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The art and science of using quality control to understand and improve fMRI data

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Teves et al “The art and science of using quality control to understand and improve fMRI data” Front. Neurosci. (2023) https://doi.org/10.3389/fnins.2023.1100544

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I have no disclosures

Take home messages

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- Reproducible & relevant science requires knowing your data
  - Pipelines and sample size do not matter if your data is not good
  - The definition of ”good data” varies with context & application
- Quality control **protocols** are central to knowing your data
  - Automation is great, but insufficient
  - Training on how to do QC needs more attention
  - QC is an active area of research & should be more active

Why focus on quality control now?

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Significant transitions in the field

Good: Large N studies and shared data!

Neutral: Different people design, collect, preprocess, and analyze data

Less good:

- People make assumptions about data quality from previous phases
- Teaching data quality is often hands-on & reaches fewer people
- A pandemic where a cohort of trainees collected less or no data

A (mildly provocative) case study

There is no such thing as ”gold standard data”

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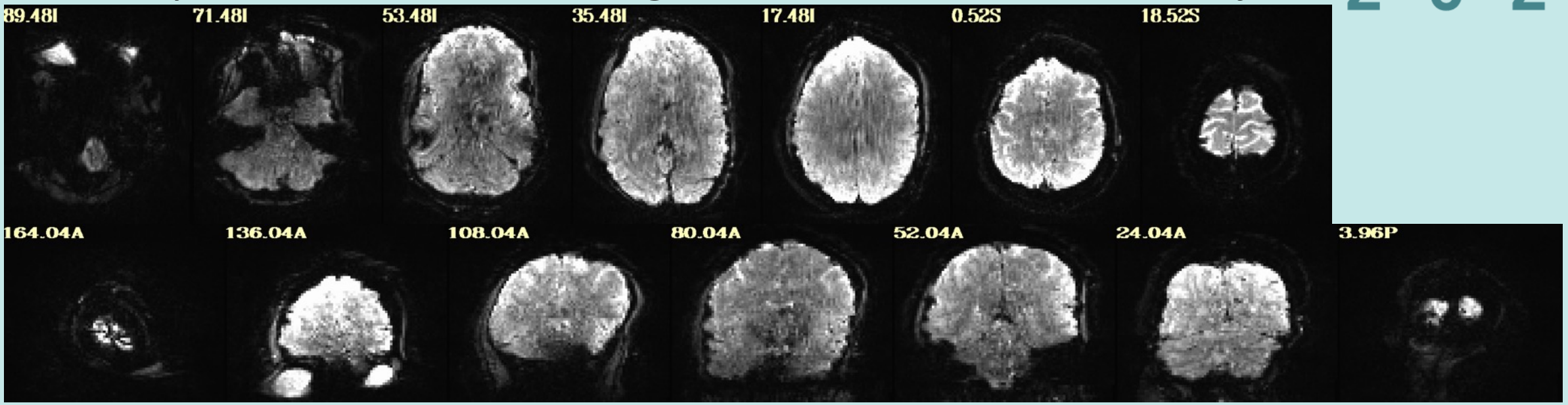
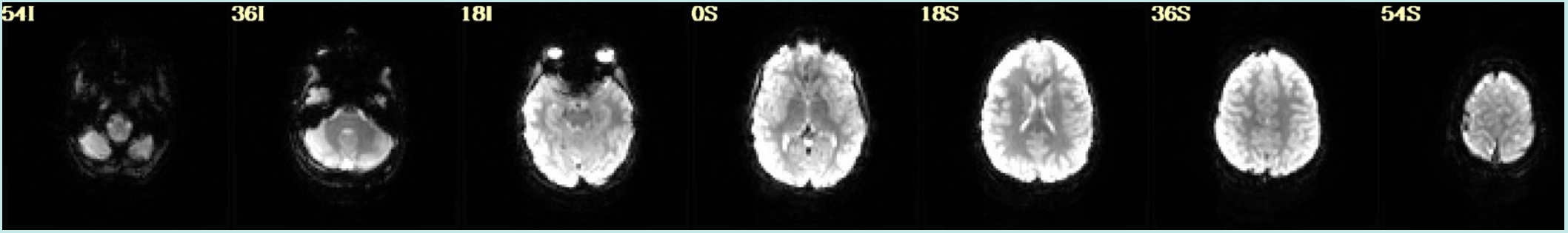
Arbitrary volunteer from the original Human Connectome Project



Arbitrary volunteer from ABIDE



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A (mildly provocative) case study

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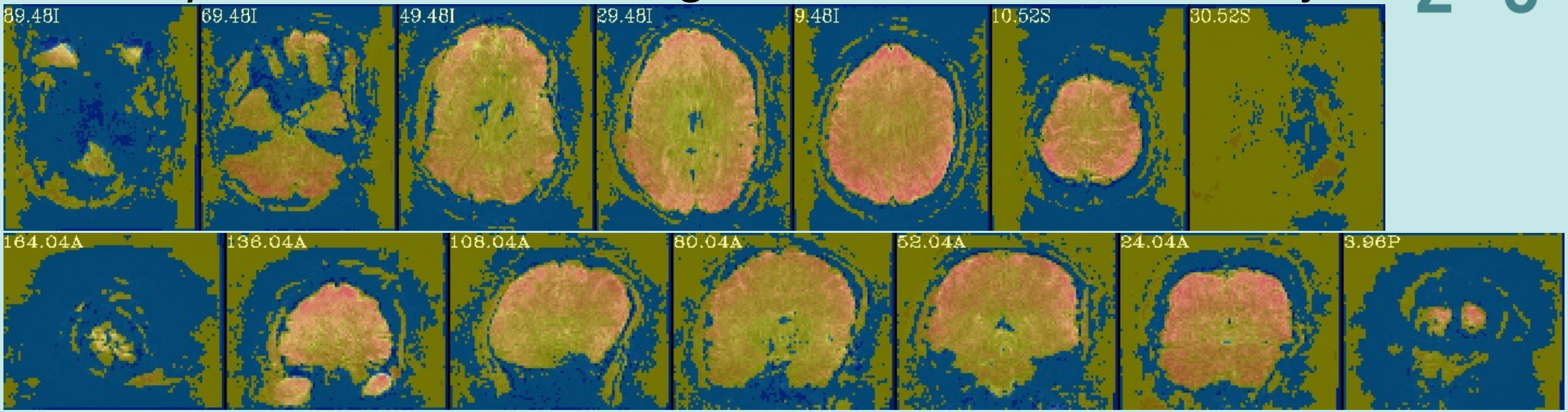
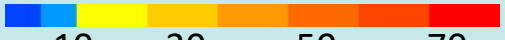
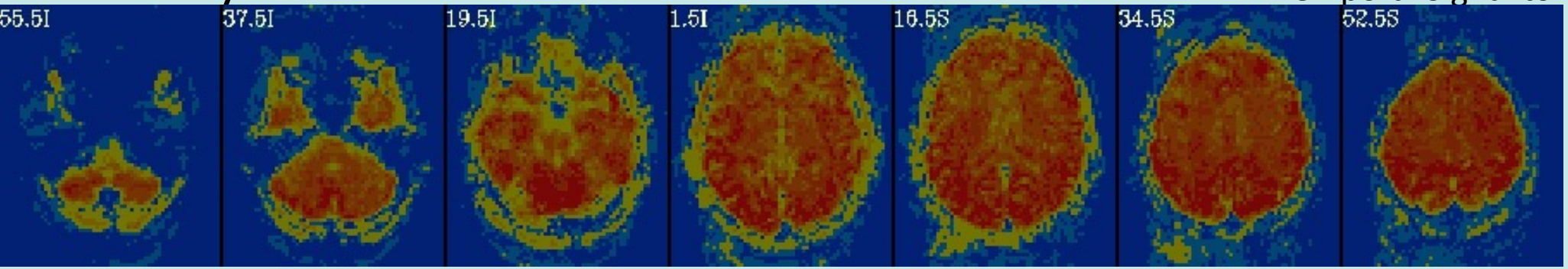




Temporal Signal to noise ratio (TSNR)

Arbitrary volunteer from the ABIDE



TSNR

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Context and applications matter

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- Successful Research using HCP data
  - ROIs that average across multiple small voxels
  - Correlation or task studies that summarize data across time
  - Averages across the large population
- HCP weaknesses
  - Studies that fully take advantage of the short TR **and** smallish voxel size
  - Brain-wide association studies that require robust signal in individuals' data
- **Note:** This is a broad & not completely fair generalization.
- **Take home message**
  - Great data for one application, but not be great for all applications
  - Identify and view data quality metrics relevant to your application

Approaching QC

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- Will these data have the potential to accurately and effectively answer my scientific question?

  …and future questions others might ask?

- Identify data anomalies or unexpected variations that might skew or hide key results

  Reduce problems through processing or removal.

