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

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Cognitive control/ executive function

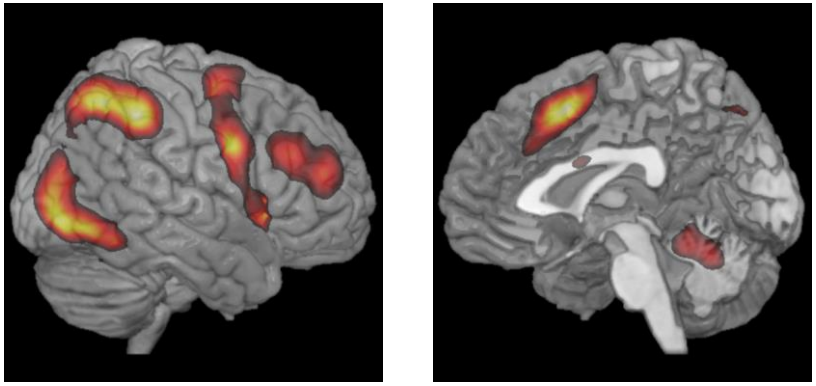
Wisconsin card-sorting: attentional shifting

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

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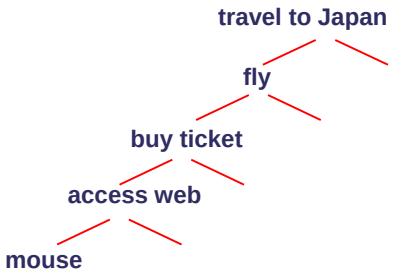
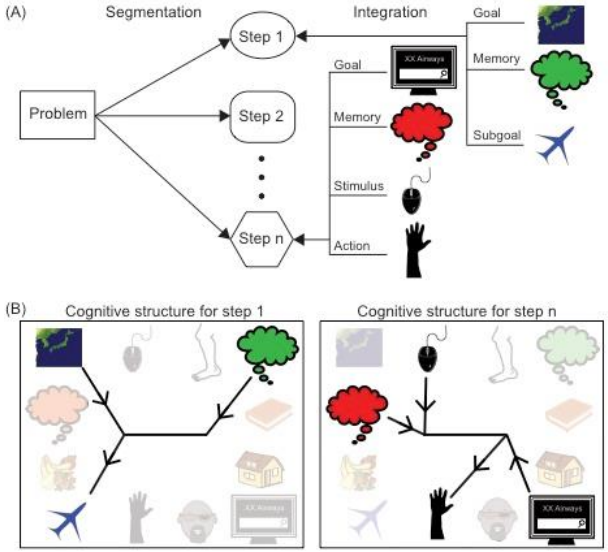




“attentional integration” – the core of cognitive control

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

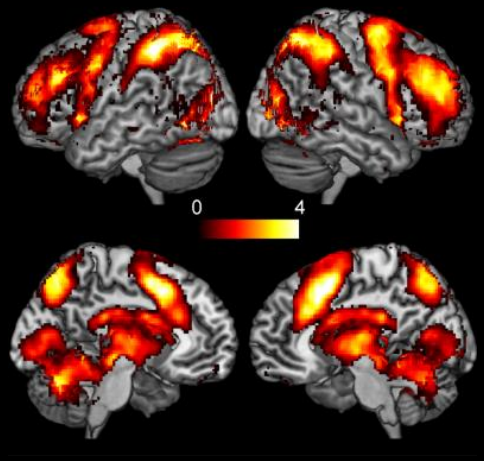
with traditional methods, precision is too low to tell

what happens when precision increases?

Multiple-demand system

Yet no consensus on:

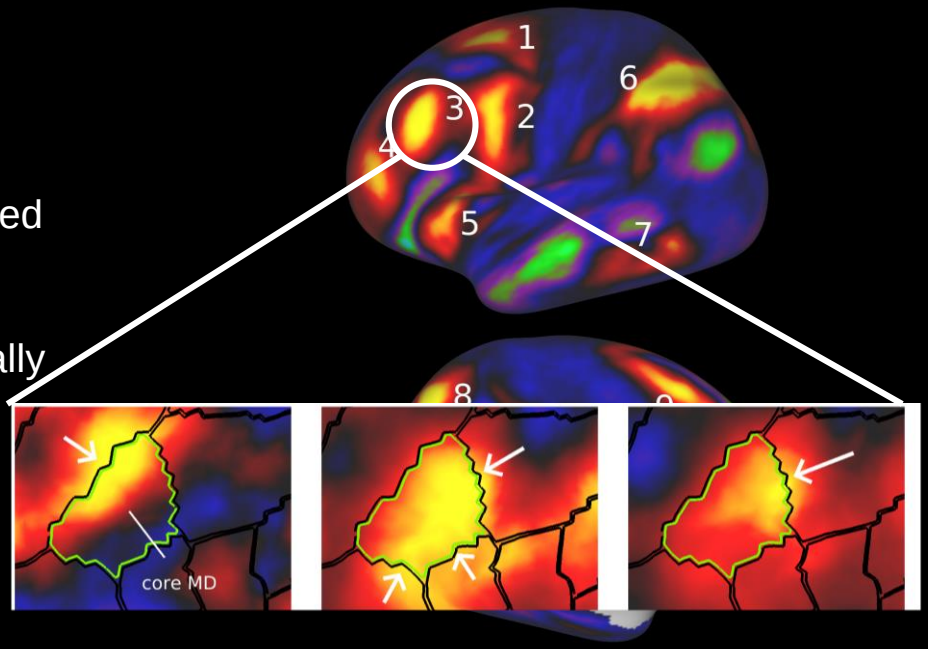
- Functional preferences
- Precise location
- Connectivity profile



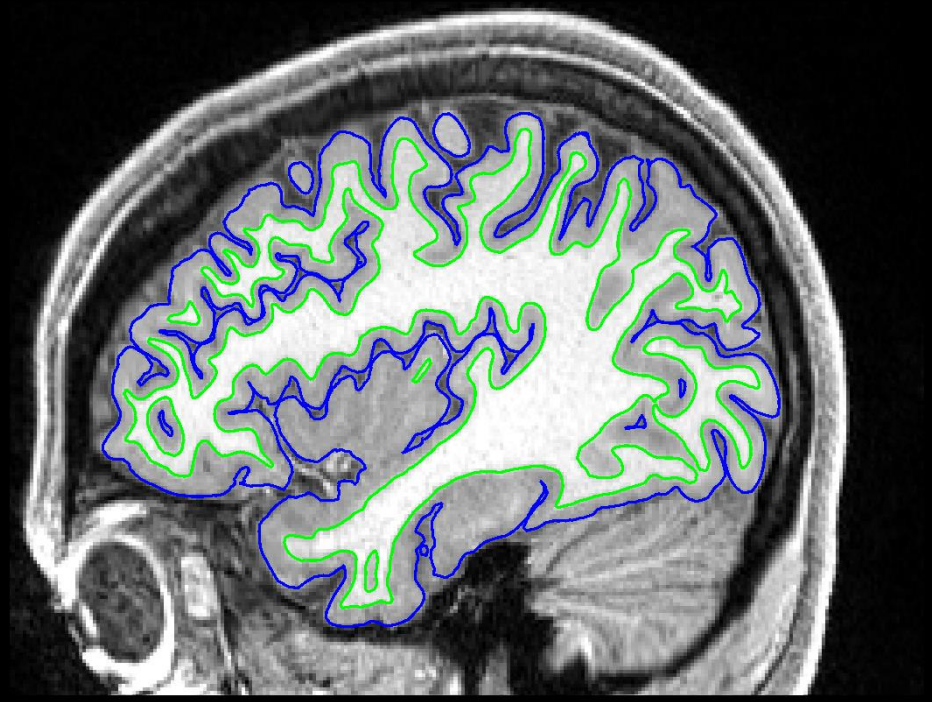
Human Connectome Project neuroimaging approach

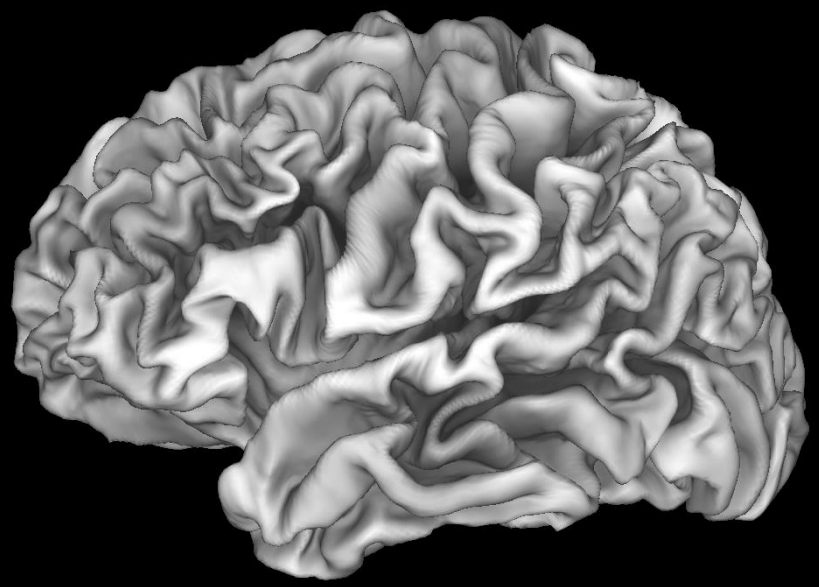
Three main methodological advances:

