HowTo: ArtRepair with RaBIDS

User manual on running the ArtRepair toolbox for SPM with MRI data in BIDS format

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1 About

This manual explains how users of RaBIDS can use certain functions of the ArtRepair toolbox to fix noisy fMRI data. The scripts are wrappers for the art_global and art_summary functions, that is, they are handy matlab-scripts to run these functions over your subject data without any further programming and clicking the ArtRepair Graphical User Interface (GUI). The scripts from this manual are available on my github, see RaBIDS project in the auxiliary tools directory (https://github.com/christianparet/RaBIDS/tree/master/auxiliary%20tools).

Information about the ArtRepair program in this document is based on the artrepair-instructions that are available online https://cibsr.stanford.edu/tools/human-brain-project/artrepair-software/artrepairinstructions.html (retrieved on 12.04.2021)

Assumptions that must be met:

- fMRI derivative data (i.e., preprocessed data) is available in BIDS. The program has been developed with derivative data from fMRIPrep version 20.2.0; note that data may look differently if you used other pipelines for preprocessing and the scripts may crash.
- A RaBIDS-datasheet is available and has the information that was used for import to BIDS (tested with RaBIDS version 0.2.2)
- Runs with spm12, tested with Matlab R2020a.
- The ArtRepair toolbox programs have been installed in the spm toolbox directory according to instructions on the ArtRepair website https://cibsr.stanford.edu/tools/human-brain-project/artrepair-software.html
- You have installed ArtRepair version 5b
- Works only for experiments with a single session (i.e., only one “scan”, in SPM terminology, enters the first level model for each subject)

