Preprocessing II: Between Subjects

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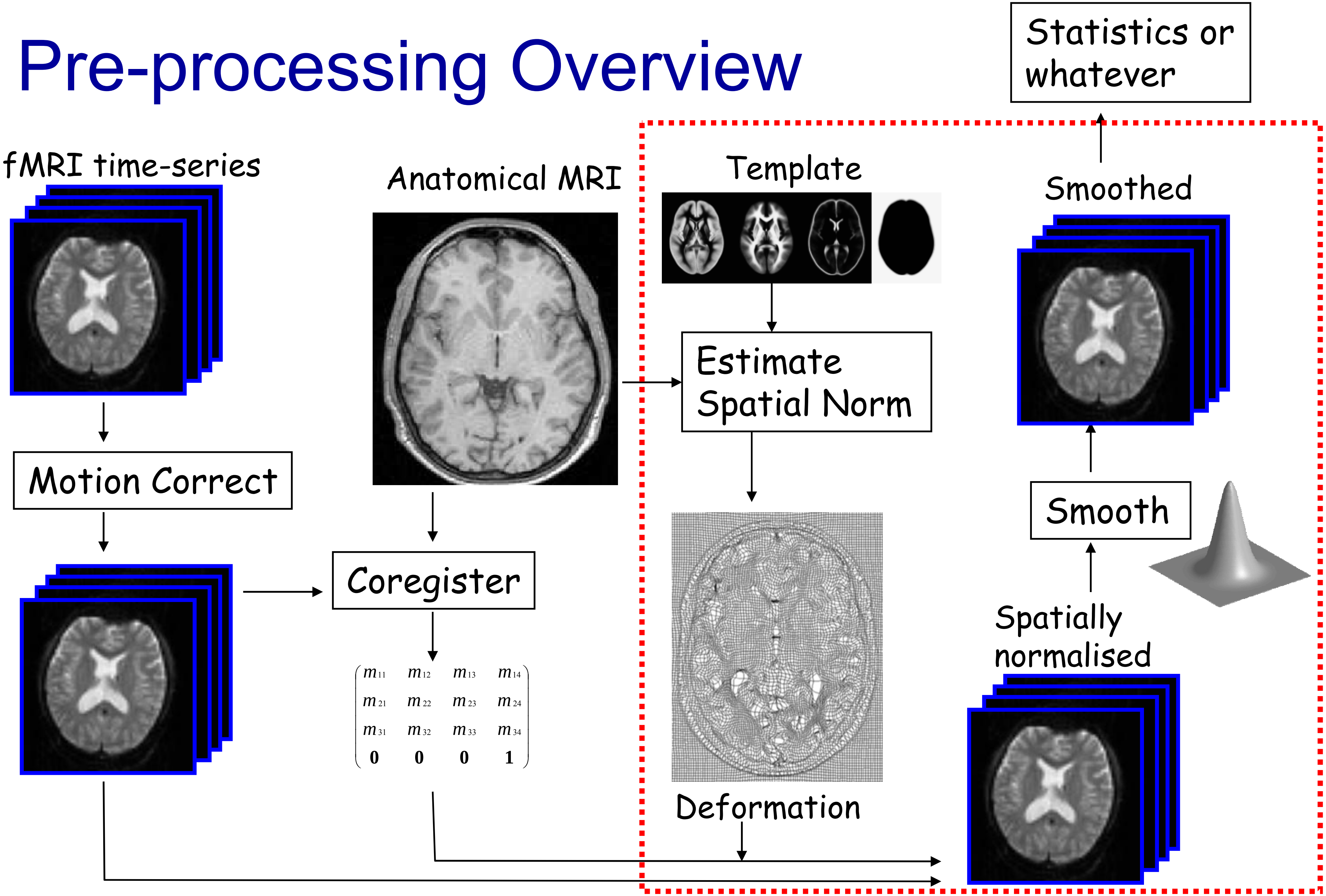
Pre-processing Overview



Spatial Normalisation

* Brains of different subjects vary in shape and size.
* Need to bring them all into a common anatomical space.
  * Examine homologous regions across subjects
    * Improve anatomical specificity
    * Improve sensitivity
  * Report findings in a common anatomical space (eg MNI space)

* In SPM, alignment is achieved by matching grey matter with grey matter and white matter with white matter.
  * Need to segment.

Contents

* **Segment**

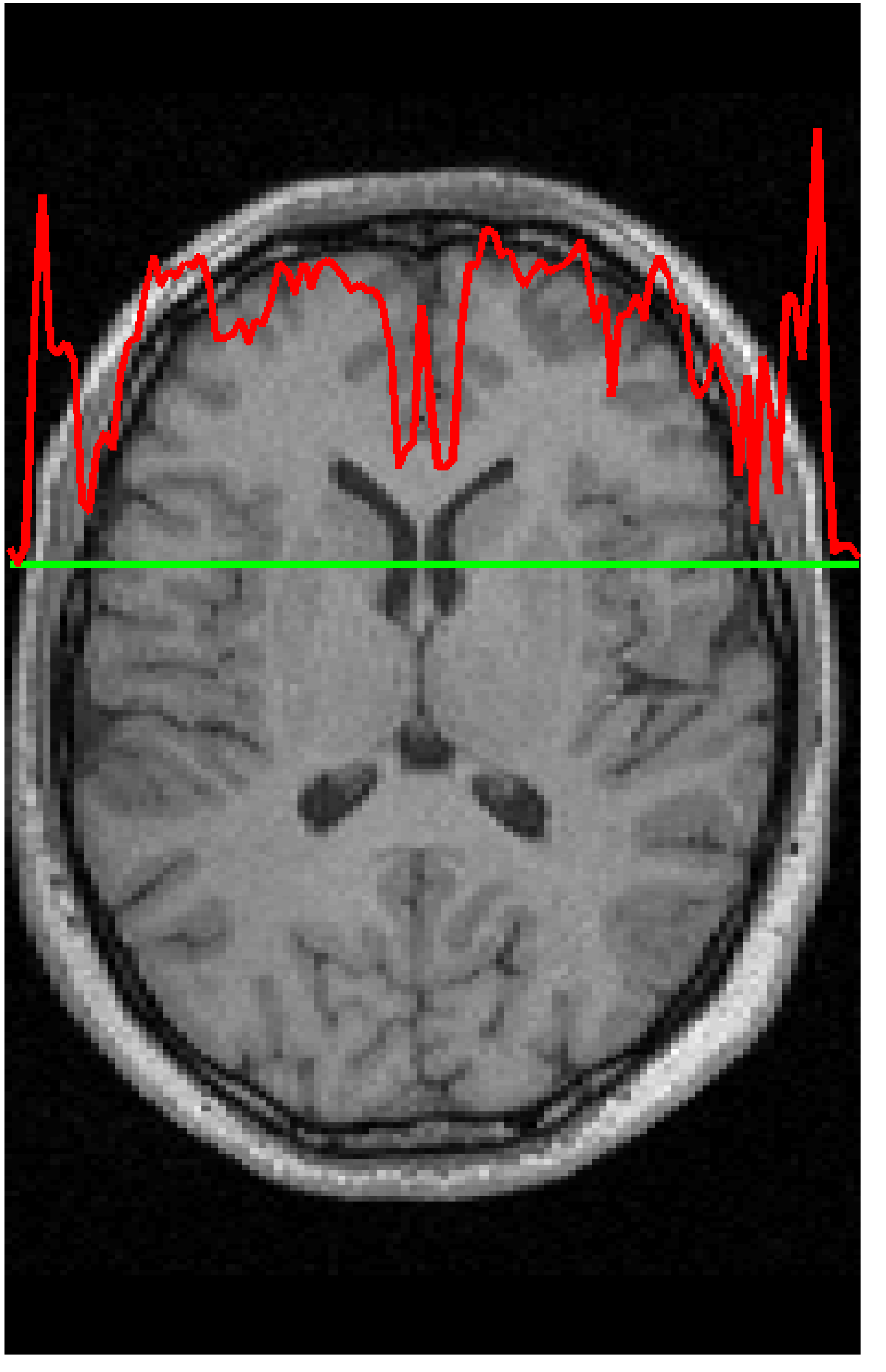
  Use segmentation routine for spatial normalisation

  * **Gaussian mixture model**
  * **Intensity non-uniformity correction**
  * **Deformed tissue probability maps**
* Dartel
* Smoothing

Segmentation

* Segmentation in SPM8 also estimates a spatial transformation that can be used for spatially normalising images.

* It uses a generative model, which involves:
    * Mixture of Gaussians (MOG)
    * Bias Correction Component
    * Warping (Non-linear Registration) Component



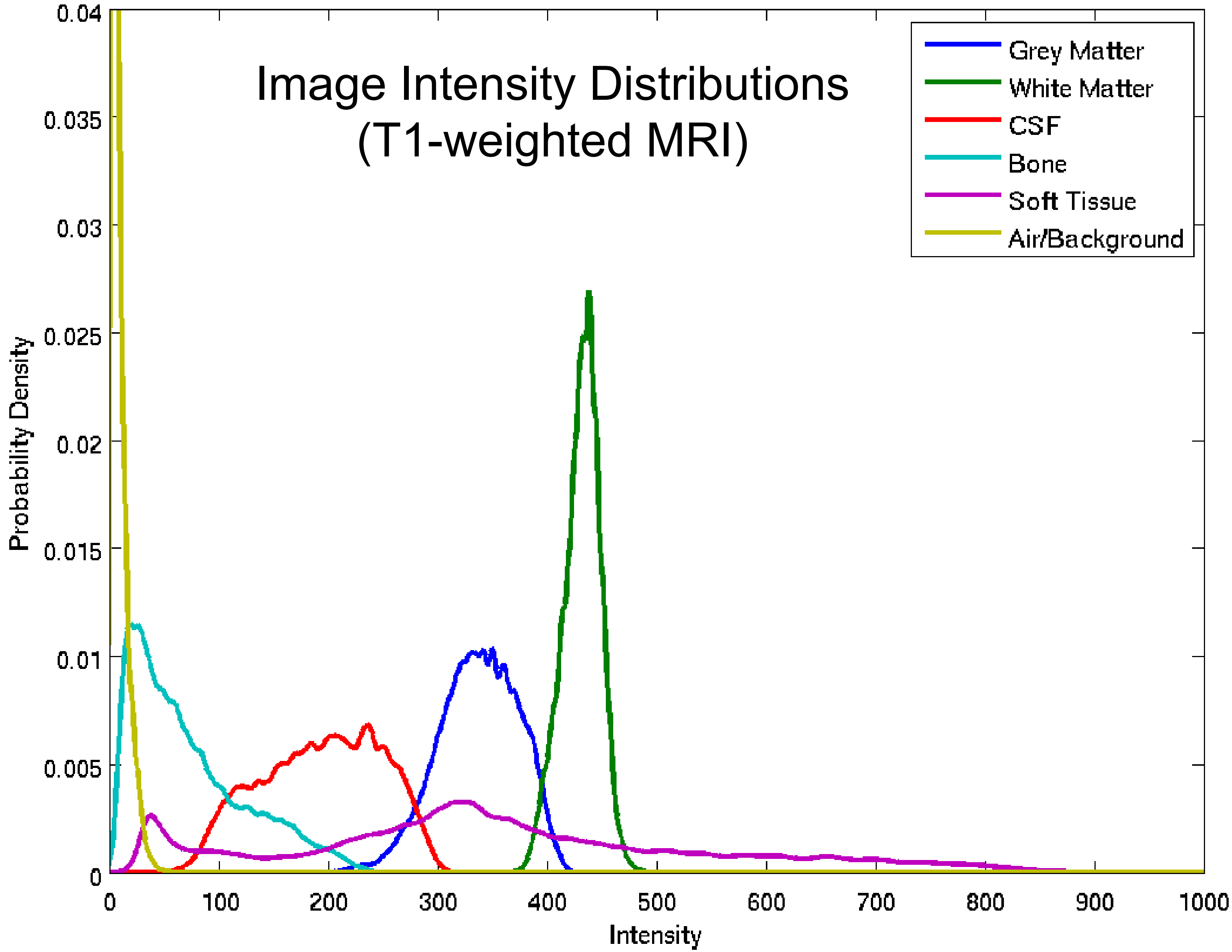
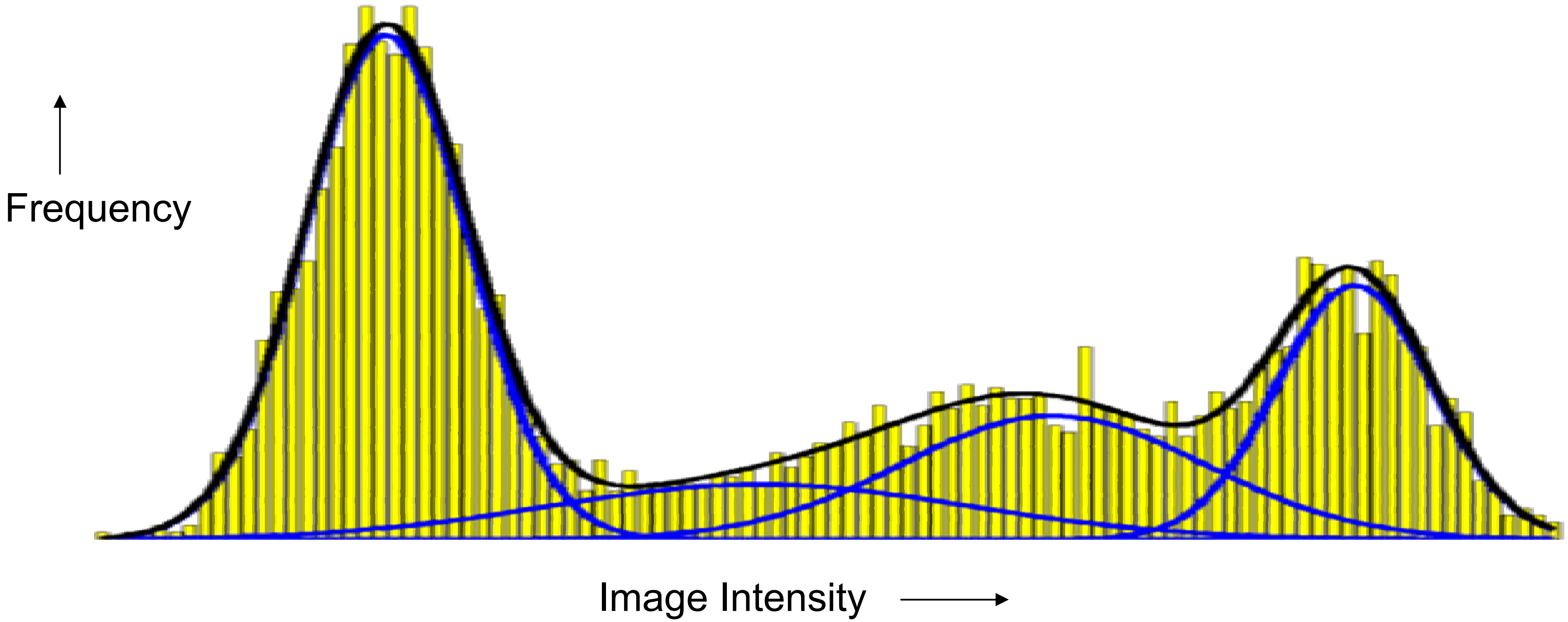


Image Intensity Distributions
(T1-weighted MRI)
Grey Matter
White Matter
CSF
Bone
Soft Tissue
Air/Background
Probability Density
Intensity
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0
100
200
300
400
500
600
700
800
900
1000

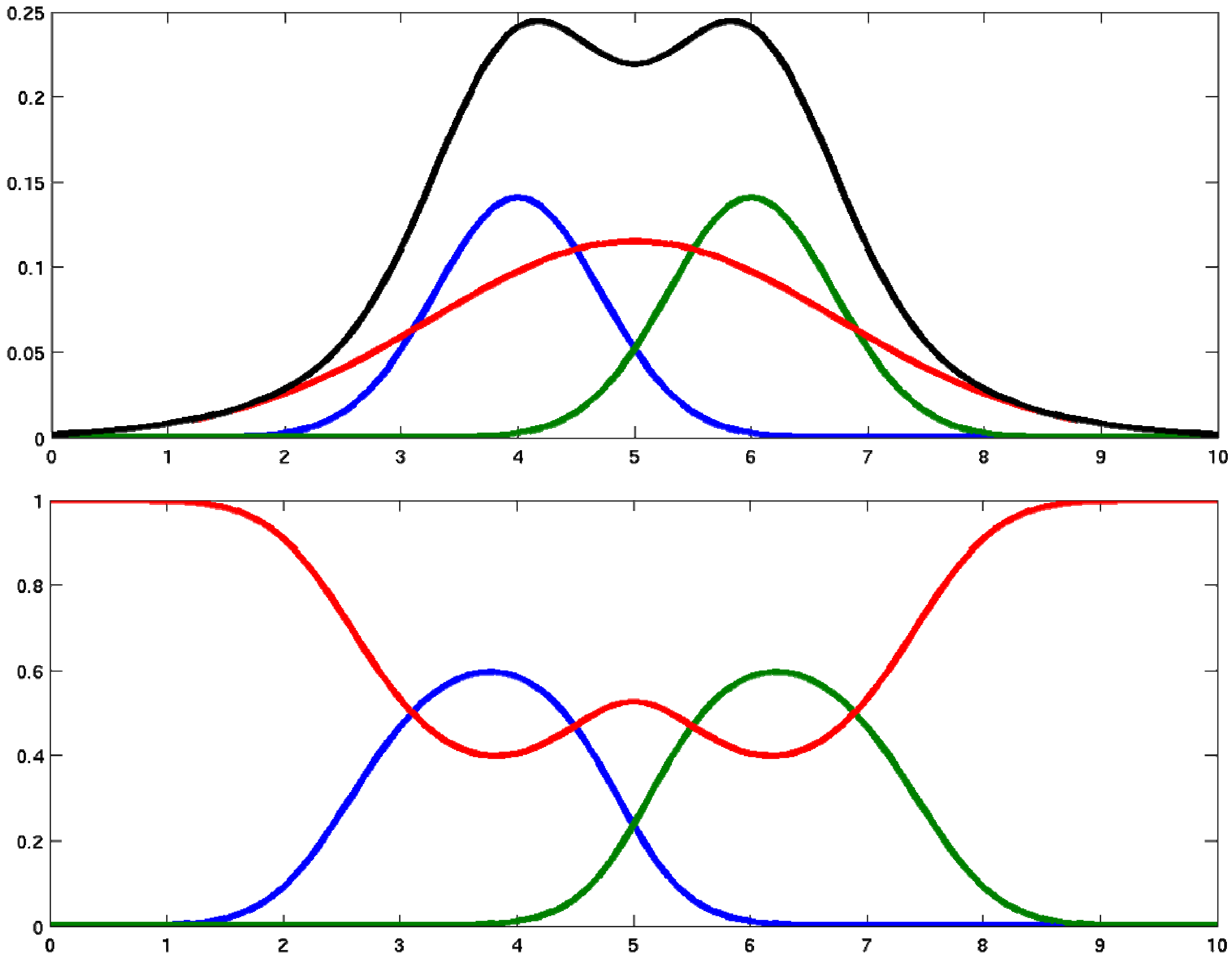
Mixture of Gaussians (MOG)

* Classification is based on a Mixture of Gaussians model (MOG), which represents the intensity probability density by a number of Gaussian distributions.