- **All datasets have problems**
  - Not checking → Incorrect or misleading interpretations of results
  - Checking → **Fewer** unknown problems
- Wang and Strong 1996:

  QC has both intrinsic and contextual measures

Questions for a QC Protocol

Priority	Context & Examples
General	
Which voxels have usable data?	Voxel-wise data quality & coverage*
Are locations of voxels accurately defined?	Distortion & alignment to anatomy & templates*
Define context	Scientific questions & study priorities affect what is or is not good quality data
During study planning	
QC measures to support study goals	Particularly for study-specific QC priorities, this is a good time to seek expert advice
Operation procedures to decrease acquisition errors	Good procedures are critical for making sure data are accessible and consistently documented
Additional measures to collect	Experimenter notes, behavior logs, respiratory & cardiac traces
Organization & sharing QC measures	Inaccessible information is not useful
Piloting acquisition & processing	Evaluate and improve a QC protocol as part of study piloting
During Acquisition	
Real-time monitoring of severe image distortions, head motion, task non-compliance	Observing problems during acquisition can give time to recollect data or fix problems for the current or future scans
Monitor peripheral measures	Respiration, cardiac, eye tracking
Soon after acquisition or download	
Expected data are all present and properly documented	Missing, duplicated, or corrupted files, incomplete runs.* For MRI data, behavioral logs, and peripheral measurements
Data consistency & documented parameters match data	Consistent MRI field of view, contrast, orientation, number of runs, & run lengths match documentation*+
Documentation on QC during acquisition or pre-sharing exists	No documentation means there are undocumented problems
Data plausibly useful for study goals	Regions of interest should have full coverage. No substantive temporal artifacts that affect connectivity measures
Atypical brain structures, acquisition artifacts, drop out, and distortion	May still be fine`, but might require altered processing. AFNI's instacorr can be useful for assessment

During and after processing	
Scripts ran properly	Expected logs, QC metrics, & outputs created*
Appropriate voxels retained or removed	Voxels with good SNR in brain are within mask and voxels outside of brain are removed.*
Voxels lost to dropout or field of view	Check that similar voxels are retained across the population+
Consistent measures of temporal signal-to-noise and intrinsic spatial smoothness across population	Sessions with non-trivially lower TSNR or different smoothness can be a warning sign of other problems*
Automatically removed data	Number of censored volumed and DOF lost from noise regression, temporal filtering, & censoring*
Artifacts like ghosting, phase wrapping, or leakage	Instacorr is useful for checking if the temporal signal from an article is folding over into other brain regions
Partially-thresholded activation maps	Are areas with the largest model fits in anatomically plausible patterns inside the brain?*
Task correlated head motion or breathing	Not commonly checked and can bias results.* (AFNI automatically checks motion, but not breathing.)
Skull properly masked for anatomical & functional data	Can cause problems with alignment. Part of report from AFNI's SSwarper
Intensity inhomogeneity	Brighter signal on the surface can be expected, but can cause problems with masking and alignment*
Good anatomical to functional alignment & alignment across days/runs	Can be a serious hidden problem if one just looks at group maps.+
Left & right hemispheres flipped between anatomical & functional data	More common than it should be & requires excluding data unless the true left/right can be determined*
Good anatomical to anatomical alignment across participants	Often correctable and causes problems if not corrected+
Group coverage across population	A summation of aligned functional masks highlights brain areas missing in part of the population+
Processed peripheral data are good	Plausible behavioral timing files, good peak detection in respiratory & cardiac traces

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- Study planning
- (Hardware QC)
- During data acquisition
- Soon after acquisition
- During processing

Phases interact

Questions

Not a checklist

Teves et al "The art and science of using quality control to understand and improve fMRI data" Front. Neurosci. (2023) https://doi.org/10.3389/fnins.2023.1100544

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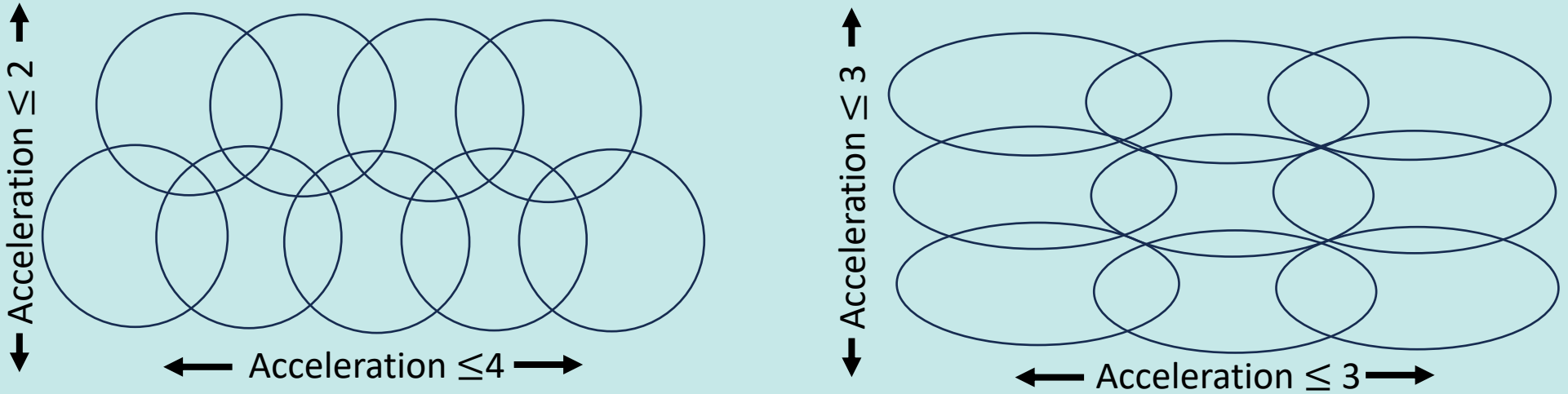
Study planning

- What QC measures matter for my study?
  - Brain coverage? Distortion? TSNR?
- Operating procedures:
  - Documentation and real-time checks
  - Data & meta-data to store. What **and** how
- **Piloting**
  - Testing QC measures
  - Testing operating procedures

Always pilot a study

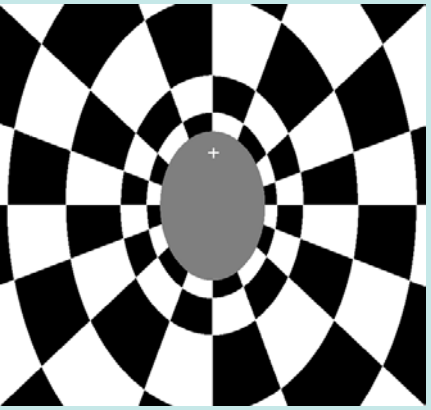
- Do not use scanning parameters just because they worked for someone else
- Do not use scanning parameters just because they worked for someone else
- If you're not an expert in MRI physics, things you did not consider might affect data quality.

Alternate geometries for a 9-channel head coil



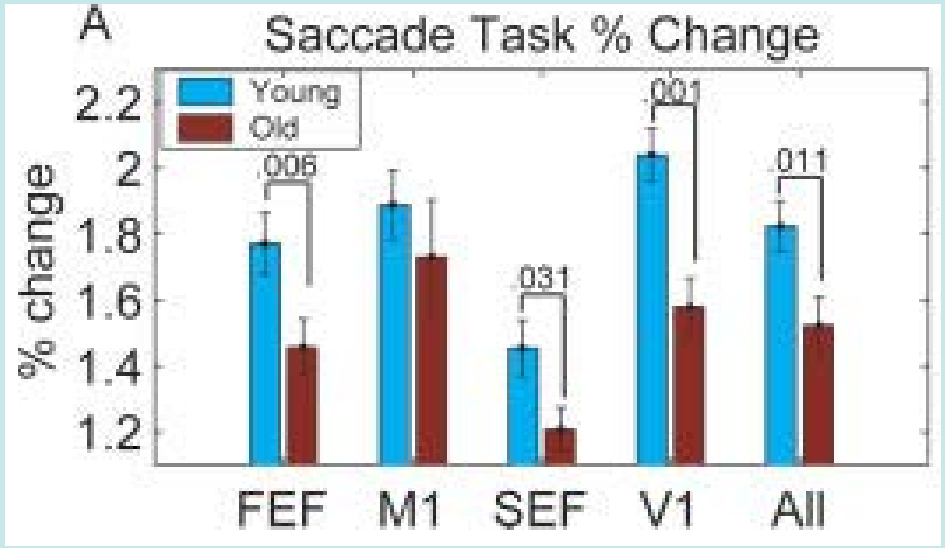
- If you are an expert in MRI physics, you're even more likely to collect pilot data

Collect breathing and pulse!



