

Artifact detection and repair in fMRI

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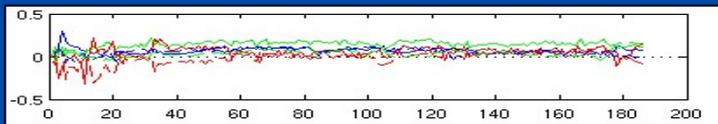
Stanford University School of Medicine

UCLA Advanced NeuroImaging Summer Program

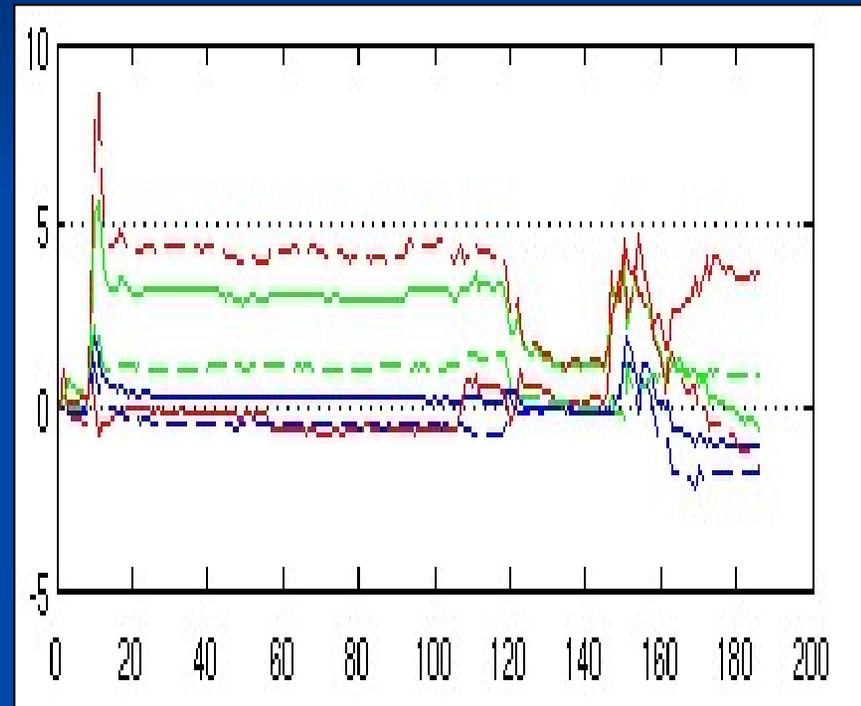
Aug. 10, 2015

Clinical fMRI data can be different!

Typical adult
0.3 mm motion

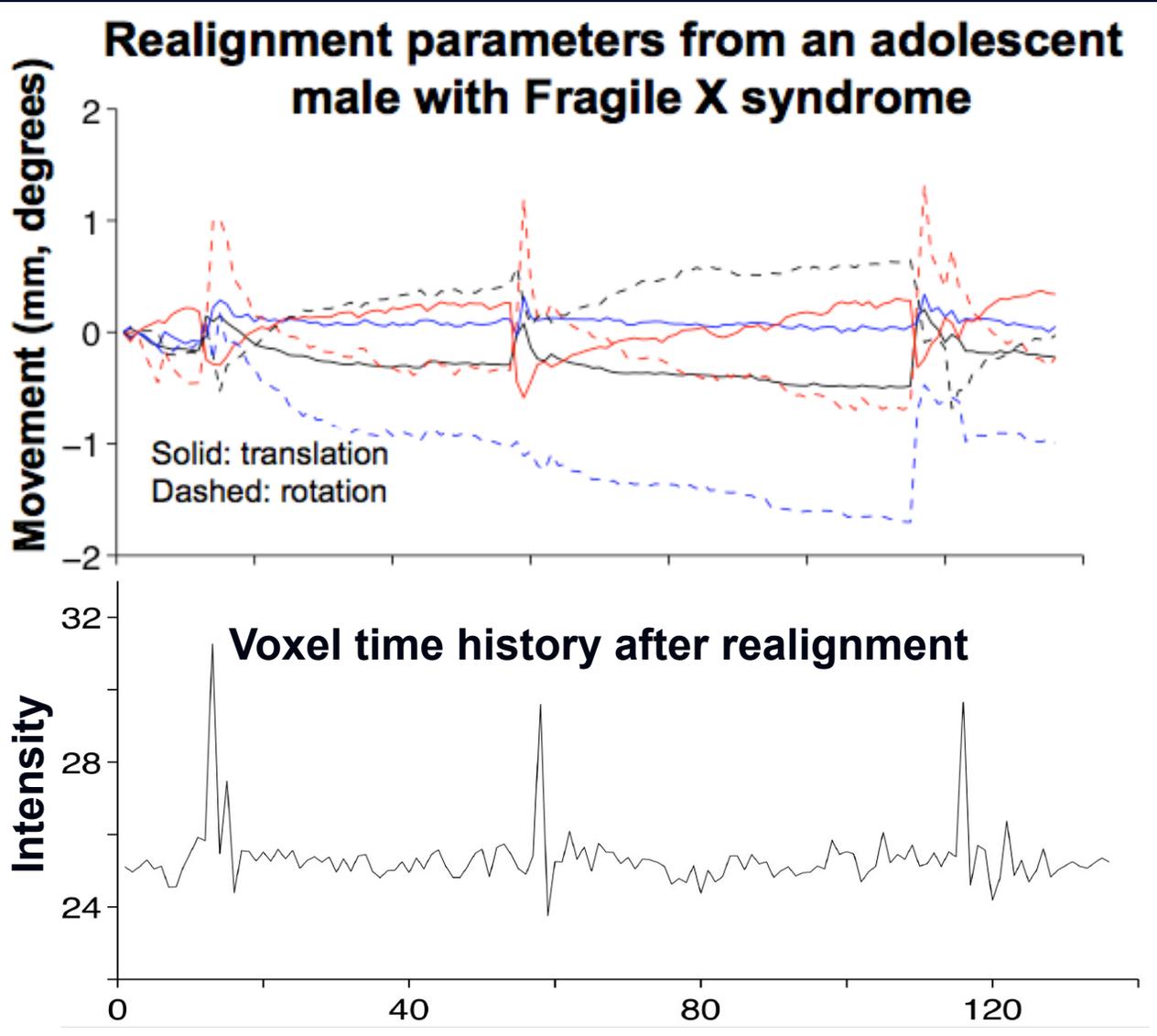


Clinical subject 8 mm



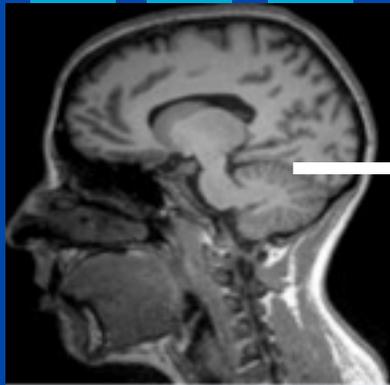
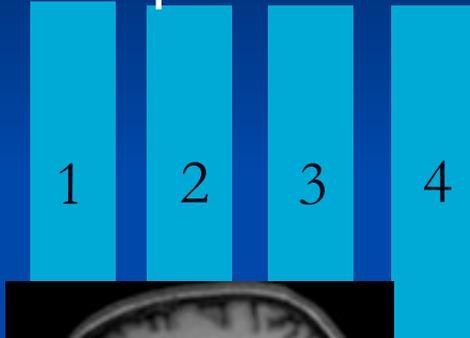
Outline

- The main culprit: Spin history artifacts
- How to detect and repair them
- How to prevent them: *Best Practices*
- Other kinds of artifacts
- Group analyses

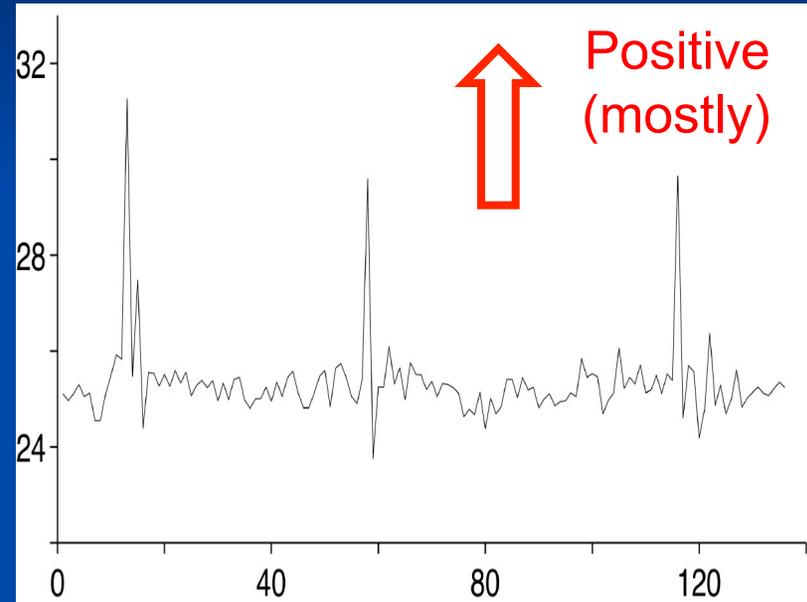


Spin history artifacts

Slice acquisition order →

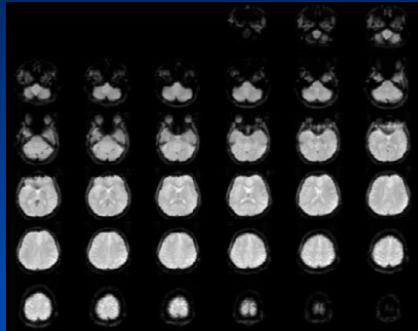


Previously excited protons are moved under another slice



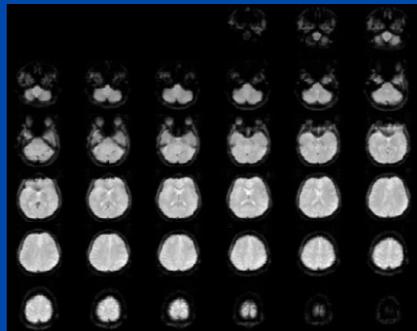
Large time series spikes remain after realignment

