ABCD-ReproNim: An ABCD Course on Reproducible Data Analyses

ABCD: Imaging Measures

Damien Fair, PA-C, Ph.D.

Redleaf Endowed Director, Masonic Institute for the Developing Brain

Professor, Institute of Child Development, College of Education and Human Development

Professor, Department of Pediatrics, Medical School

faird@umn.edu

ABCD-ReproNim: An ABCD Course on Reproducible Data Analyses

ABCD: Introduction to the ABCD Study®

Conflict Statement: Damien Fair and Nico Dosenbach are co-Founder of Nous Imaging Inc., which is commercializing the FIRMM motion monitoring software products

MASONIC INSTITUTE FOR THE DEVELOPING BRAIN
UNIVERSITY OF MINNESOTA
Driven to Discover℠

ABCD-ReproNim

Learning Objectives of this Lecture

ABCD-ReproNim

- Imaging Protocol and Pulse Sequences (Structural and Functional)
- Quality Assurance
- fMRI Task Description, Justification, Age-Appropriateness, and Relevance to ABCD Study
- Minimally Processed Pipelines
- ABCC - Collection 3165

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Imaging Protocol

ABCD-ReproNim

Contents lists available at ScienceDirect

Developmental Cognitive Neuroscience

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The Adolescent Brain Cognitive Development (ABCD) study: Imaging acquisition across 21 sites

B.J. Casey[a,b,*], Tariq Cannonier[a], May I. Conley[a,b], Alexandra O. Cohen[b], Deanna M. Barch[c], Mary M. Heitzeg[d], Mary E. Soules[d], Theresa Teslovich[b], Danielle V. Dellarco[b], Hugh Garavan[e], Catherine A. Orr[f], Tor D. Wager[b], Marie T. Banich[b], Nicole K. Speer[b], Matthew T. Sutherland[g], Michael C. Riedel[i], Anthony S. Dick[j], James M. Bjork[k], Kathleen M. Thomas[l], Bader Chaarani[e], Margie H. Mejia[i], Donald J. Hagler Jr.[i], M. Daniela Cornejo[i], Chelsea S. Sicat[i], Michael P. Harms[d], Nico U.F. Dosenbach[n], Monica Rosenberg[o], Eric Earl[m], Hauke Bartsch[i], Richard Watts[p], Jonathan R. Polimeni[q], Joshua M. Kuperman[i], Damien A. Fair[m], Anders M. Dale[i], the ABCD Imaging Acquisition Workgroup[1]

Casey et al, DCN, 2018

Imaging Protocol

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Casey et al, DCN, 2018

Imaging Protocol

ABCD-ReproNim

ABCD harmonized imaging scanning parameters for Siemens Prisma, Phillips & GE 750 3T

Siemens (Prisma VE11B-C)	Matrix	Slices	FOV	% FOV phase	Resolution (mm)	TR (ms)	TE (ms)	TI (ms)	Flip Angle (deg)	Parallel Imaging	Multiband Acceleration	Phase partial Fourier	Diffusion Directions	b-values	Acquisition Time
T1	256 × 256	176	256 × 256	100%	1.0 × 1.0 × 1.0	2500	2.88	1060	8	2×	Off	Off	N/A	N/A	07:12
T2	256 × 256	176	256 × 256	100%	1.0 × 1.0 × 1.0	3200	565	N/A	Variable	2×	Off	Off	N/A	N/A	06:35
Diffusion	140 × 140	81	240 × 240	100%	1.7 × 1.7 × 1.7	4100	88	N/A	90	Off	3	6/8	96	500 (6-dirs); 1000; (15-dirs) 2000; (15-dirs); 3000 (60-dirs)	07:31
fMRI	90 × 90	60	216 × 216	100%	2.4 × 2.4 × 2.4	800	30	N/A	52	Off	6	Off	N/A	N/A	

Philips (Achieva dStream, Ingenia)	Matrix	Slices	FOV	% FOV phase	Resolution (mm)	TR (ms)	TE (ms)	TI (ms)	Flip Angle (deg)	Parallel Imaging	Multiband Acceleration	Half Scan Factor	Diffusion Directions	b-values	Acquisition Time
T1	256 × 256	225	256 × 240	93.75%	1.0 × 1.0 × 1.0	6.31	2.9	1060	8	1.5 × 2.2	Off	N/A	N/A	N/A	05:38
T2	256 × 256	256	256 × 256	100%	1.0 × 1.0 × 1.0	2500	251.6	N/A	90	1.5 × 2.0	Off	N/A	N/A	N/A	02:53
Diffusion	140 × 140	81	240 × 240	100%	1.7 × 1.7 × 1.7	5300	89	N/A	78	Off	3	0.6	96	500 (6-dirs); 1000; (15-dirs) 2000; (15-dirs); 3000 (60-dirs)	09:14
fMRI	90 × 90	60	216 × 216	100%	2.4 × 2.4 × 2.4	800	30	N/A	52	Off	6	0.9	N/A	N/A	

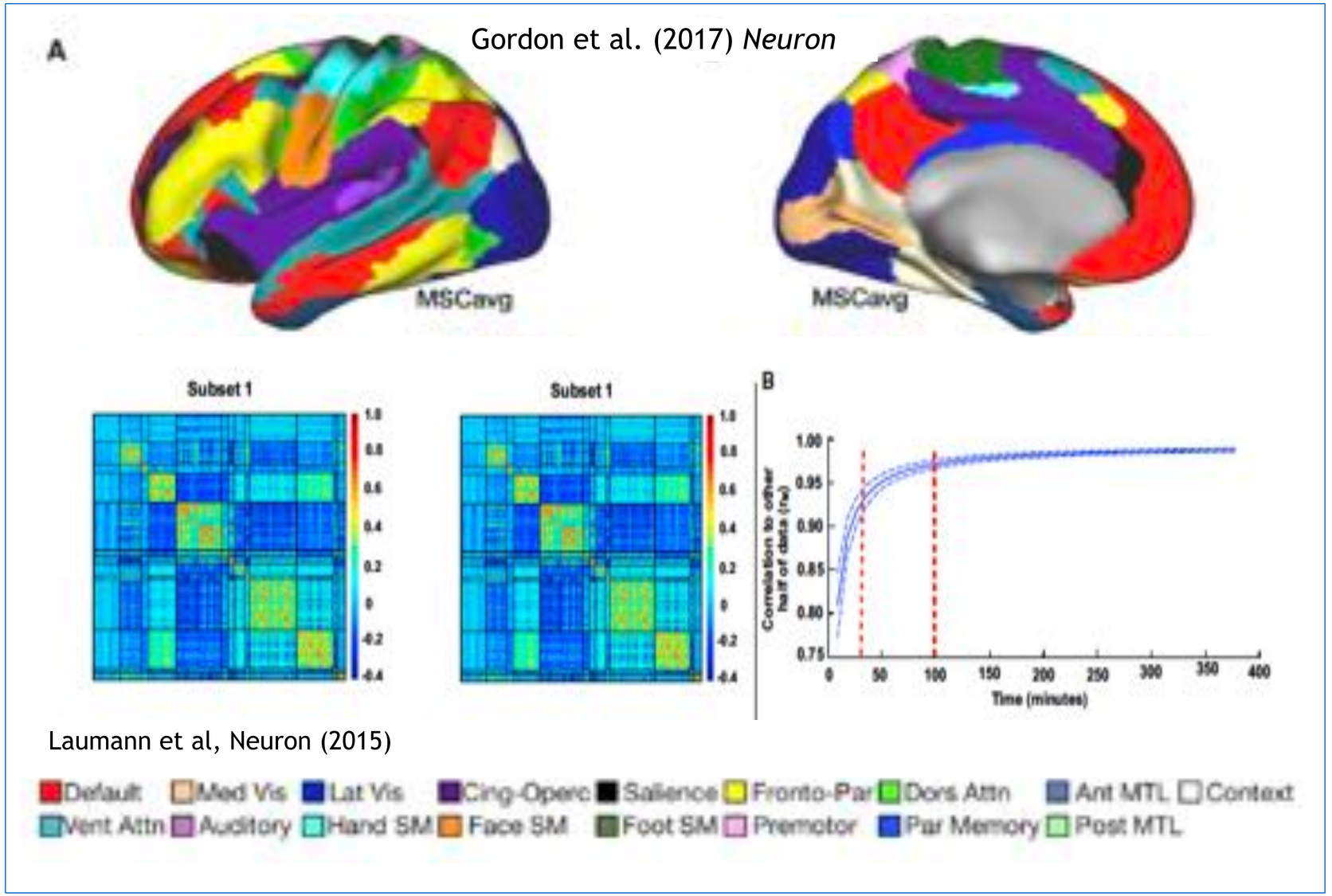
GE (MR750, DV25-26)	Matrix	Slices	FOV	% FOV phase	Resolution (mm)	TR (ms)	TE (ms)	TI (ms)	Flip Angle (deg)	Parallel Imaging	Multiband Acceleration	Phase partial Fourier	Diffusion Directions	b-values	Acquisition Time
T1	256 × 256	208	256 × 256	100%	1.0 × 1.0 × 1.0	2500	2	1060	8	2×	Off	Off	N/A	N/A	06:09
T2	256 × 256	208	256 × 256	100%	1.0 × 1.0 × 1.0	3200	60	N/A	Variable	2×	Off	Off	N/A	N/A	05:50
Diffusion	140 × 140	81	240 × 240	100%	1.7 × 1.7 × 1.7	4100	81.9	N/A	77	Off	3	5.5/8	96	500 (6-dirs); 1000; (15-dirs) 2000 (15-dirs); 3000 (60-dirs)	07:30
fMRI	90 × 90	60	216 × 216	100%	2.4 × 2.4 × 2.4	800	30	N/A	52	Off	6	Off	N/A	N/A	

Casey et al, DCN, 2018

Imaging Protocol

ABCD-ReproNim

Rest, 15-20 minutes of data collected



Gordon et al. (2017) *Neuron*

Laumann et al, Neuron (2015)

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Quality Assurance

ABCD-ReproNim

Updates from the 3.0 Release

ABCD Recommended Imaging Inclusion	abcd_imgincl01
ABCD MRI QC Raw Part 1	mriqc102
ABCD MRI QC Raw Part 2	mriqcp202
ABCD MRI QC Raw Part 3	mriqcp302
FreeSurfer QC	freesqc01
ABCD dMRI Post Processing QC	dmriqc01
Manual fMRI Post-Processing QC	fmriqc01
Automated Post-Processing QC Metrics	abcd_auto_postqc01

Quality Assurance

ABCD MRI QC Raw

Protocol compliance checking

- performed by on-site FIONA workstations to provide feedback to scan operators
- out-of-compliance series reviewed by DAIC staff
- criteria included whether key imaging parameters matched expected values for a given scanner, such as voxel size or repetition time
- presence or absence of B0 distortion field map series was checked for diffusion MRI (dMRI) and functional MRI (fMRI) series
- each imaging series checked for completeness (i.e., no missing files)

Quality Assurance

ABCD MRI QC Raw

Automated quality control metrics

- Structural MRI (sMRI): mean and standard deviation of brain values and spatial SNR
- dMRI: mean motion (average framewise displacement), and the number of slices and frames affected by slice dropout caused by abrupt head motion
- fMRI: mean motion (average framewise displacement), the number of seconds with framewise displacements less than 0.2, 0.3, or 0.4 mm (Power, et al., 2012), temporal SNR (tSNR) (Triantafyllou, et al., 2005)

Quality Assurance

ABCD-ReproNim

Series	Description	Frames	TR (sec)	Time (min)	< 0.2 mm (min) (%)	< 0.3 mm (min) (%)	< 0.4 mm (min) (%)
15	ep2d_bold_nonad_movie_1A	164	2.5	6:50	6:02 (88.4%)	6:30 (95.1%)	6:32 (95.7%)
14	ep2d_bold_movie_rest_3C	164	2.5	6:50	6:15 (91.5%)	6:47 (99.4%)	6:50 (100.0%)
13	ep2d_bold_ad_movie_2B	164	2.5	6:50	6:05 (89.0%)	6:40 (97.6%)	6:47 (99.4%)
9	ep2d_bold_ad_rest	164	2.5	6:50	4:17 (62.8%)	5:00 (73.2%)	5:20 (78.0%)
8	ep2d_bold_nonad_rest	164	2.5	6:50	5:47 (84.8%)	6:10 (90.2%)	6:22 (93.3%)
7	ep2d_bold_rest2	164	2.5	6:50	6:10 (90.2%)	6:27 (94.5%)	6:42 (98.2%)
6	ep2d_bold_rest1	164	2.5	6:50	5:47 (84.8%)	6:07 (89.6%)	6:15 (91.5%)

	< 0.2 mm	< 0.3 mm	< 0.4 mm
Good Time (min) (%)	40:25 (84.5%)	43:42 (91.4%)	44:50 (93.7%)
Good Frames	970	1049	1076
Bad Frames	178	99	72

	< 0.2 mm	< 0.3 mm	< 0.4 mm
Minutes to Criteria	0:00	0:00	0:00

http://firmm.io/

Quality Assurance

ABCD MRI QC Raw

Manual review of data quality

- reviewers assigned binary QC score
  - 0 = reject
    - most severe artifacts or irregularities
    - rejected series excluded from subsequent processing and analysis
  - 1 = accept
- types of images reviewed
  - T1w, T2w, dMRI, dMRI field map, fMRI, and fMRI field map
  - raw and some derived images were reviewed
  - dMRI derived images included average b=0 image, FA, MD, tensor fit residual error, and direction encoded color image
  - fMRI derived images included the average across time and the temporal standard deviation
- inspected for signs of artifacts and poor image quality
  - presence of wrap-around field of view artifacts
  - brain cut-off due to the participant motion outside prescribed slices
  - magnetic susceptibility artifacts due to dental implants
  - T1w and T2w motion artifact (e.g. smearing and ghosting)

ABCD MRI QC postprocessing

FreeSurfer QC (manual)

- Manual review of FreeSurfer cortical surface reconstruction
    - reviewers assigned binary (0l1) QC score
        - 0 = reject
            - most severe artifacts or irregularities
            - results still included in shared tabulated data
            - recommended exclusion from group analyses involving cortical surface ROIs
        - 1 = accept
    - reviewers gauged the severity of five types of artifact
        - motion
        - intensity inhomogeneity
        - white matter underestimation
        - pial overestimation
        - magnetic susceptibility artifact
    - numeric values assigned on a scale of 0-3
        - absent, mild, moderate, or severe, respectively
        - QC score of 0 assigned if severity score of 3 for any artifact type

Note: imaging-derived results are included in shared tabulated data regardless of post-processing QC. QC variables (derived from procedures described above) are included in shared tabulated data. The overall, binary QC score described above indicates whether inclusion or exclusion is recommended.

Quality Assurance

ABCD-ReproNim

ABCD MRI QC postprocessing

dMRI Post Processing QC (manual)

- Manual review of DTI reconstruction
    - reviewers assigned binary (0l1) QC score
        - 0 = reject
            - most severe artifacts or irregularities
            - results still included in shared tabulated data
            - recommended exclusion from group analyses involving cortical, subcortical, and tract-based ROIs
        - 1 = accept
    - reviewers gauged the severity of five types of artifact
        - B0 warping
        - image quality based on motion-related artifacts and magnetic susceptibility artifact
        - full head coverage
        - registration with T1w image
        - accuracy of fiber tract segmentation
    - numeric values assigned on a scale of 0-3
        - absent, mild, moderate, or severe, respectively
        - QC score of 0 assigned if severity score of 3 for any artifact type

Note: The dMRI Post Processing QC covers ~ 10% subjects and is primarily used as an internal QC measure.

ABCD MRI QC postprocessing

fMRI Post Processing QC (manual)

- Manual review of fMRI reconstruction
    - reviewers assigned binary (0l1) QC score
        - 0 = reject
            - most severe artifacts or irregularities
            - results still included in shared tabulated data
            - recommended exclusion from group analyses involving cortical, subcortical, and tract-based ROIs
        - 1 = accept
    - reviewers gauged the severity of five types of artifact
        - B0 warping
        - image quality based primarily on magnetic susceptibility artifact
        - full head coverage
        - registration with T1w image
    - numeric values assigned on a scale of 0-3
        - absent, mild, moderate, or severe, respectively
        - QC score of 0 assigned if severity score of 3 for any artifact type

Note: The fMRI Post Processing QC covers ~ 10% subjects and is primarily used as an internal QC measure.

Automated Post Processing QC

Automated QC measures were defined and calculated based on processed imaging data.

- FreeSurfer
    - number of topological defects
        - calculated from Euler number
    - dMRI
    - field of view (FOV) brain cutoff
        - quantified by % intersection of brain mask with frame borders
    - registration to T1w
        - window-based estimation of geometric registration discrepancy with respect to the T1 scan, decomposed into rigid and warp components for calculation of registration error
    - fMRI
    - field of view (FOV) brain cutoff
        - quantified by % intersection of brain mask with frame borders
    - registration to T1w
        - window-based estimation of geometric registration discrepancy with respect to the T1 scan, decomposed into rigid and warp components for calculation of registration error
    - sMRI T2w
    - registration to T1w
        - window-based estimation of geometric registration discrepancy with respect to the T1 scan, decomposed into rigid and warp components for calculation of registration error
        -

Quality Assurance

ABCD-ReproNim

18. NDA 3.0 MRI Quality Control

T1w data recommended for inclusion

T1w series meets all criteria for inclusion (imgincl_t1w_include = 1).

T1w Criteria	Instrument	Element value
T1 series passed rawQC	mriqcrp102	iqc_t1_ok_ser > 0
FreeSurfer QC not failed	freesqc01	fsqc_qc ~= 0

Quality Assurance

18. NDA 3.0 MRI Quality Control

T2w data recommended for inclusion

T2w series meets all criteria for inclusion (imgincl_t2w_include = 1).

