Artifact Detection and Repair: Overview and Sample Outputs

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Programs originated in Gabrieli Neuroscience Laboratory, updated and enhanced at Center for Interdisciplinary Brain Science Research, Stanford University.

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ArtRepair Overview

- ArtRepair software
  - Detects and repairs artifacts at the volume, slice, and voxel level
  - Specifies scans to deweight for more accurate estimation
  - Compares estimation accuracy using Global Quality measure
- Credits
  - Original version by Susan Whitfield, and Jeff Cooper in Gabrieli Neurosciences Lab. Updated and enhanced by Paul Mazaika for clinical subjects in Center for Interdisciplinary Brain Science Research in Stanford Psychiatry and Behavioral Sciences.
  - Grant support from National Institute of Mental Health
- Reference
  - **"Detection and Repair of Transient Artifacts in fMRI Data", by Paul Mazaika, Susan Whitfield, and Jeffrey C. Cooper, HBM 2005.**
- Bugs and questions: mazaika@stanford.edu

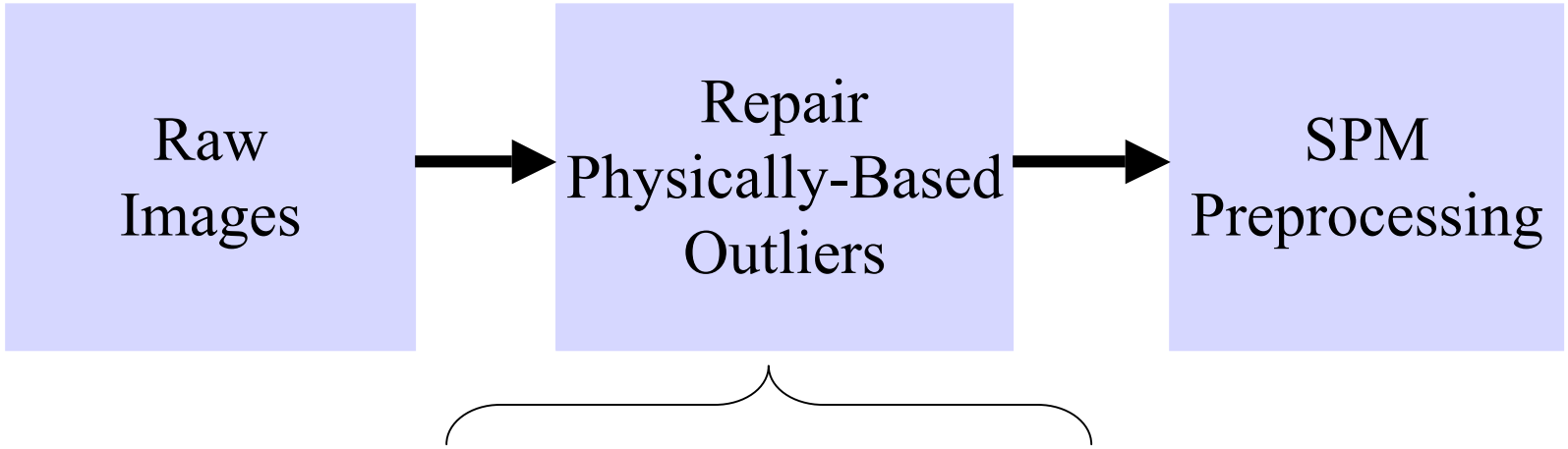
Start-Up

- Install the ArtRepair software
  - Insert ArtRepair software folder into SPM toolbox folder
- Start the ArtRepair interface
  - Select ArtRepair in the SPM toolbox
- Five main programs
  - **Contrast Movie** to visualize all the data
  - **Noise Filtering** to remove noise spikes and bad slices
  - **Artifact Repair** to repair outlier volumes
  - **Repair and Compare** to re-analyze results after repairs
  - **Global Quality** to review quality of estimates from SPM

Procedure to repair Outliers

- Preview the data before any preprocessing
  - art_global to locate unusual scans in the time series
  - art_movie to look at EVERY voxel over a range of images
- Repair bad slices and voxel spike noise, before preprocessing
  - art_slice automatically locates bad slices, or suppresses all spike noise
  - Can use art_movie to observe data before and after repairs
- Repair bad volume data just before estimation, after preprocessing
  - art_global, using realignment files, finds large scan-to-scan motion
- Re-analyze an existing SPM result with Repair and Compare
  - Set up a new folder for Repaired Results
  - art_redo starts with existing SPM.mat results, repairs image data (preserving all existing data!), runs SPM with the repaired data, and compares the Global Quality of results before and after repairs.
- Review quality of estimation results for each subject
  - art_summary measures distribution of contrasts and noise over the head
  - Writes file GlobalQuality.txt that summarizes the results.

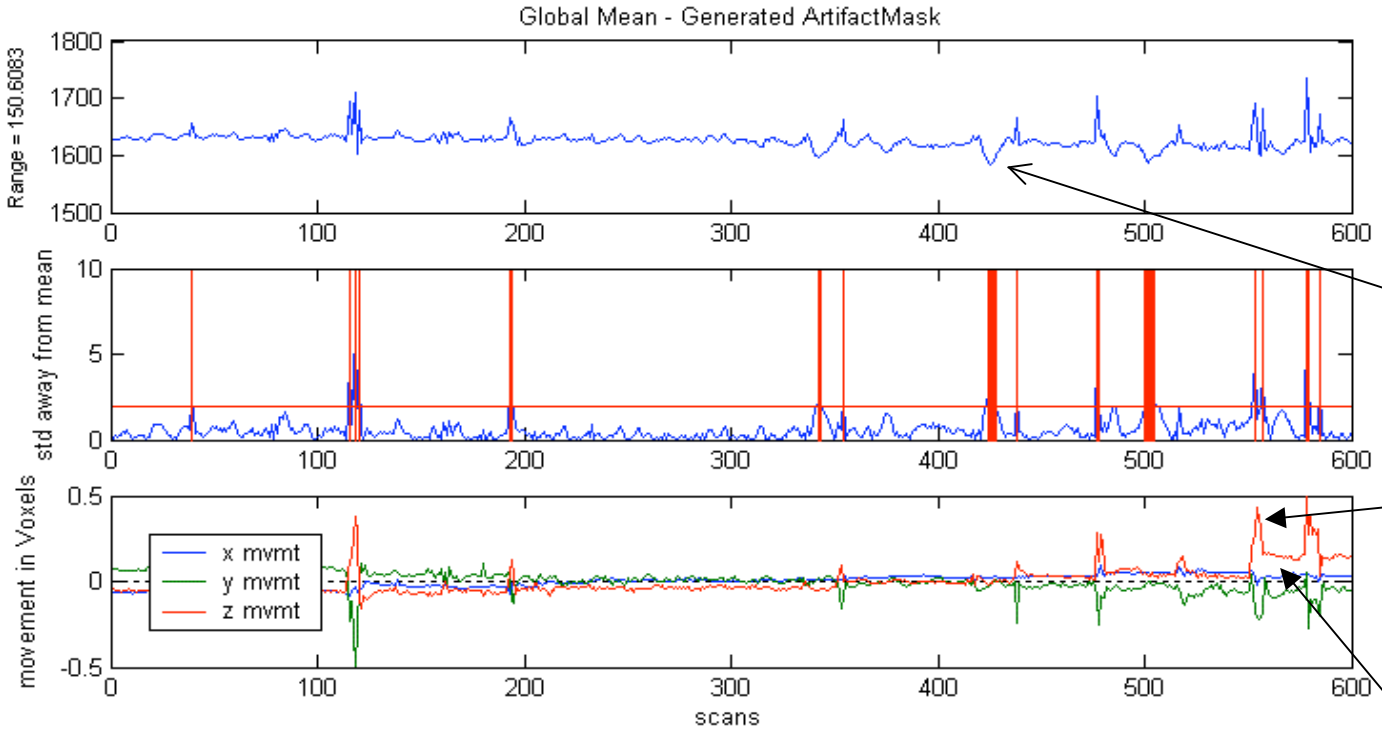
Detect and repair noise and bad slices before preprocessing