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



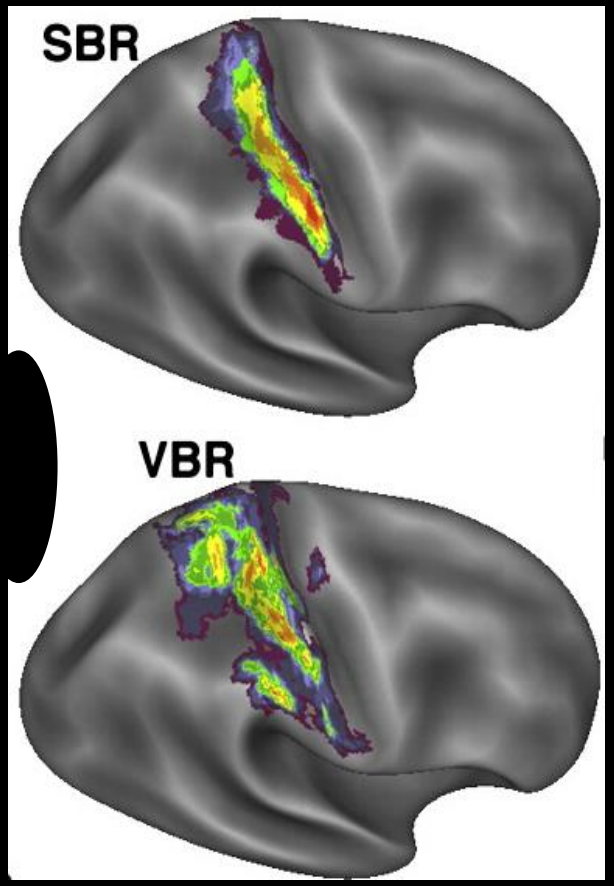
The cortex is a folded 2D sheet



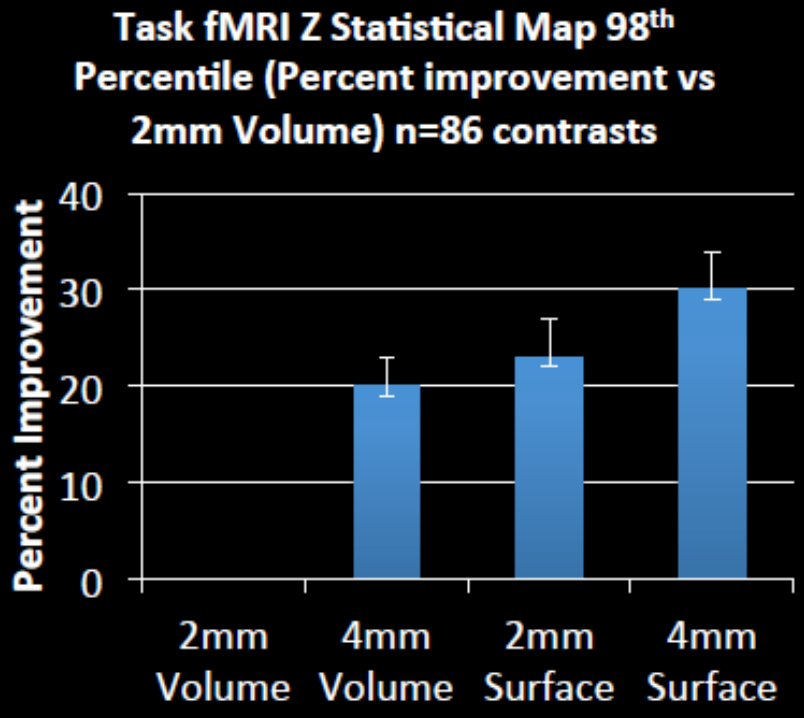


Example subject from HCP-style data scanned at CBU

Surface-based approaches significantly outperform volumetric approaches



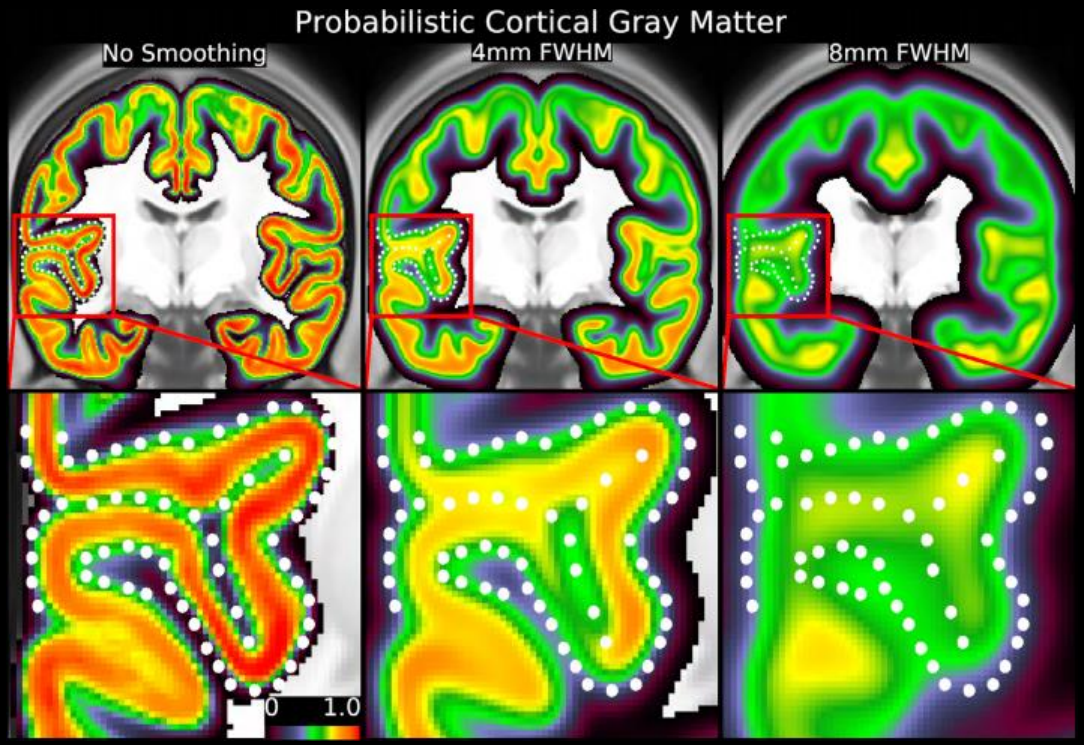
Van Essen D.C. (2012)
NeuroImage



HCP course slides 2017

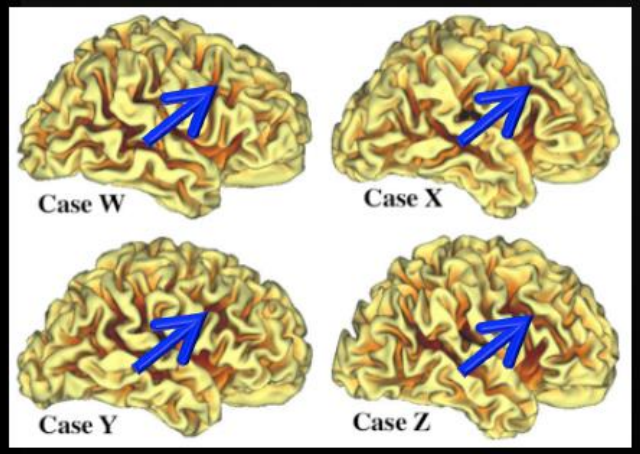
Unconstrained volumetric smoothing

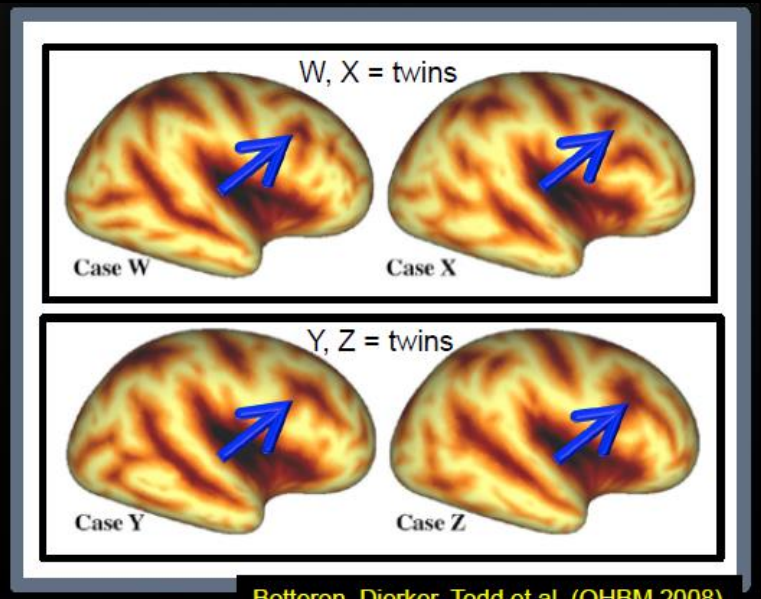
- Unconstrained spatial smoothing



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

- Heavy reliance on cortical folding patterns for inter-subject alignment





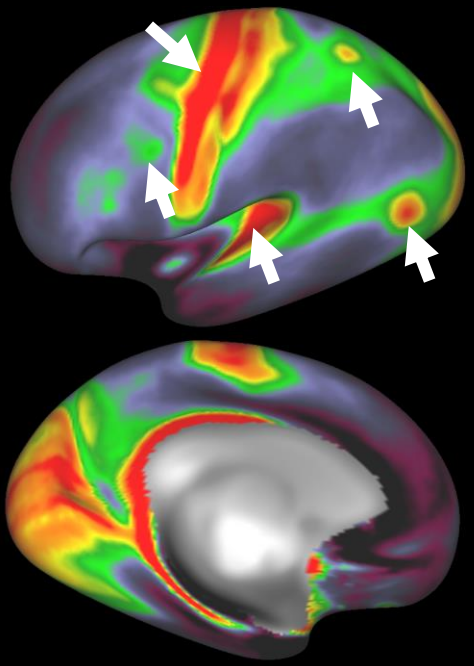
Botteron, Dierker, Todd et al. (OHBM 2008)