T2w Criteria	Instrument	Element value
T2 series passed rawQC	mriqcrp102	iqc_t2_ok_ser > 0
T1 series passed rawQC	mriqcrp102	iqc_t1_ok_ser > 0
FreeSurfer QC not failed	freesqc01	fsqc_qc ~= 0
T2w registration to T1w: Less than 10	abcd_auto_postqc01	apqc_smri_t2w_regt1_rigid < 10

Quality Assurance

ABCD-ReproNim

18. NDA 3.0 MRI Quality Control

dMRI (DTI/RSI) data recommended for inclusion

dMRI (DTI/RSI) series meets all criteria for inclusion (imgincl_dmri_include = 1).

dMRI Criteria	Instrument	Element value
dMRI series passed rawQC	mriqcrp102	iqc_dmri_ok_ser > 0
dMRI Total number of repetitions for all OK scans is 103 or more	mriqcrp102	iqc_dmri_ok_nreps >= 103
T1 series passed rawQC	mriqcrp102	iqc_t1_ok_ser > 0
dMRI B0 Unwarp available	abcd_auto_postqc01	apqc_dmri_bounwarp_flag == 1
FreeSurfer QC not failed	freesqc01	fsqc_qc ~= 0
dMRI Manual Post-Processing QC not failed	dmriqc01	dmri_postqc_qc ~= 0
dMRI registration to T1w: less than 17	abcd_auto_postqc01	apqc_dmri_regt1_rigid < 17
dMRI Maximum dorsal cutoff score: less than 47	abcd_auto_postqc01	apqc_dmri_fov_cutoff_dorsal < 47
dMRI Maximum ventral cutoff score: less than 54	abcd_auto_postqc01	apqc_dmri_fov_cutoff_ventral < 54

Quality Assurance

18. NDA 3.0 MRI Quality Control

rs-fMRI data recommended for inclusion

rsfMRI series meets all criteria for inclusion (imgincl_rsfmri_include = 1).

rsfMRI Criteria	Instrument	Element value
rsfMRI tfMRI series passed rawQC	mriqcrp102	iqc_rsfmri_ok_ser > 0
T1 series passed rawQC	mriqcrp102	iqc_t1_ok_ser > 0
rsfMRI Number of frames > 375	abcd_betnet02	rsfmri_c_ngd_ntpoints > 375
fMRI B0 Unwarp available	abcd_auto_postqc01	apqc_fmri_bounwarp_flag == 1
FreeSurfer QC not failed	freesqc01	fsqc_qc ~= 0
fMRI Manual Post-Processing QC not failed	fmriqc01	fmri_postqc_qc ~= 0
fMRI registration to T1w: less than 19	abcd_auto_postqc01	apqc_fmri_regt1_rigid < 19
fMRI Maximum dorsal cutoff score: less than 65	abcd_auto_postqc01	apqc_fmri_fov_cutoff_dorsal < 65
fMRI Maximum ventral cutoff score: less than 60	abcd_auto_postqc01	apqc_fmri_fov_cutoff_ventral < 60

Quality Assurance

ABCD-ReproNim

18. NDA 3.0 MRI Quality Control

MID task-fMRI data recommended for inclusion

MID tfMRI series meets all criteria for inclusion (imgincl_mid_include = 1).

MID Criteria	Instrument	Element value
MID tfMRI series passed rawQC	mriqcrp102	iqc_mid_ok_ser > 0
T1 series passed rawQC	mriqcrp102	iqc_t1_ok_ser > 0
MID Behavior passed	abcd_mid02	tfmri_mid_beh_performflag == 1
MID degrees of freedom > 200	midaparc03	tfmri_mid_all_b_dof > 200
MID Total number of trials is 100	abcd_mid02	tfmri_mid_all_beh_t_nt = 100
MID E-prime timing match OR ignore E-prime mismatch	mriqcrp302	iqc_mid_ep_t_series_match == 1 || eprime_mismatch_ok_mid == 1
fMRI B0 Unwarp available	abcd_auto_postqc01	apqc_fmri_bounwarp_flag == 1
FreeSurfer QC not failed	freesqc01	fsqc_qc ~= 0
fMRI Manual Post-Processing QC not failed	fmriqc01	fmri_postqc_qc ~= 0
fMRI registration to T1w: less than 19	abcd_auto_postqc01	apqc_fmri_regt1_rigid < 19
fMRI Maximum dorsal cutoff score: less than 65	abcd_auto_postqc01	apqc_fmri_fov_cutoff_dorsal < 65
fMRI Maximum ventral cutoff score: less than 60	abcd_auto_postqc01	apqc_fmri_fov_cutoff_ventral < 60

Quality Assurance

ABCD-ReproNim

18. NDA 3.0 MRI Quality Control

nBack task-fMRI data recommended for inclusion

nBack tfMRI series meets all criteria for inclusion (imgincl_nback_include = 1).

nBack Criteria	Instrument	Element value
nBack tfMRI series passed rawQC	mriqcrp102	iqc_nback_ok_ser > 0
T1 series passed rawQC	mriqcrp102	iqc_t1_ok_ser > 0
nBack Behavior passed	abcd_nback02	tfmri_nback_beh_performflag == 1
nBack degrees of freedom > 200	midaparc03	tfmri_nback_all_b_dof > 200
nBack Total number of trials is 100	abcd_nback02	tfmri_nback_all_beh_t_nt = 100
nBack E-prime timing match OR ignore E-prime mismatch	mriqcrp302	iqc_nback_ep_t_series_match == 1 || eprime_mismatch_ok_nback == 1
fMRI B0 Unwarp available	abcd_auto_postqc01	apqc_fmri_bounwarp_flag == 1
FreeSurfer QC not failed	freesqc01	fsqc_qc ~= 0
fMRI Manual Post-Processing QC not failed	fmriqc01	fmri_postqc_qc ~= 0
fMRI registration to T1w: less than 19	abcd_auto_postqc01	apqc_fmri_regt1_rigid < 19
fMRI Maximum dorsal cutoff score: less than 65	abcd_auto_postqc01	apqc_fmri_fov_cutoff_dorsal < 65
fMRI Maximum ventral cutoff score: less than 60	abcd_auto_postqc01	apqc_fmri_fov_cutoff_ventral < 60

Quality Assurance

ABCD-ReproNim

18. NDA 3.0 MRI Quality Control

SST task-fMRI data recommended for inclusion

SST tfMRI series meets all criteria for inclusion (imgincl_sst_include = 1).

SST Criteria	Instrument	Element value
SST tfMRI series passed rawQC	mriqcrp102	iqc_sst_ok_ser > 0
T1 series passed rawQC	mriqcrp102	iqc_t1_ok_ser > 0
SST Behavior passed	abcd_sst02	tfmri_sst_beh_performflag == 1
SST degrees of freedom > 200	midaparc03	tfmri_sst_all_b_dof > 200
SST Total number of trials is 100	abcd_sst02	tfmri_sst_all_beh_t_nt = 100
SST E-prime timing match OR ignore E-prime mismatch	mriqcrp302	iqc_sst_ep_t_series_match == 1 || eprime_mismatch_ok_sst == 1
fMRI B0 Unwarp available	abcd_auto_postqc01	apqc_fmri_bounwarp_flag == 1
FreeSurfer QC not failed	freesqc01	fsqc_qc ~= 0
fMRI Manual Post-Processing QC not failed	fmriqc01	fmri_postqc_qc ~= 0
fMRI registration to T1w: less than 19	abcd_auto_postqc01	apqc_fmri_regt1_rigid < 19
fMRI Maximum dorsal cutoff score: less than 65	abcd_auto_postqc01	apqc_fmri_fov_cutoff_dorsal < 65
fMRI Maximum ventral cutoff score: less than 60	abcd_auto_postqc01	apqc_fmri_fov_cutoff_ventral <= 60

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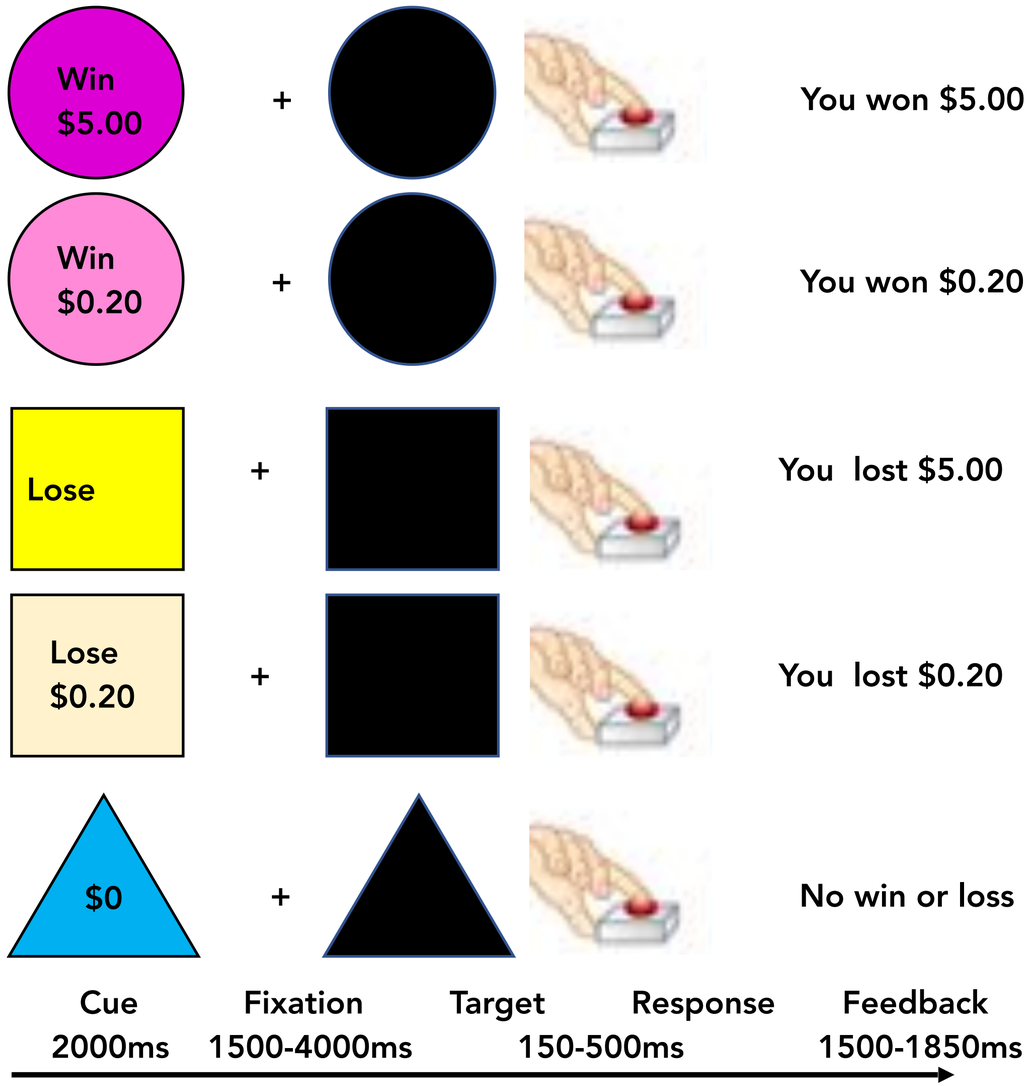
Monetary Incentive Delay Task

Participants attempted to win or avoid losing money by quickly responding to cued stimuli using a response box in their dominant hand.

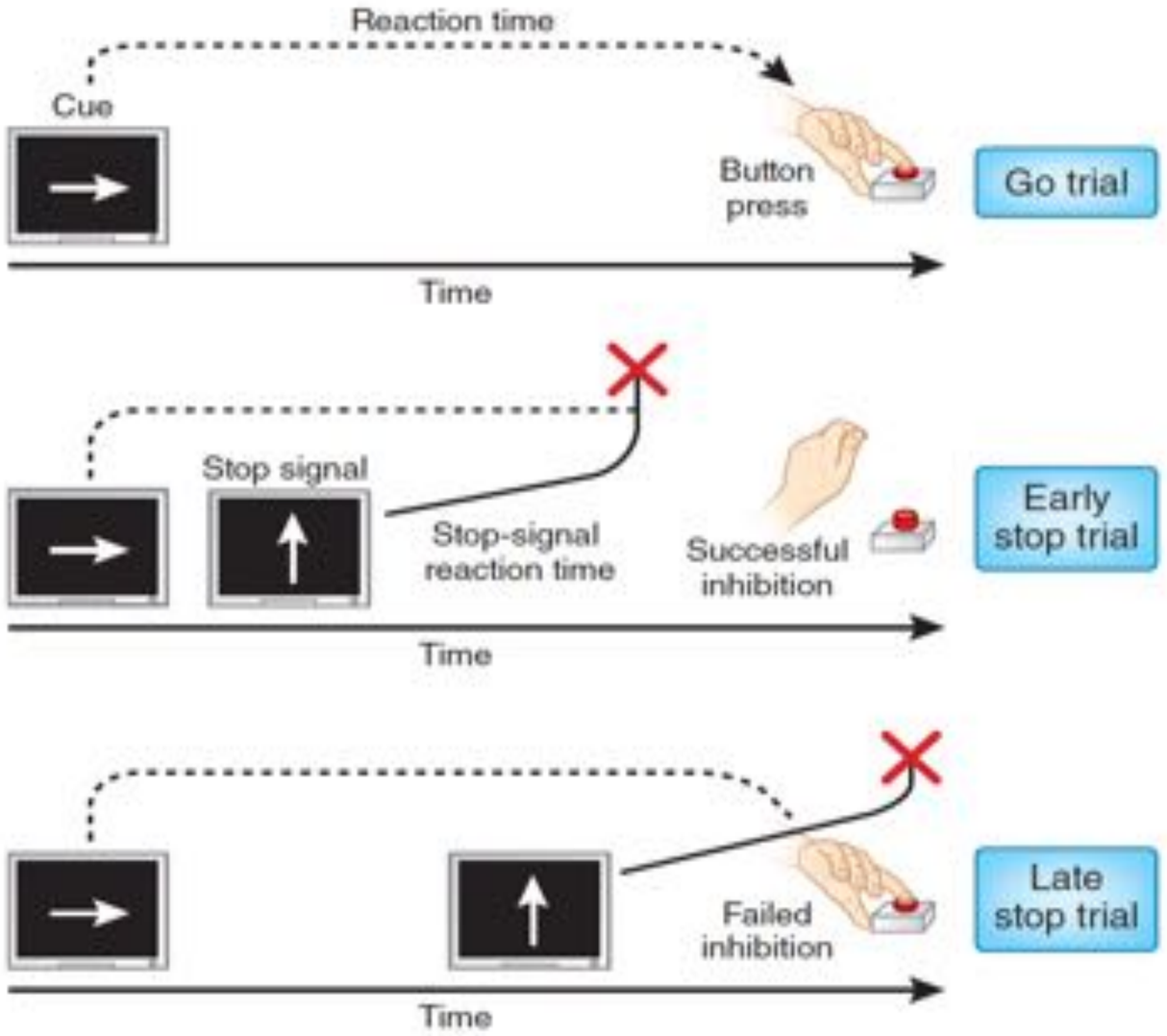


* 50 contiguous trials (10 per trial type) in each of two runs.

* Target duration is based on the participant's performance during a practice session prior to scanning, and adjusted during scanning with an adaptive algorithm (targeting 60% accuracy).

* Task performance is translated into actual payment amounts for participants.

STOP Signal Task



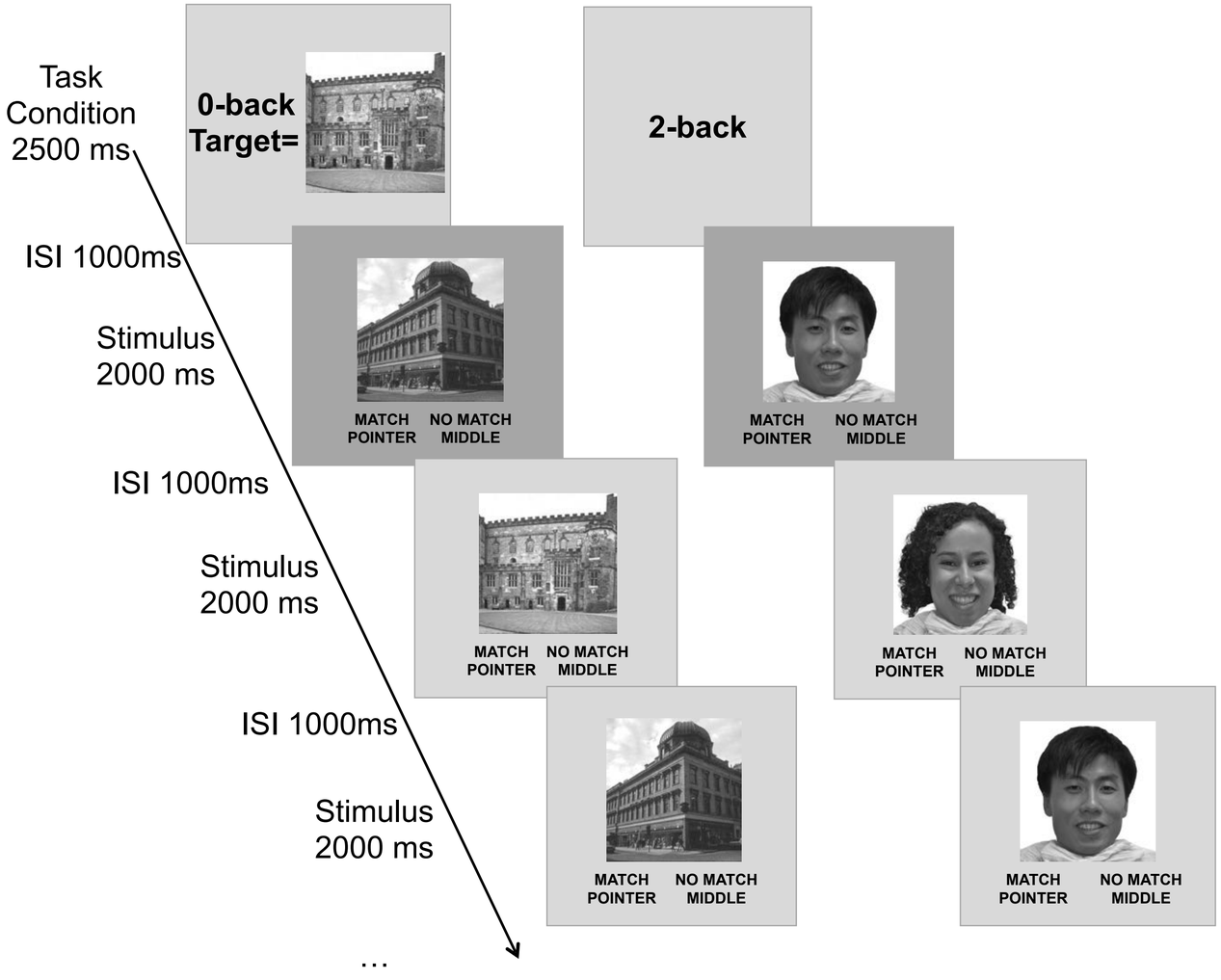
*The SST 2 presented leftward and rightward facing arrows in serial order (“go” stimuli).

*Participants were instructed to respond as quickly and accurately as possible but were told not to respond on trials in which a left or right arrow was followed by an arrow pointing upward (the “Stop” signal).

