

Diffusion Magnetic Resonance Imaging

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List of Instruments

Name of Instrument	Table Name
<i>Diffusion Tensor Imaging (DTI)</i>	
DTI (Full Shell) - Fractional Anisotropy (AtlasTrack)	mri_y_dti_fa_fs_at
DTI (Inner Shell) - Fractional Anisotropy (AtlasTrack)	mri_y_dti_fa_is_at
DTI (Full Shell) - Fractional Anisotropy-Gray Matter (Desikan)	mri_y_dti_fa_fs_gm_dsk
DTI (Full Shell) - Fractional Anisotropy-Gray/White Contrast (Desikan)	mri_y_dti_fa_fs_gwc_dsk
DTI (Full Shell) - Fractional Anisotropy-White Matter (Desikan)	mri_y_dti_fa_fs_wm_dsk
DTI (Inner Shell) - Fractional Anisotropy-Gray Matter (Desikan)	mri_y_dti_fa_is_gm_dsk
DTI (Inner Shell) - Fractional Anisotropy-Gray/White Contrast (Desikan)	mri_y_dti_fa_is_gwc_dsk
DTI (Inner Shell) - Fractional Anisotropy-White Matter (Desikan)	mri_y_dti_fa_is_wm_dsk
DTI (Full Shell) - Fractional Anisotropy-Gray Matter (Destrieux)	mri_y_dti_fa_fs_gm_dst
DTI (Full Shell) - Fractional Anisotropy-Gray/White Contrast (Destrieux)	mri_y_dti_fa_fs_gwc_dst
DTI (Full Shell) - Fractional Anisotropy-White Matter (Destrieux)	mri_y_dti_fa_fs_wm_dst
DTI (Inner Shell) - Fractional Anisotropy-Gray Matter (Destrieux)	mri_y_dti_fa_is_gm_dst
DTI (Inner Shell) - Fractional Anisotropy-Gray/White Contrast (Destrieux)	mri_y_dti_fa_is_gwc_dst
DTI (Inner Shell) - Fractional Anisotropy-White Matter (Destrieux)	mri_y_dti_fa_is_wm_dst
DTI (Full Shell) - Fractional Anisotropy (Subcortical)	mri_y_dti_fa_fs_aseg

DTI (Inner Shell) - Fractional Anisotropy (Subcortical)	<u>mri_y_dti_fa_is_aseg</u>
DTI (Full Shell) - Longitudinal Diffusivity (AtlasTrack)	<u>mri_y_dti_ld_fs_at</u>
DTI (Inner Shell) - Longitudinal Diffusivity (AtlasTrack)	<u>mri_y_dti_ld_is_at</u>
DTI (Full Shell) - Longitudinal Diffusivity-Gray Matter (Desikan)	<u>mri_y_dti_ld_fs_gm_dsk</u>
DTI (Full Shell) - Longitudinal Diffusivity-Gray/White Contrast (Desikan)	<u>mri_y_dti_ld_fs_gwc_dsk</u>
DTI (Full Shell) - Longitudinal Diffusivity-White Matter (Desikan)	<u>mri_y_dti_ld_fs_wm_dsk</u>
DTI (Inner Shell) - Longitudinal Diffusivity-Gray Matter (Desikan)	<u>mri_y_dti_ld_is_gm_dsk</u>
DTI (Inner Shell) - Longitudinal Diffusivity-Gray/White Contrast (Desikan)	<u>mri_y_dti_ld_is_gwc_dsk</u>
DTI (Inner Shell) - Longitudinal Diffusivity-White Matter (Desikan)	<u>mri_y_dti_ld_is_wm_dsk</u>
DTI (Full Shell) - Longitudinal Diffusivity-Gray Matter (Destrieux)	<u>mri_y_dti_ld_fs_gm_dst</u>
DTI (Full Shell) - Longitudinal Diffusivity-Gray/White Contrast (Destrieux)	<u>mri_y_dti_ld_fs_gwc_dst</u>
DTI (Full Shell) - Longitudinal Diffusivity-White Matter (Destrieux)	<u>mri_y_dti_ld_fs_wm_dst</u>
DTI (Inner Shell) - Longitudinal Diffusivity-Gray Matter (Destrieux)	<u>mri_y_dti_ld_is_gm_dst</u>
DTI (Inner Shell) - Longitudinal Diffusivity-Gray/White Contrast (Destrieux)	<u>mri_y_dti_ld_is_gwc_dst</u>
DTI (Inner Shell) - Longitudinal Diffusivity-White Matter (Destrieux)	<u>mri_y_dti_ld_is_wm_dst</u>
DTI (Full Shell) - Longitudinal Diffusivity (Subcortical)	<u>mri_y_dti_ld_fs_aseg</u>
DTI (Inner Shell) - Longitudinal Diffusivity (Subcortical)	<u>mri_y_dti_ld_is_aseg</u>
DTI (Full Shell) - Mean Diffusivity (AtlasTrack)	<u>mri_y_dti_md_fs_at</u>
DTI (Inner Shell) - Mean Diffusivity (AtlasTrack)	<u>mri_y_dti_md_is_at</u>
DTI (Full Shell) - Mean Diffusivity-Gray Matter (Desikan)	<u>mri_y_dti_md_fs_gm_dsk</u>
DTI (Full Shell) - Mean Diffusivity-Gray/White Contrast (Desikan)	<u>mri_y_dti_md_fs_gwc_dsk</u>
DTI (Full Shell) - Mean Diffusivity-White Matter (Desikan)	<u>mri_y_dti_md_fs_wm_dsk</u>
DTI (Inner Shell) - Mean Diffusivity-Gray Matter (Desikan)	<u>mri_y_dti_md_is_gm_dsk</u>