Visualize small changes on all voxels with contrast images



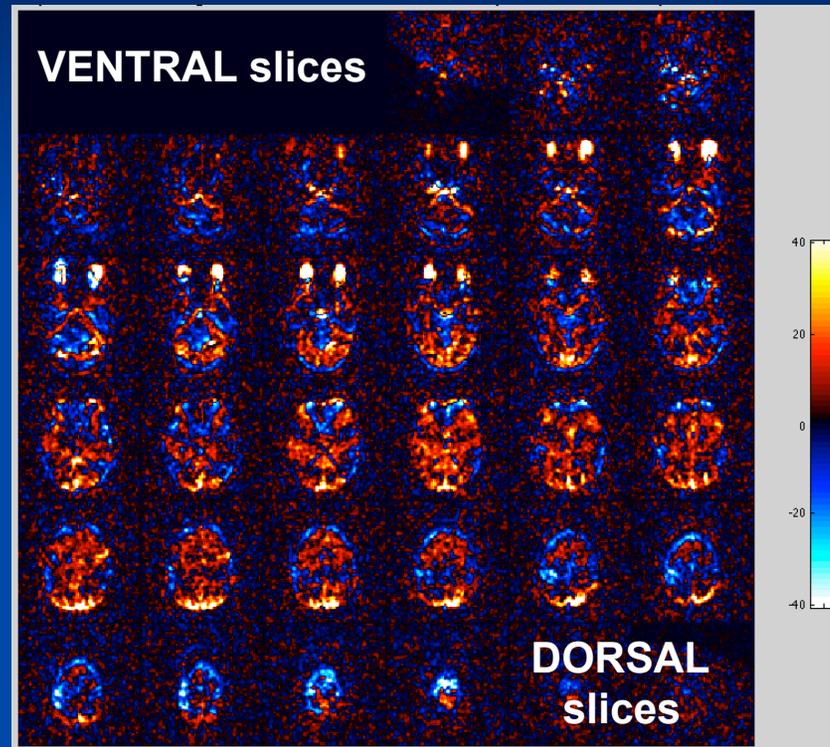
Visual stimulus (vol. 21)

—



Rest (vol. 8)

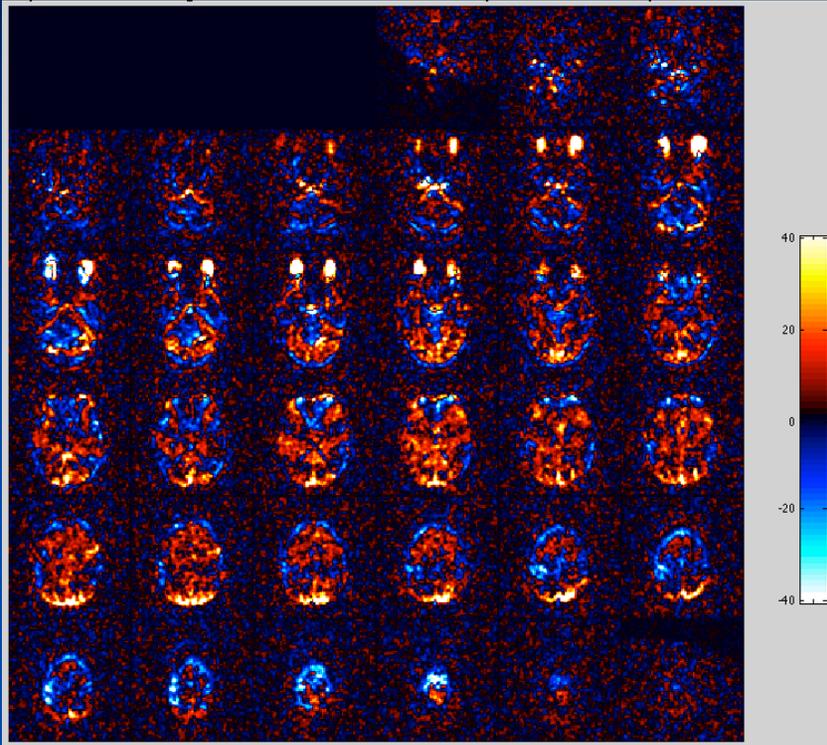
=



**Percent signal change
= 100 * difference / brain mean**

Program: art_movie

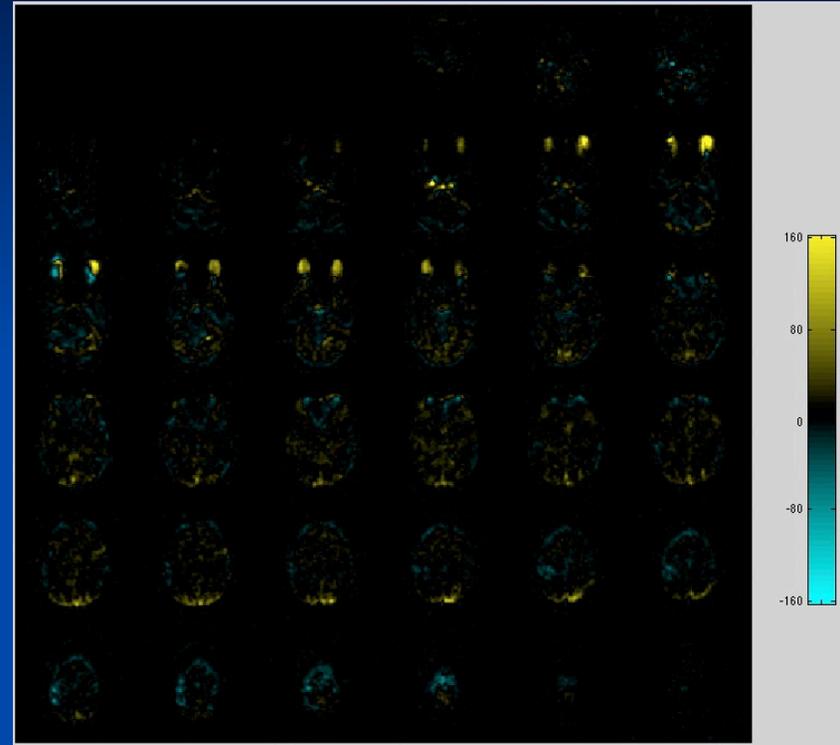
High contrast mode



Range [- 4%,+ 4%]

Program: art_movie

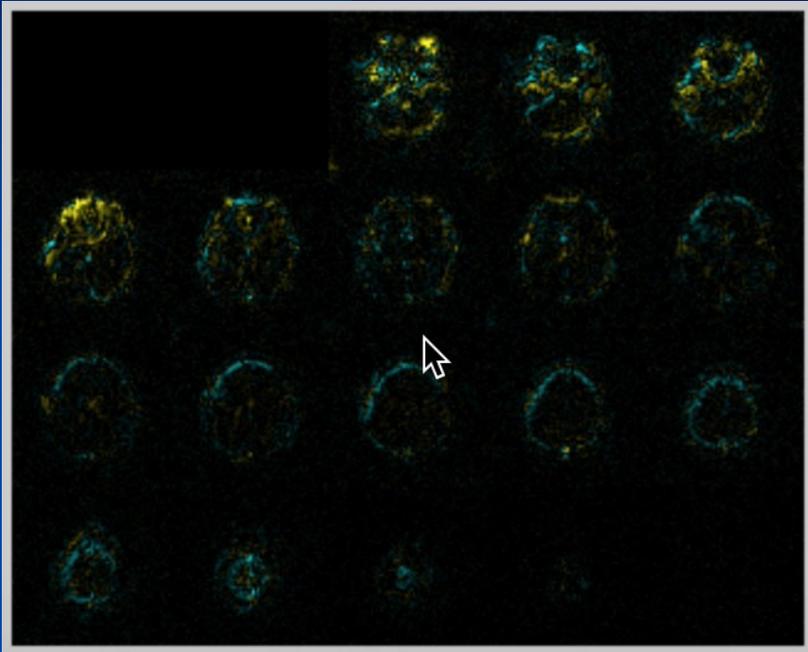
Contrast mode



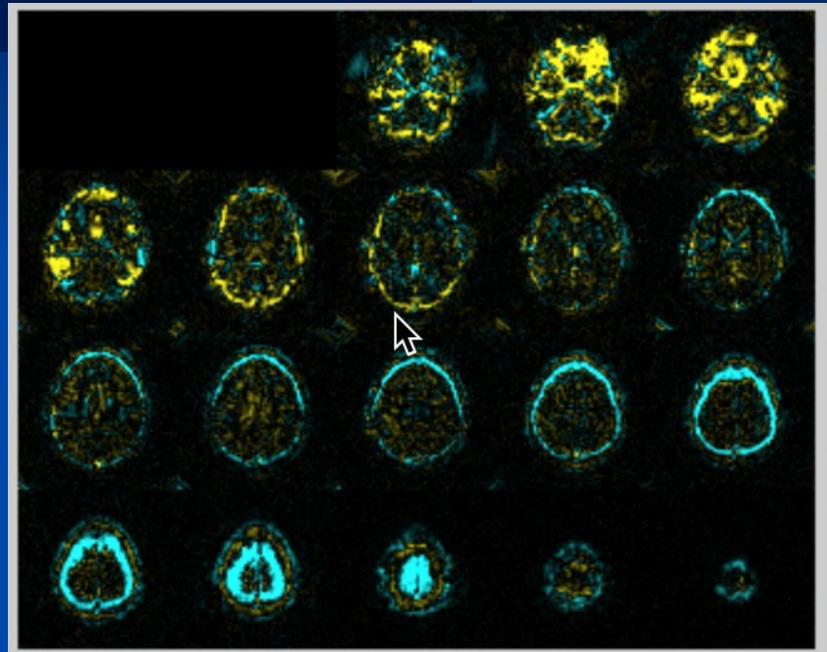
Range [- 16%,+ 16%]

Anything visible
is likely a large artifact!