*Two runs: Each had 180 trials, of which 30 were “Stop” trials

*The time between the “go” and “stop” signals (the Stop-Signal Delay; SSD) varied dynamically based on a participant’s success on the prior trial so as to achieve a 50% success rate

Emotional Nback Task



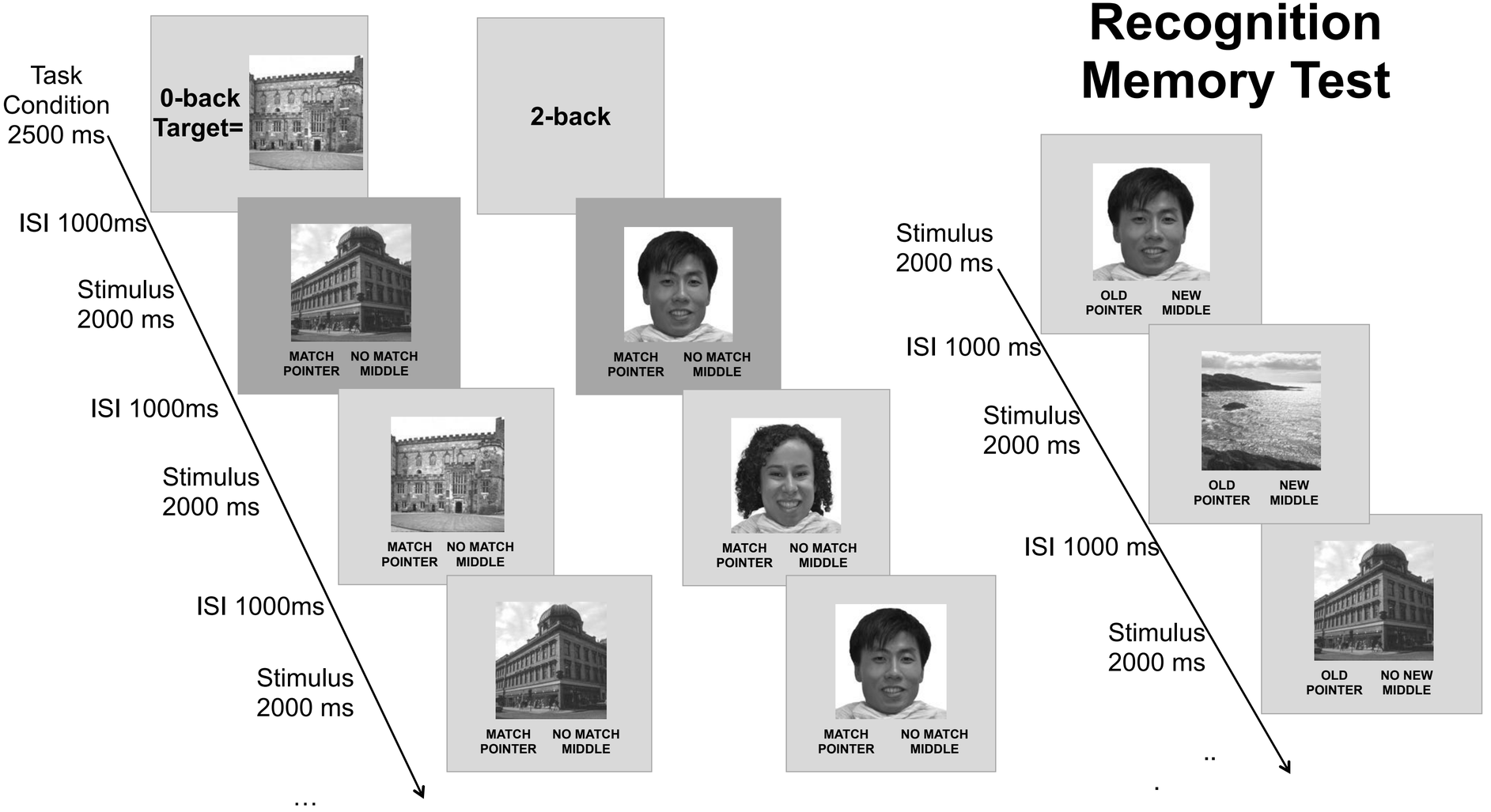
* Two runs, each containing 8 blocks, half of which are 0-Back and half 2-Back.

* Each block contains 10 trials, 2 of which are targets.

*Face stimuli include happy, fearful and neutral facial expressions from the NimStim emotional stimulus set (Tottenham et al., 2009) and the Racially Diverse Affective Expressions (RADIATE) set of stimuli (Conley, Dellarco et al., 2017).

*Additionally images of places was used as a 4th stimuli

Emotional Nback Task



fMRI task descriptions

ABCD-ReproNim

Tasks were chosen with the following criteria in mind:

1) **Implication in addiction (*validity*);**
2) **Feasibility in developmental studies (*developmentally-appropriate*);**
3) **Well-characterized neural activations (*specificity*);**
4) **Reliable activation over time within subjects (*reliability*);**
5) **Consistent patterns of activity across subjects (*sensitivity*);**
6) **Leveraging of other complementary developmental imaging initiatives that use similar measures (*generalizability*).**

fMRI task descriptions

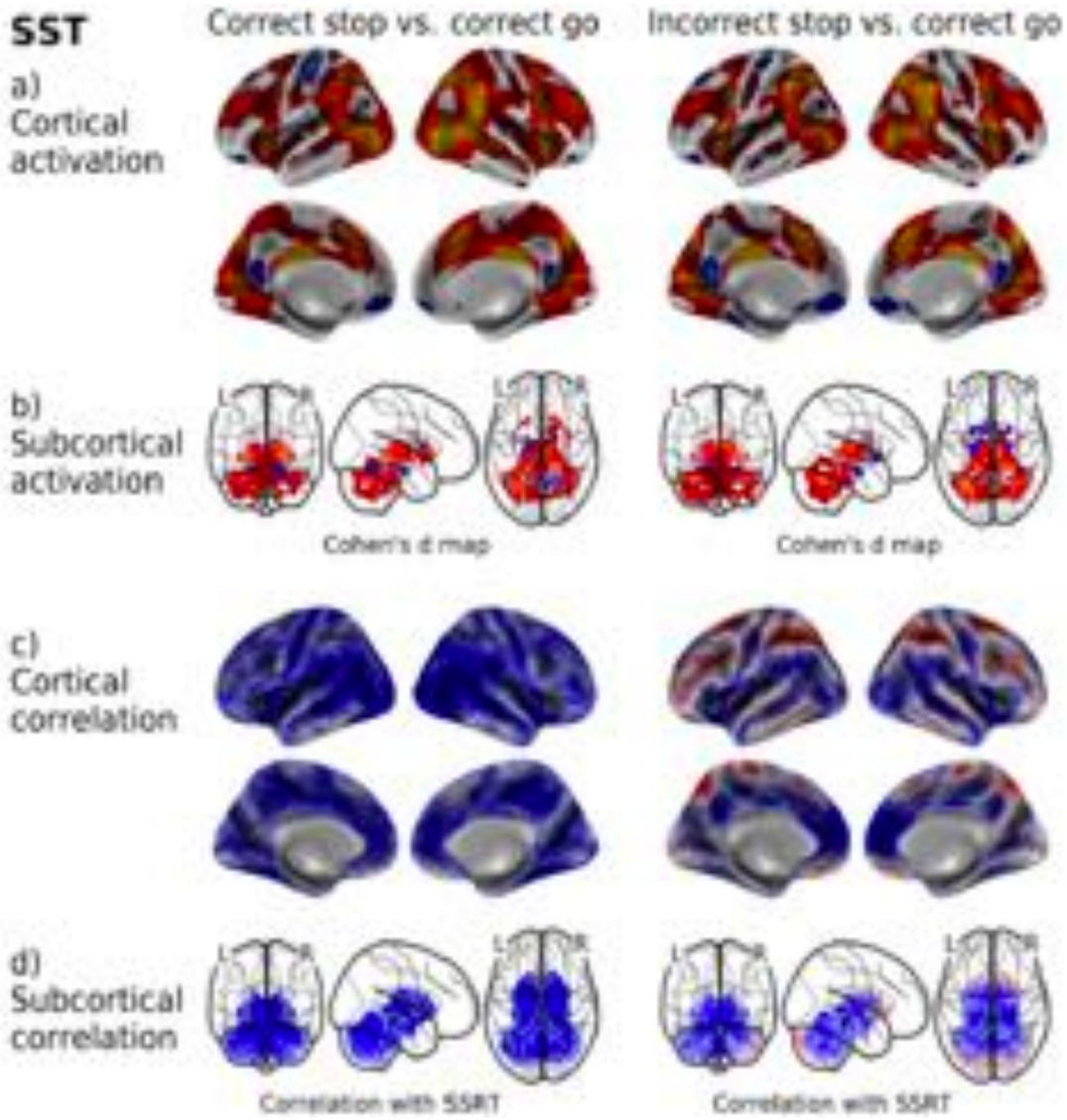
ABCD-ReproNim

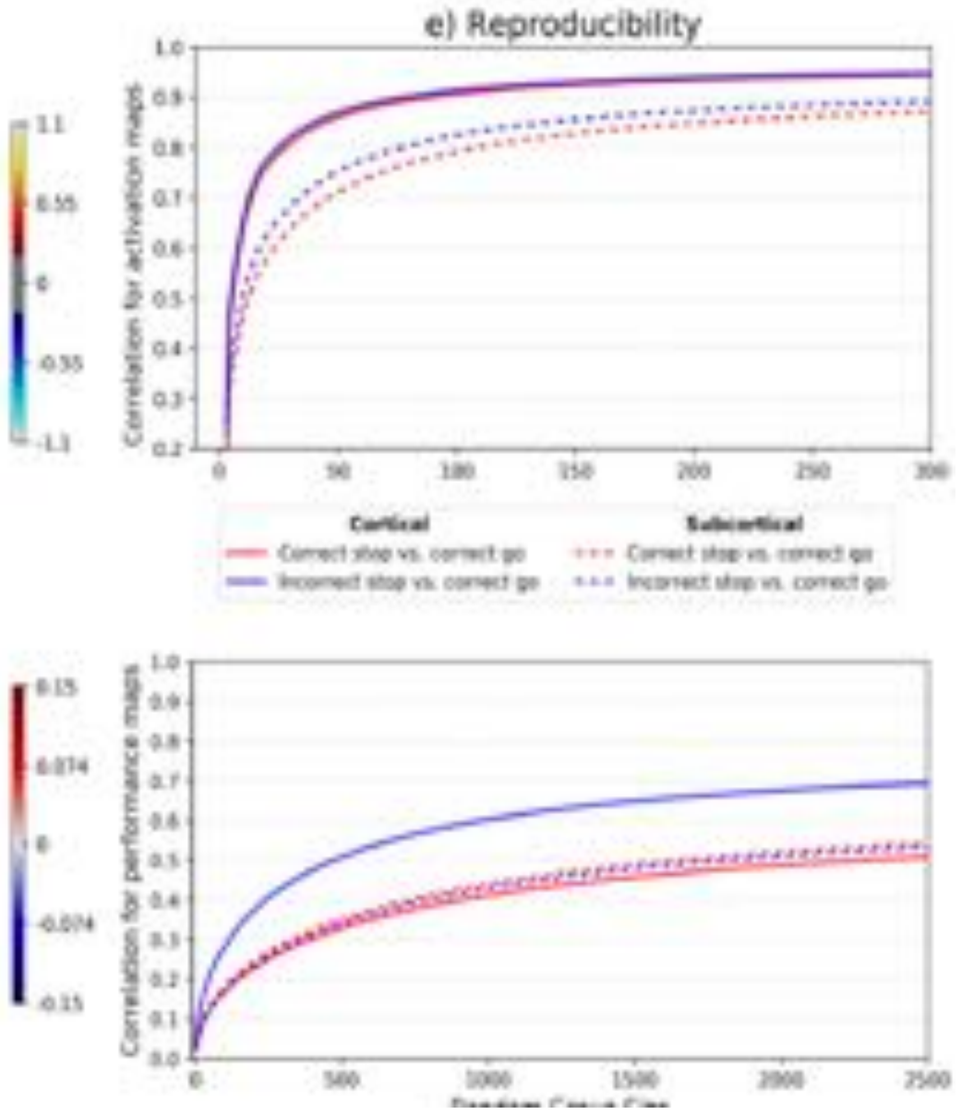
RFA Domain	Task	Processes	Neural Correlates
Reward Processing	Monetary Incentive Delay	Anticipation and outcome of reward and loss	Ventral striatum, orbitofrontal and medial prefrontal cortex
Motivation	Monetary Incentive Delay, response to cue	Anticipation of responding for outcome	Ventral striatum and ventromedial prefrontal cortex
Impulsivity	Stop Signal Task: Failed Stops	Impulsivity, error monitoring	Dorsal striatum, anterior cingulate cortex
Impulse Control	Stop Signal Task: Correct Stops	Impulse control, conflict monitoring and resolution	Lateral prefrontal cortex anterior cingulate cortex
Memory	Emotional n-back: 2-back vs 0-back, Recognition task: old vs new items	Working memory, encoding, retrieval, forgetting, recognition	Dorsolateral prefrontal cortex, parietal cortex, hippocampus, parahippocampus
Emotion Regulation	Emotional n-back: Fearful or happy vs neutral faces	Emotion regulation and reactivity	Dorsolateral prefrontal cortex, ventromedial prefrontal cortex, amygdala, ventral striatum

Note: Task order is varied but held constant within families and over time for a participant.

Note: Numerous stimulus orders for the STOP and MID tasks.

fMRI task descriptions





fMRI task descriptions

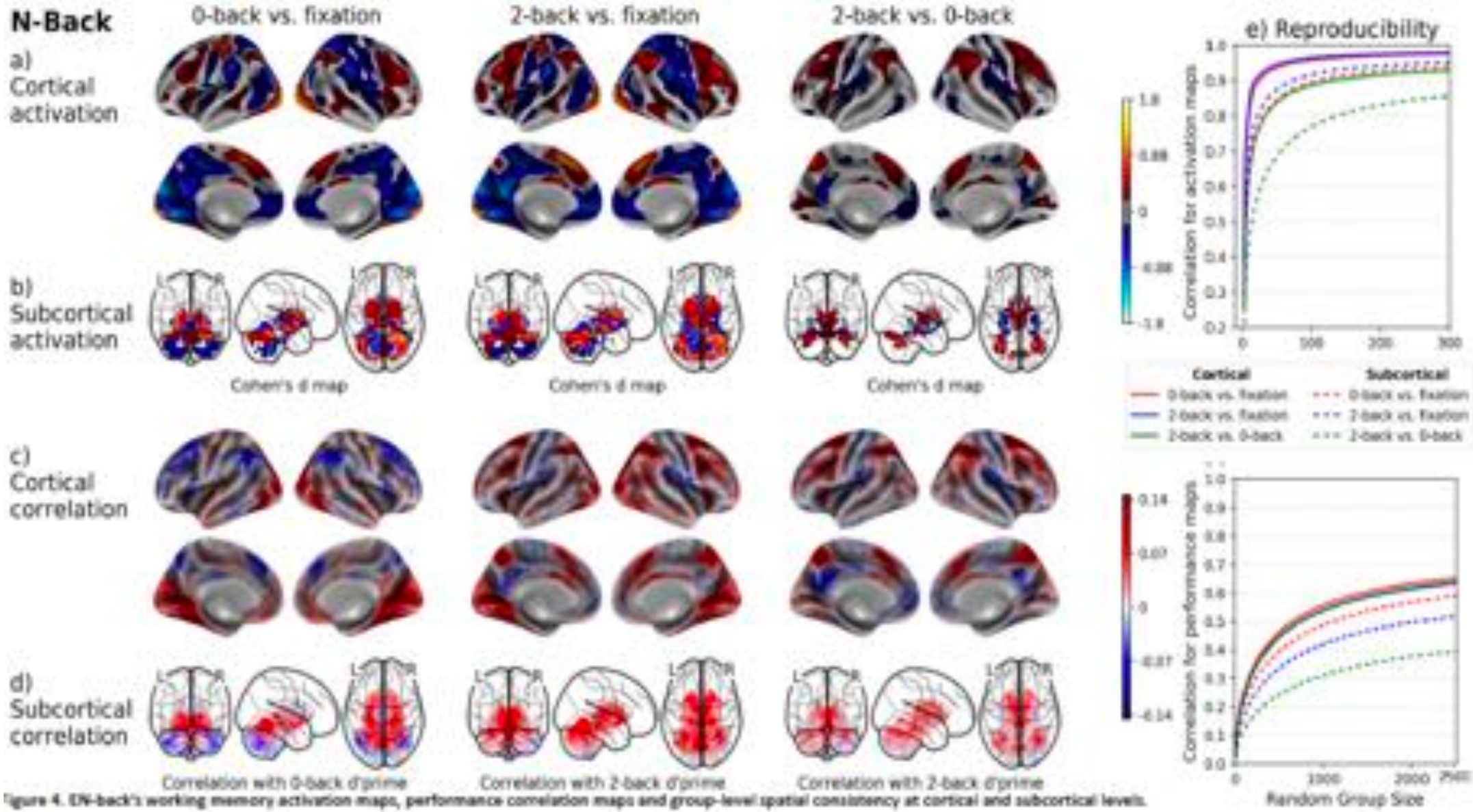


Figure 4. EN-back's working memory activation maps, performance correlation maps and group-level spatial consistency at cortical and subcortical levels.