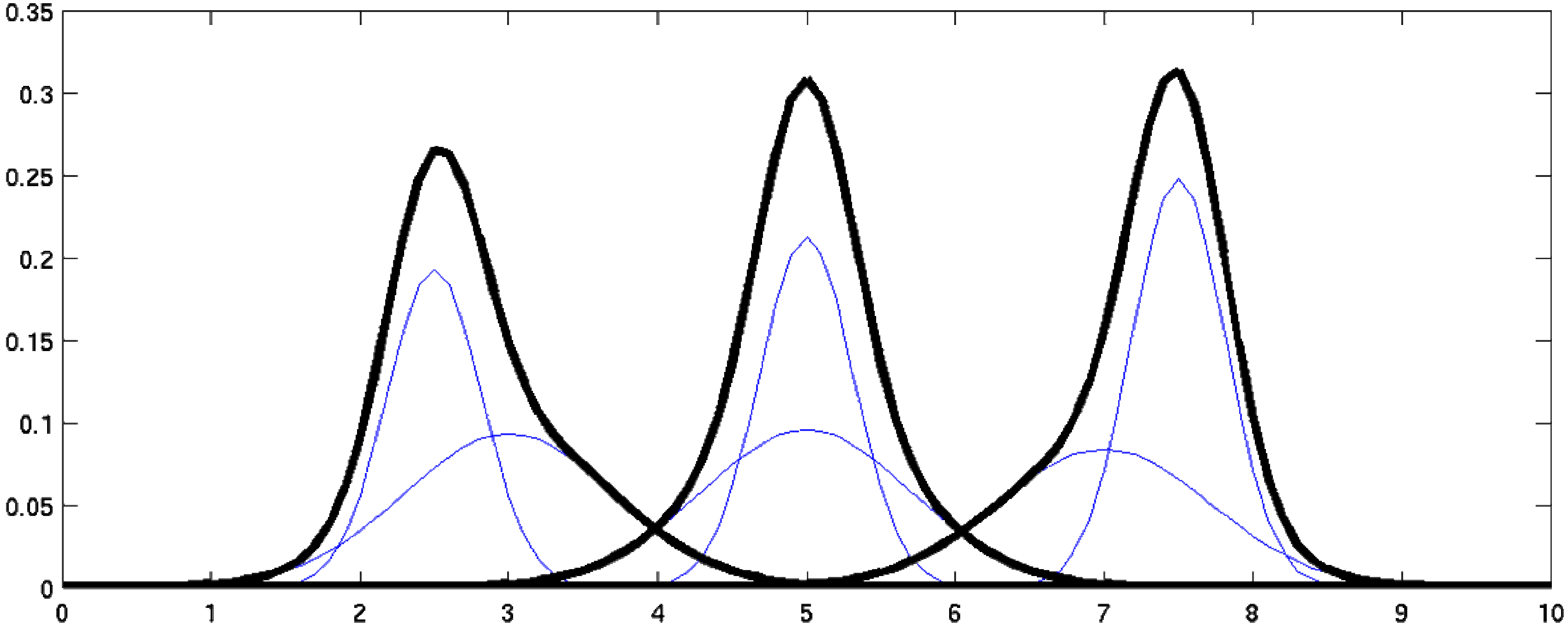
Belonging Probabilities

Belonging probabilities are assigned by normalising to one.

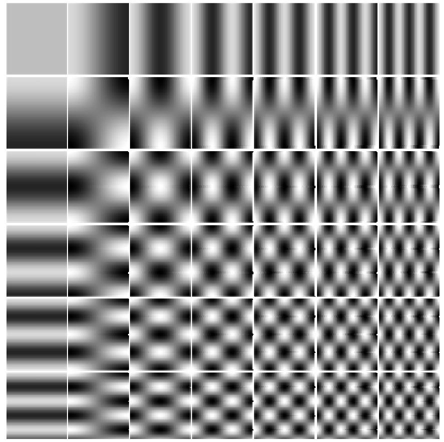


Non-Gaussian Intensity Distributions

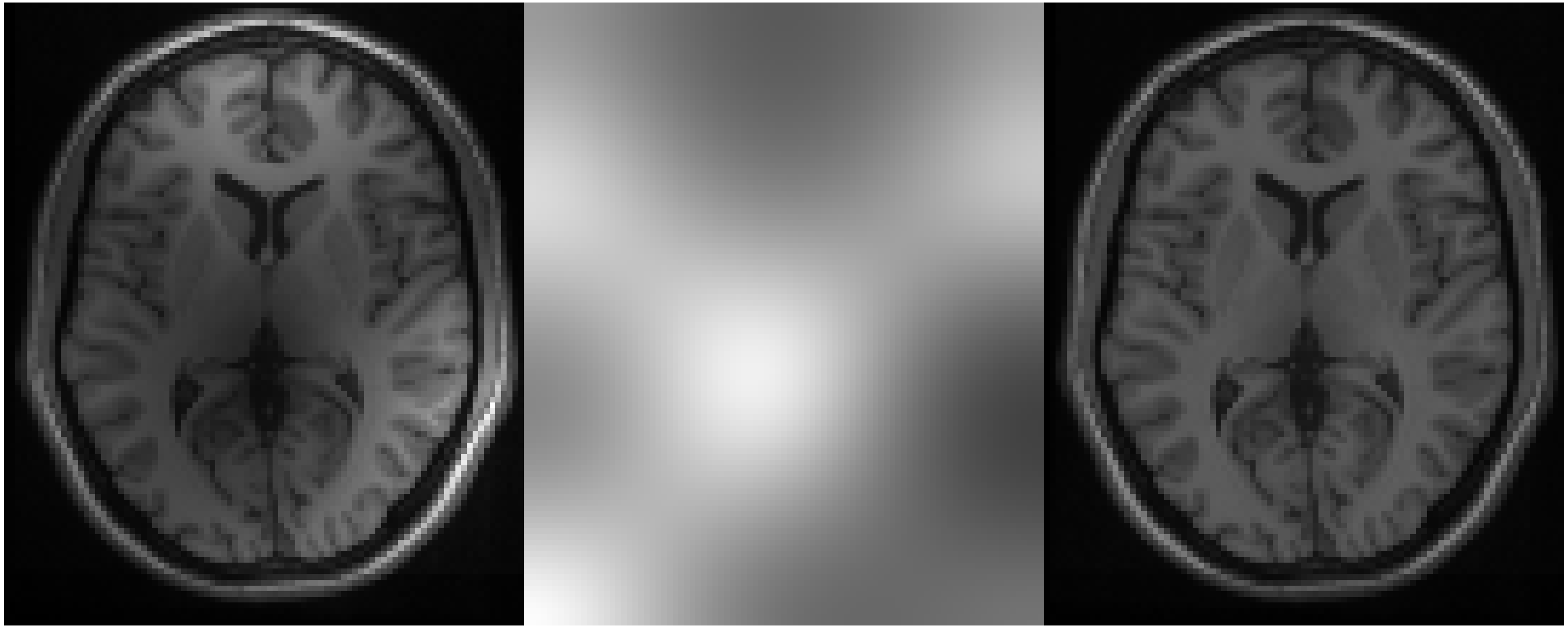
* Multiple Gaussians per tissue class allow non-Gaussian intensity distributions to be modelled.
  * E.g. accounting for partial volume effects



Modelling a Bias Field



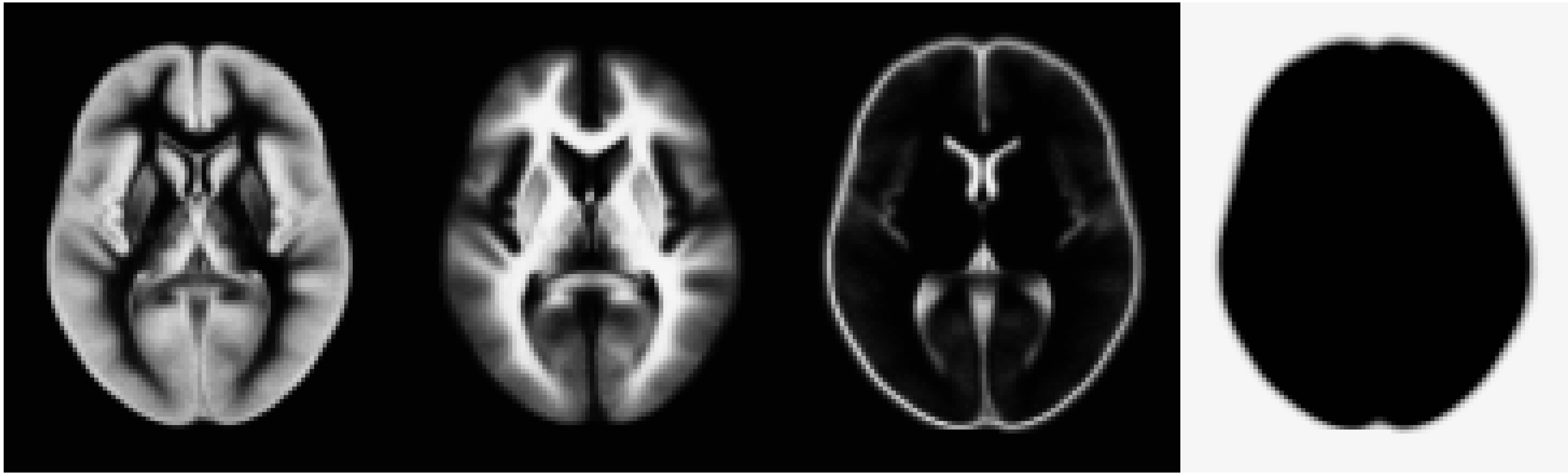
* A bias field is modelled as a linear combination of basis functions.



Corrupted image   Bias Field   Corrected image

Tissue Probability Maps

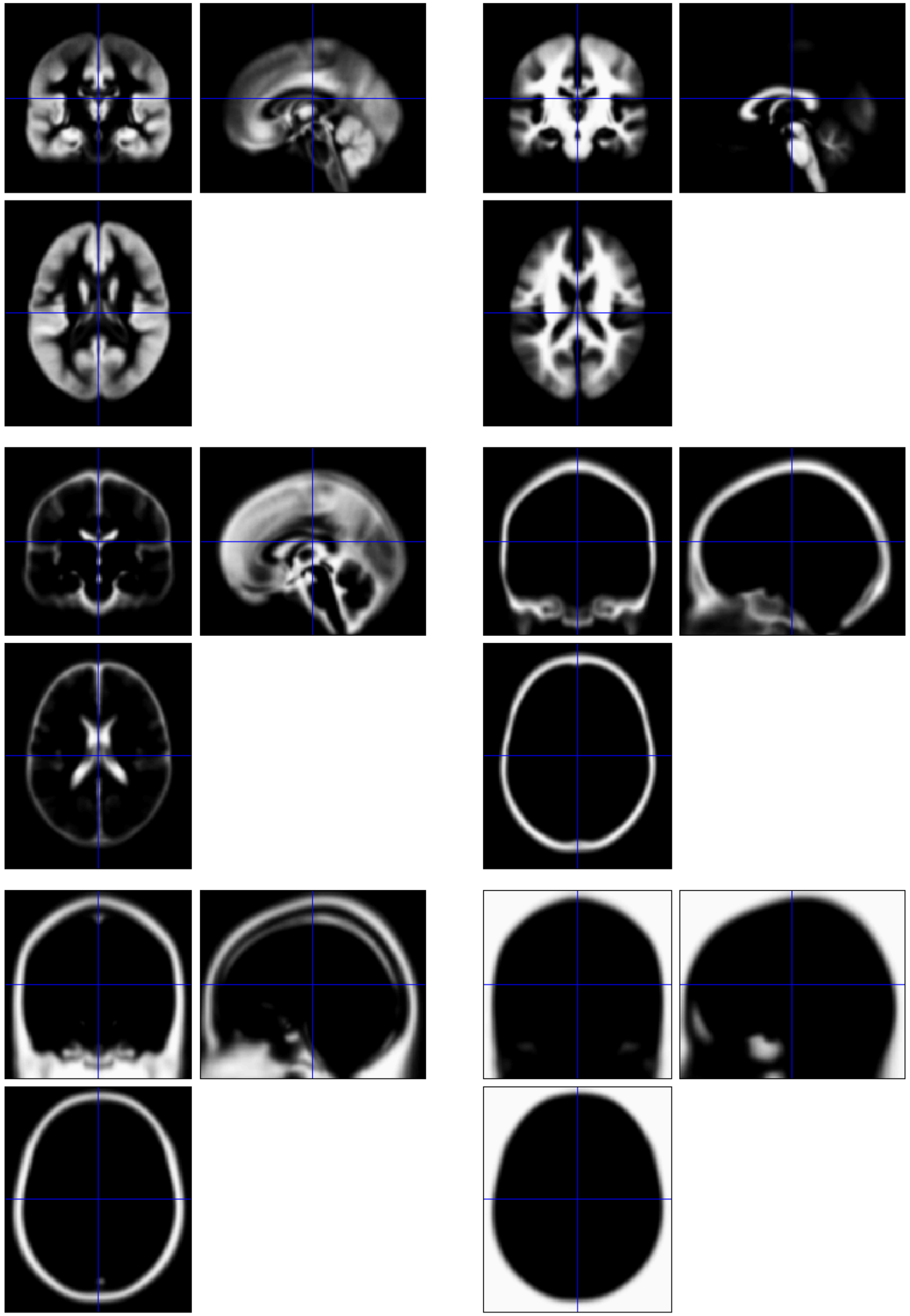
* Tissue probability maps (TPMs) are used instead of the proportion of voxels in each Gaussian as the prior.

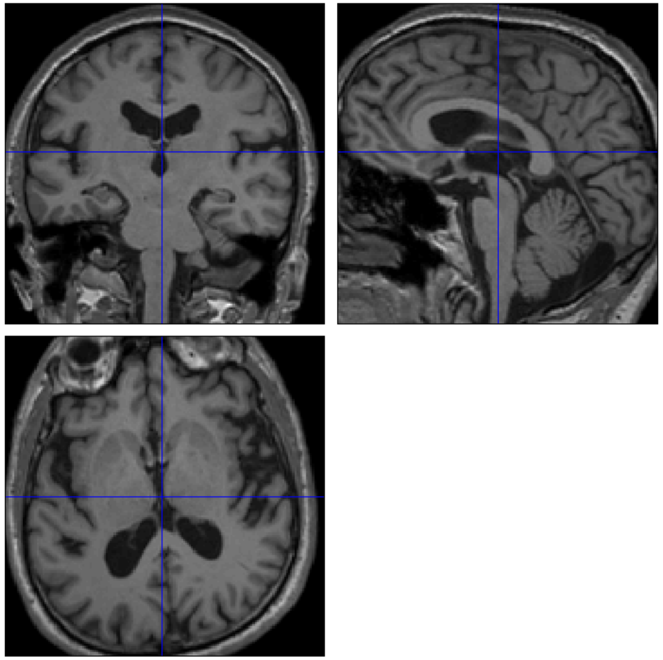


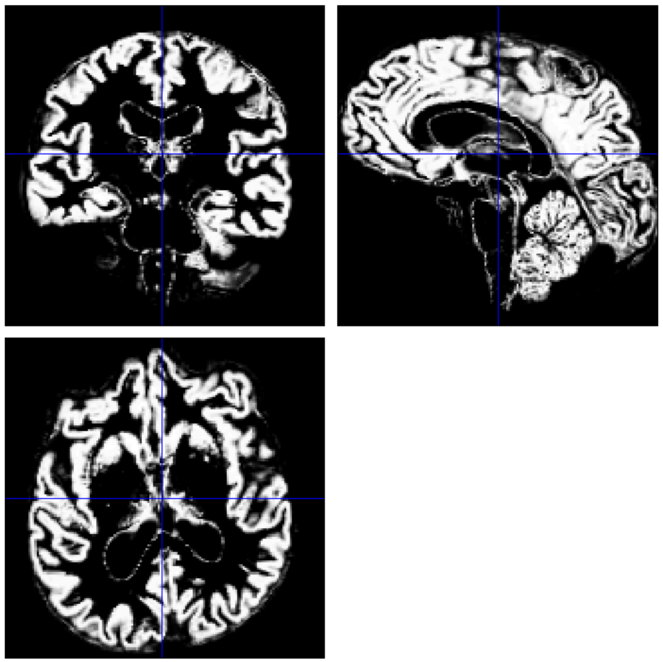
ICBM Tissue Probabilistic Atlases. These tissue probability maps are kindly provided by the **International Consortium for Brain Mapping**, John C. Mazziotta and Arthur W. Toga.

