Motion Correction in Structural and Diffusion MRI: How has it and how could it help?

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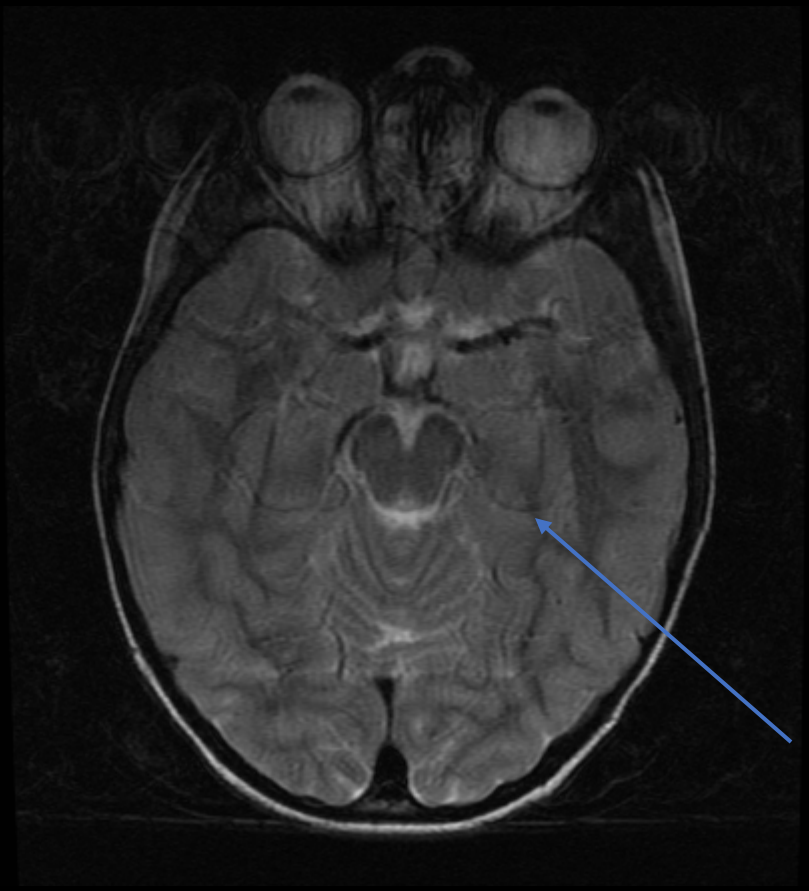
Goals

- Why is motion a problem for MR imaging of the brain? (focus on research imaging vs. clinical)
- What are the characteristics of motion artifacts in MR acquisitions commonly used in research studies?
- How does motion impact extracted parameters?
- What types of motion correction techniques are available?
- How have they helped MR imaging?
- How could they help MR imaging?

Why is motion a problem?

- Research imaging involves analysis of images with software
  - Extracting values (e.g. cortical thickness)
  - Calculating quantitative parameters (e.g. mean diffusivity)
  - Determining group differences
- Research imagining exams are long
  - Small voxels desired
  - Multiple volumes for calculating quantitative parameters
- Research imaging is restricted in use of sedation.

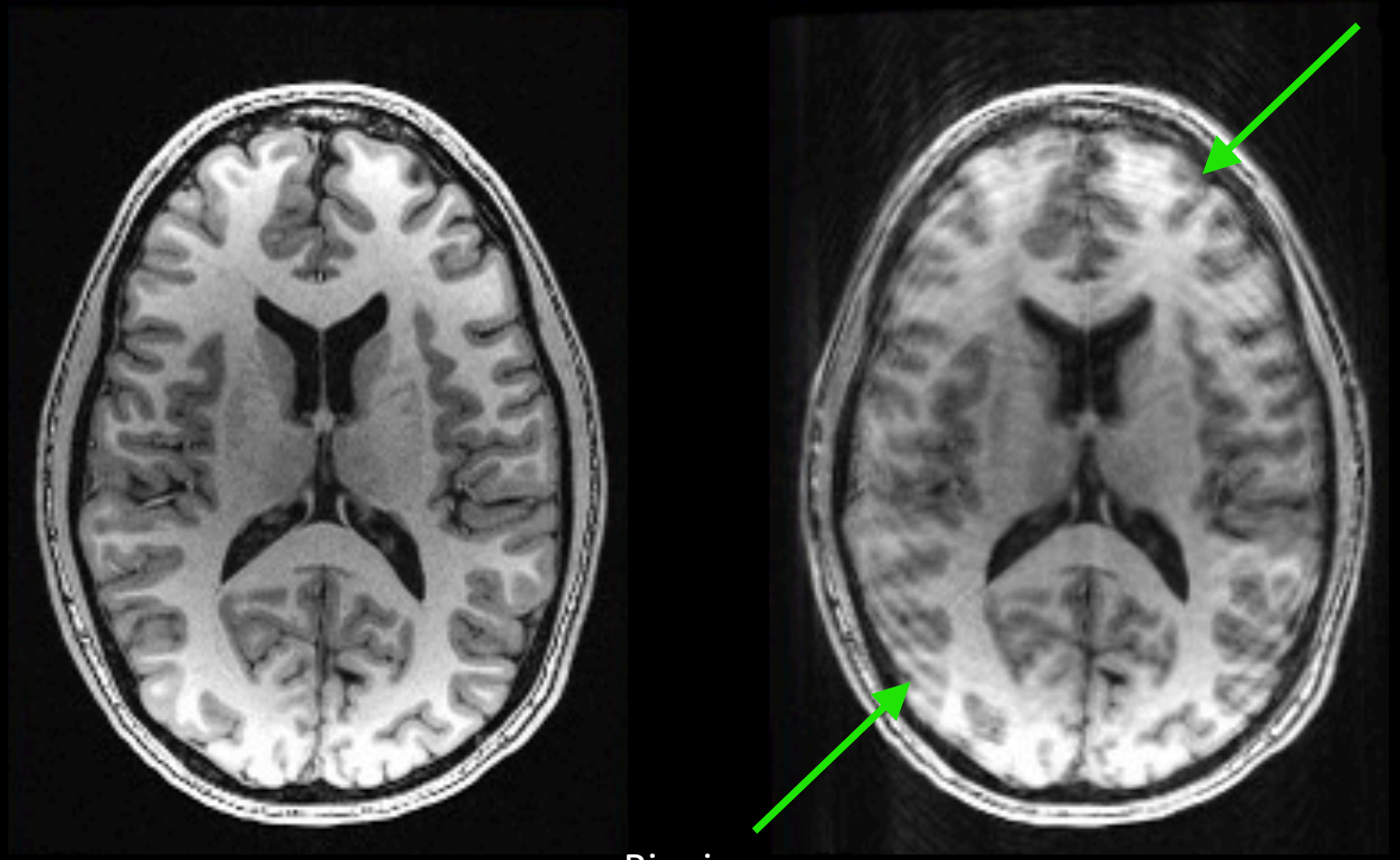
Man vs. Machine

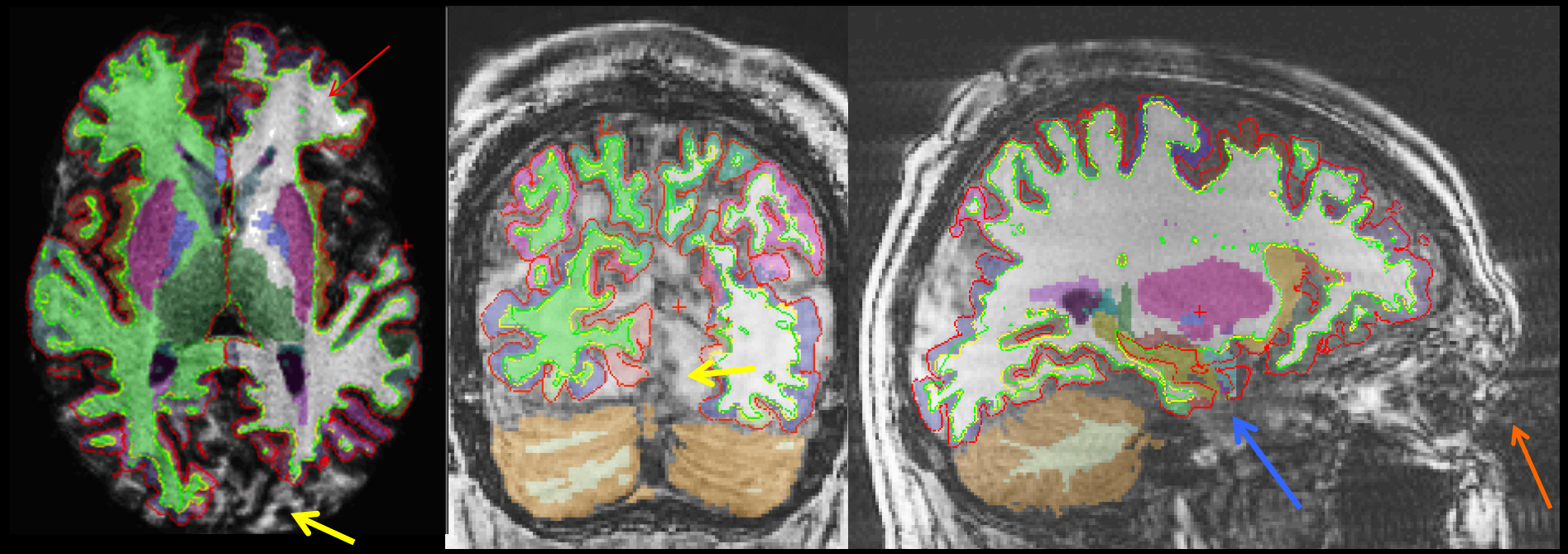


Structural Imaging
Why is motion a problem?

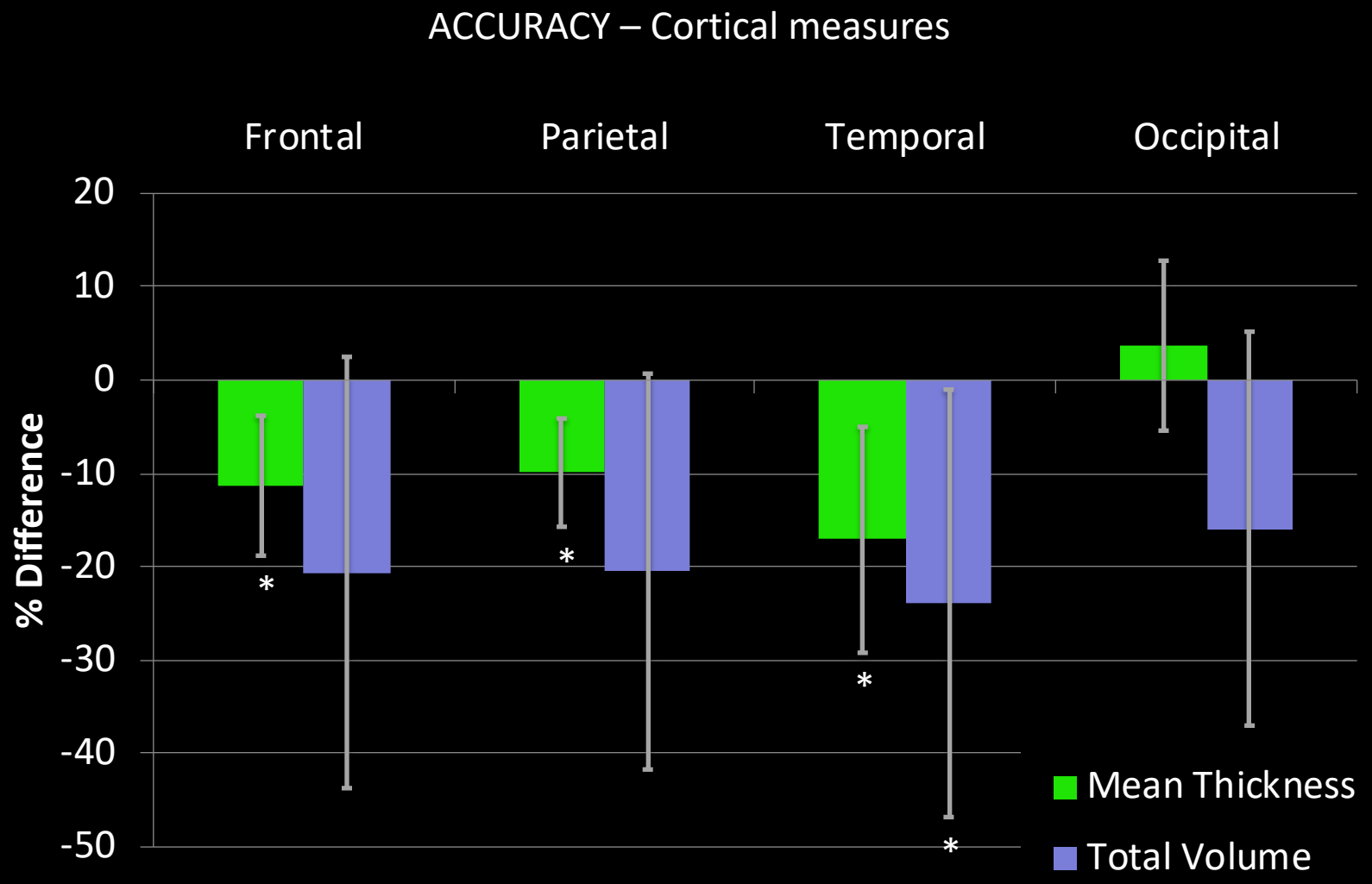
- Morphometry studies typically utilize T1-weighted MRI (MPRAGE or FLASH)
  - High resolution (more precise measure)
    - ➢ Long scan times
  - 3D (for greater SNR)
    - ➢ All the k-space data is used to reconstruct every voxel
- Morphometry measures are based on automated tissue segmentation
  - Requires high gray/white matter contrast needed and sharp boundaries

What does motion look like?



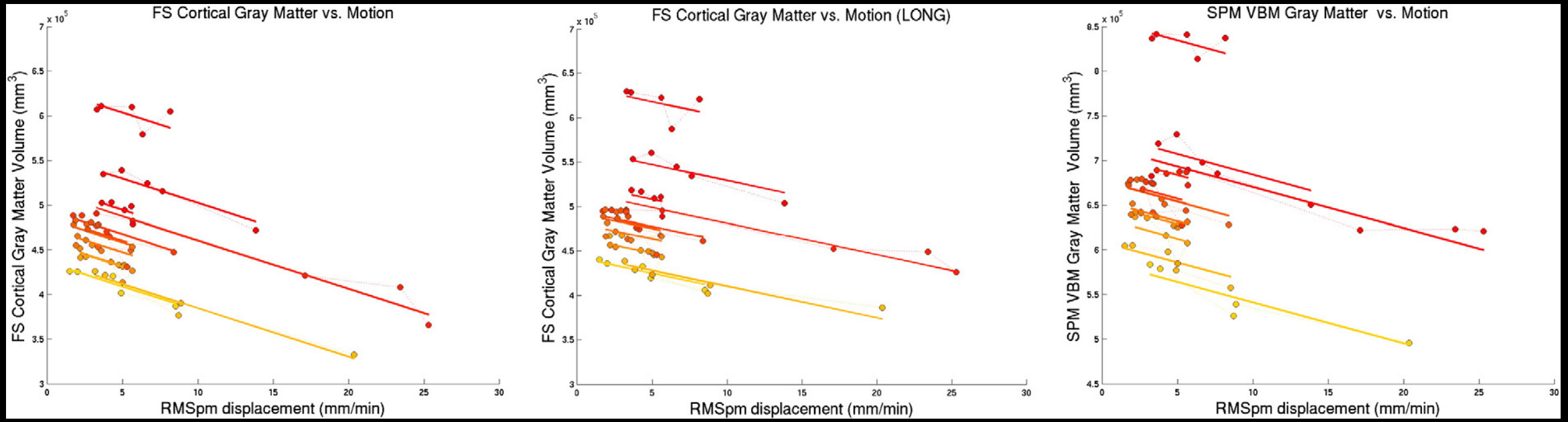


How does motion impact results?