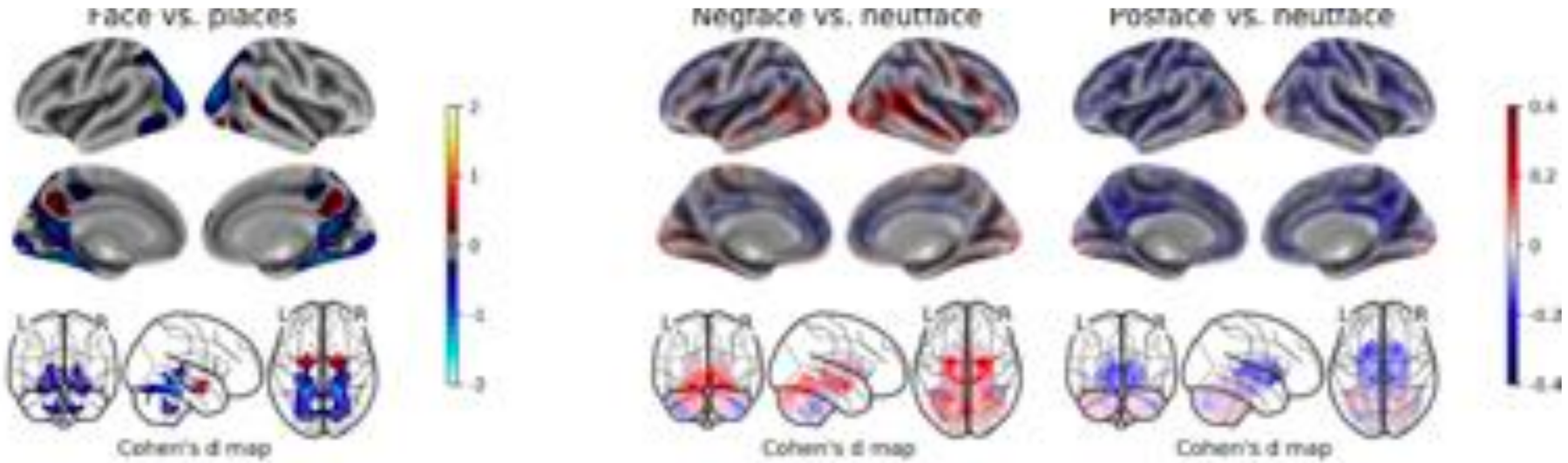
fMRI task descriptions

ABCD-ReproNim

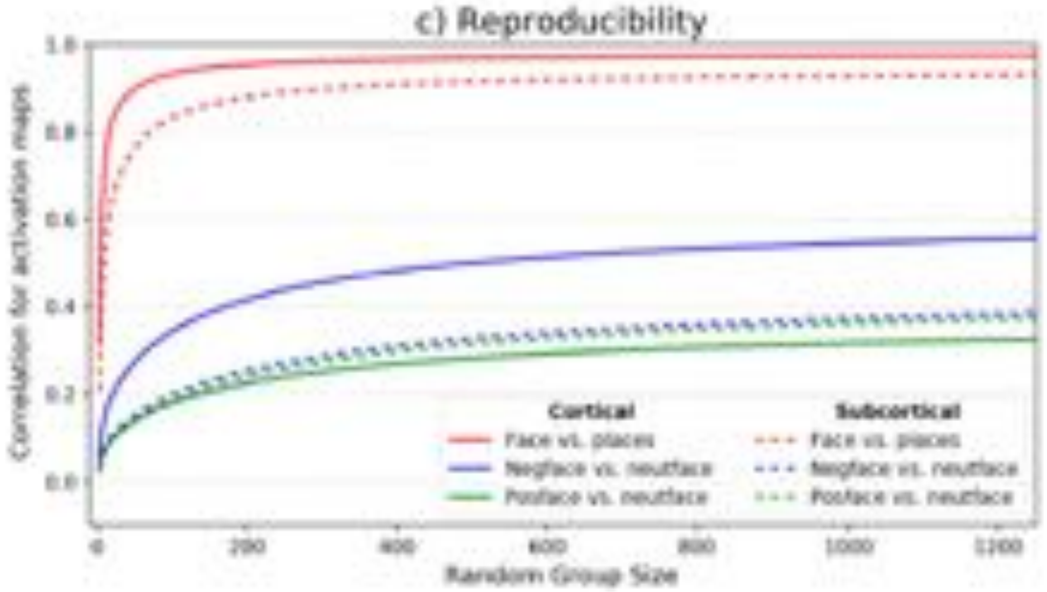
En-Back

a) Cortical activation

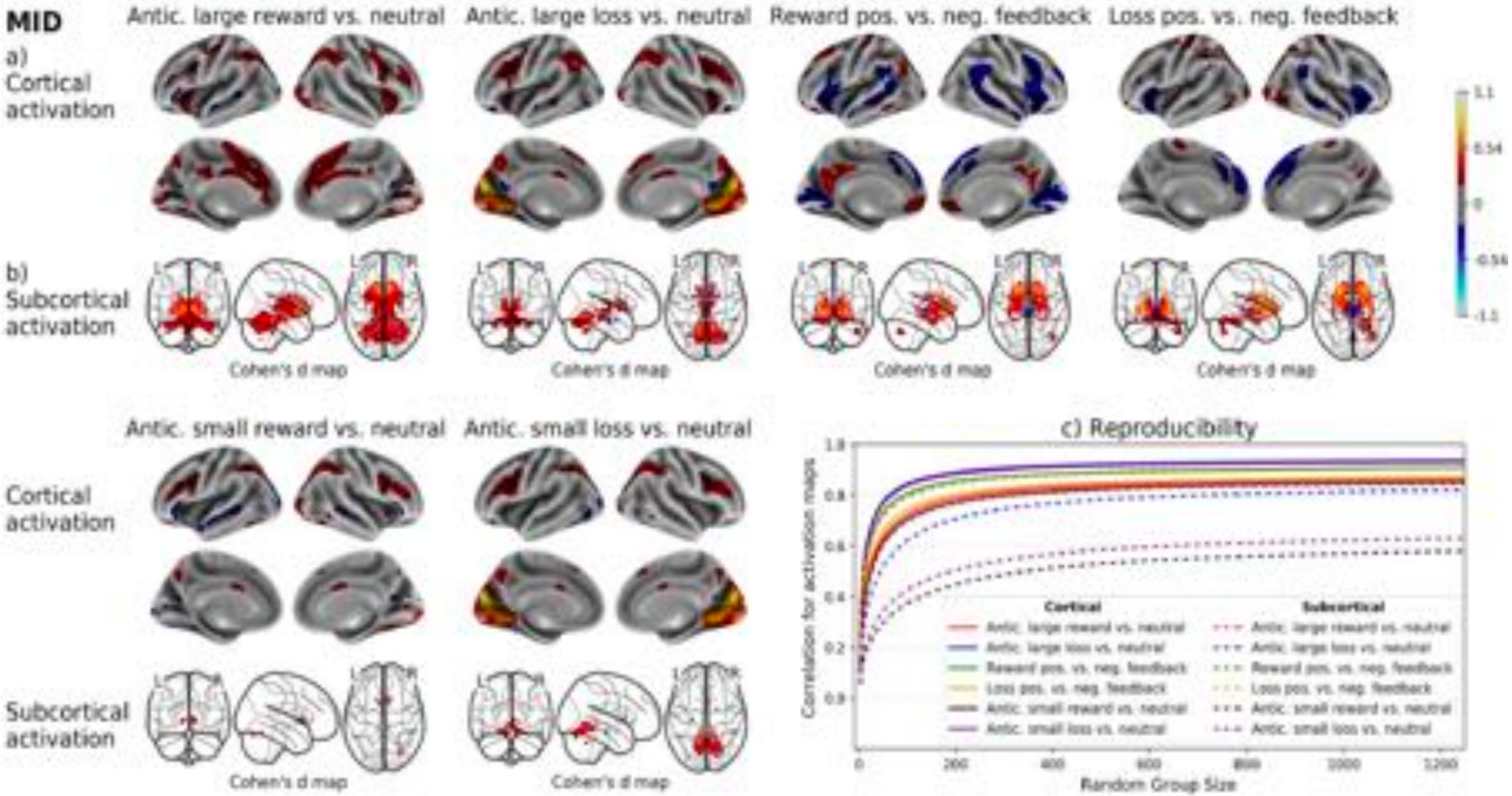
b) Subcortical activation



Cortical activation



fMRI task descriptions



Learning Objectives of this Lecture

ABCD-ReproNim

- Imaging Protocol and Pulse Sequences (Structural and Functional)
- Quality Assurance
- fMRI Task Description, Justification, Age-Appropriateness, and Relevance to ABCD Study
- Minimally Processed Pipelines
- ABCC - Collection 3165

Processing Pipelines

ABCD-ReproNim

Don Hagler

Sean Hatton

ELSEVIER

NeuroImage

Available online 12 August 2019, 116091

In Press, Journal Pre-proof

Image processing and analysis methods for the Adolescent Brain Cognitive Development Study

Donald J. Hagler Jr. [a], SeanN. Hatton [a], M. Daniela Cornejo [a], Carolina Makowski [b], Damien A. Fair [c], Anthony Steven Dick [d], Matthew T. Sutherland [d], B.J. Casey [e], Deanna M. Barch [f], Michael P. Harms [f], Richard Watts [e], James M. Bjork [g], Hugh P. Garavan [h], Laura Hilmer [a], Christopher J. Pung [a], Chelsea S. Sicat [a], Joshua Kuperman [a], Hauke Bartsch [a] ... Anders M. Dale [a]

Show more

https://doi.org/10.1016/j.neuroimage.2019.116091

Structural MRI

T1-weighted

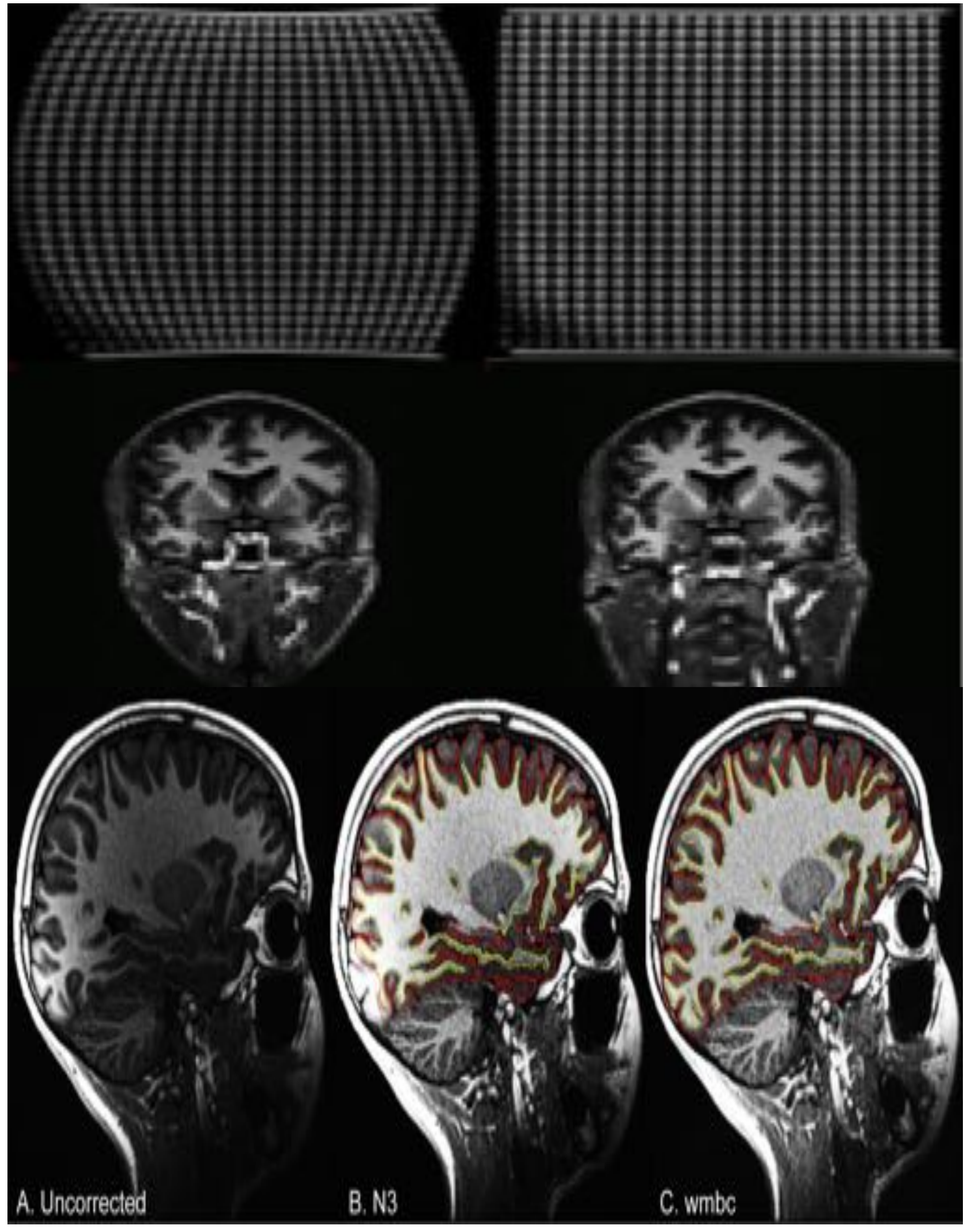
T2-weighted

Processing Pipelines

ABCD-ReproNim

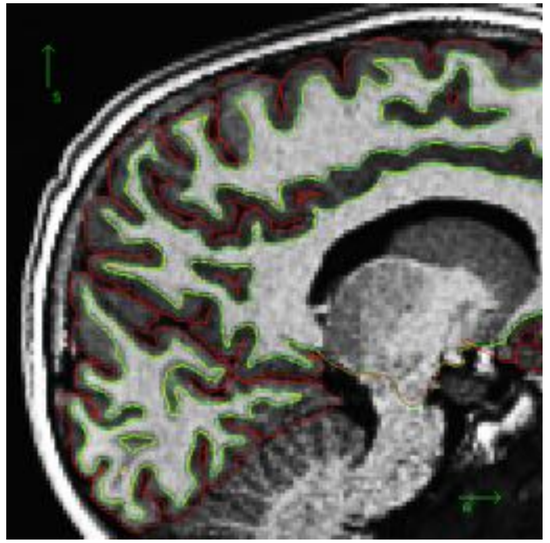
sMRI processing

- gradient nonlinearity distortion correction
  T_1-weighted (T_1w) and T_2-weighted (T_2w) structural images (minimally preprocessed)
- registration of T_2w images to T_1w images
  using mutual information and atlas-based pre-registration (minimally preprocessed)
- intensity non-uniformity correction
  white matter bias correction (wmbc)
  based on tissue segmentation and sparse spatial smoothing (minimally preprocessed)
- resampling into rigid-body registration with a custom atlas with 1 mm isotropic voxels (minimally preprocessed)
- brain segmentation and
  cortical surface reconstruction
  from T1w images using FreeSurfer v5.3.0



sMRI derived measures

- morphometric measures
  cortical thickness, area, volume, sulcal depth, and gyrification
- image intensity measures
  T_1w, T_2w, and cortical contrast (normalized gray/white difference)
- cortical surface ROIs
  using standard FreeSurfer parcellations
- subcortical ROIs
  intensity-based measures and volumes



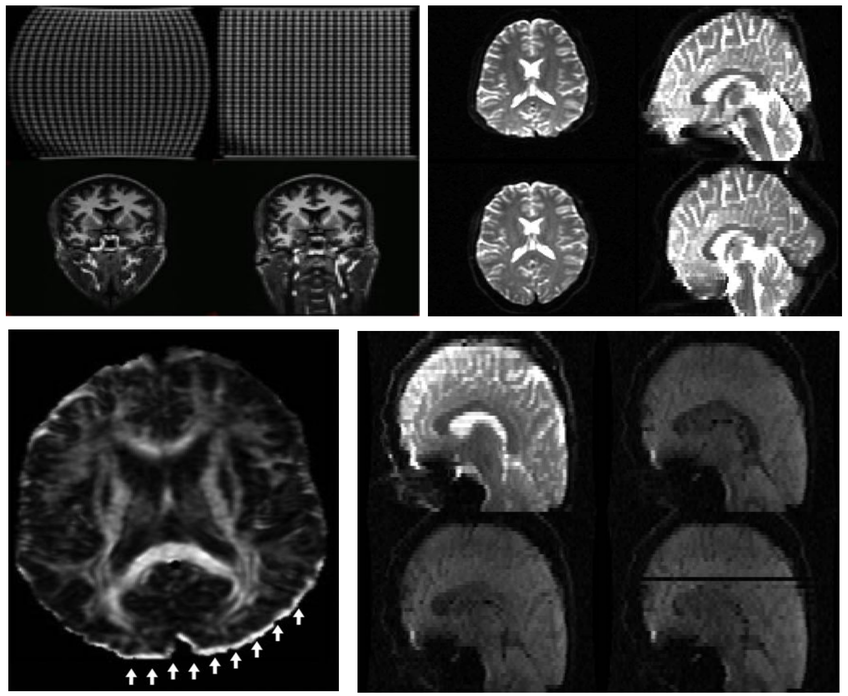
Diffusion MRI

Diffusion Tensor Imaging (DTI)

Restriction Spectrum Imaging (RSI)

dMRI preprocessing

- head motion correction
  registration to synthesized diffusion weighted volumes
  diffusion gradient matrix adjusted for head rotation
- correction of spatial distortions
  caused by B0 field inhomogeneity, eddy currents, gradient nonlinearities
- robust diffusion tensor estimation
  to identify and replace dark slices caused by abrupt head motion
- registration of T2-weighted b=0 images
  to T1w structural images using mutual information
- resampled into a standard orientation
  with 1.7 mm isotropic voxels



Jones and Cercignani, 2010

dMRI-derived measures

- diffusion tensor imaging (DTI)

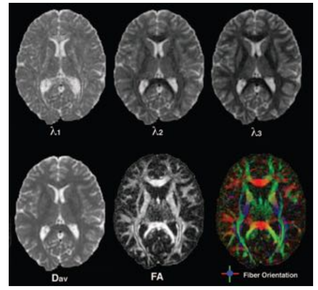
  estimate principal diffusion orientations, fractional anisotropy, and mean, radial, and axial diffusivity

- restriction spectrum imaging (RSI)

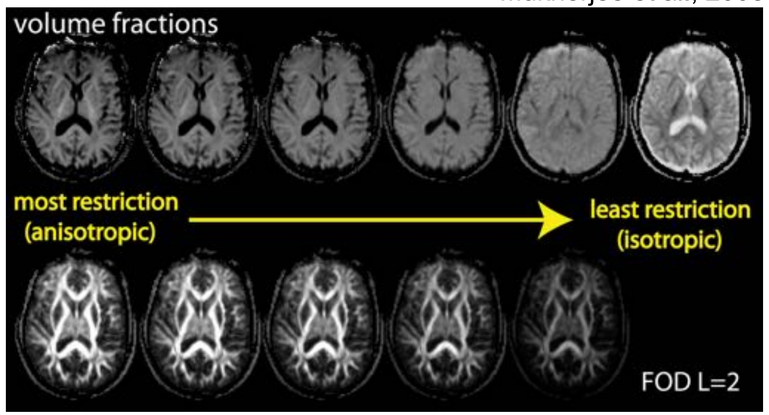
  “restricted” and “hindered” diffusion within individual voxels - intracellular and extracellular signal fractions

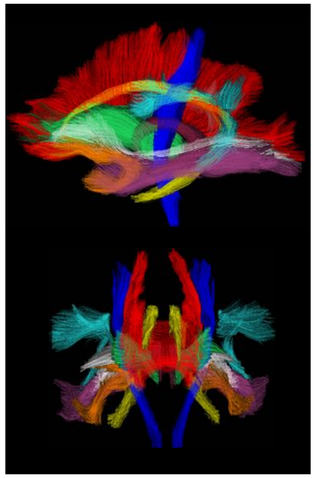
- average dMRI-derived measures

  white matter tracts, subcortical gray matter structures, cortical parcellations (cortical gray matter and peri-cortical white matter)