Programs (in ArtRepair toolbox)
- art_global (to locate the bad volumes)
- art_movie (visualization)
- art_slice (bad slices)

Repair bad data before preprocessing, otherwise large outliers will propagate to good data through slicetiming and realignment.

Detection of Bad Volumes (art_global)



dip

fast motion

typical motion

This subject is a squirmy child – healthy adult data looks like region from scans 200 to 300.

This GUI interface is the 2005 version. The updated 2006 version is shown later.

Art_global identifies volume outliers with red lines. Use it to locate bad volumes to review with the Contrast Movie. Recommend not to repair any volumes until after preprocessing.

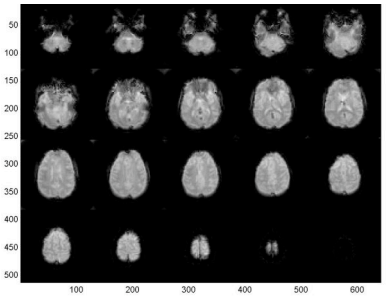
342 343 [Hit return to update after editing]

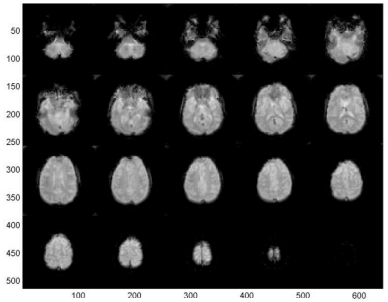
Repair

Contrast x 10 to view Artifacts (art_movie)

A Contrast Image of good data should be nearly black.

