Data pre-processing framework in SPM

Bogdan Draganski

With special thanks to Ged Ridgway, Guillaume Flandin, John Ashburner and FIL’s Methods group
Outline

• Why do we need pre-processing?

• Overview

• Structural MRI pre-processing

• fMRI pre-processing
Why do we need pre-processing?
What do we want?
• Inter-subject averaging
  – Increase sensitivity with more subjects
    • Fixed-effects analysis
  – Extrapolate findings to the population as a whole
    • Mixed-effects analysis

• Make results from different studies comparable by aligning them to standard space
  – e.g. The T&T convention, using the MNI template
Movement
Distortions
Non-gaussian distribution
Motion correction

Smoothing

(fCo-registration and) Spatial normalisation

Standard template

fMRI time-series

kernel

Design matrix

General Linear Model

Parameter Estimates

Statistical Parametric Map
Outline

Objectives

Overview

Structural

Functional

- Slice timing correction
- Realignment
- Distortion correction (optional)
- Coregistration to sMRI
- Spatial normalisation (based on sMRI)
- Smoothing

- Inhomogeneity correction
- Segmentation
- Spatial normalisation
- Modulation
- Smoothing
Pre-processing Overview

fMRI time-series

Motion Correct

Anatomical MRI

Coregister

Estimate Spatial Norm

Template

Spatial Norm

Spatially normalised

Smoothed

Smooth

Spatially normalised

Template

Deformation

Smoothed
• MR Images are corrupted by smoothly varying intensity **inhomogeneity** caused by magnetic field imperfections and subject-field interactions

  — Would make intensity distribution spatially variable

• A smooth intensity **correction** can be modelled by a linear combination of DCT (discrete cosine transform) basis functions
Inhomogeneity correction

- Field inhomogeneity will disrupt intensity based segmentation
- Bias correction required

![Brain images](image-url)

- **no correction**
- **Estimate**
- **$T_1$**
- **GM**
- **WM**
Tissue intensity distributions – T1w MRI

![Graph showing tissue intensity distributions for different tissue types in T1w MRI. The x-axis represents intensity, and the y-axis represents probability density. The graph includes curves for Grey Matter, White Matter, CSF, Bone, Soft Tissue, and Air/Background.]
• Find the “best” parameters according to an “objective function” (minimised or maximised)
• Objective functions can often be related to a probabilistic model (Bayes -> MAP -> ML -> LSQ)
Optimum

Contours of a two-dimensional objective function “landscape”
Segmentation results

Spatial normalisation

Affine registration

Non-linear registration
Without regularisation, the non-linear spatial normalisation can introduce unwanted deformation.

**Affine registration**
(error = 472.1)

**Non-linear registration without regularisation**
(error = 287.3)

**Non-linear registration**
using regularisation
(error = 302.7)

Template image
Spatial normalisation - Limitations

• Seek to match **functionally** homologous regions, but...
  – No exact match between structure and function
  – Different cortices can have different folding patterns
  – Challenging high-dimensional optimisation
    • Many local optima
• Compromise
  – Correct relatively large-scale variability (sizes of structures)
  – Smooth over finer-scale residual differences
Uses information from tissue probability maps (TPMs) and the intensities of voxels in the image to work out the probability of a voxel being GM, WM or CSF.

Old Segmentation

New Segmentation
• If someone has atrophy, normalisation will stretch grey matter to make brain match healthy template

• This will reduce ability to detect differences
Analogy: as we blow up a balloon, the surface becomes thinner.

Likewise, as we expand a brain area its volume is reduced.
• Multiplication of the warped (normalised) tissue intensities so that their regional or global volume is preserved
  
  – Can detect differences in completely registered areas

• Otherwise, we preserve concentrations, and are detecting mesoscopic effects that remain after approximate registration has removed the macroscopic effects

  – Flexible (not necessarily “perfect”) registration may not leave any such differences

Native intensity = tissue density

Unmodulated

Modulated
• Why would we deliberately blur the data?
  – Improves spatial overlap by blurring over minor anatomical differences and registration errors
  – Averaging neighbouring voxels suppresses noise
  – Increases sensitivity to effects of similar scale to kernel (matched filter theorem)
  – Makes data more normally distributed (central limit theorem)
  – Reduces the effective number of multiple comparisons
• How is it implemented?
  – Convolution with a 3D Gaussian kernel, of specified full-width at half-maximum (FWHM) in mm
Smoothing

• Smoothing kernel - should match the shape and size of the expected effect

• Benefits
  – more “Gaussian distribution” of the data
  – Smooth out incorrect registration

• RFT requires FWHM > 3 voxels
Shape is really a multivariate concept

- Dependencies among volumes in different regions

SPM is mass univariate

- Combining voxel-wise information with “global” integrated tissue volume provides a compromise

Above: (ii) is globally thicker, but locally thinner than (i) – either of these effects may be of interest to us.