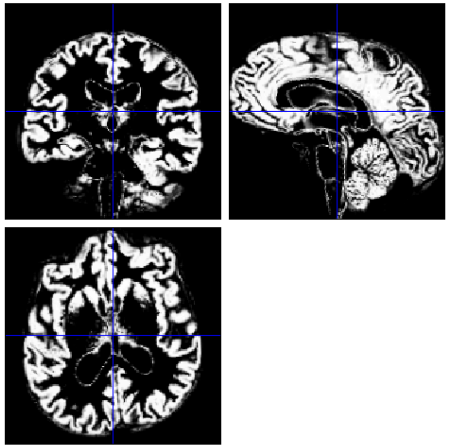
Tissue Probability Maps for “New Segment”

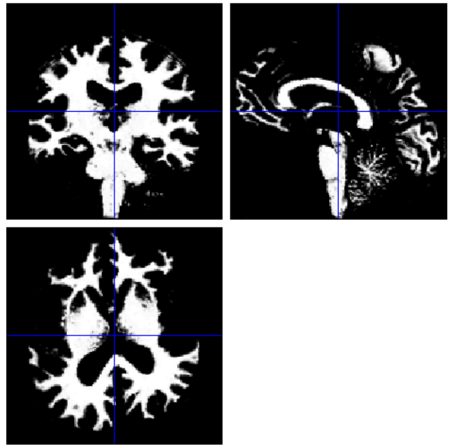
Includes additional non-brain tissue classes (bone, and soft tissue)

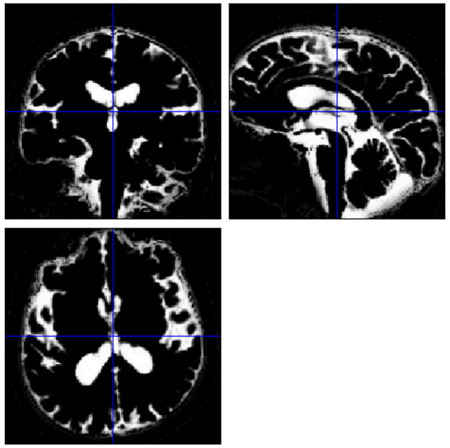


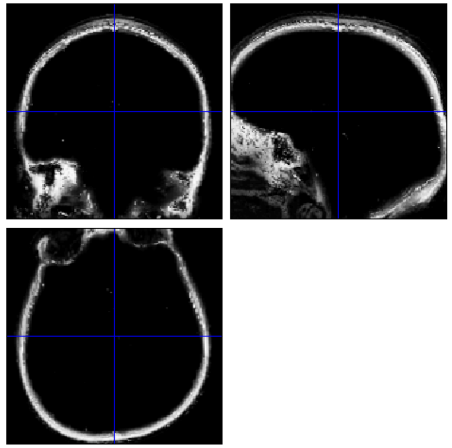


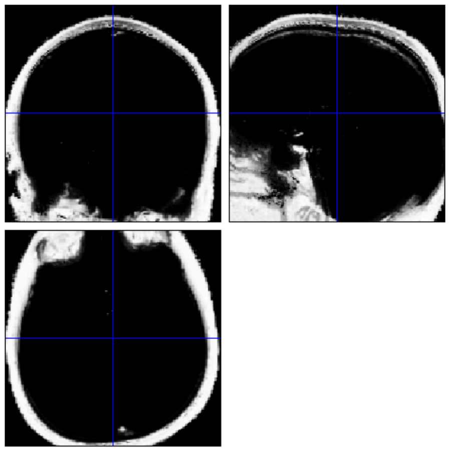


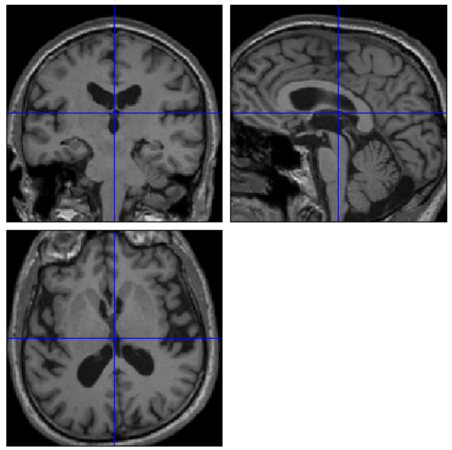






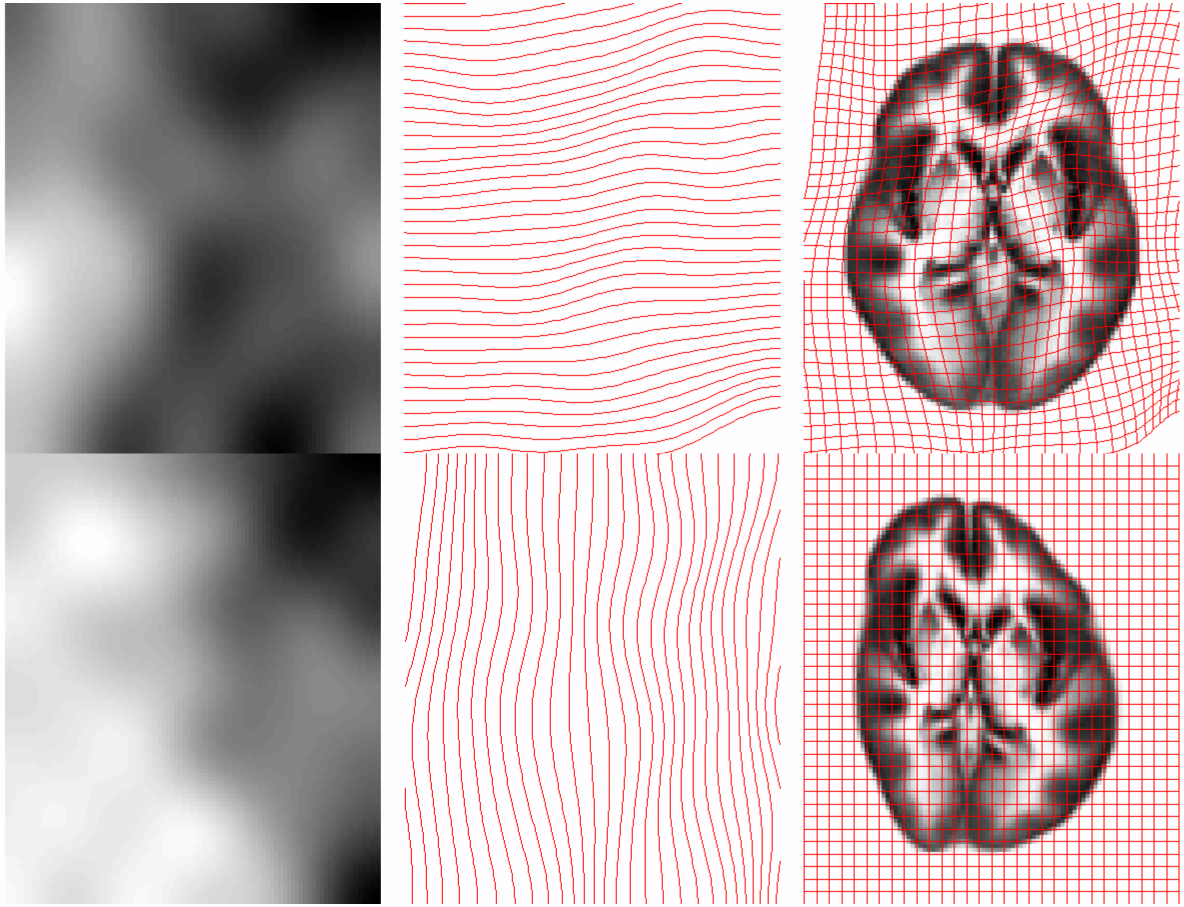






Deforming the Tissue Probability Maps

* Tissue probability images are deformed so that they can be overlaid on top of the image to segment.

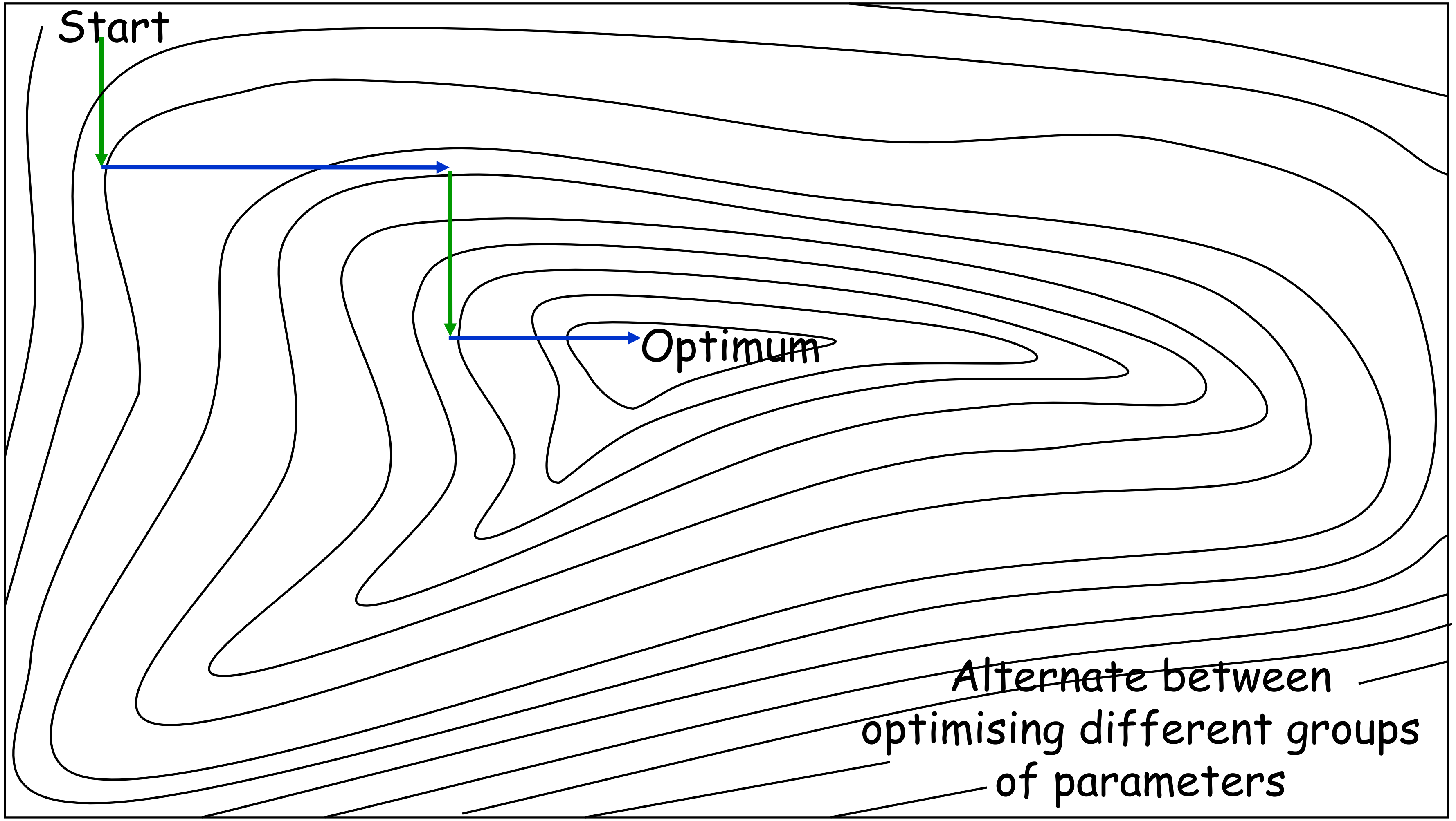


Optimisation

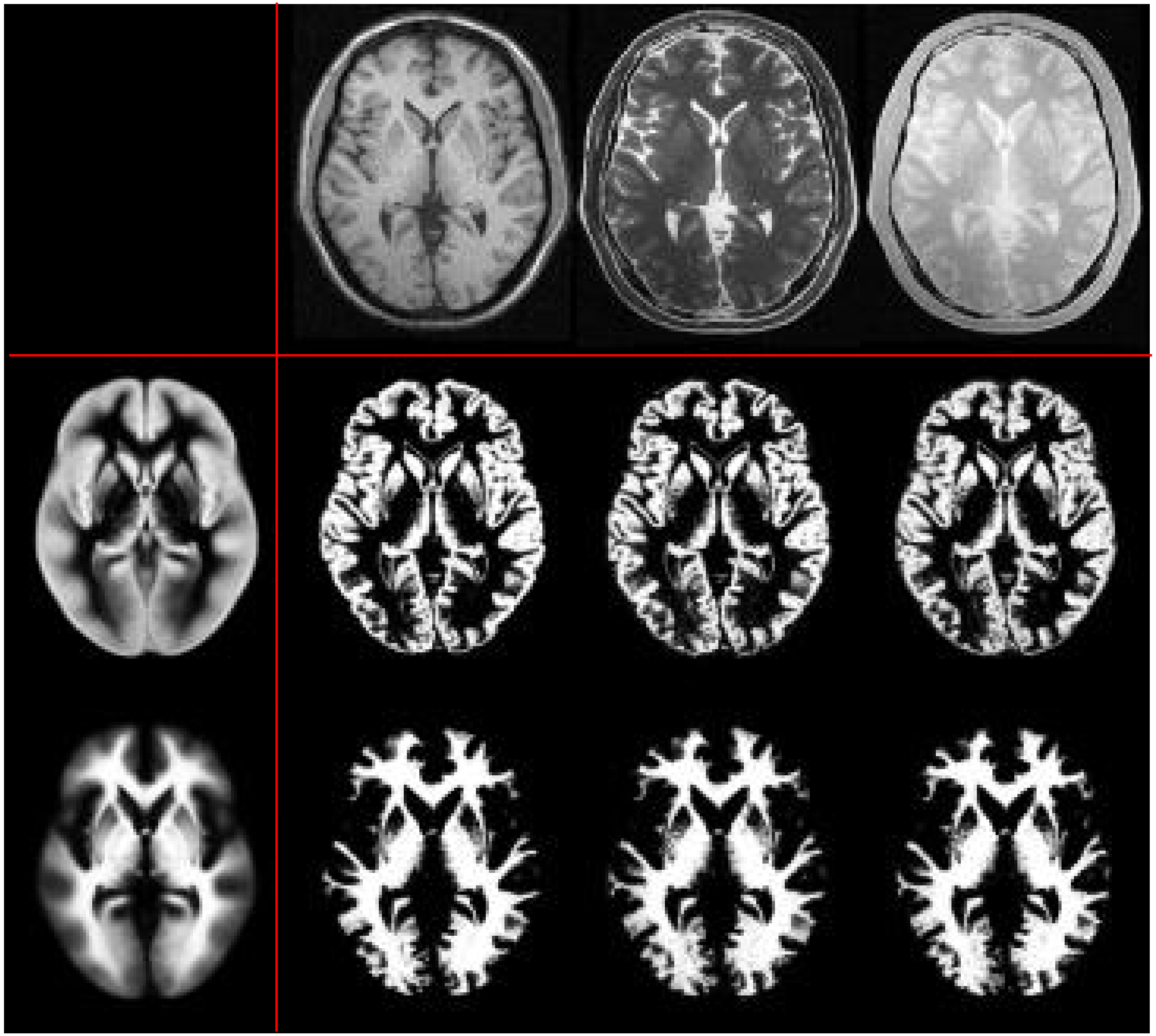
* The "best" parameters are those that minimise this objective function.
* Optimisation involves finding them.
* Begin with starting estimates, and repeatedly change them so that the objective function decreases each time.

$$E = -\sum_{i=1}^{I} \log\left[\rho_i(\beta)\sum_{k=1}^{K}\frac{\gamma_k b_{ik}(\alpha)}{\sum_{j=1}^{K}\gamma_j b_{ij}(\alpha)}\frac{1}{\sqrt{2\pi\sigma_k^2}}\exp\left(-\frac{(\rho_i(\beta)y_i-\mu_k)^2}{2\sigma_k^2}\right)\right]$$