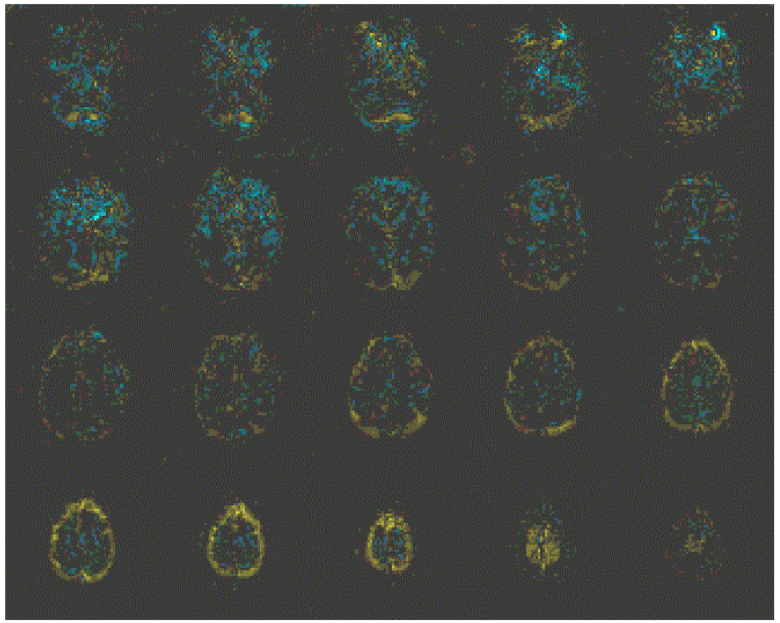
Full head slice montage

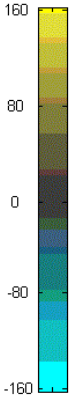




Reference Image

VENTRAL





+10%

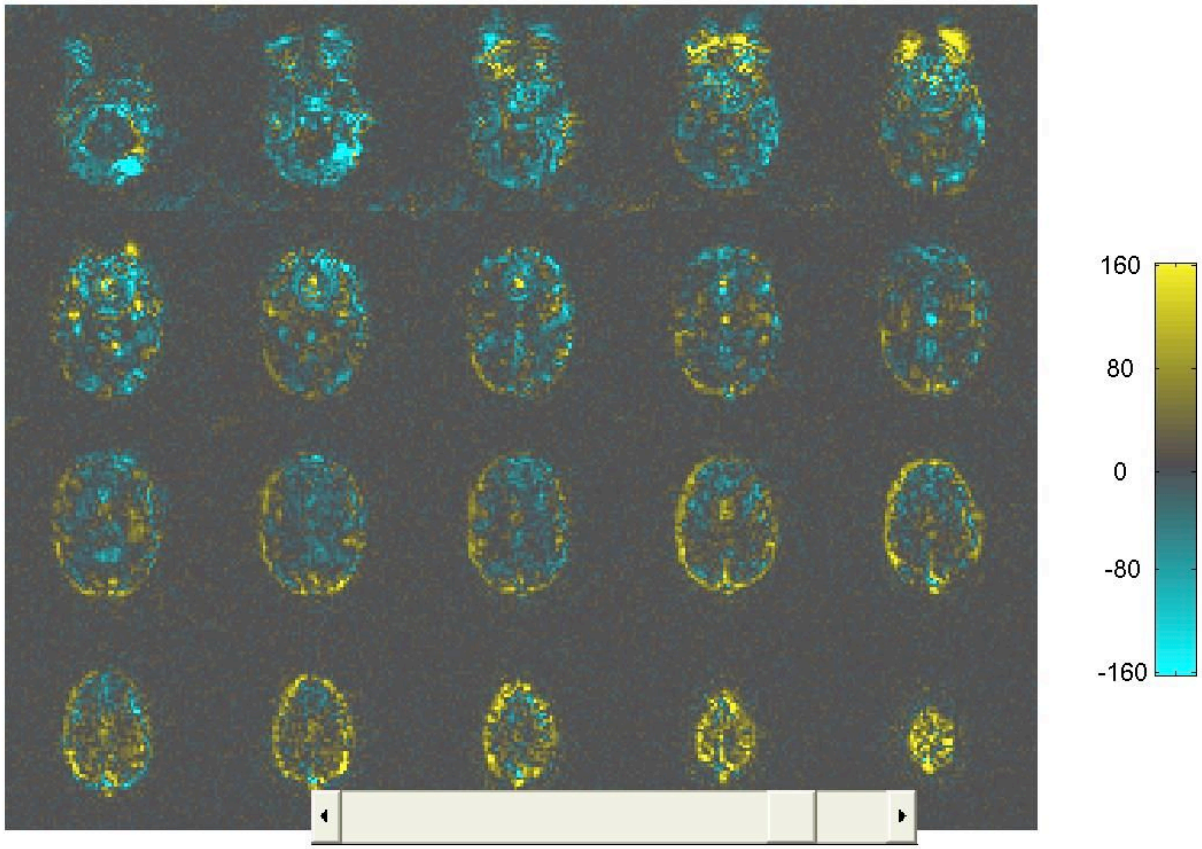
-10%

DORSAL

Contrast Image shows difference of each volume from a reference volume, enhanced 10x.

Contrast scale is 160 counts (+ or – 10% for 1600 mean). All input images are scaled to this size.

"Normal" Contrast Image (vol.575)

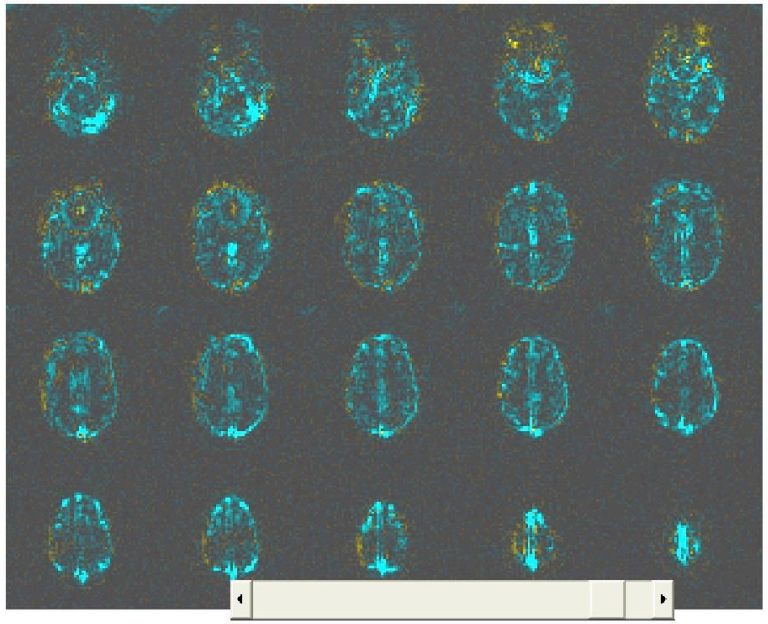


On slider, click arrow to move one volume, click box area to move ten volumes.

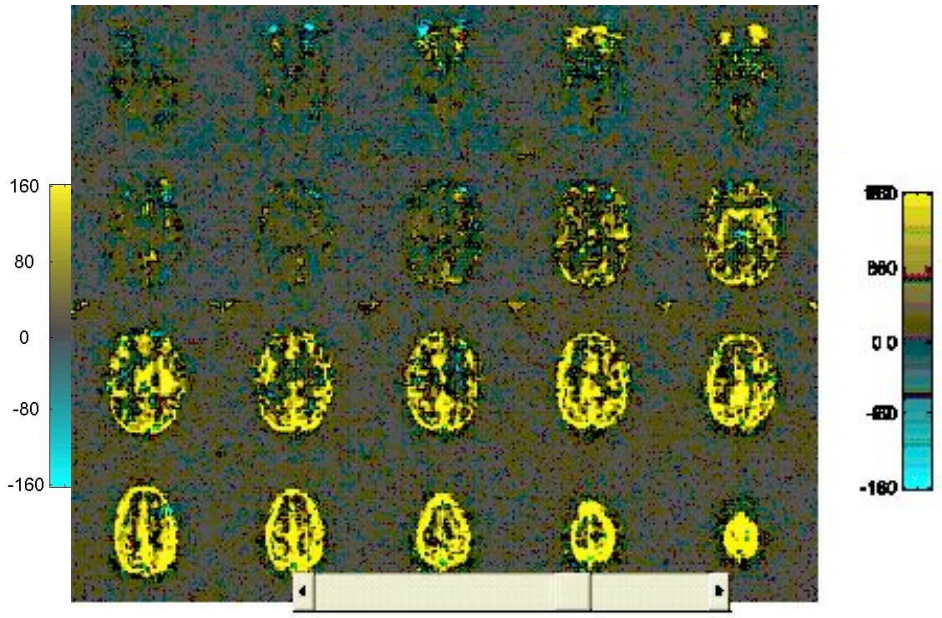
Typical image showing subject motion in +z direction, eye movement or blink, and dropouts in anterior slices.

Subject Induced Artifacts

Vol 430



Vol 560



Global Dip

Unusual effect, perhaps hyperventilation.
Volume should be discarded.

Sudden subject motion

Volume should be discarded.

