ABCD Human Subjects Study

Adolescent Brain Cognitive Development – ABCDSTUDY.org

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

Task-Based Functional Magnetic Resonance Imaging (task-fMRI)

http://dx.doi.org/10.15154/1523041

October 2021

Change Log
October 2021 – ABCD Data Release 4.0

- Initial release

List of Instruments

Instruments	Short Name
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 (Release 2.0.1)	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

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*.

Overview

- Image types
    - field maps: spin echo images with opposite phase encode polarity
    - multi-frame, gradient echo, echo-planar imaging
- Image processing (common to all fMRI)
    - head motion corrected by registering each frame to the first using AFNI's 3dvolreg (Cox, 1996)
    - B_0 distortions were corrected using the reversing gradient method with FSL's TOPUP (Andersson et al., 2003, Smith et al., 2004)
    - displacement field estimated from spin-echo field map scans
    - applied to gradient-echo images after adjustment for between-scan head motion
    - corrected for gradient nonlinearity distortions (Jovicich, et al., 2006)
    - between scan motion correction across all fMRI scans in imaging event
    - registration between T_2-weighted, spin-echo B_0 calibration scans and T_1-weighted structural images performed using mutual information (Wells, et al., 1996)
- task-fMRI specific pre-processing -- NOTE: not included in "minimal processing" (minproc)
    - removal of initial volumes
        - Siemens: 8 TRs
        - Philips: 8 TRs
        - GE DV25: 5 TRs
        - GE DV26: 16 TRs
    - normalization and demean
        - divide by the mean of each voxel, subtract 1, multiply by 100
- Estimation of task-related activation strength
    - general linear model (GLM) using AFNI's 3dDeconvolve (Cox, 1996)
    - nuisance regressors to model baseline, quadratic trend, and motion (Power, et al., 2014)
        - motion estimates, derivatives, and squared estimates and derivatives included
    - time points with framewise displacement (FD) > 0.9 mm censored (Siegel, et al., 2014)
    - 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 n-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
    - Monetary Incentive Delay (MID)
        - predictors for anticipation of large, small, and no rewards and feedback for large, small, and no rewards for wins and losses
        - linear contrasts computed for anticipation of large and small reward vs. no reward, anticipation of large and small loss vs. no reward, feedback of win vs. no reward, and feedback of loss vs. no reward
    - Stop Signal Task (SST)
        - predictors for successful go trial, failed go trial, successful stop trial, and failed stop trial
        - contrasts computed for successful vs. failed stop trials and successful vs. failed go trials
    - Emotional n-back (EN-back)
        - predictors for each type of stimulus (i.e. place and emotional face) in each of the n-back conditions (i.e., 0-back and 2-back) plus fixation
        - linear contrasts computed for 2-back vs. 0-back across stimulus types, emotional faces vs. places across memory loads, 2-back vs. 0-back for each stimulus type, and each memory load and each stimulus type vs. fixation
- Regions of interest (ROIs)
    - subcortical structures labeled with atlas-based segmentation (Fischl, et al., 2002)
    - cortical regions labeled with the Desikan atlas-based classification (Desikan, et al., 2006)
    - cortical regions labeled with the Destrieux atlas-based classification (Destrieux, et al., 2010)
    - ROI average coefficients and t-statistics for each run were averaged across two runs, weighted by degrees of freedom

Additional Notes

Mismatched E-prime output files and imaging data

The task fMRI behavioral and stimulus timing files, which are exported from the E-prime stimulus presentation program, have a date and time stamp recording when the stimulus program was started for a particular task run. E-prime timing is compared to date and time derived from imaging DICOM metadata to identify events with potentially mismatched E-prime file and imaging data. In some cases, these mismatches are due to clock offsets on stimulus computers relative to the MRI console computer; e.g., on days of transition to and from Daylight Saving Time (DST), or small, fixed differences in clock time. In other cases, imaging sites uploaded E-prime files for one participant but assigned them to a different pGUID, which can result in very large timing differences. Participant-events with timing mismatches less than 12.5 minutes are identified by these variables:

MID E-prime timing match: *mriqcrp302*:iqc_mid_ep_t_series_match
EN-Back E-prime timing match: *mriqcrp302*:iqc_nback_ep_t_series_match
SST E-prime timing match: *mriqcrp302*:iqc_sst_ep_t_series_match

Participant-events for which timing mismatches can be ignored, e.g., DST transitions or persistent clock offsets, are identified by these variables:

MID ignore E-prime mismatch: *mriqcrp302*:eprime_mismatch_ok_mid
EN-nack ignore E-prime mismatch: *mriqcrp302*:eprime_mismatch_ok_nback
SST ignore E-prime mismatch: *mriqcrp302*:eprime_mismatch_ok_sst

These variables have been included in the recommended imaging inclusion criteria and the imaging inclusion flags. Refer to *ABCD Imaging Instruments* Release Notes for more details.