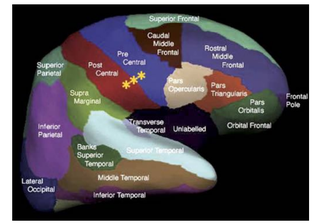


Mukherjee et al., 2008





Fischl et al., 2002



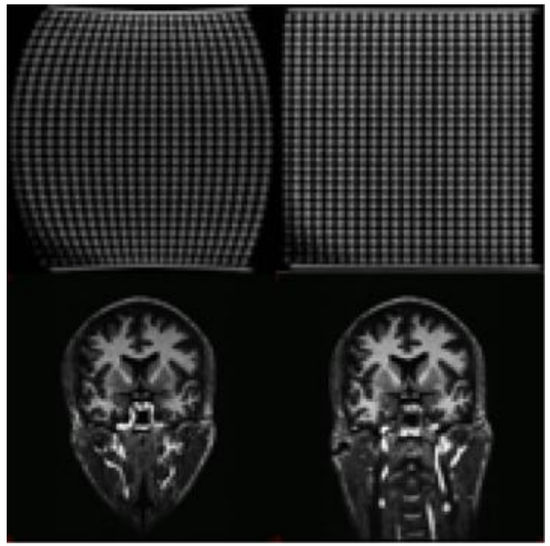
Desikan et al., 2006

Hagler et al., 2009

Resting state fMRI

fMRI preprocessing

- B0 distortion correction using reversing gradient method
  - B_0 distortion field estimated from spin echo images and applied to each gradient echo frame after accounting for head motion
  - note: spin-echo calibration scans do not suffer from signal “drop-out” like the gradient-echo images, for more accurate estimation of distortion field
- gradient nonlinearity distortion correction
- head motion correction
  - each frame registered to first using AFNI’s 3dvolreg
  - between scan motion correction across all fMRI scans in imaging event
- registration to T1
  - between T_2-weighted, spin-echo B_0 calibration scans and T_1-weighted structural images performed using mutual information



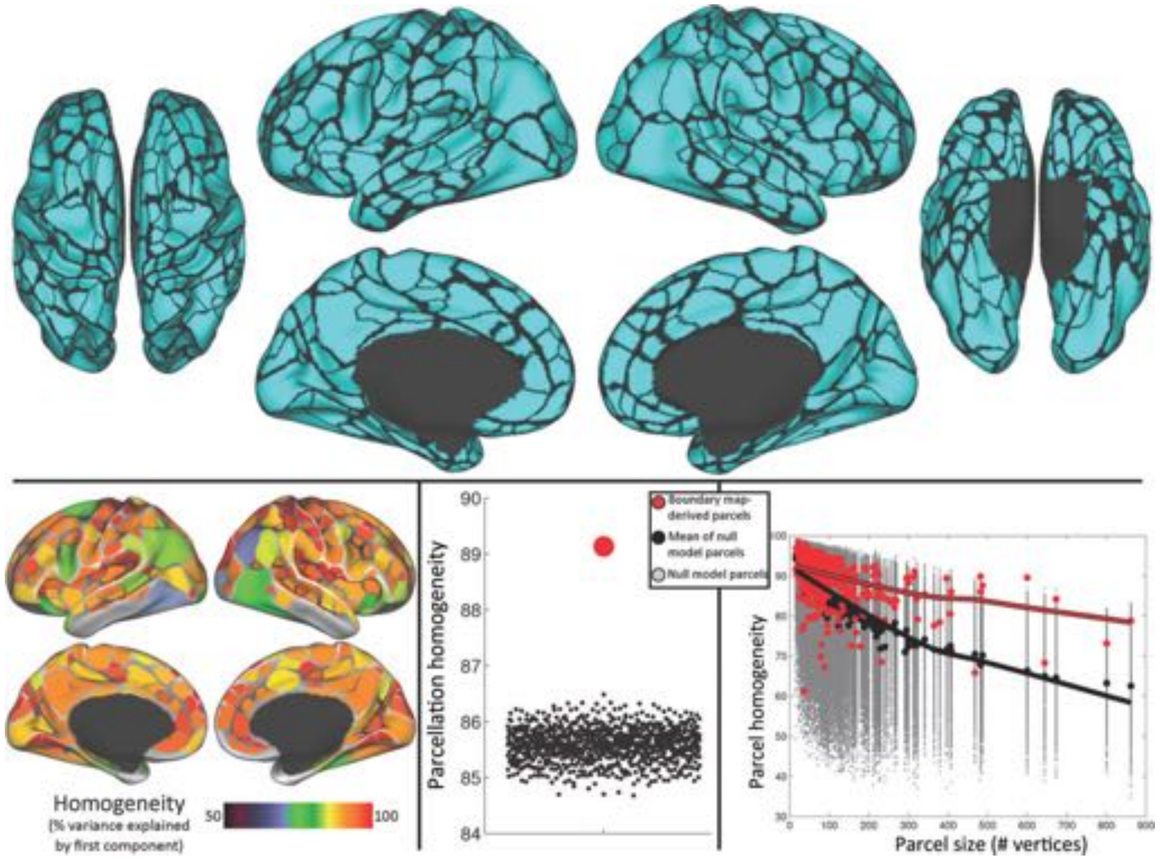
Minimally Preprocessed

Resting-state fMRI specific preprocessing

- remove of initial volumes
  - Siemens: 8 TRs
  - Philips: 8 TRs
  - GE: 5 TRs (DV25) or 16 TRs (DV26)
- filter data
  - normalize and detrend time courses
  - regress out signals correlated with motion, mean white matter, ventricles, and whole brain
  - censor frames with excessive motion: > 0.2 mm FD, >= 5 contiguous frames, motion filtered for respiratory signals
  - bandpass filter: 0.009 - 0.08 Hz
- resample voxel timeseries data to cortical surface mesh vertices
  - 1 mm projection away from gray/white boundary along normal vector (trilinear interpolation, perpendicular to surface)

Seed-based correlation analysis

- average time courses
  - within cortical surface and subcortical ROIs
- pair-wise correlations between ROIs
  - functionally-defined parcels and subcortical ROIs
  - Fisher Z transform of r values
- average correlation within and between pre-defined networks
  - e.g. default, fronto-parietal, dorsal attention, etc.
- correlation between each subcortical ROI and each network



Gordon, E.M., et al., Generation and Evaluation of a Cortical Area Parcellation from Resting-State Correlations. Cereb Cortex, 2014.

Task fMRI

Monetary Incentive Delay (MID) Task
Stop Signal Task (SST)
Emotional N-Back (nBack) Task
Behavioral performance

Task-related fMRI analysis

- task-fMRI specific preprocessing
  - remove initial volumes: Siemens: 8 TRs, Philips: 8 TRs, GE: 5 TRs (DV25) or 16 TRs (DV26)
  - normalize and demean time courses
- general linear model (GLM) using AFNI's 3dDeconvolve
  - nuisance regressors to model baseline, cubic polynomial, and motion
    - motion estimates, derivatives, and squared estimates and derivatives included
  - time points with framewise displacement (FD) > 0.9 mm censored
  - hemodynamic response function
    - modelled as gamma functions with temporal derivatives, using AFNI's SPMG model
    - for MID and SST models, events modeled as instantaneous
    - for EN-back, duration of cues (~3 s) and trial blocks (~24 s) modeled as square waves convolved with SPMG
- GLM coefficients and t-statistics sampled onto cortical surface
  - projected 1mm into cortical gray matter along surface normal vector
- ROI analyses
  - subcortical segmentation and anatomical parcellation

Task fMRI behavior

After exclusion criteria, task fMRI behavior failed:

- MID 6.3%
  - High incentive and/or
  - Low performance criteria
- SST 11.1%
- nBack 15.0%
  - Fatigue?

Current/future pipeline development

- Enhanced processing QC
- fMRI visual QC, MRIQC
- Enhanced DTI preprocessing
- Enhanced fMRI motion correction
- FreeSurfer 6/FSL 6
- Derived data in BIDS format (e.g. FreeSurfer)
- Follow-up identification
- Longitudinal metrics
- Between scan correction (T1w/T2w/DTI)

Learning Objectives of this Lecture

ABCD-ReproNim

- Imaging Protocol and Pulse Sequences (Structural and Functional)
- Quality Assurance
- fMRI Task Description, Justification, Age-Appropriateness, and Relevance to ABCD Study
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- ABCC - Collection 3165

ABCD-BIDS Community Collection (ABCC)

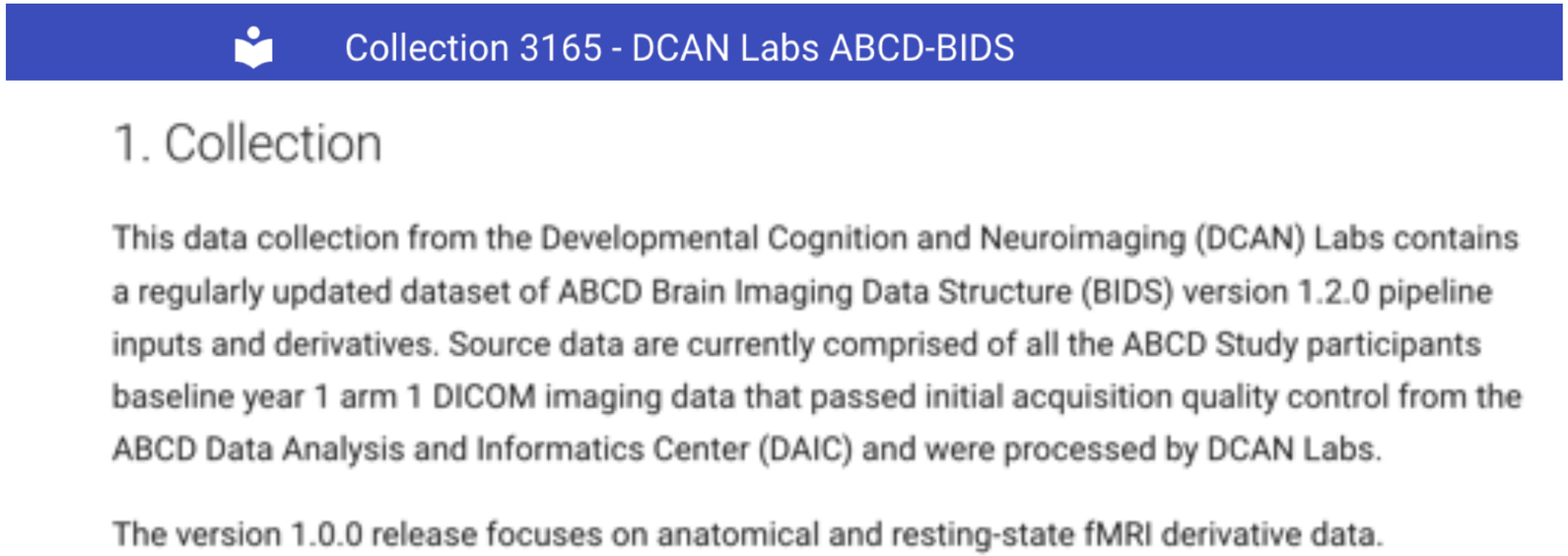
ABCD-ReproNim

The ABCC data (ABCD-3165) and ABCC analytic utilities were designed to:

1) supplement current data sharing via collection 3165 with an accessible platform for community sharing of derived data via our NDA BIDS prepare and upload tool (https://github.com/DCAN-Labs/nda-bids-upload)

2) assist investigators in conducting state-of-the art statistical analyses using software packages designed to work with ABCD-3165

3) provide integrated data and analytical utilities for result verification.



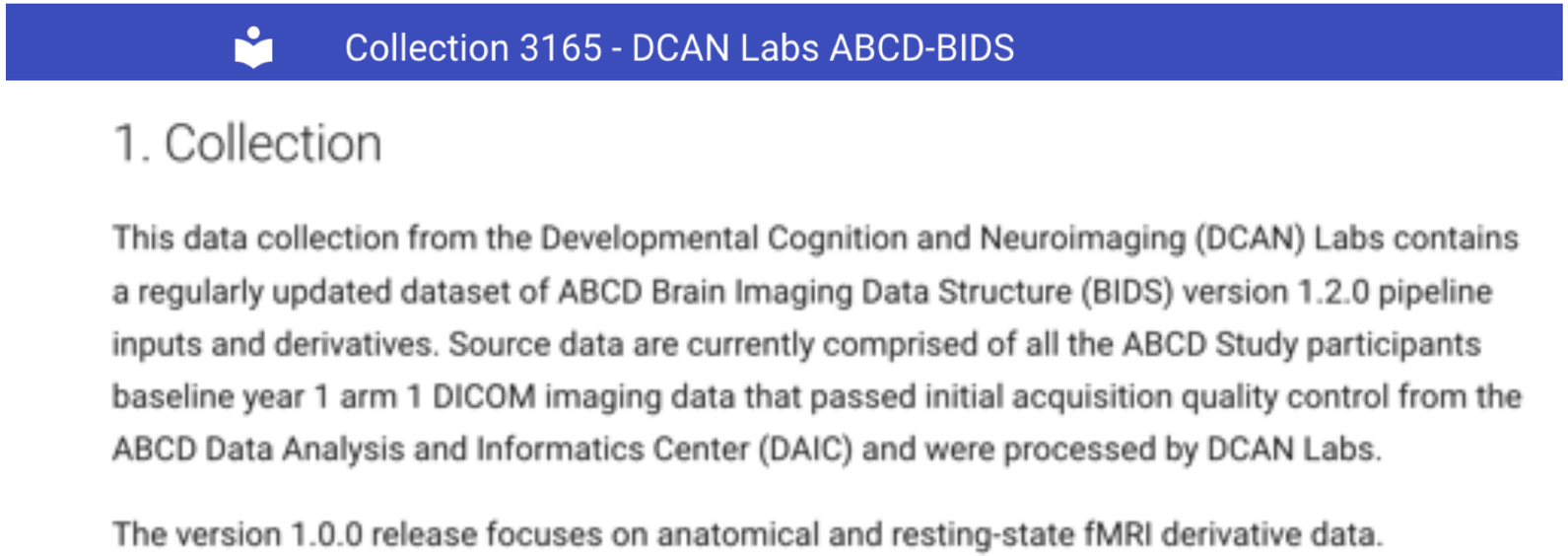
https://collection3165.readthedocs.io/

https://github.com/ABCD-STUDY/nda-abcd-collection-3165

ABCD-BIDS Community Collection (ABCC)

ABCD-ReproNim

The *ABCD BIDS Community Collection* (ABCC, ABCD-3165) enables community contributions and usage, with standardized formatting, and a governance structure for contributions (BIDS derivatives structure) to maintain compliance with the NDA's important data usage standards.



https://collection3165.readthedocs.io/ https://github.com/ABCD-STUDY/nda-abcd-collection-3165

ABCD-BIDS Community Collection (ABCC)

ABCD-ReproNim

- Built on the BIDS Standard
  - Tools to assist the community downloading from ABCC, converting their data to the BIDS and contributing to the ABCC
    - nda-abcd-s3-downloader: https://github.com/ABCD-STUDY/nda-abcd-s3-downloader
    - ABCD-DICOM2BIDS: https://github.com/ABCD-STUDY/abcd-dicom2bids
    - File-Mapper: https://github.com/DCAN-Labs/file-mapper
    - NDA-BIDS uploader: https://github.com/DCAN-Labs/nda-bids-upload

FILE OR FOLDER NAME	DESCRIPTION
ABCD-BIDS (where #### means sub-SUBID_ses-SESID) ├── dataset_description.json ├── README ├── CHANGES ├── task-(MID|nback|rest|SST)_bold.json	Root folder of the whole ABCD-BIDS dataset. JSON and text files describe the contents of the repository and recent updates.
├── derivatives │ ├── freesurfer-5.3.0-HCP/sub-SUBID/ses-SESID/stats/* │ └── abcd-hcp-pipeline │ └── sub-SUBID │ └── ses-SESID │ ├── img/* │ ├── ####.html │ ├── anat │ │ ├── ####_hemi-(L|R)_space-(MNI|T1w)_mesh-(fsLR32k|fsLR164k|native)_midthickness.surf.gii │ └── func │ ├── ####_task-(MID|nback|rest|SST)_bold_desc-filtered_timeseries.dtseries.nii	A folder for data derived from processing - can contain multiple derived datasets separated by folder (e.g. freesurfer vs. DCAN-abcd-pipeline) DCAN-abcd-pipeline outputs are sorted by subject and session DCAN labs executive summary HTML images folder and HTML file Anatomical imaging derivatives Functional imaging derivatives
├── sourcedata │ └── sub-SUBID │ └── ses-SESID │ └── func │ └── ####_task-(MID|nback|SST)_run-0#_bold_EventRelatedInformation.txt	A folder containing external data acquired during scanning, such as event timing files from task runs. Files sorted by subject, session, and data type
└── sub-SUBID └── ses-SESID ├── anat/####(_rec-normalized)_(T1w|T2w).(json|nii.gz)	Input imaging data sorted by subject, session, and data type

