



 Imaging > MRI Quality Control

MRI Quality Control & Recommended Image Inclusion Criteria

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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](#).

Recommended Imaging Inclusion

Users of the imaging data are advised to choose inclusion criteria that are appropriate for their analyses. We provide a set of recommended inclusion criteria for each modality that take into account factors such as imaging QC, task performance, etc., and for convenience, we provide an instrument [mri_y_qc_incl](#) with modality-specific imaging inclusion flags based on those criteria. Each modality (T₁w, T₂w, DTI/RSI, rsfMRI, SST, nBack, and MID tfMRI) is scored as 1=include, 0=exclude.

T₁w data recommended for inclusion

T₁w series meets all criteria for inclusion (`imgincl_t1w_include = 1`).

T ₁ w Criteria	Instrument	Element value
<i>T₁ series passed rawQC</i>	mri_y_qc_raw_smr_t1	<code>iqc_t1_ok_ser > 0</code>
<i>FreeSurfer QC not failed</i>	mri_y_qc_man_fsurf	<code>fsqc_qc != 0</code>
<i>Derived results exist</i>	mri_y_smr_t1_aseg	<code>smri_t1w_scs_cbwmatterlh != NA</code>

T₂w data recommended for inclusion

T₂w series meets all criteria for inclusion (`imgincl_t2w_include = 1`).

T ₂ w Criteria	Instrument	Element value
<i>T₂ series passed rawQC</i>	mri_y_qc_raw_smr_t2	<code>iqc_t2_ok_ser > 0</code>

T₂w Criteria	Instrument	Element value
<i>T₁ series passed rawQC</i>	mri_y_qc_raw_smr_t1	<code>iqc_t1_ok_ser > 0</code>
<i>FreeSurfer QC not failed</i>	mri_y_qc_man_fsurf	<code>fsqc_qc != 0</code>
<i>T₂w manual post-processing QC not failed</i>	mri_y_qc_man_post_t2w	<code>t2w_postqc_qc != 0</code>
<i>T₂w registration to T₁w</i>	mri_y_qc_auto_post	<code>apqc_smri_t2w_regt1_rigid < 10</code>
<i>Derived results exist</i>	mri_y_smr_t2_aseg	<code>smri_t2w_scs_cbwmatterlh != NA</code>

dMRI (DTI/RSI) data recommended for inclusion

dMRI (DTI/RSI) series meets all criteria for inclusion (`imgincl_dmri_include = 1`).

dMRI Criteria	Instrument	Element value
<i>dMRI series passed rawQC</i>	mri_y_qc_raw_dmr	<code>iqc_dmri_ok_ser > 0</code>
<i>dMRI total number of repetitions</i>	mri_y_qc_raw_dmr	<code>iqc_dmri_ok_nreps >= 103</code> OR <code>(mri_info_manufacturer = Philips AND iqc_dmri_ok_ser >= 2 AND iqc_dmri_ok_nreps = 51)</code>
<i>T₁ series passed rawQC</i>	mri_y_qc_raw_smr_t1	<code>iqc_t1_ok_ser > 0</code>
<i>dMRI B0 unwarp available</i>	mri_y_qc_auto_post	<code>apqc_dmri_bounwarp_flag = 1</code>
<i>FreeSurfer QC not failed</i>	mri_y_qc_man_fsurf	<code>fsqc_qc != 0</code>
<i>dMRI manual post-processing QC not failed</i>	mri_y_qc_man_post_dmr	<code>dmri_dti_postqc_qc != 0</code>
<i>dMRI registration to T₁w</i>	mri_y_qc_auto_post	<code>apqc_dmri_regt1_rigid < 17</code>