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

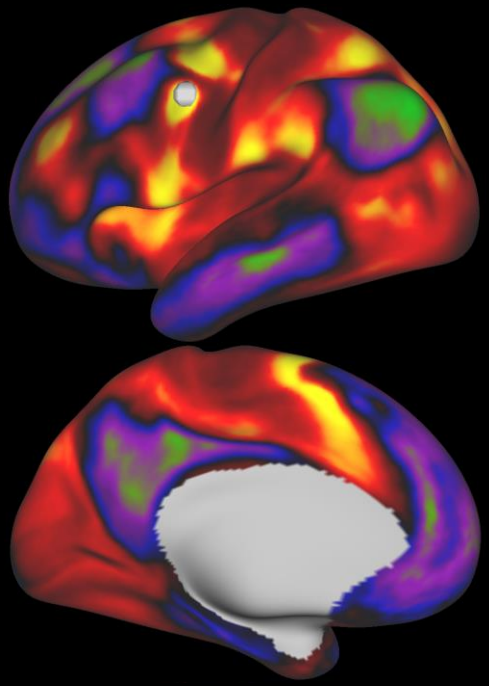
From 2017 HCP course

Areal feature-based surface registration

Myelin Map
T1w/T2w

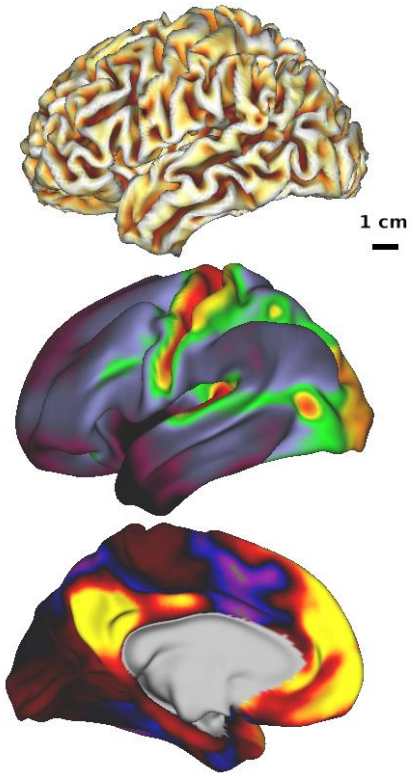


fMRI connectivity maps



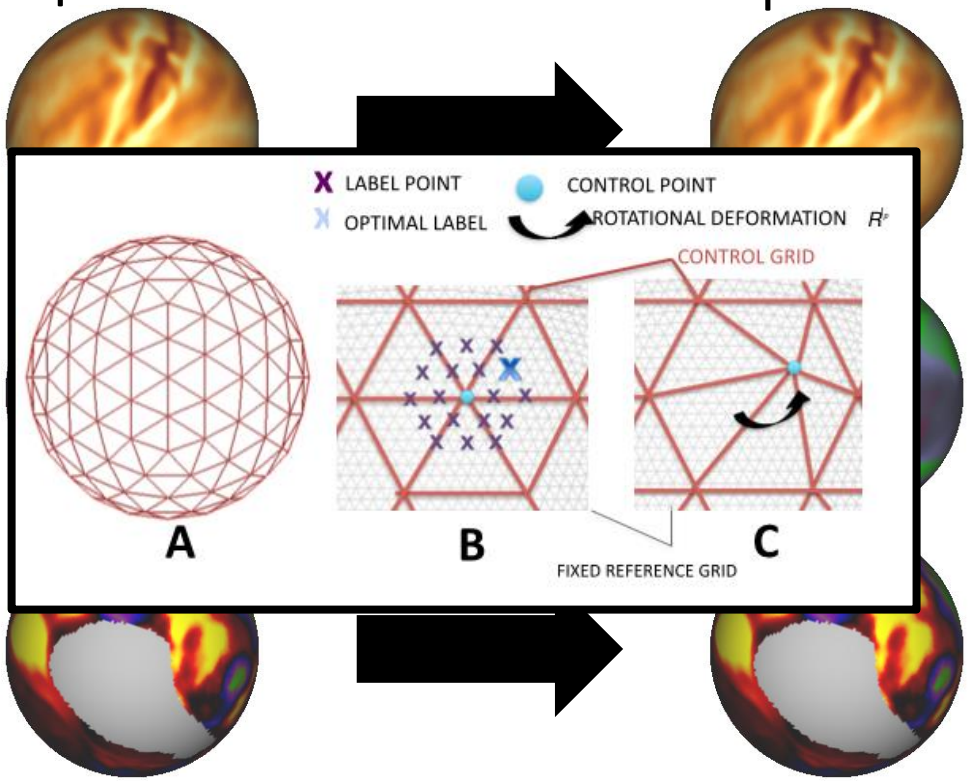
Glasser & Van Essen (2011)

Multimodal surface matching



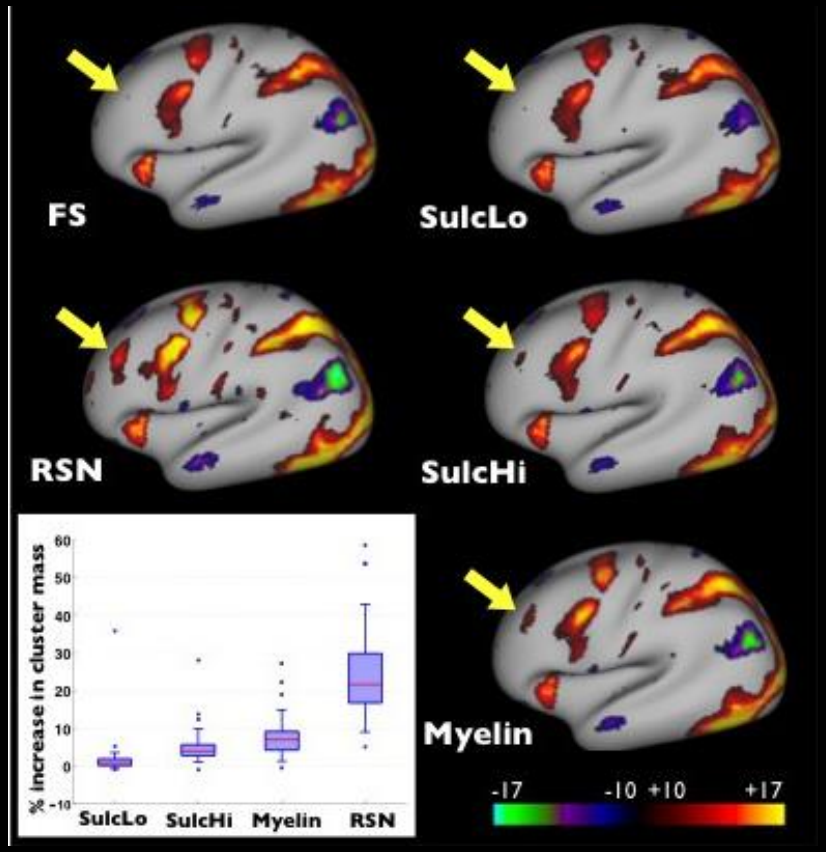
Moving sphere

Target sphere



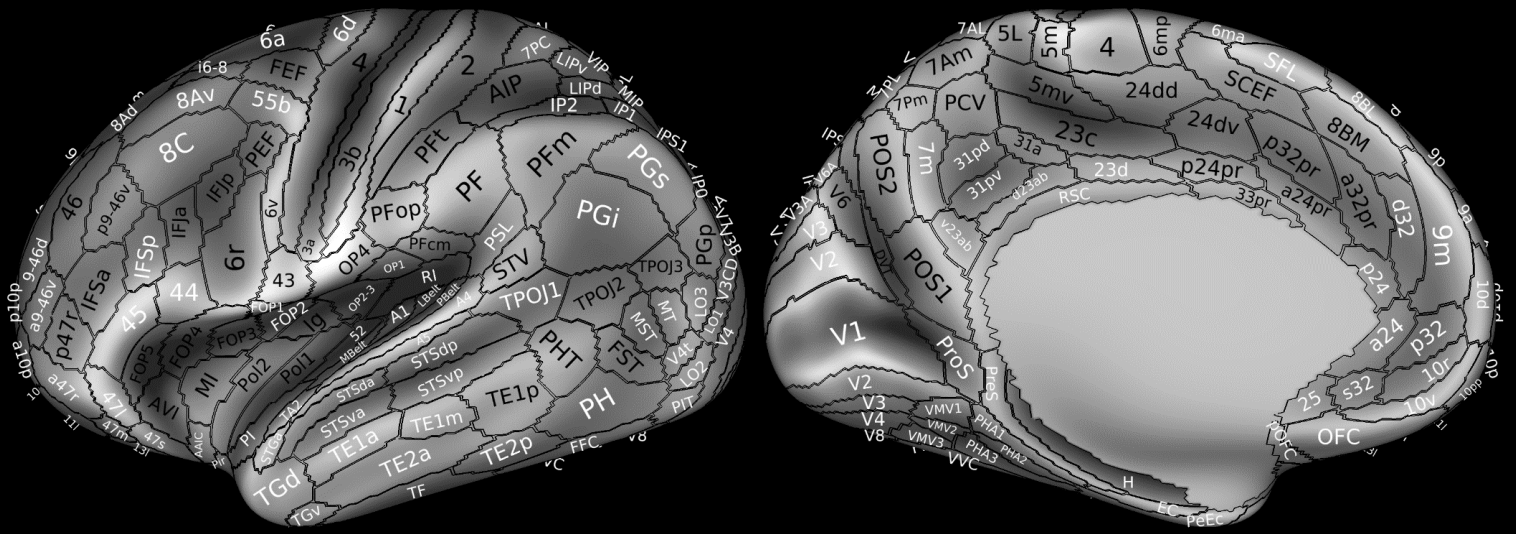
Robinson et al (2014 & 2018) *NeuroImage*