ABCD-BIDS utilities

ABCD-BIDS pipeline

CONTAINERIZED SOFTWARE

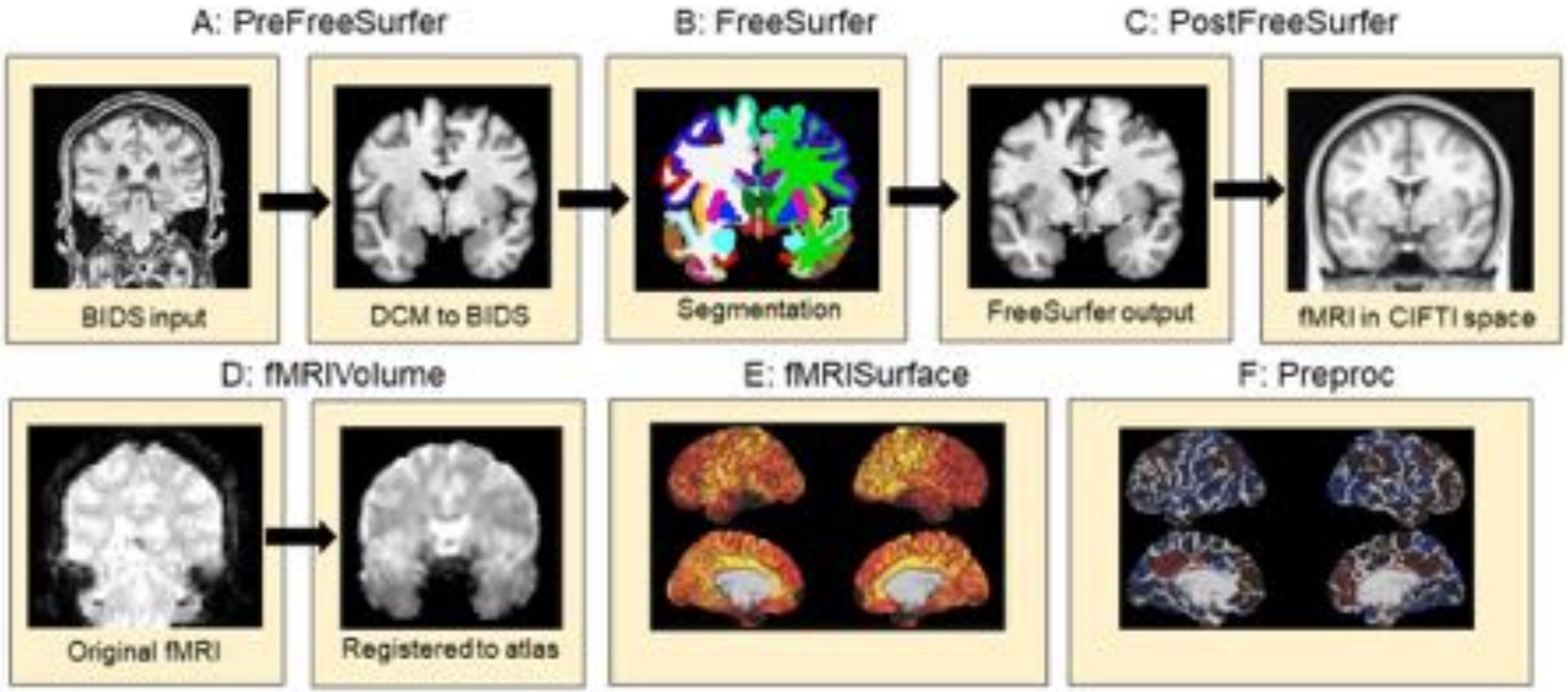
STANDARDIZED INPUTS

MINIMALISTIC INTERFACE

https://github.com/DCAN-Labs/abcd-hcp-pipeline

ABCD-BIDS data utilities

ABCD-BIDS pipeline



https://github.com/DCAN-Labs/abcd-hcp-pipeline

ABCD-BIDS utilities

ABCD-BIDS pipeline

Minimalistic Interface

There are many additional options available, but the pipeline can be run by providing only the input and output folders.

```
docker run \
-v /path/to/input:/bids_input  \
-v /path/to/output:/output  \
-v /path/to/freesurfer/license.txt:/license \
abcd-hcp-pipeline /bids_input /output –freesurfer-license=/license
[OPTS]
```

The arguments highlighted in yellow are the only ones the user provided here.

ABCD-BIDS utilities

ABCD-BIDS pipeline

Options/Features/Differences with HCP pipelines

1. Detects any modality configuration
2. PreFreeSurfer and PostFreeSurfer modifications to improve performance on certain datasets
3. Study Specific Template for improved Masking and Nonlinear Registration, useful for aging populations with larger ventricles
4. Functional Connectivity Preprocessing Module
5. Respiratory Artifact filtering parameters
6. Quality Control Image Module

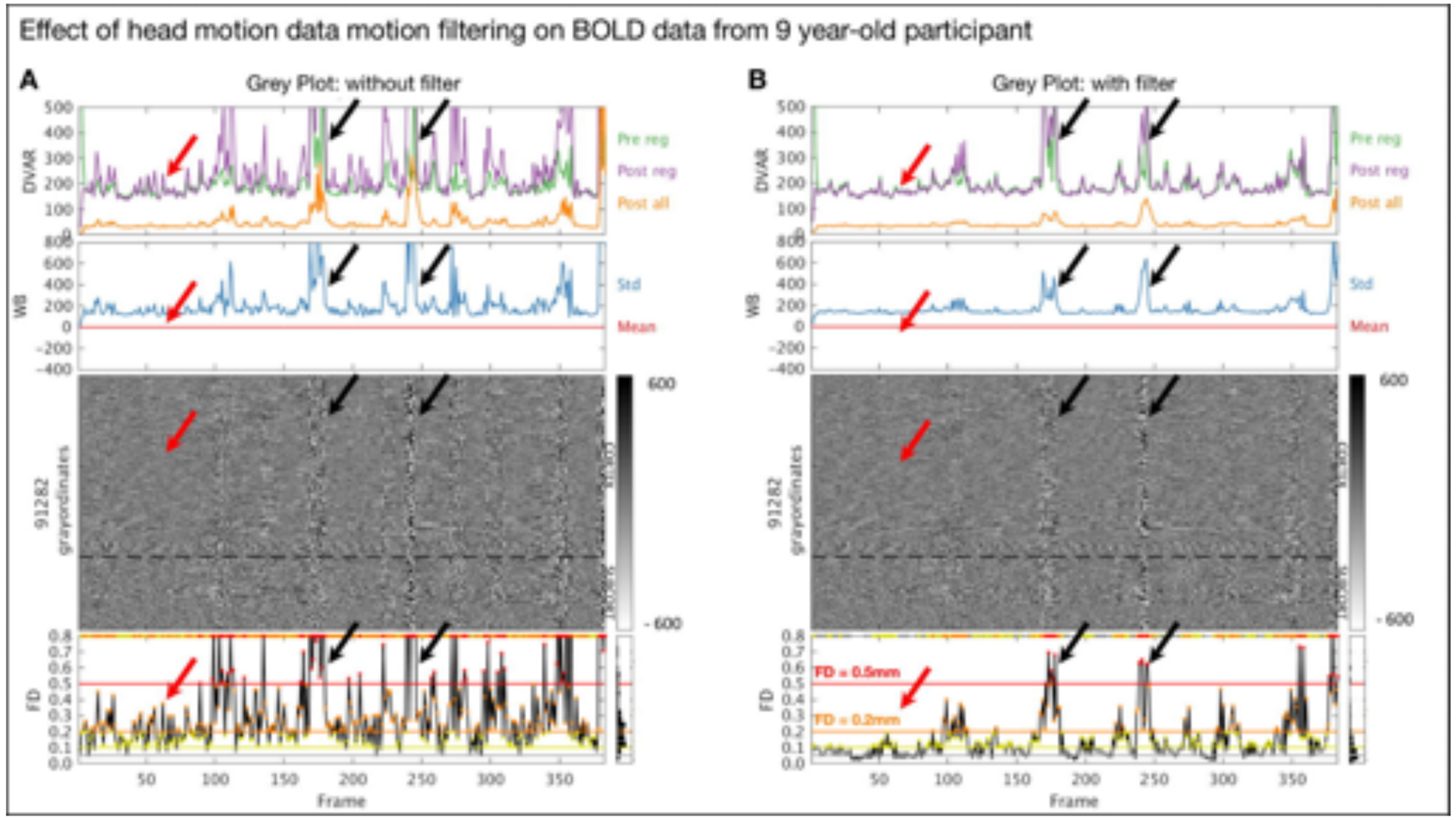
ABCD-BIDS utilities

ABCD-BIDS pipeline

- Works with ABCD Data
- Works with Legacy/Non-ABCD Data acquisitions
- Works with Specialized populations (e.g. Aging)

https://github.com/DCAN-Labs/abcd-hcp-pipeline

ABCD-BIDS utilities

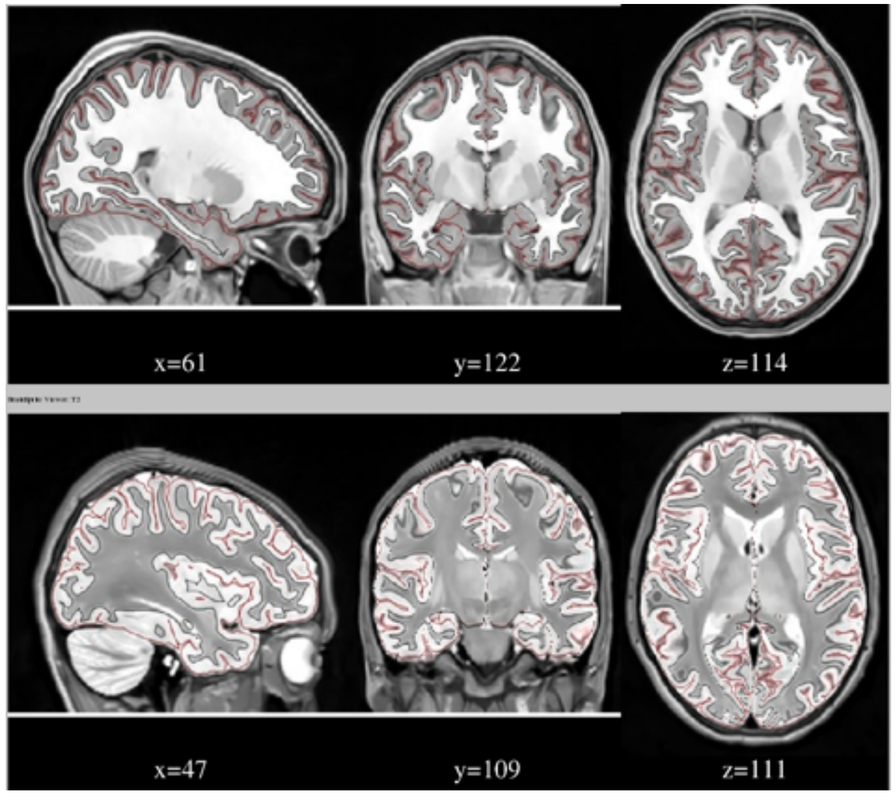


Fair et al, Neuroimage ,2020

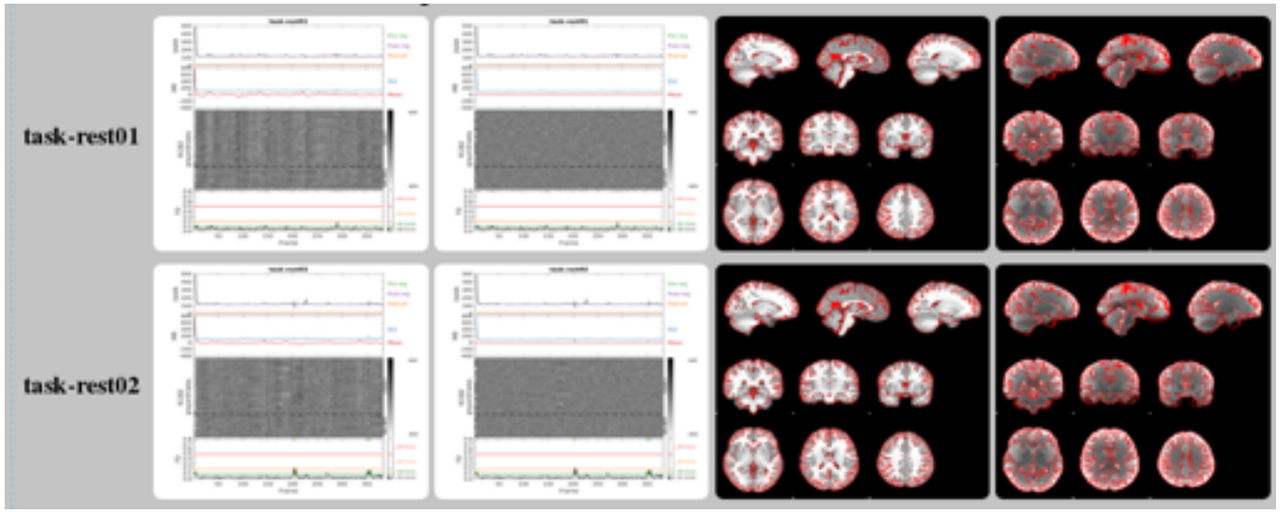
https://github.com/DCAN-Labs/abcd-hcp-pipeline

ABCD-BIDS utilities

Executive Summary



Quality control images are formatted into a web page at the end of the pipeline,



https://github.com/DCAN-Labs/abcd-hcp-pipeline

ABCD-BIDS utilities

ABCD-BIDS pipeline

- Compatible with fMRIprep
  - *Data Release winter of 2020*
- Compatible with QSIprep
  - *Data Release winter of 2020-2021*
- Task Module Update
  - *Data Release winter of 2020*

https://github.com/DCAN-Labs/abcd-hcp-pipeline

ABCD-BIDS utilities

On Reproducibility

MENU

nature

Article | Published: 20 May 2020

Variability in the analysis of a single neuroimaging dataset by many teams

Rotem Botvinik-Nezer, Felix Holzmeister, [...] Tom Schonberg

Nature **582**, 84–88(2020) | Cite this article

25k Accesses | **9** Citations | **950** Altmetric | Metrics

Towards Reproducible Brain-Wide Association Studies (BWAS)

Scott Marek

Brenden Tervo-Clemmens

Nico Dosenbach

Damien Fair

Scott Marek*, Brenden Tervo-Clemmens*, Finnegan J. Calabro, David F. Montez , Benjamin P. Kay , Alexander S. Hatoum, Meghan Rose Donohue, William Foran, Ryland L. Miller, Eric Feczko, Oscar Miranda-Dominguez, Alice M. Graham, Eric A. Earl, Anders J. Perrone, Michaela Cordova, Olivia Doyle, Lucille A. Moore, Greg Conan, Johnny Uriarte, Kathy Snide, Angela Tam, Jianzhong Chen, Dillan J. Newbold, Annie Zheng, Nicole A. Seider, Andrew N. Van, Timothy O. Laumann, Wesley K. Thompson, Deanna J. Greene, Steven E. Petersen, Thomas E. Nichols, B.T. Thomas Yeo, Deanna M. Barch , Hugh Garavan, Beatriz Luna, Damien A. Fair#, Nico U.F. Dosenbach#

*Shared First Author
#Shared Senior Author

Adolescent Brain Cognitive Development

PITTSBURGH SUPERCOMPUTING CENTER

What are the effect sizes of brain-behavior correlations?

The largest univariate effect size was |r|=.16, top 1% |r| = .06, median |r| = .01

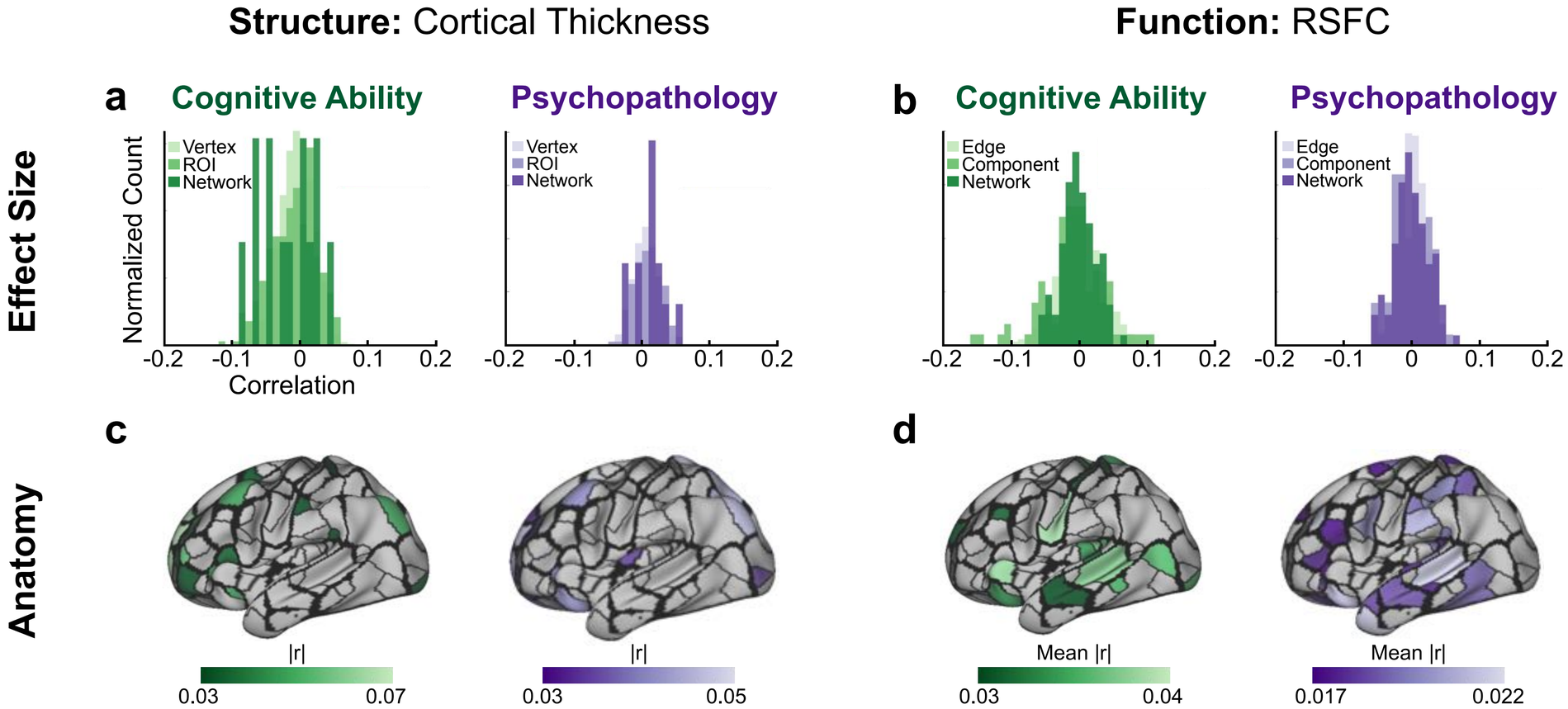


Figure 1: Marek & Tervo-Clemmens* et al., 2020*

What are the effect sizes of brain-behavior correlations?

Effect Sizes are Small!