Task fMRI results have not been generated for participants with timing mismatches (e.g., iqc_mid_ep_t_series_match = 0) unless they can be ignored (i.e., eprime_mismatch_ok_mid = 1). The ABCD DAIRC continues to work with ABCD imaging sites to recover missing or mismatched E-prime files to enable the inclusion of these participants' results in future releases.

Irregular acquisitions

In a small percentage of participant-events (< 2%), the number of scans acquired and the number of task runs documented in E-prime output files differed, leading to potential ambiguity in the assignment of stimulus runs to imaging scan. To prevent matching a stimulus run to the wrong scan and using an incorrect stimulus event time series in the GLM analysis of the imaging data, the task fMRI GLM analysis is currently skipped for participant-events with an irregular acquisition, resulting in missing derived values in the task fMRI tabulated data and missing minimally processed data. Examples of irregular acquisitions creating potential ambiguity include the collection of 3 scans but only 2 stimulus runs, or 1 scan but 2 stimulus runs. This sometimes occurs because of a scan was aborted at the participant's request. The correct mapping between scan and run can sometimes be ascertained with information about all of scans collected and which of those were aborted. However, variation and special cases can make it difficult to fashion general rules that work correctly for all. Future efforts will be devoted to testing a more permissive approach allowing analysis in potentially ambiguous cases when appropriate.

In a very small number of participant-events (< 0.1%), the RA or scan operator used the wrong scan protocol for the first of two runs; e.g., using the MID scan protocol while using the SST stimulus. Because the length of the scans differs for the different tasks, mismatched scans and tasks are not analyzed. The second scan of the mismatched pair can be correctly analyzed if assigned to the second stimulus run. These situations were identified as having only one scan of a given task that was immediately preceded by a scan of a different task instead of a field map scan.

For approximately 2.0-2.4% of participant-events, only a single imaging scan was available for analysis for one or more task, either because only one scan was acquired for that task, one of two scans was aborted during acquisition, or one of two scans failed raw QC. For the SST, if only the second scan was analyzed, these tfMRI data are currently assigned to run1 variables in the tabulated data releases. For the MID and EN-back, if there were errors with run1 scans, neither scan1 or scan2 task fMRI data were analyzed. If there were no issues with the first scan, these data were analyzed. For future releases, modifications to the task fMRI analysis pipeline will enable the analysis of valid run2 data for all three tasks and correct assignment to run2 variables in the tabulated data.

Task fMRI outliers

Some participants exhibit frequent periods of motion, and depending on when supra-threshold head movements (FD>0.9 mm) occur relative to instances of a given event type, some conditions may be under-represented. In rare cases, this results in extreme values for the beta and SEM estimates, as much as several orders of magnitude different from typical values for a given contrast. The presence of extreme outliers violates standard parametric assumptions, so group-level statistical analyses would produce invalid and nonsensical results. To prevent this, we censor the beta and SEM values if they are identified as having extremely high SEM values and therefore low reliability beta estimates (see Hagler et al., 2019). We censor the beta and SEM values for all ROIs for those contrasts that have RMS of SEM values across the cortical surface greater than 5% signal change. This represents less than 0.5% of all subject-task-contrast-run combinations. The censored values are replaced with empty cells in the tabulated data. Despite this censoring, some outlier beta values (defined as being outside the mean ± 3 * standard deviation) remain in the tabulated data. These cases are more likely to have outliers in a limited number of ROIs, and are possibly related to image quality issues not detected in raw or post-processing manual QC.

Users of the task fMRI tabulated data are advised to examine outliers in the data and choose inclusion criteria that are appropriate for their analyses. We have provided a set of recommended inclusion criteria for each modality that take into account factors such as imaging QC, task performance, etc. (see ***18. NDA 4.0 MRI Quality Control Recommended Inclusion***), and for convenience, we provide a data structure with modality-specific imaging inclusion flags based on those criteria (*abcd_imgincl01*). We also now provide, as additional documentation, a table listing participant-events with one or more outlier beta values (***fMRI_outliers_ABCD4.0.csv***). The columns *exclude_nback*, *exclude_sst*, and *exclude_mid* indicate whether a given participant-event has an excessive number of outliers for a given task.