Multimodal Surface Matching (MSM)



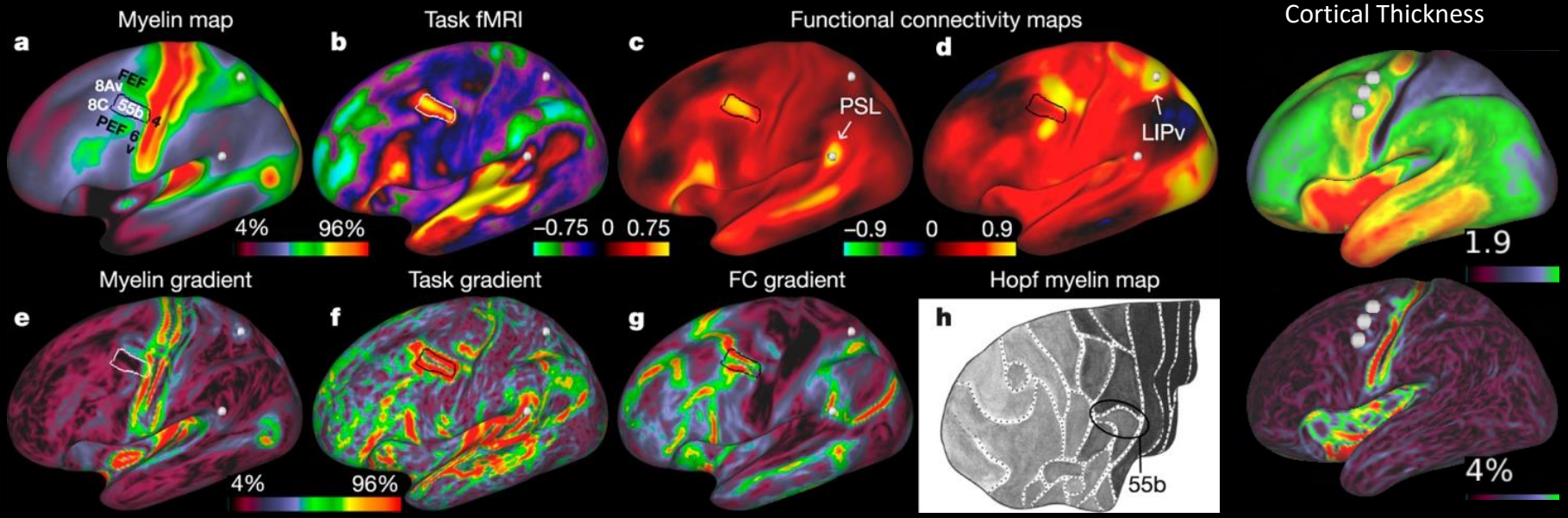
Robinson et al (2014 & 2018) *NeuroImage*