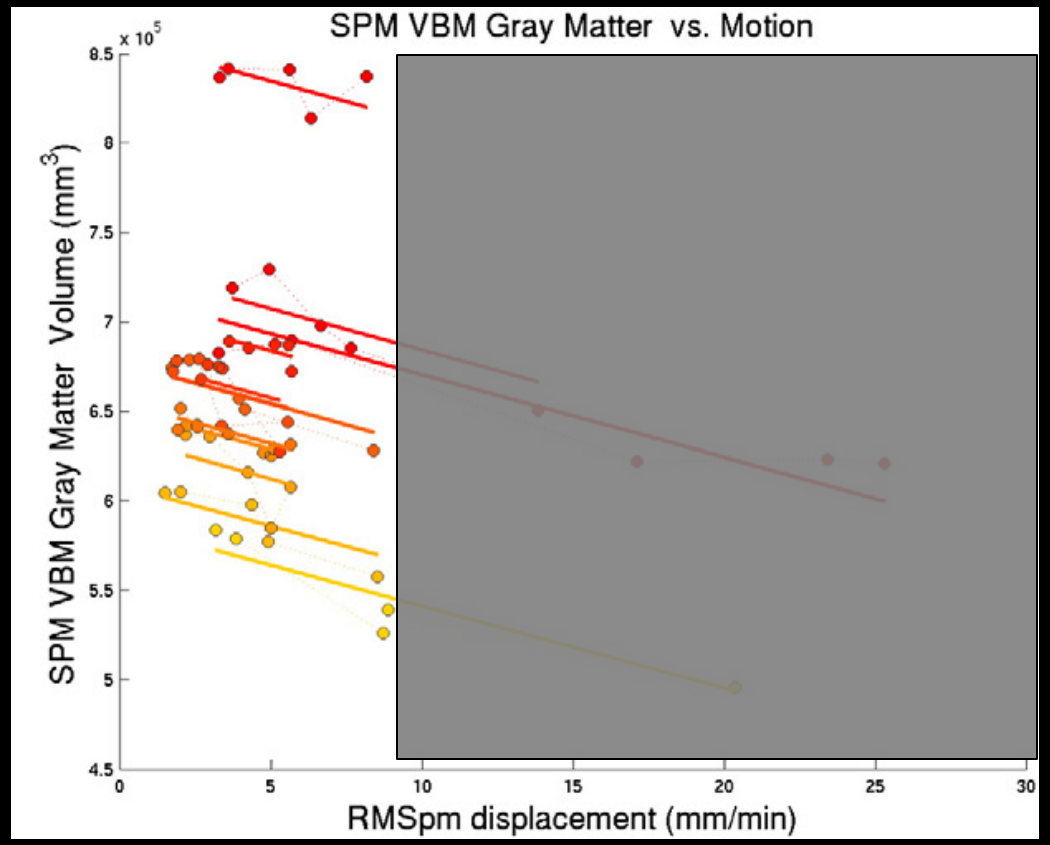


Sarlls et. al. PLOS1 2018; doi: 10.1371/journal.pone.0199372

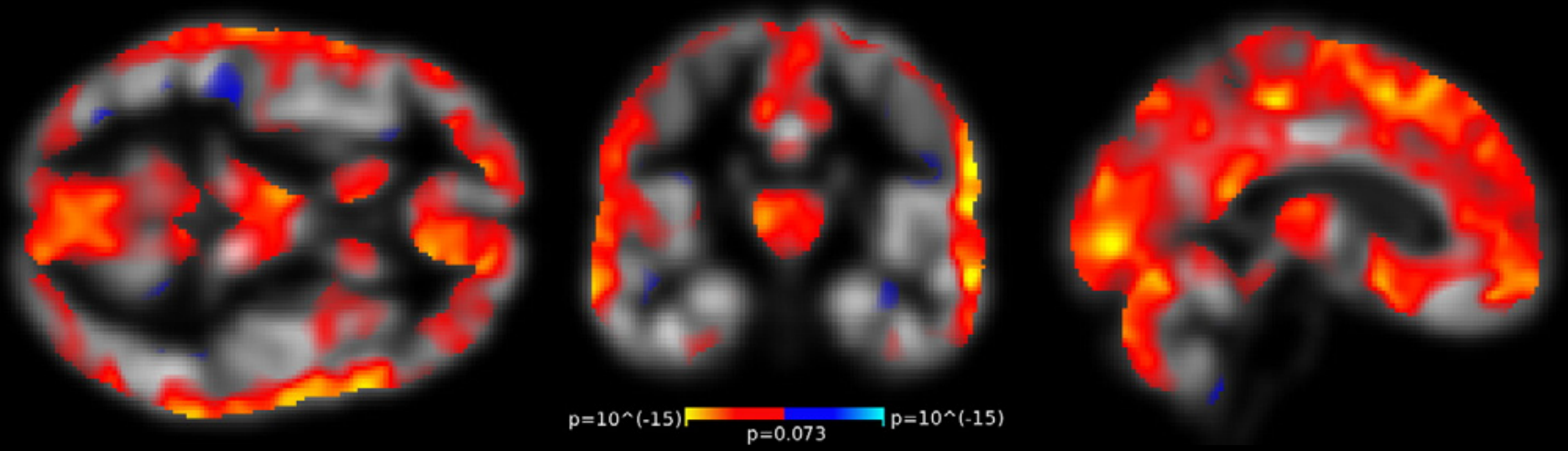
Correlation – Cortical Volume



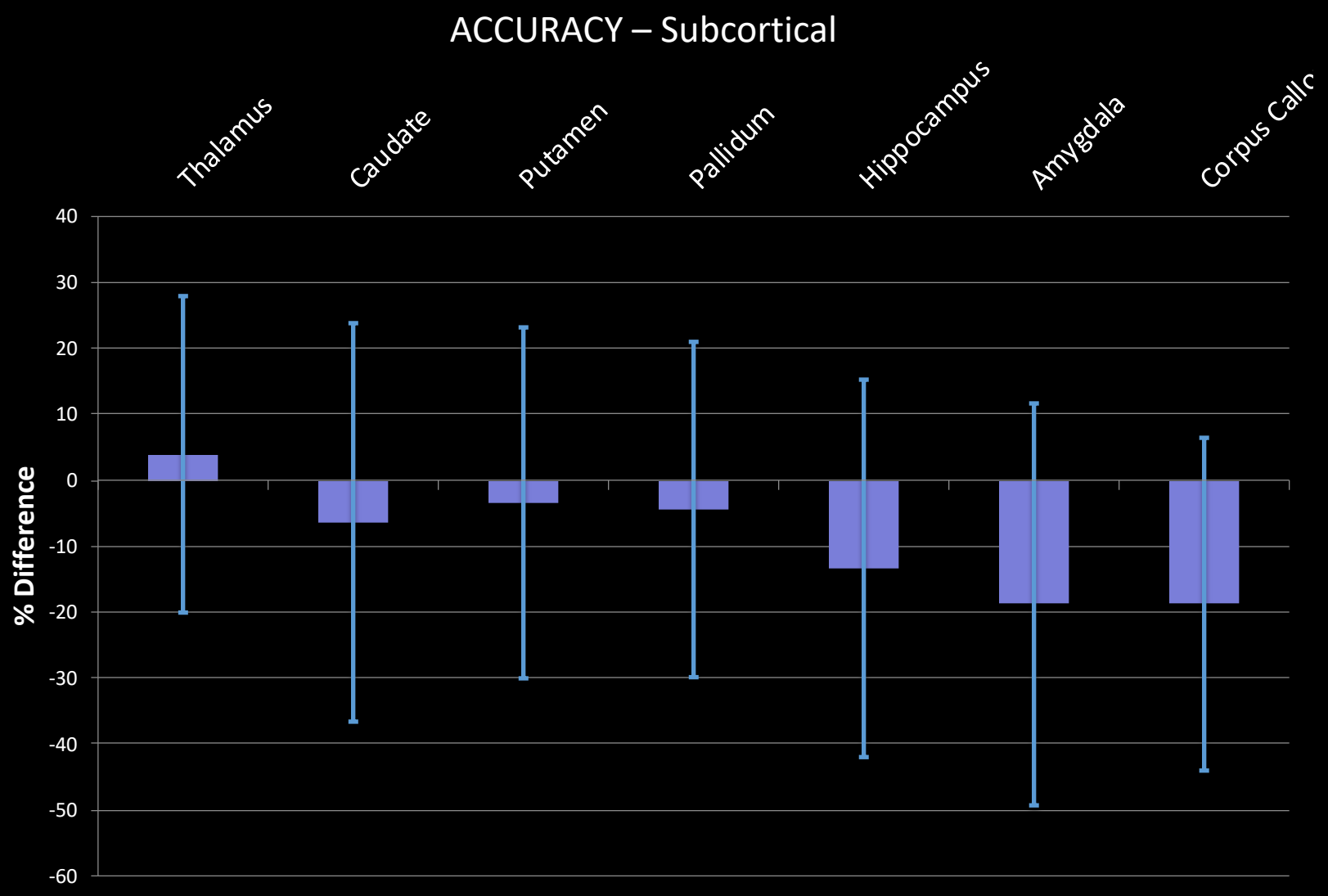
Reuter and Tisdall et. al. NeuroImage 2015; 107:107-115


SPM VBM Gray Matter vs. Motion
x 10^5
8.5
8
7.5
7
6.5
6
5.5
5
4.5
SPM VBM Gray Matter Volume (mm^3)
0
5
10
15
20
25
30
RMSpm displacement (mm/min)

Correlation remains after standard QC



Reuter and Tisdall et. al. NeuroImage 2015; 107:107-115



Sarlls et. al. PLOS1 2018; doi: 10.1371/journal.pone.0199372

Motion Correction Techniques

- Physically Restricting
  - Bite bar
  - Headcase

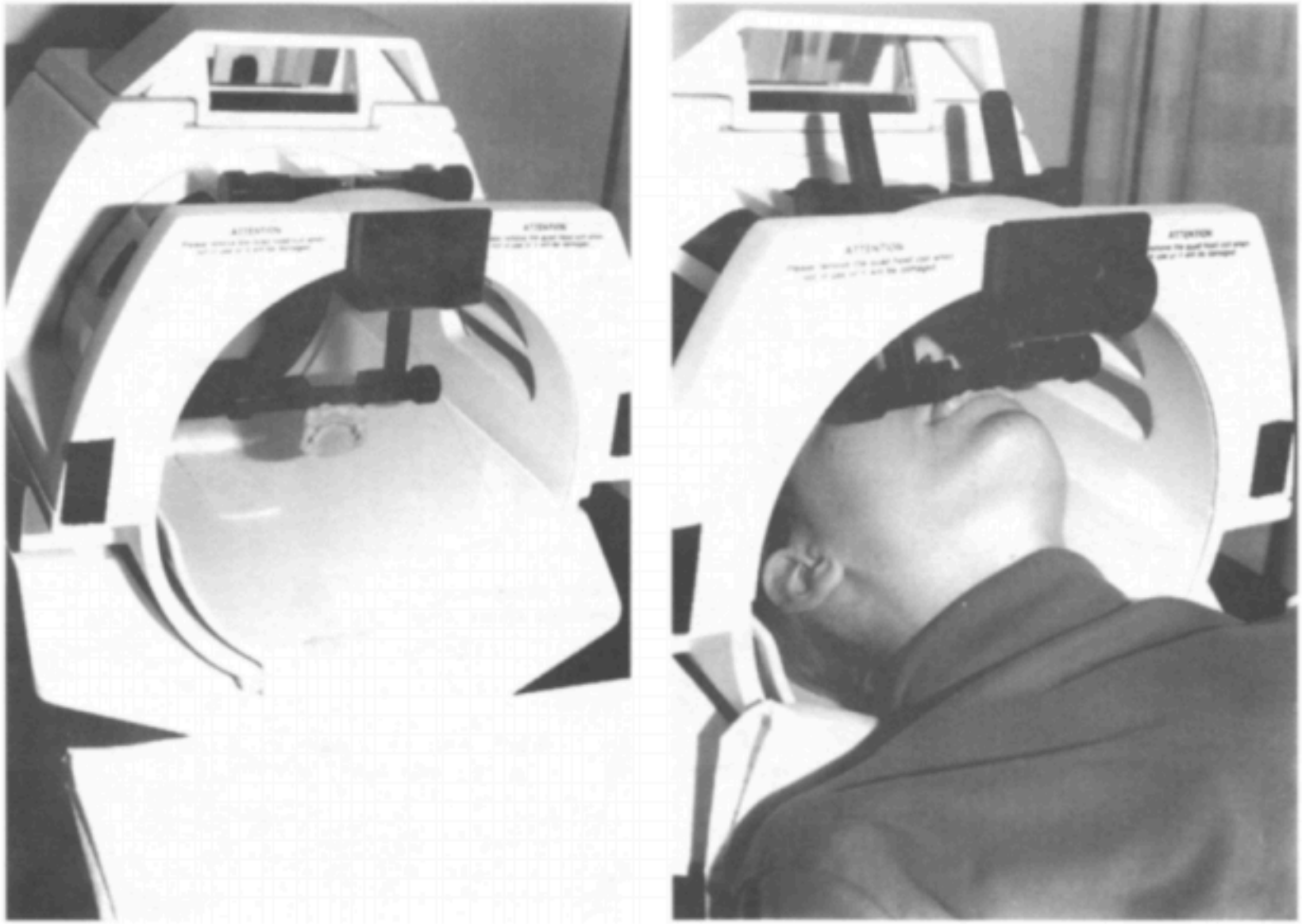
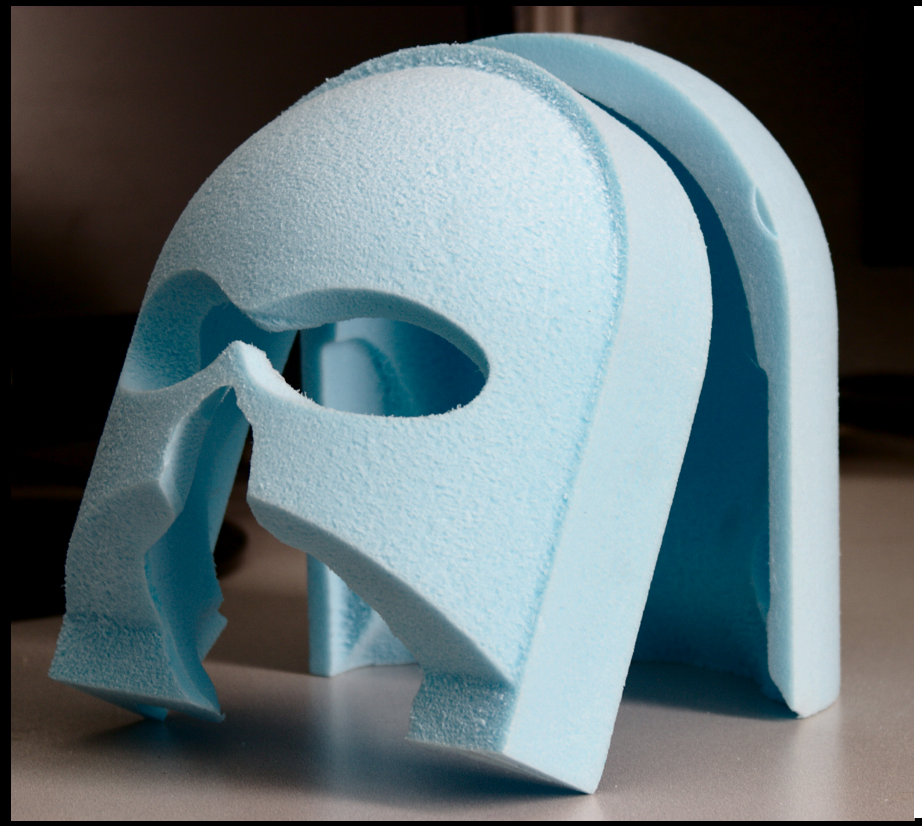
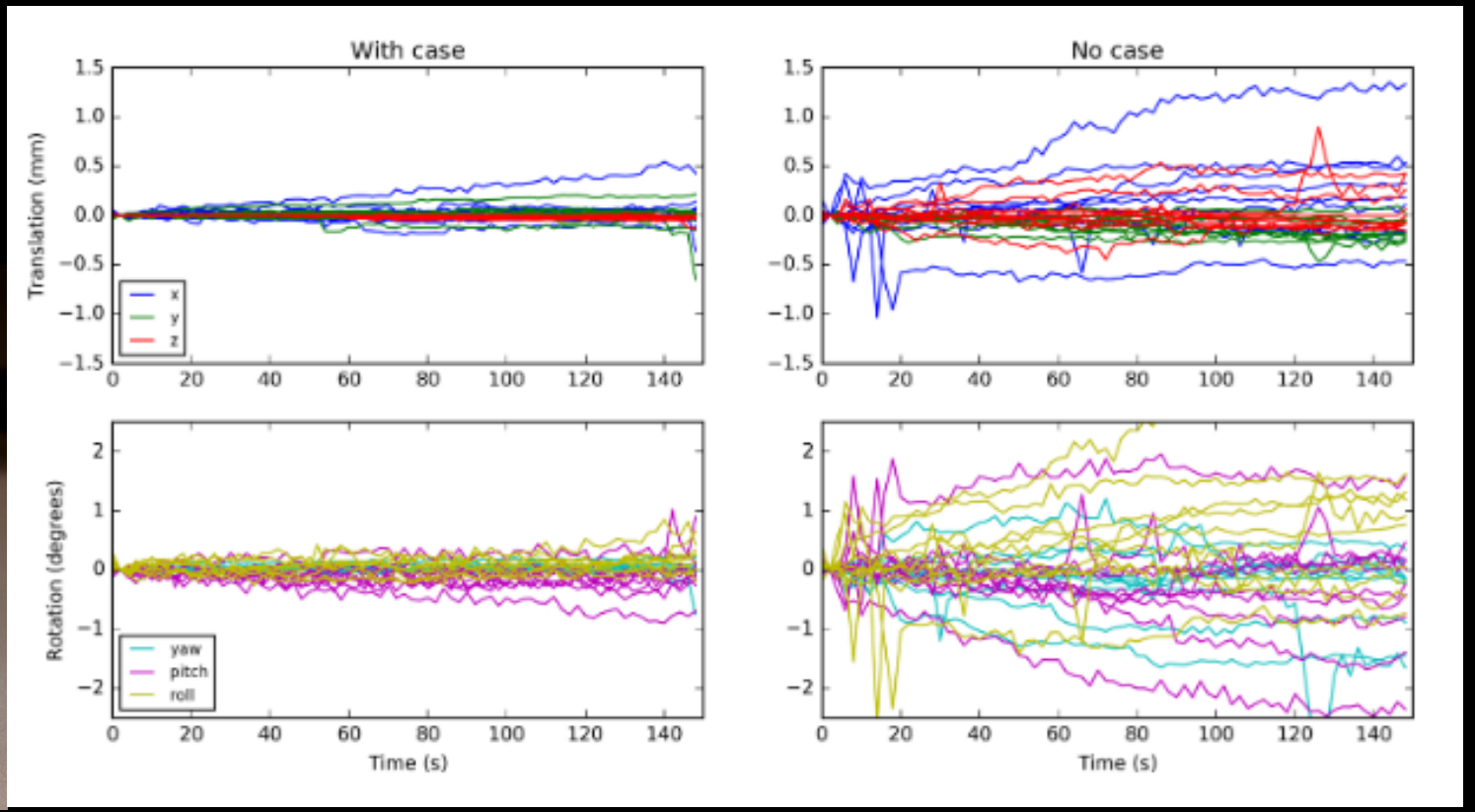


