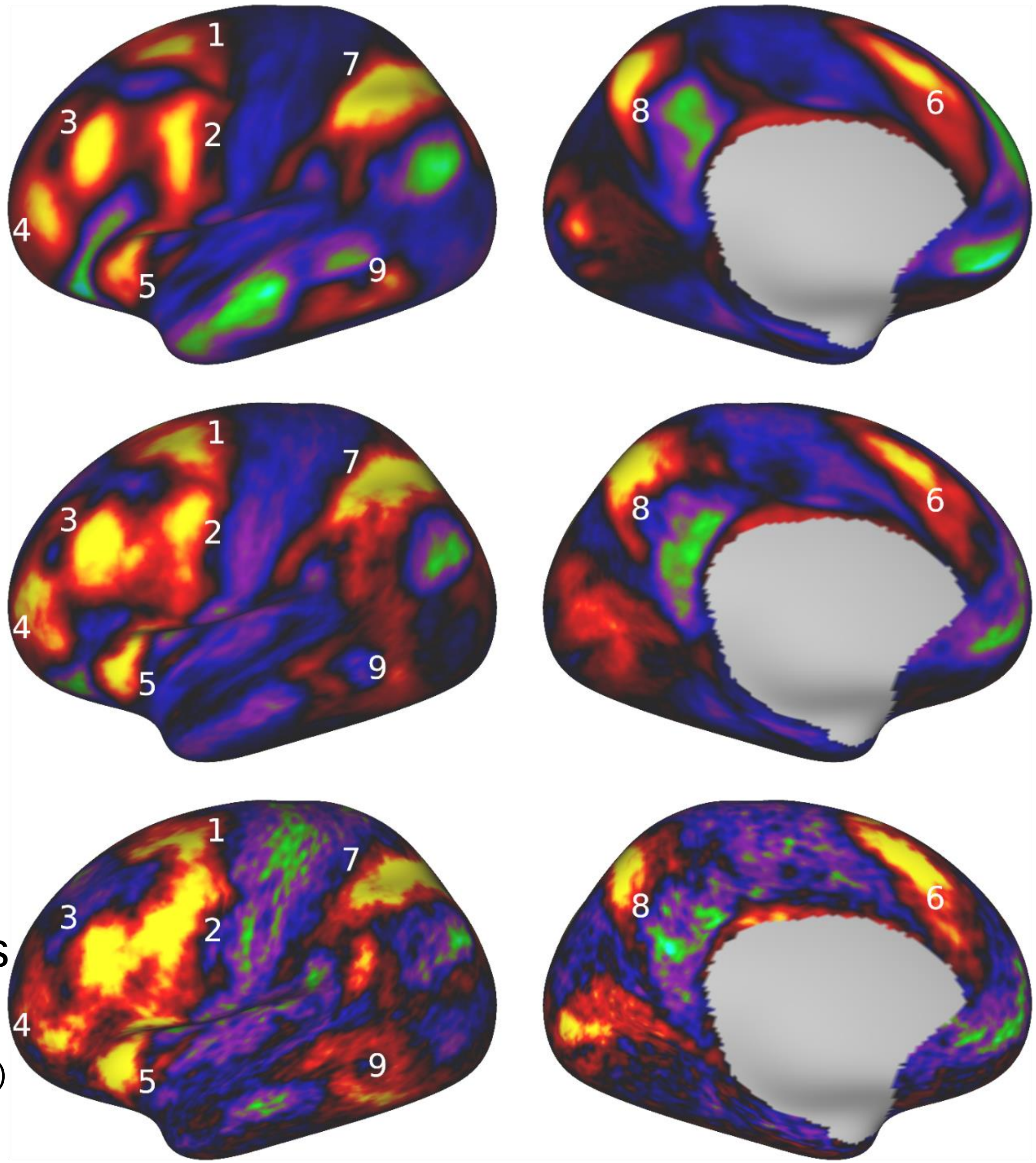
Assem et al 2020

4 CBU
exec tasks
(n=37)

Assem et al 2022
Assem et al (in prep)

5 CBU
Non-exec tasks
(n=15-20)

(Data collection on going)



H>E n-back (V)
H>E reasoning (V)
Math>story (A)

H>E n-back (A&V)
H>E switch (V)
Stop>no stop (V)

H>E language (A)
H>E memory (V)
H>E mental rotation (V)
H>E theory of mind (V)
H>E salience (V)

HCP approach

- Glasser et al (2016) **The Human Connectome Project's neuroimaging approach.** Nature Neuroscience
- Coalson et al (2018) **The impact of traditional neuroimaging methods on the spatial localization of cortical areas.** PNAS

Acquisition and Preprocessing pipelines

- Ugurbil et al (2013) **Pushing spatial and temporal resolution for functional and diffusion MRI in the Human Connectome Project.** Neuroimage
- Glasser et al (2016) **A multi-modal parcellation of human cerebral cortex.** Nature
- Glasser et al (2013) **The minimal preprocessing pipelines for the Human Connectome Project.** Neuroimage
- Salimi-Khorshidi (2014) **Automatic denoising of functional MRI data: Combining independent component analysis and hierarchical fusion of classifiers.** Neuroimage
- Griffanti et al (2017) **Hand classification of fMRI ICA noise components.** Neuroimage
- Glasser et al (2018) **Using temporal ICA to selectively remove global noise while preserving global signal in functional MRI data**. Neuroimage
- Robinson et al (2018) **Multimodal surface matching with higher-order smoothness constraints.** Neuroimage
- Robinson et al (2014) **MSM: A new flexible framework for Multimodal surface matching.** Neuroimage
- HCP courses: https://store.humanconnectome.org/courses/2019/exploring-the-human-connectome.php

HCP resting state and task data

- Barch et al (2013) **Function in the human connectome: Task-fMRI and individual differences in behaviour**. Neuroimage

Analysing legacy data in HCP style

- Dickie et al (2019) **ciftify: A framework for surface-based analysis of legacy MR acquisitions.** Neuroimage
- Also check latest HCP pipelines github page

Neurobiologically informed cortical parcellation

- Van Essen & Glasser (2018**) Parcellating cerebral cortex: How invasive animal studies inform noninvasive mapmaking in humans.** Neuron

Using HCP to precisely image the MD system

- Assem et al (2020) **A Domain-General Cognitive Core Defined in Multimodally Parcellated Human Cortex.** Cerebral Cortex
- Duncan et al (2020) **Integrated intelligence from distributed brain activity.** Trends in Cognitive Sciences
- Assem et al (2022) **Precise Topology of Adjacent Domain-General and Sensory-Biased Regions in the Human Brain.** Cerebral Cortex
- Assem et al (bioRxiv preprint soon) **The unity and diversity of executive functions explained by fine-grained intrinsic architecture of cortical and subcortical brain networks.**

Acknowledgments

HCP team (Wash. U. in St louis)

- Matthew F. Glasser
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CBU

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- Gavin Shields (ongoing data collection)
- MRI methods and IT teams

UKRI

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