Steepest Descent



Spatially normalised BrainWeb phantoms (T1, T2 and PD)



Tissue probability maps of GM and WM

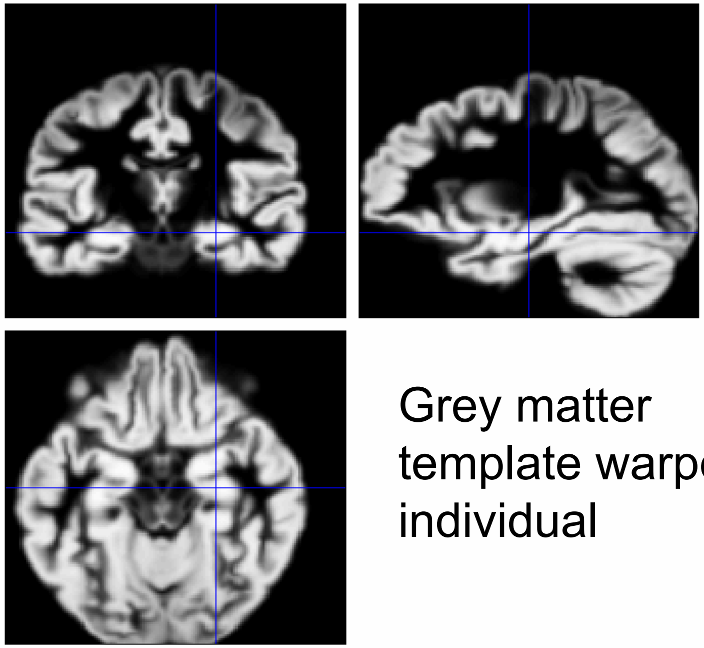
Cocosco, Kollokian, Kwan & Evans. "*BrainWeb: Online Interface to a 3D MRI Simulated Brain Database*". NeuroImage 5(4):S425 (1997)

Contents

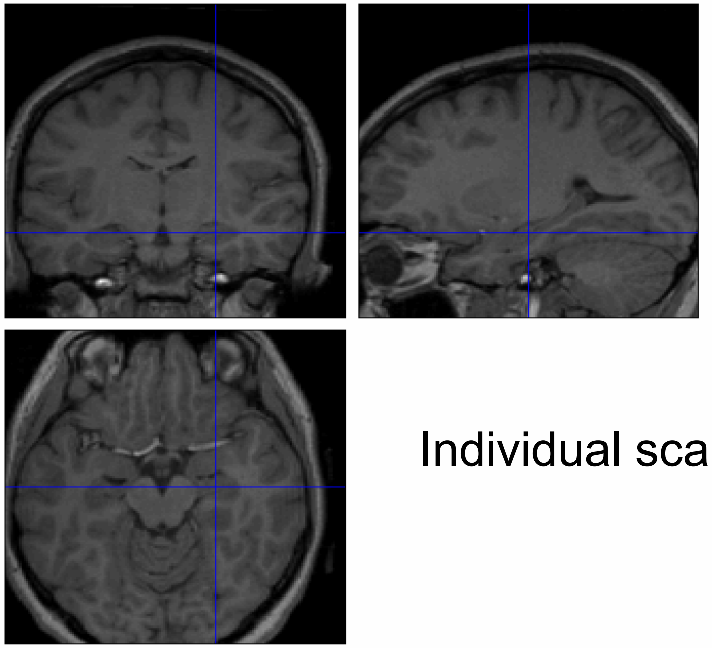
* Segment
* **DARTEL**
  * **Flow field parameterisation**
  * **Objective function**
  * **Template creation**
  * **Examples**
* Smooth

DARTEL Image Registration

* Uses fast approximations
  * Deformation integrated using scaling and squaring
* Uses Levenberg-Marquardt optimiser
  * Multi-grid matrix solver
* Matches GM with GM, WM with WM etc
* Diffeomorphic registration takes about 30 mins per image pair (121×145×121 images).

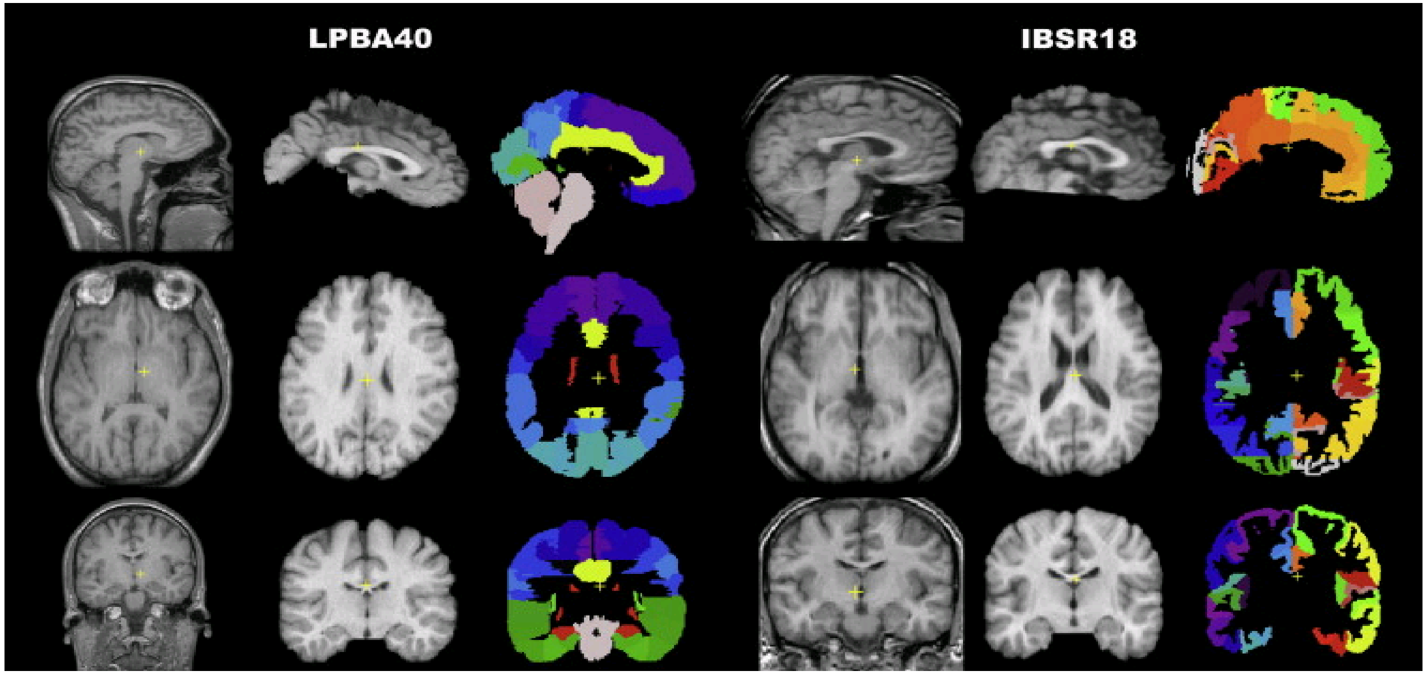


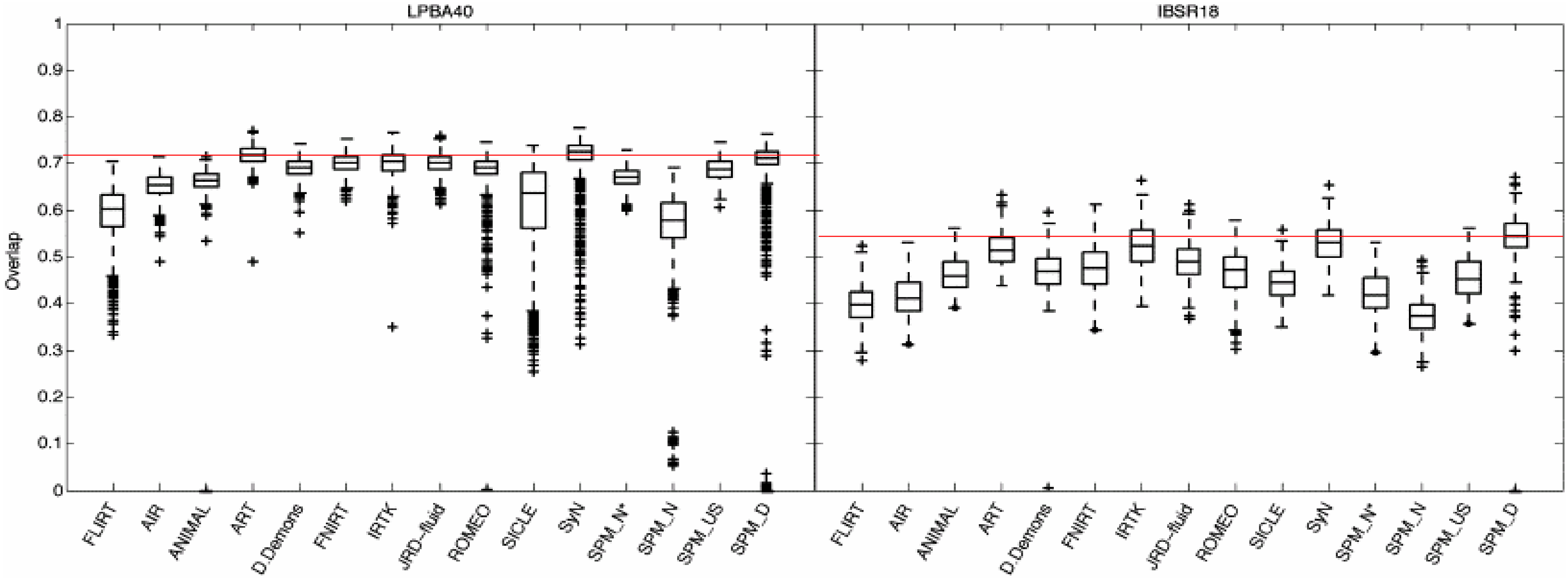
Grey matter template warped to individual



Individual scan

Evaluations of nonlinear registration algorithms

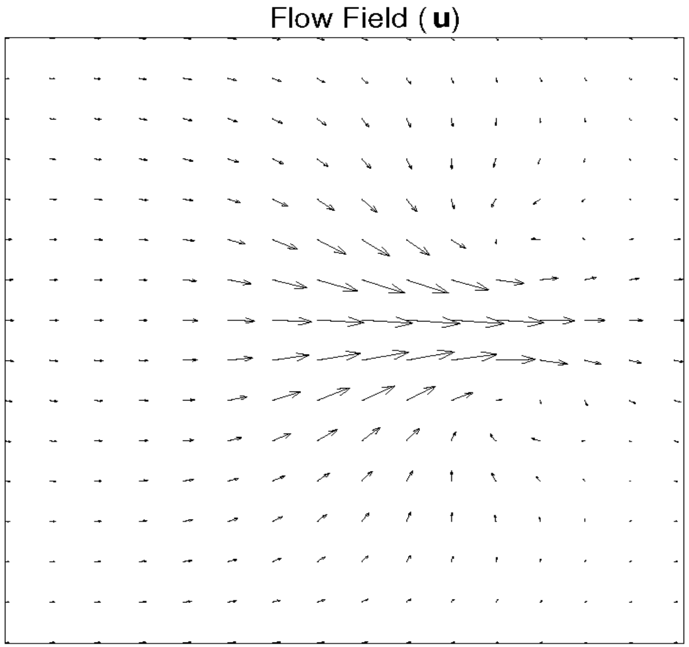


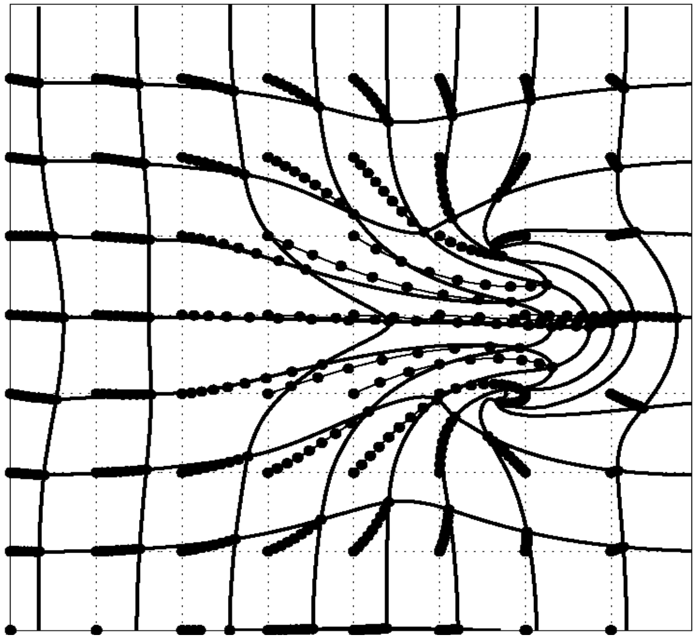


DARTEL

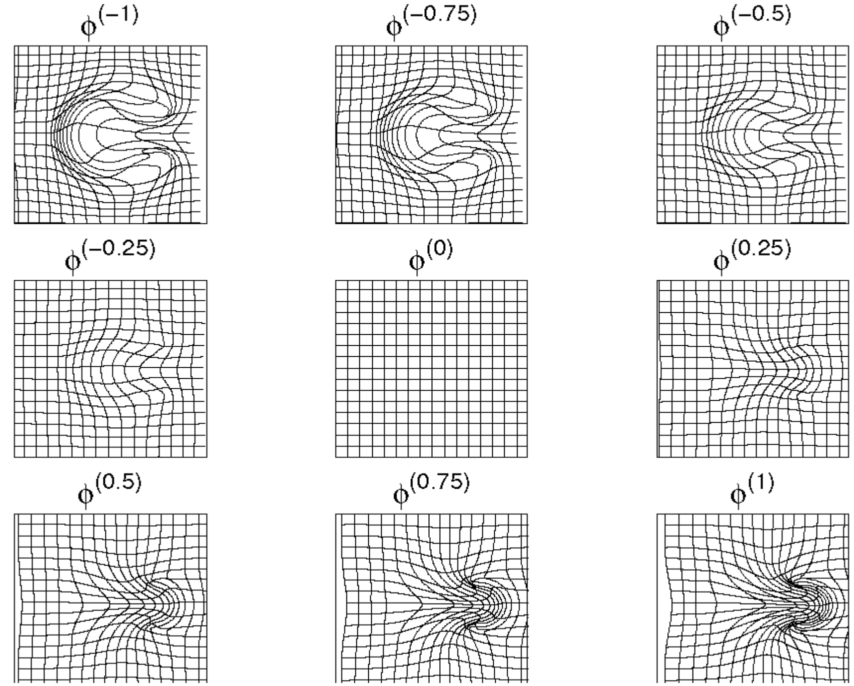
* Parameterising the deformation
* $\boldsymbol{\varphi}^{(0)} = \text{Identity}$
* $\boldsymbol{\varphi}^{(1)} = \int_{t=0}^{1} \mathbf{u}(\boldsymbol{\varphi}^{(t)})dt$
* $\mathbf{u}$ is a flow field to be estimated

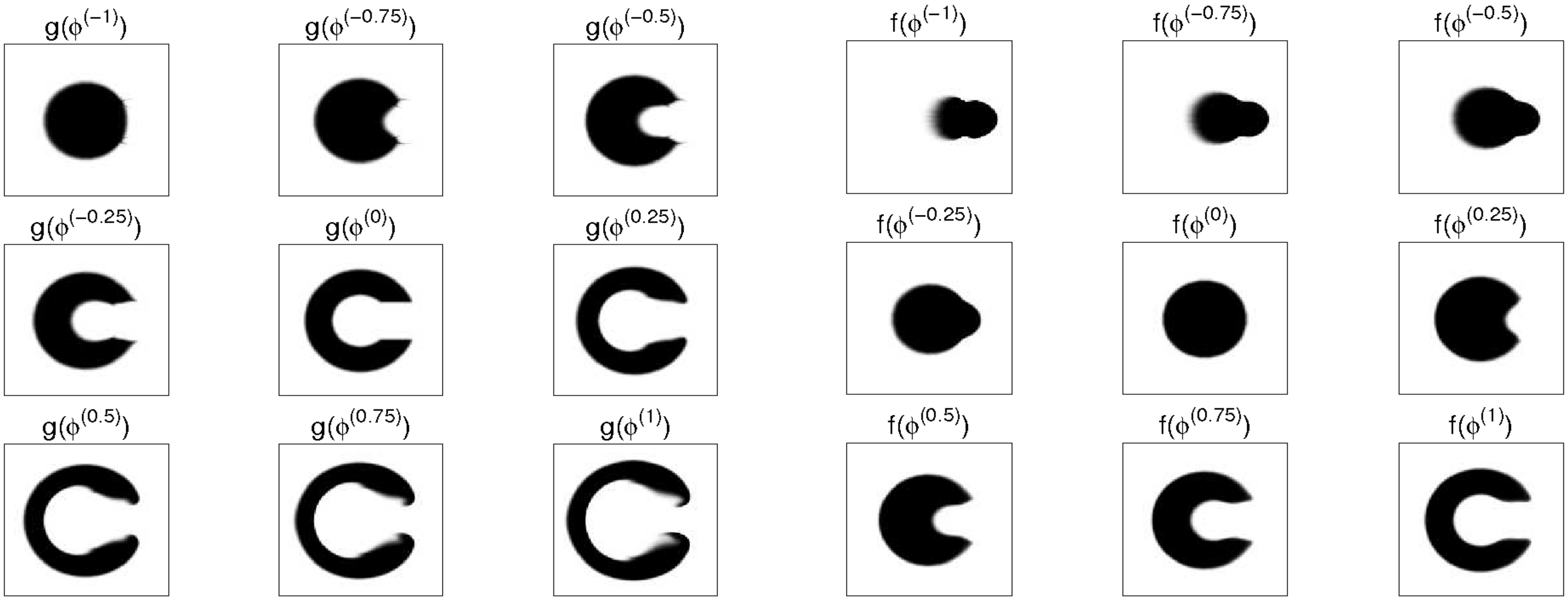
* Scaling and squaring is used to generate deformations.





