ABCD Human Subjects Study

Adolescent Brain Cognitive Development – ABCDSTUDY.org

Release Notes: Adolescent Brain Cognitive Development Study℠ (ABCD Study®) Data Release 4.0

ABCD Imaging Instruments

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October 2021

Change Log
October 2021– ABCD Data Release 4.0

- Initial release.

General Information

The following information refers to the Adolescent Brain Cognitive Development Study℠ (ABCD) Data Release 4.0 available from https://nda.nih.gov/abcd. An overview of the ABCD Study® is at https://abcdstudy.org and detailed descriptions of the assessment protocols can be viewed at https://abcdstudy.org/scientists/protocols.

This document describes the contents of various instruments available for download. To understand the context of this information, see *Release Notes ABCD README FIRST* and *Release Notes ABCD Imaging Instruments*.

This document details how to query the NDA database to obtain information, metrics, and imaging files from the magnetic resonance imaging (MRI) components of the ABCD Study. An in-depth discussion and reference resource on the ABCD processing pipeline is available at https://doi.org/10.1016/j.neuroimage.2019.116091.

Nomenclature

Within the ABCD Study, all data tables provided are referred to as instruments. Changes of instrument names between releases are detailed in the *ABCD_release_4.0_mapping_file.* Abbreviations of anatomical locations are detailed in *Supplementary Imaging Tables*.

> TIP: The mapping file can be used as a data dictionary. Using the Find feature in many spreadsheet applications will help locate an ROI, the full description, and alternate names for the ROIs between tabulated data and DEAP.

MRI Scanner Information

Measure	NDA Short Name	Description
ABCD MRI Info	abcd_mri01	MRI Scanner Information

For each subject visit, information on the MRI scanner manufacturer, model, magnetic field strength, device software version etc. are detailed in the *Other Imaging Instruments* Release Notes.

Note: all scanners use 32 channel head coils with the exception of these Siemens scanners that use 64 channel head coils (mri_info_deviceserialnumber):

- HASH7911780b
- HASH03db707f
- HASH65b39280
- HASHe4f6957a
- HASH31ce566d

MRI Processed Data File Sharing

Measure	NDA Short Name	Description
Processed MRI Data	fmriresults01	Index of minimally processed data

Minimally processed MRI file sharing

The ABCD Data Release 4.0 contains minimally processed neuroimaging data for all the baseline ABCD Study participants, including:

- High-resolution structural data (3D T1w and T2w scans)
- Advanced diffusion MRI (multiple b-values and directions)
- Resting State fMRI
- Task fMRI (Monetary Incentive Delay, Stop-Signal, and Emotional N-Back) with event files for each fMRI run

These series have been run through standard modality-specific pre-processing stages including conversion from raw to compressed files, distortion correction, movement correction, alignment to standard space, and initial quality control (refer to *MRI Quality Control (QC)* Release Notes). This is to enable researchers to use the ABCD neuroimaging data in their own processing pipelines more quickly and efficiently than starting with raw data. Note that minimal processing is identical for rs-fMRI and task-fMRI and does not include analysis-specific pre-processing

steps (e.g. removal of initial TRs, normalization by mean, etc.). Researchers intending to use minimally processed data should take note of the appropriate acknowledgement language to include in any public disclosure of results. The available minimally processed files are detailed in the *Other Imaging Instruments* Release Notes.

Expected File Sets

The number of expected files changes due to subject scheduling, scanner manufacturer requirements, and repeat acquisitions during scanning. Scanning sessions are typically performed in one session for ~2 hours. However, sometimes the family prefer to do this over two 1-hour sessions within a few days of each other. If the scanning is split over two sessions, an initial T1 is acquired for reference at the start of both sessions, leading to two available T1 images. Additionally, because the T1 is the first, short essential scan of the session, the operator will repeat the scan if there is a problem with the acquisition (e.g. excessive motion). Other series may also have a repeat acquisition if there is enough time. If there are multiple acquisitions beyond the expected number of files please manually inspect the images for quality.