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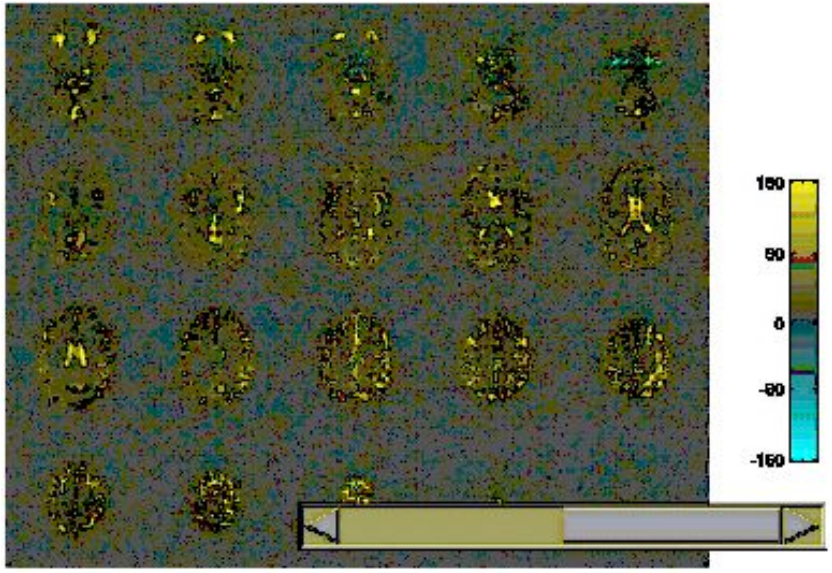
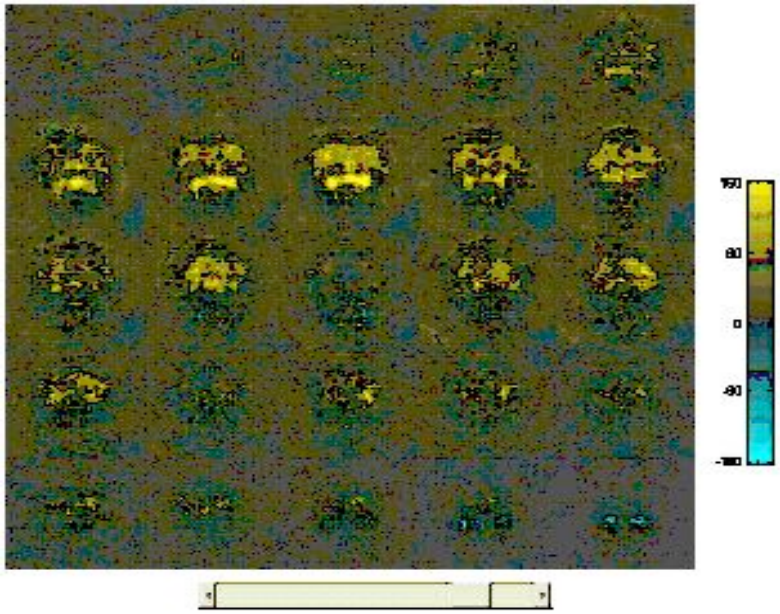
Scanner Artifacts



Warm-Up Scan (Vol. 002)

Overall gain has not stabilized.
Warm up volumes should be discarded.



Bad volume

Should be discarded.

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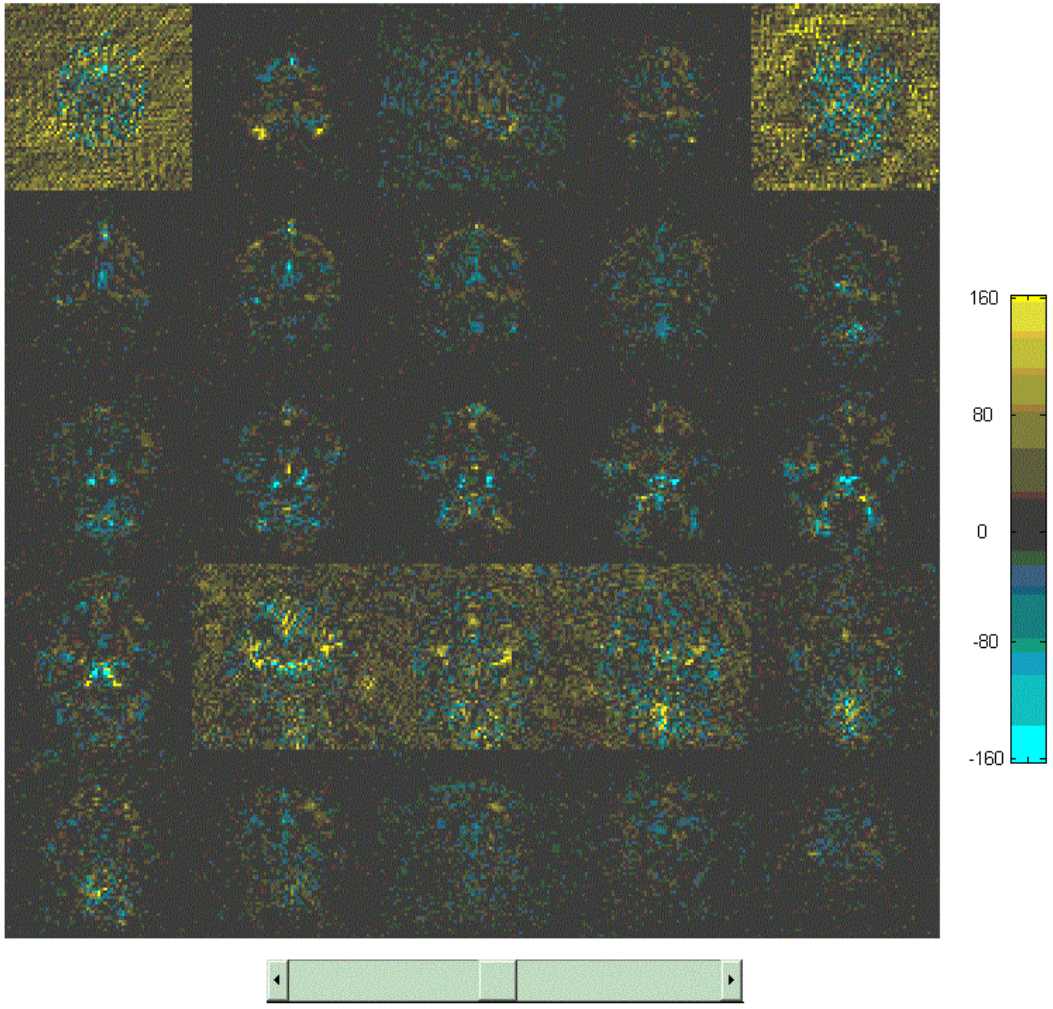
Example of Bad Slices