As mentioned above, contrast-specific exclusion thresholds for beta values in a single ROI were calculated as the mean ± 3*standard deviations of beta values within the sample for that contrast-ROI. The participant-events marked for potential exclusion had 25% or more of their ROIs detected as outliers, which we consider a reasonable compromise between data quality and loss. The percentage of subjects having one or more ROIs with large beta-weights (>5) that remain in the sample after applying these outlier exclusion flags is 0.015% for the SST, 0.5% for the MID, and 0.7% for the n-Back. All of these participant-events have only one or two ROIs across all primary contrasts per task (with the majority having only 1) with large beta-weights.

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 below.

Changes for ABCD 3.0

Philips fMRI data

In Release 2.0.1 and earlier, all task and resting-state fMRI data obtained on Phillips scanners were incorrectly processed. The field map direction for these data was mistakenly flipped, which led to increased distortion in processed fMRI images. 1512 participants were affected by this issue, which is 13% of baseline MRI visits. This has been corrected in Release 3.0.

fMRI B0 distortion correction

As for dMRI, the previously used tool for estimation of B0 distortion (Holland, et al., 2010), was replaced with FSL's TOPUP (FSL v5.0.2.2) (Andersson, et al., 2003), which was found to provide more accurate B_0 distortion correction in the presence of head motion between forward and reverse phase-encode polarity scans.

For fMRI, we also found in some cases that residual distortion was due to poor registration between the spin echo field mapping scans used to estimate B0 distortions and the gradient echo fMRI scans. Inaccurate registration in such cases was caused by the use of a brain mask, derived from log transformed intensities of the the spin echo and gradient echo images, that omitted the center of the brain, due to the strong intensity differences related to distance from the coils. We replaced this method for generating a brain mask for use in registration with FSL's brain extraction tool (bet, FSL v5.0.2.2), which robustly estimates a brain mask from T1- or T2-weighted images without interior holes. This change corrected the registration between the field map and fMRI scans, resulting in more accurate B0 distortion correction for those scans.

Task fMRI analysis exclusions

For task fMRI analysis, data collected for some participants should be excluded from the individual subject analysis processing to prevent matching task fMRI imaging data to the wrong event time series derived from stimulus and response timing files exported from E-prime. For example, in some cases, due to human error, E-prime files associated with a given participant were actually acquired with a different participant at the same imaging site, leading to large inconsistencies in time stamps in the E-prime files and associated task fMRI imaging data. In other cases, due to irregularities in data acquisition, such as aborted scans and/or additional scans, it can be difficult to determine the correct matching between E-prime files and tfMRI scans.

In previous releases, participants with significant timing delays were excluded after processing from the tfMRI tabulated data based on a list of pGUID-events with timing mismatches between E-prime files and tfMRI scans greater than 12.5 minutes. This list was manually edited to remove pGUID-events for whom timing mismatches could be explained; e.g., consistent clock differences between stimulus laptop and scanner console computers. Note that variable timing offsets (e.g., 1-3 minutes) are common and related to imprecision in the recorded SeriesTime in DICOM files. For Release 3.0, the task fMRI analysis software was modified to automatically exclude events from tfMRI analysis processing if there was a timing mismatch greater than 12.5 minutes (i.e., iqc_mid_ep_t_series_match = 0) unless the timing mismatch had been marked as acceptable (i.e., eprime_mismatch_ok_mid = 1). Concerning which pGUID-events for whom task fMRI results ended up being included in Release 3.0, this was a change in procedure, but generally not outcome.