HCP MMP 1.0

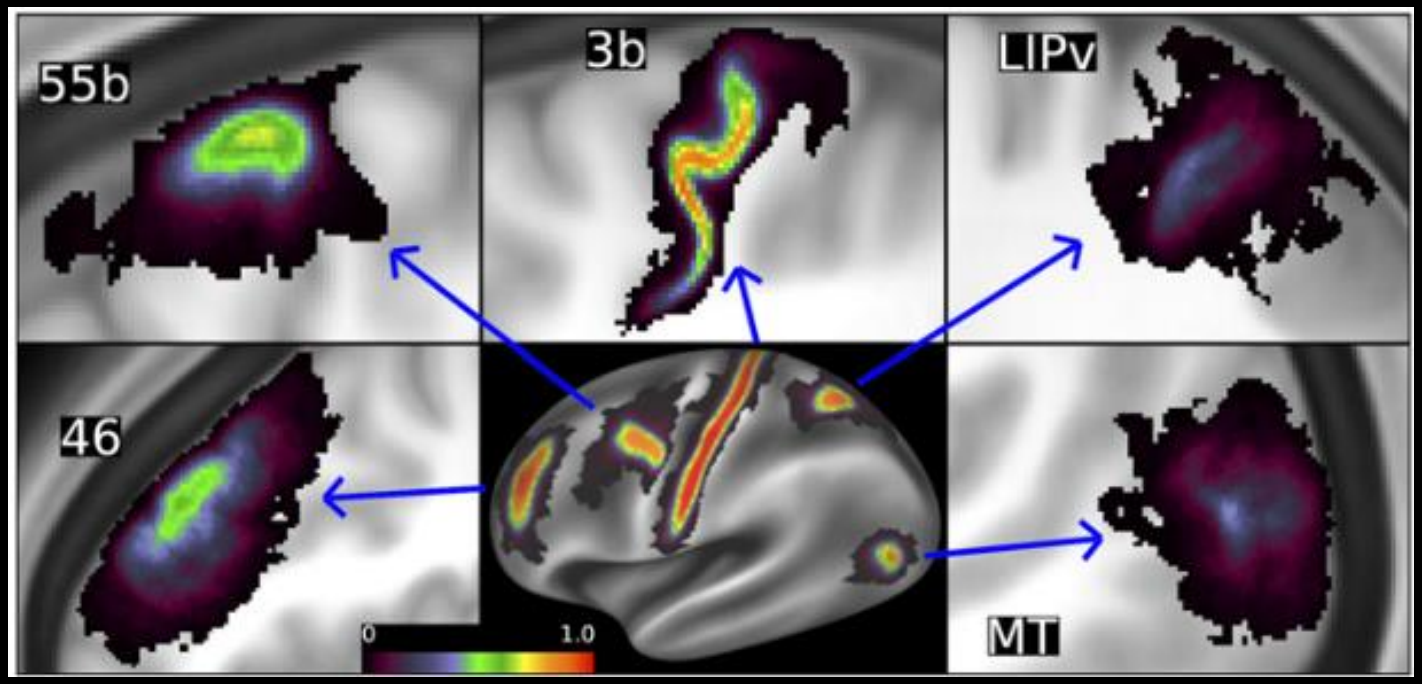


Glasser et al. (2016) *Nature*

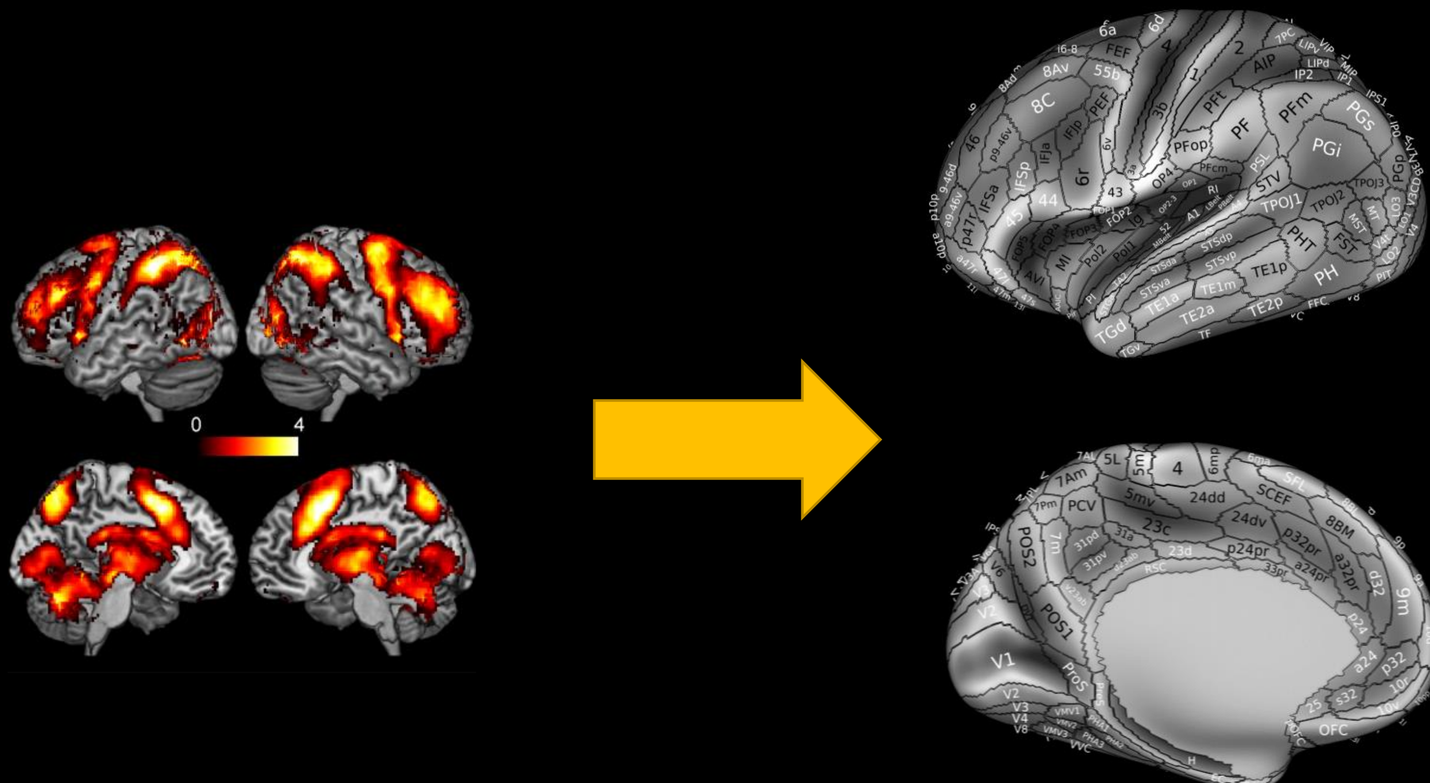
Multi-modal parcellation



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

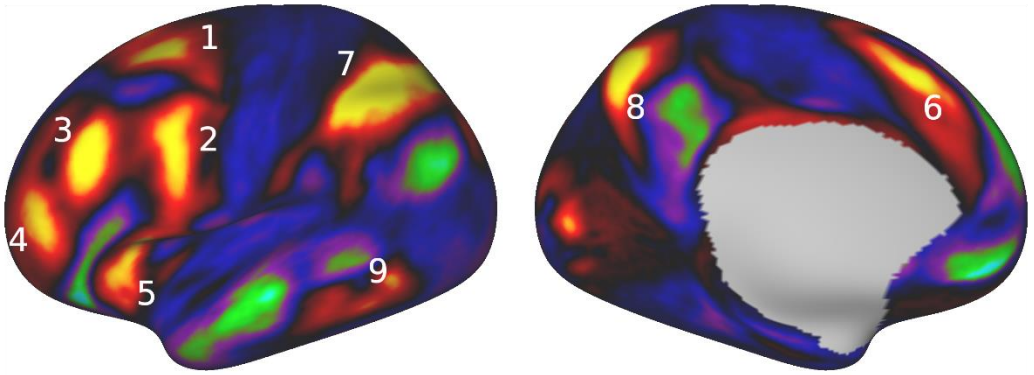


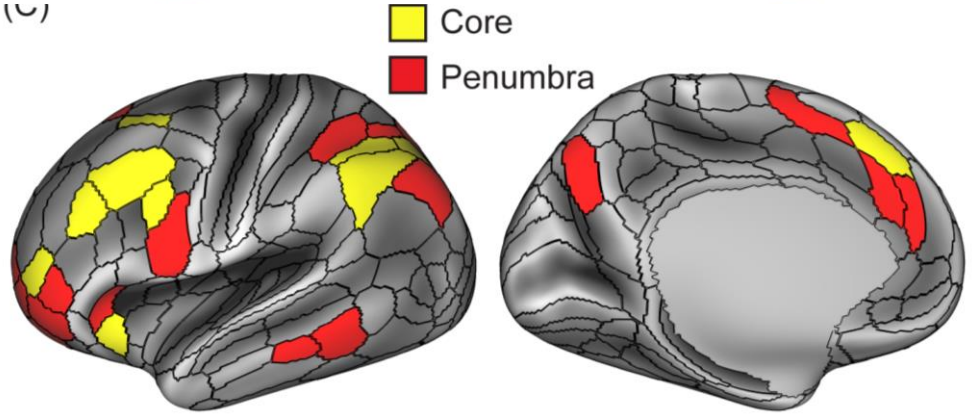
0
4
6a
6d
FEF
55b
8Av
8C
4
2
1
3b
AIP
PFt
PF
PFm
PGs
PGi
PFop
46
IFSa
IFSp
IFJa
IFJp
PEF
6r
44
45
43
OP4
STV
TPOJ1
TPOJ2
TPOJ3
PHT
FST
PH
TE1p
TE1a
TE1m
TE2a
TE2p
TGd
STSdp
STSvp
STSva
A1
MI
AVI
PoI1
PoI2
FOP2
FOP3
5L
5m
4
6mp
7Am
7Pm
PCV
5mv
24dd
SCEF
SFL
8BM
24dv
23c
p32pr
a32pr
d32
9m
23d
p24pr
a24pr
p24
a24
p32
10r
s32
25
OFC
31pd
31pv
31a
RSC
7m
POS2
POS1
ProS
V1
V2
V3
V4
V6
V8
VMV1
VMV3
VVC
H

Extended MD system

Average of 3 HCP contrasts (n=449)

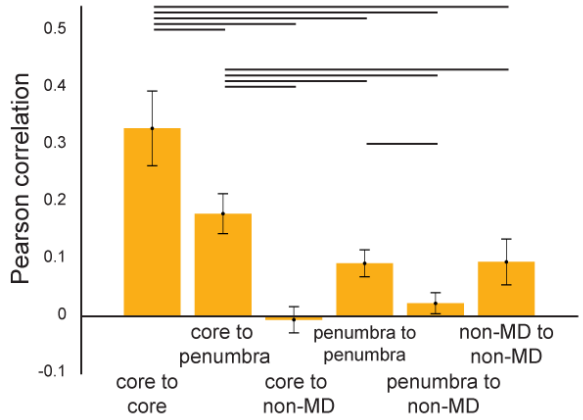
- Hard>easy working memory
- Hard>easy reasoning
- Math>story





Conjunction of 3 HCP contrasts

rfMRI connectivity

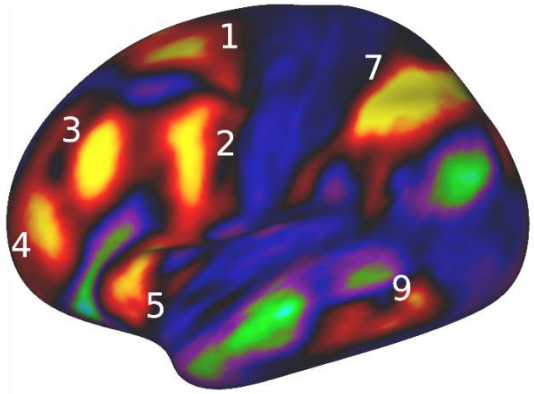


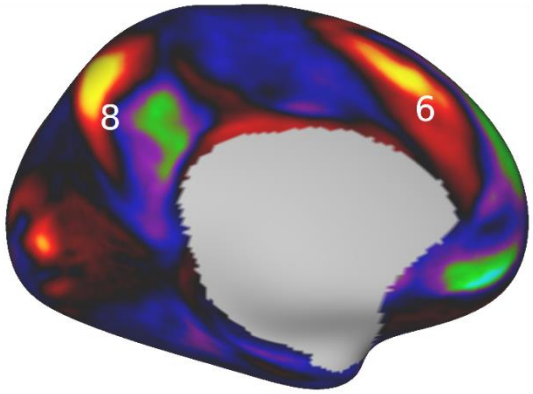
Assem et al (2020) Cerebral Cortex

9 MD patches

3 HCP tasks
(n=449)

Assem et al 2020

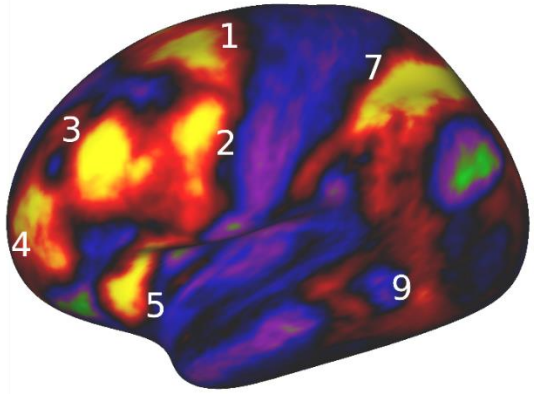


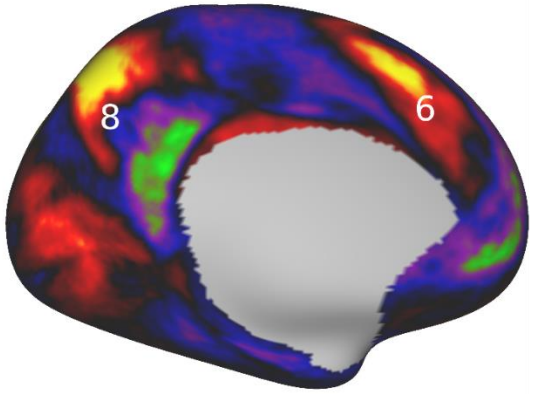


H>E n-back (V)
H>E reasoning (V)
Math>story (A)

4 CBU
exec tasks
(n=37)

Assem et al 2021
Assem et al (in prep)