Present a 200ms flickering checkerboard every 18-24s

Volunteers press a button and move their eyes



Handwerker, Gazzaley, et al 2007

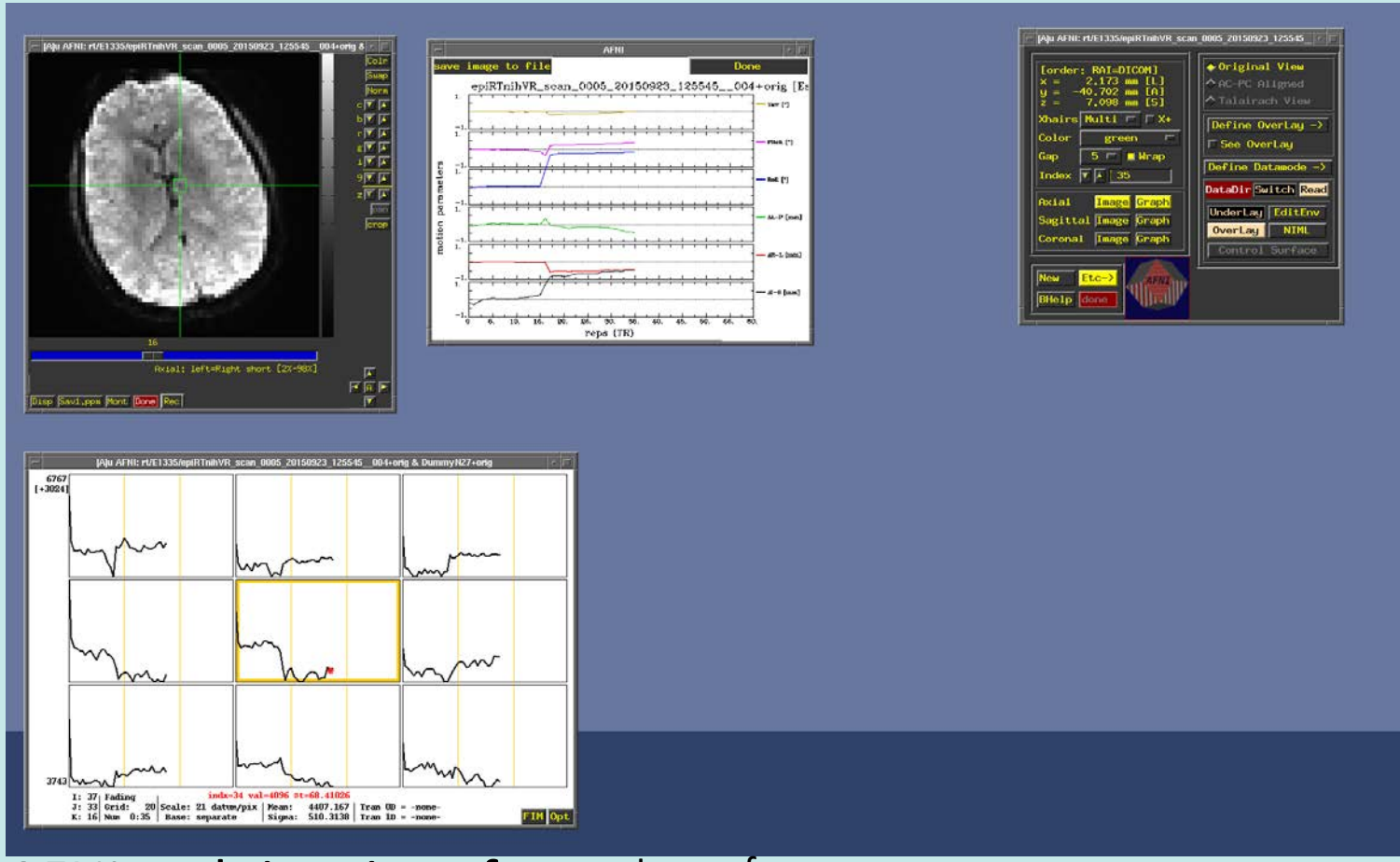
The unpublished part

- Stimuli presented for 3s, 6s & 12s durations
- A non-trivial # of volunteers held their breath for the stimulus duration
- No respiration data →
  Visually appealing results →
  Misinterpreted results

See also: Birn, Murphy, et al, NeuroImage 2009

Data acquisition

- Check outputs as soon as possible!
  - Neuroimaging, peripheral measures, and behavior
- Document anything atypical or different from acquisition plan
  - Altered run order or bad runs, faulty response recording
  - Volunteer sleepiness/non-compliance
  - Obvious artifacts or atypical brain structures



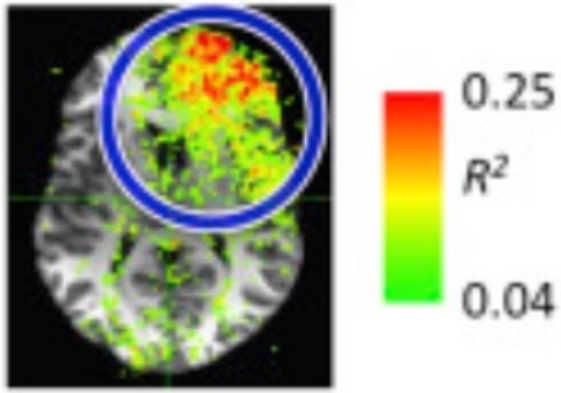
AFNI real time interface

Image from
Vinai Roopchansingh

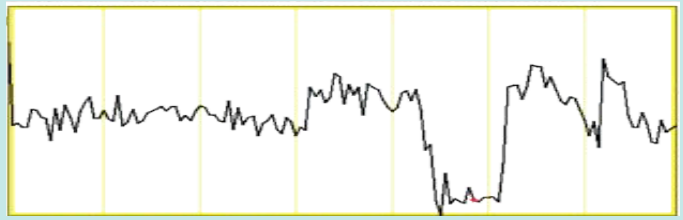
Soon after acquisition

- Did you store what you planned to store?
- Is result quality similar to pilot scans?
- Data useful for study goals:
  - Good signal quality in brain regions of interest
  - No artifacts that will affect analysis
    - Signs of scanner problems
    - Warnings to reconsider acquisition protocol

Temporal instability in one receiver coil



ANATICOR
Local correlation to white matter
Jo, Comp Bio & Med (2020)



Processing: Coverage map

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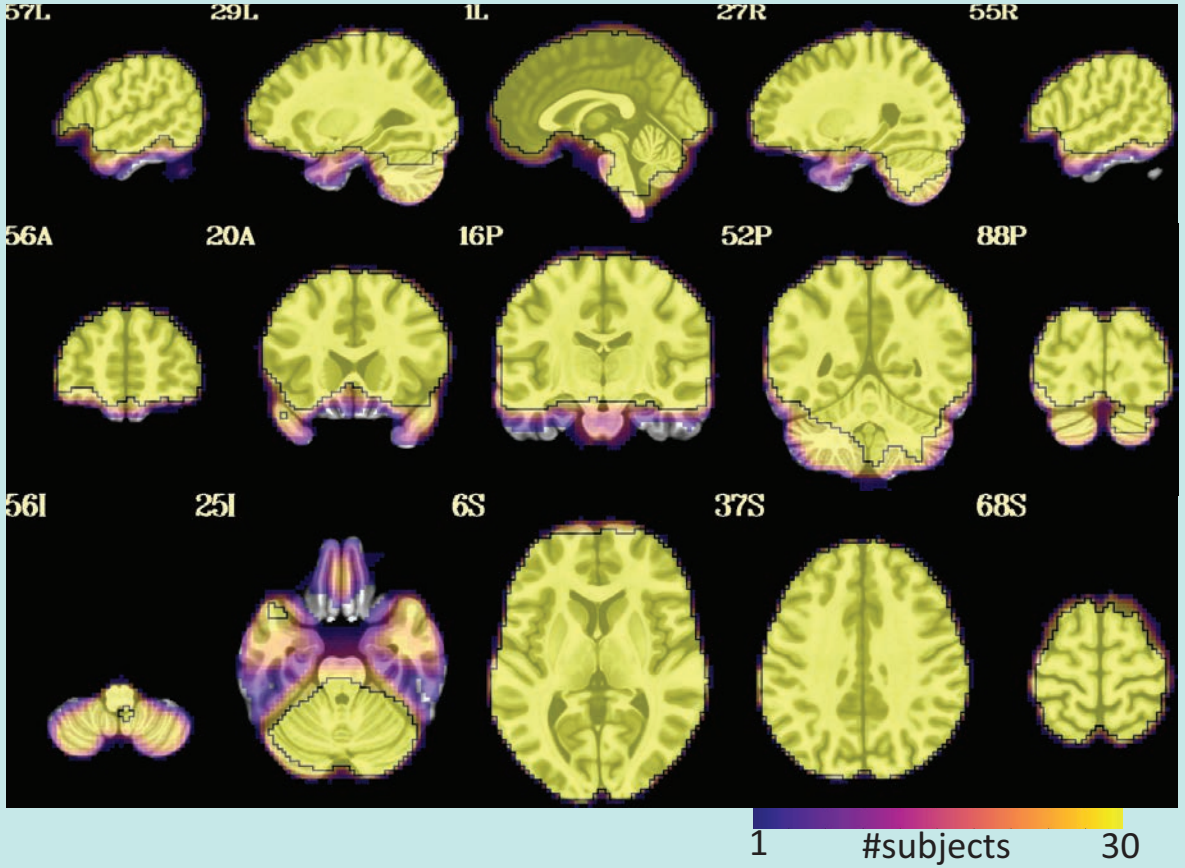
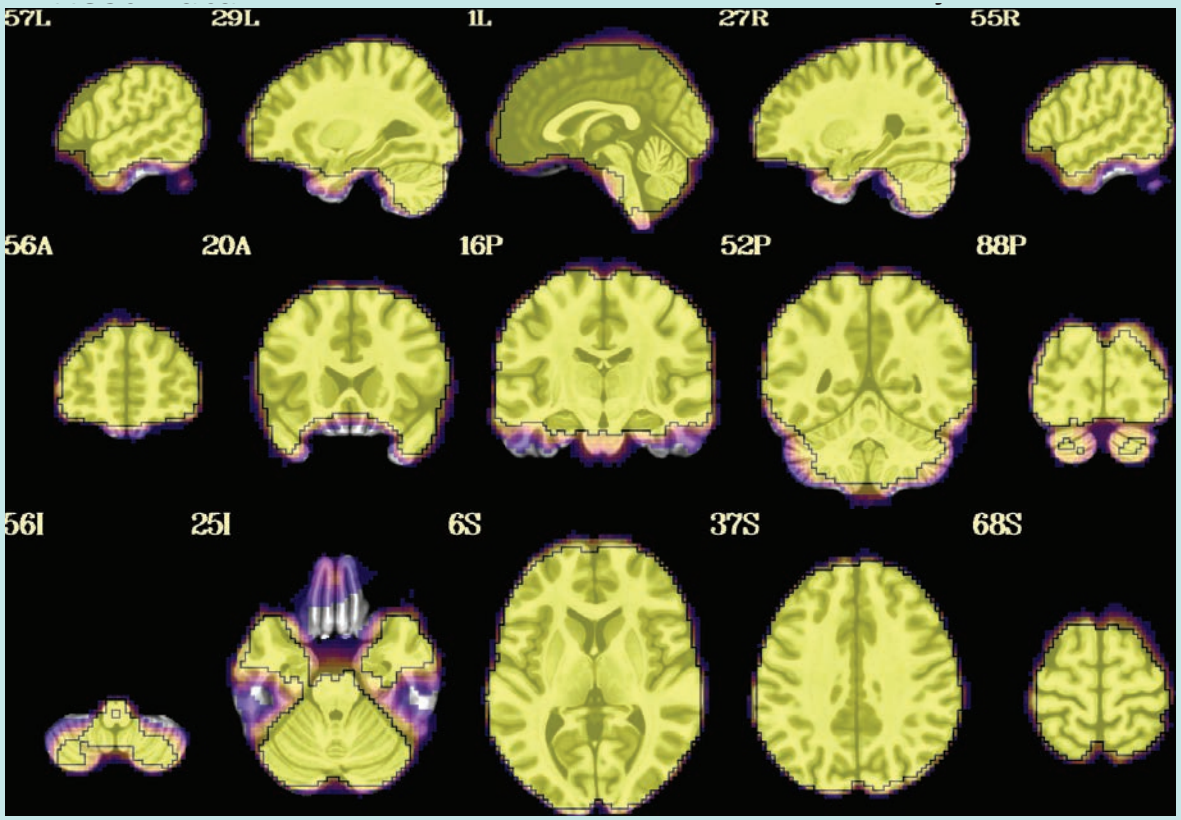
Task data