Below is a guide to the expected number of files per modality/scanner manufacturer:

Modality	*GE*	*Philips*	*Siemens*
sMRI	1 T1 1 T2	1 T1 1 T2	1 T1_NORM 1 T2_NORM
dMRI	1 Field map 1 DWI	2 Field maps 2 DWIs	2 Field maps 1 DWIs
rs-fMRI	2 Field maps 4 BOLD	4 Field maps 4 BOLD	4 Field maps 4 BOLD
MID task fMRI	1 Field map 2 BOLD runs	2 Field maps 2 BOLD runs	2 Field maps 2 BOLD runs
nBack task fMRI	1 Field map 2 BOLD runs	2 Field maps 2 BOLD runs	2 Field maps 2 BOLD runs
SST task fMRI	1 Field map 2 BOLD runs	2 Field maps 2 BOLD runs	2 Field maps 2 BOLD runs

Table 1: Expected file sets

Note that the order of the fMRI series acquisition is randomized per subject.

MRI Raw Data File Sharing

Measure	**NDA Short Name**	**Description**
Raw MRI Data	image03	Index of Fast Track raw data
Raw MRI QC	fasttrackqc	QC info for Fast Track data

Fast Track DICOM file sharing

If unprocessed raw imaging data is needed, DICOM files are also made publicly available via a Fast Track mechanism. These DICOM files are released on NDA on a continual basis within approximately one month of data collection using the ABCD fast-track image sharing scripts

(RRID: SCR_016021). DICOM files are arranged in BIDS-compliant directory trees and packaged in individual archive files (tgz) for each series. Metadata are included in the form of json-format text files, and for task-fMRI series, also included are the files containing stimulus and behavioral response timing information exported from the stimulus program (E-prime). A copy of the metadata is uploaded to NDA's image (version 03 – image03) database to link information to non-imaging-based assessments for the same participants. Raw DICOM Fast Track data have not undergone quality control or curation. The up-to-date index of Fast Track shared DICOM files can be downloaded in a separate image03 instrument.

TIP: Some Siemens fMRI data have been reported to have negative values for the Siemens CSA slice timing parameter which can prevent the conversion of DICOMs files in some software. This issue has been overcome in some software (e.g. current version of dcm2niix available for download at https://github.com/rordenlab/dcm2niix).

TIP: GE scanners are unable to correctly encode complex multi-shell EPI gradient table into the DICOM header (a generic default is applied instead). Raw diffusion gradient tables (b values and vectors) per scanner manufacturer have been provided as an accompanying compressed file (ABCD_Diffusion_Tables.zip).

dMRI gradient tables for Fast Track dMRI DICOMs

Raw diffusion gradient tables (b values and vectors) per scanner manufacturer have been provided as an accompanying compressed file (ABCD_Diffusion_Tables.zip). This is primarily provided for ease of use. Additionally, this is to overcome the limitation of GE scanners which are unable to correctly encode complex multishell EPI gradient table into the DICOM header (a generic default is applied instead).

Note: the gradient tables (ABCD_Diffusion_Tables.zip) are only for raw Fast Track dMRI DICOM data. For minimally processed data, new vector tables are generated following motion correction and provided with the minimally processed data.

High density, phased array head coils

The ABCD acquisition sites use either 32 channel head or 64 channel head/neck coils, depending on availability. Standard correction methods, such as those used by FreeSurfer, are limited when compensating for steep spatial intensity variation, leading to inaccurate brain segmentation or cortical surface reconstruction. For example, brain tissue farther from the coils, such as the temporal and frontal poles, typically have lower intensity values resulting in focal underestimation of the white matter surface or the elimination of large pieces of the cortical surface reconstruction. Furthermore, brain tissue close to coils with extremely high intensity values may be mistaken for non-brain tissue (e.g., scalp). To overcome this, the ABCD minimally processed structural MRI (sMRI) files include an improved intensity inhomogeneity correction, using a smoothly varying bias field optimized to standardize image intensities within all white matter voxels.

Siemens normalized sMRI DICOMs

Siemens scanners provide an intensity normalization procedure to correct for bias fields. As a result, Siemens scanners have two sets of DICOMs for each sMRI data series (i.e. T1, T1_NORM, T2, and T2_NORM). The non-normalized images with large intensity ranges (e.g. with a 64 channel head coil) may be clipped at 4095, impairing cortical reconstruction. The ABCD pipeline uses only the normalized sMRI (T1_NORM and T2_NORM).

Tabulated ROI-based Analysis

Individual instruments can be identified on NDA by the short name (second column) in the following table.