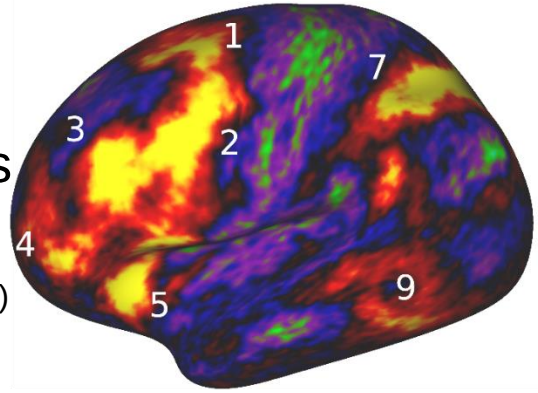


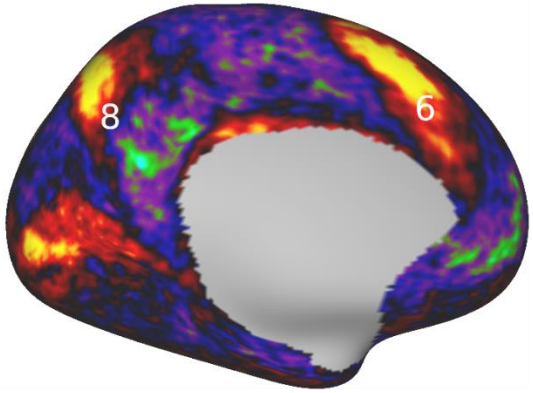


H>E n-back (A&V)
H>E switch (V)
Stop>no stop (V)

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

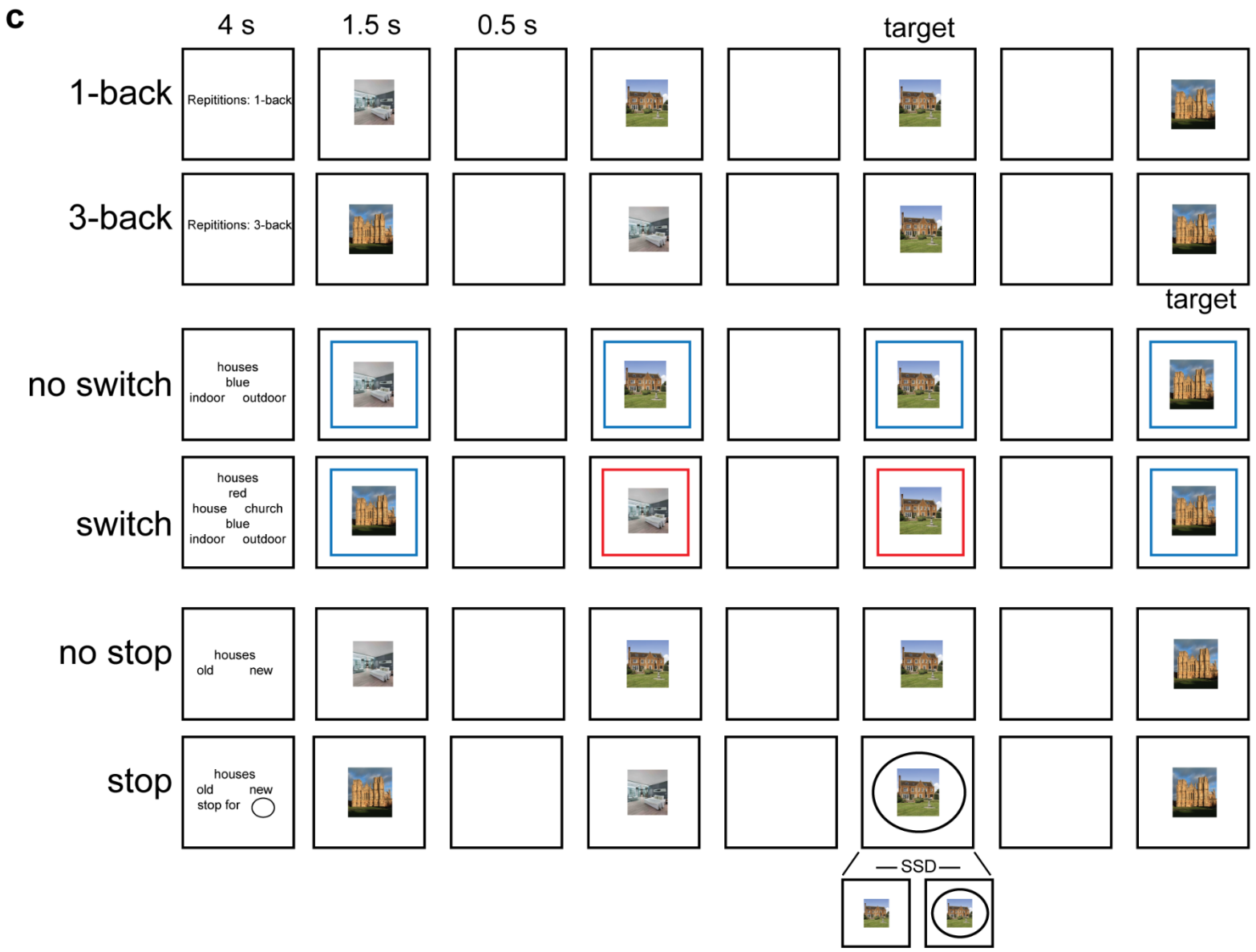
(Data collection on going)