Rest data



Coverage differs between studies: Sufficient” coverage is study-specific

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Head motion

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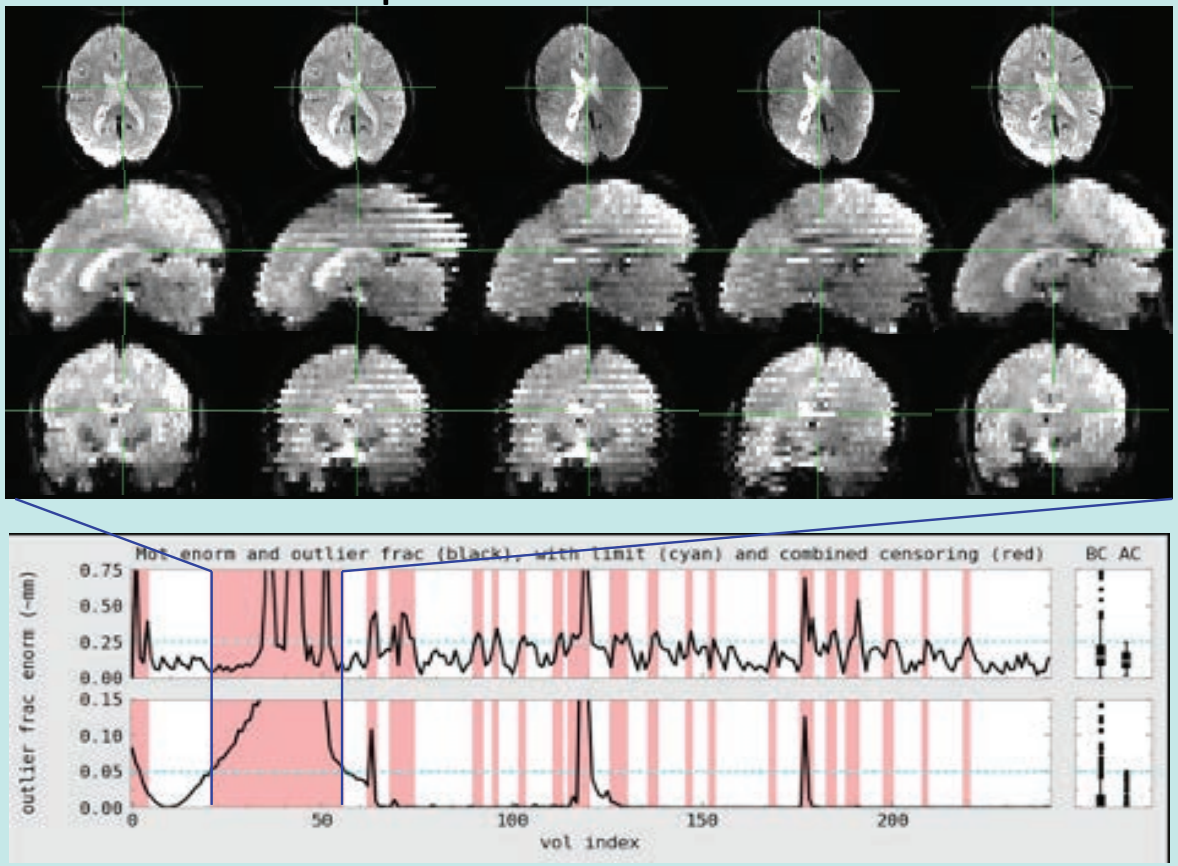
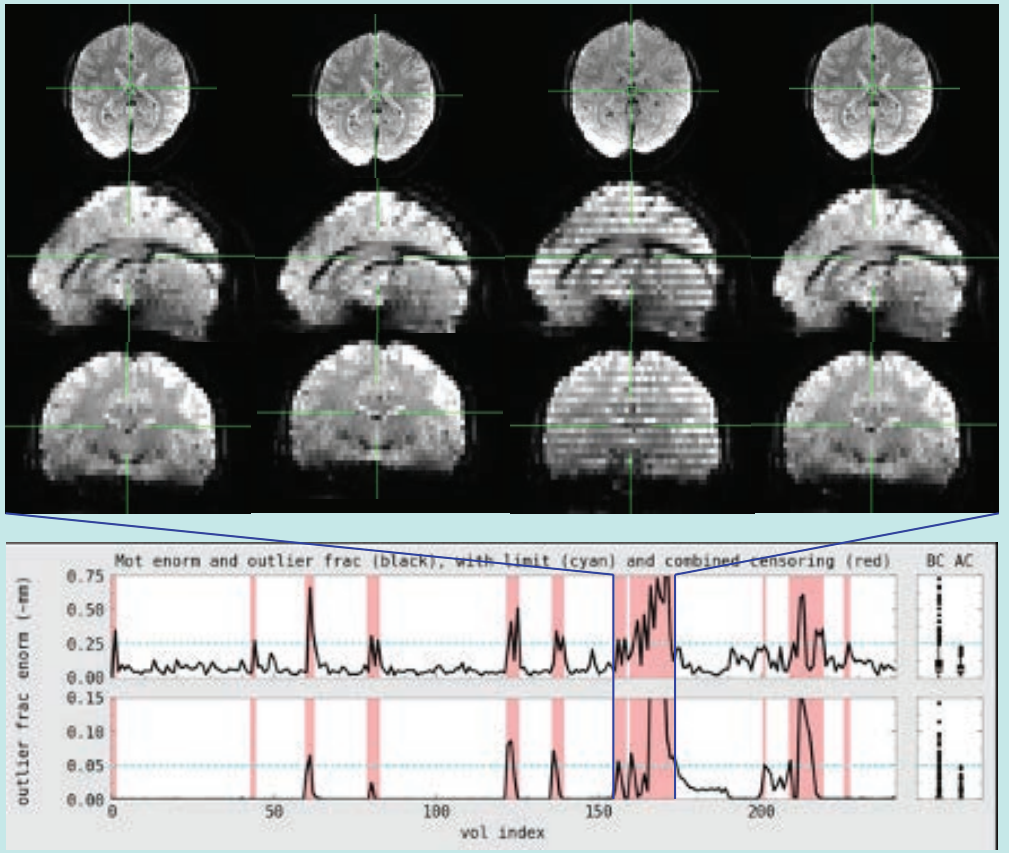
Frequent motion artifacts



