ABCD Human Subjects Study

Adolescent Brain Cognitive Development – ABCDSTUDY.org

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

Diffusion Magnetic Resonance Imaging (dMRI)

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

October 2021

Change Log

October 2021 – ABCD Data Release 4.0

- Initial release

List of Instruments

Name of Instrument	Short Name
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

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: non-diffusion weighted images with opposite phase encode polarity
  - multi-b-value, multi-direction diffusion weighted images
- Image processing
  - eddy current distortion correction with a nonlinear estimation using diffusion gradient orientations and amplitudes to predict the pattern of distortions (Zhuang, et al., 2006)
  - head motion corrected by registering to images synthesized from tensor fit (Hagler, et al., 2009)
  - diffusion gradients adjusted for head rotation (Hagler, et al., 2009; Leemans and Jones, 2009)
  - robust diffusion tensor estimation (Chang, et al., 2005) used to identify and replace dark slices caused by abrupt head motion
  - B_0 distortions were corrected using the reversing gradient method with FSL's TOPUP (Andersson et al., 2003, Smith et al., 2004)
  - gradient nonlinearity distortion correction (Jovicich, et al., 2006)
  - T_2-weighted b=0 images to T_1w structural images using mutual information (Wells, et al., 1996)
  - resampled into a standard orientation with 1.7 mm isotropic resolution

- Diffusion tensor imaging (DTI) analysis
  - conventional DTI methods (Basser, et al., 1994; Le Bihan, et al., 2001; Pierpaoli, et al., 1996)
  - two modeling approaches
    - DTI inner shell (DTI_{IS}): b values > 1000 excluded from tensor fitting to avoid need for nonlinear estimation; metric prefix is “dti”
    - DTI full shell (DTI_{FS}): all b values used in the tensor fitting; metric prefix is “dti_full”
  - measures of microstructural tissue properties
    - fractional anisotropy (FA)
    - mean diffusivity (MD)
    - longitudinal (or axial) diffusivity (LD)
    - transverse (or radial) diffusivity (TD)
- Restriction Spectrum Imaging (RSI)
  - linear estimation approach allowing for mixtures of “restricted” and “hindered” diffusion pools within individual voxels (White, et al., 2013a; White, et al., 2014; White, et al., 2013b)
  - takes advantage of multiple b-value acquisition
  - two signal fractions modeled as fiber orientation density (FOD) functions
    - longitudinal diffusivity constant for both fractions, with a value of 1.0×10^{-3} mm^2/s
    - restricted fraction (e.g. intracellular): transverse diffusivity modelled as 0
    - hindered fraction (e.g. extracellular): transverse diffusivity modelled as 0.9×10^{-3} mm^2/s
  - one signal fractions modeled as isotropic free water diffusion
    - free fraction (e.g., CSF): isotropic diffusivity modeled as 3.0×10^{-3} mm^2/s
  - measures derived from the RSI model fit
    - restricted normalized isotropic (RNI, aka N0)
      - square of the 0th order spherical harmonic coefficient of the restricted fraction divided by the sum of squares of all model coefficients
    - restricted normalized directional or "neurite density" (RND, aka ND)
      - sum of squared 2nd and 4th order spherical harmonic coefficients of the restricted fraction divided by the norm of the model coefficients
    - restricted normalized total (RNT, aka NT)
      - sum of squared 0th, 2nd, and 4th order spherical harmonic coefficients of the restricted fraction divided by the norm of the model coefficients
    - hindered normalized isotropic (HNI, aka N0_s2)
      - square of the 0th order spherical harmonic coefficient of the hindered fraction divided by the sum of squares of all model coefficients
    - hindered normalized directional (HND, aka ND_s2)
      - sum of squared 2nd and 4th order spherical harmonic coefficients of the hindered fraction divided by the norm of the model coefficients
    - hindered normalized total (HNT, aka NT_s2)
      - sum of squared 0th, 2nd, and 4th order spherical harmonic coefficients of the hindered fraction divided by the norm of the model coefficients
    - free normalized isotropic (FNI)

        - square of the 0th order spherical harmonic coefficient of the hindered fraction divided by the sum of squares of all model coefficients
- 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)
        - white and gray matter values sampled near gray/white boundary (Elman, et al., 2017)
    - major white matter tracts labelled using AtlasTrack (Hagler, et al., 2009)
        - voxels containing primarily gray matter or cerebral spinal fluid excluded from analysis
        - atlas files and additional AtlasTrack documentation available here: https://www.nitrc.org/projects/atlastrack

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

dMRI B0 distortion correction

Moderate to severe residual B0 distortion was noted in manual post-processing QC of a small, but significant portion of dMRI included in previous ABCD releases. Such difficulties were typically caused substantial head motion during the field mapping scans. 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.

Changes for ABCD 4.0

dMRI registration to T1w

The procedure for registration of T2-weighted images (including dMRI b=0 images) 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.

dMRI processing: between-scan registration

Between-scan registration procedures for dMRI were modified to use a more robust method for generating a brain mask from the dMRI 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, *dMRI registration to T1w*.

dMRI 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 proceed 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.

RSI model and data structures

The restriction spectrum imaging (RSI) model used to fit the multishell diffusion data was modified to include a "free water" component, complementing the "restricted" and "hindered" signal fractions. As before, the signal fractions representing restricted (e.g., intracellular) and hindered (e.g., extracellular) diffusion were modeled as fourth order spherical harmonic, fiber orientation density (FOD) functions. For both of these fractions, the LD is modeled as $1x10^{-3}$ mm^2/s. For the restricted fraction, TD is modelled as 0. For the hindered fraction, TD is modelled as 0.9×10^{-3} mm^2/s. The free water fraction was modeled as isotropic diffusion with an apparent diffusion coefficient (ADC) of $3.0x10^{-3}$ mm^2/s.

Measures derived from this RSI model fit included restricted normalized isotropic (RNI), restricted normalized directional (RND), restricted normalized total (RNT), hindered normalized

isotropic (HNI), hindered normalized directional (HND), and hindered normalized total (HNT), and free normalized isotropic (FNI). These normalized RSI measures are unitless and range from 0 to 1. Note that thes abbreviations differ from those used in previous releases and in Hagler et al., 2019. RNI and HNI were previously called N0 and N0_s2, respectively. RND and HND were previously called ND and ND_s2. RNT and HNT were previously called NT and NT_s2. FNI was not previously included. The tabulated data structures for RSI-derived ROI average measures have been replaced for ABCD Release 4.0 (abcd_drsip101, abcd_drsip201, abcd_drsip301, abcd_drsip401, abcd_drsip501, abcd_drsip601, and abcd_drsip701), with each data structure corresponding to one RSI-derived measure for all ROIs.

Changes to data dictionaries

- new data structures *abcd_drsip101*, *abcd_drsip201*, *abcd_drsip301*, *abcd_drsip401*, *abcd_drsip501*, *abcd_drsip601*, and *abcd_drsip701* replacing *mri_rsi_p102*, *mri_rsi_p202*, *abcd_drsidp101*, *abcd_drsidp201*, *and abcd_drsidp301*
    - new element names, descriptions, and DEAP aliases
    - variables grouped into instruments by measure
    - new free normalized isotropic (FNI) measures in *abcd_drsip701*

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