Forward and backward transforms



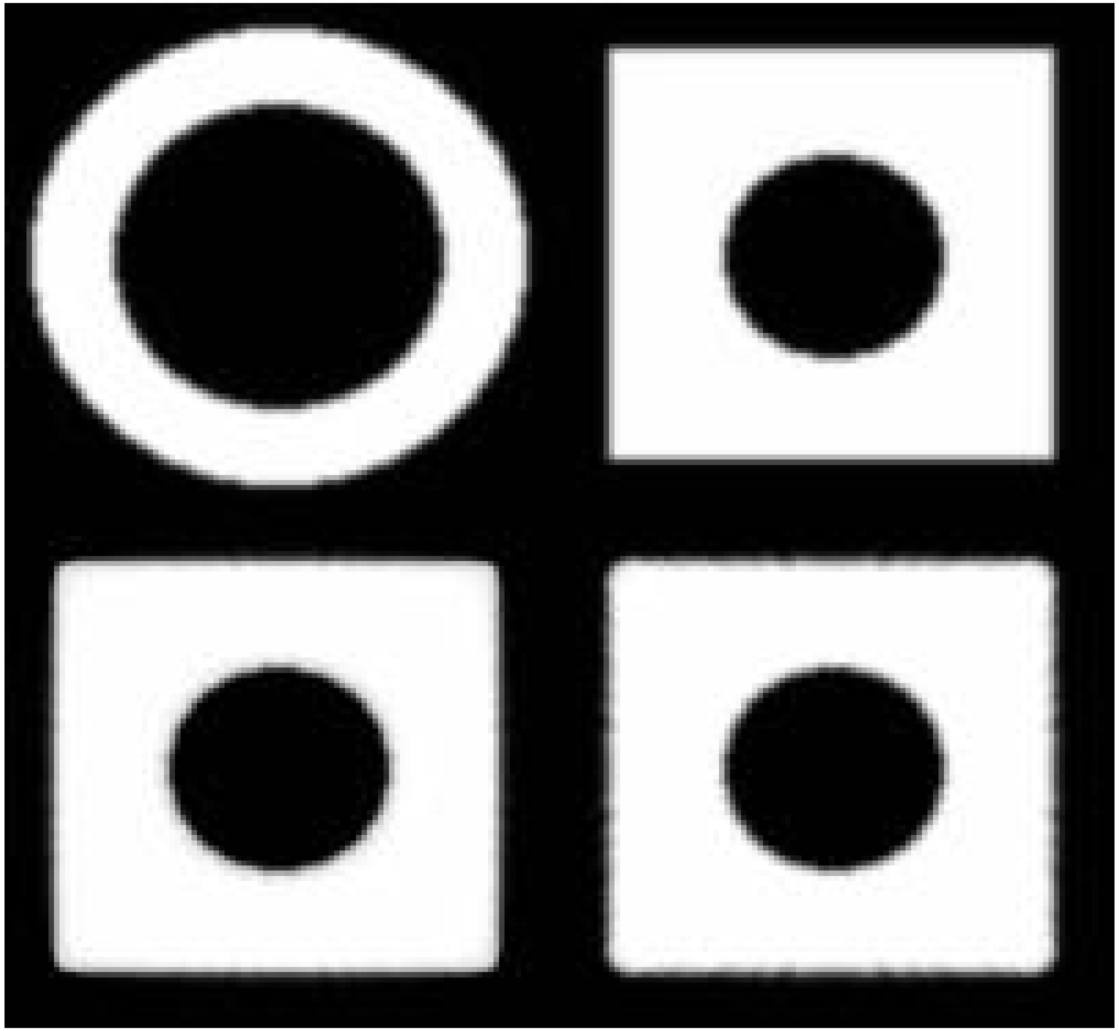


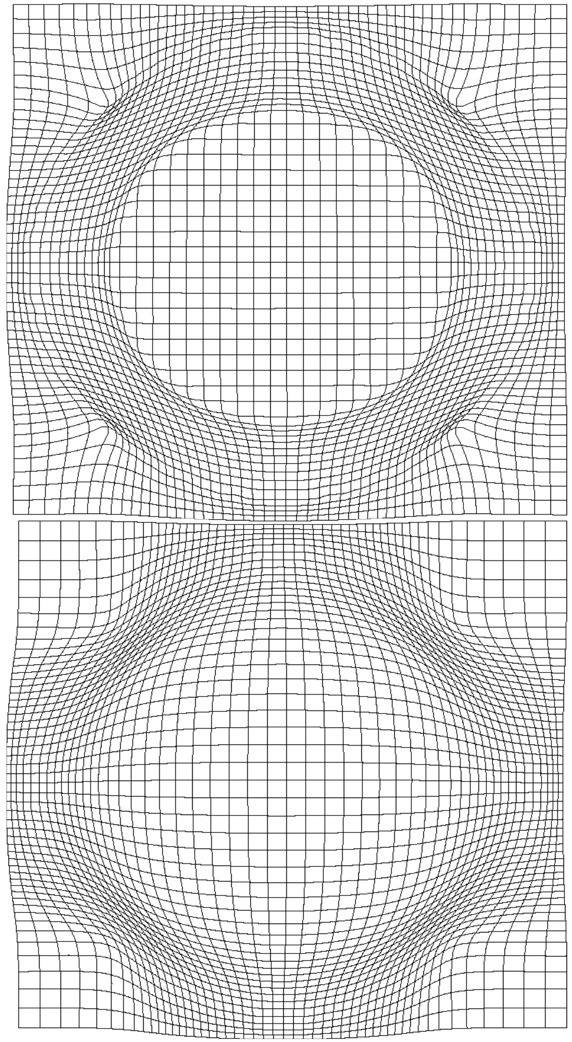
Registration objective function

* Simultaneously minimize the sum of:
    * Matching Term
        * Drives the matching of the images.
        * Multinomial assumption
    * Regularisation term
        * A measure of deformation roughness
        * Regularises the registration.

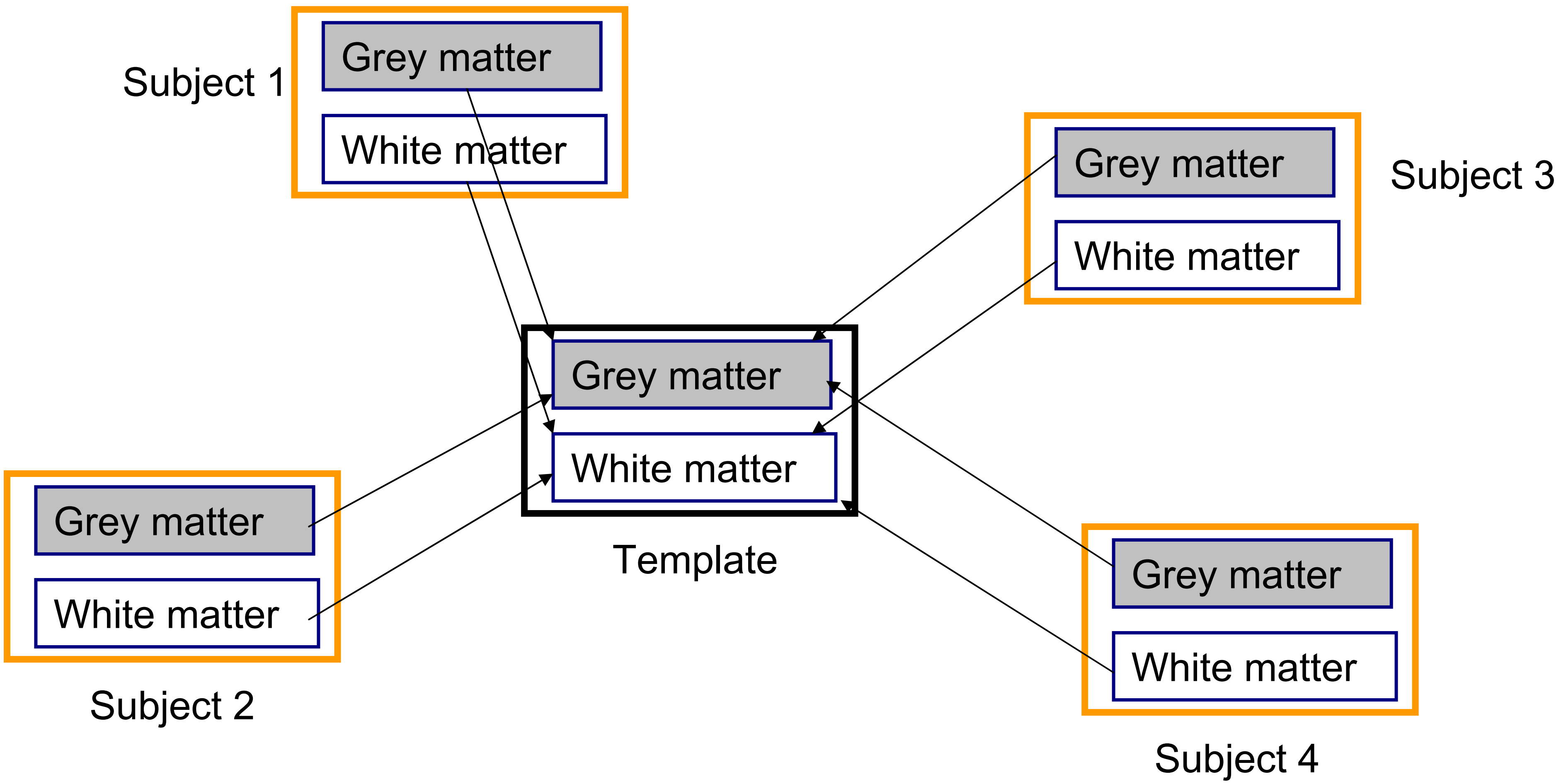
* A balance between the two terms.