Figure 4. Left: The bite-bar holder clamped to the head coil. The bite bar with the subject's dental impression is attached to the frame of the holder with the two slotted mounting bars. Right: View of a subject biting on bar in the head coil.

Caseforge



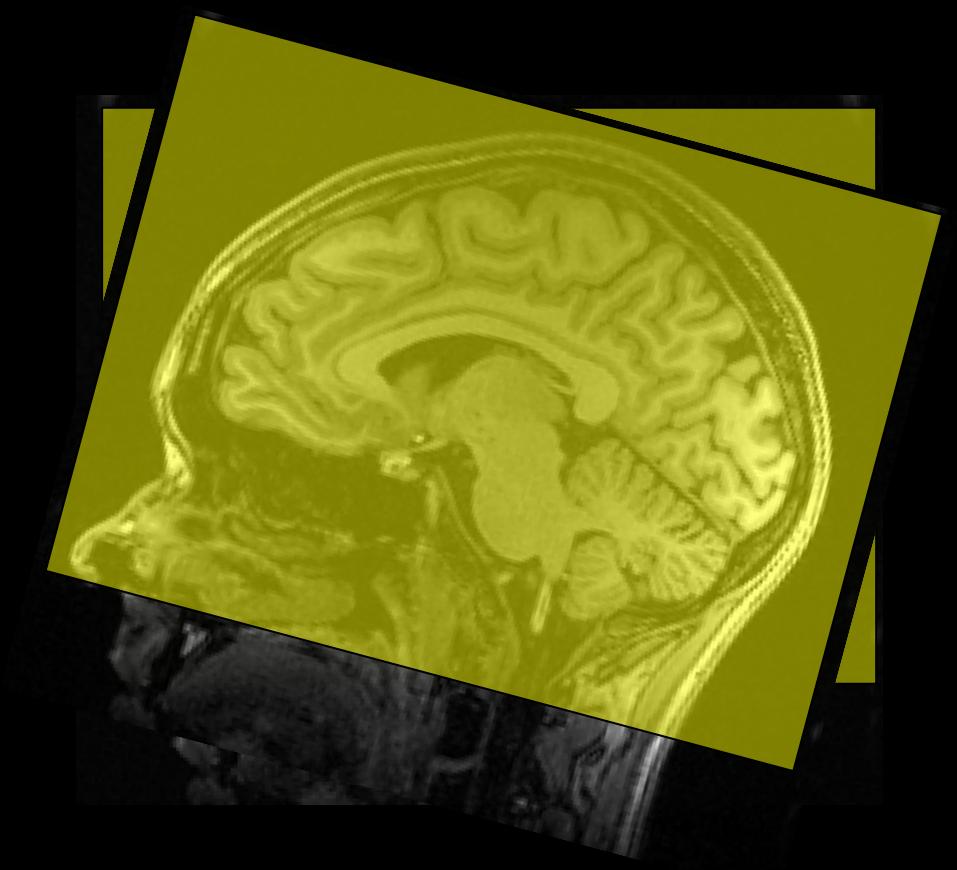


https://caseforge.co

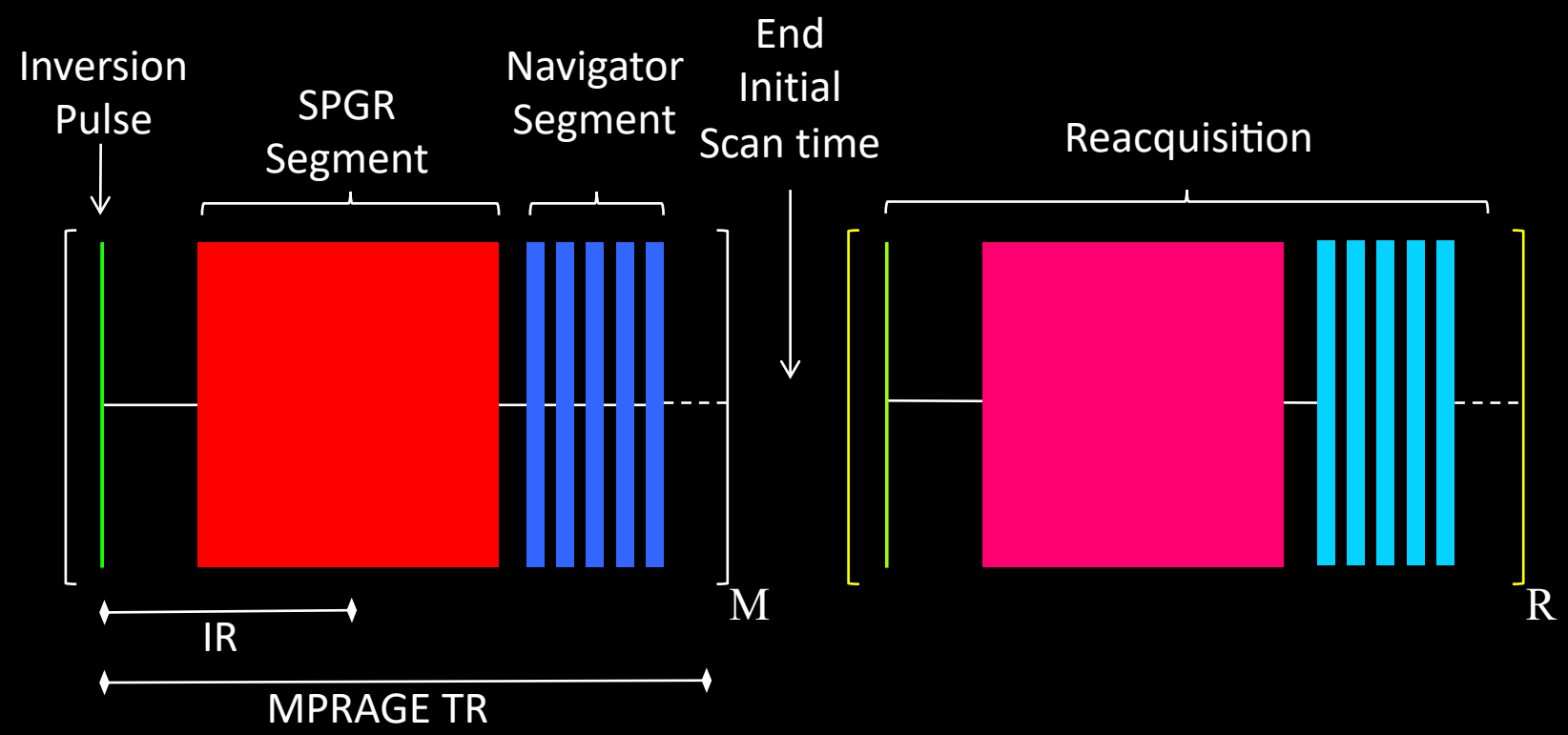
Motion Correction Techniques

- Physically Restricting
  - Bite bar
  - Headcase
- Prospective Motion Correction
  - MRI Navigators
  - Optical tracking

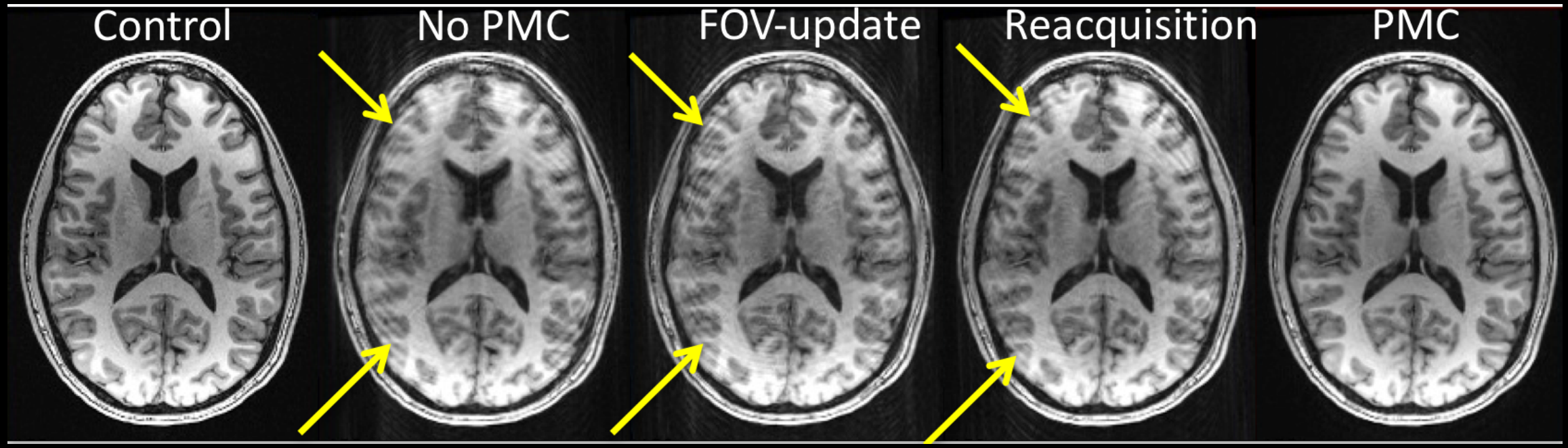
Prospective Motion Correction



Prospective Motion Correction - Navigators

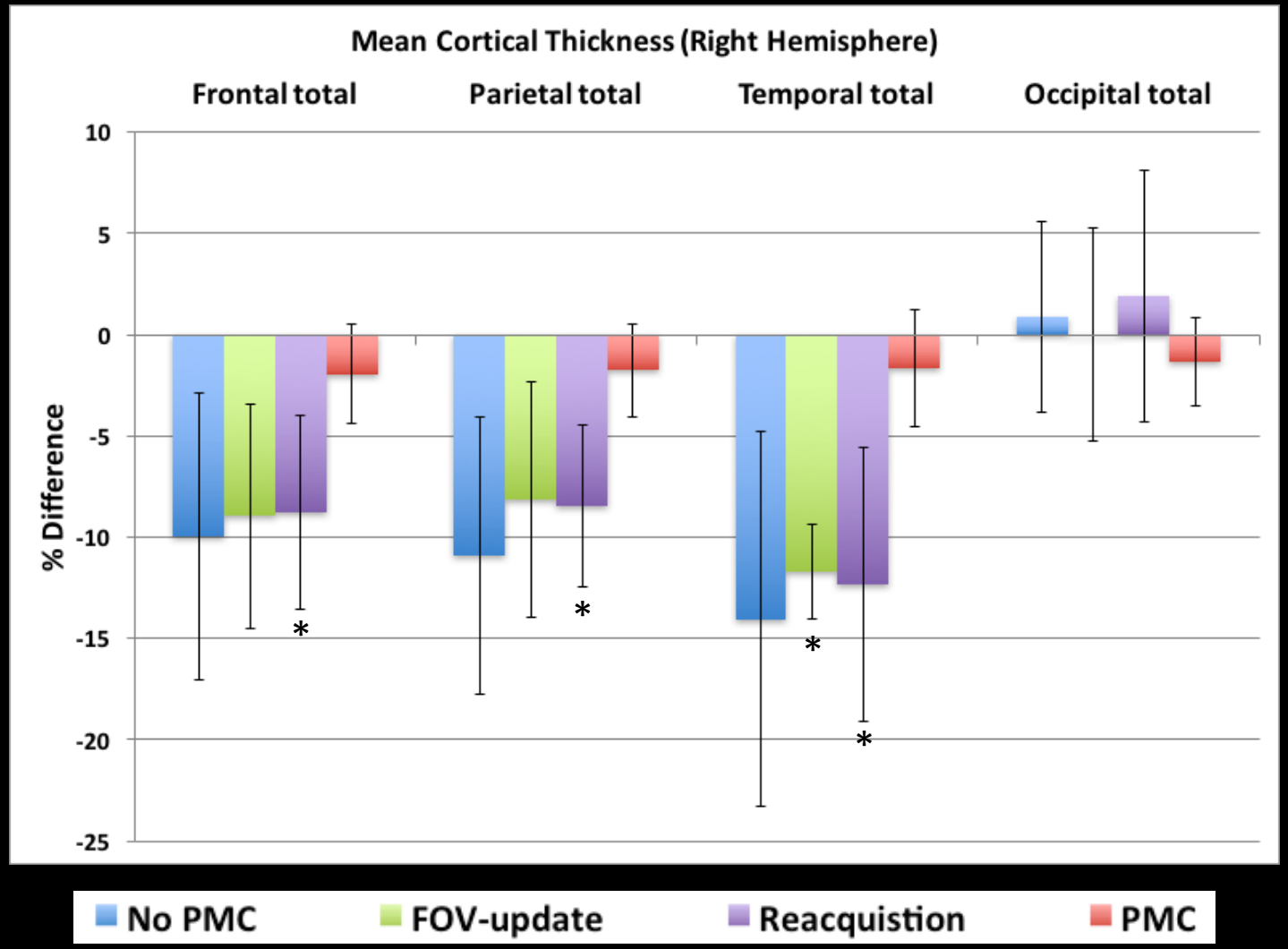


Prospective Motion Correction (PMC)