<i>dMRI dorsal cutoff score</i>	mri_y_qc_auto_post	<code>apqc_dmri_fov_cutoff_dorsal < 47</code>
<i>dMRI ventral cutoff score</i>	mri_y_qc_auto_post	<code>apqc_dmri_fov_cutoff_ventral < 54</code>
<i>Derived results exist</i>	mri_y_rsi_rnd_at	<code>dmri_rsi_rnd_fib_allfib != NA</code>

rs-fMRI data recommended for inclusion

rsfMRI series meets all criteria for inclusion (`imgincl_rsfmri_include = 1`).

rsfMRI Criteria	Instrument	Element value
<i>rsfMRI tfMRI series passed rawQC</i>	mri_y_qc_raw_rsfmr	<code>iqc_rsfmri_ok_ser > 0</code>
<i>T₁ series passed rawQC</i>	mri_y_qc_raw_smr_t1	<code>iqc_t1_ok_ser > 0</code>
<i>rsfMRI number of frames after censoring</i>	mri_y_qc_motion	<code>rsfmri_ntpoints > 375</code>
<i>fMRI B0 unwarp available</i>	mri_y_qc_auto_post	<code>apqc_fmri_bounwarp_flag = 1</code>
<i>FreeSurfer QC not failed</i>	mri_y_qc_man_fsrf	<code>fsqc_qc != 0</code>
<i>fMRI manual post-processing QC not failed</i>	mri_y_qc_man_post_fmr	<code>fmri_postqc_qc != 0</code>
<i>fMRI registration to T_{1w}</i>	mri_y_qc_auto_post	<code>apqc_fmri_regt1_rigid < 19</code>
<i>fMRI dorsal cutoff score</i>	mri_y_qc_auto_post	<code>apqc_fmri_fov_cutoff_dorsal < 65</code>
<i>fMRI ventral cutoff score</i>	mri_y_qc_auto_post	<code>apqc_fmri_fov_cutoff_ventral < 60</code>
<i>Derived results exist</i>	mri_y_rsfmr_cor_gp	<code>rsfmri_c_ngd_dt_ngd_sa != NA</code>

MID task-fMRI data recommended for inclusion

MID tfMRI series meets all criteria for inclusion (`imgincl_mid_include = 1`).

MID Criteria	Instrument	Element value
MID tfMRI series passed rawQC	mri_y_qc_raw_tf_mr_mid	iqc_mid_ok_ser > 0
T ₁ series passed rawQC	mri_y_qc_raw_sm_r_t1	iqc_t1_ok_ser > 0
MID behavior passed	mri_y_tfmr_mid_beh	tfmri_mid_beh_performflag = 1
MID degrees of freedom > 200	mri_y_qc_motion	tfmri_mid_all_dof > 200
MID E-prime timing match OR ignore E- prime mismatch	mri_y_qc_raw_tf_mr_mid	iqc_mid_ep_t_series_match = 1 OR eprime_mismatch_ok_mid = 1
fMRI B0 unwarp available	mri_y_qc_auto_p_ost	apqc_fmri_bounwarp_flag = 1
FreeSurfer QC not failed	mri_y_qc_man_fs_urf	fsqc_qc != 0
fMRI manual post-processing QC not failed	mri_y_qc_man_post_fmri	fmri_postqc_qc != 0
fMRI registration to T ₁ w	mri_y_qc_auto_p_ost	apqc_fmri_regt1_rigid < 19
fMRI dorsal cutoff score	mri_y_qc_auto_p_ost	apqc_fmri_fov_cutoff_dorsal < 65
fMRI ventral cutoff score	mri_y_qc_auto_p_ost	apqc_fmri_fov_cutoff_ventral < 60
Derived results exist	mri_y_tfmr_mid_arvn_aseg	tfmri_ma_acdn_b_scs_cbwmlh != NA

nBack task-fMRI data recommended for inclusion

nBack tfMRI series meets all criteria for inclusion (imgincl_nback_include = 1).