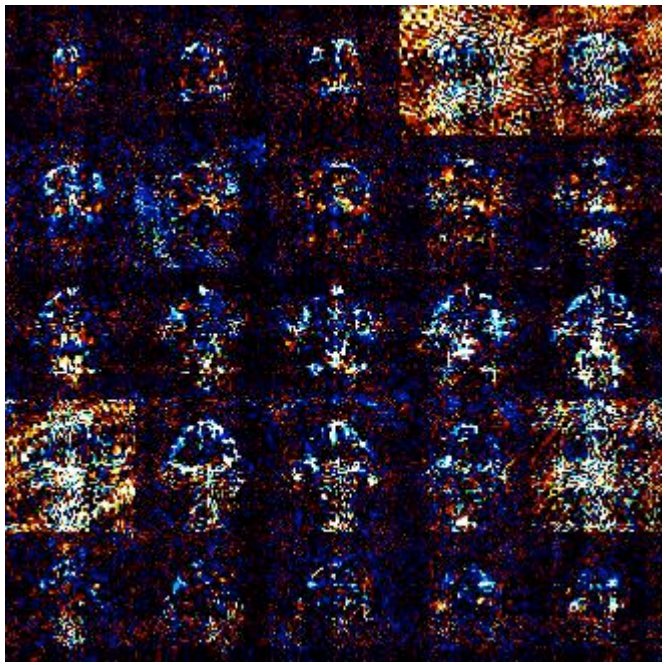
Slice artifacts probably due to RF-coil fluctuation.

Slice-time alignment will smear this noise over time on a voxel.

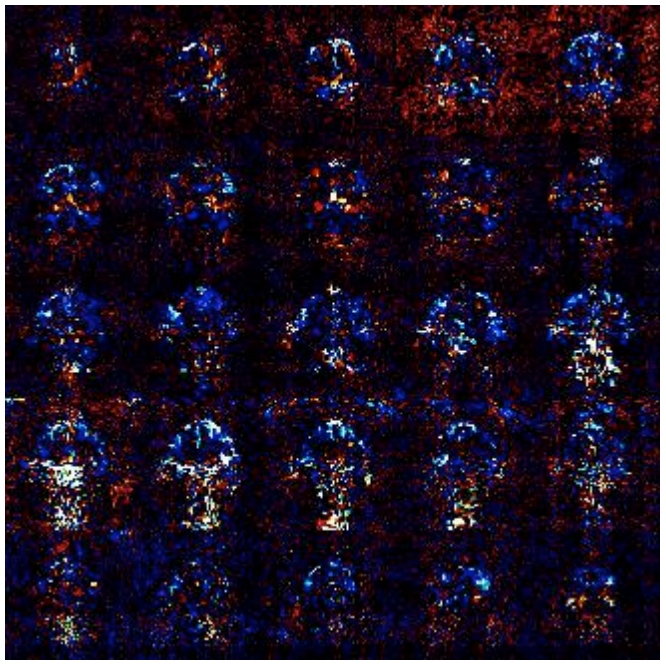
Most of the data Is good – art_slice program can fix it.

Bad Slice and Speckle Repair (art_slice)

Raw data

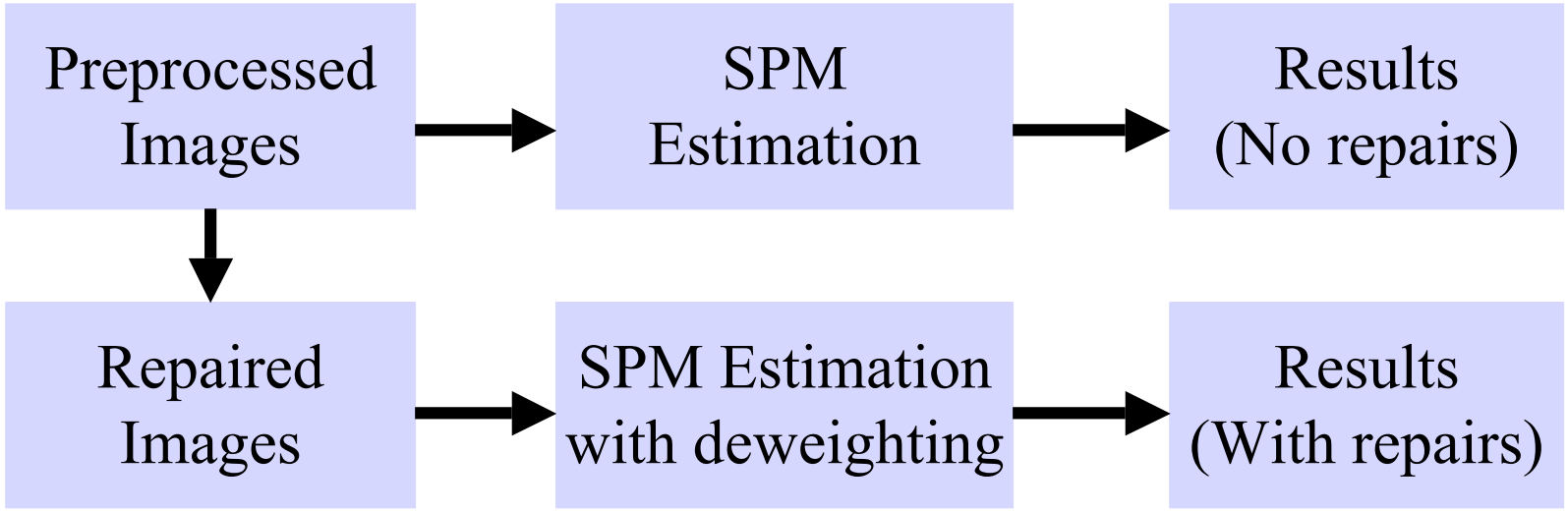


After median filter and head mask



Art_slice finds slice outliers
- repair bad slices by interpolation (TR > 2) & writes logfile
- repair all data by median filter (TR < 2)