Sample movies: *Range [-16%,+16%]*



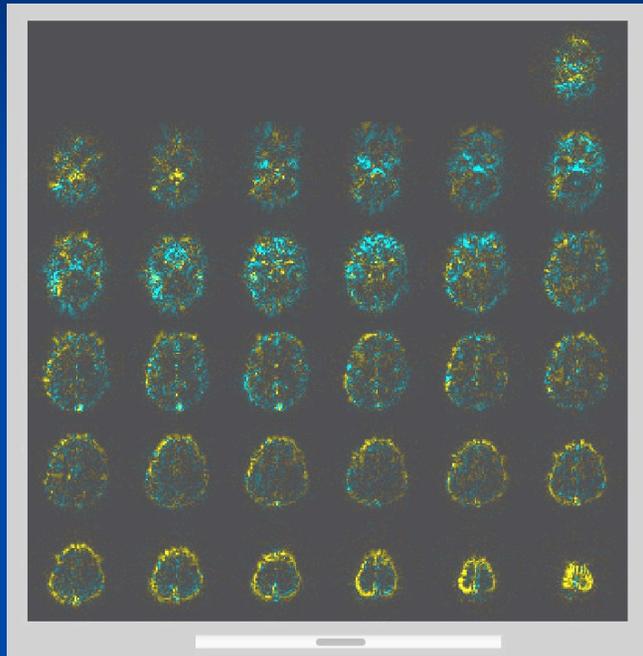
ERgaze data set



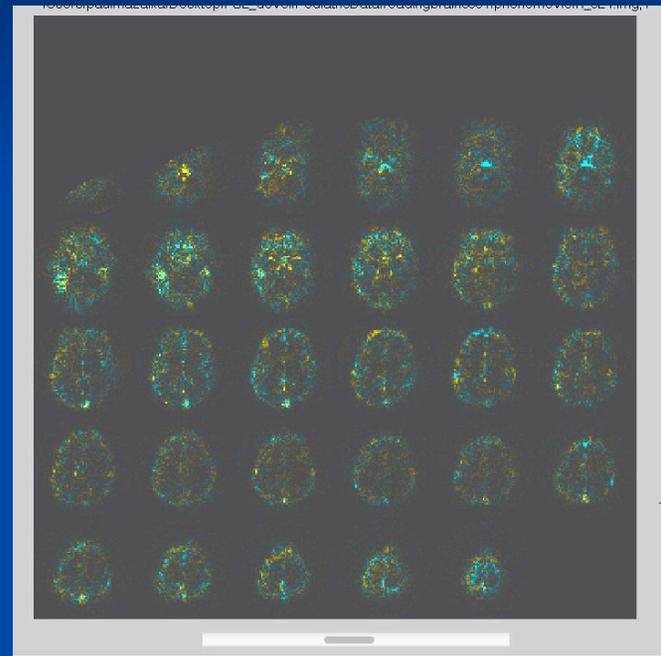
GoNoGo data set

Realignment reduces contrasts between volumes, as expected

Raw data



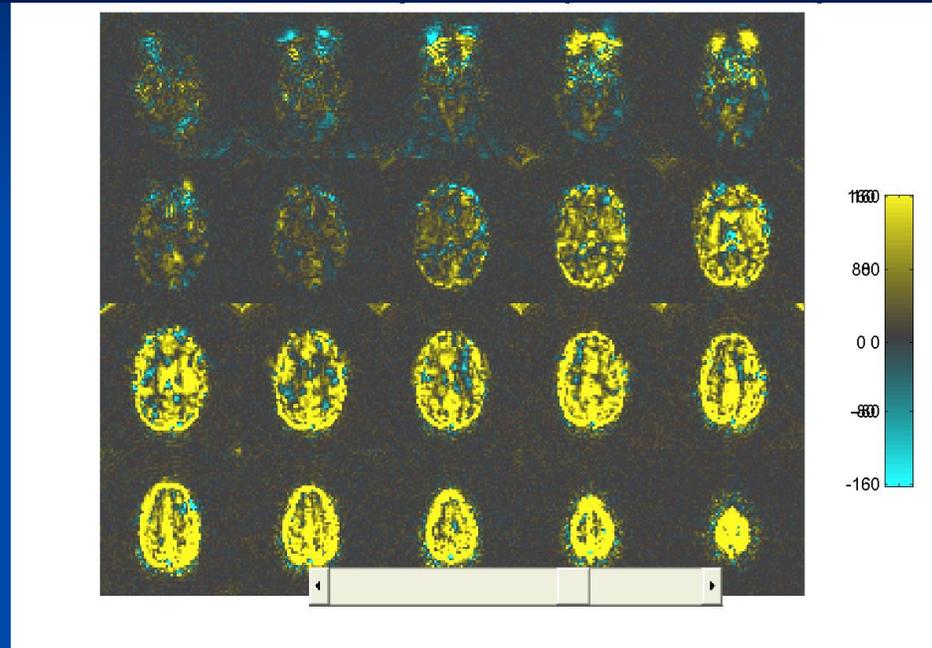
After realignment



Compares two volumes
0.5 mm different position

Large artifacts occur on many voxels from rapid scan to scan motion

Spin history effects are always positive!



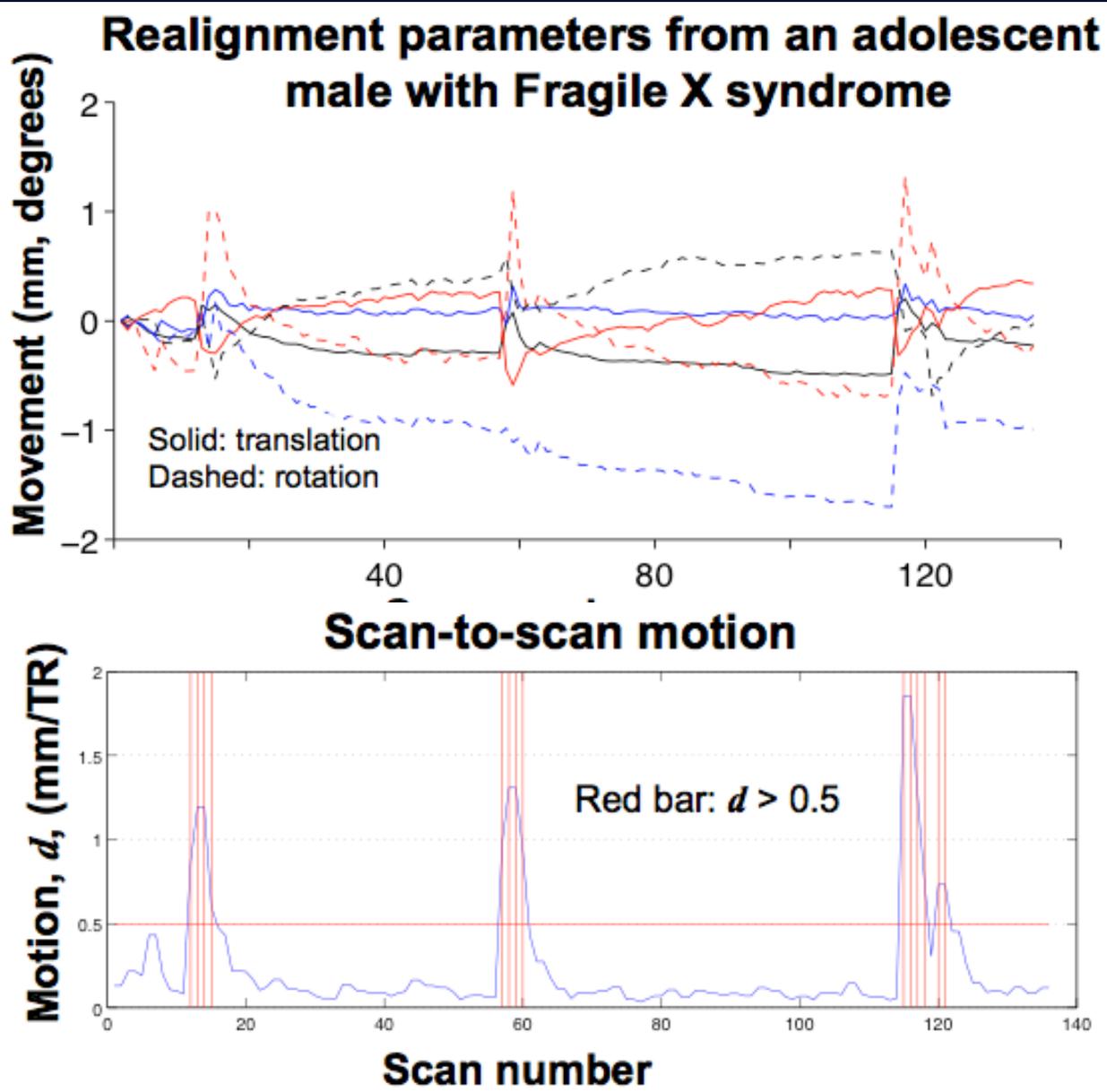
Spin history effect (>16% amplitude)
Volume should be discarded.