Measure	NDA Short Name
ABCD sMRI Part 1	abcd_smrip102
ABCD sMRI Part 2	abcd_smrip202
ABCD sMRI Part 3	abcd_smrip302
ABCD sMRI Destrieux Parcellation Part 1	abcd_mrisdp102
ABCD sMRI Destrieux Parcellation Part 2	abcd_mrisdp202
ABCD sMRI Destrieux Parcellation Part 3	abcd_mrisdp302
ABCD dMRI DTI Part 1	abcd_dti_p101
ABCD dMRI DTI Part 2	abcd_dti_p201
ABCD dMRI DTI Destrieux Parcellations Part 1	abcd_ddtidp101
ABCD dMRI DTI Destrieux Parcellations Part 2	abcd_ddtidp201
ABCD dMRI DTI Full Part 1	abcd_dmdtifp101
ABCD dMRI DTI Full Part 2	abcd_dmdtifp202
ABCD dMRI DTI Full Destrieux Parcellation Part 1	abcd_ddtifp101
ABCD dMRI DTI Full Destrieux Parcellation Part 2	abcd_ddtifp201
ABCD dMRI RSI Part 1 (RNI: restricted normalized isotropic)	abcd_drsip101
ABCD dMRI RSI Part 2 (RND: restricted normalized directional)	abcd_drsip201
ABCD dMRI RSI Part 3 (RNT: restricted normalized total)	abcd_drsip301
ABCD dMRI RSI Part 4 (HNI: hindered normalized isotropic)	abcd_drsip401
ABCD dMRI RSI Part 5 (HND: hindered normalized directional)	abcd_drsip501
ABCD dMRI RSI Part 6 (HNT: hindered normalized total)	abcd_drsip601
ABCD dMRI RSI Part 7 (FNI: free normalized isotropic)	abcd_drsip701
ABCD rsfMRI Gordon Network Correlations	abcd_betnet02
ABCD rsfMRI Network to Subcortical ROI Correlations	mrirscor02
ABCD rsfMRI Temporal Variance	abcd_mrirstv02
ABCD rsfMRI Destrieux	abcd_mrirsfd01
ABCD Task fMRI MID Run 1 Beta Weights Part 1	abcd_midr1bwp102
ABCD Task fMRI MID Run 1 Beta Weights Part 2	abcd_midr1bwp202
ABCD Task fMRI MID Run 1 Beta Weights Destrieux Parcellations Part 1	abcd_midr1bwdp101
ABCD Task fMRI MID Run 1 Beta Weights Destrieux Parcellations Part 2	abcd_midr1bwdp202
ABCD Task fMRI MID Run 1 Standard Error of the Mean Part 1	abcd_midsemp102