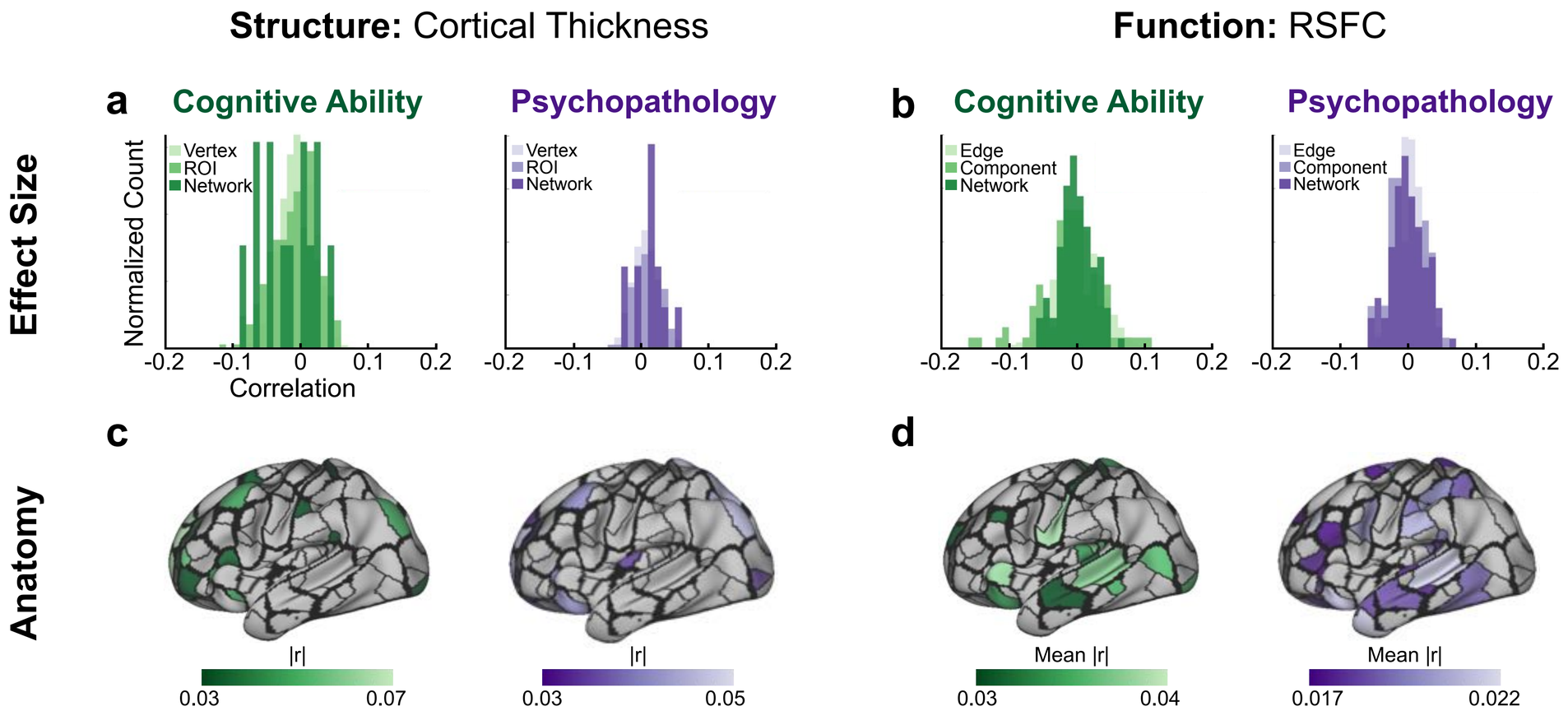


Figure 1: Marek & Tervo-Clemmens* et al., 2020*

ARMS: ABCD Reproducible Matched Samples

ABCD Resource Demographics table			
continuous	**Group1 (N=5786)**	**Group2 (N=5786)**	**Group3 (N=303)**
	mean (sd)	**mean (sd)**	**mean (sd)**
age (months)	119.01 (7.47)	118.87 (7.43)	119.07 (7.81)
demo_ed_v2	4.22 (.79)	4.21 (.79)	4.28 (.76)
max parent ed.	17.07 (2.67)	17.06 (2.66)	16.75 (2.83)
combined inc.	7.24 (2.42)	7.23 (2.42)	6.93 (2.5)
categorical	**Group1 (N=5786)**	**Group2 (N=5786)**	**Group3 (N=303)**
	count (%)	**count (%)**	**count (%)**
# female	2799 (48.4)	2734 (47.3)	148 (48.8)
# anesthesia	1839 (31.8)	1828 (31.6)	87 (28.7)
# right handed	4605 (79.6)	4580 (79.2)	238 (78.5)
race	**Group1 (N=5786)**	**Group2 (N=5786)**	**Group3 (N=303)**
	count (%)	**count (%)**	**count (%)**
white	3719 (64.3)	3638 (62.9)	158 (52.1)
black	892 (15.4)	918 (15.9)	54 (17.8)
AIAK	27 (.5)	30 (.5)	5 (1.7)
NHPI	10 (.2)	6 (.1)	0
asian	130 (2.2)	136 (2.4)	10 (3.3)
other	239 (4.1)	244 (4.2)	38 (12.5)
unkown	87 (1.5)	86 (1.5)	12 (4.0)
combined	682 (11.8)	728 (12.6)	23 (7.6)
latinx	1176 (20.6)	1172 (20.3)	59 (19.5)

site	Group1 (N=5786)	Group2 (N=5786)	Group3 (N=303)
	count (%)	count (%)	count (%)
1	194 (3.4)	203 (3.5)	9 (3.0)
2	274 (4.7)	273 (4.7)	14 (4.6)
3	318 (5.5)	307 (5.3)	8 (2.6)
4	366 (6.3)	362 (6.3)	15 (5.0)
5	180 (3.1)	185 (3.2)	13 (4.3)
6	279 (4.8)	279 (4.8)	27 (8.9)
7	165 (2.9)	166 (2.9)	8 (2.6)
8	175 (3.0)	174 (3.0)	6 (2.0)
9	212 (3.7)	210 (3.6)	10 (3.3)
10	360 (6.2)	361 (6.2)	20 (6.6)
11	222 (3.8)	220 (3.8)	12 (4.0)
12	291 (5.0)	295 (5.1)	19 (6.3)
13	351 (6.1)	353 (6.1)	19 (6.3)
14	297 (5.1)	294 (5.1)	16 (5.3)
15	229 (4.0)	213 (3.7)	12 (4.0)
16	479 (8.3)	506 (8.7)	20 (6.6)
17	286 (4.9)	278 (4.8)	14 (4.6)
18	187 (3.2)	187 (3.2)	10 (3.3)
19	270 (4.7)	268 (4.6)	14 (4.6)
20	343 (5.9)	342 (5.9)	18 (5.9)
21	308 (5.3)	310 (5.4)	16 (5.3)

Big Data is Hard

* Brain-wide association studies (BWAS) often must take into account covariates that may impact an analysis of interest.

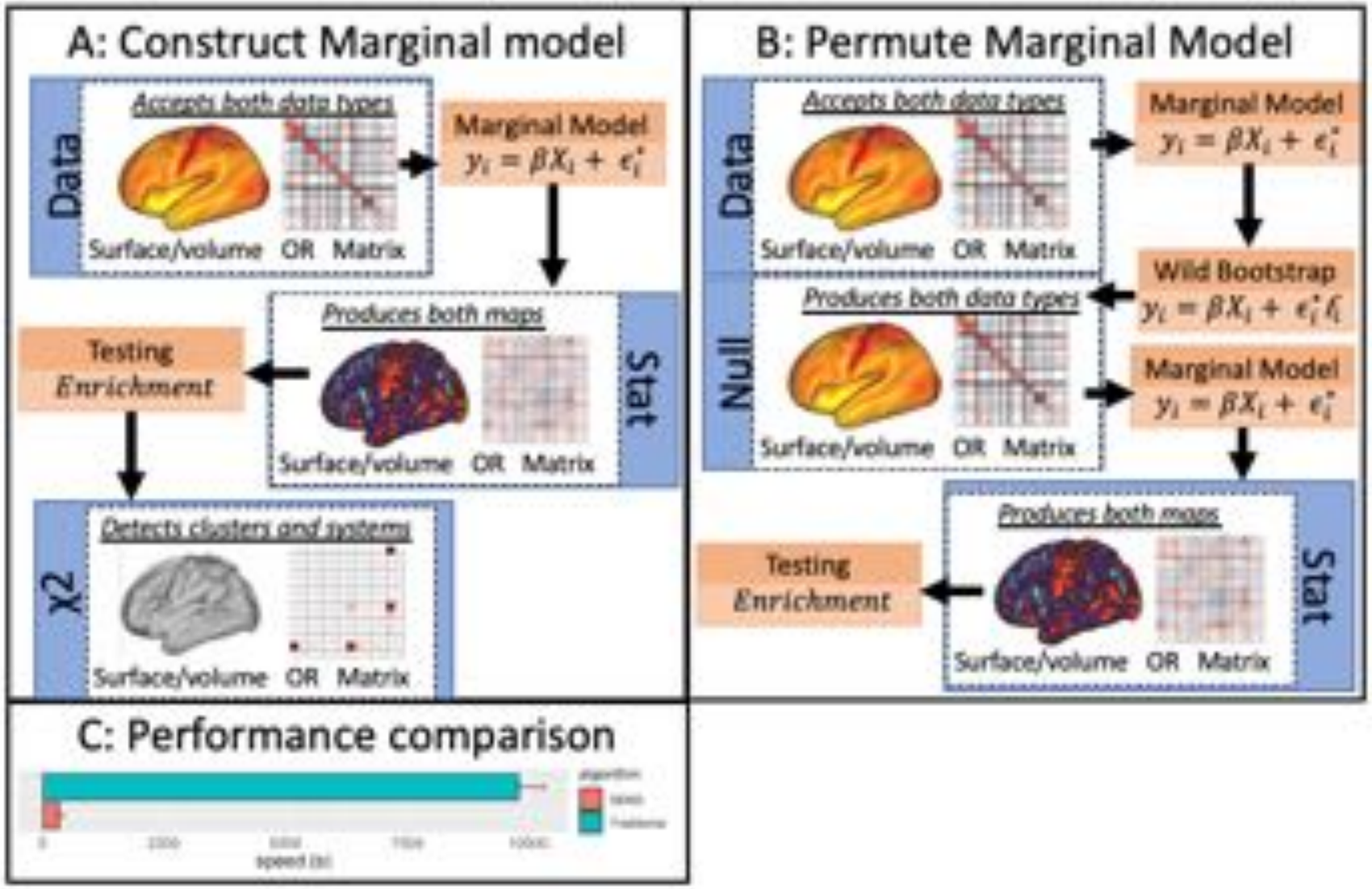
* ABCD study contains normally independent covariates that are “nested”.
    * For example, from 21 sites, MRI data were acquired across three different platforms (GE, Siemens, Philips). As a result, site and platform effects are likely to impact the measured data. Because not all dependent measures are overlapping (e.g., not every site has a different scanner platform), the covariance structure of the data is “nested”.

* “Nested” covariance structure can be accounted for with linear mixed effects models.
    * However, in imaging datasets where each image itself comprises 10’s of thousands of data elements, the sheer size and complexity of the ABCD study requires computationally intensive analyses – in some cases, statistics over a billion data points.

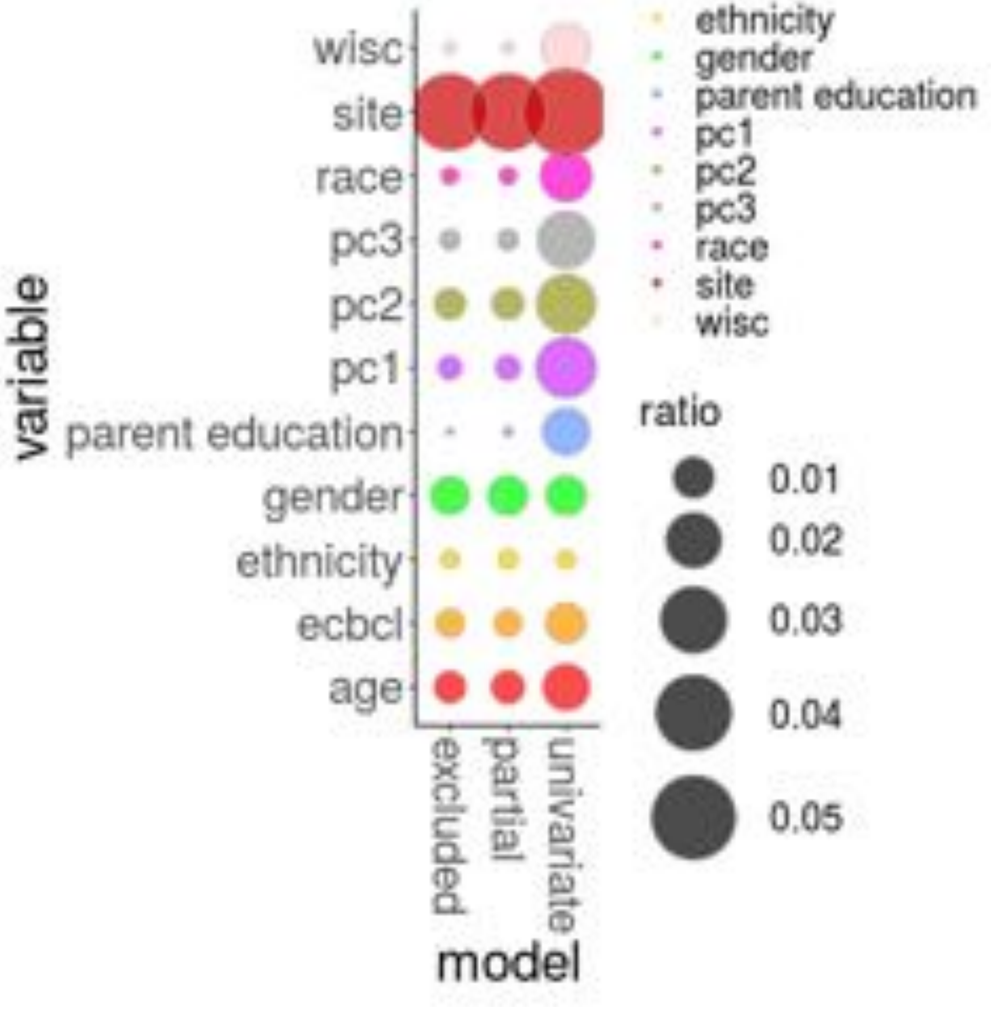
    * In addition, properly adjusting statistical significance in this scenario (for example, when using permutation testing becomes less reliable as the number of tested variables increases).

    * Therefore, the marginal model approach (Guillaume et al., 2014) was developed and a software package for testing brain behavior associations in large-scale studies like ABCD - the Sandwich Estimator For Neuroimaging Data (*SEND)*.

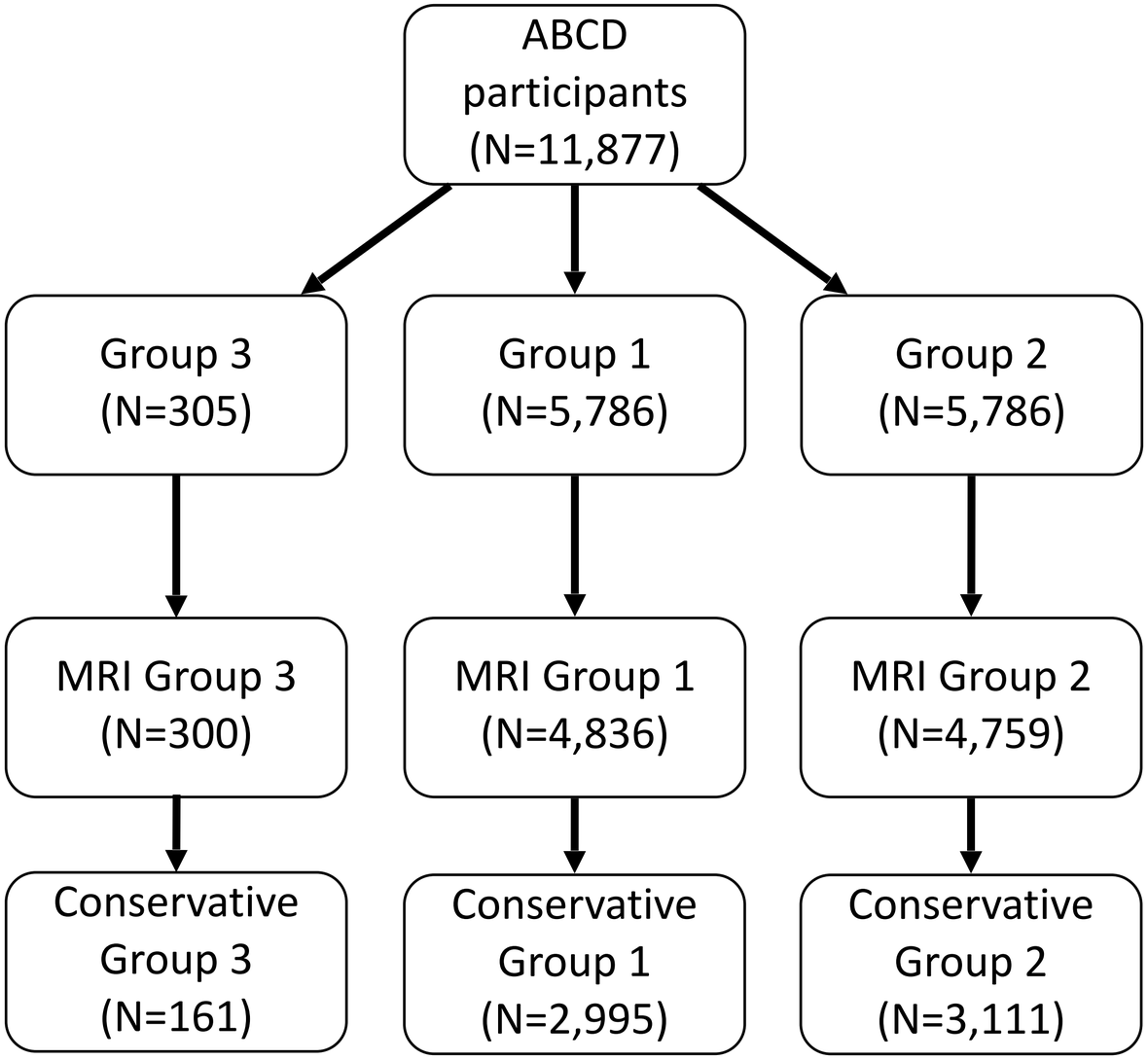
Sandwich Estimator for Neuroimaging Data (SEND): Robust BWAS



