ABCD Human Subjects Study

Adolescent Brain Cognitive Development – ABCDSTUDY.org

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

Resting-State Functional Magnetic Resonance Imaging (rs-fMRI)

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October 2021

Change Log
October 2021 – Data Release 4.0
- Initial release

List of Instruments

Name of Instrument	Short Name
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

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)
- rs-fMRI specific pre-processing -- NOTE: not included in "minimal processing"
    - 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
    - regression
        - linear regression to remove quadratic trends and signals correlated with motion and mean time courses of cerebral white matter, ventricles, and whole brain, plus first derivatives (Power, et al., 2014; Satterthwaite, et al., 2012)
        - motion regression included 6 parameters plus derivatives and squares
        - frames with displacement > 0.3 mm were excluded from the regression (Power, et al., 2014)
        - values for censored frames were replaced using linear interpolation
    - temporal filtering
        - band-pass filtered between 0.009 and 0.08 Hz (Hallquist, et al., 2013)
    - pre-processed time courses were sampled onto the cortical surface
        - projecting 1mm into cortical gray matter along surface normal vector
    - motion censoring to reduce residual effects of head (Power, et al., 2012; Power, et al., 2014)
        - motion estimates filtered to attenuate signals (0.31 - 0.43 Hz) associated with respiration (18.6 - 25.7 respirations / minute)
        - time points with FD > 0.2 mm excluded from variance and correlation calculations

        - time periods with < 5 contiguous, sub-threshold time points also excluded
        - time points that were outliers in standard deviation across ROIs also excluded
- Regions of interest (ROI)
    - 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)
    - functionally-defined parcels derived resting-state functional connectivity patterns (Gordon, et al., 2014)
- Functional connectivity analysis
    - seed-based, correlational approach (Van Dijk, et al., 2010)
        - adapted for cortical surface based analysis (Seibert and Brewer, 2011)
        - networks defined as pre-defined groups of cortical parcels (Gordon, et al., 2014)
            - e.g., default, fronto-parietal, dorsal attention, etc.
        - calculation of average within- and between-network mean correlation (Van Dijk, et al., 2010)
            - correlation between each pair of ROIs
            - Fisher transformed to z-statistics
            - averaged to provide measure of network correlation strength
        - calculation of correlation between each network and each subcortical ROI
    - variance across time calculated for each ROI
        - magnitude of low frequency oscillations

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.

Global signal regression for participants with small ventricles

As part of the rs-fMRI analysis preprocessing, average time series in eroded white matter, whole brain, and ventricles are used for global signal regression. A small number of participants with very small ventricles had missing results because no ventricle voxels survived a 1-voxel erosion, which previously led to a processing error. In such cases, the non-existent ventricle time series was omitted from the global signal regression.

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.

rsfMRI analysis-specific preprocessing

Processing and analysis of rsfMRI data include analysis-specific preprocessing steps, following the "minimal processing" in common with task fMRI. These preprocessing steps include regression and residualization to remove signals related to global oscillations or head motion, with frames with displacement (FD) greater than 0.3 mm excluded (or censored) from the regression. A subsequent linear interpolation step, in which values for the censored frames are replaced through linear interpolation, is important for preventing motion contamination in the subsequent band-pass filtering but was previously omitted. This omission has now been corrected, resulting in a large reduction in the number of subjects with high outlier temporal variance values and a slight reduction in the overall median temporal variance. The across-participant averages of between-ROI correlations were generally unchanged, but there was a substantial reduction in between-participant variation.

rsfMRI analysis

A minor coding error in the rsfMRI analysis pipeline led to missing derived results in rare cases if the first rsfMRI scan in a scan session had no usable data (i.e., due to excessive motion). Fixing this led to the recovery of derived results for the remaining scans with usable data for such participant-events.

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