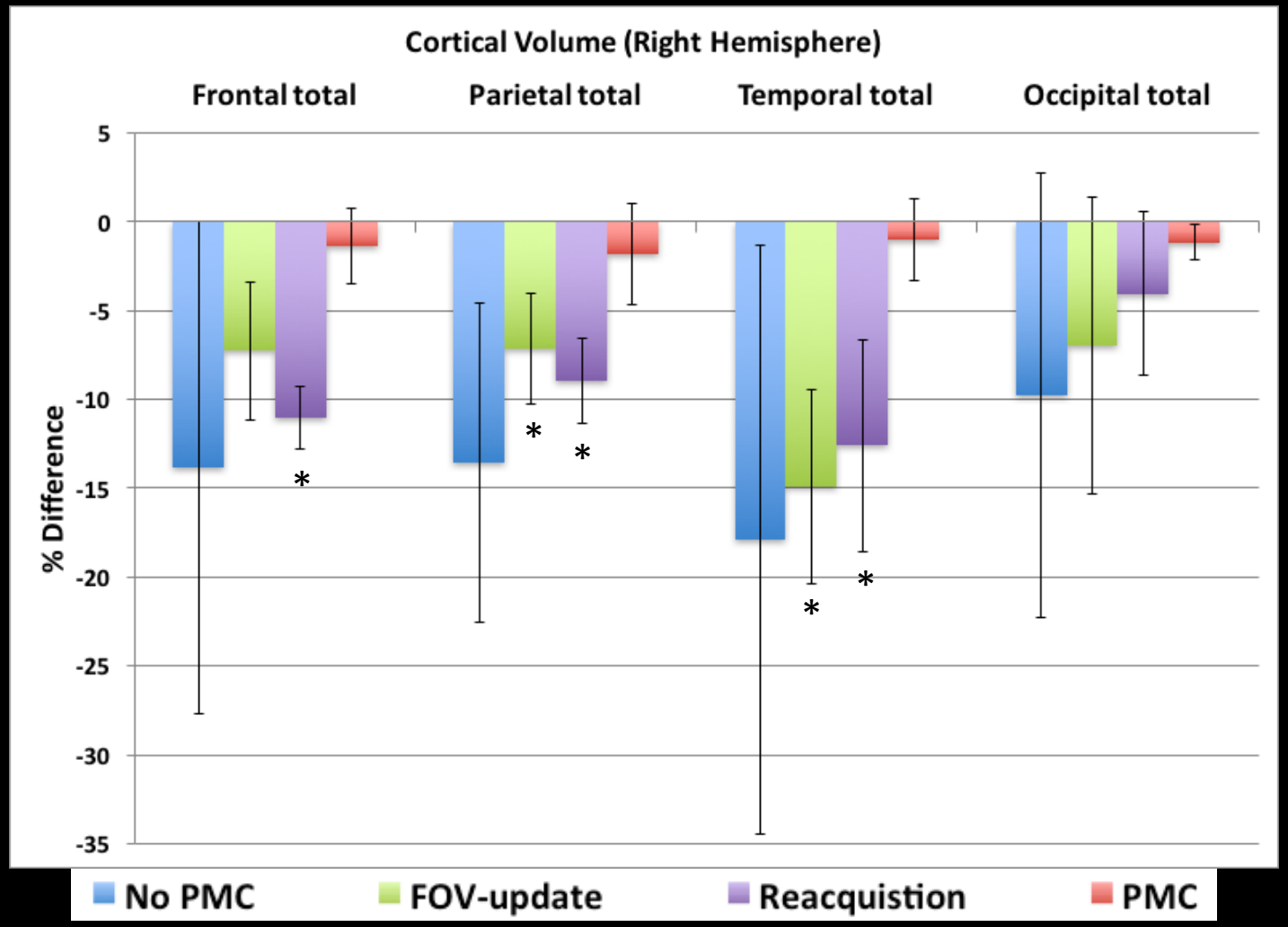


Sarlls et. al. PLOS1 2018; doi: 10.1371/journal.pone.0199372

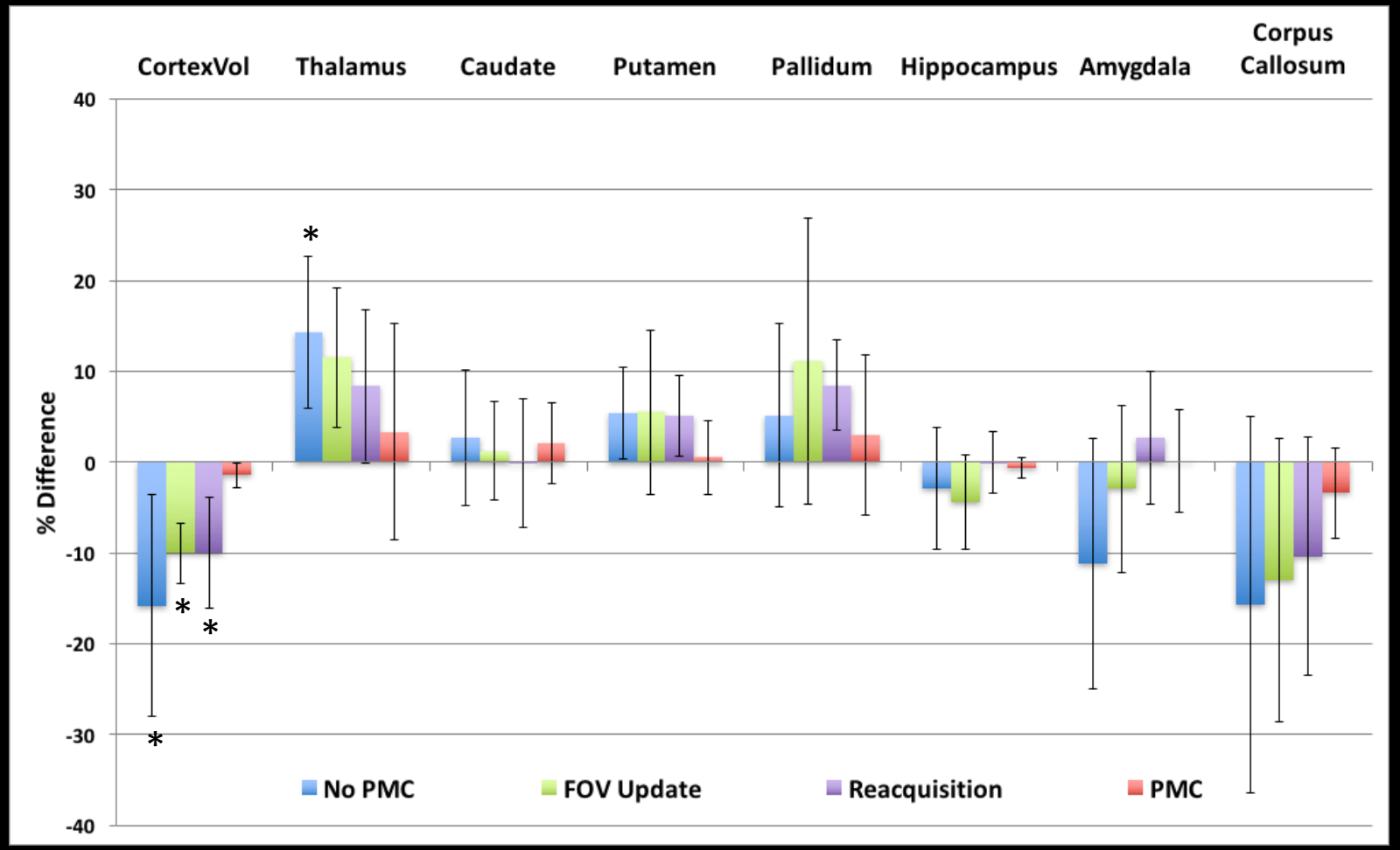
ACCURACY – Cortical thickness

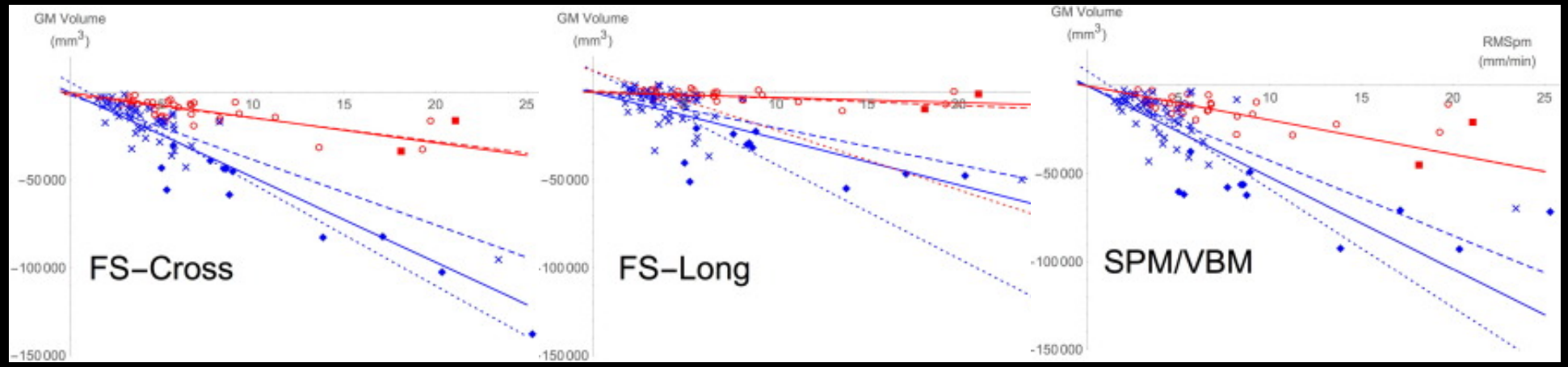


ACCURACY – Cortical volume



ACCURACY – Subcortical volume



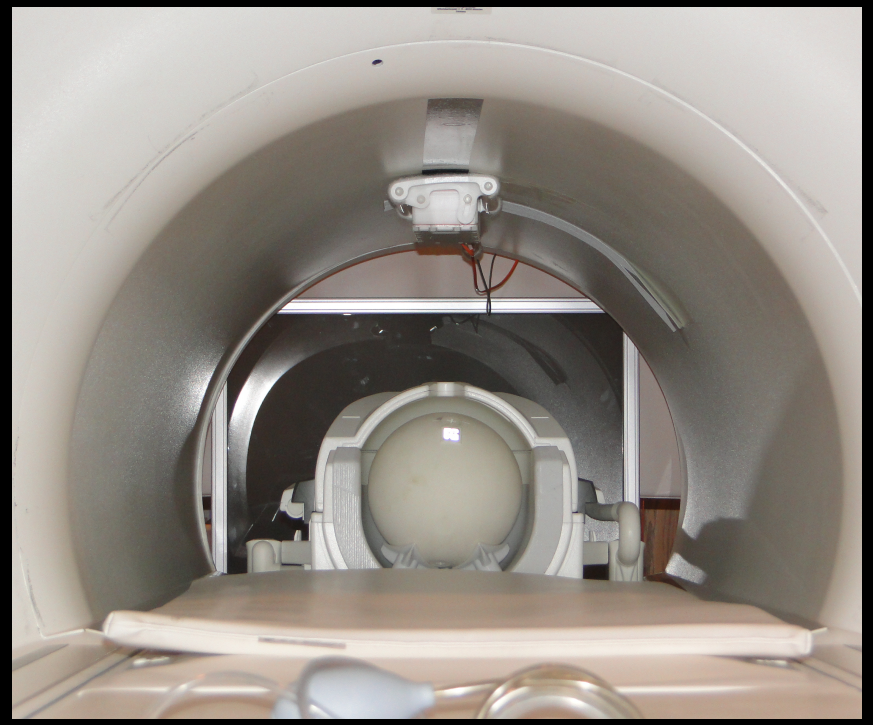


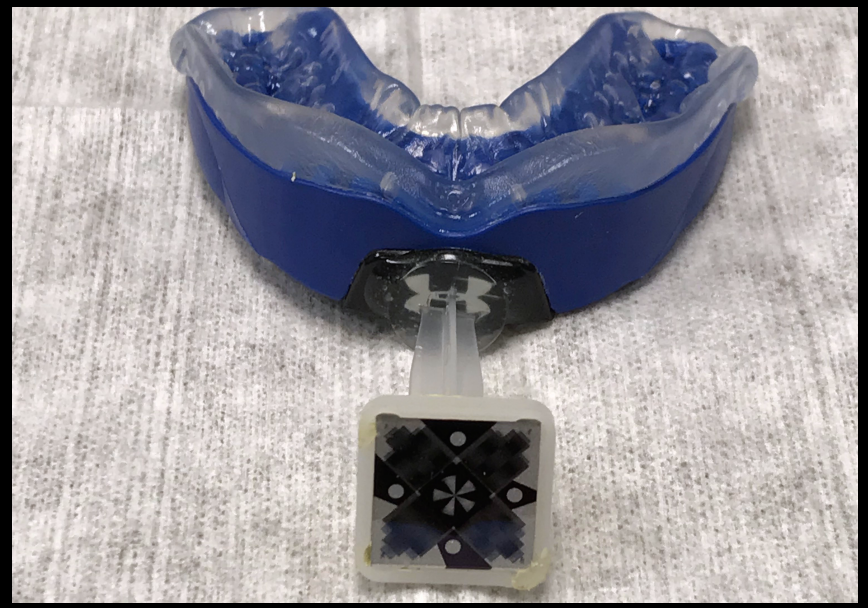
	Failed QC	Pass QC	Full data	QC filtered	Motion filtered
No PMC	■	✖	—	– –	·–
PMC	◆	○	—	– –	·–

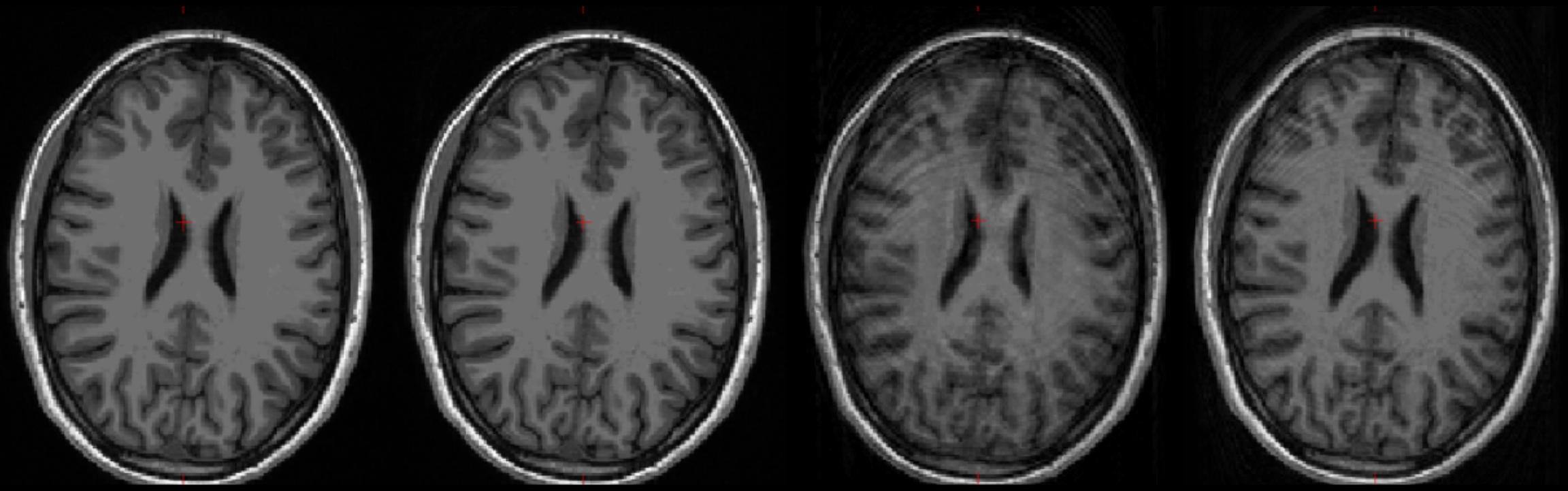
Tisdall and Reuter et. al. NeuroImage 2016; 127:11-22