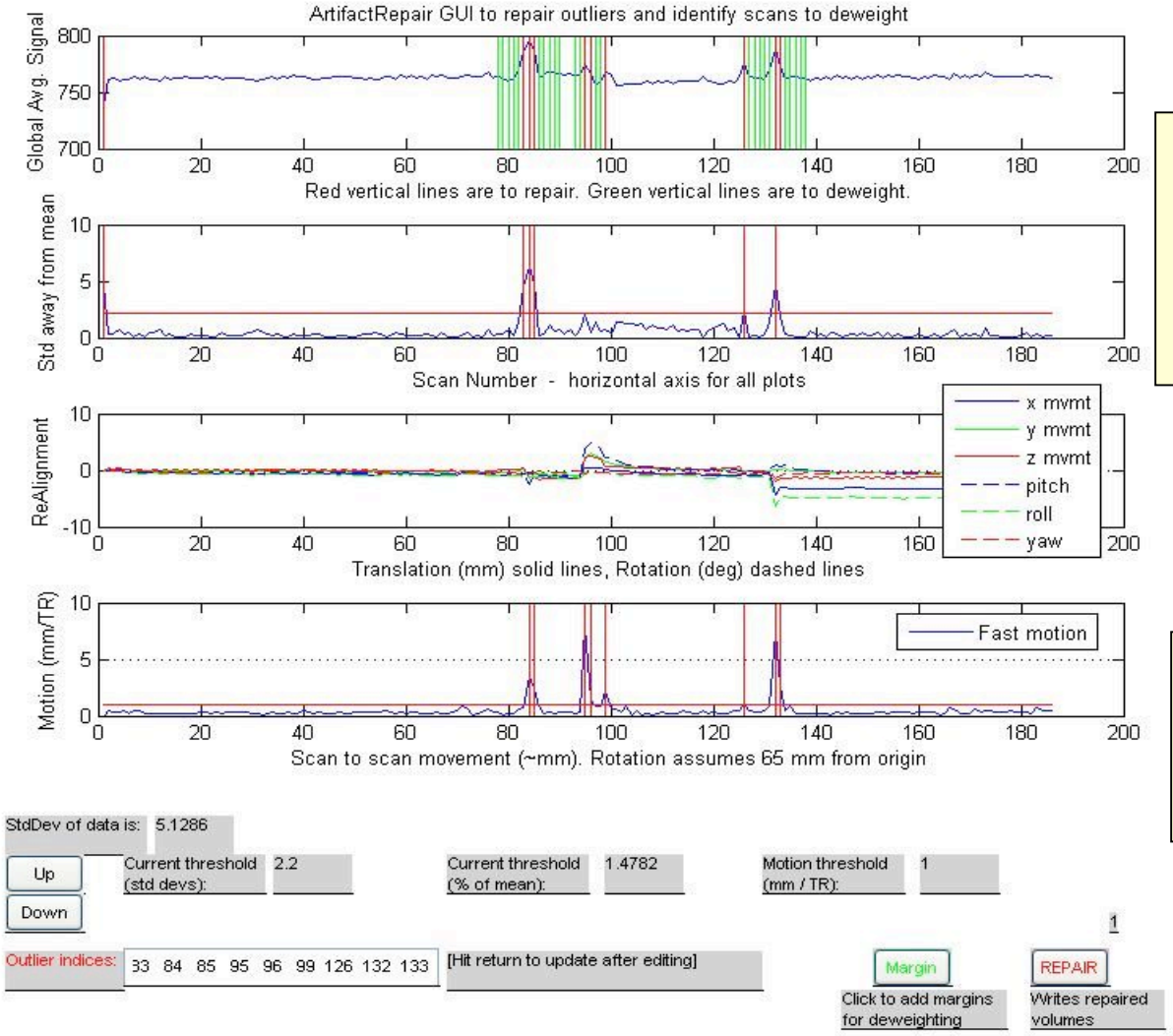
Detect and repair bad volumes just before estimation



Programs (in ArtRepair toolbox)

- art_global (to repair the bad volumes)
- art_redo (re-estimate with deweighting)
- art_summary (to measure Global Quality)

Detection and Repair of bad volumes, after realignment and smoothing (art_global)



Clinical subject data with high motion from FraX child

See software notes on following page.

Notes on art_global

- Outliers are selected by large variations in average global intensity, or excessive scan-to-scan motion
- Thresholds for outliers are user adjustable
  - Individual outlier editing is also possible
- Outliers are marked by red vertical lines
- Additional volumes (marked in green) are recommended for deweighting in estimation, to satisfy "slowly-varying background" assumption of the GLM.
- When user hits "repair" button, a new set of repaired images is written to the same folder. Outlier volumes are changed, all other images remain the same.
  - All old images are preserved.

How to measure performance?

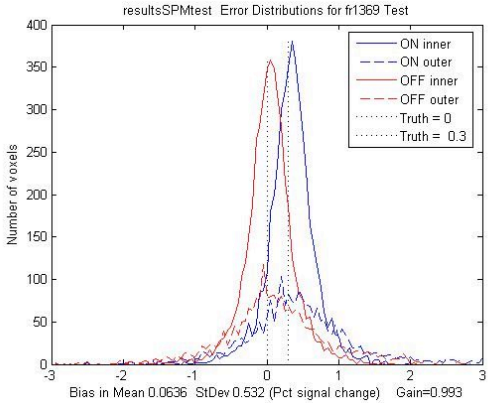
- Usual GLM-based accuracy measures may not be reliable
  - Since artifacts and large motion could make activations falsely high or low, simple activation strength is not reliable.
  - Since artifacts make the data non-stationary, the model residual ResMS is not reliable.

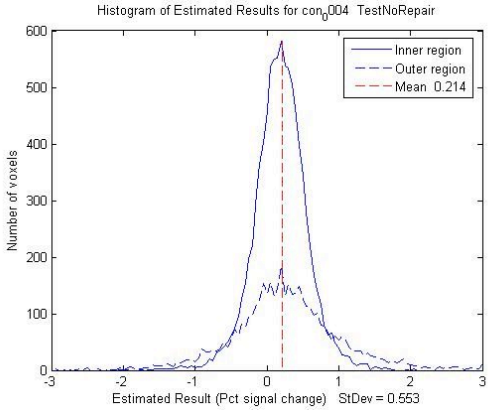
- Global Quality assumptions
  - For artifacts and large motion, the motion-induced noise (residual after motion correction) is often far larger than the true cognitive contrasts.
  - Assume the true contrasts are small, then the concentration of the ensemble of contrasts (effect sizes) over all the voxels in the head reflects the statistical efficiency of the GLM estimator operating in this data.

- Validation
  - Inject known test pulses into clinical data sets, and then measure the accuracy of estimations relative to truth, and the Global Quality relative to the accuracy of estimations.

Validation of Repair effectiveness and Global Quality measure of repair

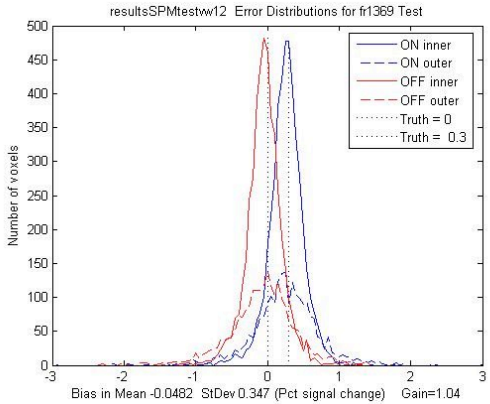
1. Add test injections to real clinical data, and measure accuracy of estimates.