nBack Criteria	Instrument	Element value
nBack tfMRI series passed rawQC	mri_y_qc_raw_tf_mr_nback	iqc_nback_ok_ser > 0

nBack Criteria	Instrument	Element value
<i>T₁ series passed rawQC</i>	mri_y_qc_raw_sm_r_t1	<code>iqc_t1_ok_ser > 0</code>
<i>nBack behavior passed</i>	mri_y_tfmr_nback_k_beh	<code>tfmri_nback_beh_performflag = 1</code>
<i>nBack degrees of freedom > 200</i>	mri_y_qc_motion	<code>tfmri_nback_all_dof > 200</code>
<i>nBack E-prime timing match OR ignore E- prime mismatch</i>	mri_y_qc_raw_tf_mr_nback	<code>iqc_nback_ep_t_series_match = 1 OR eprime_mismatch_ok_nback = 1</code>
<i>fMRI B0 unwarp available</i>	mri_y_qc_auto_post	<code>apqc_fmri_bounwarp_flag = 1</code>
<i>FreeSurfer QC not failed</i>	mri_y_qc_man_fsurf	<code>fsqc_qc != 0</code>
<i>fMRI manual post-processing QC not failed</i>	mri_y_qc_man_post_fmr	<code>fmri_postqc_qc != 0</code>
<i>fMRI registration to T₁w</i>	mri_y_qc_auto_post	<code>apqc_fmri_regt1_rigid < 19</code>
<i>fMRI dorsal cutoff score</i>	mri_y_qc_auto_post	<code>apqc_fmri_fov_cutoff_dorsal < 65</code>
<i>fMRI ventral cutoff score</i>	mri_y_qc_auto_post	<code>apqc_fmri_fov_cutoff_ventral < 60</code>
<i>Derived results exist</i>	mri_y_tfmr_nback_k_0b_aseg	<code>tfmri_nback_all_4 != NA</code>

SST task-fMRI data recommended for inclusion

SST tfMRI series meets all criteria for inclusion (`imgincl_sst_include = 1`).

SST Criteria	Instrument	Element value
<i>SST tfMRI series passed rawQC</i>	mri_y_qc_raw_tf_mr_sst	<code>iqc_sst_ok_ser > 0</code>
<i>T₁ series passed rawQC</i>	mri_y_qc_raw_sm_r_t1	<code>iqc_t1_ok_ser > 0</code>

SST Criteria	Instrument	Element value
<i>SST behavior passed</i>	mri_y_tfmr_sst_beh	tfmri_sst_beh_performflag = 1
<i>SST task had no glitch</i>	mri_y_tfmr_sst_beh	tfmri_sst_beh_glitchflag = 0
<i>SST degrees of freedom > 200</i>	mri_y_qc_motion	tfmri_sst_all_dof > 200
<i>SST E-prime timing match OR ignore E- prime mismatch</i>	mri_y_qc_raw_tf_mr_sst	iqc_sst_ep_t_series_match = 1 OR eprime_mismatch_ok_sst = 1
<i>fMRI B0 unwarp available</i>	mri_y_qc_auto_p_ost	apqc_fmri_bounwarp_flag = 1
<i>FreeSurfer QC not failed</i>	mri_y_qc_man_fsurf	fsqc_qc != 0
<i>fMRI manual post-processing QC not failed</i>	mri_y_qc_man_post_fmri	fmri_postqc_qc != 0
<i>fMRI registration to T₁w</i>	mri_y_qc_auto_p_ost	apqc_fmri_regt1_rigid < 19
<i>fMRI dorsal cutoff score</i>	mri_y_qc_auto_p_ost	apqc_fmri_fov_cutoff_dorsal < 65
<i>fMRI ventral cutoff score</i>	mri_y_qc_auto_p_ost	apqc_fmri_fov_cutoff_ventral <= 60
<i>*Derived results exist**</i>	mri_y_tfmr_sst_cgvmf_aseg	tfmri_sacgmf_bscs_cbwmlh != NA

Automated post-processing QC metrics were statistically characterized in association with manual QC variables from ABCD Release 3.0. The statistical association between manual and automated QC variables was used to guide the identification of automated QC variables that were predictive of manual QC scores. The pairwise analysis of manual-vs-auto QC scores lead to automated QC variable thresholds needed to identify anomalous scans with desired false alarm ratings. For the variables listed below, the thresholds are listed to achieve conservatively low false alarm ratings of 0.05%.

