Quality control and data preprocessing

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NITP Summer School, 2008
Outline

• Quality control and artifact detection
• Artifacts in fMRI data
• Motion and motion correction
• Using ICA to detect and remove artifacts
• Slice timing correction
• Spatial smoothing
Processing stream for fMRI data: SPM

Data acquisition

- Data acquisition
- Image reconstruction
- Raw data QC

Artifact correction

- Slice timing correction
- Motion correction
- Distortion correction

Spatial preprocessing

- Spatial smoothing
- Spatial normalization

Statistical analysis on normalized data

- Individual statistical analysis
- Group statistical analysis
Processing stream for fMRI data: FSL

Data acquisition → Image reconstruction → Raw data QC → Slice timing correction → Motion correction → Distortion correction → Spatial smoothing → Individual statistical analysis → Spatial normalization → Group Statistical analysis

Statistical analysis on native space data
Quality control

• It is essential that you perform QC checks at multiple points in your data analysis stream
  – You MUST know how to look at raw data!
  – You can’t trust your analysis package to do everything for you.

• Things to look for
  – Data acquisition artifacts
  – Subject-related artifacts
  – Analysis-related artifacts
MR data artifacts

• Things to look for:
  – Spikes
  – Ghosting
  – Geometric distortions
  – Signal dropout
Spikes

From M. Cohen
EPI ghosting

- Caused by phase errors in odd and even lines of k-space traversal

From MRC-CBU
Geometric distortions in EPI

• Caused by inhomogeneities of magnetic field
Susceptibility dropout in EPI

Ojemann et al.
Effects of TE and slice thickness on dropouts

From Larry Wald, MGH
Basic steps for QC

• Look at the data!
  – View the timeseries as a movie
  – Examine the mean and variance image
  – Use ICA (more later)
Viewing timeseries as movies
Motion

• Motion is probably the biggest source of artifact in fMRI data

• Subjects are going to move
  – Can we detect it and fix it when it happens?
  – Can we prevent it?
Effects of head motion on fMRI data.

(A) 

(B) 

(C) 

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Motion-related edge artifacts
Problems with motion correction

• Re-sampling can introduce errors
  – Especially tri-linear interpolation
  – Always use sinc for final resampling

• Distortions and other artifacts in the images
  – do not move according to the same rigid body rules as the subject

• Slices are not acquired simultaneously
  – rapid movements between slices not accounted for by rigid body model
Task-correlated motion
Modeling motion

- Motion parameters can be included in the statistical model as a nuisance regressor
  - Effects of motion are separated from effects of task
- If motion is uncorrelated with task, then this works well
- However, with task-correlated motion (which is common), this can remove signals of interest
  - For blocked designs, it is difficult to decorrelate motion and HRF
  - For ER designs, this is less of a problem
    - Due to delay in HRF
    - Can also take advantage of this to let subjects speak in the scanner
Benefits of event-related designs for separating motion from activation

\[ r = 0.6 \]

\[ r = -0.12 \]
How can we remove the residual effects of motion?

• Even after motion correction, some effects of motion may remain
  – E.g., effects that do not obey rigid body model

• We can detect and remove these using exploratory multivariate data analysis techniques
Exploratory data analysis techniques

- Techniques for finding unknown interesting signals in the data
- Principal components analysis
  - Finds orthogonal (uncorrelated), axes of maximal covariance
- Independent components analysis
  - Finds independent axes based on non-Gaussian features in the data
  - \[ X = A \times s \]
    - \( X \) - data (known)
    - \( A \) - mixing matrix (unknown)
    - \( s \) - independent components (unknown)
  - Goal: estimate a “unmixing” matrix \( W = A^{-1} \) that results in maximally independent \( s = W \times x \)
Non-Gaussianity and PCA/ICA

Gaussian data

Non-Gaussian data

Non-Gaussian data

PCA components must be orthogonal

from C. Beckmann, Oxford FMRIB
MELODIC ICA

- Part of the FSL software package
- Performs probabilistic ICA
  \[ X = A \ast s + e \]
Uses for ICA in fMRI data analysis

• Model-free analysis of activation
  – Difficult to combine across subjects since components may differ for each subject

• Detection and removal of artifacts
  – MELODIC allows data denoising by removal of selected components
Task
Abrupt motion
High frequency noise
Head restraint systems.
Correcting geometric distortions

- Presence of air-bone and air-tissue interfaces results in inhomogeneities in the magnetic field
- These result in:
  - Spatial distortions (primarily in phase-encoding direction)
  - Dropout (due to through-plane dephasing)
B0 field mapping

- The B0 field at each voxel can be mapped using EPI acquisitions with two different TE’s
  - The difference in the B0 field is proportional to the difference in phase at the two TE’s
    - Requires complex data
  - The amount of pixel shift is proportional to the difference in magnetic field
    - This allows unwarping of the data based on the field map
Correcting B0 inhomogeneity

From FSL course slides
Timing of slice acquisition

Each slice is acquired within <100 ms
-usually interleaved, such that adjacent slices are acquired at non-adjacent times
10.4 Effects of slice acquisition time upon the hemodynamic response.
Slice-timing correction

- Interpolate data in time so that all slices are lined up

Reference slice (10)

To-be-corrected slice (20)

- May introduce errors due to interpolation and interaction with motion
Smoothing

Each voxel after smoothing effectively becomes the result of applying a weighted region of interest (ROI).
Why smooth?

• Ensure assumptions of random field theory
• Increase signal/noise ratio
  – Only for signals of the same size as the filter!
• Reduce effects of anatomical and functional spatial heterogeneity
Why not smooth?

• Resolution is expensive!
  – Why wouldn’t you want to just collect the data at low resolution?
• Reduces ability to find signals that mismatch the filter
• Gaussian filtering blurs together tissues of different types
• Could obscure interesting spatial heterogeneity
Effects of smoothing