Prospective Motion Correction - Optical

- Camera mounted in the bore with processing unit
- Marker on subject that's visible by camera
- Motion parameters generated by camera system are captured by scanner and used to update the FOV before acquisition of each k-space line
- Real-time updates with ~20 ms lag time







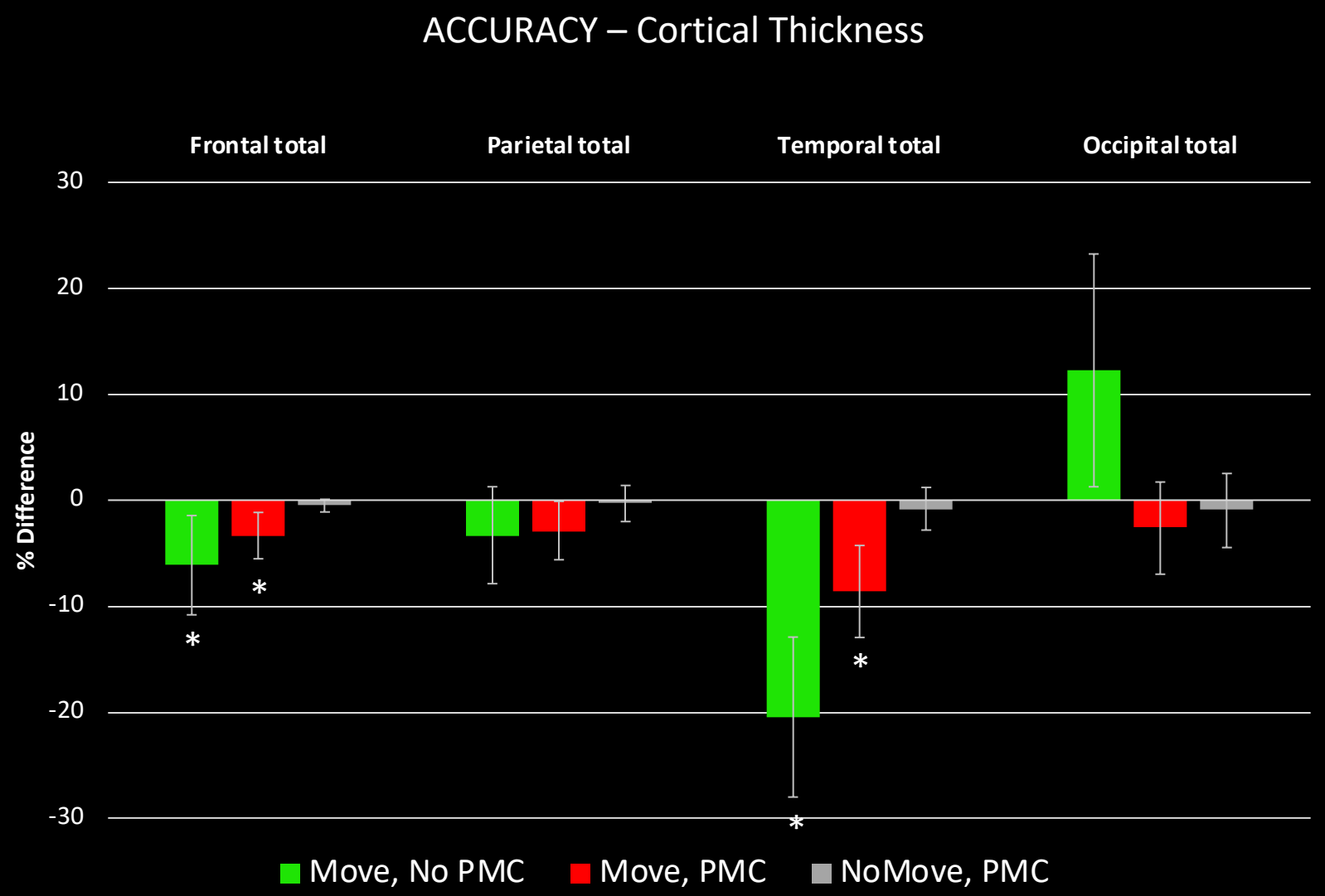
No Move, No PMC (Control)

No Move, PMC

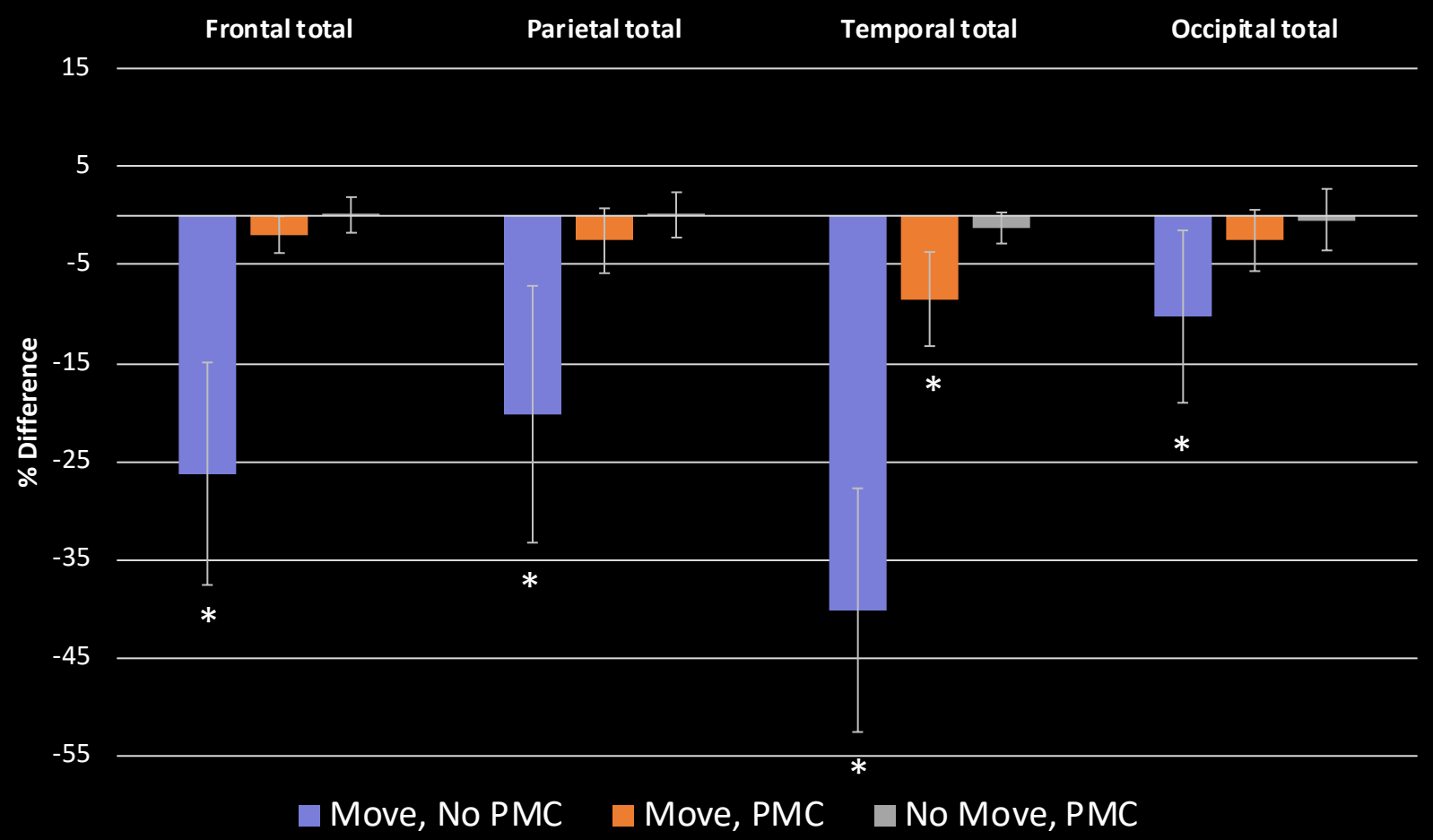
Move, No PMC

Move, PMC

Sarlls et. al. ISMRM 2018; p. 3245


ACCURACY – Cortical Thickness
Frontal total
Parietal total
Temporal total
Occipital total
30
20
10
0
-10
-20
-30
% Difference
*
*
*
*
Move, No PMC
Move, PMC
NoMove, PMC

ACCURACY – Cortical volume



Ultra High-resolution Structural Imaging

- Very long scan times, up to hours
- Requires PMC, even for cooperative subjects
- Movement from breathing greater than voxel dimensions
- Movements are slow
- Cannot be navigator based
  - Temporal resolution too low
  - Long readouts require updates per k-space line

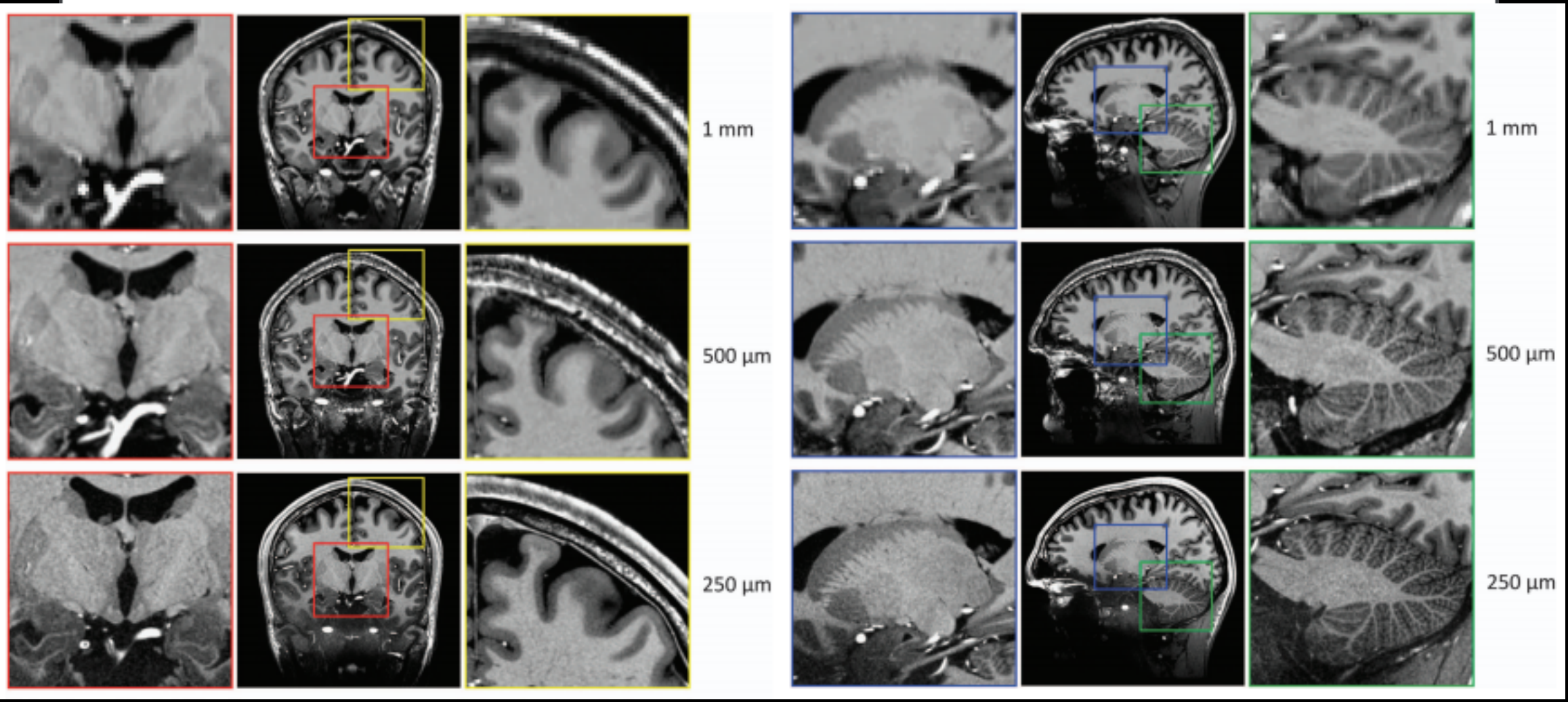
0.6 mm MPRAGE at 3T in 33 minutes

No PMC

PMC

0.25 mm MPRAGE at 7T in 7 hours

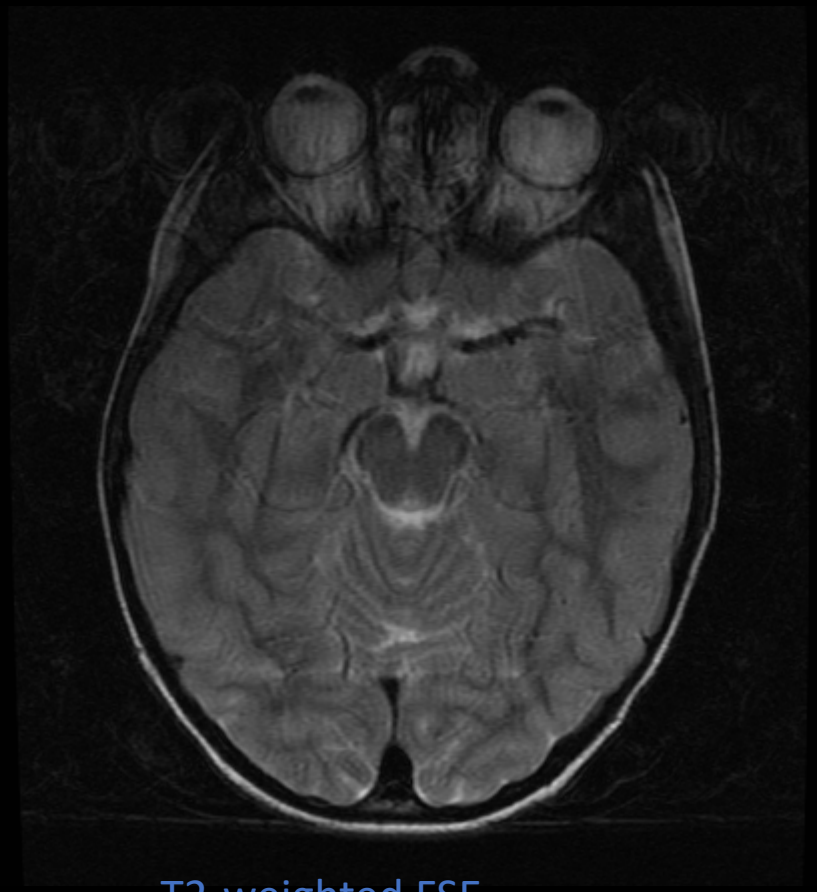
www.nature.com/scientificdata



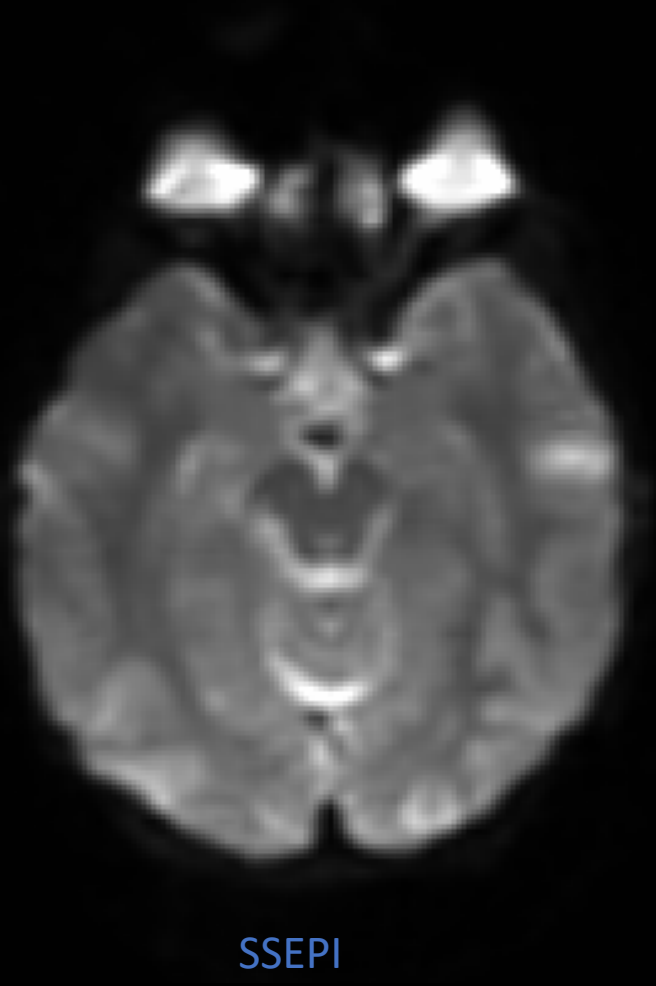
Diffusion-weighted Imaging
Why is motion a problem?