Spin history summary

- Spin history causes a large amplitude, spatially widespread, positively biased artifacts
 - Violates the Gaussian noise assumption of GLM statistics
 - May cause false activations on a voxel
 - May cause false clusters, even corrected for Family-Wise Error (FWE)
- Removing the artifacts improves validity of results

Artifact detection methods

- Detect rapid scan-to-scan motions that may cause spin history effects
- Detect large residuals after GLM
 - In FSL, use `fsl_motion_outliers`
- Include voxel-wise despiking in preprocessing
 - In AFNI, use `3dDespike`
 - In SPM, use `art_despike` in ArtRepair Toolbox



Where to set the threshold?

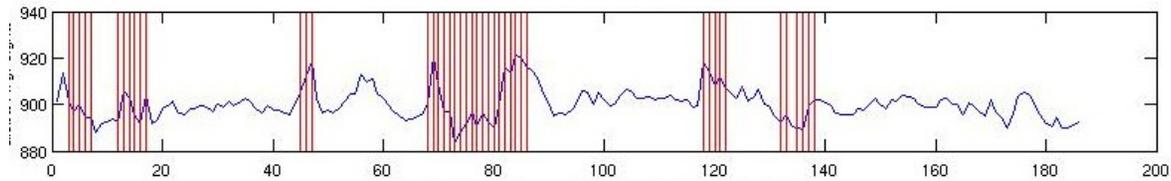
- Include rotation parameters in scan-to-scan motion
 - Tendency for head rolls in some subjects (7/56 with BD)
- Fixed threshold or statistical threshold ?
 - Fixed threshold assures uniform quality for all subjects in a group study
 - Statistical threshold is more justified for single subject activation analysis, but threshold changes with the data
- Visually review the data after artifacts are corrected to see if all the artifacts are gone (*use art_movie*)

Artifact repair methods

- Delete bad volumes(“censoring”, ”scrubbing”)
 - *Luo and Nichols, 2003; Power, 2011, etc.*
- *or*, Add null covariates for bad volumes
 - *Lemieux, 2007, etc.*
- *or*, Impute values from temporal interpolation
 - Errors are small for estimates used in group studies
- *or*, Deweight the imputed volumes
 - *Diedrichsen, 2005; Wager, 2005*

ArtRepair (art_global display)

GLOBAL
AVERAGE
OVER HEAD



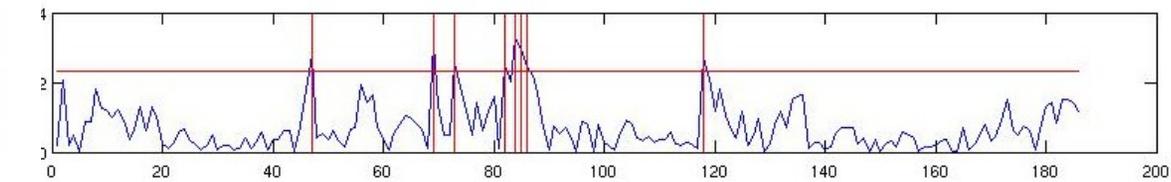
COMBINED
OUTLIERS



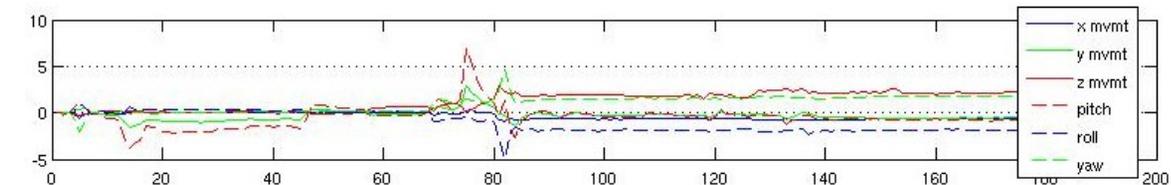
INTENSITY
OUTLIERS

RAPID
MOTION
OUTLIERS

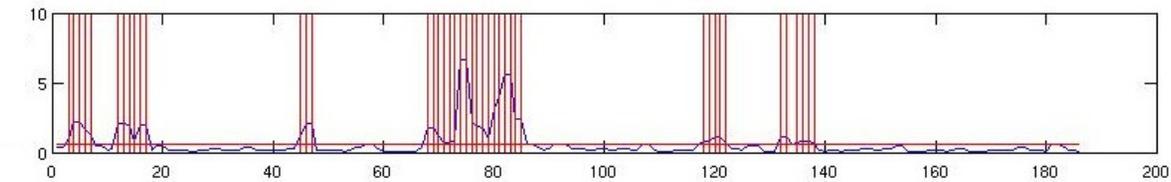
DEVIATION
FROM MEAN
OVER TIME



REALIGNMENT
PARAMETERS



SCAN-TO-SCAN
MOVEMENT
(mm / TR)



AUTOMATED or USER ADJUSTABLE THRESHOLDS

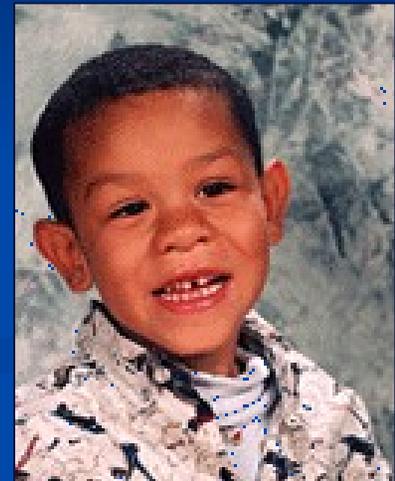
Program: art_global

Take aways

- Any artifact removal method is much better than not using one
- ArtRepair default values
 - Detect rapid scan-to-scan motions based on changes in translation and rotation parameters ($d > 0.5 \text{ mm}$)
 - Interpolates from nearest good scans
 - Reject subjects with $> 20\%$ repairs (group analysis)
 - Use a tighter limit on repairs for single subject activations
 - Or, *ARTutility* includes null covariates www.nitrc.org

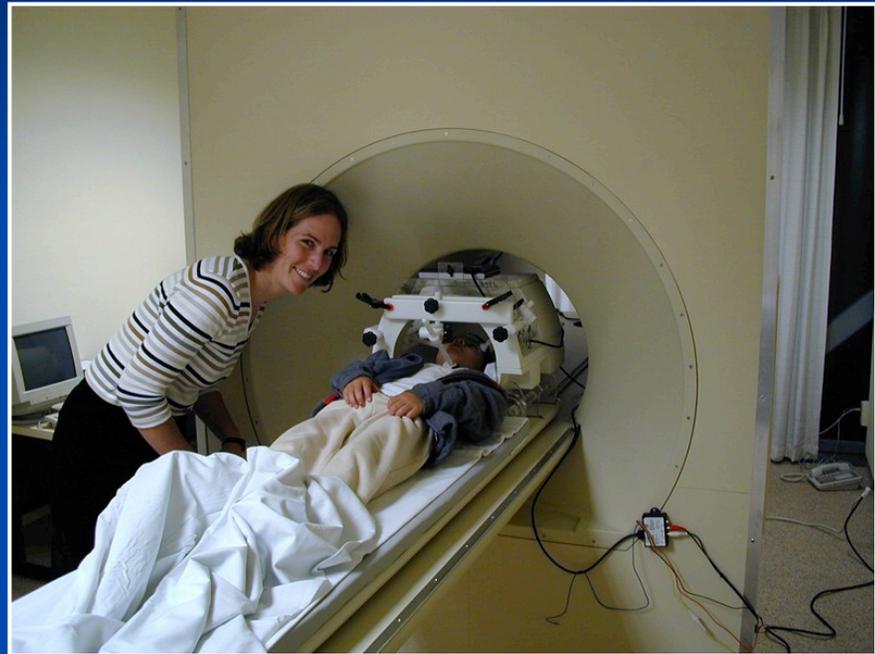
Best practices to prevent artifacts

- Division of Interdisciplinary Brain Sciences
 - Director, Prof. Allan Reiss, M.D.
- Thousands of data sets
 - Children, adolescents and adults; longitudinal data
 - Conditions of interest include neurogenetic-neurodevelopmental (fragile X syndrome, autism, preterm birth), neuropsychiatric (depression, bipolar disorder) and illness (diabetes)
 - Structural MRI, DTI, fMRI, MRS
- Valuable data, often not repeatable
 - Family travel, cognitive battery, MRI training
- Clinical scanners



