Artifact Removal: Motion

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Signal-to-Noise Ratios: 7T

Hutton et al., Neuroimage, 2011
Spatial vs. temporal SNR

Triantafyllou et al., Neuroimage, 2005
Low-frequency drifts

Lund et al., Neuroimage, 2006
Residual movement effects

Lund et al., Neuroimage, 2006
Respiratory noise

Lund et al., Neuroimage, 2006
Cardiac noise

Lund et al., Neuroimage, 2006
Comparison

Low-frequency Residual motion Respiratory noise Cardiac noise Activation

Lund et al., Neuroimage, 2006
Motion-affected areas

Just a problem for border regions? **NO!**

Jo et al., J Appl Math, 2013
Quantifying motion

- Framewise displacement FD
  \[ \Delta d_{ix} = d_{(i-1)x} - d_{ix} \]
  \[ FD_i = |\Delta d_{ix}| + |\Delta d_{iy}| + |\Delta d_{iz}| + |\Delta \alpha_i| + |\Delta \beta_i| + |\Delta \gamma_i| \]

- DVARS
  \[ DVARS(\Delta I)_i = \sqrt{\langle [\Delta I_i(\vec{x})]^2 \rangle} = \sqrt{\langle [I_i(\vec{x}) - I_{i-1}(\vec{x})]^2 \rangle} \]

• Power et al, Neuroimage, 2012
• Smyser et al, Neuroimage, 2011
Motion and signal changes

Single subject

\(|\Delta \%BOLD \times 10|\)

0 0.2 0.4

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8 9 10

fMRIAT
Motion and (f)ALFF

Küblböck et al., Neuroimage, 2014
Why is non-Gaussian noise a problem?

- Causes artificial correlations between the time courses of independent regions
- False positive connectivity estimates

Seed voxel

RFX group analysis result, 30 subjects
p<0.05 FWE corrected

Weissenbacher et al., Neuroimage, 2009
Non-Gaussian noise is a challenge

- Compensate / Correct
- Separate / Project
- Modify / disregard affected time points ("scrubbing")
Part 1
Correcting motion effects
fMRI Preprocessing Pipeline

1. slice-timing correction
2. realignment motion correction
3. normalization
4. spatial smoothing
Correcting Head Motion

• Rigid body transformation
  – 6 parameters: 3 translation, 3 rotation
• Minimization of some cost function
  – weighted least squares
  – normalised correlation
• Optimisation technique
  – Iterative gradient descent
  – Gauss-Newton
Motion correction increases TP

Oakes et al., Neuroimage, 2005
Motion correction reduces FP

Oakes et al., Neuroimage, 2005
Limitations of Motion Correction

• Artifact-related limitations
  – Loss of data at edges of imaging volume
  – Ghosts in image do not change in same manner as real data

• Distortions in fMRI images
  – Distortions may be dependent on position in field, not position in head (realign & unwarp)

• Intrinsic problems with correction of both slice timing and head motion
Part 2
Modelling motion effects
Modelling residual motion effects

- Use of nuisance regressors in the GLM
- 6 motion correction regressors
  - 3 transitions, 3 rotations
- Add temporal derivatives to account for temporal shifts
- Add squared regressors for modelling non-linear effects
- Up to 24 additional regressors of no interest
Could there be a problem with including realignment parameters?

- In rs-fMRI: Not really

- In task fMRI: Yes, if realignment parameters are correlated to task-regressors
  - Stimulus-correlated motion
  - "perfect subject effect": Motion correction is based on image intensity variations over time. If these variations are caused by strong, wide-spread BOLD activation then images are moved in error and realignment parameters will be strongly correlated with task regressors (orthogonalisation will not help!)
## Additional Regressors

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<th>regressors:</th>
<th>correction against:</th>
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<td>rigid-body realignment parameters</td>
<td>subject motion</td>
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Nuisance regression (f)ALFF

Mean No Regression

Mean All Regressions

Student’s t-tests

Woletz et al., RSBC Conference, 2016
Nuisance regression ALFF
DMN at 7T

effects of nuisance regression

No nuisance regressors
Mean WM
Mean CSF
TPCA WM (5)
TPCA CSF (5)

Hoffmann et al., RSBC Conference, 2016
Part 3
Scrubbing & Co
Artefact removal approaches

Remove short, spike-like signal changes from sudden subject motion

- Despiking
- Scrubbing
- Artrepair toolbox
Despiking

• Example: AFNI 3dDespike procedure
  – Fourier Fit
  – Spikes are identified by comparing residuals against the standard deviation of the residuals
  – Spike signals are remapped

\[ s' = c_1 + (c_2 - c_1) \tanh \left( \frac{s - c_1}{c_2 - c_1} \right) \]

upper signal limit after despiking

spike threshold
Scrubbing / Motion censoring

- Determine affected time points either via
  - Framewise displacement (FD) over threshold
  - DVARS over threshold
- Ignore these time points during analysis
  - Task-based fMRI: Weighted GLM analysis
  - R-fMRI: additional regressor for each censored time point

Bandpass filtering time courses with temporal discontinuities is not recommended
Scrubbing / Motion censoring

Power et al., Neuroimage, 2012
Scrubbing / Motion censoring

Power et al., Neuroimage, 2012
Artrepair

- Toolbox for SPM
- 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


Mazaika et al., HBM, 2005
Artrepair Pipeline I

- **Raw images**
- **Repair Physically-Based Outliers**
- **SPM Preprocessing**

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

Mazaika et al., HBM, 2005
Artrepaire Pipeline II

1. Preprocessed images
2. SPM estimation
3. Results (w/o Artrepaire)
4. Images after Artrepaire
5. SPM estimation (deweighting)
6. Results (with Artrepaire)

Mazaika et al., HBM, 2005
Summary

Preprocessing

- Despiking
- Motion correction (realignment)
- Normalisation
- Smoothing

GLM Analysis

- Nuisance regressors
- Weighted parameter estimation (motion censoring, scrubbing)
- Band-pass filtering (only for R-fMRI)
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