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

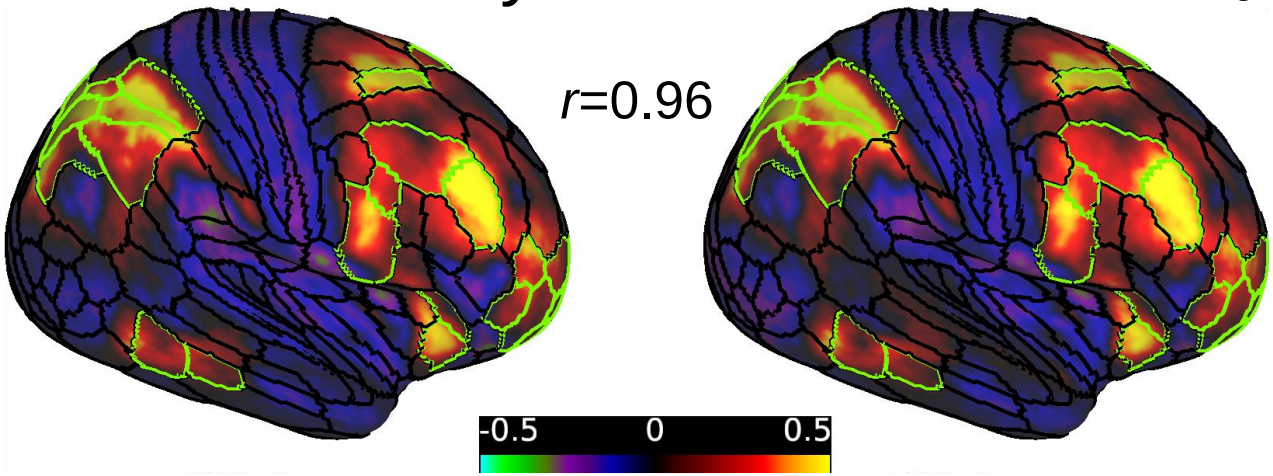
Executive tasks



Session 1
Hard>easy

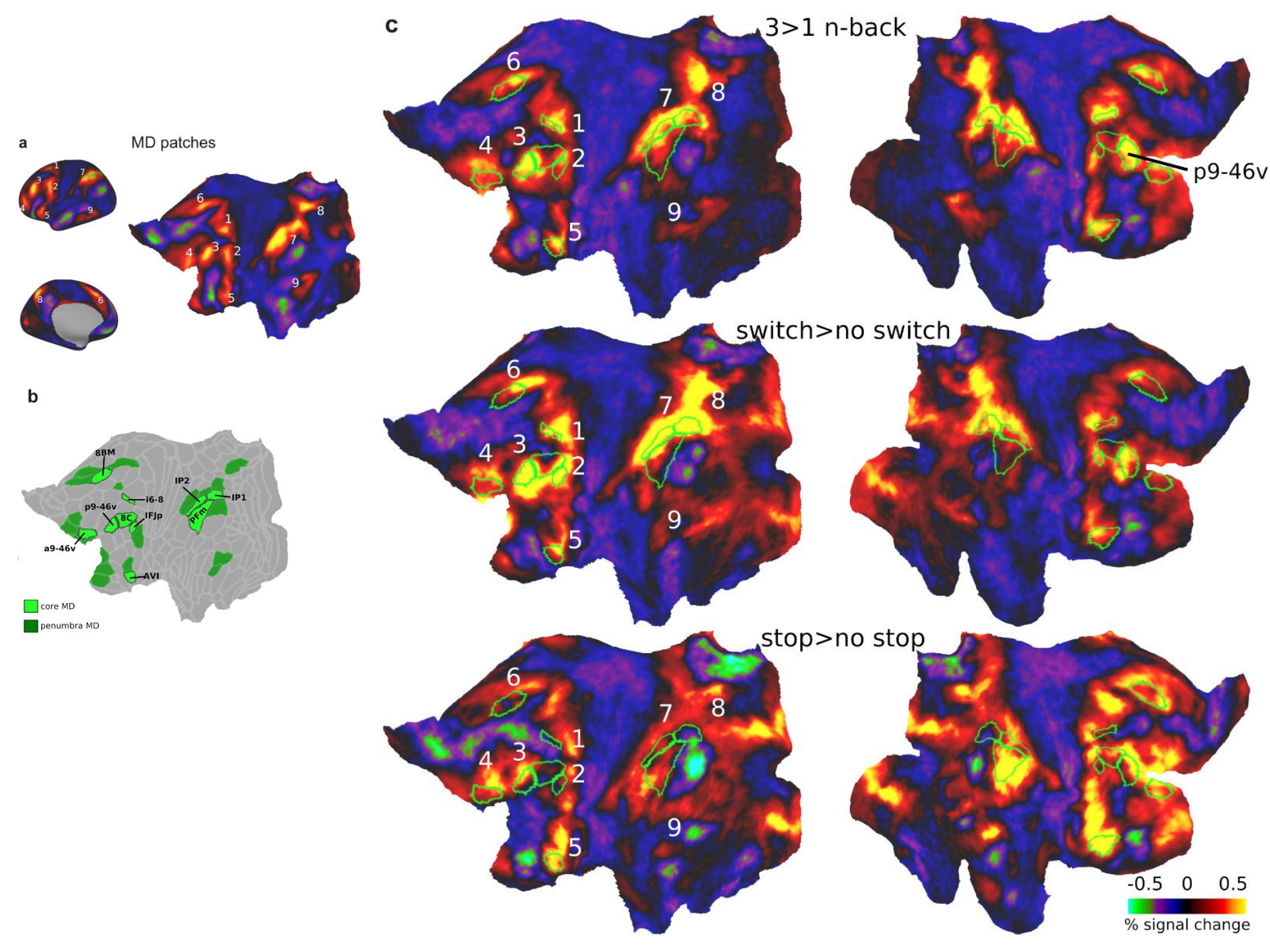
Session 2
Hard>easy

Group average

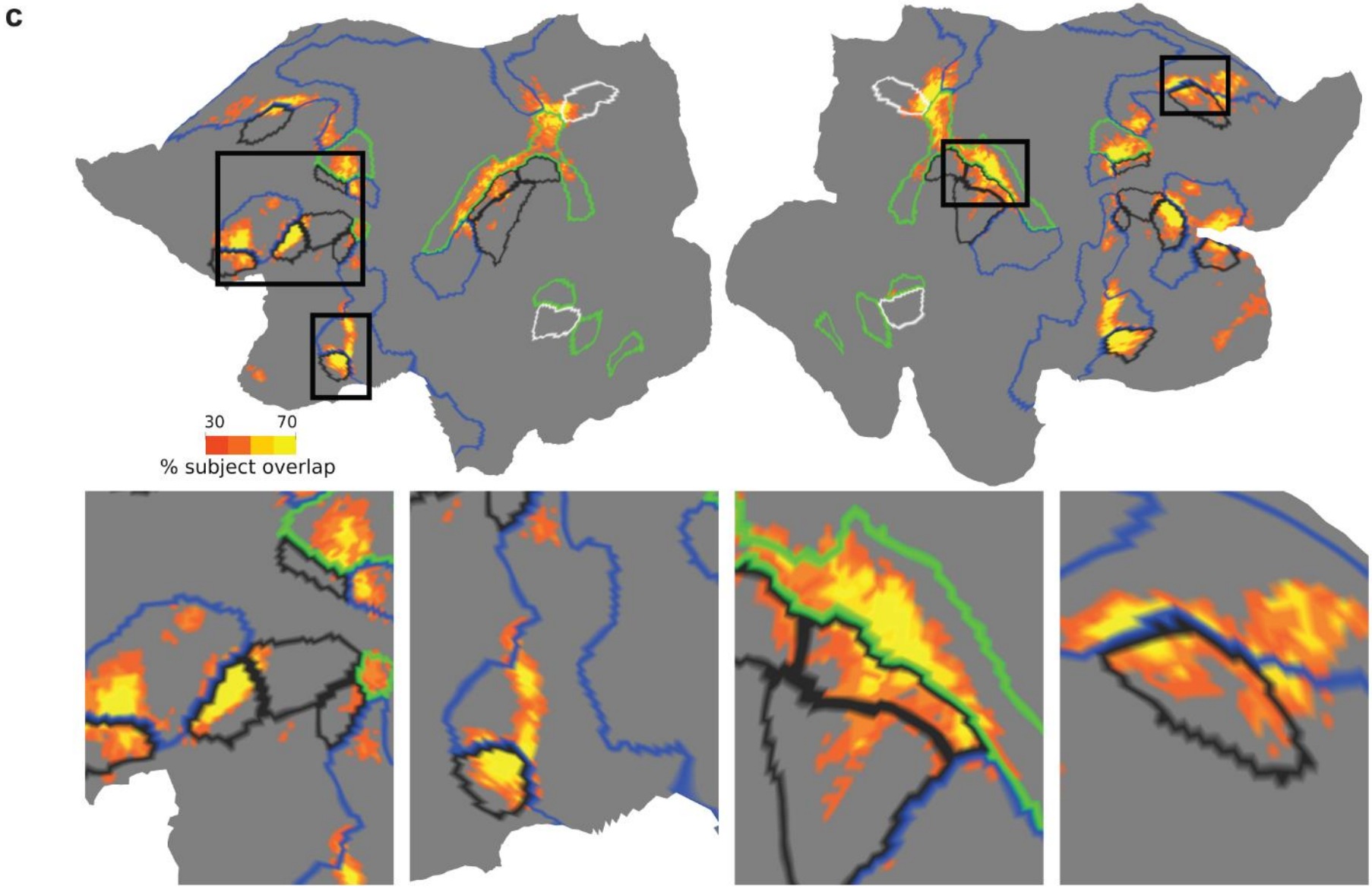


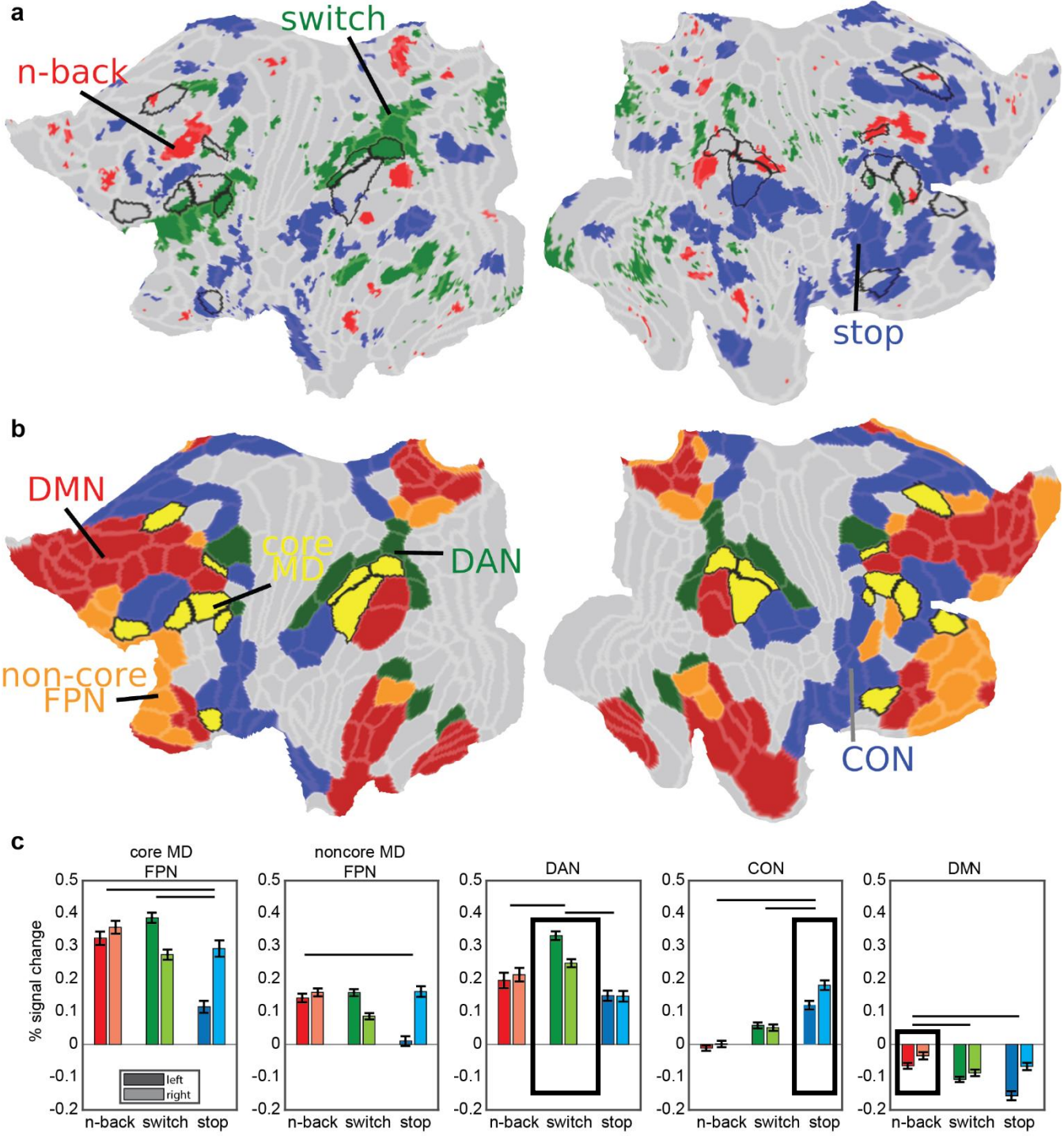
mean r=0.71

Assem et al (2022) cerebral cortex

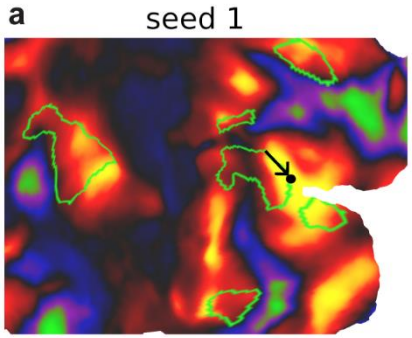

a
MD patches
b
8BM
IP2
IP1
i6-8
p9-46v
8C
IFJp
PFm
a9-46v
AVI
core MD
penumbra MD
c
3>1 n-back
p9-46v
switch>no switch
stop>no stop
-0.5 0 0.5
% signal change