In previous releases, participants were also excluded from tfMRI analysis processing if the number of valid scans did not match the number of E-prime runs. For Release 3.0, this was

loosened slightly to allow analysis processing in cases with one of two scans being unavailable, either because the other scan was incomplete (i.e., aborted) or failed raw QC. For the SST task, this single scan analysis was allowed whether it was the first or second run; but for MID and nBack tasks, the single scan analysis was allowed only if it was the first run. This difference reflects the interchangeability of the SST runs and a difference between the first and second runs for the MID and nBack tasks. Analysis processing was still skipped for other cases of non-standard acquisitions (e.g., three scans and two available E-prime runs). An additional change that allowed analysis in some cases not previously allowed applied to multiple pairs of task fMRI scans, sometimes collected on two different imaging study dates (e.g., a repeat acquisition to correct for problems with first attempt). In those cases, the last valid pair of scans corresponding to the same E-prime file was used for analysis. Another change related to a rare scenario where the first of two runs for a given task was done with the scan protocol for one of the other tasks. In previous releases, those cases would be excluded from analsyis processing because the number of scans labeled correctly did not match the number of E-prime runs. For Release 3.0, in cases where a single scan was proceeded by a scan of one of the other task fMRI types, the valid scan would be allowed for analysis as a single run (SST only), matching to the second E-prime run.

E-prime file handling and time delay calculation

Minor changes were made to recover task fMRI derived results for a small number of pGUID-events, for example by handling unusual file naming for E-prime exported files (e.g., duplicate file extension: ".txt.txt") or irregularities within the E-prime files (e.g., nback experiments terminated before last run completed).

Changes to E-prime file handling were made related to how the relative time delay variables were calculated, to match each scan to individual runs within a given E-prime file and to exclude non-ABCD-compliant (i.e., aborted scans) from time-difference calculations, reducing the maximum delay calculated for some participant-event-tasks.

Changes for ABCD 4.0

fMRI registration to T1w

The procedure for registration of T2-weighted images (including fMRI field map scans) to T1-weighted images involves a pre-registration of the T1w image to a T1w atlas, pre-registration of the T2w image to a T2w atlas (co-registered to the T1w atlas), and then fine registration between the T2w and T1w images using mutual information. In rare cases, the pre-registration of the T1w image to the T1w atlas essentially failed, subsequently resulting in a poor registration between the T2w and T1w images. To reduce the likelihood of registration failure, the T1w atlas was edited by applying a brain mask, preventing non-brain regions of the atlas from influencing the registration.

fMRI processing: between-scan registration

Between-scan registration procedures for fMRI were modified to use a more robust method for generating a brain mask from the fMRI images for use in constraining the registration between scans of the same modality. The previous method generated a brain mask by applying a cumulative probability threshold to log transformed intensities. In some cases with strong intensity differences related to distance from the coils, the center of the brain was omitted from the mask, resulting in inaccurate between-scan registration in those cases. We replaced this

method with the use of FSL's brain extraction tool (bet, FSL v5.0.2.2), which robustly estimates a brain mask from T1- or T2-weighted images without interior holes. This change generally had very little effect for most participant-events, but prevented bad registration between scans in those rare cases with brain masks that omitted a large portion of the center of the brain. See also above, *fMRI registration to T1w*.

fMRI processing: field map slice prescription mismatches

In some scanning sessions, participants need to exit and return to the scanner midway through the scan session, leading to differences in the exact slice prescription for scans of the same type. Specifically for the estimation of B0 distortion fields from forward and reverse phase-encode polarity "field map" scans, such differences in slice prescription invalidate assumptions underlying the basic estimation approach. Differences in the slice prescription can also be associated with differences in head position that may lead to differences in the B0 distortion field, again invalidating assumptions and potentially leading to grossly inaccurate B0 distortion corrections. To avoid these potential problems in past version of the processing pipeline, processing was aborted for those cases where there was a mismatch in the voxel to scanner space transformation (vox2ras) between the forward and reverse field map scans.
In the current processing pipeline, we have relaxed this requirement, allowing the estimation of B0 distortion fields to procede despite relatively large slice position offset differences (< 10 mm) of the slice prescription. This is made possible by the use of FSL's topup, which corrects for head motion between the forward and reverse scans when estimating the B0 distortion field. Differences in voxel dimensions between forward and reverse scans are still not allowed in the current processing pipeline. A further modification was to pre-select the pairs of forward and reverse field map scans in a scan session with matching voxel dimensions and minimal slice position offsets. This prevents unnecessary processing failures in rare cases in which there were multiple scans with varying slice prescriptions and/or voxel dimensions.

fMRI processing: between scan registration

Between scan registration for fMRI (using AFNI’s 3dvolreg) sometimes failed (i.e., produced grossly inaccurate registrations) in cases with large differences in the slice position offset relative to scanner coordinates, e.g., due to exiting and re-entering the scanner midway through the scan session. This problem was corrected by replacing the voxel to scanner coordinate transformation (vox2ras matrix) for a given scan with that of the registration target volume if the difference in slice position offset was greater than 1 mm, as long as there was no rotation of the slice plane. In rare cases with with such rotations, the input image was resampled before registration to remove rotations as well as the nominal offset. See also above, *dMRI and fMRI processing: between-scan registration*, *dMRI and fMRI processing: field map slice prescription mismatches*, and *dMRI, fMRI, and T2w registration to T1w*.