sub-017: Unlikely to be usable

Sporadic motion artifacts



sub-029: Potentially usable with censoring

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Statistical maps

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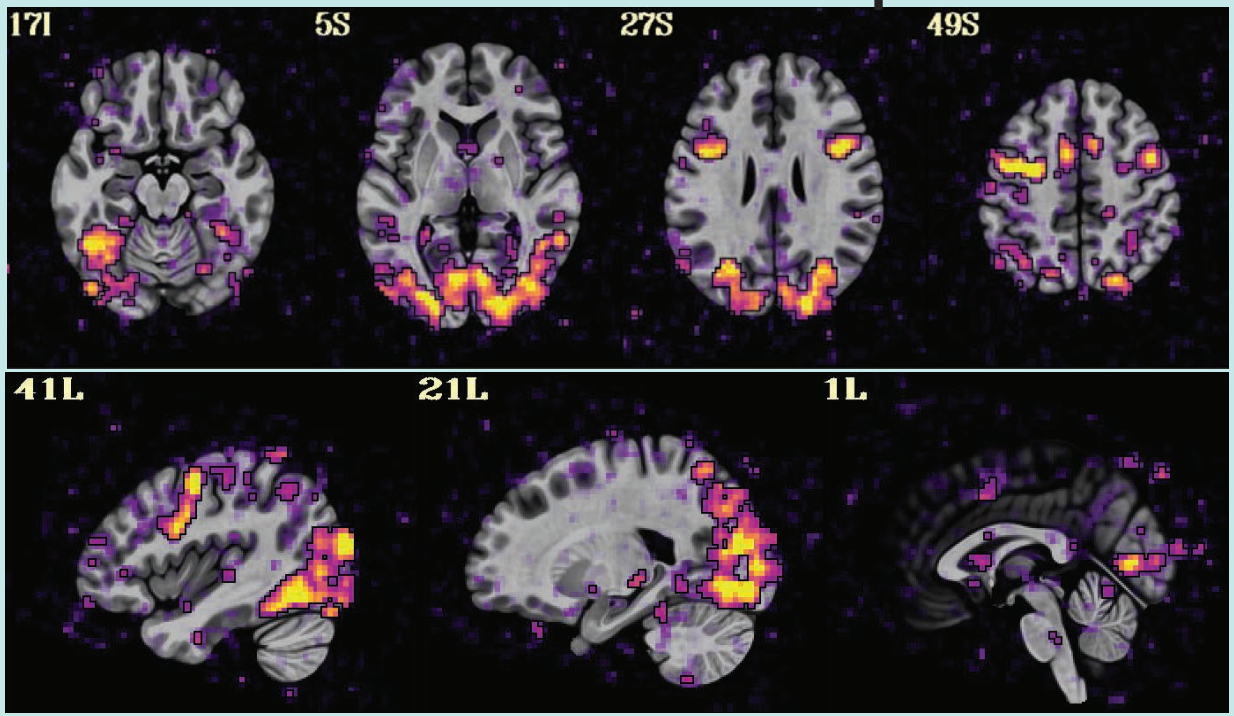
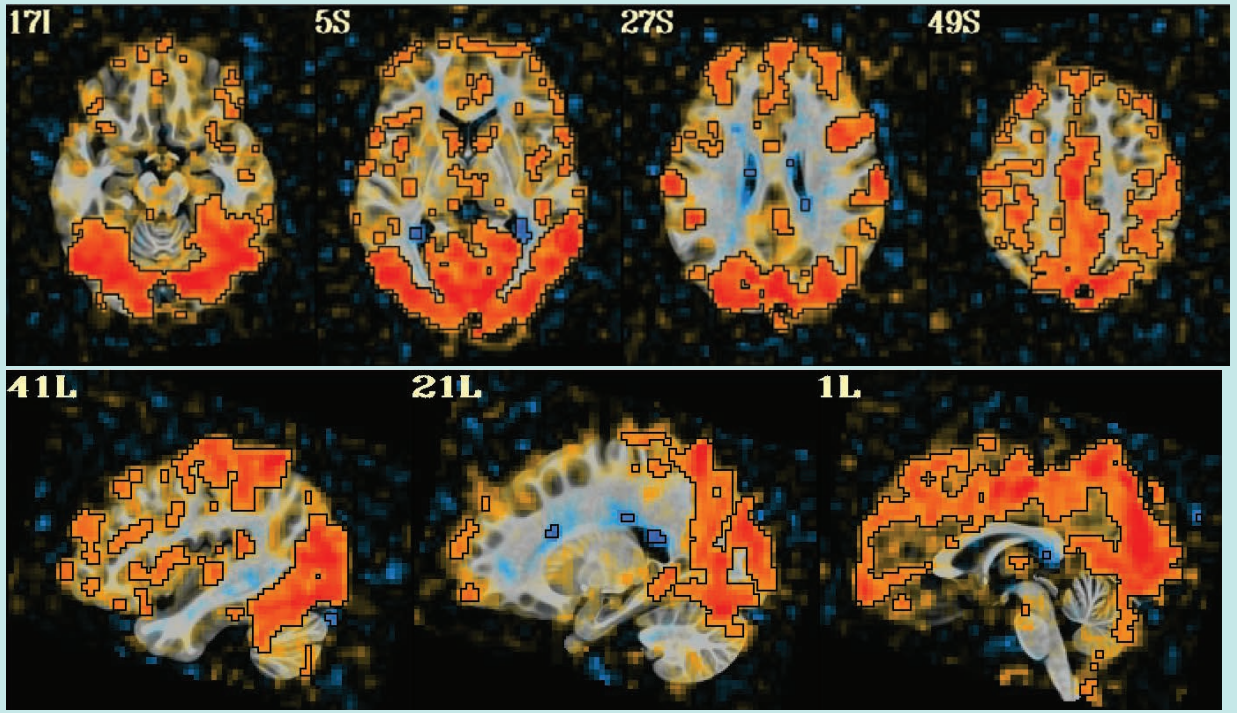
Full F stat map



0 24.3

Correlation to white matter ROI



-0.6 0.6

sub-001 (included)

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Statistical maps

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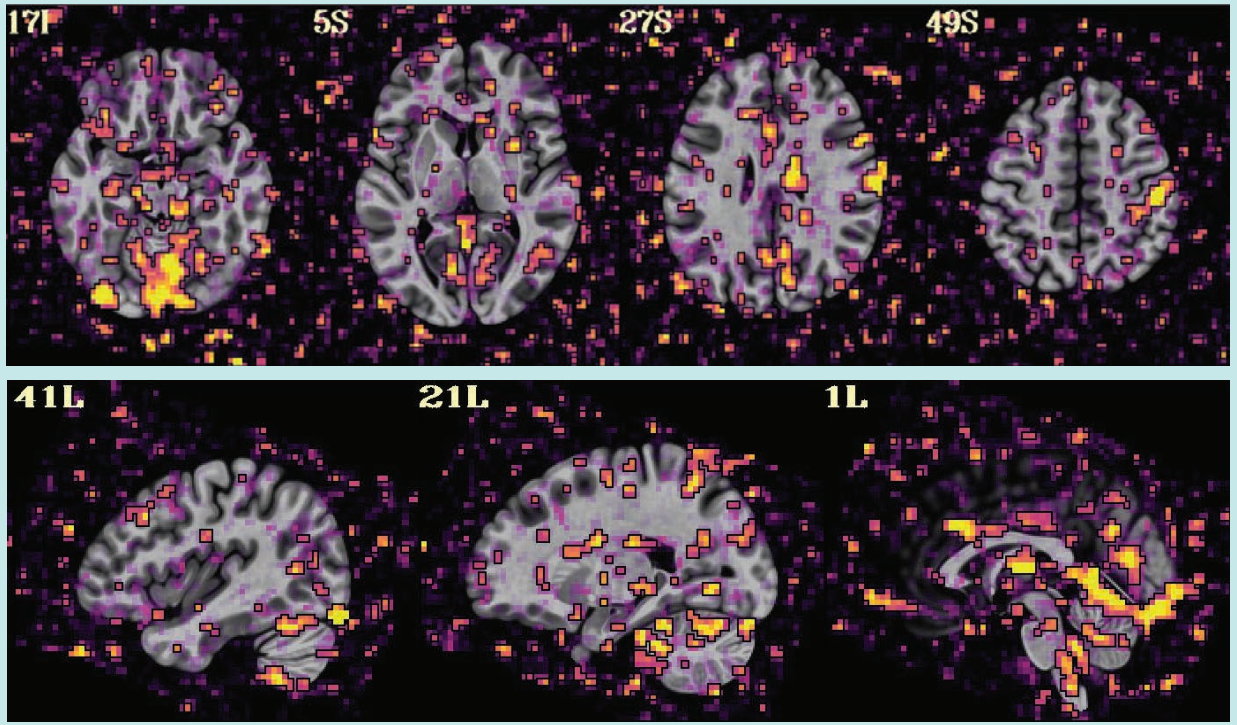
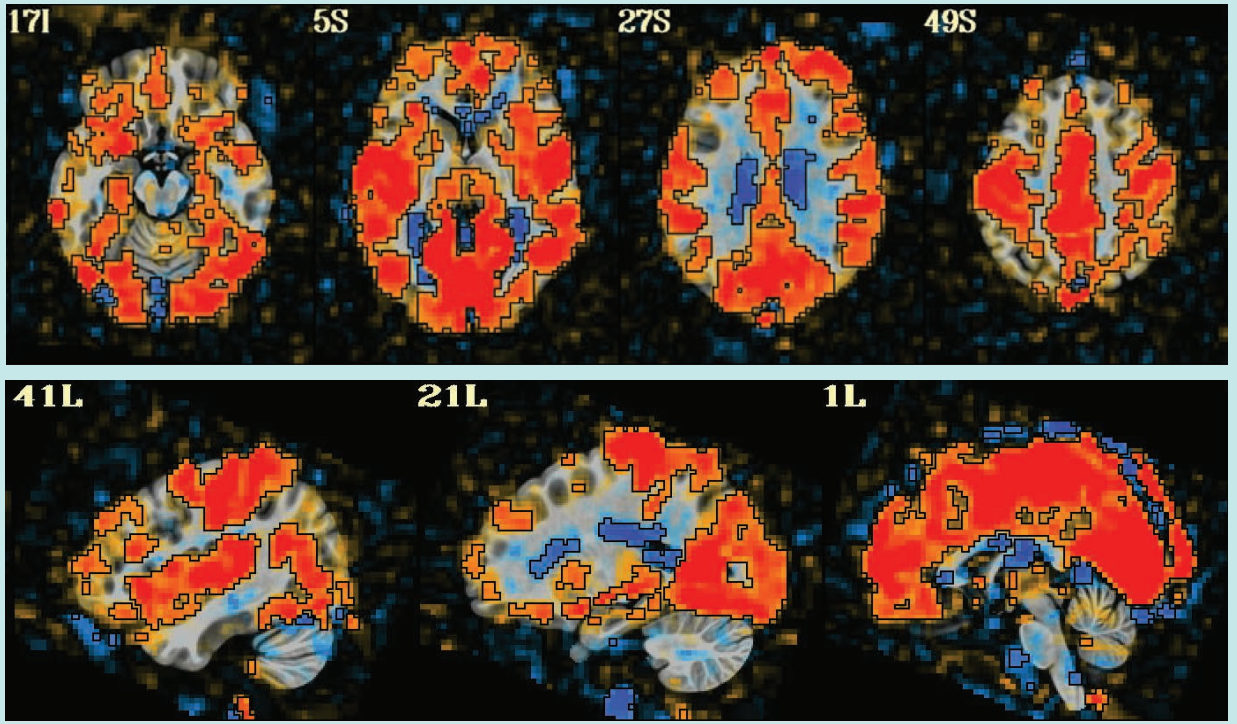
Full F stat map



Correlation to white matter ROI



0 6.6

-0.6 0.6

sub-016 (excluded)
Task condition, but not control condition mildly correlated to head motion

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Human interaction (instacorr)