Effect of Different Regularisation Terms





Simultaneous registration of GM to GM and WM to WM

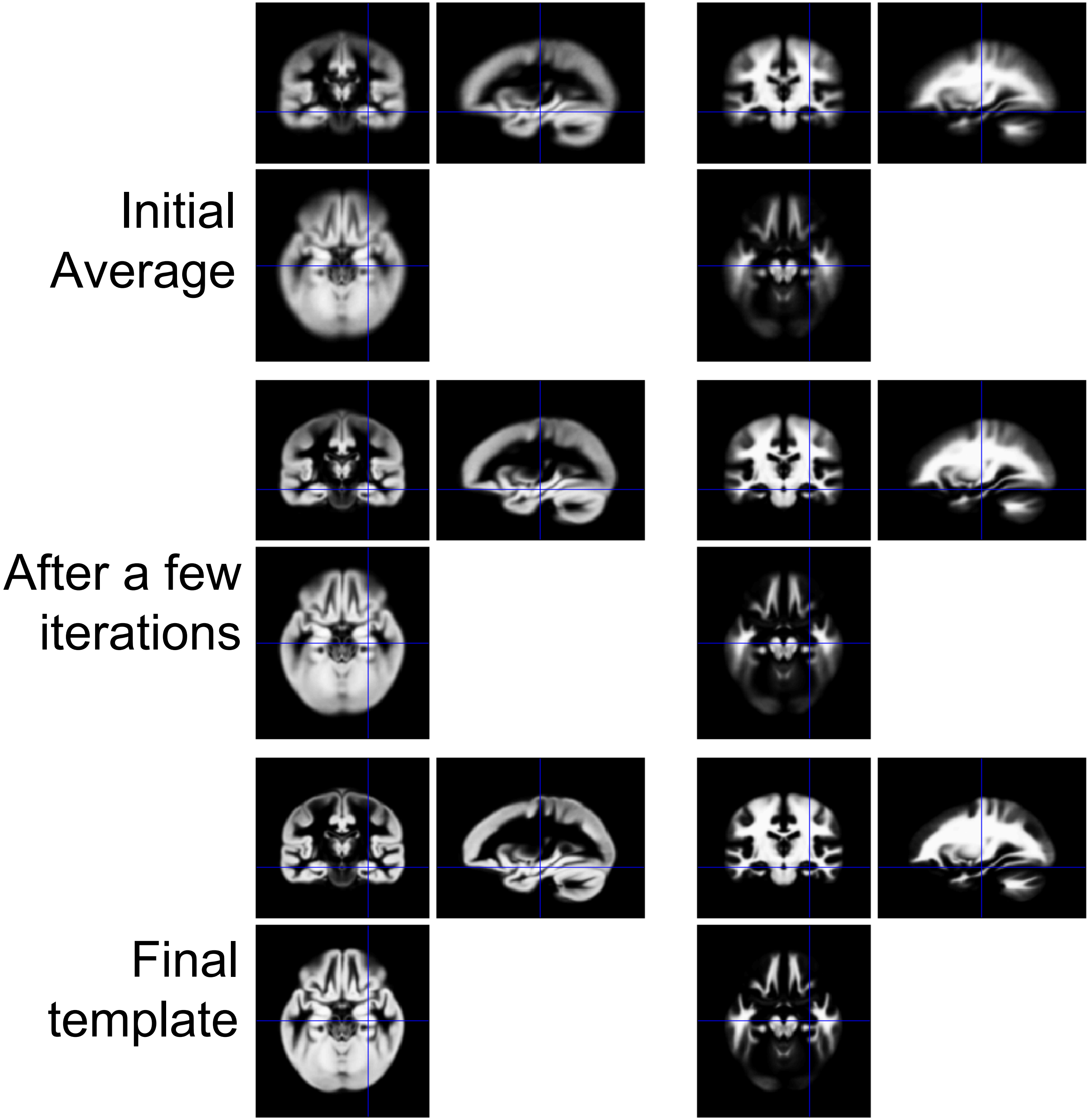


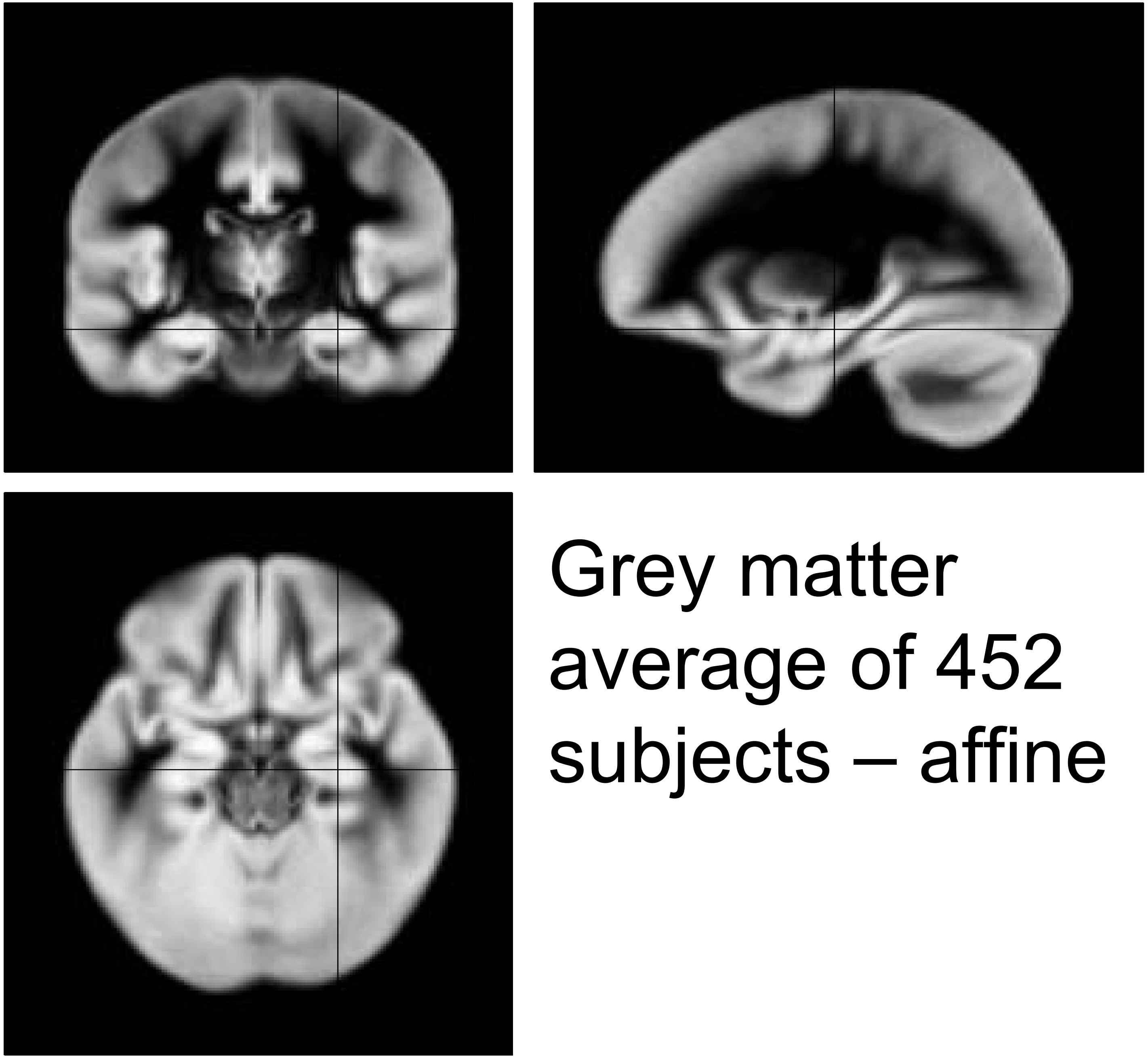
Template

Iteratively generated from 471 subjects

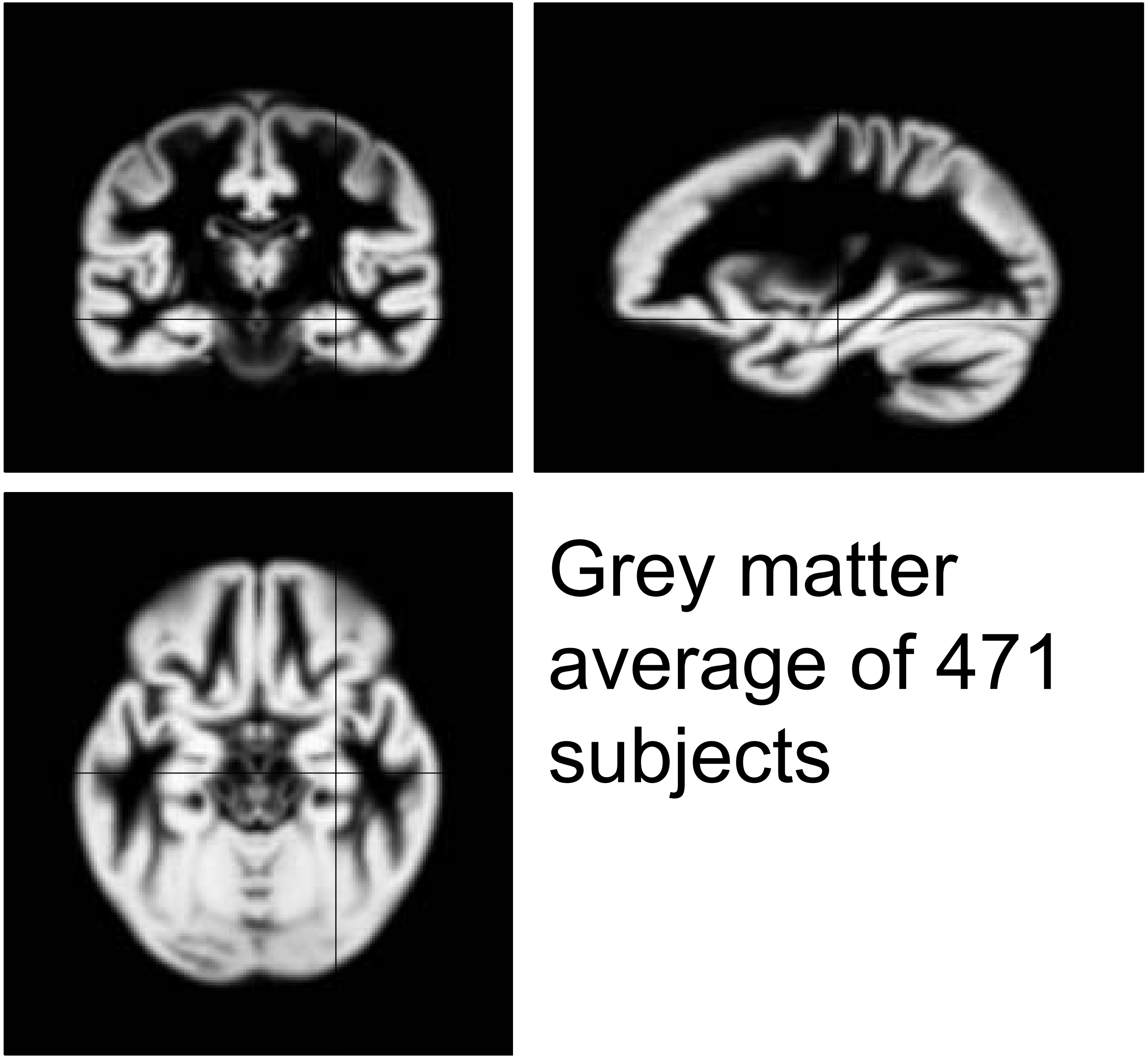
Began with rigidly aligned tissue probability maps