Unity: vertex-level

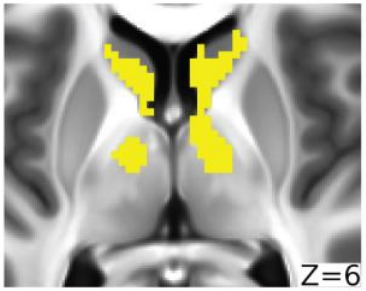


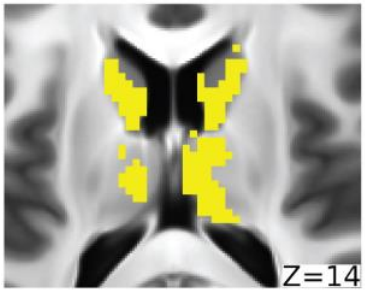

a
n-back
switch
stop
b
DMN
core MD
DAN
non-core FPN
CON
c
core MD FPN
noncore MD FPN
DAN
CON
DMN
% signal change
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
left
right
n-back switch stop

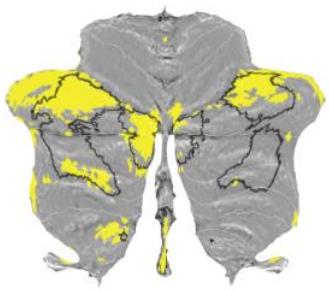
Fine-grained connectivity

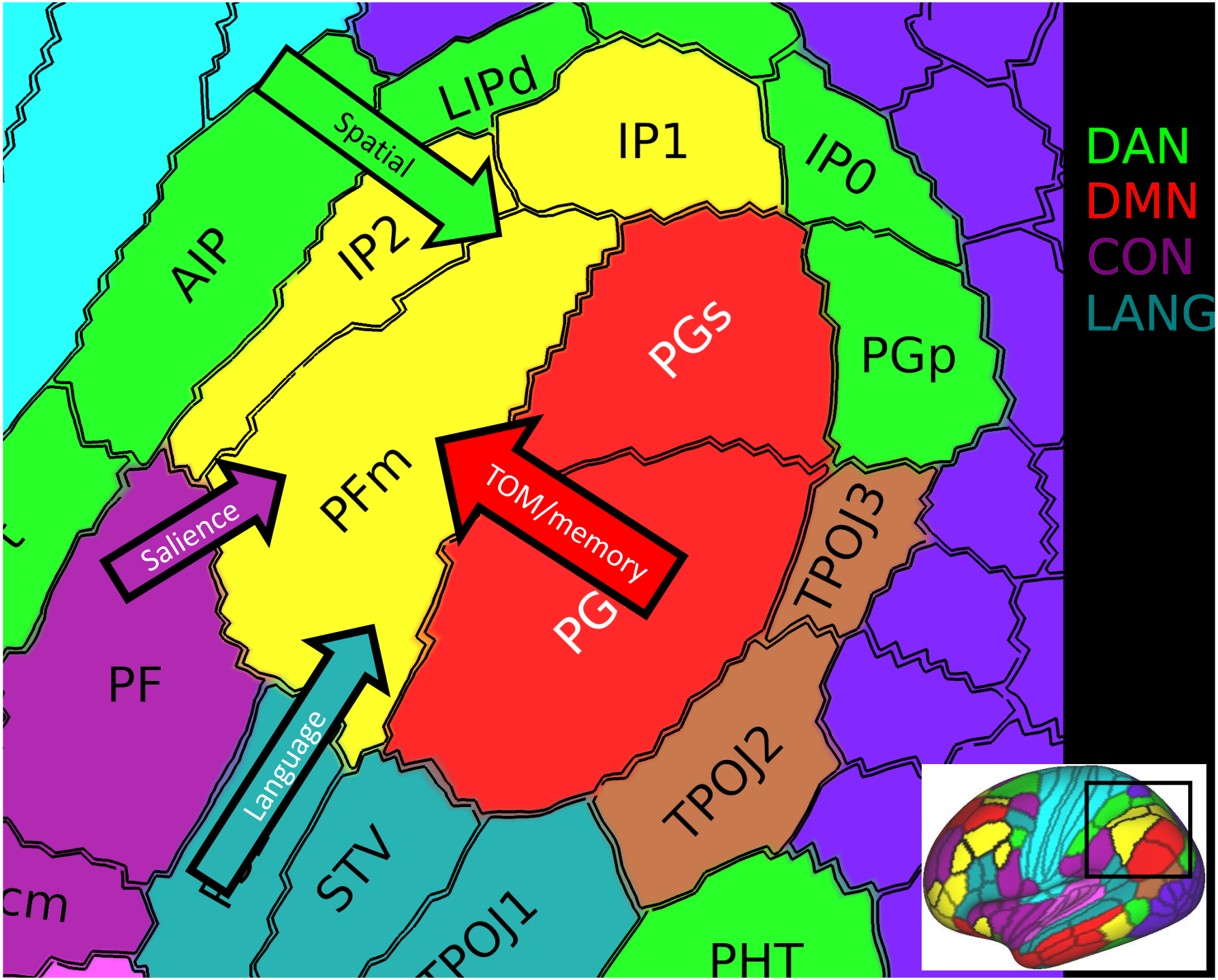


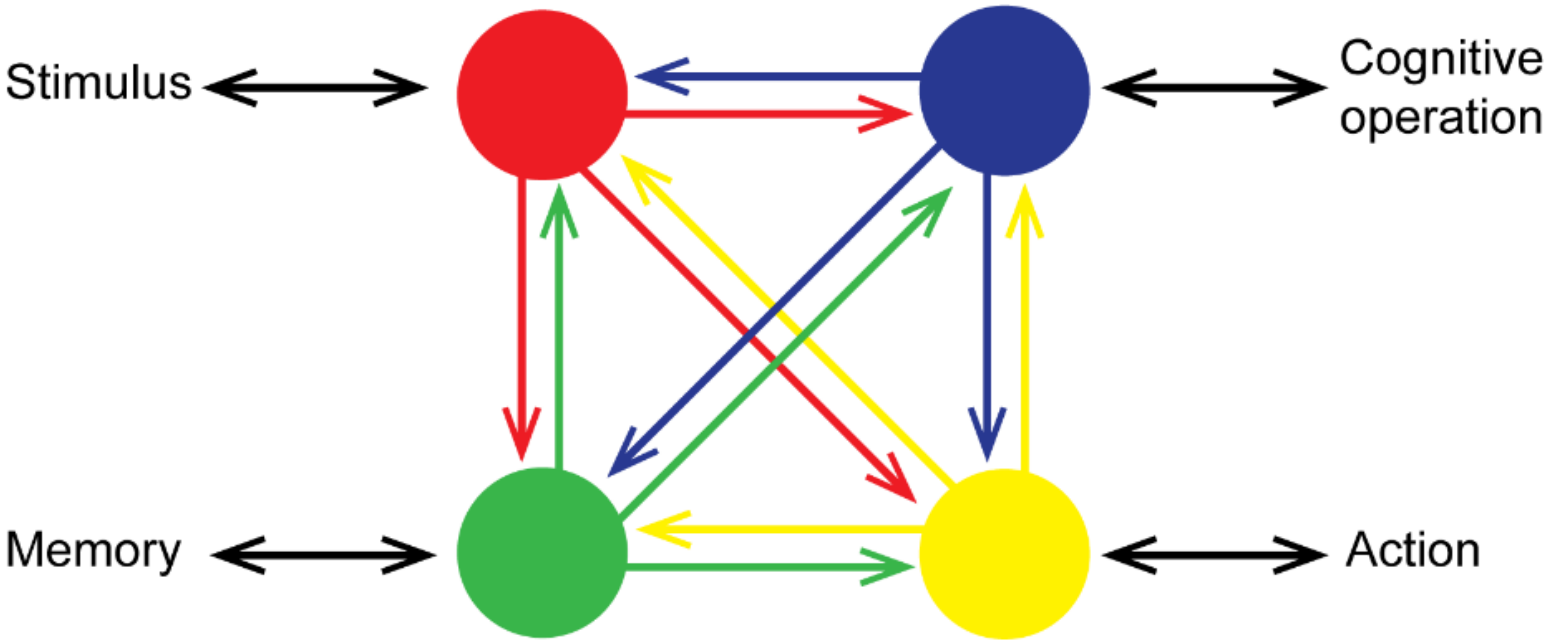
a Conjunction








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



Duncan, Assem & Shashidhara (2020) *Trends in Cog. Sci*

Summary

How are executive functions are assembled in the human brain?

1. Executive functions show overlapping activations within cortical, subcortical and cerebellar domain-general MD regions
2. Each executive demand shows unique functional preferences within MD regions that extend to nearby canonical RSNs
3. Linking this unity and diversity are strong activations at the intersection of core MD and adjacent partially-specialized RSNs

<u>Novel proposal:</u> Domain-specific areas recruit adjacent MD areas from different spatial locations on the cortical sheet to generate executive functions, likely far more diverse than the three studied here

Mainstream view

Novel view