- sMRI T₂w registration to T₁w: < 10
- dMRI registration to T₁w: < 17
- dMRI Maximum dorsal cutoff score: < 47

- dMRI Maximum ventral cutoff score: < 54
- fMRI registration to T₁w: < 19
- fMRI Maximum dorsal cutoff score: < 65
- fMRI Maximum ventral cutoff score: < 60

Notes:

- All imaging series have been manually reviewed at the preprocessing stage ("raw"). Series failing raw QC do not get processed (e.g., `iqc_t1_ok_ser` is 0 or empty).
- For task fMRI, the average degrees of freedom is set at an arbitrary 200; this can be increased for a more restrictive selection criteria. For single runs, the required degrees of freedom are halved (i.e., dof > 100).

MRI Clinical Findings

T₁w and T₂w-weighted 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).

The most important measure is the Report Score (`mrif_score`):

- 0 = Image artifacts prevent radiology read
- 1 = No abnormal findings
- 2 = Normal anatomical variant of no clinical significance
- 3 = Consider clinical referral
- 4 = Consider immediate clinical referral

Although not included in the recommended inclusion criteria, users may, depending on their research question and analytical design, opt to exclude participants with `mrif_score != 3 OR mrif_score !=4`.

MRI Raw QC

- Protocol compliance checking
 - performed by on-site FIONA workstations to provide feedback to scan operators
 - out-of-compliance series reviewed by DAIC staff
 - criteria included whether key imaging parameters matched expected values for a given scanner, such as voxel size or repetition time
 - presence or absence of B0 distortion field map series was checked for diffusion MRI (dMRI) and functional MRI (fMRI) series
 - each imaging series checked for completeness (i.e., no missing files)
- Automated quality control metrics
 - Structural MRI (sMRI): mean and standard deviation of brain values and spatial SNR
 - dMRI: mean motion (average framewise displacement), and the number of slices and frames affected by slice dropout caused by abrupt head motion

- fMRI: mean motion (average framewise displacement), the number of seconds with framewise displacements less than 0.2, 0.3, or 0.4 mm (Power, et al., 2012), temporal SNR (tSNR) (Triantafyllou, et al., 2005)
- Manual review of data quality
 - reviewers assigned binary QC score
 - 0 = reject
 - most severe artifacts or irregularities
 - rejected series excluded from subsequent processing and analysis
 - 1 = accept
 - types of images reviewed
 - T₁w, T₂w, dMRI, dMRI field map, fMRI, and fMRI field map
 - raw and some derived images were reviewed
 - dMRI derived images included average b=0 image, FA, MD, tensor fit residual error, and direction encoded color image
 - fMRI derived images included the average across time and the temporal standard deviation
 - inspected for signs of artifacts and poor image quality
 - presence of wrap-around field of view artifacts
 - brain cut-off due to the participant motion outside prescribed slices
 - magnetic susceptibility artifacts due to dental implants
 - T₁w and T₂w motion artifact (e.g. blurring and ghosting)

FreeSurfer QC

- Manual review of FreeSurfer cortical surface reconstruction
 - reviewers assigned binary (0|1) QC score
 - 0 = reject
 - most severe artifacts or irregularities
 - results still included in shared tabulated data
 - recommended exclusion from group analyses involving cortical surface ROIs
 - 1 = accept
 - reviewers gauged the severity of five types of artifact or processing problem
 - motion
 - intensity inhomogeneity
 - white matter underestimation
 - pial overestimation
 - magnetic susceptibility artifact
 - numeric values assigned on a scale of 0-3
 - absent, mild, moderate, or severe, respectively
 - QC score of 0 assigned if severity score of 3 for any artifact type

Note: Imaging-derived results are included in shared tabulated data regardless of post-processing QC. QC variables (derived from procedures described above) are included in shared tabulated data. The overall, binary QC score described above indicates whether inclusion or exclusion is

recommended based on this criterion alone (see above [Recommended Imaging Inclusion](#)). FreeSurfer QC covers ~6.6% of participant-events with imaging data.