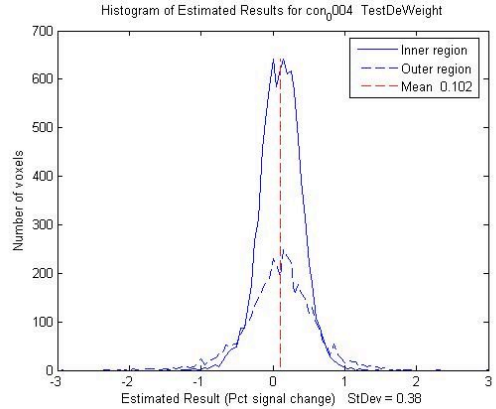




3. Find art_summary of estimates from the same test injected data.

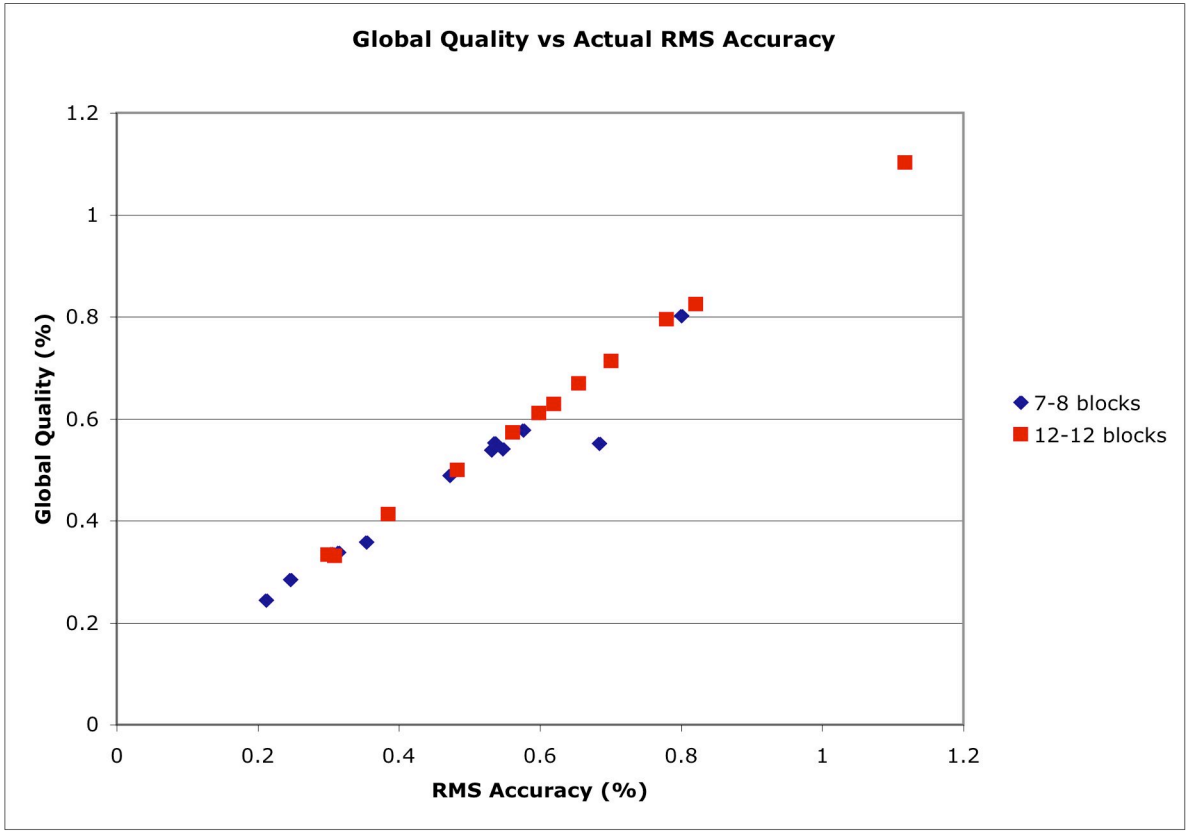
2. Repair the data after test injections, and measure accuracy of estimates. Since StDev is smaller, the repairs are effective.