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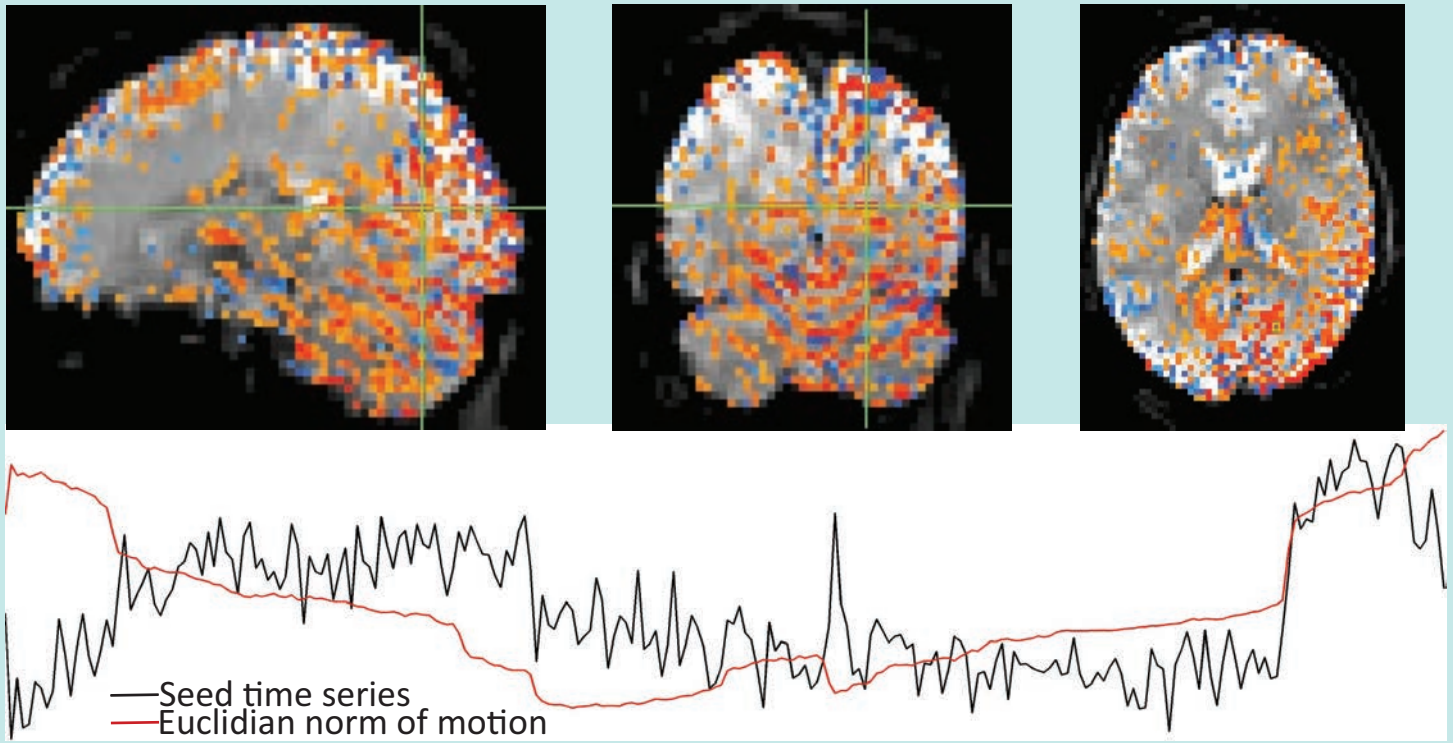
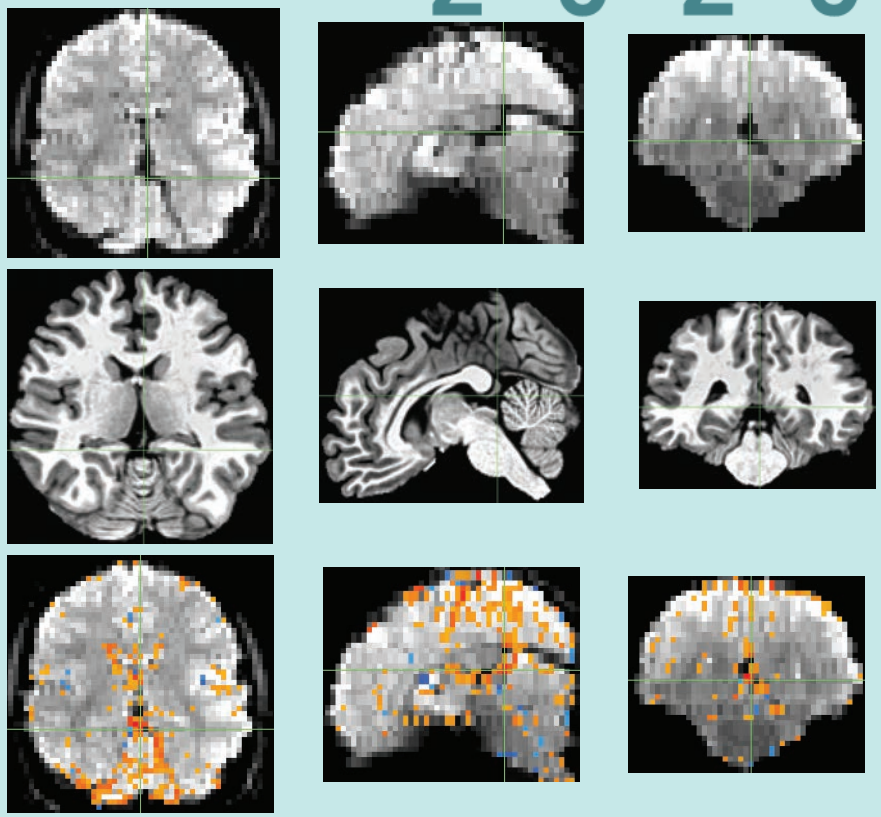
A



Sub-018: Investigated artifact with “high EPI variance” warning

B



Sub-002: Investigated hypointensity

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More automated correlation-based measures

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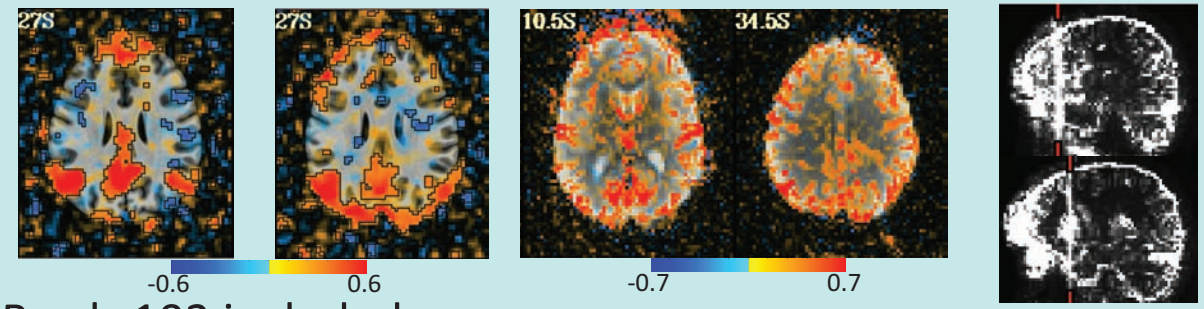
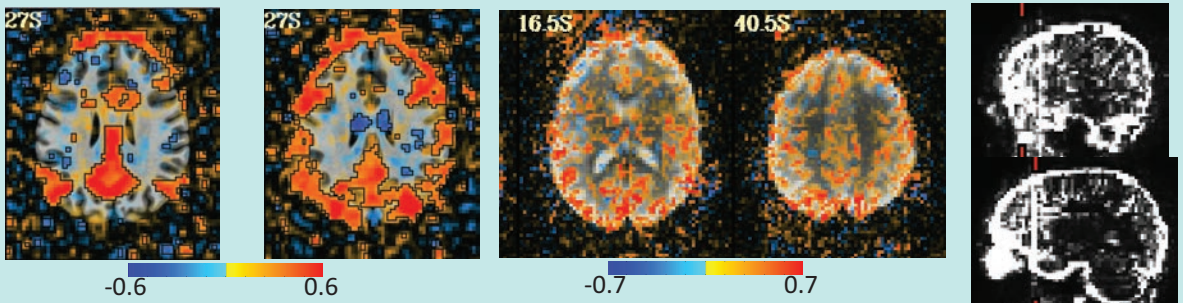
A sub-109 included

Corr to PCC | Corr to WM | Local corr | EPI variance



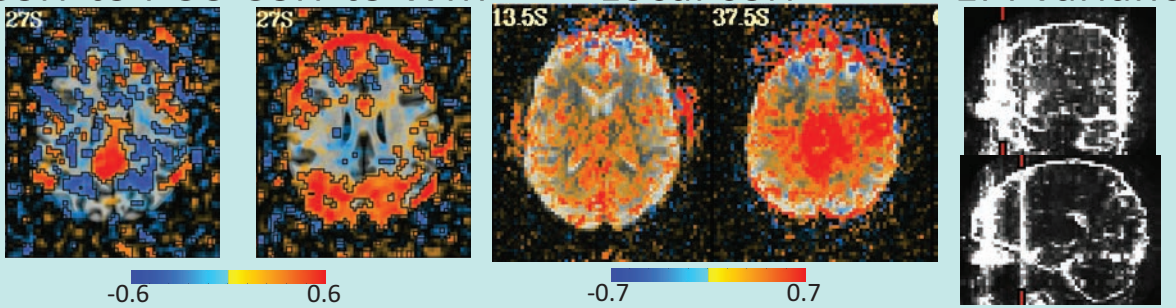
B sub-102 included

Corr to PCC | Corr to WM | Local corr | EPI variance



C sub-114 excluded

Corr to PCC | Corr to WM | Local corr | EPI variance



Expected network plausible?

Corr to white-matter non-global?

Local corrs follow anatomy

EPI variance for follow-up.