Used an inverse consistent formulation



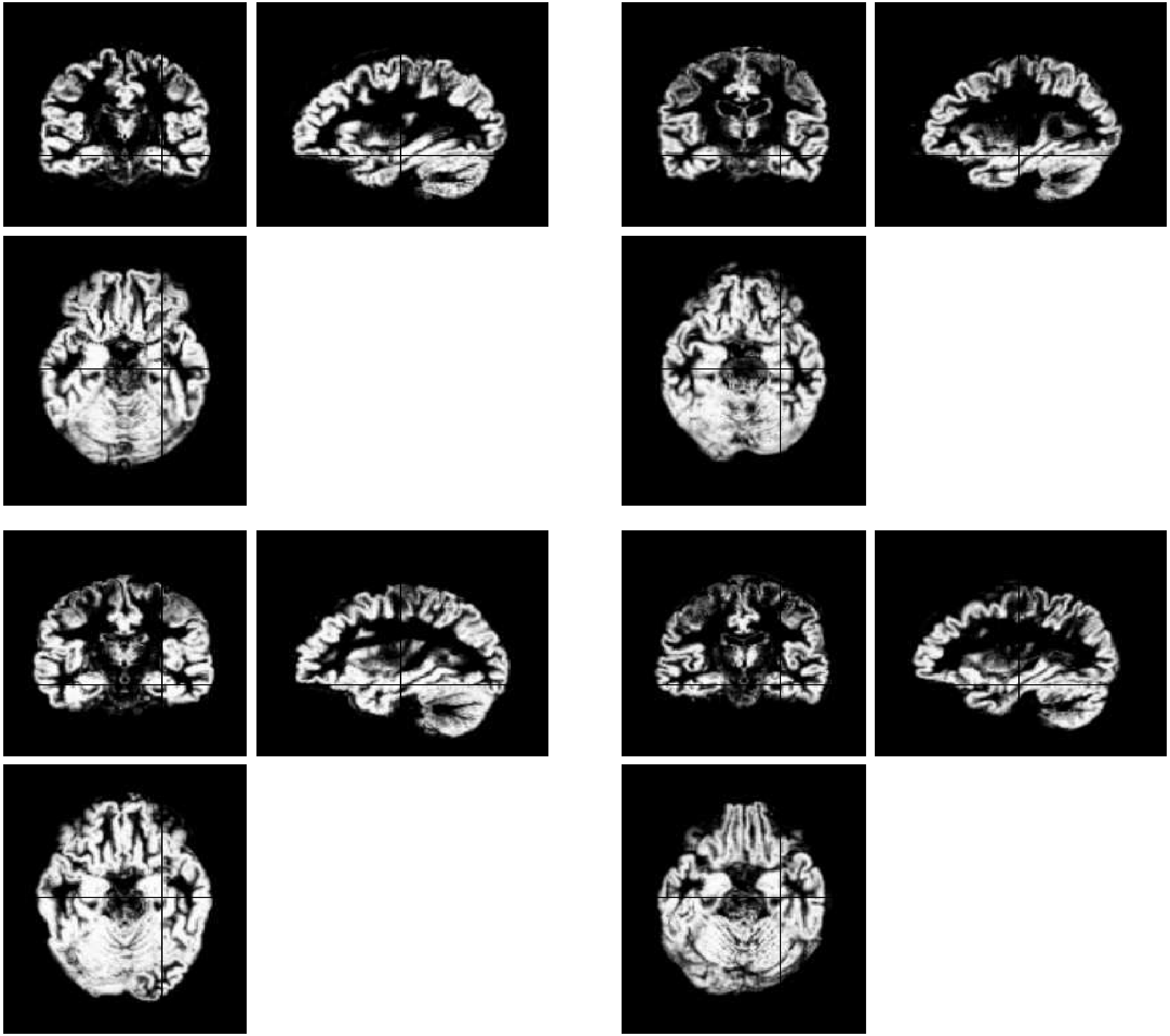


Grey matter average of 452 subjects – affine

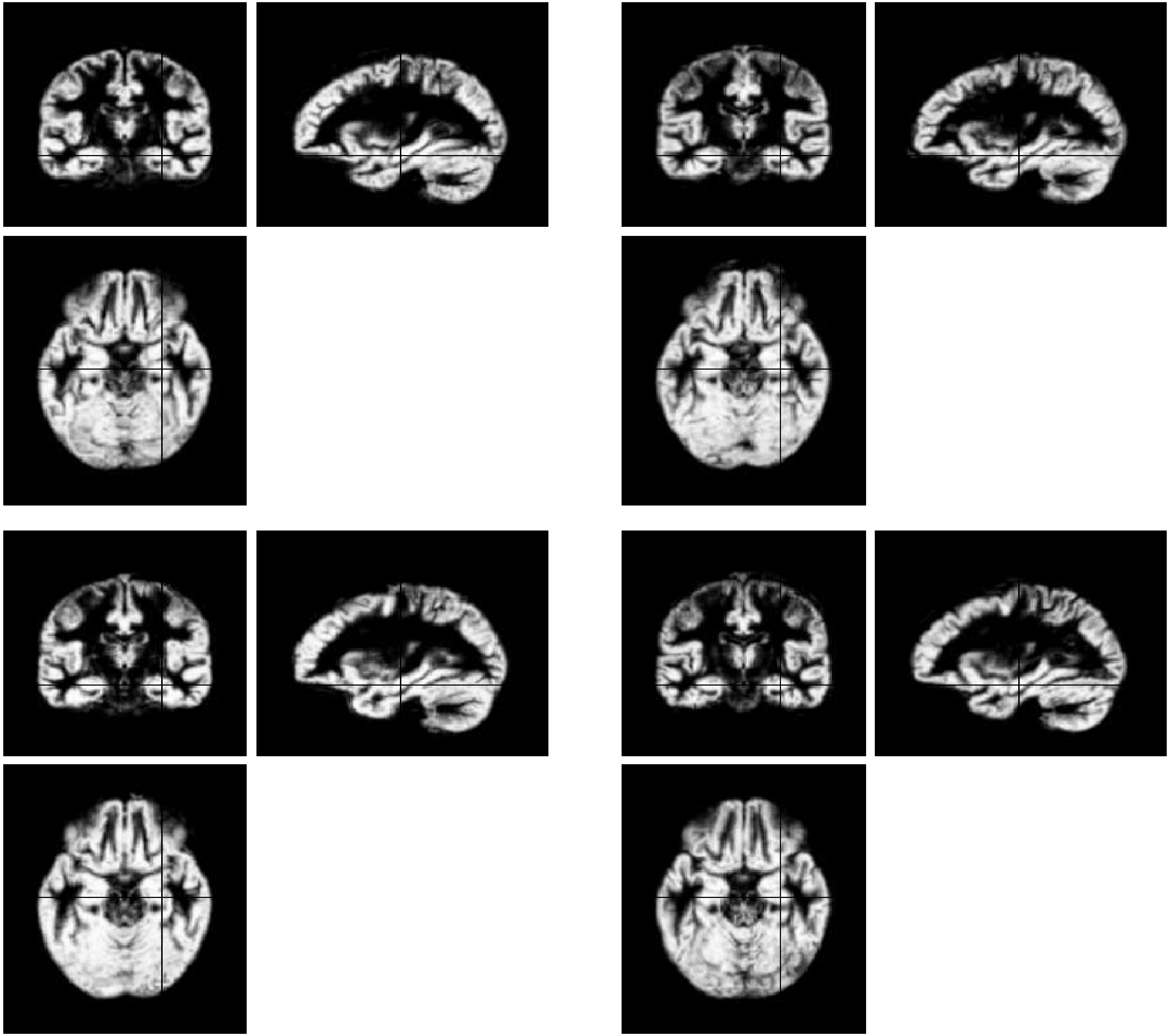


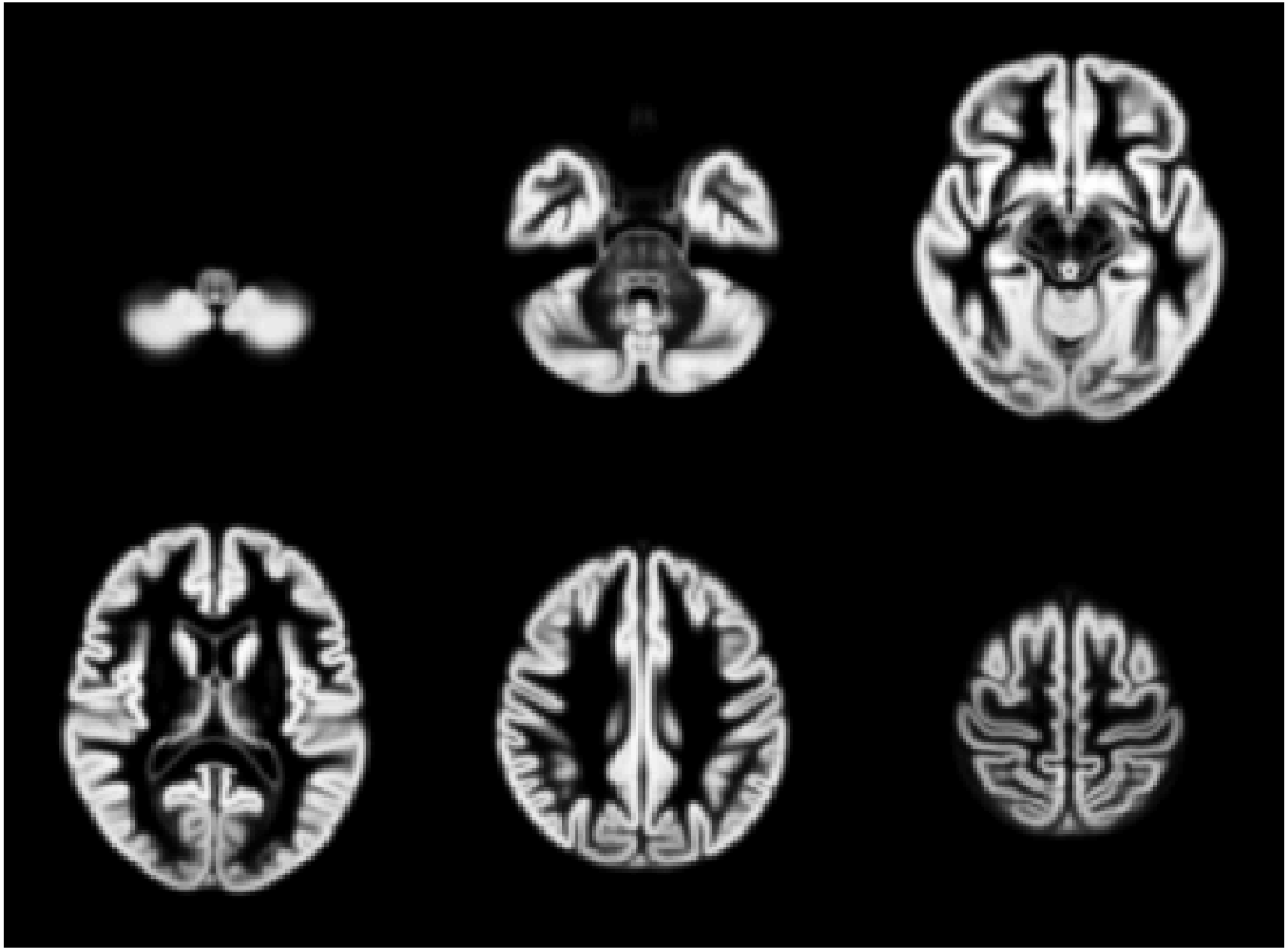
Grey matter average of 471 subjects

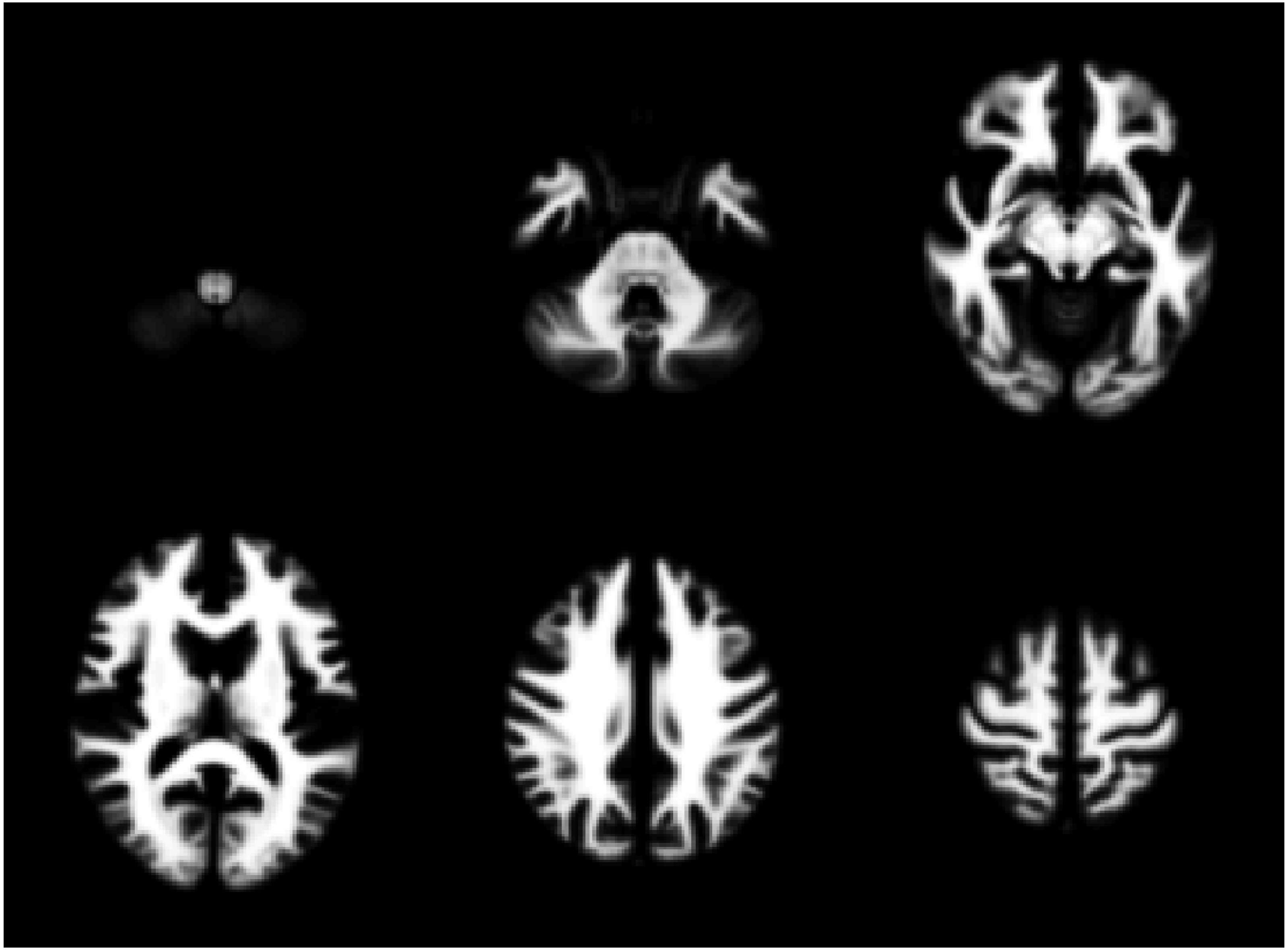
Initial
GM images

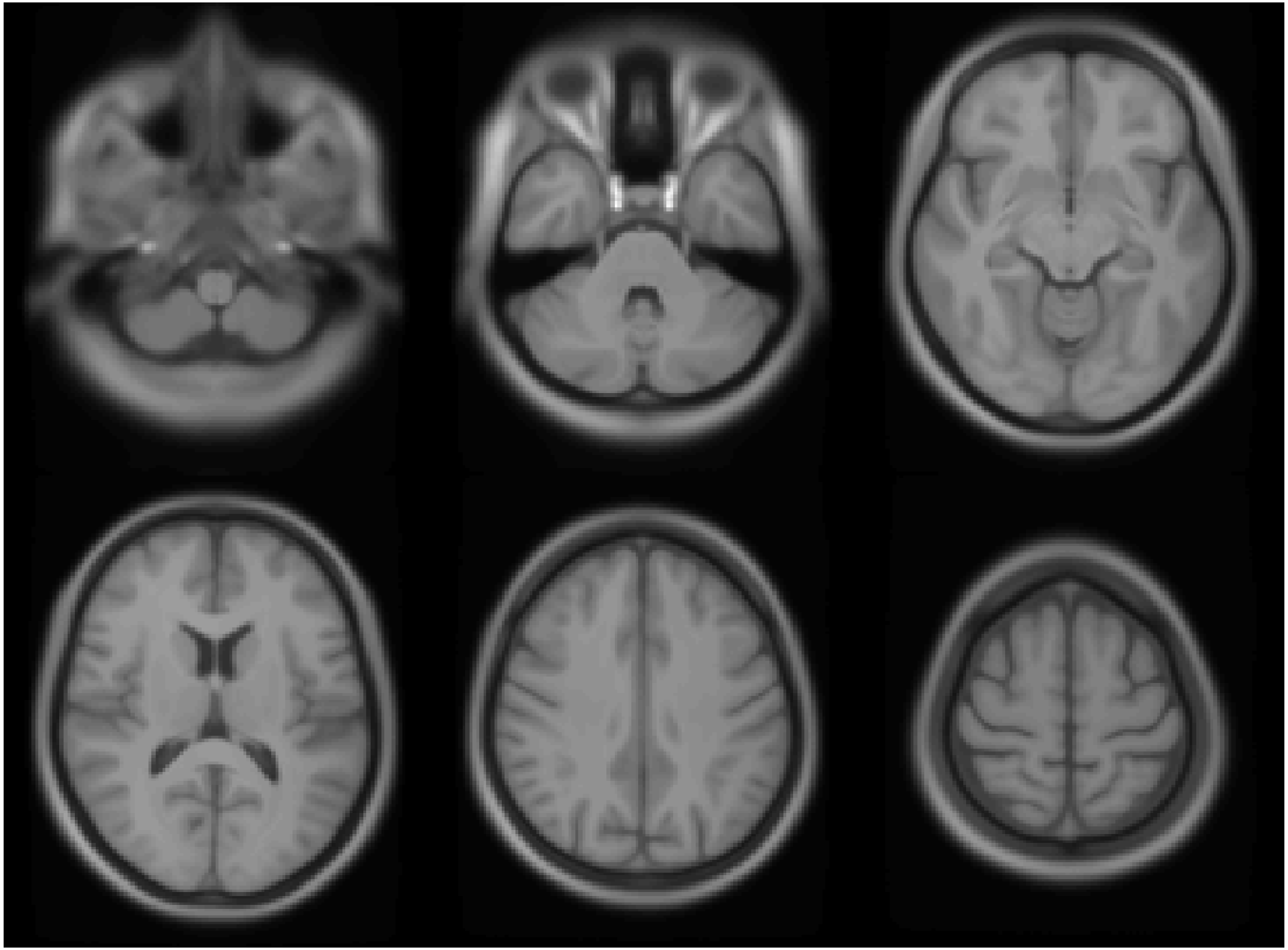


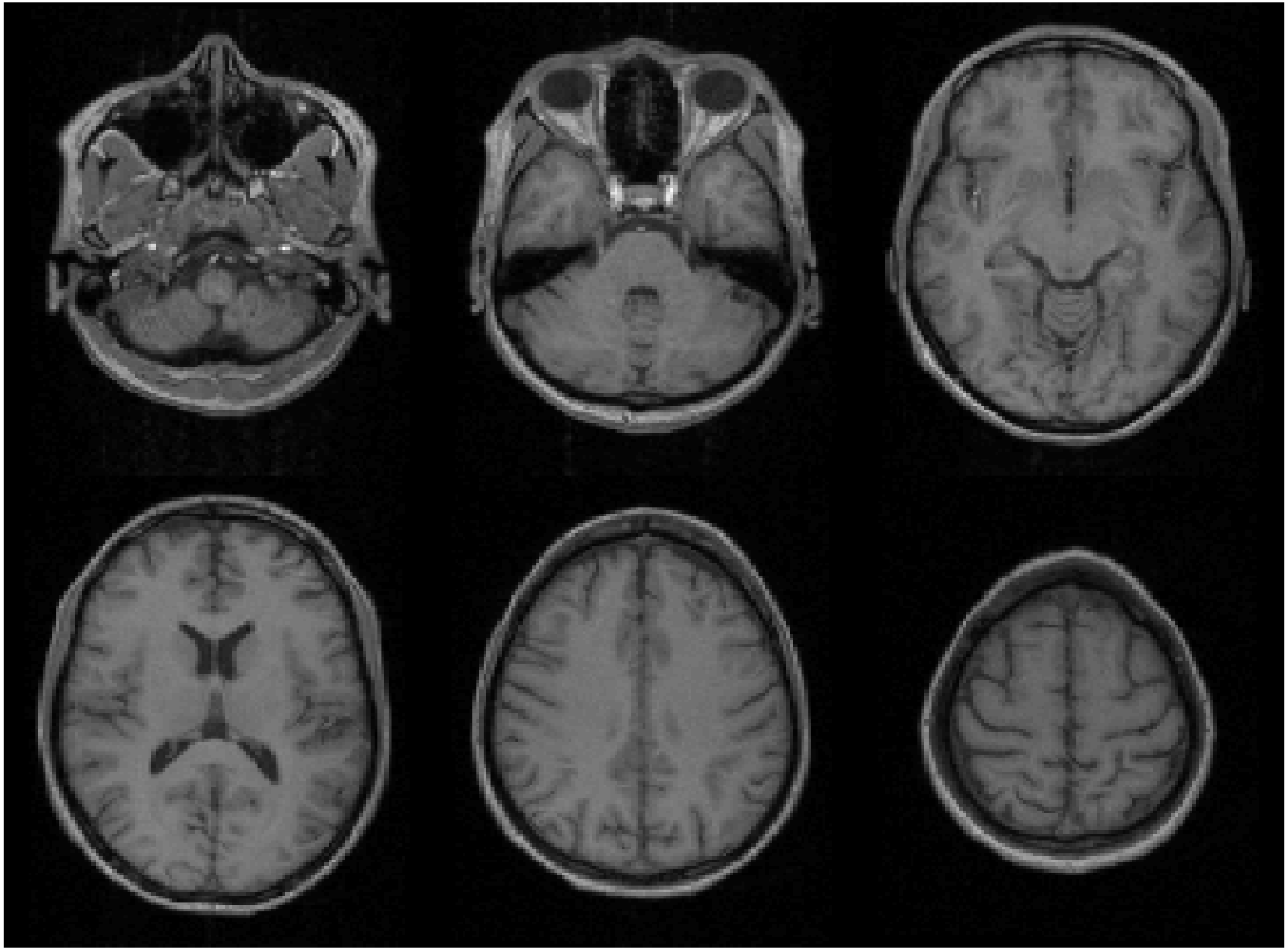
Warped
GM images

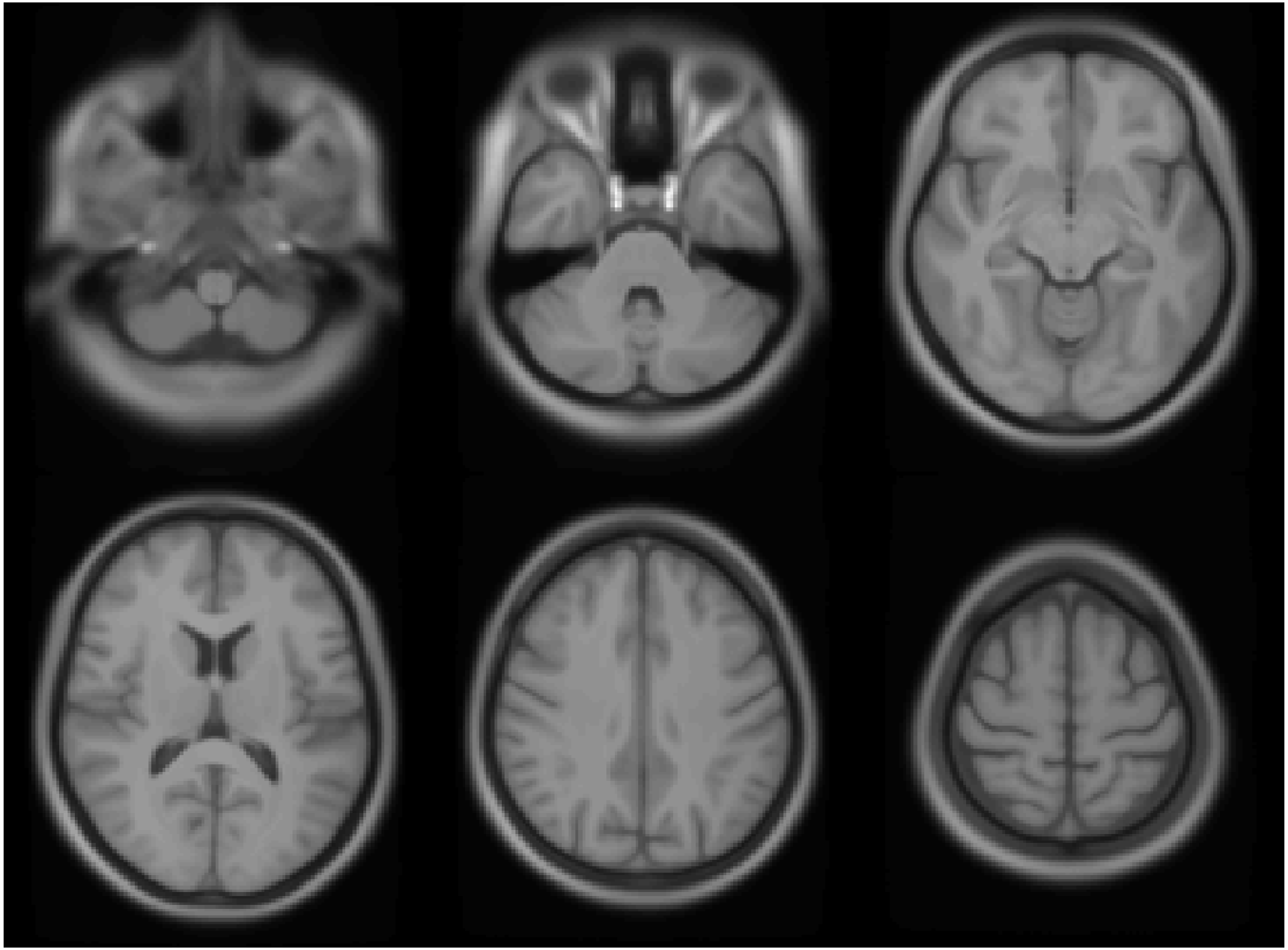


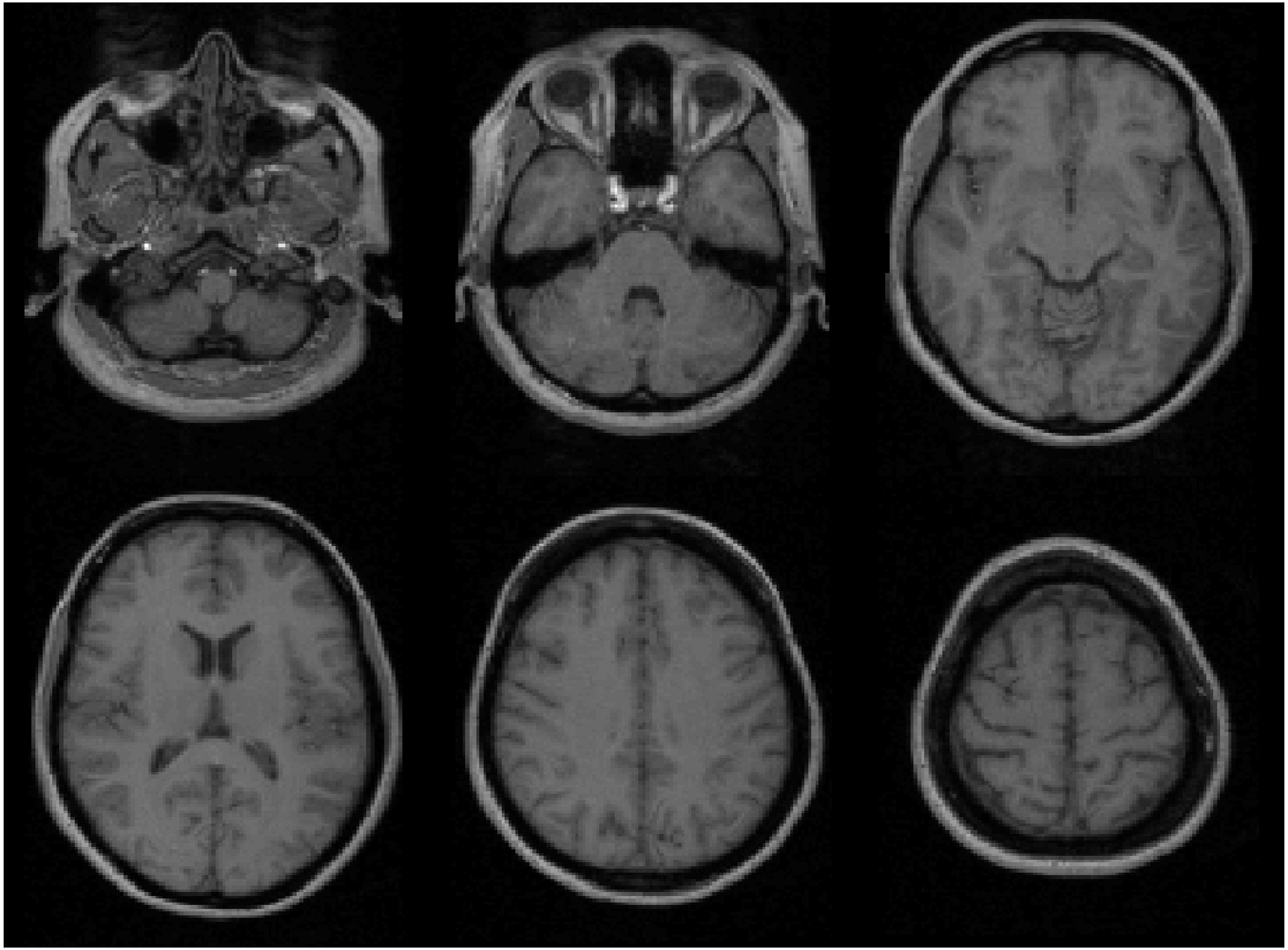


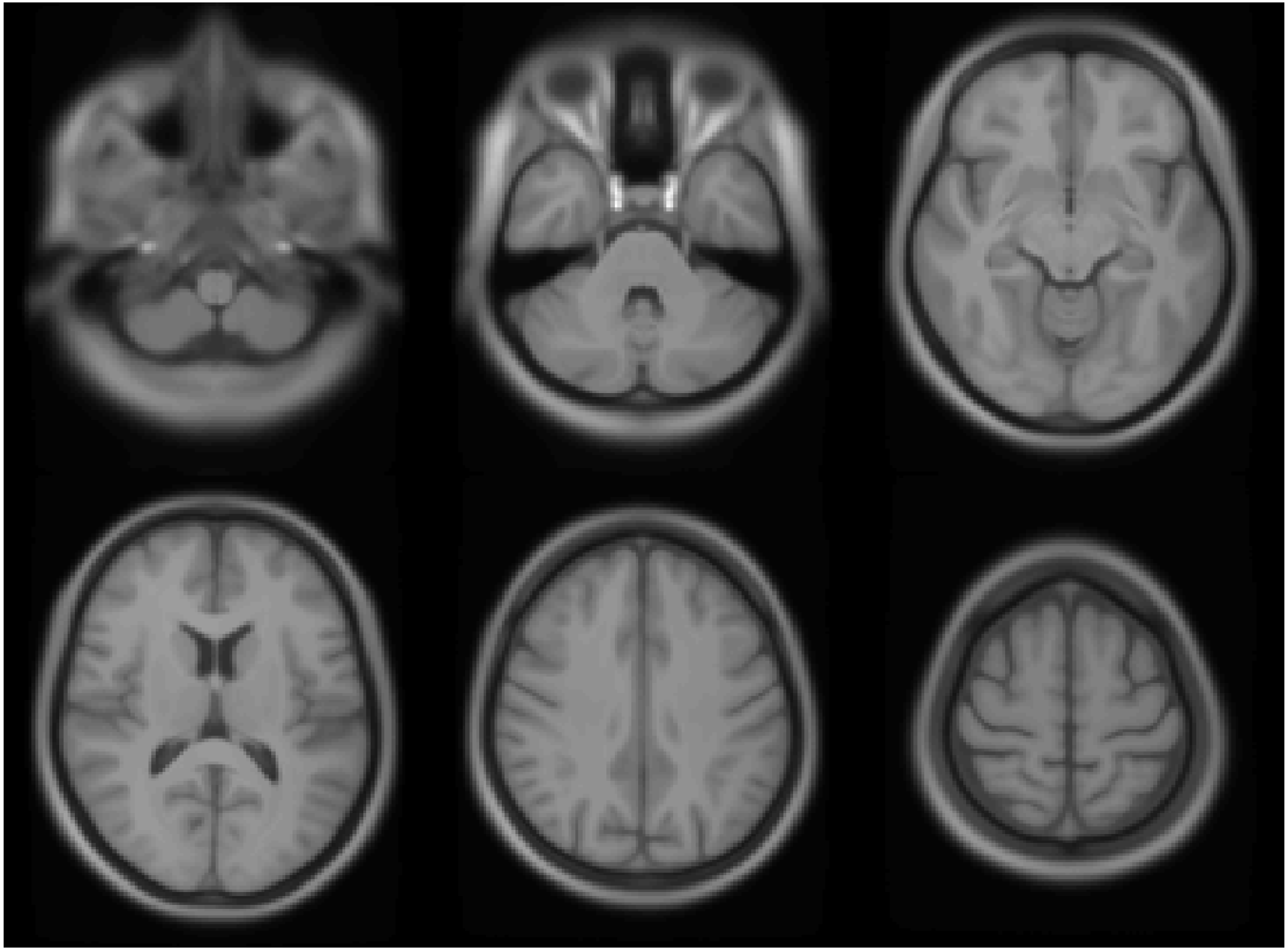