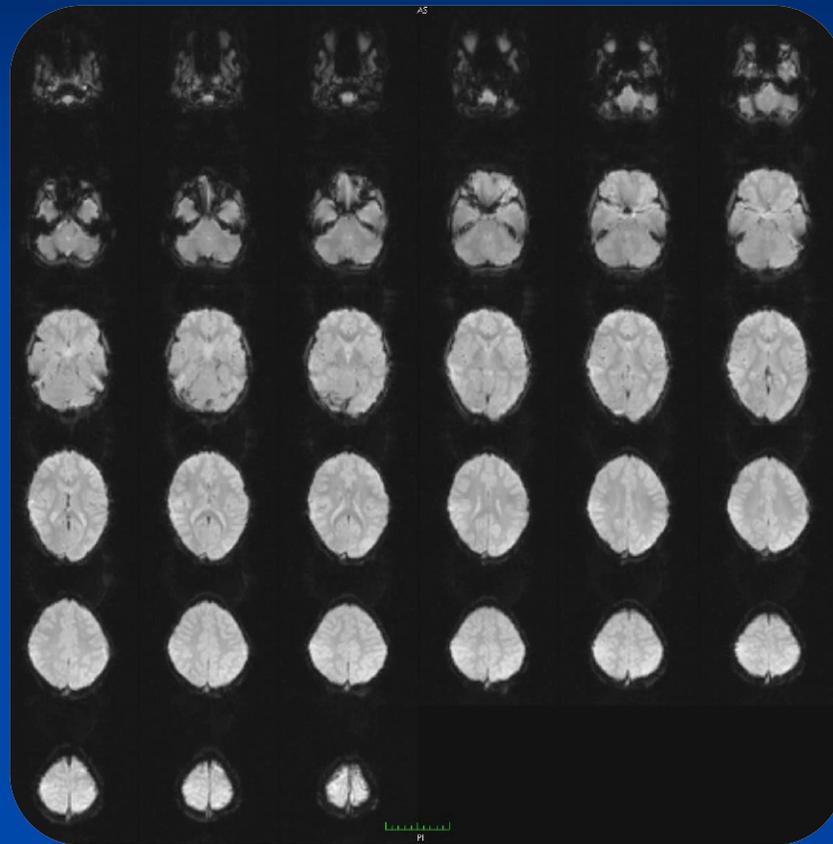
Best practice: Subject preparation

- Subject screening for potential compliance
- In-home materials and games
- Audio-visual materials (CD, DVD)
- Visit to the actual MRI scanner
- Mock scanner



<http://cibsr.stanford.edu/participating/GettingReady.html>.

Best practice: Review motion at scan



Best practice: Pulse sequences

- Calibrate fMRI noise at the scanner
 - Agar gel phantom (*Friedman and Glover, 2006*)
 - fBIRN (functional Brain Imaging Research Network)
 - Use a head coil while testing noise levels
 - Measure noise in white matter (in-house method)
- Allow gaps in slice prescription
 - Called distance factor in Siemens
- Consider prospective motion correction

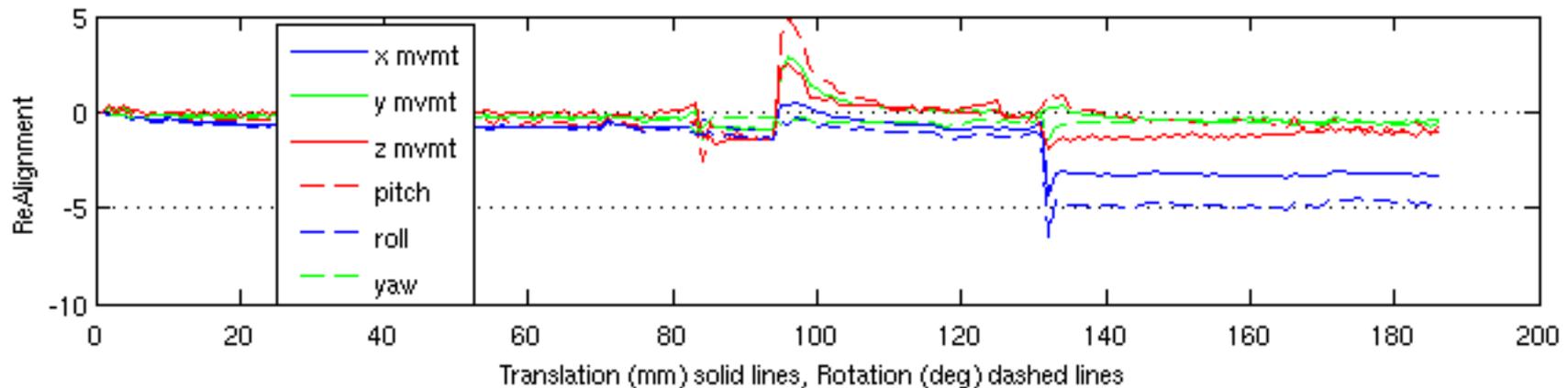


Other kinds of artifacts (without rapid scan-to-scan motion)

- Motion adjustment for small slow motions
 - Add realignment covariates to GLM (*Friston, 1996; Lund, 2005*)
- Slow large (> 2mm) motions
- Spontaneous deep breaths
- Transient bursts of electrical scanner noise
- Very rapid intra-volume motions

Large motion example (> 5 mm)

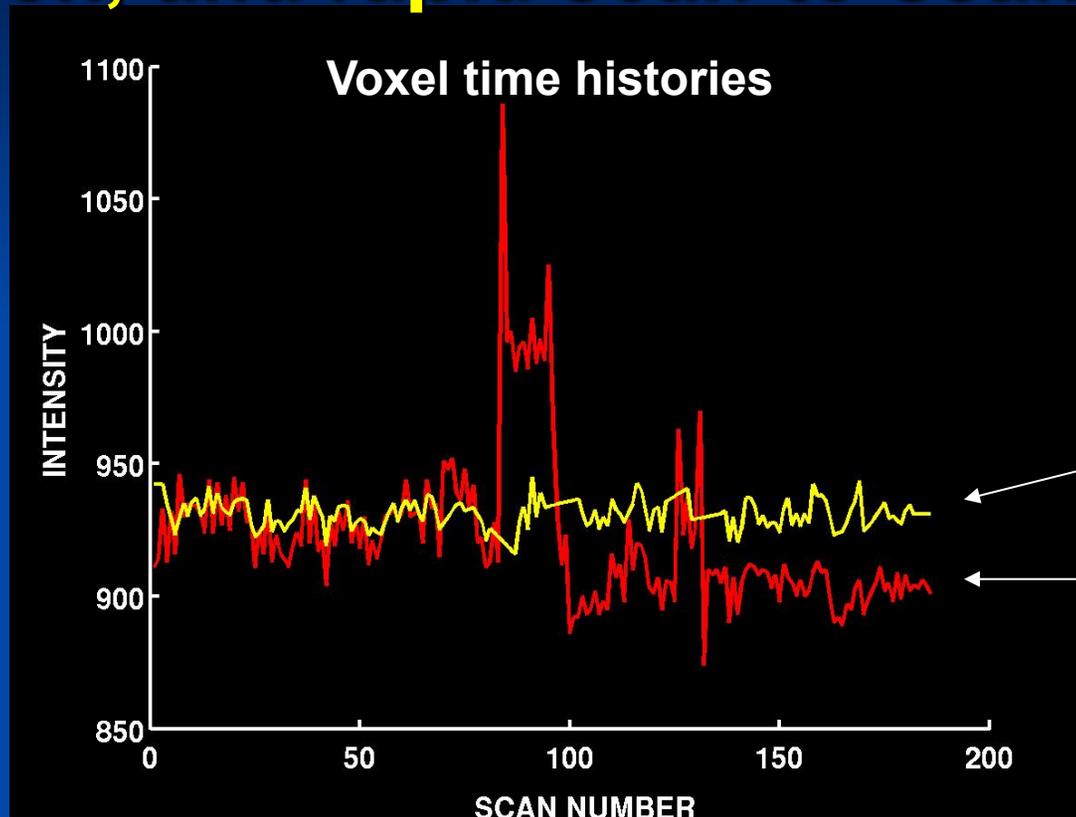
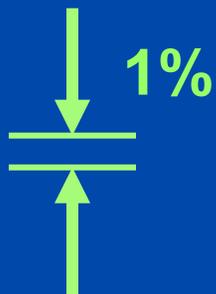
Young male with Fragile X syndrome



After realignment, residual motion errors are periodic in voxel size (*Grootoenk, 2000*)

Implemented as voxel-wise non-linear regressors in ArtRepair (*art_motionregress*)

Example: Correction of large amplitude motion, and rapid scan-to-scan motion.