- DWI contrast comes from microscopic random motion of water
  - Sensitive to macroscopic motion
  - Measured as change in intensity
- Utilizes large amplitude and long duration diffusion gradients
  - Head rotation induces additional gradient moment
- Multiple volumes required
  - Long scan times

Single-Shot EPI

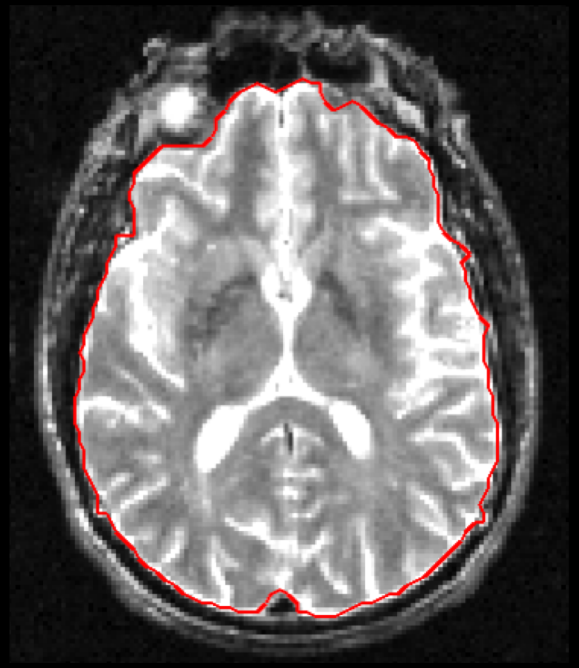


T2-weighted FSE

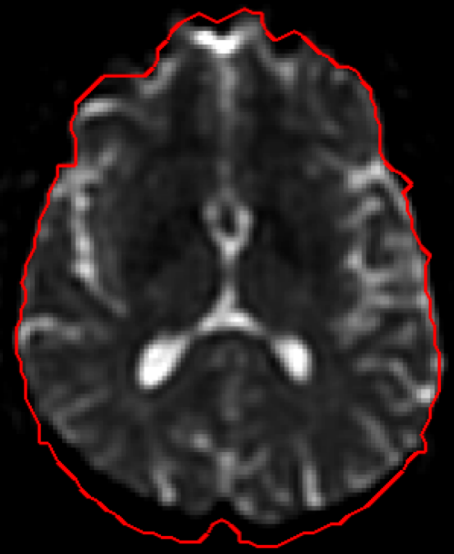


SSEPI

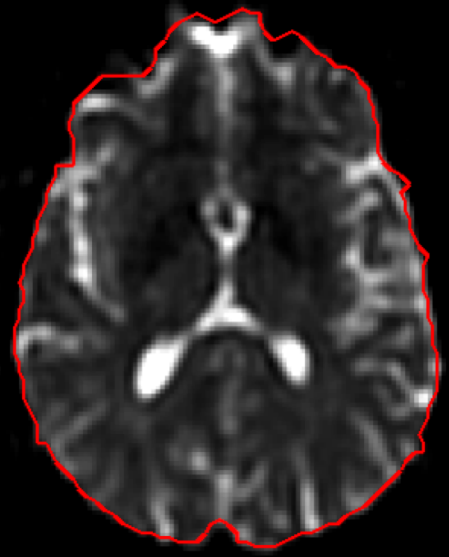
CON: Distortions from field inhomogeneities



T2-weighted
FSE

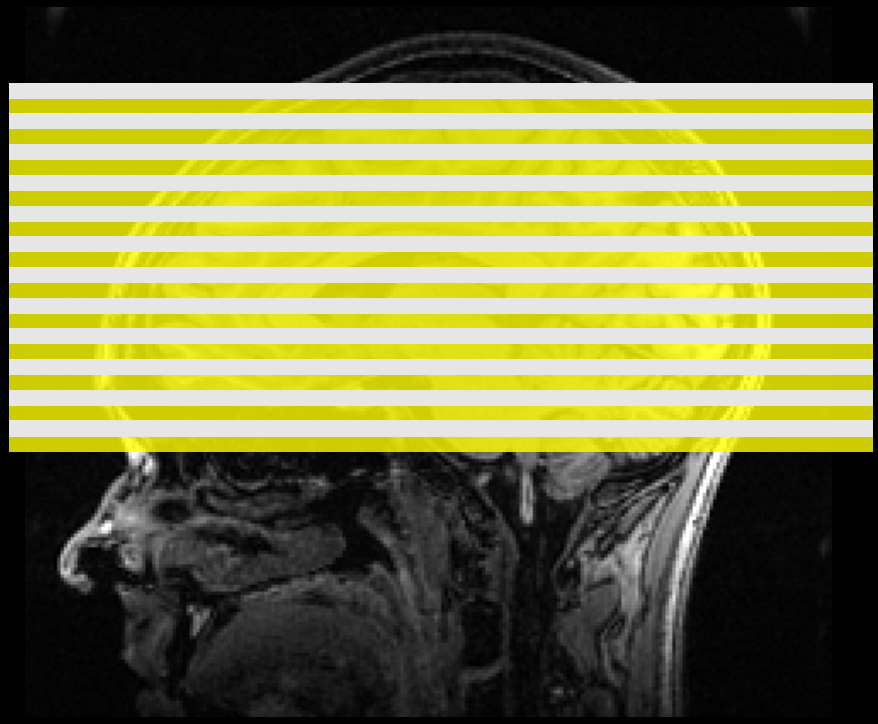


SSEPI



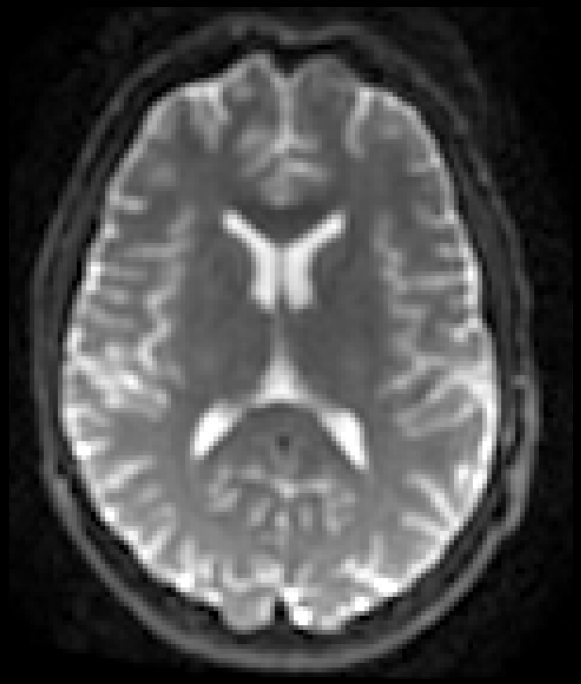
SSEPI
corrected

Interleaved Slice Acquisition

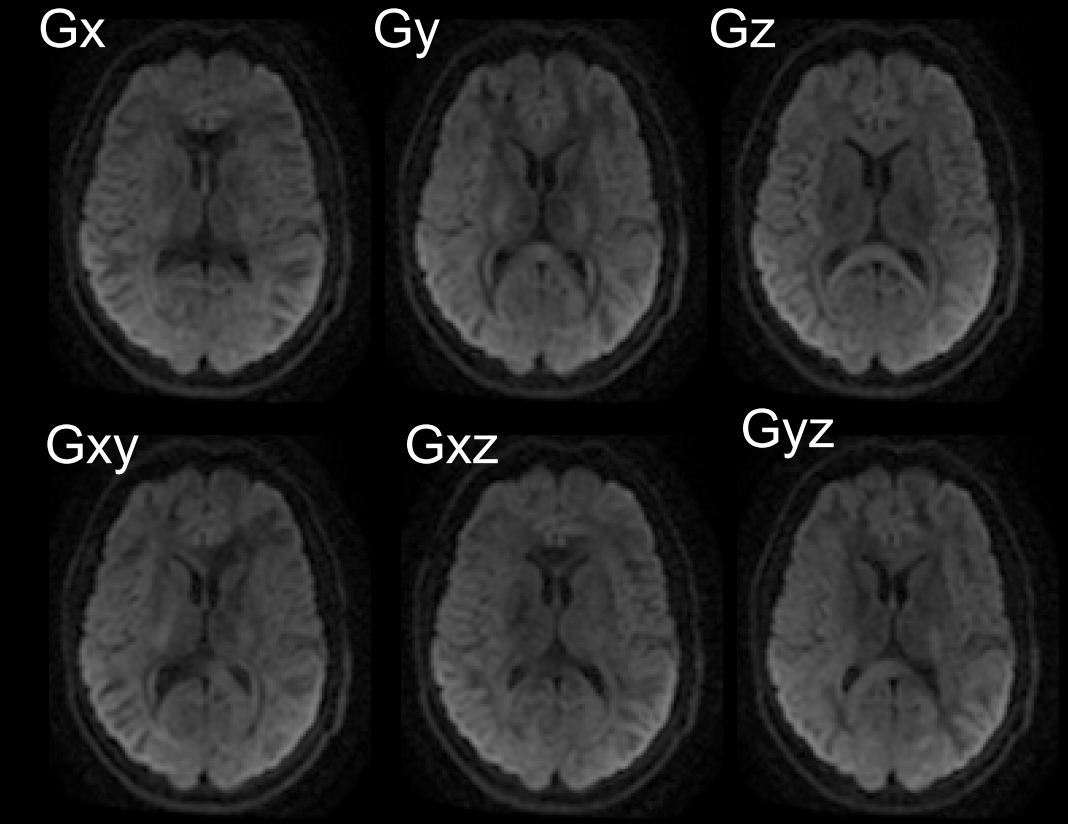


Interleaved Slice Acquisition

DTI



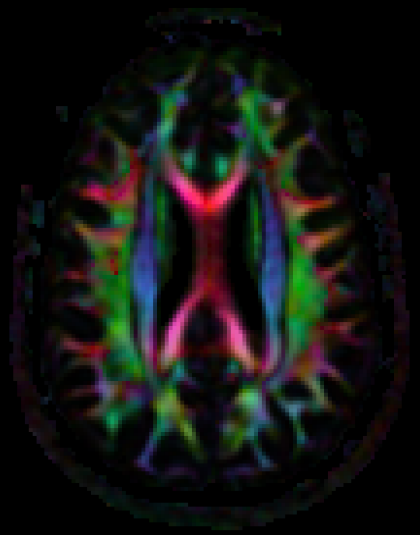
b = 0 s/mm^2



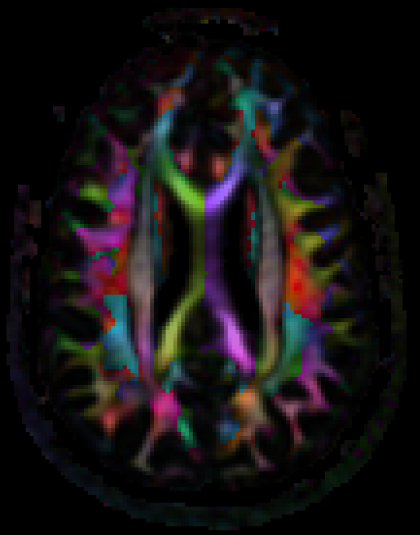
b = 1100 s/mm^2

<D>

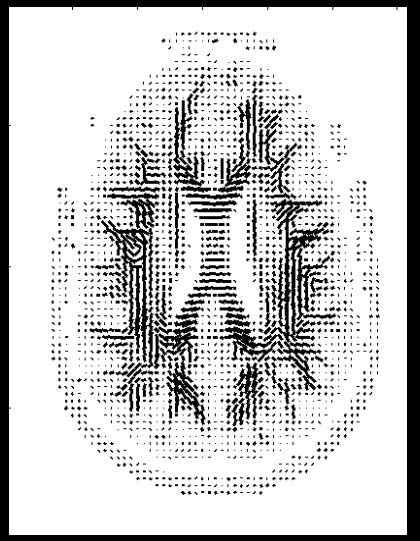
FA



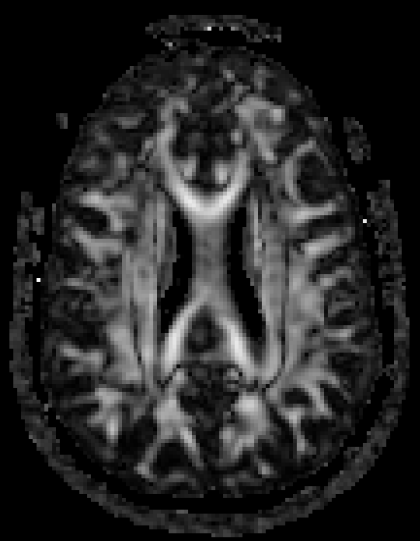
DEC



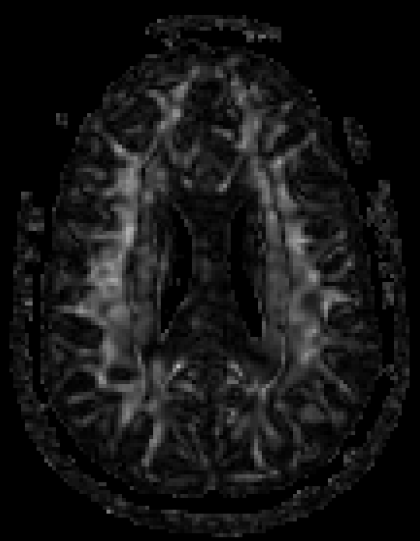
No sym DEC



Line Field



Linear



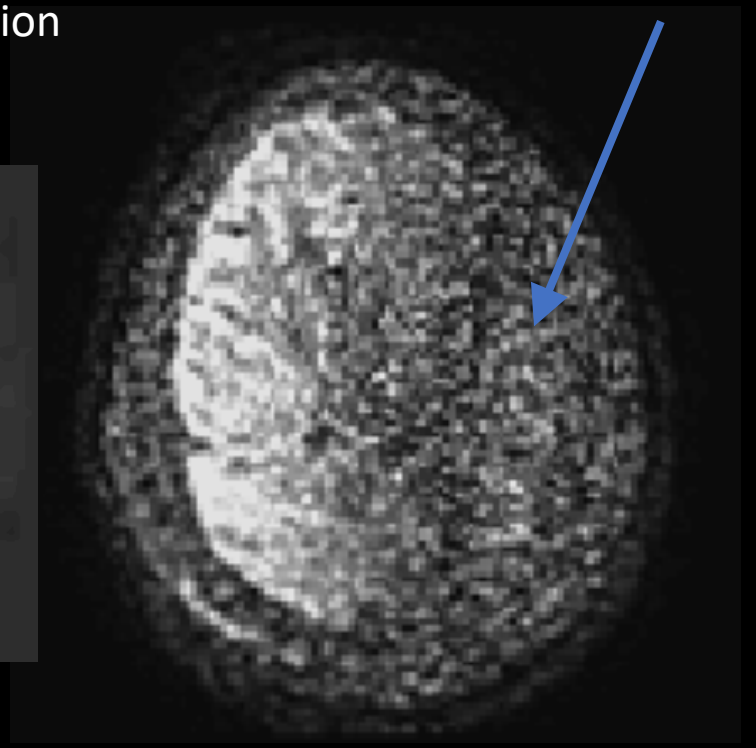
Planar

Spherical

What does motion look like?