Manual Post Processing QC

sMRI T₂w Post Processing QC

- Manual review of DTI reconstruction
 - reviewers assigned binary (0|1) QC score
 - 0 = reject
 - most severe artifacts or irregularities
 - results still included in shared tabulated data
 - recommended exclusion from group analyses involving cortical, subcortical, and tract-based ROIs
 - 1 = accept
 - reviewers gauged the severity of four types of artifact or processing problem
 - motion
 - intensity inhomogeneity
 - magnetic susceptibility artifact
 - registration with T₁w image
 - numeric values assigned on a scale of 0-3
 - absent, mild, moderate, or severe, respectively
 - QC score of 0 assigned if severity score of 3 for any artifact type

Note: The T₂w Post Processing QC covers ~2.4% of participant-events with imaging data.

dMRI Post Processing QC

- Manual review of processed dMRI data
 - reviewers assigned binary (0|1) QC score
 - 0 = reject
 - most severe artifacts or irregularities
 - results still included in shared tabulated data
 - recommended exclusion from group analyses involving cortical, subcortical, and tract-based ROIs
 - 1 = accept
 - reviewers gauged the severity of five types of artifact or processing problem
 - B0 warping
 - image quality based on motion-related artifacts and magnetic susceptibility artifact
 - full head coverage
 - registration with T₁w image
 - accuracy of fiber tract segmentation
 - numeric values assigned on a scale of 0-3

- absent, mild, moderate, or severe, respectively
- QC score of 0 assigned if severity score of 3 for any artifact type

Note: The dMRI Post Processing QC covers ~7.4% of participant-events with imaging data.

fMRI Post Processing QC

- Manual review of processed fMRI data
 - reviewers assigned binary (0|1) QC score
 - 0 = reject
 - most severe artifacts or irregularities
 - results still included in shared tabulated data
 - recommended exclusion from group analyses involving cortical, subcortical, and tract-based ROIs
 - 1 = accept
 - reviewers gauged the severity of five types of artifact or processing problem
 - B0 warping
 - image quality based primarily on magnetic susceptibility artifact
 - full head coverage
 - registration with T₁w image
 - numeric values assigned on a scale of 0-3
 - absent, mild, moderate, or severe, respectively
 - QC score of 0 assigned if severity score of 3 for any artifact type

Note: The fMRI Post Processing QC covers ~6.3% of participant-events with imaging data.

Automated Post Processing QC

Automated QC measures were defined and calculated based on processed imaging data.

- FreeSurfer
 - number of topological defects
 - calculated from Euler number
- dMRI
 - field of view (FOV) brain cutoff
 - quantified by % intersection of brain mask with frame borders
 - registration to T₁w
 - window-based estimation of geometric registration discrepancy with respect to the T₁ scan, decomposed into rigid and warp components for calculation of registration error
- fMRI
 - field of view (FOV) brain cutoff
 - quantified by % intersection of brain mask with frame borders
 - registration to T₁w

- window-based estimation of geometric registration discrepancy with respect to the T_1 scan, decomposed into rigid and warp components for calculation of registration error
- sMRI T_2w
 - registration to T_1w
 - window-based estimation of geometric registration discrepancy with respect to the T_1 scan, decomposed into rigid and warp components for calculation of registration error