Fragile X male,
4.5 mm motion,
5° pitch, 6° roll

**Motion adjust,
Artifact repair**

**Realigned and
smoothed does
not fix all errors**

Output of *art_motionregress*

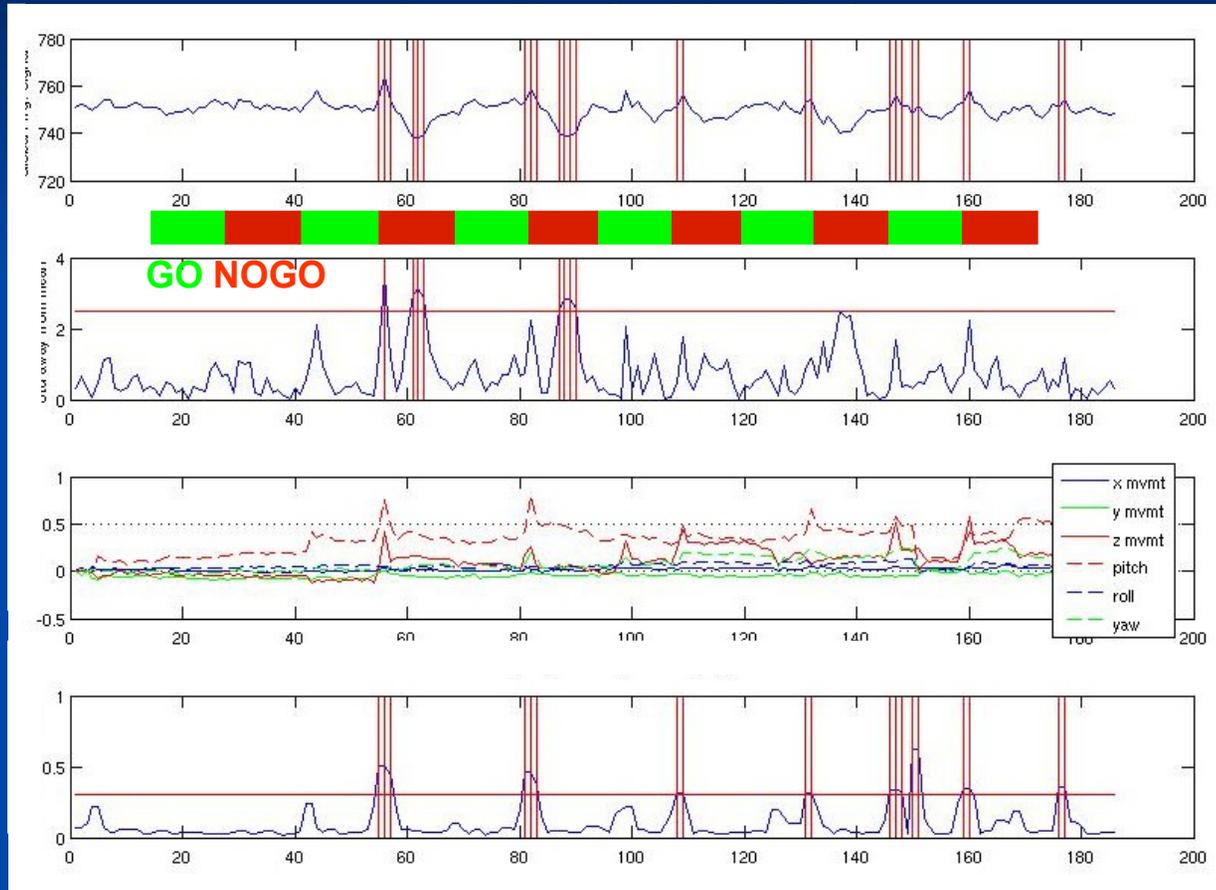
Spontaneous deep breath example

GLOBAL
AVERAGE
OVER HEAD

DEVIATION
FROM MEAN
OVER TIME

REALIGNMENT
PARAMETERS

SCAN-TO-SCAN
MOVEMENT
(mm / TR)



COMBINED
OUTLIERS

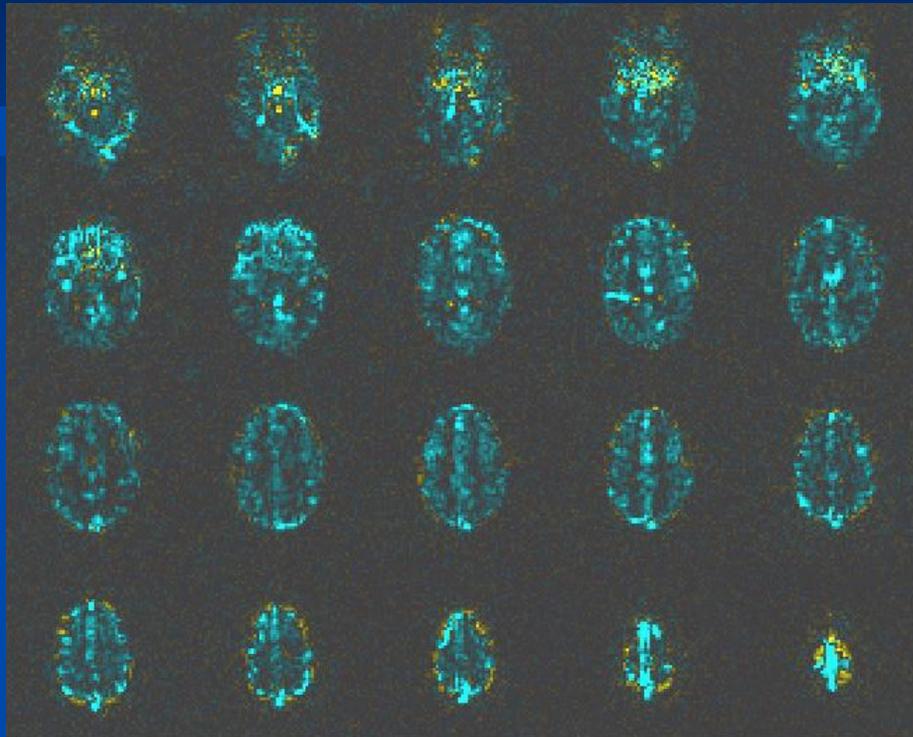
↑↑
INTENSITY
OUTLIERS

↑
RAPID
MOTION
OUTLIERS

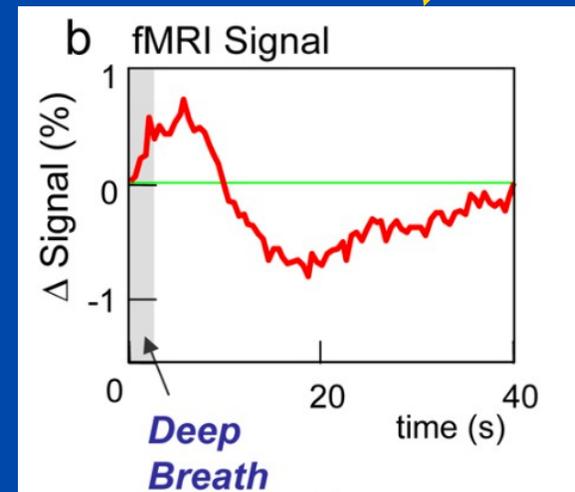
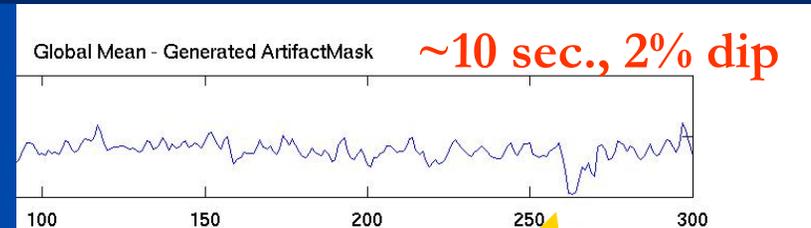
AUTOMATED or USER ADJUSTABLE THRESHOLDS