Below: The two “cortices” on the right both have equal volume…

Figures from: *Voxel-based morphometry of the human brain…* Mechelli et al, 2005
fMRI pre-processing

- Slice timing correction (optional)
- Realignment (Motion correction)
- Unwarping (Motion correction x B0 correction)
- Co-registration
  - Link functional scans to anatomical scan
- Spatial normalisation (unified segmentation)
  - Fitting images to a standard brain
- Smoothing
  - Increases signal-to-noise ratio and approximates a Gaussian distribution
Pre-processing Overview

- **fMRI time-series**
- **Motion Correct**
- **Coregister**
- **Anatomical MRI**
- **Template**
  - **Estimate Spatial Norm**
  - **Spatially normalised**
  - **Deformation**
- **Smoothed**
  - **Smooth**
  - **Spatially normalised**
Slice timing (optional)
Slice timing (optional)
Realignent - motion correction

Translation

Rotation

Objectives

Overview

Structural

Functional
## Realignment - motion correction

Rigid body transformations parameterised by:

<table>
<thead>
<tr>
<th>Translations</th>
<th>Pitch about X axis</th>
<th>Roll about Y axis</th>
<th>Yaw about Z axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \begin{bmatrix} 1 &amp; 0 &amp; 0 &amp; X_{\text{trans}} \end{bmatrix} )</td>
<td>( \begin{bmatrix} 1 &amp; 0 &amp; 0 &amp; 0 \end{bmatrix} )</td>
<td>( \begin{bmatrix} \cos(\Theta) &amp; 0 &amp; \sin(\Theta) &amp; 0 \end{bmatrix} )</td>
<td>( \begin{bmatrix} \cos(\Omega) &amp; \sin(\Omega) &amp; 0 &amp; 0 \end{bmatrix} )</td>
</tr>
<tr>
<td>( \begin{bmatrix} 0 &amp; 1 &amp; 0 &amp; Y_{\text{trans}} \end{bmatrix} )</td>
<td>( \begin{bmatrix} 0 &amp; \cos(\Phi) &amp; \sin(\Phi) &amp; 0 \end{bmatrix} )</td>
<td>( \begin{bmatrix} 0 &amp; 1 &amp; 0 &amp; 0 \end{bmatrix} )</td>
<td>( \begin{bmatrix} \sin(\Omega) &amp; \cos(\Omega) &amp; 0 &amp; 0 \end{bmatrix} )</td>
</tr>
<tr>
<td>( \begin{bmatrix} 0 &amp; 0 &amp; 1 &amp; Z_{\text{trans}} \end{bmatrix} )</td>
<td>( \begin{bmatrix} 0 &amp; -\sin(\Phi) &amp; \cos(\Phi) &amp; 0 \end{bmatrix} )</td>
<td>( \begin{bmatrix} \sin(\Theta) &amp; 0 &amp; \cos(\Theta) &amp; 0 \end{bmatrix} )</td>
<td>( \begin{bmatrix} 0 &amp; 0 &amp; 1 &amp; 0 \end{bmatrix} )</td>
</tr>
<tr>
<td>( \begin{bmatrix} 0 &amp; 0 &amp; 0 &amp; 1 \end{bmatrix} )</td>
<td>( \begin{bmatrix} 0 &amp; 0 &amp; 0 &amp; 1 \end{bmatrix} )</td>
<td>( \begin{bmatrix} 0 &amp; 0 &amp; 0 &amp; 1 \end{bmatrix} )</td>
<td>( \begin{bmatrix} 0 &amp; 0 &amp; 0 &amp; 1 \end{bmatrix} )</td>
</tr>
</tbody>
</table>

Minimizing the squared difference (error) between the images
Realignement motion correction
Unwarp

Fieldmap

Raw EPI  Undistorted EPI
Unwarp can estimate changes in distortion from movement.

- distortions in a reference image (FieldMap)
- subject motion parameters (that we obtain in realignment)
- change in deformation field with subject movement (estimated via iteration)
Co-registration

Normalized mutual information

functional and structural images in the same space
Co-registration

T2 intensity

T1 intensity

T2

T1

I(F,G)=0.711615,

I(F,G)=1.33347,

15mm displacement

T1 intensity
Spatial registration

Registration of structural images to a standard brain template (standard space)

→ The obtained transformation (warping) parameters can be applied on co-registered fMRI data

→ Improved spatial normalization based on high resolution structural information
Smoothing
Smoothing
Thank you

www.unil.ch/lren  www.facebook.com/LRENNlab