DTI (Inner Shell) - Mean Diffusivity-Gray/White Contrast (Desikan)	<u>mri_y_dti_md_is_gwc_dsk</u>
DTI (Inner Shell) - Mean Diffusivity-White Matter (Desikan)	<u>mri_y_dti_md_is_wm_dsk</u>
DTI (Full Shell) - Mean Diffusivity-Gray Matter (Destrieux)	<u>mri_y_dti_md_fs_gm_dst</u>
DTI (Full Shell) - Mean Diffusivity-Gray/White Contrast (Destrieux)	<u>mri_y_dti_md_fs_gwc_dst</u>
DTI (Full Shell) - Mean Diffusivity-White Matter (Destrieux)	<u>mri_y_dti_md_fs_wm_dst</u>
DTI (Inner Shell) - Mean Diffusivity-Gray Matter (Destrieux)	<u>mri_y_dti_md_is_gm_dst</u>
DTI (Inner Shell) - Mean Diffusivity-Gray/White Contrast (Destrieux)	<u>mri_y_dti_md_is_gwc_dst</u>
DTI (Inner Shell) - Mean Diffusivity-White Matter (Destrieux)	<u>mri_y_dti_md_is_wm_dst</u>
DTI (Full Shell) - Mean Diffusivity (Subcortical)	<u>mri_y_dti_md_fs_aseg</u>
DTI (Inner Shell) - Mean Diffusivity (Subcortical)	<u>mri_y_dti_md_is_aseg</u>
DTI (Full Shell) - Transverse Diffusivity (AtlasTrack)	<u>mri_y_dti_td_fs_at</u>
DTI (Inner Shell) - Transverse Diffusivity (AtlasTrack)	<u>mri_y_dti_td_is_at</u>
DTI (Full Shell) - Transverse Diffusivity-Gray Matter (Desikan)	<u>mri_y_dti_td_fs_gm_dsk</u>
DTI (Full Shell) - Transverse Diffusivity-Gray/White Contrast (Desikan)	<u>mri_y_dti_td_fs_gwc_dsk</u>
DTI (Full Shell) - Transverse Diffusivity-White Matter (Desikan)	<u>mri_y_dti_td_fs_wm_dsk</u>
DTI (Inner Shell) - Transverse Diffusivity-Gray Matter (Desikan)	<u>mri_y_dti_td_is_gm_dsk</u>
DTI (Inner Shell) - Transverse Diffusivity-Gray/White Contrast (Desikan)	<u>mri_y_dti_td_is_gwc_dsk</u>
DTI (Inner Shell) - Transverse Diffusivity-White Matter (Desikan)	<u>mri_y_dti_td_is_wm_dsk</u>
DTI (Full Shell) - Transverse Diffusivity-Gray Matter (Destrieux)	<u>mri_y_dti_td_fs_gm_dst</u>
DTI (Full Shell) - Transverse Diffusivity-Gray/White Contrast (Destrieux)	<u>mri_y_dti_td_fs_gwc_dst</u>
DTI (Full Shell) - Transverse Diffusivity-White Matter (Destrieux)	<u>mri_y_dti_td_fs_wm_dst</u>
DTI (Inner Shell) - Transverse Diffusivity-Gray Matter (Destrieux)	<u>mri_y_dti_td_is_gm_dst</u>