ABCD Task fMRI MID Run 1 Standard Error of the Mean Part 2	abcd_midsemp202
ABCD Task fMRI MID Run 1 SEM Destrieux Parcellations Part 1	abcd_tmidr1semdp101
ABCD Task fMRI MID Run 1 SEM Destrieux Parcellations Part 2	abcd_tmidr1semdp202
ABCD Task fMRI MID Run 2 Beta Weights Part 1	midr2bwp102
ABCD Task fMRI MID Run 2 Beta Weights Part 2	midr2bwp202
ABCD Task fMRI MID Run 2 Beta Weights Destrieux Parcellations Part 1	abcd_tr2bwdp01
ABCD Task fMRI MID Run 2 Beta Weights Destrieux Parcellations Part 2	abcd_tr2bwdp202
ABCD Task fMRI MID Run 2 Standard Error of the Mean Part 1	abcd_midr2semp102
ABCD Task fMRI MID Run 2 Standard Error of the Mean Part 2	abcd_midr2semp202
ABCD Task fMRI MID Run 2 SEM Destrieux Parcellations Part 1	abcd_tr2semdp101
ABCD Task fMRI MID Run 2 SEM Destrieux Parcellations Part 2	abcd_tr2semdp201
ABCD Task fMRI MID Average Beta Weights Part 1	midaparc03
ABCD Task fMRI MID Average Beta Weights Part 2	midaparcp203
ABCD Task fMRI MID Average Beta Weights Destrieux Parcellations Part 1	abcd_midabwdp01
ABCD Task fMRI MID Average Beta Weights Destrieux Parcellations Part 2	abcd_midabwdp202
ABCD Task fMRI MID Average Standard Error of the Mean Part 1	abcd_midasemp102
ABCD Task fMRI MID Average Standard Error of the Mean Part 2	abcd_midasemp202
ABCD Task fMRI MID Average SEM Destrieux Parcellations Part 1	abcd_midasemdp101
ABCD Task fMRI MID Average SEM Destrieux Parcellations Part 2	abcd_midasemdp202
ABCD Task fMRI SST Run 1 Beta Weights	mrisstr1bw01
ABCD Task fMRI SST Run 1 Beta Weights Destrieux Parcellations Part 1	abcd_tfsstr1bwdp101
ABCD Task fMRI SST Run 1 Beta Weights Destrieux Parcellations Part 2	abcd_tfsstr1bwdp201
ABCD Task fMRI SST Run 1 Standard Error of the Mean	mrisstr1sem01
ABCD Task fMRI SST Run 1 SEM Destrieux Parcellations Part 1	abcd_tfsstr1semdp101
ABCD Task fMRI SST Run 1 SEM Destrieux Parcellations Part 2	abcd_tfsstr1semdp201
ABCD Task fMRI SST Run 2 Beta Weights	mrisstr2bw01
ABCD Task fMRI SST Run 2 Beta Weights Destrieux Parcellations Part 1	abcd_tfsstr2bwdp101
ABCD Task fMRI SST Run 2 Beta Weights Destrieux Parcellations Part 2	abcd_tfsstr2bwdp201
ABCD Task fMRI SST Run 2 Standard Error of the Mean	mrisstr2bwsem01
ABCD Task fMRI SST Run 2 SEM Destrieux Parcellations Part 1	abcd_tfsstr2semdp101
ABCD Task fMRI SST Run 2 SEM Destrieux Parcellations Part 2	abcd_tfsstr2semdp201
ABCD Task fMRI SST Average Beta Weights	mrisst02
ABCD Task fMRI SST Average Beta Weights Destrieux Parcellations Part 1	abcd_tfsstabwdp101
ABCD Task fMRI SST Average Beta Weights Destrieux Parcellations Part 2	abcd_tfsstabwdp201
ABCD Task fMRI SST Average Standard Error of the Mean	mrisstsem01

ABCD Task fMRI SST Average SEM Destrieux Parcellations Part 1	abcd_tfsstasemdp101
ABCD Task fMRI SST Average SEM Destrieux Parcellations Part 2	abcd_tfsstasemdp201
ABCD Task fMRI nBack Run 1 Beta Weights	nbackr101
ABCD Task fMRI nBack Run 1 Beta Weights Destrieux Parcellations Part 1	abcd_tfncr1bwdp101
ABCD Task fMRI nBack Run 1 Beta Weights Destrieux Parcellations Part 2	abcd_tfncr1bwdp201
ABCD Task fMRI nBack Run 1 Standard Error of the Mean	nbackr1sem01
ABCD Task fMRI nBack Run 1 SEM Destrieux Parcellations Part 1	abcd_tfnbr1semdp101
ABCD Task fMRI nBack Run 1 SEM Destrieux Parcellations Part 2	abcd_tfnbr1semdp201
ABCD Task fMRI nBack Run 2 Beta Weights	nbackr201
ABCD Task fMRI nBack Run 2 Beta Weights Destrieux Parcellations Part 1	abcd_tfnbr2bwdp101
ABCD Task fMRI nBack Run 2 Beta Weights Destrieux Parcellations Part 2	abcd_tfnbr2bwdp201
ABCD Task fMRI nBack Run 2 Standard Error of the Mean	nbackr2sem01
ABCD Task fMRI nBack Run 2 SEM Destrieux Parcellations Part 1	abcd_tfnbr2dp101
ABCD Task fMRI nBack Run 2 SEM Destrieux Parcellations Part 2	abcd_tfnbr2dp201
ABCD Task fMRI nBack Average Beta Weights	nback_bwroi02
ABCD Task fMRI nBack Average Beta Weights Destrieux Parcellations Part 1	abcd_tfabwdp101
ABCD Task fMRI nBack Average Beta Weights Destrieux Parcellations Part 2	abcd_tfabwdp201
ABCD Task fMRI nBack Average Standard Error of the Mean	nbackallsem01
ABCD Task fMRI nBack Average SEM Destrieux Parcellations Part 1	abcd_tnbasemdp101
ABCD Task fMRI nBack Average SEM Destrieux Parcellations Part 2	abcd_tnbasemdp201