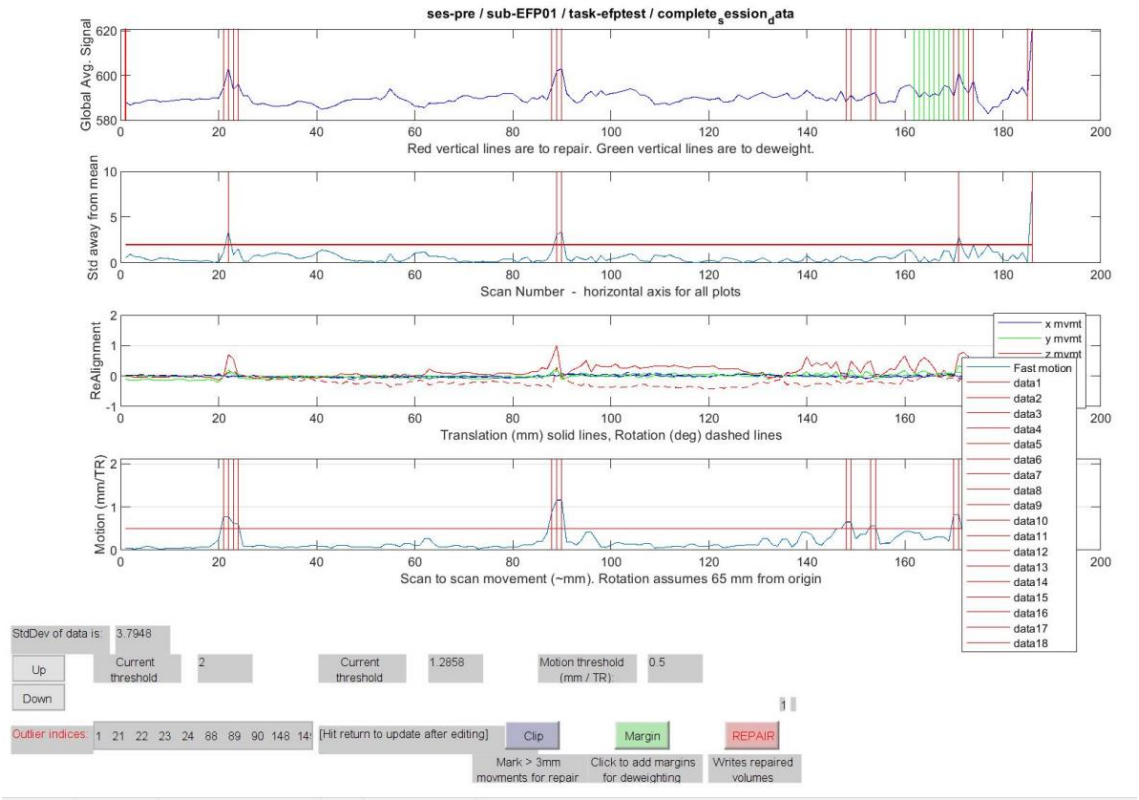
2 Repair volumes

The script repair_volumes repairs the preprocessed and smoothed volumes from all available subjects and saves them in a separate directory. Make sure that your derivative images are not zipped (file-ending .gz). You can use the unzip_niftis function from my RaBIDS auxiliary tools to unzip the files. Download the script to your code-directory (see RaBIDS manual) and run it with Matlab. This pipeline is recommended:

- Unzip nifitis (use script from RaBIDS auxiliary tools)
- Smooth images (use script SPManalysis_1_smooth_images.m from RaBIDS auxiliary tools; specify the smoothing kernel in the script!)
- Run Repair_volumens.m (open script and adjust smoothing kernel).

Repair_volumes creates 3d-nifti files from your 4d-nifti files, i.e., the repaired-images directory will contain one .nii file per volume, while the original derivative file is only one nii per scan. This is necessary because ArtRepair v5 cannot process 4d-niftis.

The program uses the art_global function to repair volumes that are affected by heavy artifact. It writes the repaired volumes to a directory called “spm_analysis” within the data analysis directory (which you have defined in your RaBIDS datasheet). The wrapper does not open the ArtRepair GUI but instead runs the function over all subject data available. If you need to adjust default thresholds in ArtRepair, you need to do this inside the art_global function. The graphical summary of the ArtRepair quality check is saved to the output directory. Here is an example figure file:



Here is what they say about this figure on the ArtRepair website:

Global Mean and Scan-to-scan Motion Summary Figure

The summary figure has four graphs. The top graph shows the time history of the mean intensity within the head region. The time history usually has a slight downward trend, and a good run has only small bumps (less than 1.5% of the mean value). The vertical scale is the dimensionless-units that come off the scanner. The head region is defined as the voxels in the ArtifactMask which was generated during the art_global program. (Use SPM Display function to review the mask ArtifactMask.img.)

The second graph shows the size of the bumps relative to the mean of the run. The vertical scale is standard deviations away from the mean. A default threshold line is plotted at 1.5% variation from the mean. The default threshold of 1.5% from the mean is an estimate. For data from the Lucas scanner, this value attempts to keep all data within normal physiological variation and discard outliers due to sudden motion or other artifact. (You can use art_movie to inspect an outlier volume.) A good run has all its peaks below this threshold.

The third graph shows the six SPM realignment parameters. (Before realignment is done, this graph shows a crude estimate of the 3 translational estimates of centroid motion. Not to be trusted, it is just locate very peculiar scans.)

The fourth graph shows the scan-to-scan movement. The vertical scale is mm/TR. (Rotation assumes a voxel is 80 mm from the origin.) A default

threshold line is plotted at 0.5 mm/TR variation. A still subject will have less than this scan-to-scan motion.

Repair and Deweight Display

The programs default thresholds are used to estimate outlier volumes and additional volumes to be deweighted during estimation.

Outlier volumes to be repaired are specified by red vertical lines. Outliers may be caused by exceeding the intensity variation threshold, or exceeding the scan-to-scan motion threshold, or by user selection. All repaired volumes are recommended for deweighting. If the data has lots of motion, we suggest using motion regressors. Then no additional deweighted scans (green lines) are necessary. If you don't wish to use motion regressors, additional volumes recommended for deweighting are specified by green vertical lines. These volumes will be close to large discontinuities in global intensity or movement EVEN AFTER REPAIR, and so may degrade the accuracy of SPM estimation.