MRI post-processing quality control

Our manual quality control process involves manual examination of brain images from a subset of participant-events for each modality, with ratings for each dataset according to pre-defined quality criteria such as brain cutoff, residual distortion, or registration to T_1 . Such measures are described above (see [FreeSurfer QC](#), [sMRI \$T_2w\$ Post Processing QC](#), [dMRI Post Processing QC](#), and [fMRI Post Processing QC](#)). Because an exhaustive manual review of every scan is not practical, we deploy statistical learning/AI guided sub-sampling methods where we generate automated metrics for an array of quality control issues (see [Automated Post Processing QC](#)) and sub-select participant-events to be sent for a given modality to manual review based on their quality measure scores. The automatic selection priority scores generally indicate how likely a dataset of a given type is to contain identifiable data quality issues such as a residual distortion or brain cutoff. ABCD Release 4.0 manual review post processing sampling categories included the following four primary groups:

Failed post-processing QC from ABCD Release 3.0: All participant-events that failed QC for a given modality in Release 3.0 were manually reviewed again after Release 4.0 processing, with the expectation that they would be likely candidates for failure, unless perhaps recovered due to improvements in the current Release 4.0 processing pipeline. These made up about 25-50% of manually reviewed participant-events.

Random selection of participant-events: Roughly 5% of the manually reviewed participant-events were chosen at random to account for possible biases and insensitivities of the automated measures that guide the sub-sampling selection process.

Statistical outliers: ROI summary vectors for all individual participant-events are used to deduce a statistical ensemble profile. Participant-events with the greatest “distance” to the ensemble are tagged as outliers and selected for manual review. The formal framework we used for defining the ensemble statistics and the “distance” measure between a scan and the ensemble is based on the Mahalanobis distance (see https://en.wikipedia.org/wiki/Mahalanobis_distance). Mahalanobis distance is a scalar measure of the distance between a point $\mathbf{P}$, defined in a multi-dimensional vector space, and a distribution $\mathbf{D}$. In our case, participant-events are sorted based on their Mahalanobis distances, and our manual review goal targeted the top 5% of that list. These made up ~20-25% of manually reviewed participant-events.

Classifier guided selections: Using the manual scoring of the above sets, namely the random samples, Release 3.0 failures, and Mahalanobis distance outliers, we collected a subset of manually labeled scan data. For each participant-event we generated a set of automated measures described below in *Automated Post Processing QC (automated review)*. Using binarized (pass/fail) manual

quality control (QC) labels associated with these measures, we constructed a Bayesian classifier (see https://en.wikipedia.org/wiki/Bayes_classifier) that calculates the probability of QC failure associated with different types of QC issues (e.g., bad registration or brain cutoff) for any given dataset. Participant-events are sorted based on their QC failure probabilities, and roughly the top 3-5% were selected for manual review for each modality, making up ~30-50% of manually reviewed participant-events.

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 (doi: [10.1016/j.neuroimage.2019.116091](https://doi.org/10.1016/j.neuroimage.2019.116091)). Changes to image processing and analysis methods in Release 3.0 and Release 4.0 are documented below.

Changes for ABCD 3.0

Post processing QC and inclusion criteria

As in ABCD Release 2.0.1, FreeSurfer cortical surface reconstructions were reviewed for all participant-events that successfully completed FreeSurfer processing. New for Release 3.0, we used a sampling approach for dMRI and fMRI, wherein approximately 20% of the dMRI/fMRI sessions were manually reviewed for postprocessing dMRI/fMRI QC. We selected participant-events for review based on random-sampling, Bayesian classifiers based on automated QC metrics, and multivariate outlier detection. Recommended inclusion criteria were updated to include manual post-processing QC, new automated post-processing QC metrics, and additional variables (e.g., E-Prime timing match to imaging series). Modality-specific imaging inclusion flags are included in a new NDA data structure, `abcd_imgincl01`.