Important Sample Characteristics: Motion

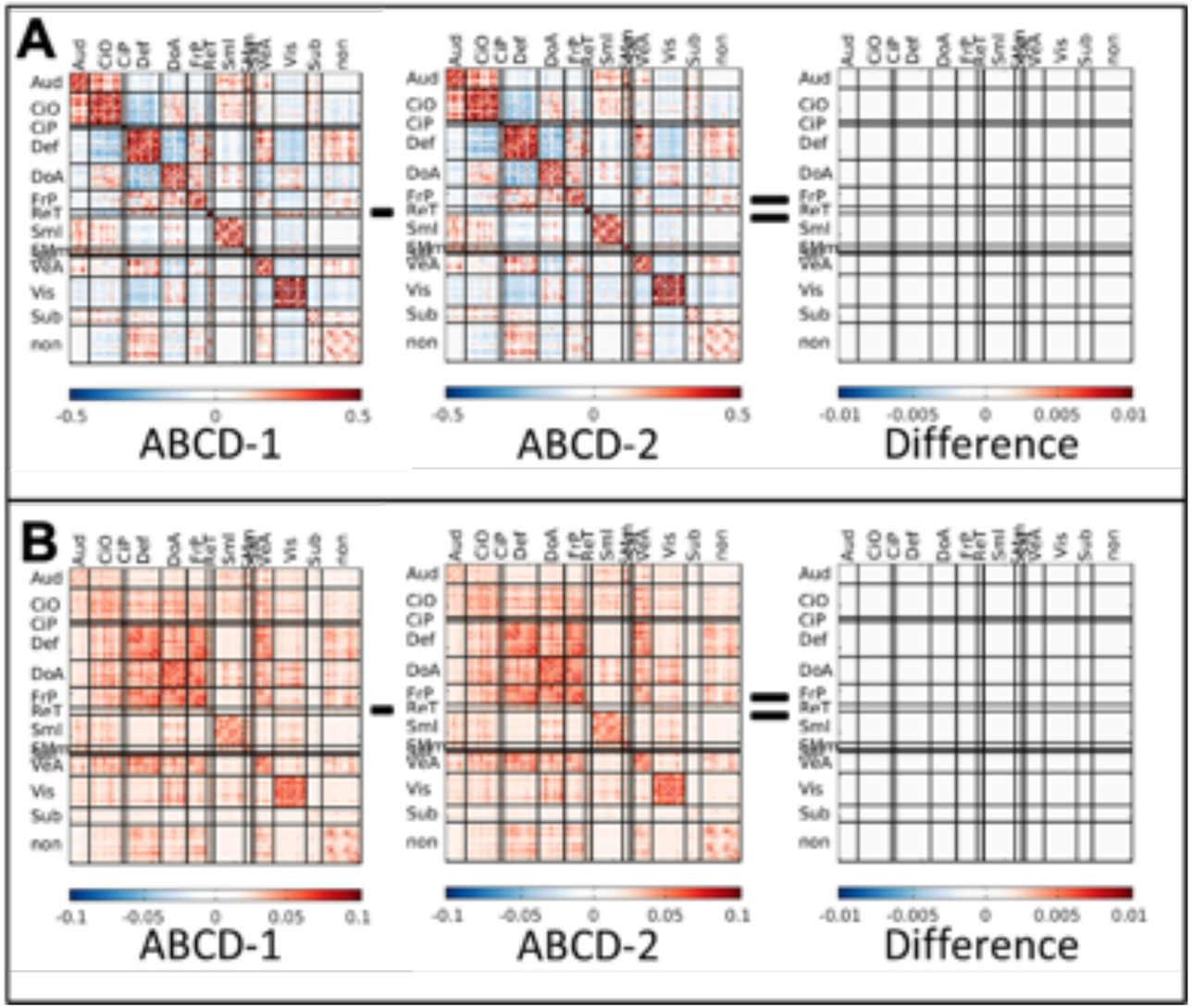


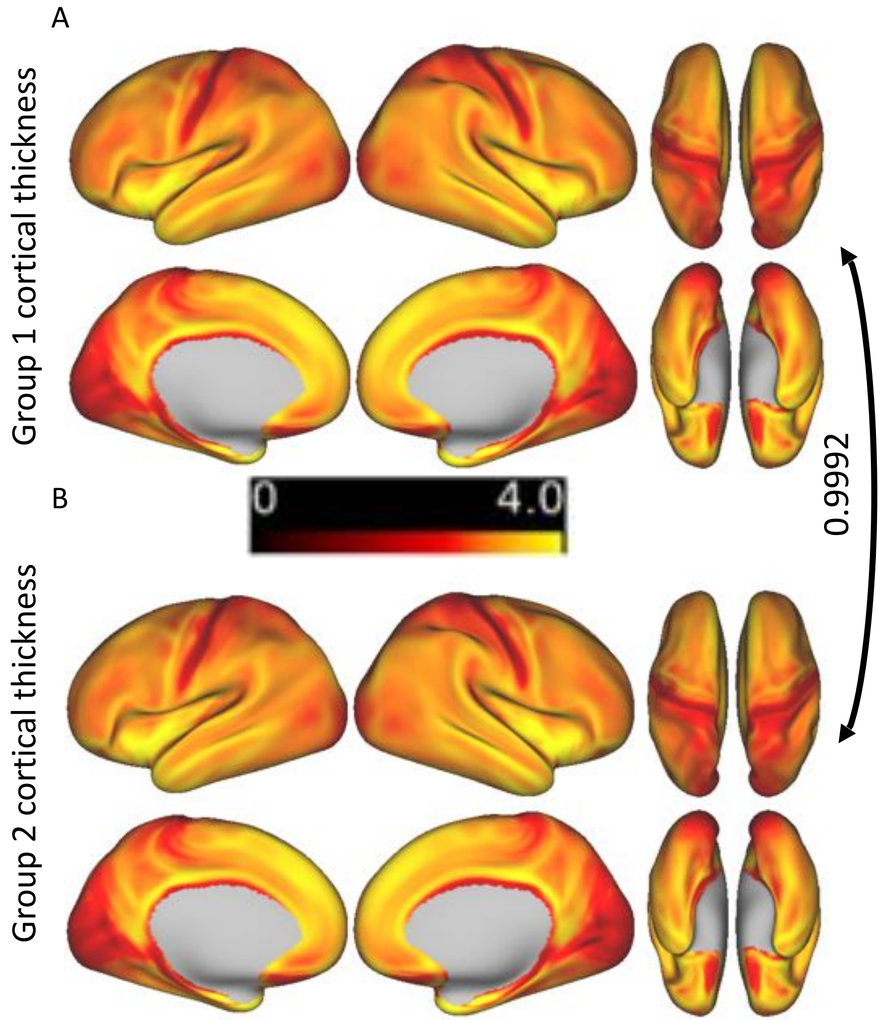
ARMS: ABCD Reproducible Matched Samples



ABCD-BIDS Community Collection (ABCC)

ABCD-ReproNim





Feczko et al., in prep

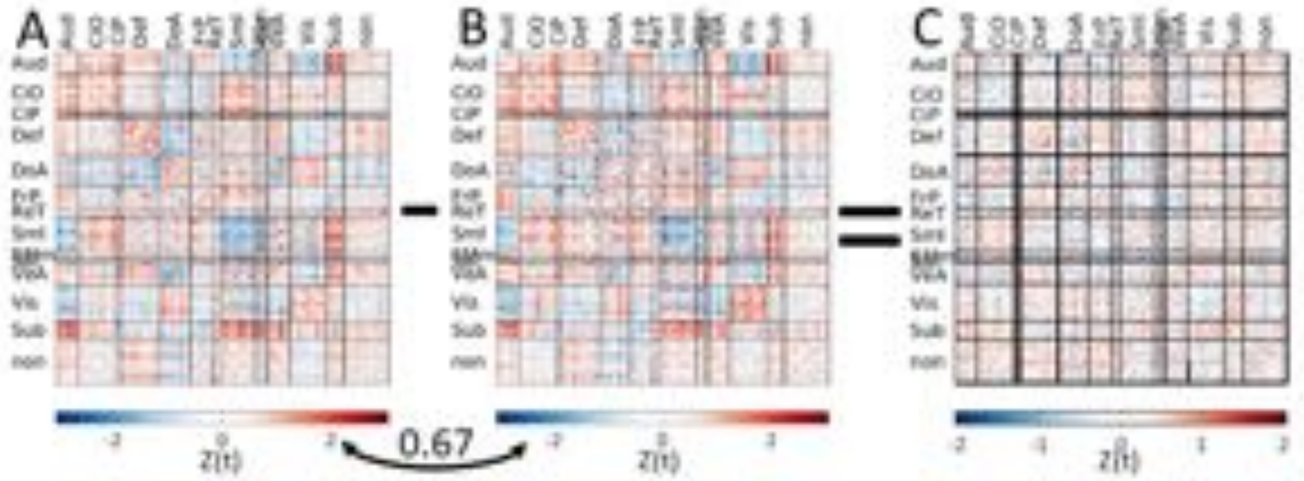
ABCC NDA Collection #3165

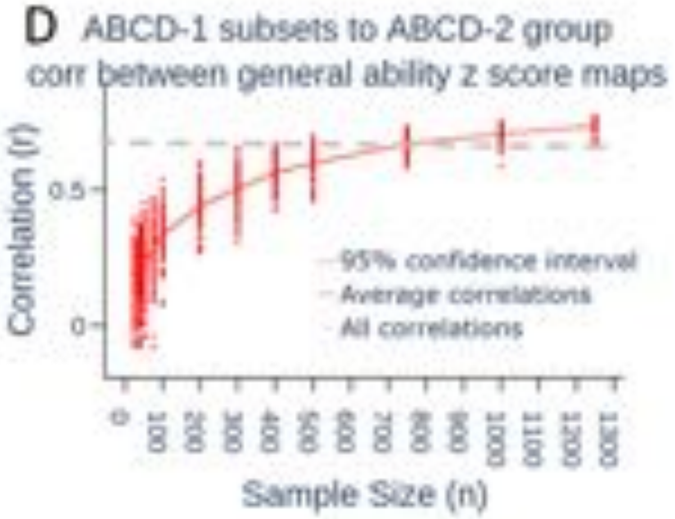
https://collection3165.readthedocs.io/en/stable/

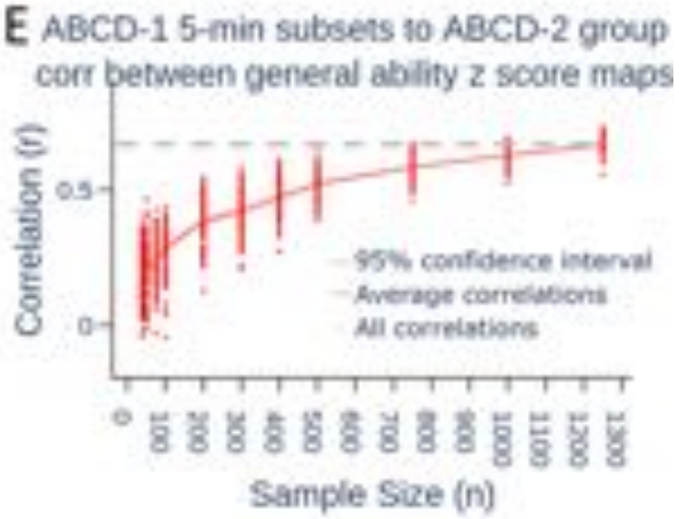
ABCD-BIDS Community Collection (ABCC)

ABCD-ReproNim

Brain-behavior Correlation (General ability)



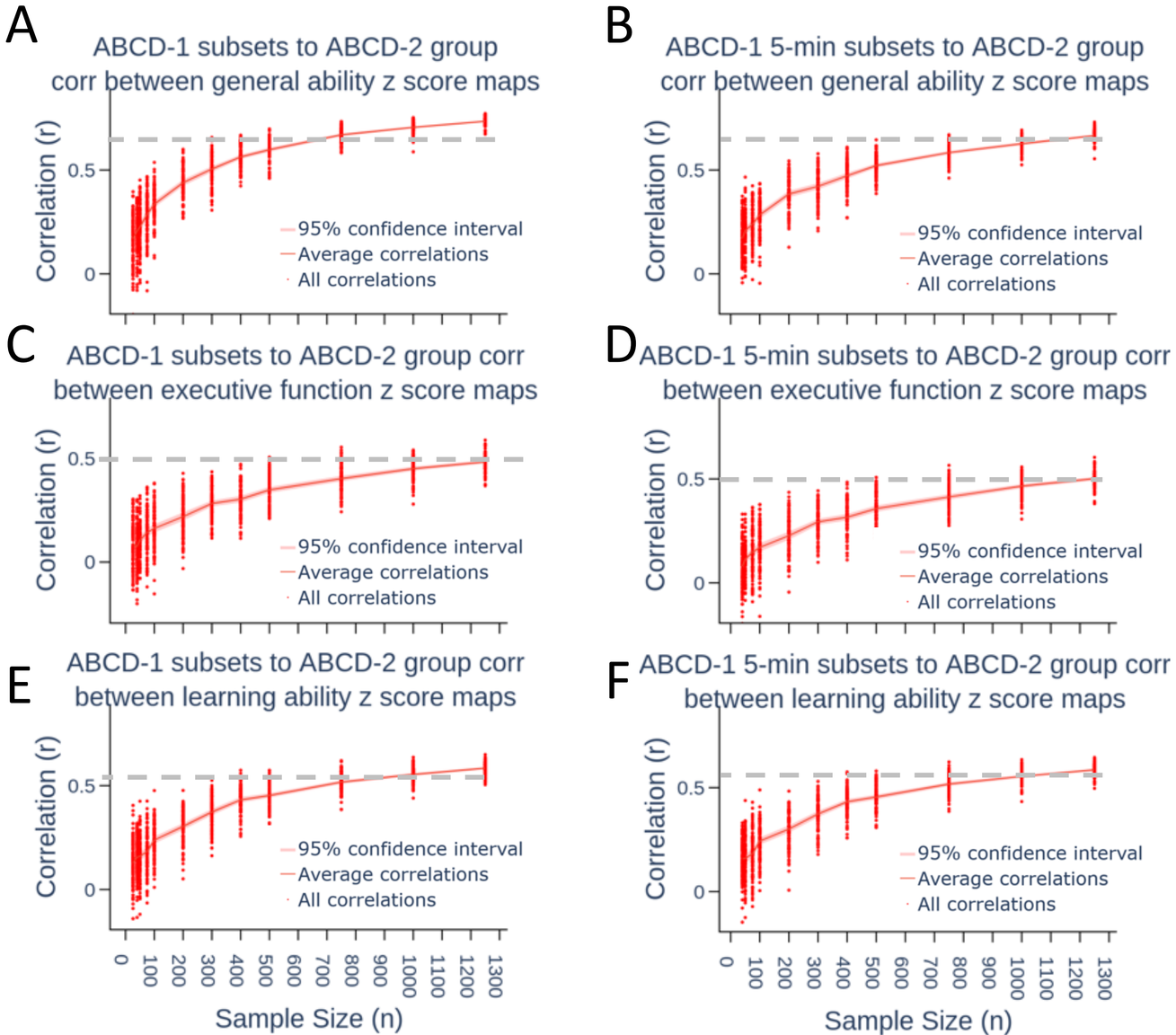




ABCD-BIDS Community Collection (ABCC)

ABCD-ReproNim

Brain-behavior Correlation



Learning Objectives of this Lecture

ABCD-ReproNim

Despite all of the efforts to maximize signal, due to remaining noise and sampling variability our studies in ABCD are likely going to require large sample sizes and group membership

- Imaging Protocol and Pulse Sequences (Structural and Functional)
- Quality Assurance
- fMRI Task Description, Justification, Age-Appropriateness, and Relevance to ABCD Study
- Minimally Processed Pipelines
- ABCC - Collection 3165

Getting help

ABCD Issues

- abcd-issues@ucsd.edu
  - Contents of associated files (images), or their metadata records in image03/fmriresults01
  - Requests for elaboration or clarification of the Release Notes
  - Contents of the Curated Annual Release dataset
  - Data downloads from DEAP/NDA
- DAIC Release email list: email abcd-data-releases-l-join@mailman.ucsd.edu, a reply email will provide further instructions.

Getting help

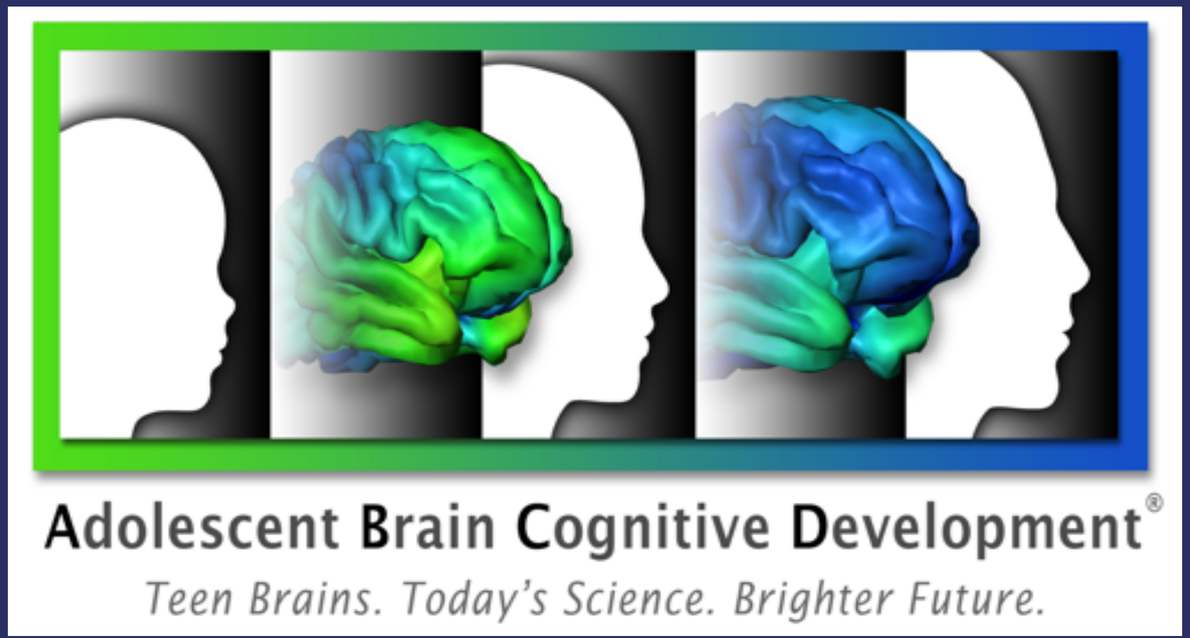
NDA Helpdesk

- https://nda.nih.gov/webinars-and-tutorials
- NDAHelp@mail.nih.gov
  - Request access, the status of a specific Data Access Request, or the status of access privileges and credentials.
  - How to package/download NDA data
  - Troubleshooting download issues
  - Verifying the contents of a package
  - NDA Website issues
  - Answers to known and documented scheduling, policy, or future data availability questions

ABCD-ReproNim: An ABCD Course on Reproducible Data Analyses

ABCD: Introduction to the ABCD Study®

Thank you!



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ABCD-ReproNim