fMRI processing: within-scan motion correction

The procedure for motion corrrection of fMRI data was modified to use the mean image as the registration target rather than the first frame of each series. The mean image was calculated by averaging over all time points, excluding the initial 16 frames. This change generally had minimal effect on the quality of registration (as assessed by within-series temporal SNR), but was done to avoid poor registration for series with poor image quality in the first frame.

Task fMRI scan to E-prime file matching and time delay calculation

The task fMRI behavioral and stimulus timing files, which are exported from the E-prime stimulus presentation program, have a date and time stamp recording when the stimulus program was started for a particular task run. E-prime timing is compared to date and time derived from imaging DICOM metadata to identify events with potentially mismatched E-prime file and imaging data (e.g., *iqc_mid_ep_t_series_match*). The method for matching tfMRI series to E-prime files was changed, affecting the calculation of relative time delays between DICOM-derived SeriesTime and E-prime file-derived time stamp. Previously, each scan was matched to the E-prime file with minimum relative time delay; i.e., if there were multiple attempted scans. In cases with a small but significant apparent time delay (e.g., 4 minutes), E-prime files from multiple attempted runs may have similar absolute delays as each other (e.g., -4 minutes and +3 minutes), resulting in ambiguity. To disambiguate such cases, we now match each scan to the individual runs in the E-prime file and attempt to find a time delay that is more or less constant across runs and tasks in a given scan session, while matching consecutive scans to consecutive runs (rather than allowing one E-prime run to be match ambiguously to more than one scan). This has the end result of a reduction in the maximum delay calculated for some pGUID-event-tasks and more confident matching of E-prime runs to each scan.

Task fMRI analysis exclusions

For most participant-events with task fMRI data, the standard acquisition protocol was followed, with two scans for each task and one stimulus and response timing file (exported from E-prime) containing timing information for two runs. However, in some cases, the standard protocol not followed, potentially introducing ambiguity in how to correctly match tfMRI scans to their corresponding E-prime behavioral run. For example, participants sometimes ask to stop a scan early; e.g., too tired, bathroom break. This results in either a single usable scan and two E-prime runs, or multiple scans and one or more runs in multiple E-prime files. More scans and/or runs than the standard acquisition can also be related reacquisition following technincal problems, e.g., non-functioning trigger or unrecorded responses. In a very small number of participant-events (< 0.1%), the wrong scan protocol was used for the first run of a given stimulus; e.g., using the MID scan protocol while using the SST stimulus. A final source of uncertainty and ambiguity comes from the possibility that, due to human error with initial data upload, the E-prime files associated with a given participant were sometimes actually acquired with a different participant-event at the same imaging site, leading to large inconsistencies in time stamps in the E-prime files and associated task fMRI imaging datas.

In ABCD Release 1 and 2, to avoid pairing the wrong stimulus run with the wrong scan, tfMRI analysis processing was only allowed in cases with the standard acquisition of two scans and two behavioral runs from a single E-prime file or one scan and one behavioral run. Results were also excluded if there was an unexplained timing mismatch; i.e., the difference between SeriesTime extracted from DICOM header and E-prime session time was greater than 12.5 minutes. Such exclusions would have resulted in missing derived values in the task fMRI tabulated data and missing minimally processed data for those participant-event-tasks.

In ABCD Release 3.0, small changes were made to the rules guiding which data were analyzed, allowing for some additional irreguluar acquisitions under limited circumstances. For example, in cases with multiple pairs of tfMRI scans, sometimes collected on two different dates, the last valid pair of scans corresponding to the same E-prime file was used for analysis. Also, single scans corresponding to the second behavioral run (e.g., because of an aborted scan, failed QC, or wrong scan protocol for first run) were allowed for analysis for SST, though not MID or nBack,

because of the interchangeability of the SST runs and differences between the first and second runs for the MID and nBack tasks. Data with a timing mismatch greater than 12.5 minutes (e.g., *iqc_mid_ep_t_series_match* = 0) were again excluded, unless the timing mismatch had been marked as acceptable (e.g., *eprime_mismatch_ok_mid* = 1).