Protocol compliance

The determination of protocol compliance for scans from GE scanners (reflected for example in elements `iqc_sst_1_pc_score` or `iqc_sst_total_passpc` in NDA data structure `mriqcrp202`) was changed to use the "ImagesInAcquisition" DICOM header attribute rather than the number of DICOM files. Imaging series with missing files, i.e., fewer files than the ImagesInAcquisition, are marked as incomplete. For Siemens and Philips scans, the same DICOM header field recording the number of images collected is not available, and so series with fewer files than expected for the given series type are marked as incomplete.

Changes for ABCD 4.0

MRI raw QC

The MRI raw QC NDA data structures `mriqcp103` and `mriqcp203` were updated to reflect a remapping of the names and abbreviations used to categorize MRI raw QC issues. This was done to

remove redundancy in the categories used previously. Also, QC issue variables were removed where inappropriate for a given scan type, such as the dMRI-specific “fa” (fractional anisotropy map issues) for sMRI or fMRI (e.g., `iqc_mid_fa_qc`).

QC issue names	Previously used names
<i>field of view (fov)</i>	dorsal cutoff (dco)
	ventral cutoff (vco)
	wrap around (wr)
<i>susceptibility artifact (sus)</i>	distortion (dis)
	signal dropout (sd)
	signal inhomogeneity (si)
<i>horizontal banding (hb)</i>	slice
	horizontal banding (hb)
<i>other</i>	flag
	other

Post processing QC and inclusion criteria

We extended the sampling approach used in Release 3.0 to include FreeSurfer, dMRI, fMRI, and sMRI T₂w post-processing QC. Approximately 2-7% of all participant-events were manually reviewed for post-processing QC for each modality. We selected participant-events for review based on post-processing QC failure in Release 3.0, multivariate outlier detection, Bayesian classifiers based on automated QC metrics, and random-sampling (~5% of total selected for review). Multivariate outlier detection was implemented using Mahalanobis distance calculated from the tabulated data (ROI averages) for a given imaging modality. Recommended inclusion criteria were updated to include manual post-processing QC for T₂w. A new manual post-processing QC NDA data structures was created for sMRI T₂w: `abcd_t2wqc01`.

The following manual post-processing QC NDA data structures were renamed:

- `freesqc01` to `abcd_fsrfqc01`
- `dmriqc01` to `abcd_dmriqc01`
- `fmriqc01` to `abcd_fmriqc01`

Changes to data dictionaries

- Raw MRI QC

- new versions of NDA data structures `mriqcrp103` and `mriqcrp203` based on `mriqcrp102` and `mriqcrp202`
 - added new elements related to types of QC issues
 - removed other elements related to unused or deprecated QC issues
 - changes to `DataType` and `Size` for some elements
- Manual post-processing QC
 - new NDA data structure `abcd_t2wqc01`
 - new NDA data structure `abcd_fmriqc01` based on `fmriqc01`
 - added deap alias `fmri_man_postqc_notes`
 - removed alias `fmri_postqc_visitid`
 - new NDA data structure `abcd_dmriqc01` based on `dmriqc01`
 - added deap aliases (with `dmri_manu_postqc...`)
 - new NDA data structure `abcd_fsrfqc01` based on `freesqc01`
 - removed alias `fsqc_visit_id`
 - added DEAP aliases (with `fsurf_manu_postqc...`)

References

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., Sicut, 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., Prescott, 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., Hettima, 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.

Power, J.D., Barnes, K.A., Snyder, A.Z., Schlaggar, B.L., Petersen, S.E. (2012) Spurious but systematic correlations in functional connectivity MRI networks arise from subject motion. *Neuroimage*, 59:2142-54.

Triantafyllou, C., Hoge, R.D., Krueger, G., Wiggins, C.J., Potthast, A., Wiggins, G.C., Wald, L.L. (2005) Comparison of physiological noise at 1.5 T, 3 T and 7 T and optimization of fMRI acquisition parameters. *Neuroimage*, 26:243-50.

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