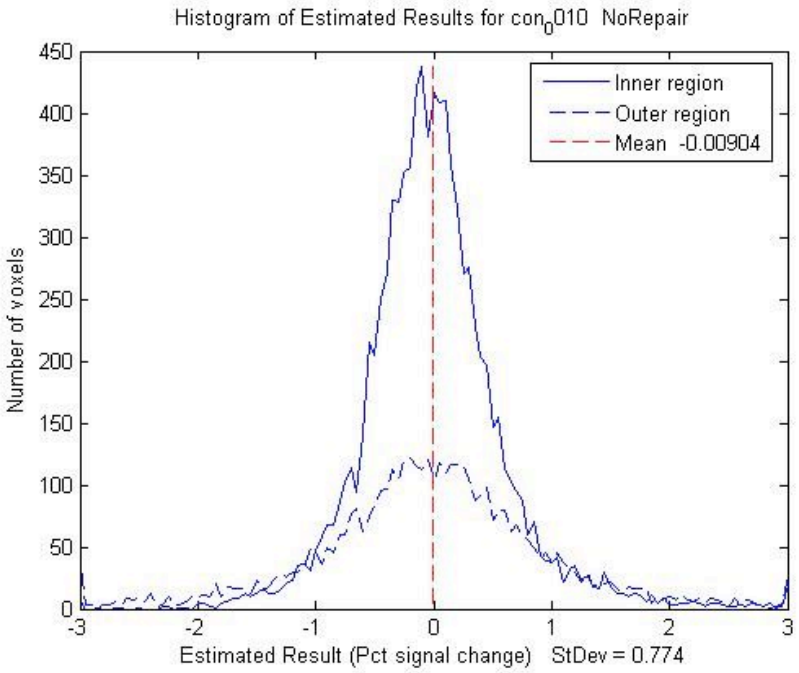


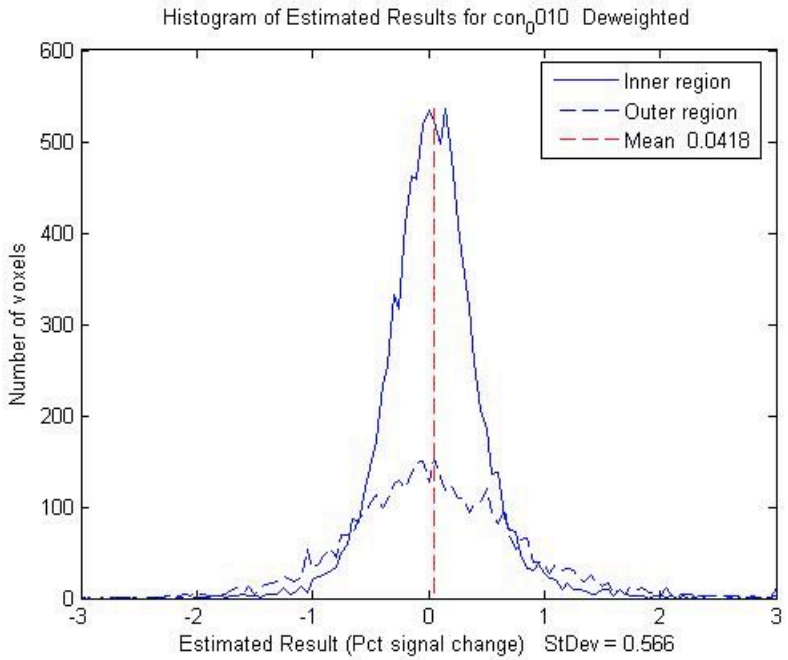
4. Compare art_summary of estimates for same repaired, test injected data. Validation means art_summary reflects repair performance.

Validation of Global Quality for 24 test cases



Effect of Repairs (art_summary)



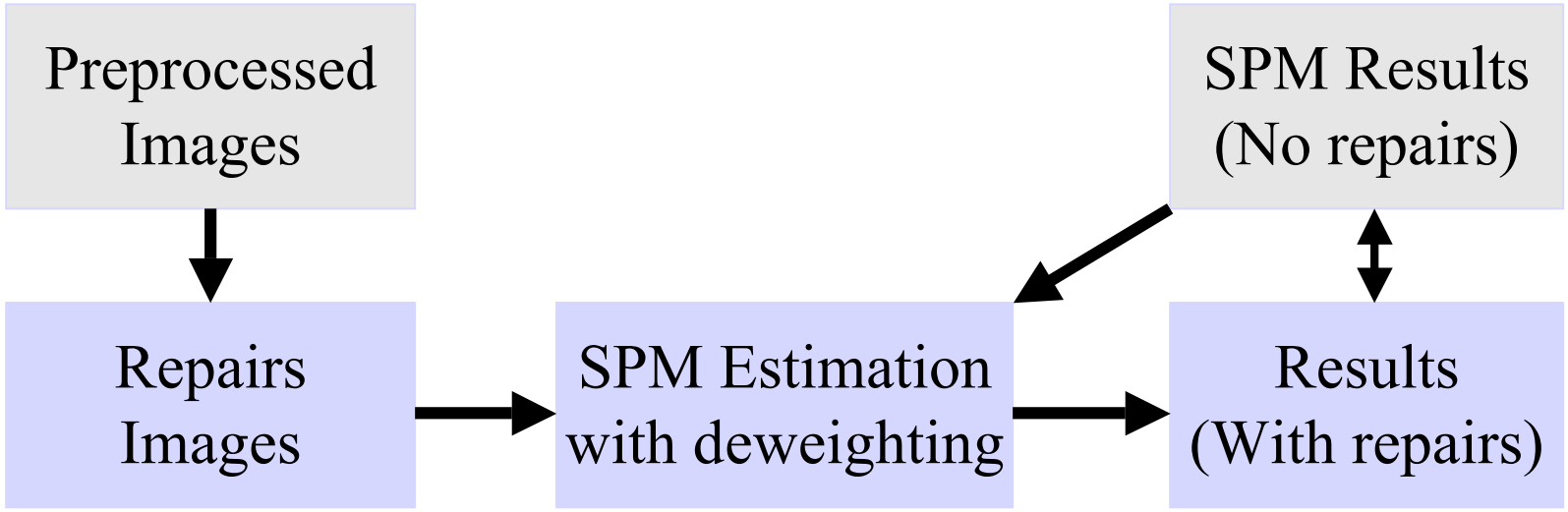


Repair results are highly variable! Sometimes spectacular (error is cut in half), sometimes good (these figures show 27% improvement), little change for controls, and occasionally worse. If the results are worse, try tweaking the threshold or just use the unrepaired results.

Notes on art_summary

- Art_summary shows a summary figure and writes results to GlobalQuality.txt above the images folder
  - GlobalQuality.txt shows results for inner region, outer region, and total for the head, where the outer region is roughly the 1 cm thick boundary of the head mask. Inner region is everything else.
  - Better estimates have small STD and bias for the contrasts, and small mean value for ResMS.
- Recommendations:
  - Try a low motion subject to learn the typical accuracy level
  - ***Always*** check repair results with art_summary. Sometimes repairs produce worse results! If so, try choosing a threshold that repairs less than 1/3 of the data.

Re-analyze an existing SPM result using repaired data. Compare results to original.



Programs (in ArtRepair toolbox)
- art_redo ("Repair and Compare" button)
- which calls art_global and art_summary

All old images and results are preserved!

Global Quality.txt file compares results before and after repairs.

Example text file 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

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

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

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
```

Global Quality is the Std value in the top row under the con_ images. SMALLER VALUES ARE BETTER. 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%.

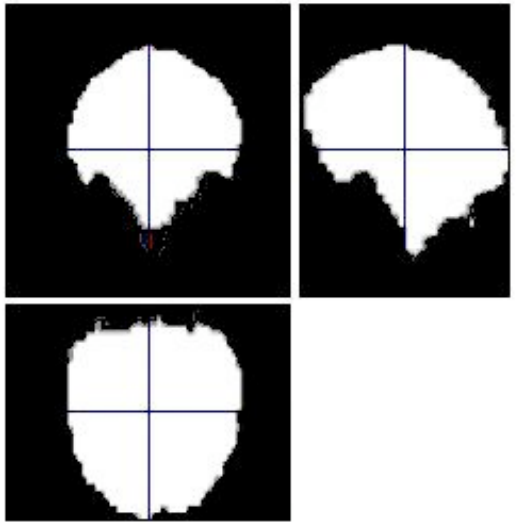
The average (over the head) of the ResMS image is the Mean value in the top row under the ResMS image. This value represents an "average" error in cases when GLM assumptions are valid. In the data above, that value is 28.5143 without repairs, and 17.3786 after repairs. With this measure, the repairs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

Both measures show that repairs are helping. The test case validations indicate that Global Quality correlates better with RMS accuracy for severe motion cases.

Create Head Mask (art_automask)

Utility program to automatically generate a full head mask from a single functional image (Alternative to SPM Mask) with special logic to eliminate wraparound artifact from spiral scan.

The mask is written out as ArtifactMask.img in the image folder.



Check mask quality using SPM Display button