For Release 4.0, the rules for skipping the analysis of task fMRI data were again updated slightly to broaden the circumstances under which the analysis processing would be run for irregular acquisitions. The changes relied on more precise matching of scans to individual behavioral runs (see *Task fMRI scan to E-prime file matching and time delay calculation*) and a check for consistency of timing delays across runs and tasks in a given scan session. In cases with two or more scans, individual scans were first excluded if they timing delay was greater than 12.5 minutes different from the median delay. For cases with multiple pairs of tfMRI scans, the last valid pair of scans corresponding to the same E-prime file or the last complete scan from the last day of scanning was used for analysis. Handling of run numbers in irregular acquisitions was changed for some cases; cases with two valid scans and two runs from separate E-prime files are now allowed for analysis. Also now allowed for each task are single scans corresponding to the second behavioral run (e.g., because of an aborted scan, failed QC, or wrong scan protocol for first run), with results now correctly assigned to the run 2 variables. In the case of two runs 1, this was allowed for SST, but not ofor MID and nBack, for which only the first singleton run was used. Analysis processing was allowed if the minimum delay for the selected scans was less than 12.5, or if there were multiple scans in the scanning session and the range of timing delays for those scans (including scans for other tasks) was less than 4 minutes, or if the timing mismatch had been marked as acceptable (e.g., *eprime_mismatch_ok_mid* = 1). Analysis was not allowed for cases with absolute timing delays greater than 720 minutes, regardless of the range of timing delays across runs and tasks. For those participant-event-tasks that had been allowed for analysis despite timing delays greater than 12.5 minutes, the *eprime_mismatch_ok_mid*, *eprime_mismatch_ok_nback, and eprime_mismatch_ok_sst* variables were set to 1 so that they would pass the inclusion criteria (see ***18. NDA 4.0 MRI Quality Control Recommended Inclusion***).

References

Andersson, J. L., Skare, S., & Ashburner, J. (2003). How to correct susceptibility distortions in spin-echo echo-planar images: application to diffusion tensor imaging. NeuroImage, 20(2), 870–888. https://doi.org/10.1016/S1053-8119(03)00336-7.

Chang, H., Fitzpatrick, J.M. (1992) A technique for accurate magnetic resonance imaging in the presenceof field inhomogeneities. IEEE Trans Med Imaging, 11:319-29.

Cox, R.W. (1996) AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. Comput Biomed Res, 29:162-73.

Desikan, R.S., Segonne, F., Fischl, B., Quinn, B.T., Dickerson, B.C., Blacker, D., Buckner, R.L., Dale, A.M., Maguire, R.P., Hyman, B.T., Albert, M.S., Killiany, R.J. (2006) An automated labeling system for subdividing the human cerebral cortex on MRI scans into gyral based regions of interest. Neuroimage, 31:968-80.

Destrieux C, Fischl B, Dale A, Halgren E. (2010) Automatic parcellation of human cortical gyri and sulci using standard anatomical nomenclature. Neuroimage. 2010 Oct 15;53(1):1-15.

Fischl, B., Salat, D.H., Busa, E., Albert, M., Dieterich, M., Haselgrove, C., van der Kouwe, A., Killiany, R., Kennedy, D., Klaveness, S., Montillo, A., Makris, N., Rosen, B., Dale, A.M. (2002) Whole brain segmentation: automated labeling of neuroanatomical structures in the human brain. Neuron, 33:341-55.