MR images are corrected for distortions and head motion, and cross-modality registrations are performed. Using the T1w sMRI scan, the cortical surface is reconstructed, and subcortical and white matter regions of the brain are segmented. From this, we carry out modality-specific analyses and extract imaging-derived measures using a variety of regions of interest (ROI). Finally, ROI analysis results are compiled across subjects and summarized in tabulated form.

Information on the different tabulated data is detailed in modality-specific release notes:

- Structural Magnetic Resonance Imaging (sMRI)
- Diffusion Magnetic Resonance Imaging (dMRI)
- Resting-State Functional Magnetic Resonance Imaging (rs-fMRI)
- Task-Based Functional Magnetic Resonance Imaging (task-fMRI)
- Behavioral Performance During task-fMRI

Despite the convenience of ROI-based analyses and the advantages related to reduced numbers of statistical comparisons, there are inherent limitations to this approach. Effects of interest (e.g., associations between cortical morphometry and cognitive variables, or task-related fMRI activation) could potentially straddle multiple ROIs, or occupy a small region of a large ROI, thereby reducing the sensitivity of an ROI-based analysis relative to mapping-based approaches. For this reason, users should be cautious about interpreting the results of ROI-based analyses, particularly for task fMRI.

Quality Control and Recommended Inclusion Criteria

Measure	NDA Short Name	Description
ABCD Recommended Imaging Inclusion	abcd_imgincl01	ABCD Recommended Imaging Inclusion
ABCD MR Findings	abcd_mrfindings02	Neuroradiology reports - scores, hydrocephalus and herniation
ABCD MRI QC Raw Part 1	mriqcp102	Raw Quality control measures (part 1)
ABCD MRI QC Raw Part 2	mriqcp202	Raw Quality control measures (part 2)
ABCD MRI QC Raw Part 3	mriqcp302	Raw Quality control measures (part 3)
FreeSurfer QC	abcd_fsurfqc01	FreeSurfer reconstruction quality control measures (manual review)
ABCD sMRI T2w Post Processing QC	abcd_t2wqc01	Processed sMRI T2w data quality control measures (manual review)
ABCD dMRI Post Processing QC	abcd_dmriqc01	Processed dMRI data quality control measures (manual review)
Manual fMRI Post-Processing QC	abcd_fmriqc01	Processed fMRI data quality control measures (manual review)
Automated Post-Processing QC Metrics	abcd_auto_postqc01	Automated post-processing QC metrics

QC procedures and image inclusion criteria are detailed in the *MRI Quality Control (QC) and Recommended Image Inclusion Criteria* Release Notes.

Recommended Inclusion Criteria

The ABCD Recommended Imaging Inclusion instrument (abcd_imgincl01) provides the simple option of include or exclude series (1 or 0) based on automated and manual QC review per MR measure - T1w, T2w, DTI/RSI, rsfMRI, SST, nBack and MID tfMRI.

Incidental Findings

T1w and T2w images, if available, were screened for incidental findings by a Board Certified Neuroradiologist. Any findings requiring clinical investigation were relayed to appropriate site personnel via the ABCD Coordinating Center (CC). These MR findings are not included in our recommended inclusion criteria but are noted here because some investigators may find them to be relevant inclusion criteria for their analyses.

Protocol Compliance and Quality Control

All ABCD MRI exams have been systematically checked for MRI protocol compliance and completeness, and images have been manually rated for quality by trained MR analysts before and after processing. All MRI data is provided to ABCD collaborators, but we highly recommend that researchers filter subjects by QC results based on the project aims and tolerance for MR artifacts/motion. Severe artifact in all T1w image in a given visit (MRI Quality Control

(QC):iqc_t1_ok_ser = 0) results in the inability to produce subsequent MR-metrics for all other modalities.