Intra-volume
Slice mis-registration

Signal Loss



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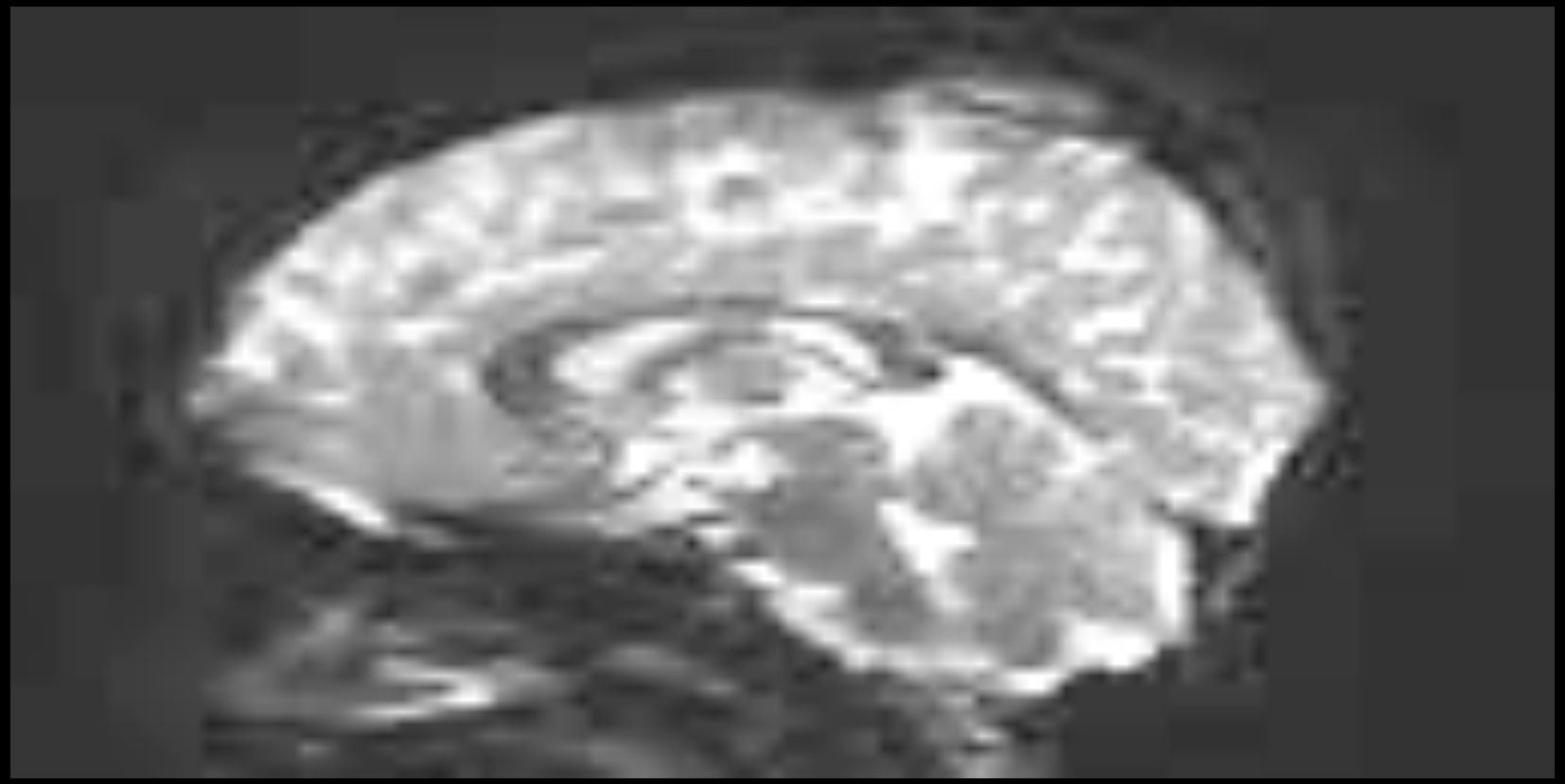
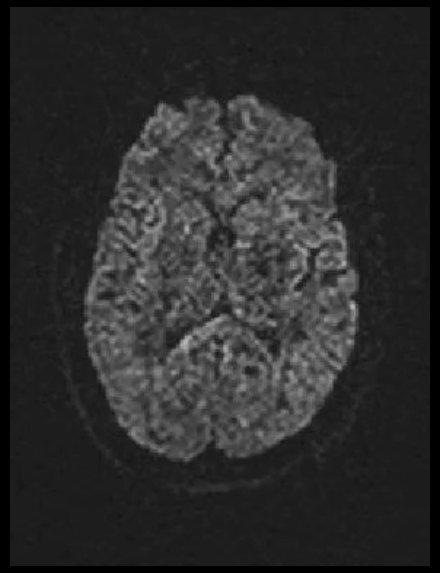


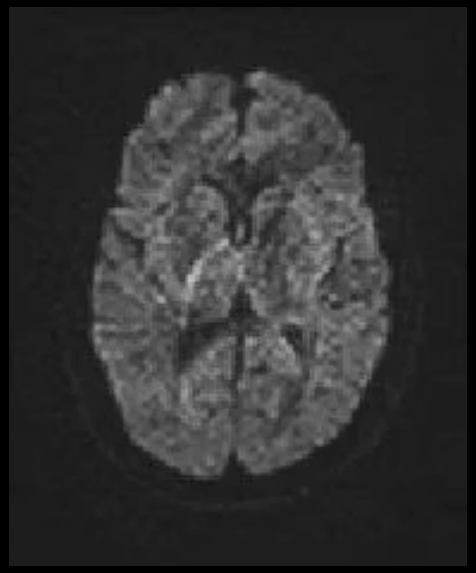
Motion Correction Techniques

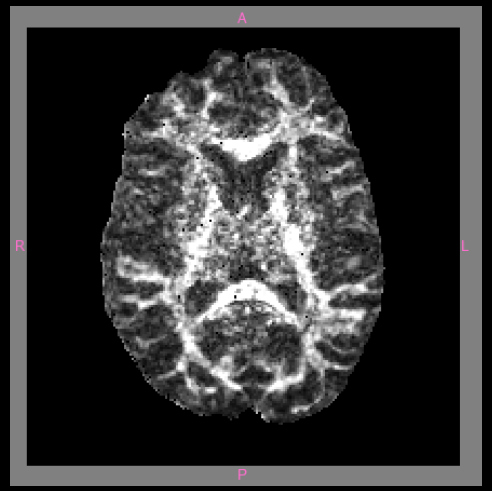
- Retrospective Motion Correction
  - Image volume registration
  - Image volume elimination
- Necessary part of any diffusion MRI processing pipeline

CON: Distortions from DW

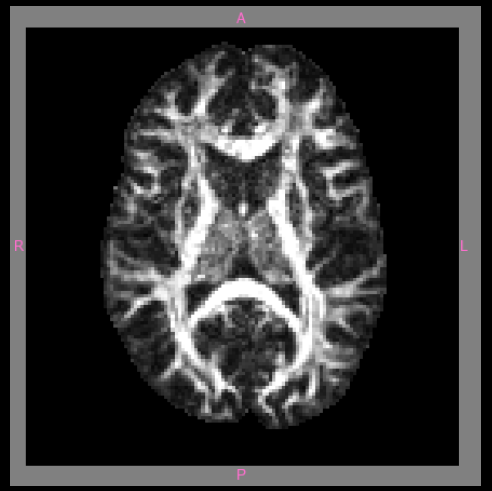


DW
SSEPI
volumes

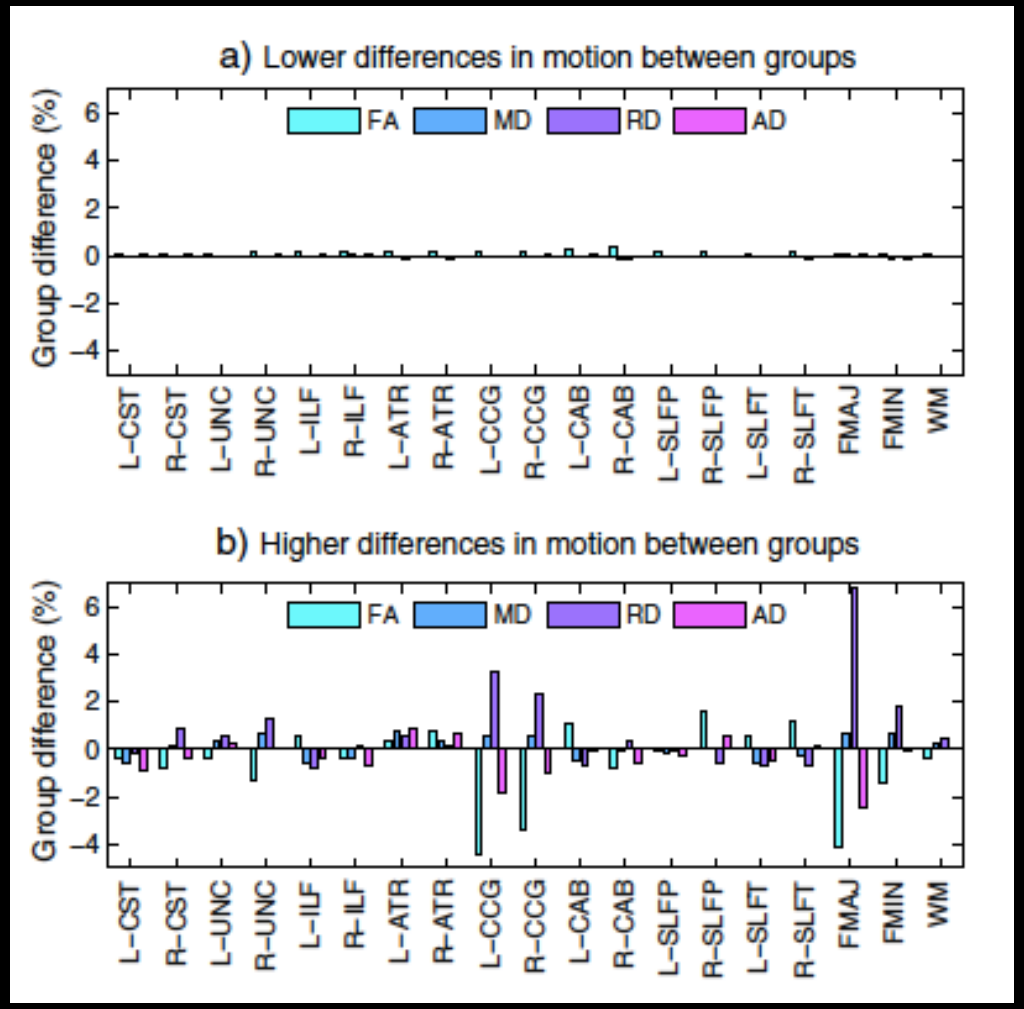




FA maps

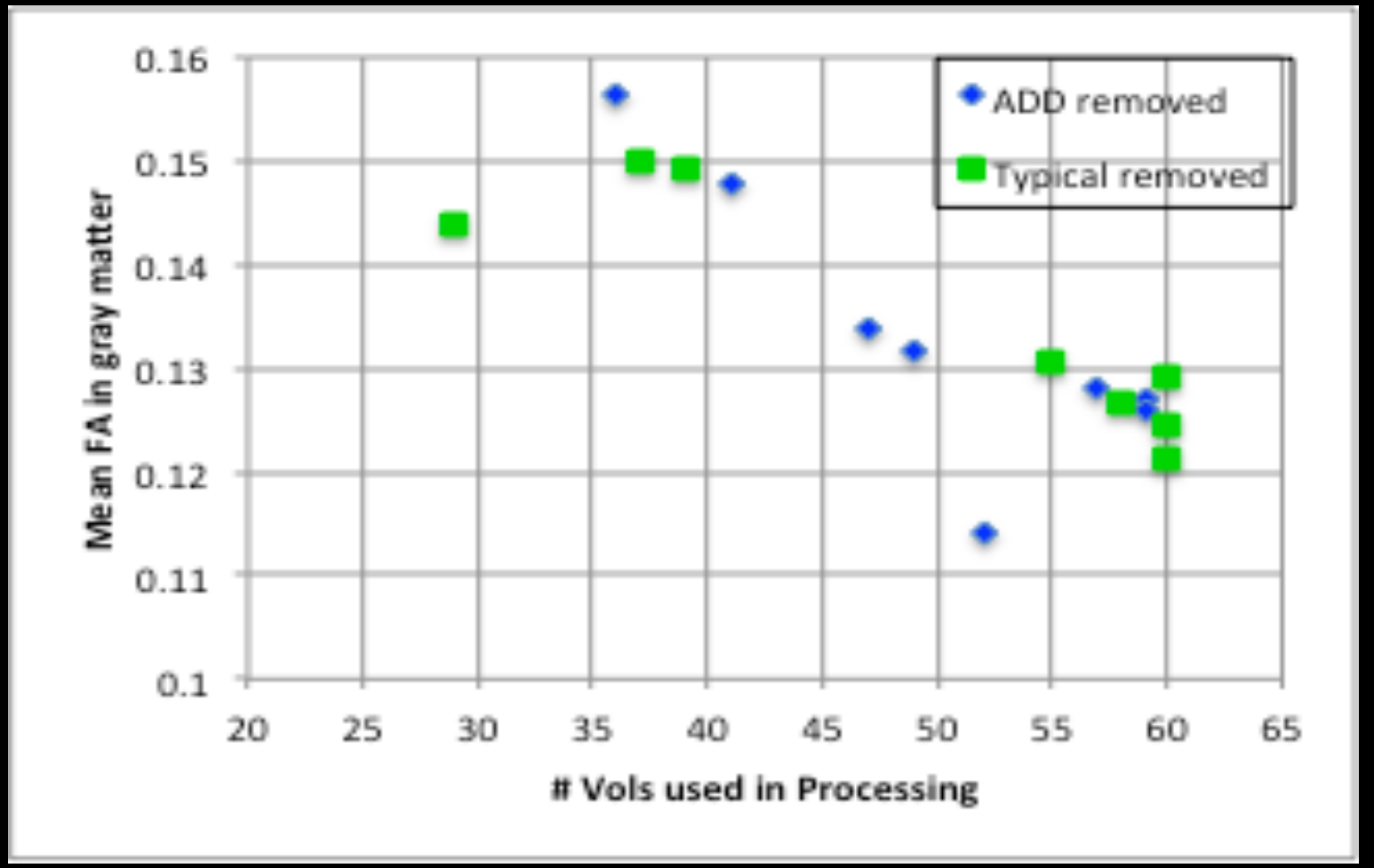


How does motion impact results?

