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
“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

• 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

Multimodal Surface Matching (MSM)

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
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
3 HCP tasks (n=449)
Assem et al 2020

4 CBU exec tasks (n=37)
Assem et al 2021
Assem et al (in prep)

5 CBU Non-exec tasks (n=15-20)
(Data collection on going)

9 MD patches

- 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)
Group average

Session 1
Hard > easy

Session 2
Hard > easy

\[ r = 0.96 \]

mean \( r = 0.71 \)

Assem et al (2022) cerebral cortex
Unity: vertex-level
Fine-grained connectivity
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

**Novel proposal:** 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