E-Prime errors in task fMRI

For task fMRI, series were also excluded due to E-Prime problems including missing, corrupted, duplicated or unsynchronized E-Prime files. The variety of E-Prime errors that would invalidate the series are generalized in the MRI Raw QC Part 3 instrument as being "mismatched" (iqc_mid_ep_t_series_match = 1, iqc_nback_ep_t_series_match = 1, iqc_sst_ep_t_series_match = 1). In manual review, some errors can be corrected, so there is an additional override to this switch when needed (eprime_mismatch_ok_mid = 1, eprime_mismatch_ok_mid = 1, eprime_mismatch_ok_mid = 1).

Behavioral performance in task fMRI

Behavioral measures calculated from participant button presses during task fMRI acquisition are also included (see Behavioral Performance During task-fMRI Release Notes). Based on those measures, behavioral performance flags were provided, indicating whether a subject's performance for each task was within acceptable standards. It is suggested that users exclude subjects from group analysis based on sub-optimal performance and possibly additional criteria such as the number of degrees of freedom (reduced by motion censoring) in the individual subject task-fMRI analysis and/or based on outlier detection on the ROI-averages themselves. Users should choose inclusion/exclusion performance criteria that are appropriate for their analyses.

Recommended Inclusion Criteria for DEAP

Predefined subsets based on the recommended inclusion criteria are available in DEAP.

1. Login to the DEAP web service https://deap.nimhda.org
2. Click on Analyze.
3. Choose your variables of interest.
4. Click on Select subset of sessions and in the Public section choose the recommended inclusion criteria that is appropriate for your variables:
    - Recommended T1w
    - Recommended T2w
    - Recommended dMRI
    - Recommended resting-state fMRI
    - Recommended task fMRI (MID)
    - Recommended task fMRI (SST)
    - Recommended task fMRI (nBack)
5. Submit your analysis.

Please ensure that the subset matches the variables of interest. For example, examining the dMRI data should be used with the Recommended dMRI subset only. For more complex subsetting, the syntax can be combined in the Limit section of DEAP.

Note: By default in the Analyze section of DEAP, one of the recommended random effects for non-imaging analysis is "Site". For imaging analysis that need to account for individual scanner

instances, we recommend that "Site" is deselected and “Device" is selected (i.e. specific MRI scanner as the random effect, not the geographical location).

Methods

Image processing and analysis methods corresponding to ABCD Release 2.0.1 are described in Hagler et al., 2019, *Image processing and analysis methods for the Adolescent Brain Cognitive Development Study.* Neuroimage, 202:116091. Changes to image processing and analysis methods in Release 3.0 and Release 4.0 are documented in the relevant release notes:

13. NDA 4.0 Structural Magnetic Resonance Imaging
14. NDA 4.0 Diffusion Magnetic Resonance Imaging
15. NDA 4.0 Resting-State Functional Magnetic Resonance Imaging
16. NDA 4.0 Behavioral Performance During task-fMRI
17. NDA 4.0 Task-Based Functional Magnetic Resonance Imaging
18. NDA 4.0 MRI Quality Control Recommended Inclusion

Changes for ABCD 3.0

Various changes and bug fixes

During pre-release data review and curation, a number of small changes and bug fixes were made in an effort to recover missing imaging results where possible. Corrupted intermediate MATLAB data files -- caused, for example, by abrupt job failure during file writing -- occurred infrequently but led to missing results in our pre-release review. These corrupt files caused error on subsequent attempts to process that data, because existing data files are not overwritten by default. To recover such cases, changes in various parts of the processing pipelines were made to automatically remove corrupt MATLAB data files when encountered so that the processing would recreate those files and proceed on subsequent processing attempts. Miscellaneous coding changes slightly reduced the missingness of derived results by handling various data irregularities.

Changes for ABCD 4.0

Event labeling

Visit name variables (e.g., *mri_info_visitid* in *abcd_mri01* or *smri_visitid* in *abcd_smrip102*) were changed to use a shortened EventName instead of StudyDate. For example, the new visit name looks like G031_INVXXX0000_baseline instead of G031_INVXX0000_20170601.

Preventing missing results due to job failures

Changes were made to how image processing, analysis, and summary jobs were generated to allow for limiting the creation of jobs for only those participant-events for whom jobs had not been previously created or did not finish sucessfully. This allowed for the recovery of results which may have been missing previously due to essentially random job failures that occasionally occur with large-scale, parallel processing on computational clusters.