DTI (Inner Shell) - Transverse Diffusivity-Gray/White Contrast (Destrieux)	<u>mri_y_dti_td_is_gwc_ds_t</u>
DTI (Inner Shell) - Transverse Diffusivity-White Matter (Destrieux)	<u>mri_y_dti_td_is_wm_dst</u>
DTI (Full Shell) - Transverse Diffusivity (Subcortical)	<u>mri_y_dti_td_fs_aseg</u>
DTI (Inner Shell) - Transverse Diffusivity (Subcortical)	<u>mri_y_dti_td_is_aseg</u>
DTI (Full Shell) - Volume (AtlasTrack)	<u>mri_y_dti_vol_fs_at</u>
DTI (Inner Shell) - Volume (AtlasTrack)	<u>mri_y_dti_vol_is_at</u>

Restriction Spectrum Imaging (RSI)

RSI - Free Normalized Isotropic (AtlasTrack)	<u>mri_y_rsi_fni_at</u>
RSI - Free Normalized Isotropic-Gray Matter (Desikan)	<u>mri_y_rsi_fni_gm_dsk</u>
RSI - Free Normalized Isotropic-Gray/White Contrast (Desikan)	<u>mri_y_rsi_fni_gwc_dsk</u>
RSI - Free Normalized Isotropic-White Matter (Desikan)	<u>mri_y_rsi_fni_wm_dsk</u>
RSI - Free Normalized Isotropic-Gray Matter (Destrieux)	<u>mri_y_rsi_fni_gm_dst</u>
RSI - Free Normalized Isotropic-Gray/White Contrast (Destrieux)	<u>mri_y_rsi_fni_gwc_dst</u>
RSI - Free Normalized Isotropic-White Matter (Destrieux)	<u>mri_y_rsi_fni_wm_dst</u>
RSI - Free Normalized Isotropic (Subcortical)	<u>mri_y_rsi_fni_aseg</u>
RSI - Hindered Normalized Directional (AtlasTrack)	<u>mri_y_rsi_hnd_at</u>
RSI - Hindered Normalized Directional-Gray Matter (Desikan)	<u>mri_y_rsi_hnd_gm_dsk</u>
RSI - Hindered Normalized Directional-Gray/White Contrast (Desikan)	<u>mri_y_rsi_hnd_gwc_dsk</u>
RSI - Hindered Normalized Directional-White Matter (Desikan)	<u>mri_y_rsi_hnd_wm_dsk</u>
RSI - Hindered Normalized Directional-Gray Matter (Destrieux)	<u>mri_y_rsi_hnd_gm_dst</u>
RSI - Hindered Normalized Directional-Gray/White Contrast (Destrieux)	<u>mri_y_rsi_hnd_gwc_dst</u>
RSI - Hindered Normalized Directional-White Matter (Destrieux)	<u>mri_y_rsi_hnd_wm_dst</u>
RSI - Hindered Normalized Directional (Subcortical)	<u>mri_y_rsi_hnd_aseg</u>
RSI - Hindered Normalized Isotropic (AtlasTrack)	<u>mri_y_rsi_hni_at</u>
RSI - Hindered Normalized Isotropic-Gray Matter (Desikan)	<u>mri_y_rsi_hni_gm_dsk</u>

RSI - Hindered Normalized Isotropic-Gray/White Contrast (Desikan)	mri_y_rsi_hni_gwc_dsk
RSI - Hindered Normalized Isotropic-White Matter (Desikan)	mri_y_rsi_hni_wm_dsk
RSI - Hindered Normalized Isotropic-Gray Matter (Destrieux)	mri_y_rsi_hni_gm_dst
RSI - Hindered Normalized Isotropic-Gray/White Contrast (Destrieux)	mri_y_rsi_hni_gwc_dst
RSI - Hindered Normalized Isotropic-White Matter (Destrieux)	mri_y_rsi_hni_wm_dst
RSI - Hindered Normalized Isotropic (Subcortical)	mri_y_rsi_hni_aseg
RSI - Hindered Normalized Total (AtlasTrack)	mri_y_rsi_hnt_at
RSI - Hindered Normalized Total-Gray Matter (Desikan)	mri_y_rsi_hnt_gm_dsk
RSI - Hindered Normalized Total-Gray/White Contrast (Desikan)	mri_y_rsi_hnt_gwc_dsk
RSI - Hindered Normalized Total-White Matter (Desikan)	mri_y_rsi_hnt_wm_dsk
RSI - Hindered Normalized Total-Gray Matter (Destrieux)	mri_y_rsi_hnt_gm_dst
RSI - Hindered Normalized Total-Gray/White Contrast (Destrieux)	mri_y_rsi_hnt_gwc_dst
RSI - Hindered Normalized Total-White Matter (Destrieux)	mri_y_rsi_hnt_wm_dst
RSI - Hindered Normalized Total (Subcortical)	mri_y_rsi_hnt_aseg
RSI - Restricted Normalized Directional (AtlasTrack)	mri_y_rsi_rnd_at
RSI - Restricted Normalized Directional-Gray Matter (Desikan)	mri_y_rsi_rnd_gm_dsk
RSI - Restricted Normalized Directional-Gray/White Contrast (Desikan)	mri_y_rsi_rnd_gwc_dsk
RSI - Restricted Normalized Directional-White Matter (Desikan)	mri_y_rsi_rnd_wm_dsk
RSI - Restricted Normalized Directional-Gray Matter (Destrieux)	mri_y_rsi_rnd_gm_dst
RSI - Restricted Normalized Directional-Gray/White Contrast (Destrieux)	mri_y_rsi_rnd_gwc_dst
RSI - Restricted Normalized Directional-White Matter (Destrieux)	mri_y_rsi_rnd_wm_dst
RSI - Restricted Normalized Directional (Subcortical)	mri_y_rsi_rnd_aseg
RSI - Restricted Normalized Isotropic (AtlasTrack)	mri_y_rsi_rni_at
RSI - Restricted Normalized Isotropic-Gray Matter (Desikan)	mri_y_rsi_rni_gm_dsk
RSI - Restricted Normalized Isotropic-Gray/White Contrast (Desikan)	mri_y_rsi_rni_gwc_dsk
RSI - Restricted Normalized Isotropic-White Matter (Desikan)	mri_y_rsi_rni_wm_dsk

