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?

- Control
- Ringing
- Move

Blurring
How does motion impact results?

ACCURACY – Cortical measures

<table>
<thead>
<tr>
<th></th>
<th>Frontal</th>
<th>Parietal</th>
<th>Temporal</th>
<th>Occipital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Thickness</td>
<td><img src="image1" alt="Mean Thickness" /></td>
<td><img src="image2" alt="Mean Thickness" /></td>
<td><img src="image3" alt="Mean Thickness" /></td>
<td><img src="image4" alt="Mean Thickness" /></td>
</tr>
<tr>
<td>Total Volume</td>
<td><img src="image5" alt="Total Volume" /></td>
<td><img src="image6" alt="Total Volume" /></td>
<td><img src="image7" alt="Total Volume" /></td>
<td><img src="image8" alt="Total Volume" /></td>
</tr>
</tbody>
</table>

Sarlls et. al. PLOS1 2018; doi: 10.1371/journal.pone.0199372
Correlation – Cortical Volume

Reuter and Tisdall et. al. Neurolmage 2015; 107:107-115
Correlation remains after standard QC

Reuter and Tisdall et. al. Neurolmage 2015; 107:107-115
Thalamus  Caudate  Putamen  Pallidum  Hippocampus  Amygdala  Corpus Callosum

ACCURACY – Subcortical

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.
Motion Correction Techniques

• Physically Restricting
  ▪ Bite bar
  ▪ Headcase

• Prospective Motion Correction
  ▪ MRI Navigators
  ▪ Optical tracking
Prospective Motion Correction
Prospective Motion Correction (PMC)

Sarlls et. al. PLOS1 2018; doi: 10.1371/journal.pone.0199372
### ACCURACY – Cortical thickness

<table>
<thead>
<tr>
<th></th>
<th>Frontal total</th>
<th>Parietal total</th>
<th>Temporal total</th>
<th>Occipital total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Cortical Thickness (Right Hemisphere)</td>
<td></td>
<td></td>
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</tbody>
</table>

#### % Difference

- No PMC
- FOV-update
- Reacquisition
- PMC

* Indicates significant difference.
ACCURACY – Cortical volume

Cortical Volume (Right Hemisphere)

Frontal total  Parietal total  Temporal total  Occipital total

% Difference

No PMC  FOV-update  Reacquisition  PMC

* Indicates significant difference
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
ACCURACY – Cortical Thickness

- Frontal total
- Parietal total
- Temporal total
- Occipital total

Move, No PMC
Move, PMC
NoMove, PMC
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
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

PRO
- Time Efficient
- Insensitive to bulk motion

CON
- Low Resolution
- Distortions due to field inhomogeneities

T2-weighted FSE

SSEPI
CON: Distortions from field inhomogeneities

T2-weighted FSE

SSEPI

SSEPI corrected
Interleaved Slice Acquisition
Interleaved Slice Acquisition
DTI

\[ b = 0 \text{ s/mm}^2 \]

\[ b = 1100 \text{ s/mm}^2 \]
<D>  FA  DEC  No sym DEC

Line Field  Linear  Planar  Spherical
What does motion look like?

- Intra-volume Slice mis-registration
- Signal Loss
What does motion look like?
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
Motion Correction Techniques

• Retrospective Motion Correction
  ▪ Image volume registration
  ▪ Image volume elimination

• Physically Restricting
  ▪ Headcase

• Prospective Motion Correction
  ▪ MRI Navigators
  ▪ Optical tracking
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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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?

Intra-volume Slice mis-registration

Signal Loss
What does motion look like?
How does motion impact results?

A) top 0.5% |Δr| |Δr| > 0.093
B) top 1% |Δr| |Δr| > 0.084
C) top 2% |Δr| |Δr| > 0.075