Nothing is changed until the REPAIR button is pushed.

Repair Button (CP: note that we do not have any buttons with the wrapper; the script will use the default settings to repair data)

The Repair button will repair any volumes that are outliers at the current threshold. No changes are made until the REPAIR button is hit. The volume repaired data is written with a prefix 'v'. Note that even unchanged images are copied to the new name. The repaired volumes are listed in the text file art_repaired.txt in the same folder. All volumes recommended for deweighting are listed in the text file art_deweighted.txt. (Note the volume index in these lists corresponds to order of the images...the index does not represent the volume number itself unless the first image was V001.)

We recommend using the INTERP button as the best method of Repair. This function fills values using linear interpolation from the nearest unrepaired scans. Mean fills values with the mean scan of the run. Despike fills values as a linear interpolation of the immediately preceding and following scans, whether they are repaired or not.

Output Files

If repairs were done, the output files will have prefix "v" added to the name. depending on the repair method used. New files art_repaired.txt and art_deweighted.txt are written to the images folder. The repair list logs which scans were repaired. The deweighted list is for the Repair and Compare program. These files only show the sequence position of the images, so they are NOT accurate if scans are discarded as part of the estimation process.

Note that the RaBIDS auxiliary tools have also a function available to trim sessions (i.e., to cut scans with large movements). If this function has been used to trim data, the repair_volumes script takes this information into account (i.e., we do not run into the problems described with regards to the sequence position of volumes).

3 Redo firstlevel analyses with repaired data

The script art_redo_wrapper uses the ArtRepair program art_redo to re-estimate existing first level models with repaired data. That is, you need to provide the estimated first level model from the original data. If you used RaBIDS to import data, I recommend to use SPManalysis_2_firstlevel.m (see RaBIDS auxiliary tools) to estimate the firstlevel model. Open the script and specify the parameters of your study that are asked in the top of the script, then run it.

The current version of my art_redo_wrapper is not a programmer's masterpiece. It does not access the RaBIDS datasheet and needs a bit care before it runs with your data. You should open it and adapt the directory names in the top of the script. Make sure that the names correspond to the file structure that was created by running the repair_volumes and/or the SPManalysis_2_firstlevel programs. After this the program is supposed to work.

Art_redo creates a new firstlevel directory with the name "repaired", next to the original "regular" firstlevel directory. On the same level of the data structure you find a text file called "GlobalQuality_overview" that contains quality metrics provided by the ArtRepair toolbox. These quality metrics were based on output from the art_summary function. The first colomns of the GlobalQuality_overview file show how much repair improved the contrast images (contrast con_001 is used by default), the improvement is given relative to the original firstlevel model (percentage improvement). The quality metrics are described on the ArtRepair website and I have copy-pasted the text below. Note, that the GlobalQuality_overview file is not automatically produced by ArtRepair but results from running my wrapper. The variable names relate to the variable description from the ArtRepair website and should be interpreted accordingly.

Additionally, a detailed global quality report (GlobalQuality.txt) was saved to each subject directory (both for the regular and the repaired model) and a figure file containing images of the residual distribution (for assessment of quality and normality) is saved here, too.

Here is what the authors of ArtRepair write on their website about it:

Use the art_summary program to see the effect of repairs on estimation accuracy before and after the repairs are applied.

The art_summary program summarizes the global distribution of estimates and ResMS values produced by the SPM estimation process. These summaries are histograms and statistics taken over the ensemble of voxels within the head mask. Generally, for good contrast estimates, the mean of the contrasts should be near zero, the distribution of the contrasts should be small, and the mean of the ResMS should be small.

The program draws a figure of the histogram of estimates, and writes a file named "GlobalQuality.txt" to the folder with the input estimates.