RSI - Restricted Normalized Isotropic-Gray Matter (Destrieux)	mri_y_rsi_rni_gm_dst
RSI - Restricted Normalized Isotropic-Gray/White Contrast (Destrieux)	mri_y_rsi_rni_gwc_dst
RSI - Restricted Normalized Isotropic-White Matter (Destrieux)	mri_y_rsi_rni_wm_dst
RSI - Restricted Normalized Isotropic (Subcortical)	mri_y_rsi_rni_aseg
RSI - Restricted Normalized Total (AtlasTrack)	mri_y_rsi_rnt_at
RSI - Restricted Normalized Total-Gray Matter (Desikan)	mri_y_rsi_rnt_gm_dsk
RSI - Restricted Normalized Total-Gray/White Contrast (Desikan)	mri_y_rsi_rnt_gwc_dsk
RSI - Restricted Normalized Total-White Matter (Desikan)	mri_y_rsi_rnt_wm_dsk
RSI - Restricted Normalized Total-Gray Matter (Destrieux)	mri_y_rsi_rnt_gm_dst
RSI - Restricted Normalized Total-Gray/White Contrast (Destrieux)	mri_y_rsi_rnt_gwc_dst
RSI - Restricted Normalized Total-White Matter (Destrieux)	mri_y_rsi_rnt_wm_dst
RSI - Restricted Normalized Total (Subcortical)	mri_y_rsi_rnt_aseg

General Information

An overview of the ABCD Study® can be found at abcdstudy.org and detailed descriptions of the assessment protocols are available at [ABCD Protocols](#). This page describes the contents of various instruments available for download. To understand the context of this information, refer to the release notes [Start Page](#) and [Imaging Overview](#).

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
 - B0 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 $1.0 \times 10^{-3} \text{ mm}^2/\text{s}$
 - restricted fraction (e.g. intracellular): transverse diffusivity modelled as 0
 - hindered fraction (e.g. extracellular): transverse diffusivity modelled as $0.9 \times 10^{-3} \text{ mm}^2/\text{s}$
 - one signal fractions modeled as isotropic free water diffusion
 - free fraction (e.g., CSF): isotropic diffusivity modeled as $3.0 \times 10^{-3} \text{ mm}^2/\text{s}$
 - measures derived from the RSI model fit
 - restricted normalized isotropic (RNI, aka N_0)
 - 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 N_D)
 - 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 N_T)
 - 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 N_{0_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 N_{D_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 N_{T_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. No significant changes were made to the processing pipeline for Release 5.0.

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 by 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 B0 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 T_1 - or T_2 -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 T_1w* .

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 versions 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 $1 \times 10^{-3} \text{ mm}^2/\text{s}$. For the restricted fraction, TD is modeled as 0. For the hindered fraction, TD is modeled as $0.9 \times 10^{-3} \text{ mm}^2/\text{s}$. The free water fraction was modeled as isotropic diffusion with an apparent diffusion coefficient (ADC) of $3.0 \times 10^{-3} \text{ mm}^2/\text{s}$.

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 these 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 NDA 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 NDA data structure `abcd_drsip701`

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