Program: *art_global*

Artifact from deep breath

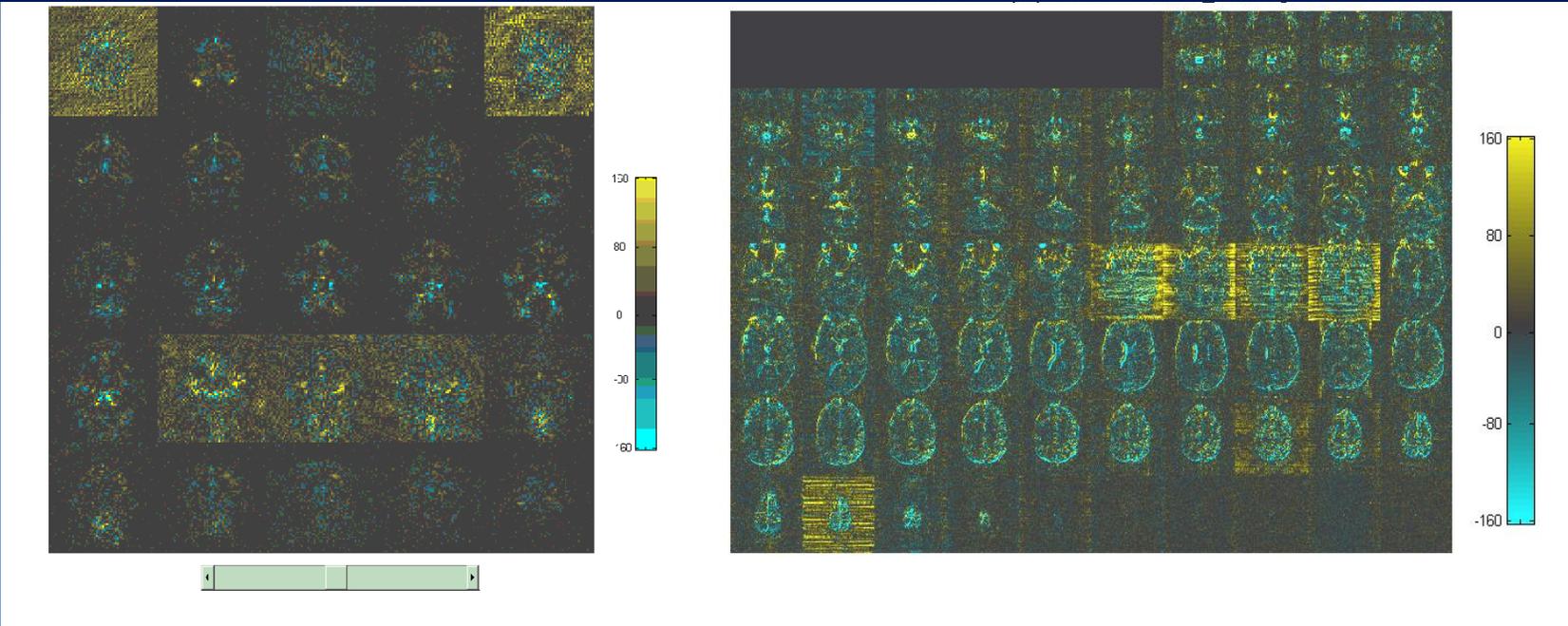


Global Signal: up to 10% dip
on all gray matter voxels



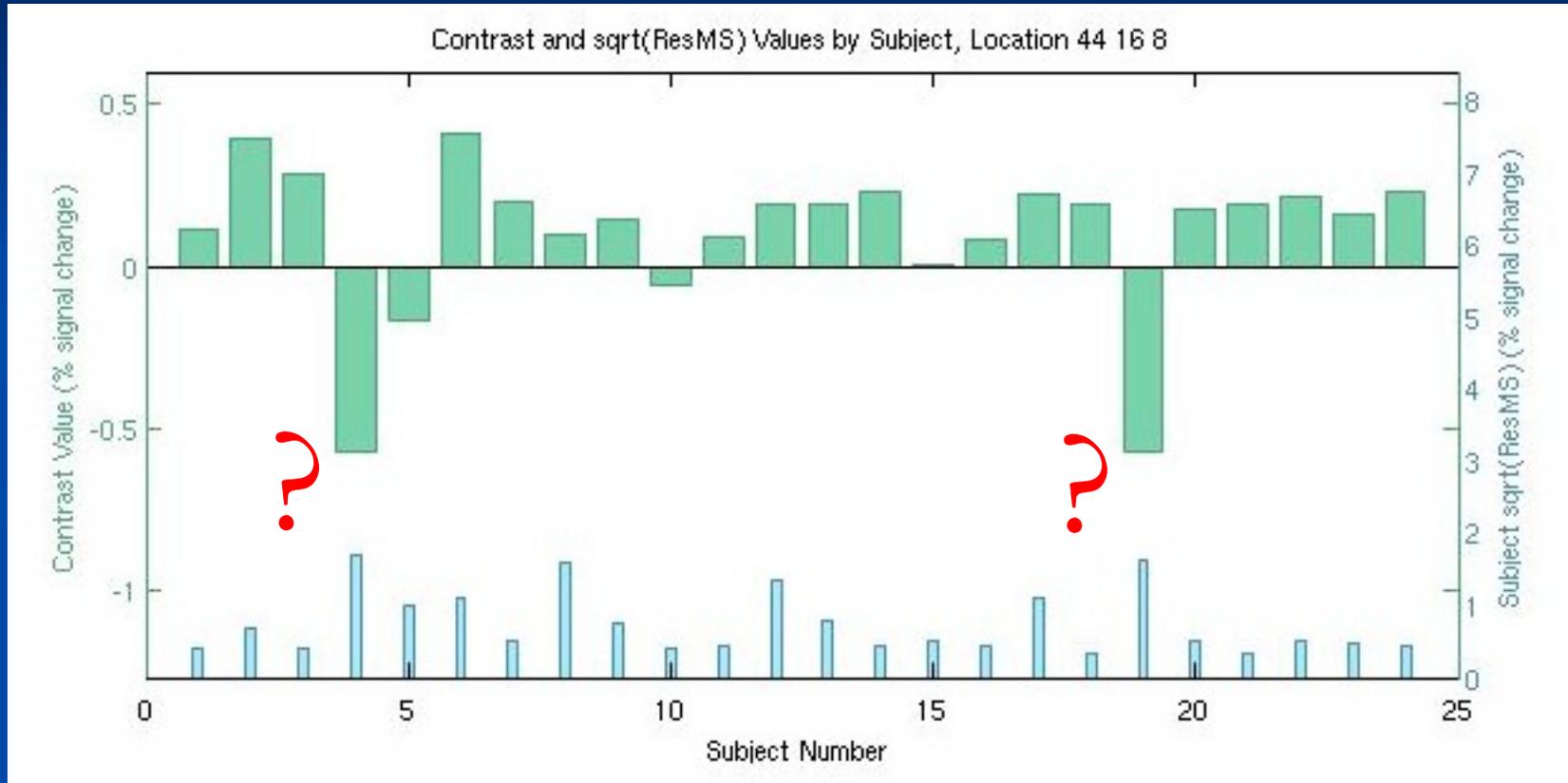
Respiration Response Function
Birn, et. al. (2008)

Artifacts from electrical noise



Transient electronic noise (slice artifacts, noisy channels in multi-channel head coils, physical vibration, electrical interference, loose connections, etc.)

Group analysis: Valid estimates, outliers, or artifacts?



Program: art_groupcheck

Estimates may be influenced by task correlated motion and other confounds

- Task correlated spin history effects (rapid scan-to-scan motion, or intravolume motion)
- Task correlated deep breaths
- Non responsive behavior
- Task correlated eye saccades (*Bruno, 2014*)

- Block designs, which are more susceptible to motion confounds (*Birn, 1999*), may be required in young or cognitively impaired populations

Detecting un-repaired artifacts

- Use statistical tests to reject outlier subjects in group studies (*Zhang, 2006; Woolrich, 2008*)
 - But not all unreasonable estimates may be rejected
- Diagnose estimate as un-repaired artifact if:
 - Unreasonable value (large percent signal change)
 - Spatial pattern of unreasonable values is similar to artifact, e.g. slice, brain edge, all gray matter, etc.

Percent signal change

- Depends on MRI strength, head coil, surface coil, etc.
- For GLM output, must scale to get percent signal change:

$$\beta(\%) = 100 * \beta * \text{peak} / \text{bmean}$$

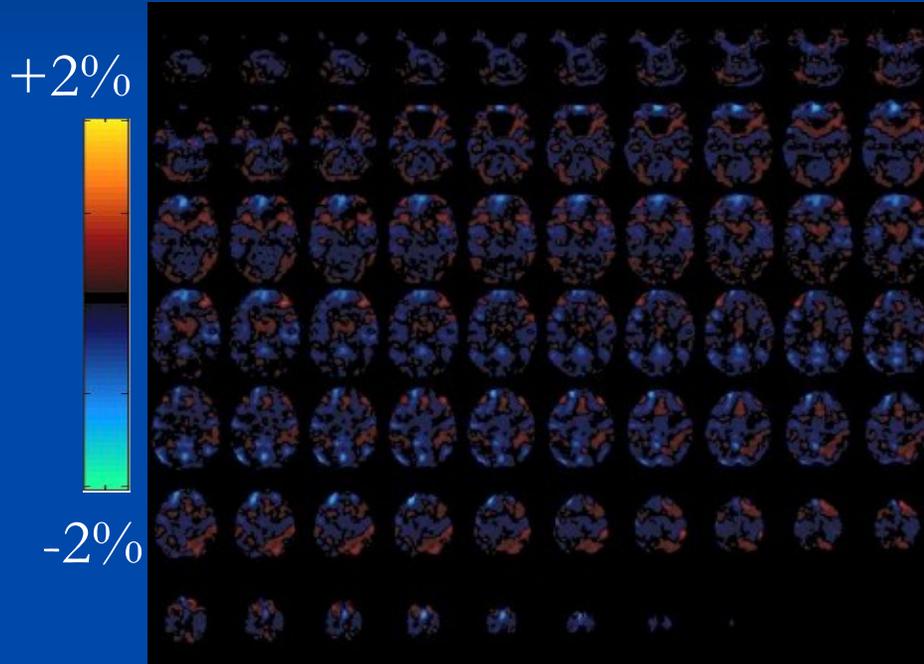
- Contrasts will be smaller

Region	Amplitude
Visual	3-5%
Auditory	2-4%
Motor	1-2%
Frontal	1%

<http://cibsr.stanford.edu/tools/human-brain-project/artrepair-software.html>

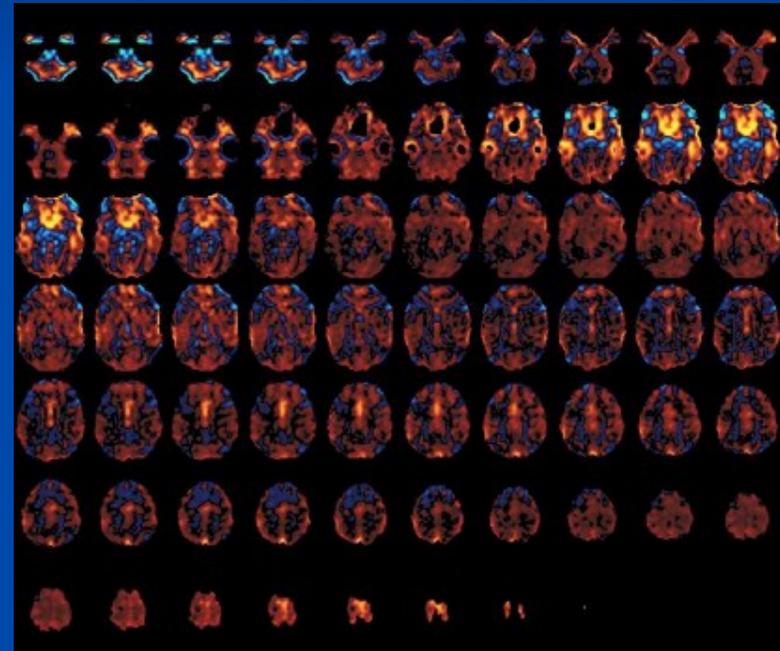
“Group level” movie reviews estimates at every voxel for every subject