Percent Signal Change

The units of Global Quality are in PERCENT SIGNAL CHANGE. See FMRIPercentSignalChange.pdf for description of how this is done. Run >> art_percentscale to find the scale factors for a con image.

Interpreting the Global Quality.txt File

A text file called Global Quality.txt will be written into the Subject folder that includes the results of both GlobalQuality runs.

Example Output: GlobalQuality.txt

C:\fraX\fr1369\ResultsSPM\con_0010.img Voxels/1000 Mean Std RMS Trimmean 90ile %Vox > 1% AbsMax 13.5820 -0.0090 0.7744 0.7744 -0.0164 0.8316 7.4216 6.1105 9.1010 -0.0024 0.6234 0.6234 -0.0219 0.6789 4.9775 6.1105 4.4810 -0.0225 1.0140 1.0143 -0.0163 1.1520 12.3856 5.8479 C:\fraX\fr1369\ResultsSPM\ResMS.img Voxels/1000 Mean Std RMS Trimmean 90ile %Vox > 1% AbsMax 13.5820 28.5143 15.4679 32.4395 26.9395 22.2822 100.0000 172.9981 9.1010 23.1666 10.4969 25.4338 22.1512 14.0100 100.0000 134.6867 4.4810 39.3756 18.0386 43.3108 38.0512 26.9696 100.0000 172.9981 C:\fraX\fr1369\ResultsRepaired\con_0010.img Voxels/1000 Mean Std RMS Trimmean 90ile %Vox > 1% AbsMax 13.5820 0.0418 0.5663 0.5678 0.0341 0.6163 4.4692 4.0296 9.1010 0.0390 0.4350 0.4368 0.0342 0.4772 2.0108 3.9293 4.4810 0.0475 0.7666 0.7681 0.0360 0.9294 9.4622 4.0296 C:\fraX\fr1369\ResultsRepaired\ResMS.img Voxels/1000 Mean Std RMS Trimmean 90ile %Vox > 1% AbsMax 13.5820 17.3786 10.5526 20.3316 16.1886 15.2464 100.0000 124.2562 9.1010 13.7456 7.0707 15.4576 12.9093

9.0196 100.0000 88.1768 4.4810 24.7574 12.4399 27.7070 23.7724 18.8811 100.0000 124.2562

The key statistic is the Std value in the top row under the con_ images. In the data above, that value is 0.7744 without repairs, and 0.5663 after repairs. Thus, the repairs reduced the STD of the estimation error for this contrast by (0.7744-0.5663)/0.7744 = 27%. Our validation tests show that this value tracks the actual RMS error of test injection examples very well, so the repair was very effective for this case.

Another interesting statistic is the Mean value in the top row under the ResMS image. This value is the average (over the head) of the ResMS image from SPM, and thus represents an "average" error in cases when GLM assumptions are valid. In the data below, that value is 28.5143 without repairs, and 17.3786 after repairs. With this measure, the repairs reduced the average ResMS error by (28.5143-17.3786)/28.5143 = 39%.

The other statistics that are printed out include:

- *For each image, the first row has statistics for all the voxels, the second row is the inner voxels, and last row is the outer voxels. Errors for the inner voxels are less than for the outer voxels, and results for all voxels are between the inner and outer results.*
- *Voxels/1000 is the number of voxels divided by 1000.*
- *The statistics are computed over the ensemble of voxels in the head.*
    - *Values under the con_ will be in percent signal change (when peak of regressor is one.)*
    - *Values under the ResMS image are relative values, related to tr(RV) from SPM.*
- *Mean and Std are the usual statistics.*
- *RMS is the combination of mean and Std, as if the truth were zero.*
- *Trimmean is the trimmed mean after clipping 5% of outliers on each extreme.*
- *90ile is distance of the 90th percentile value to the trimmean.*
- *%Vox > 1% shows the fraction of voxels with extreme contrasts.*
- *AbsMax is the most extreme value (min or max) in the distribution.*