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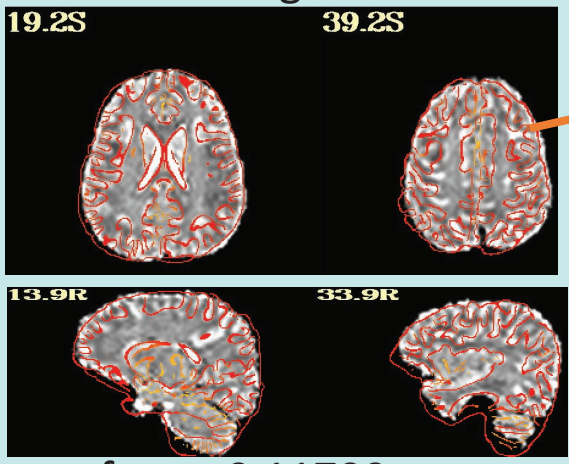
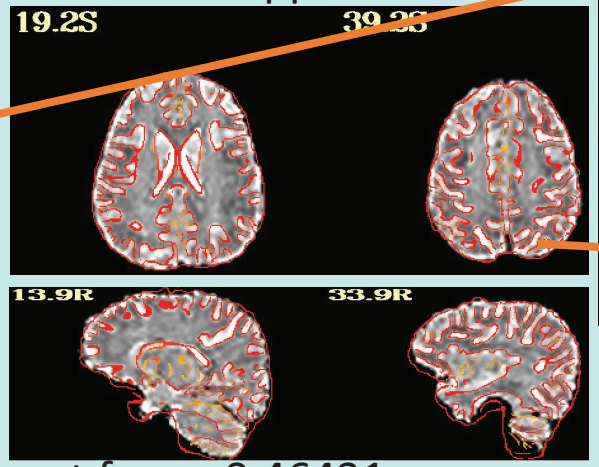
Alignment

A sub-115 Orig Orientation

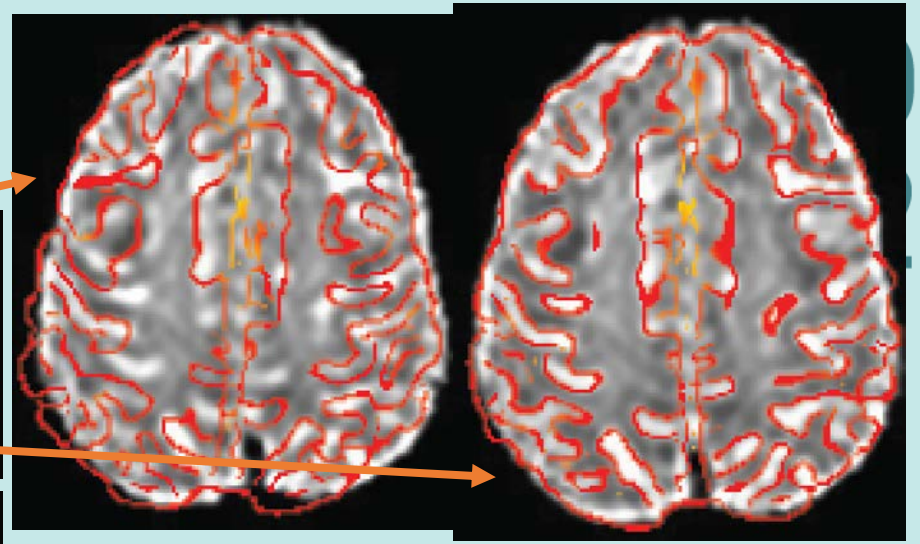


cost func: -0.11799

B sub-115 Flipped Anat



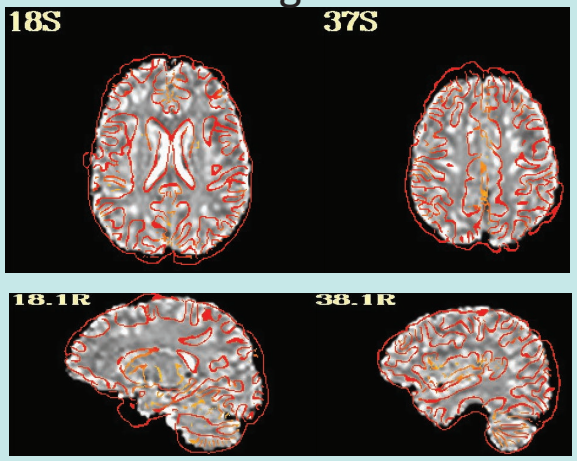
cost func: -0.46431



Flipped fits better

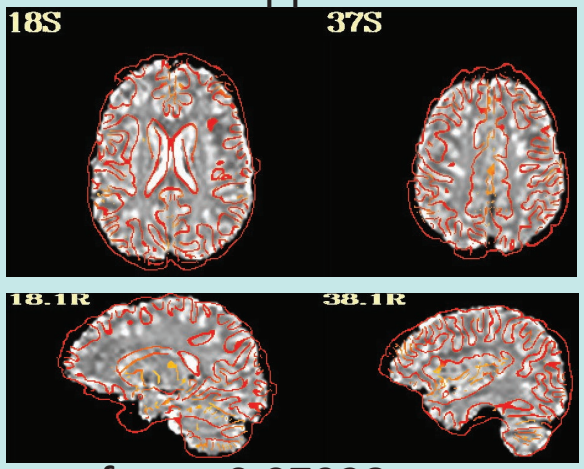
Anatomical edges over EPI volume is useful for both checking alignment and viewing if there the left & right sides of the brain were flipped

C sub-116 Orig Orientation



cost func: -0.07533

D sub-116 Flipped Anat



cost func: -0.07928

Neither fits well

Alignment: QC yourself!

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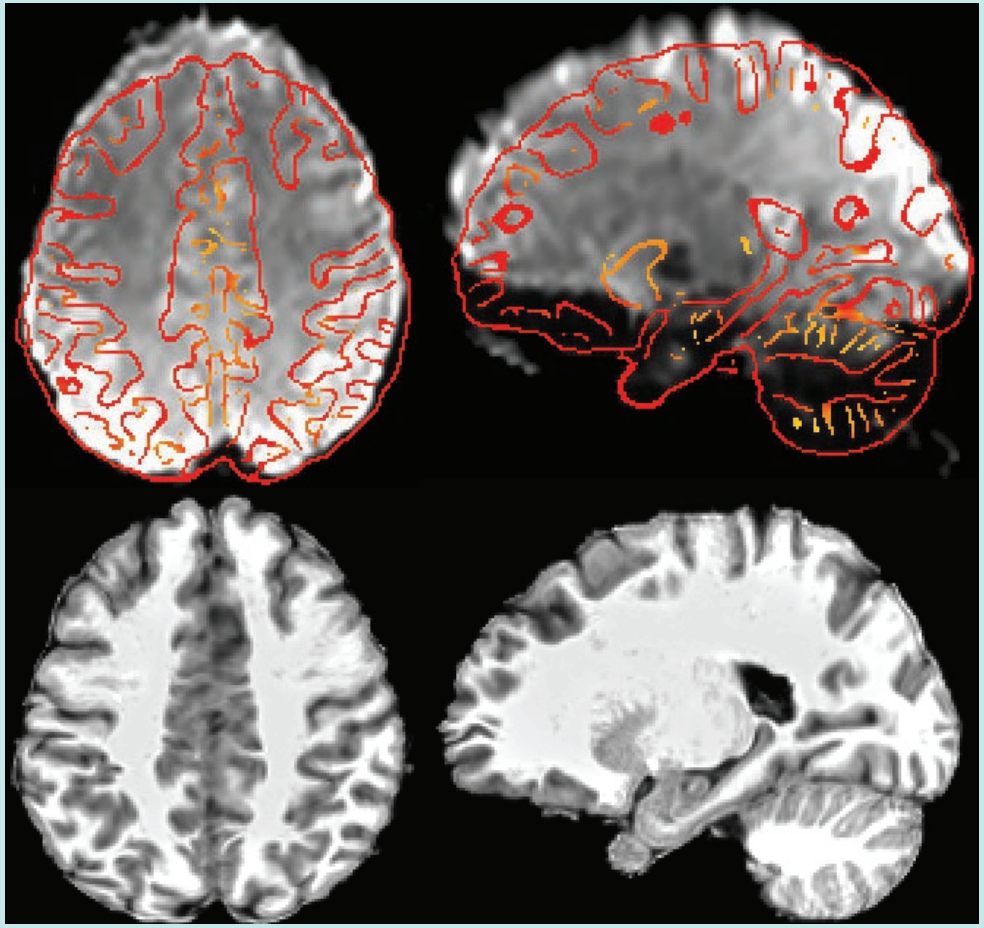
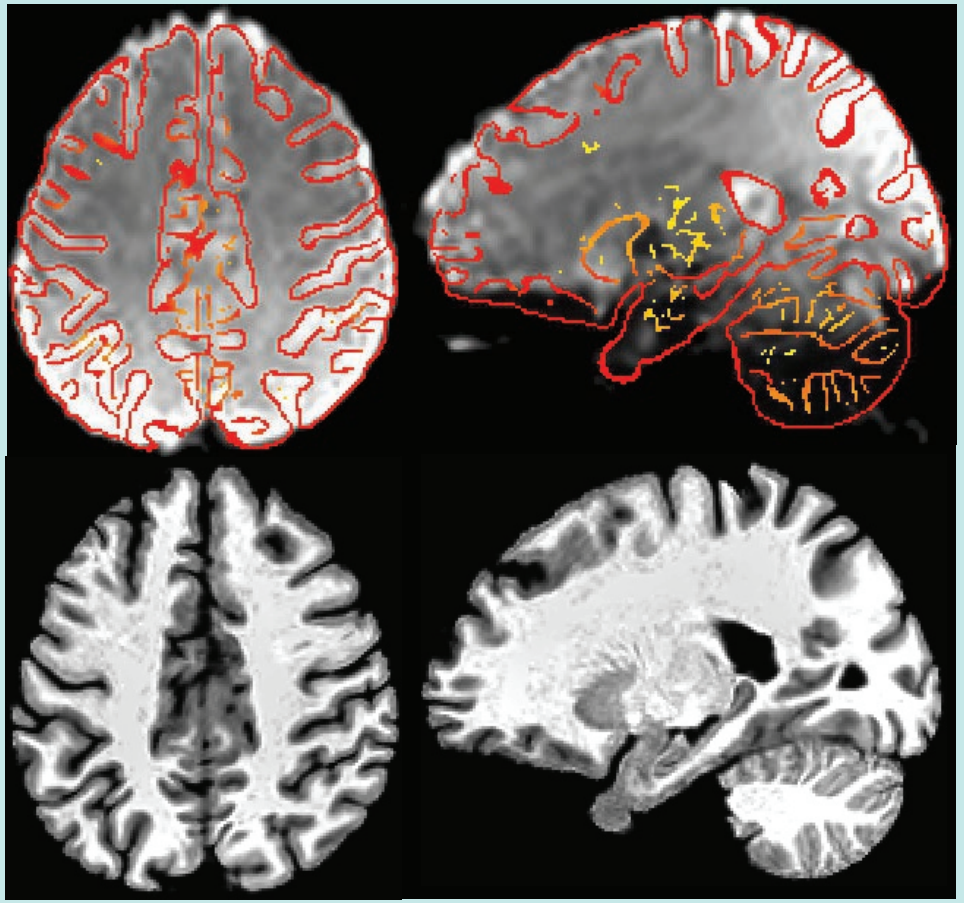
A. Anat & EPI from diff brains