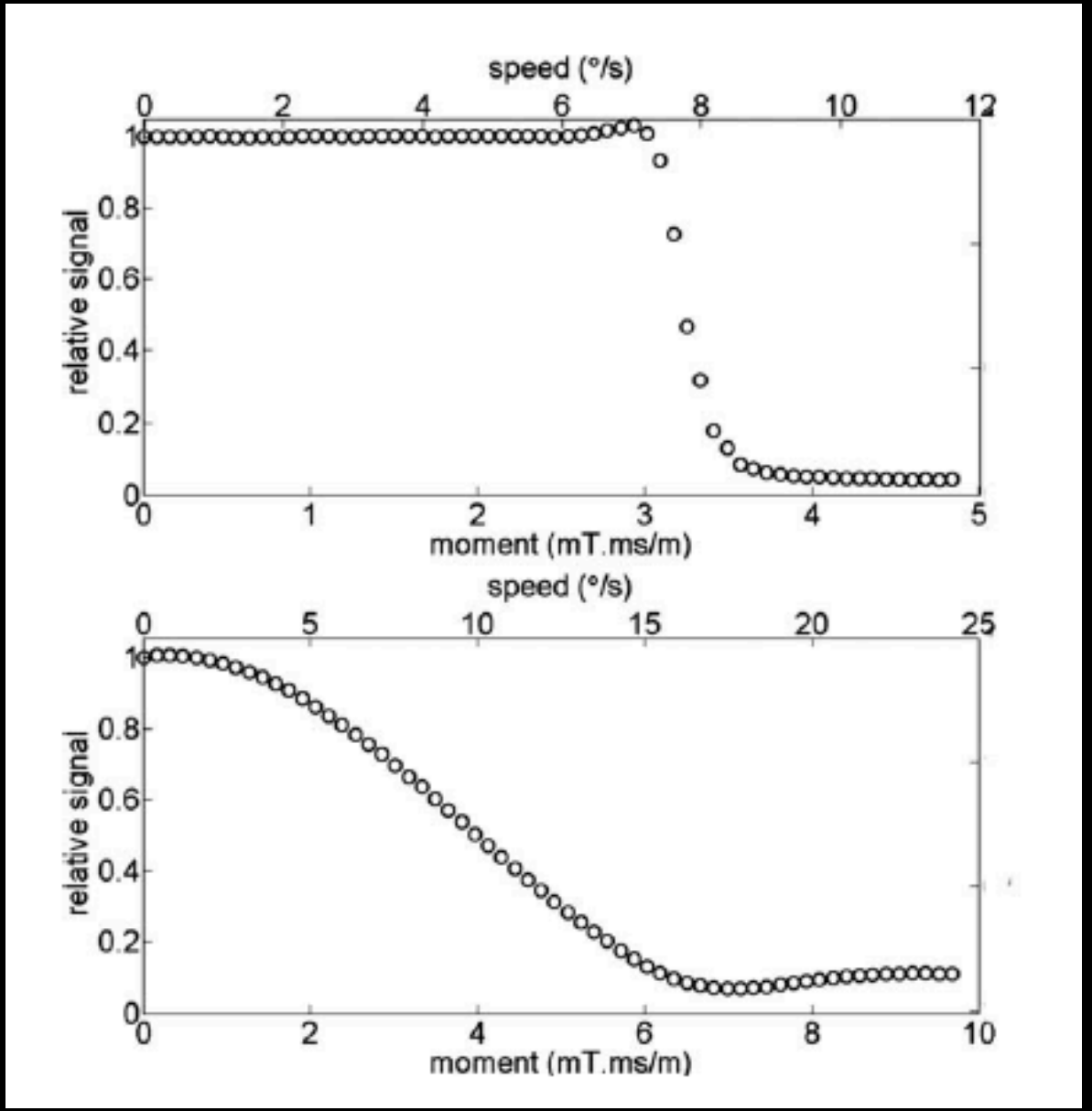


Yendiki et. al. NeuroImage 2014; 88:79-90

Bias induced after standard QC



Sarlls et. al. ISMRM 2012, p. 3551



Gumus et. al. Mag Res Med 2014; 71:2006-2013

Motion Correction Techniques

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  - Optical tracking

Pro

(2014)

Pre
Dif
Res

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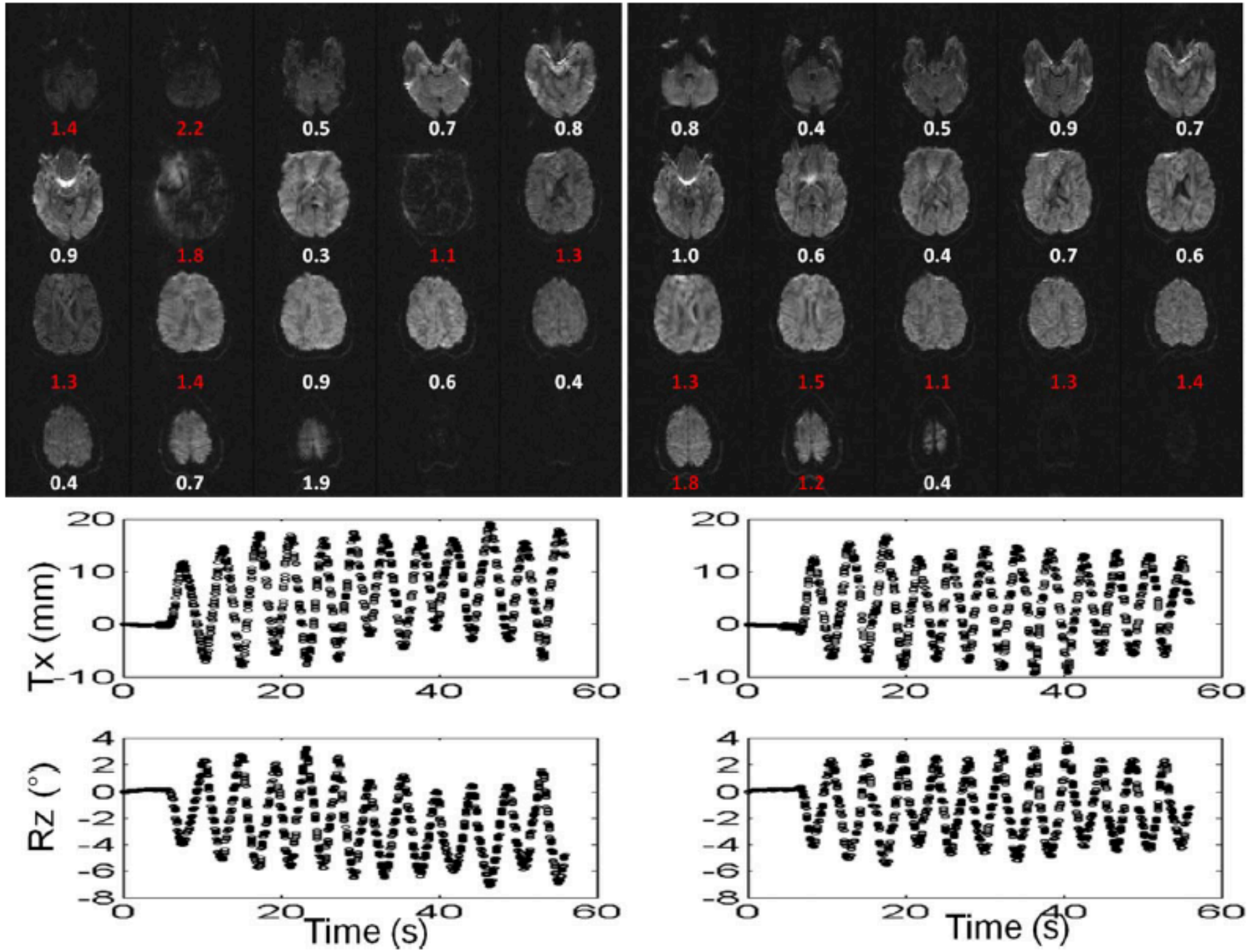
Lind
Max



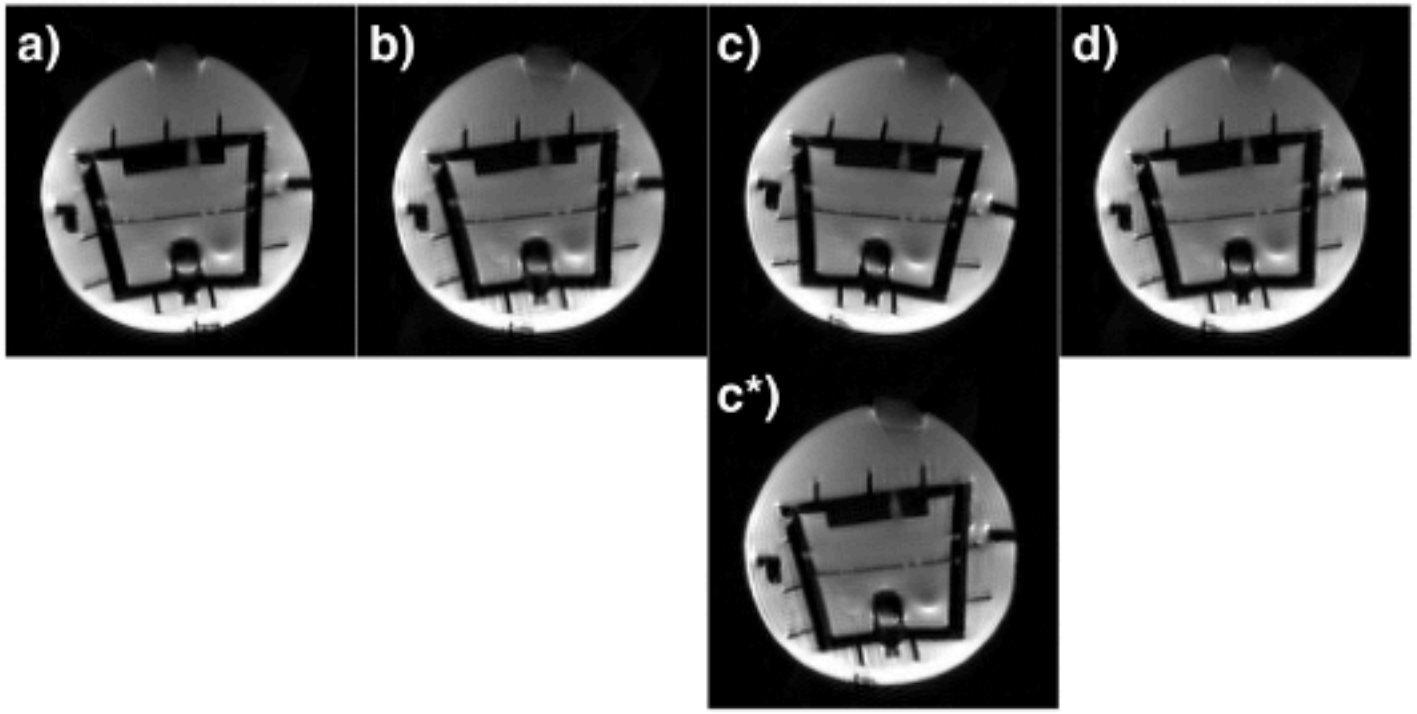


Fig. 1. A single slice of a DWI experiment at 4 time-points (no diffusion weighting). Phantom (a) in the original position, (b) after manual movement, updating the imaging volume using external tracking. The air-bubble on the top indicates the change in orientation. (c) A shift in marker position introduces an error term to the correction matrix. (c*) The PACE algorithm detects and corrects for this error term. (d) The measured marker displacement is taken into account during subsequent position updates, and the image shows good agreement with the original position shown in panel (a).

Summary

- Motion does effect extracted parameters
  - Increased variance
  - Introduce bias
- Bias may correlate with the amount of motion
  - Induce false results as motion can vary between study groups
- Removal of motion corrupted data does not alleviate these effects
  - Does not remove correlation (structural)
  - May induce bias (DTI)
- A “toolbox” of techniques is needed to compensate for motion in research imaging (Zaitsev et. al. J Magn Reson Img 2015; 42:887-901)

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Lalith Talagala, NINDS
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Contact Joelle Sarlls (sarllsjo@mail.nih.gov) with questions/comments!

THANK YOU

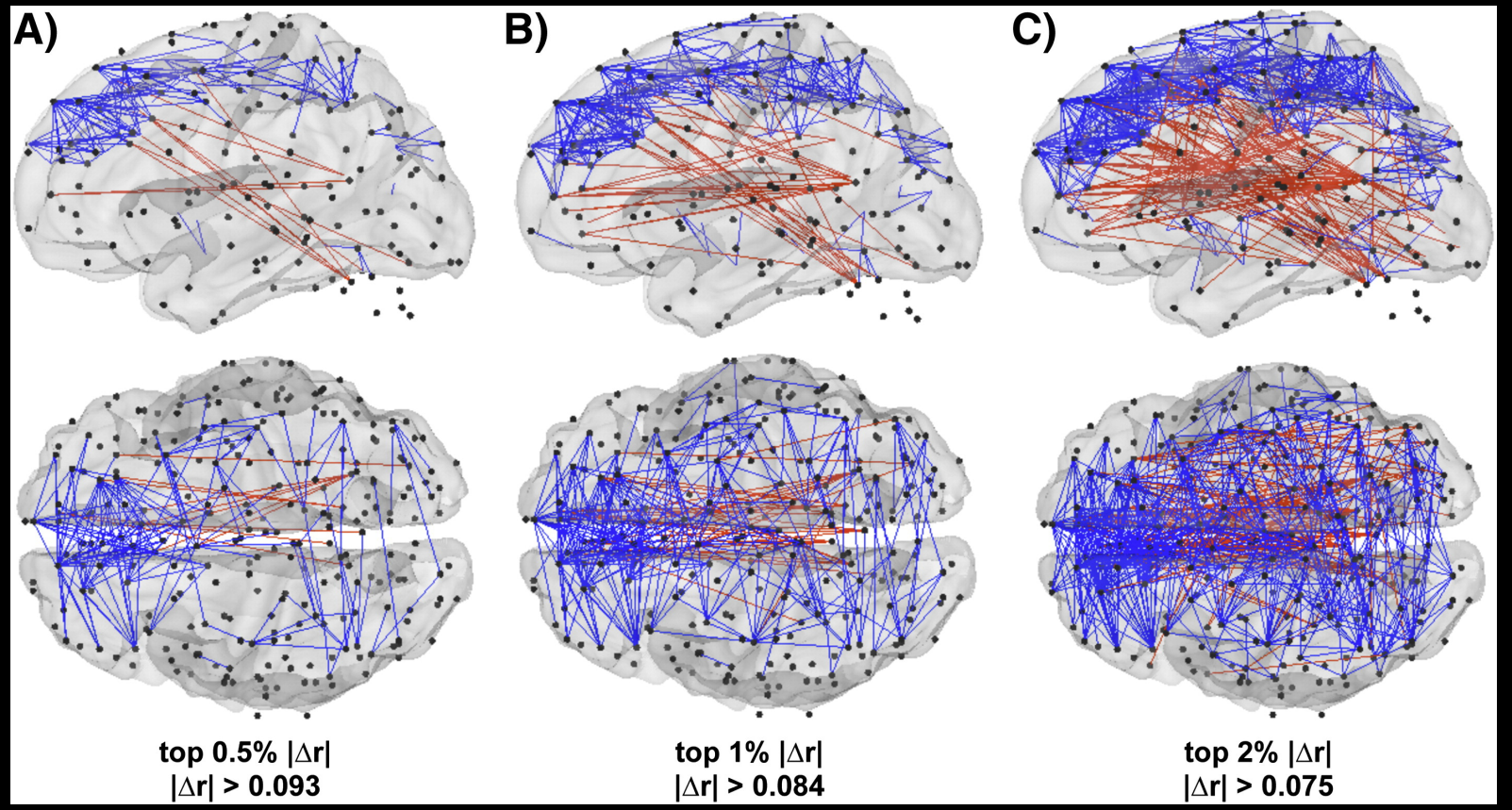
fMRI Imaging
Why is motion a problem?

- fMRI utilizes the BOLD signal
  - Measured as change in intensity
  - Typically on the order of a few%
- Multiple volumes required
  - Long scan times

What does motion look like?

What does motion look like?

How does motion impact results?



Power et. al. NeuroImage 2012; 59:2142-2154