Hagler, D.J., Jr., Hatton, S., Cornejo, M.D., Makowski, C., Fair, D.A., Dick, A.S., Sutherland, M.T., Casey, B.J., Barch, D.M., Harms, M.P., Watts, R., Bjork, J.M., Garavan, H.P., Hilmer, L., Pung, C.J., Sicat, C.S., Kuperman, J., Bartsch, H., Xue, F., Heitzeg, M.M., Laird, A.R., Trinh, T.T., Gonzalez, R., Tapert, S.F., Riedel, M.C., Squeglia, L.M., Hyde, L.W., Rosenberg, M.D., Earl, E.A., Howlett, K.D., Baker, F.C., Soules, M., Diaz, J., de Leon, O.R., Thompson, W.K., Neale, M.C., Herting, M., Sowell, E.R., Alvarez, R.P., Hawes, S.W., Sanchez, M., Bodurka, J., Breslin, F.J., Morris, A.S., Paulus, M.P., Simmons, W.K., Polimeni, J.R., van der Kouwe, A., Nencka, A.S., Gray, K.M., Pierpaoli, C., Matochik, J.A., Noronha, A., Aklin, W.M., Conway, K., Glantz, M., Hoffman, E., Little, R., Lopez, M., Pariyadath, V., Weiss, S.R., Wolff-Hughes, D.L., DelCarmen-Wiggins, R., Feldstein Ewing, S.W., Miranda-Dominguez, O., Nagel, B.J., Perrone, A.J., Sturgeon, D.T., Goldstone, A., Pfefferbaum, A., Pohl, K.M., Prouty, D., Uban, K., Bookheimer, S.Y., Dapretto, M., Galvan, A., Bagot, K., Giedd, J., Infante, M.A., Jacobus, J., Patrick, K., Shilling, P.D., Desikan, R., Li, Y., Sugrue, L., Banich, M.T., Friedman, N., Hewitt, J.K., Hopfer, C., Sakai, J., Tanabe, J., Cottler, L.B., Nixon, S.J., Chang, L., Cloak, C., Ernst, T., Reeves, G., Kennedy, D.N., Heeringa, S., Peltier, S., Schulenberg, J., Sripada, C., Zucker, R.A., Iacono, W.G., Luciana, M., Calabro, F.J., Clark, D.B., Lewis, D.A., Luna, B., Schirda, C., Brima, T., Foxe, J.J., Freedman, E.G., Mruzek, D.W., Mason, M.J., Huber, R., McGlade, E., Prescot, A., Renshaw, P.F., Yurgelun-Todd, D.A., Allgaier, N.A., Dumas, J.A., Ivanova, M., Potter, A., Florsheim, P., Larson, C., Lisdahl, K., Charness, M.E., Fuemmeler, B., Hettema, J.M., Maes, H.H., Steinberg, J., Anokhin, A.P., Glaser, P., Heath, A.C., Madden, P.A., Baskin-Sommers, A., Constable, R.T., Grant, S.J., Dowling, G.J., Brown, S.A., Jernigan, T.L., Dale, A.M. (2019) Image processing and analysis methods for the Adolescent Brain Cognitive Development Study. Neuroimage, 202:116091.
Holland, D., Kuperman, J.M., Dale, A.M. (2010) Efficient correction of inhomogeneous static magnetic field-induced distortion in Echo Planar Imaging. Neuroimage, 50:175-83.

Jovicich, J., Czanner, S., Greve, D., Haley, E., van der Kouwe, A., Gollub, R., Kennedy, D., Schmitt, F., Brown, G., Macfall, J., Fischl, B., Dale, A. (2006) Reliability in multi-site structural MRI studies: effects of gradient non-linearity correction on phantom and human data. Neuroimage, 30:436-43.

Morgan, P.S., Bowtell, R.W., McIntyre, D.J., Worthington, B.S. (2004) Correction of spatial distortion in EPI due to inhomogeneous static magnetic fields using the reversed gradient method. J Magn Reson Imaging, 19:499-507.

Power, J.D., Mitra, A., Laumann, T.O., Snyder, A.Z., Schlaggar, B.L., Petersen, S.E. (2014) Methods to detect, characterize, and remove motion artifact in resting state fMRI. Neuroimage, 84:320-41.

Siegel, J.S., Power, J.D., Dubis, J.W., Vogel, A.C., Church, J.A., Schlaggar, B.L., Petersen, S.E. (2014) Statistical improvements in functional magnetic resonance imaging analyses produced by censoring high-motion data points. Hum Brain Mapp, 35:1981-96.

Smith, S. M., Jenkinson, M., Woolrich, M. W., Beckmann, C. F., Behrens, T. E., Johansen-Berg, H., Bannister, P. R., De Luca, M., Drobnjak, I., Flitney, D. E., Niazy, R. K., Saunders, J., Vickers, J., Zhang, Y., De Stefano, N., Brady, J. M., & Matthews, P. M. (2004). Advances in functional and structural MR image analysis and implementation as FSL. NeuroImage, 23 Suppl 1, S208–S219. https://doi.org/10.1016/j.neuroimage.2004.07.051.

Wells, W.M., 3rd, Viola, P., Atsumi, H., Nakajima, S., Kikinis, R. (1996) Multi-modal volume registration by maximization of mutual information. Med Image Anal, 1:35-51.