B. Anat & EPI from same brain



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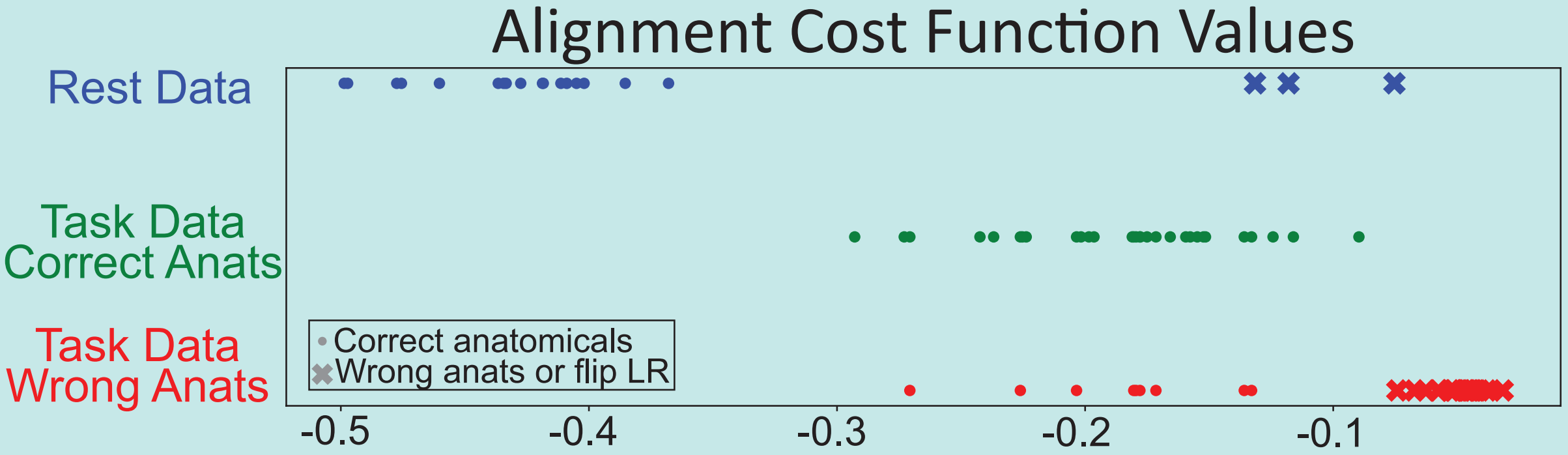
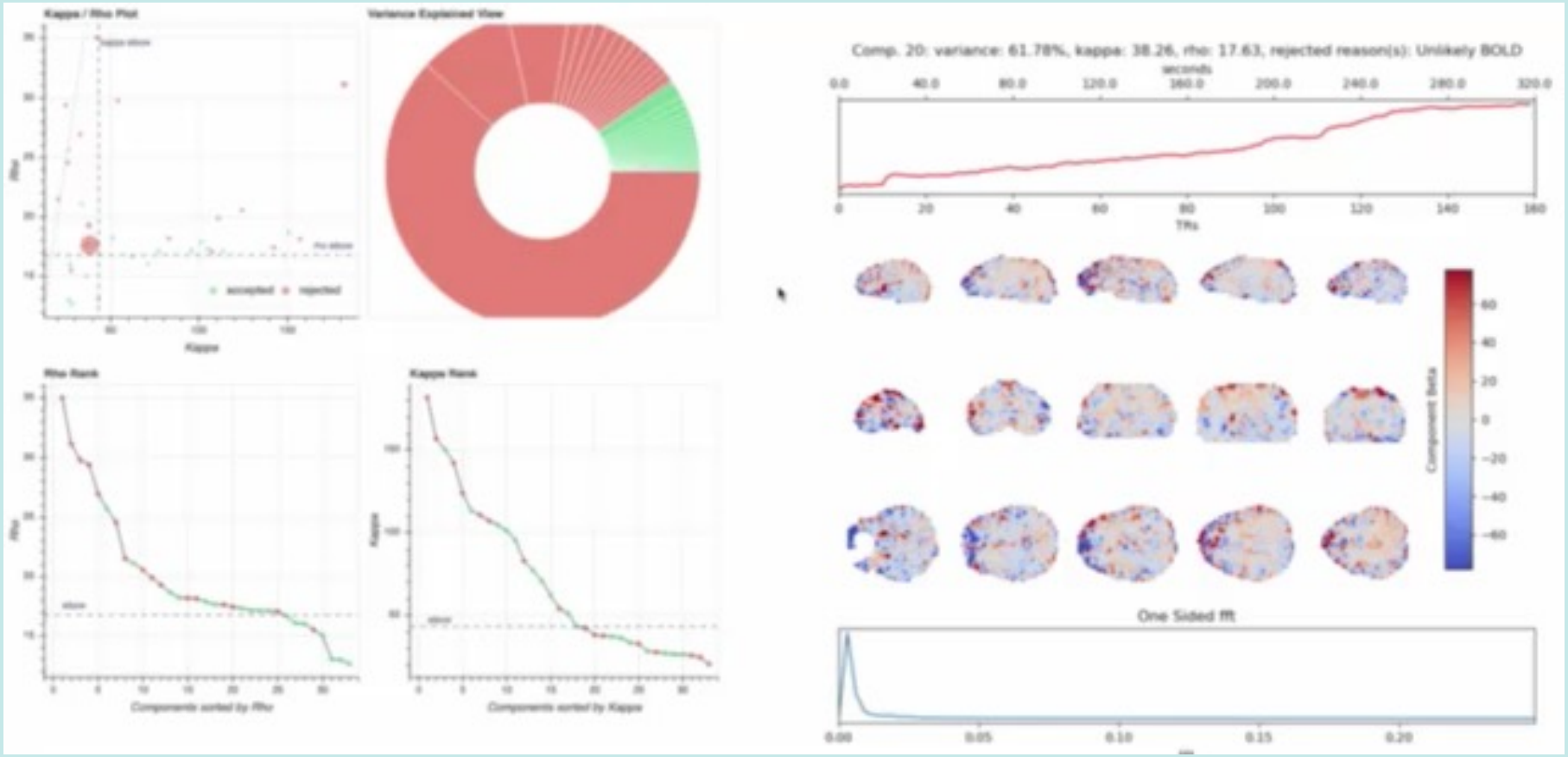
Alignment: QC research is ongoing!



Alignment cost function used to optimize a relative local minimum.

The raw values within a dataset seem to highlight bad alignments

Design QC review in parallel to new methods



tedana.readthedocs.io report for results

Take home messages

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- Care about reproducibility? The quality control process is more important than sample size or thresholding method
- Designing a QC process starts with study planning and includes every step of a study
  - Including & especially for using data collected by others
  - Document QC procedures & results particularly for data sharing
- Automated QC must be paired with human observations and interpretations
  - Where human time is most useful is a growing issue for big N studies
- QC is not just keep vs exclude. It's "What questions can I answer with these data?"
- Training on QC needs more attention
- QC is an active area of research & should be more active

Acknowledgments

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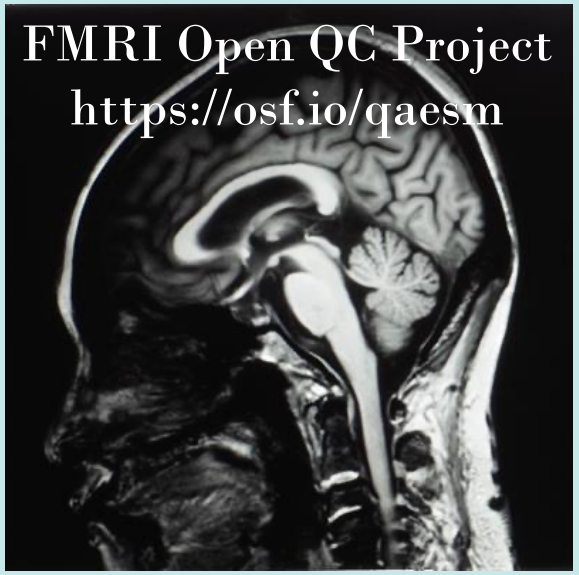
Joshua Teves, Javier Gonzalez-Castillo, Micah Holness, Megan Spurney, Peter Bandettini, Daniel Handwerker
The art and science of using quality control to understand and improve fMRI data
Front. Neurosci. 2023 https://doi.org/10.3389/fnins.2023.1100544



- Paul Taylor
- Daniel Glen
- Tyler Morgan
- Sharif Kronemer

BIOWULF
HIGH PERFORMANCE COMPUTING AT THE NIH

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