Subject 1: Reasonable estimates



Range: [-2%, +2%]

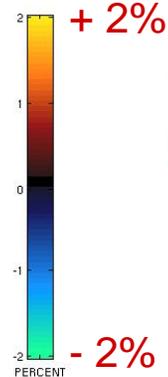
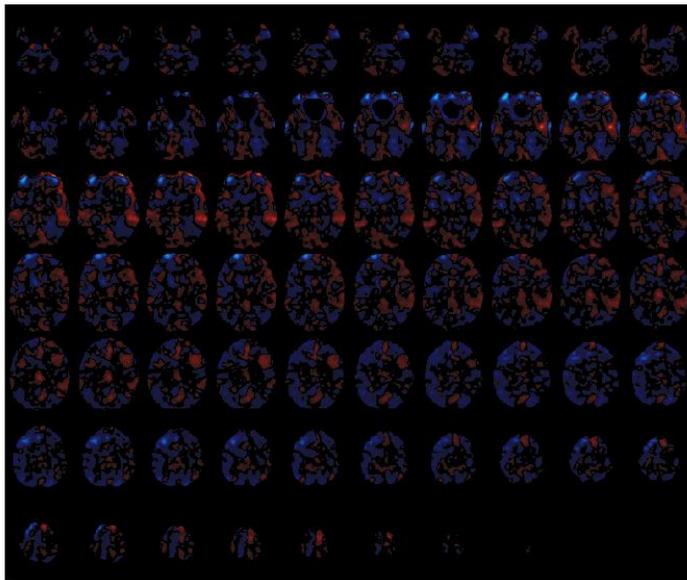
Subject 2:
Possible “deep breath” confound



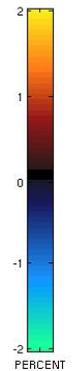
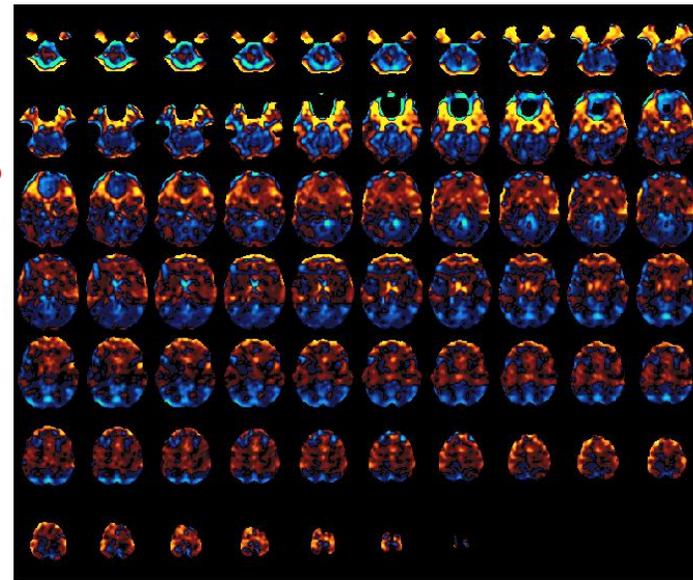
Program: art_groupcheck

Example from high motion subject (not using motion adjustment)

Low motion (<0.2mm) subject

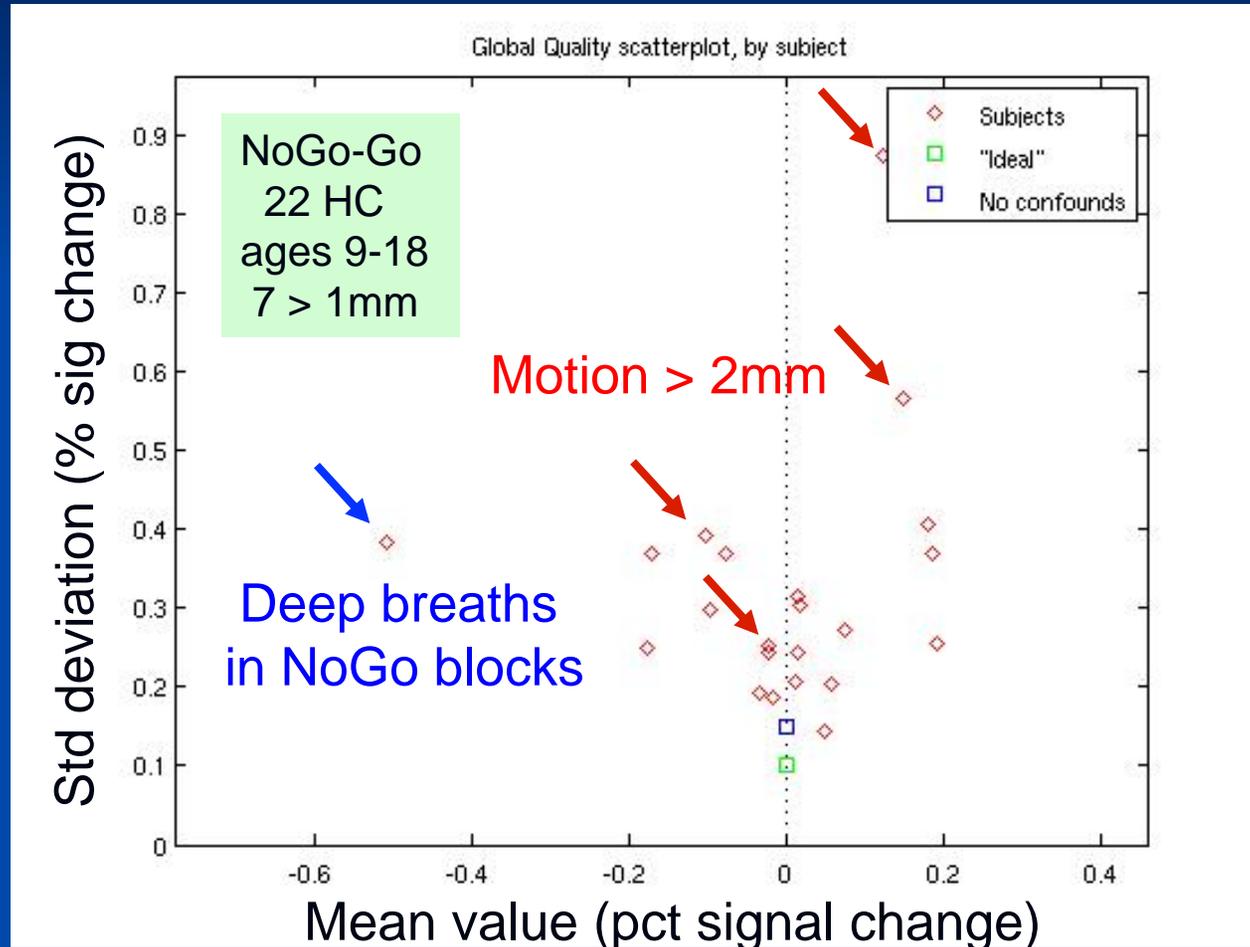


High motion (> 2mm) subject



Summary of group contrast images

Unusual values can often be traced to artifacts using art_movie



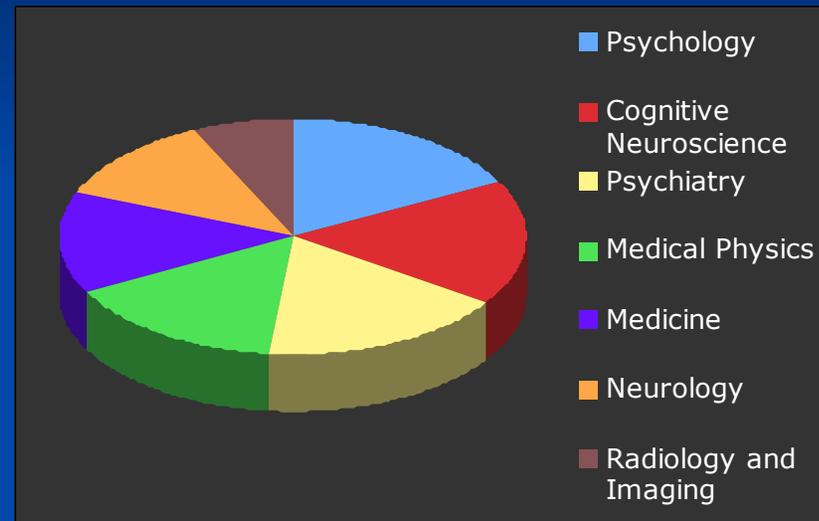
One strong un-repaired artifact
can make a difference
in a group study.

Always visually check your data.

Acknowledgements

Allan Reiss
Gary Glover

Sue Whitfield-Gabrieli
Fumiko Hoefft
&
many, many others



ArtRepair software for SPM
3100 software downloads, 21 countries

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