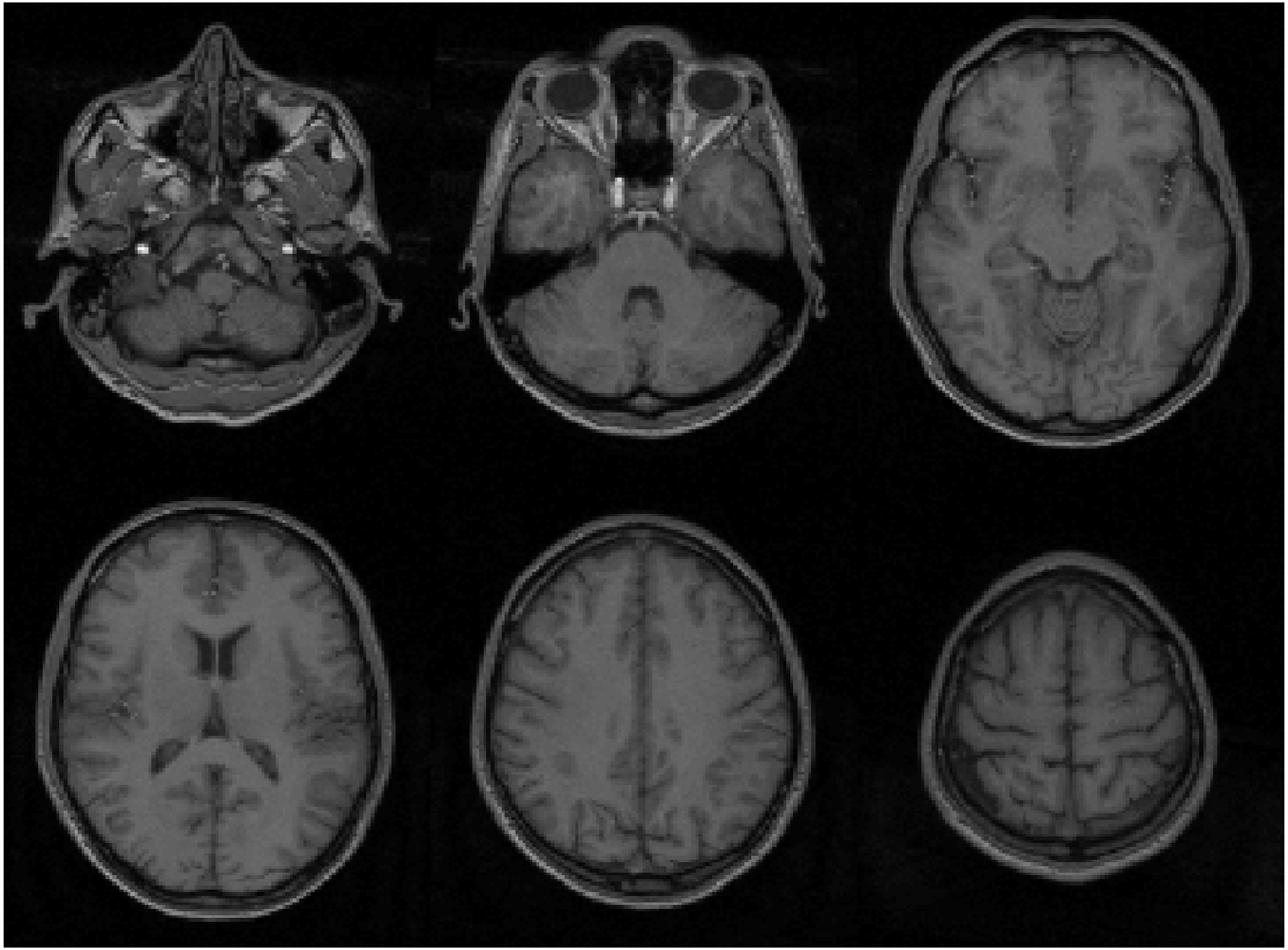


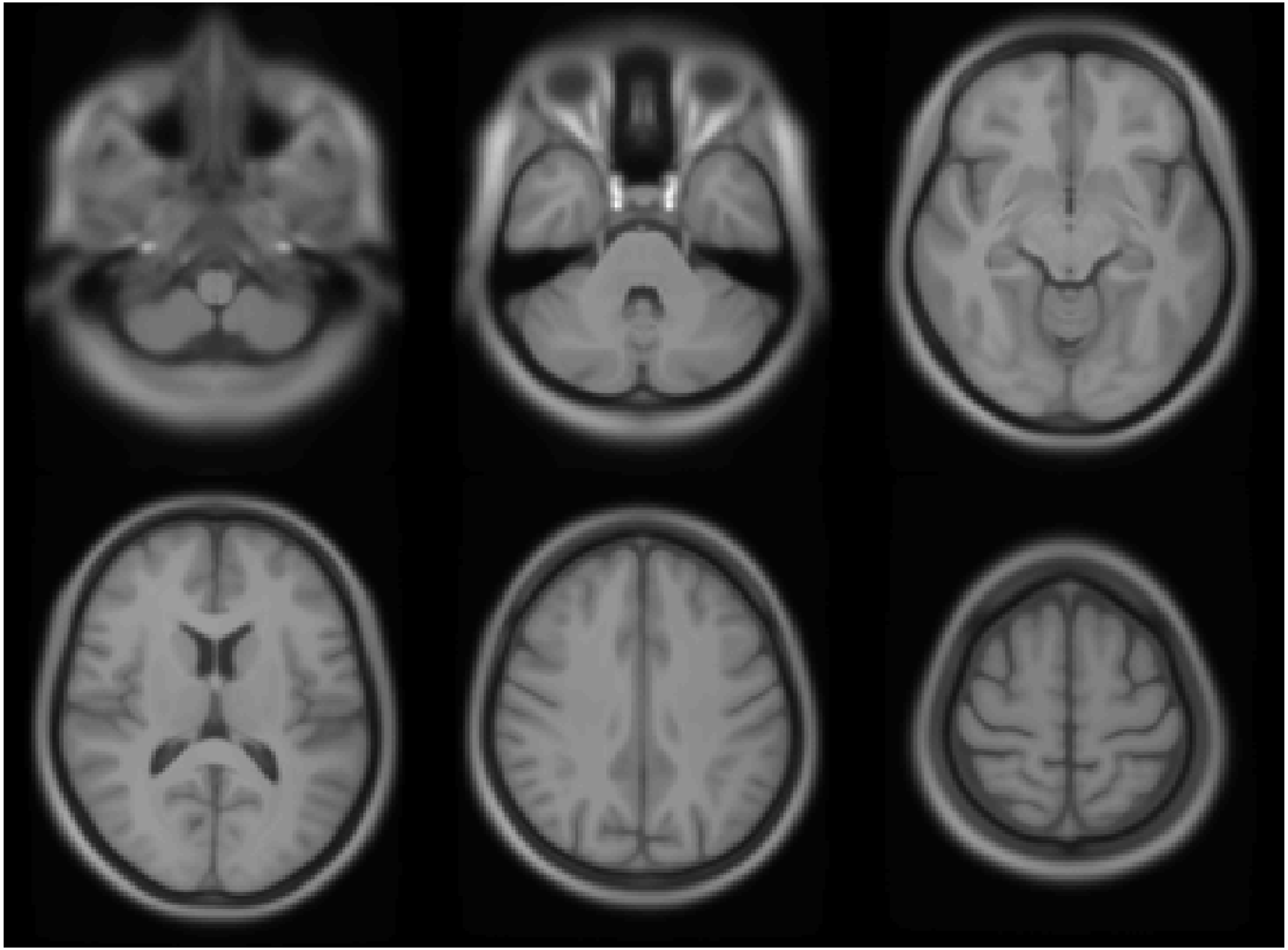








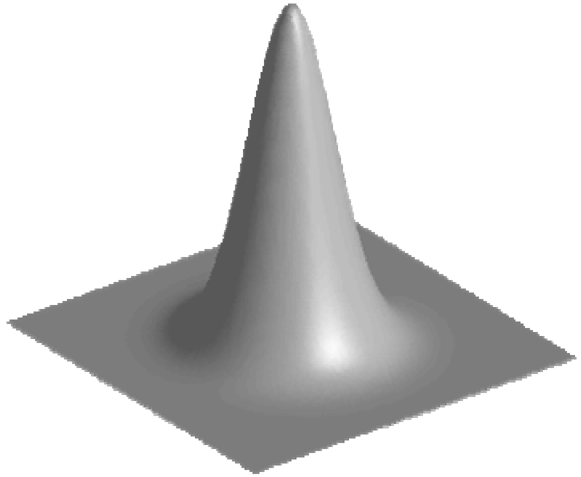




Contents

* Segment
* Dartel
* **Smoothing**
    * **Compensating for inaccuracies in inter-subject alignment**

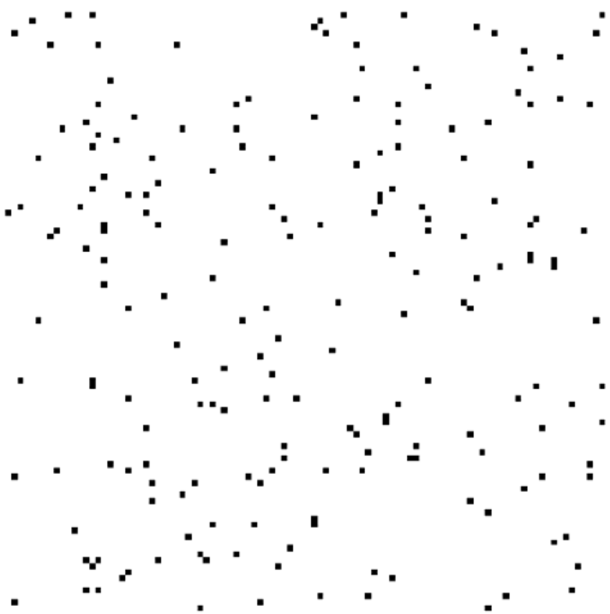
Smooth



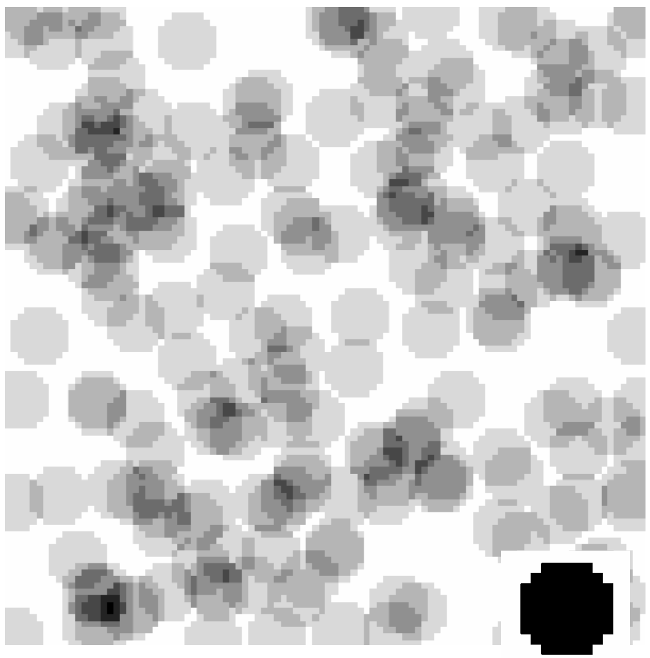
Blurring is done by convolution.

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

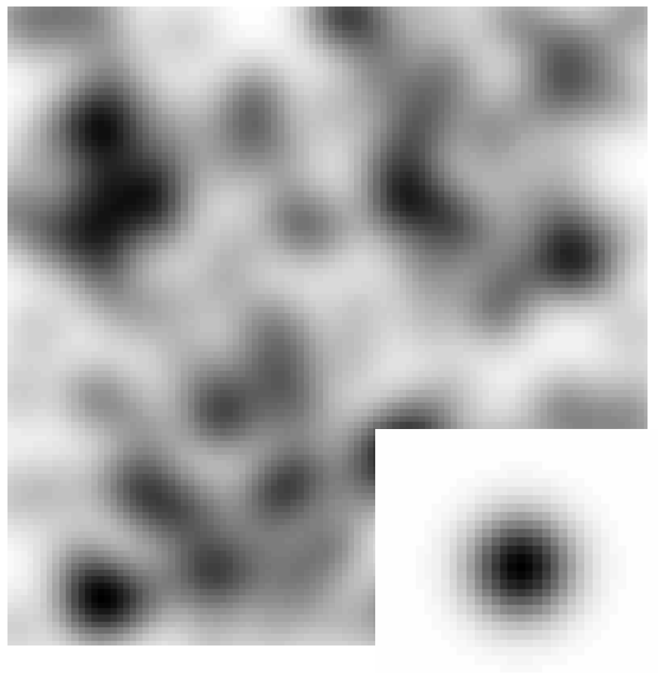
Before convolution



Convolved with a circle

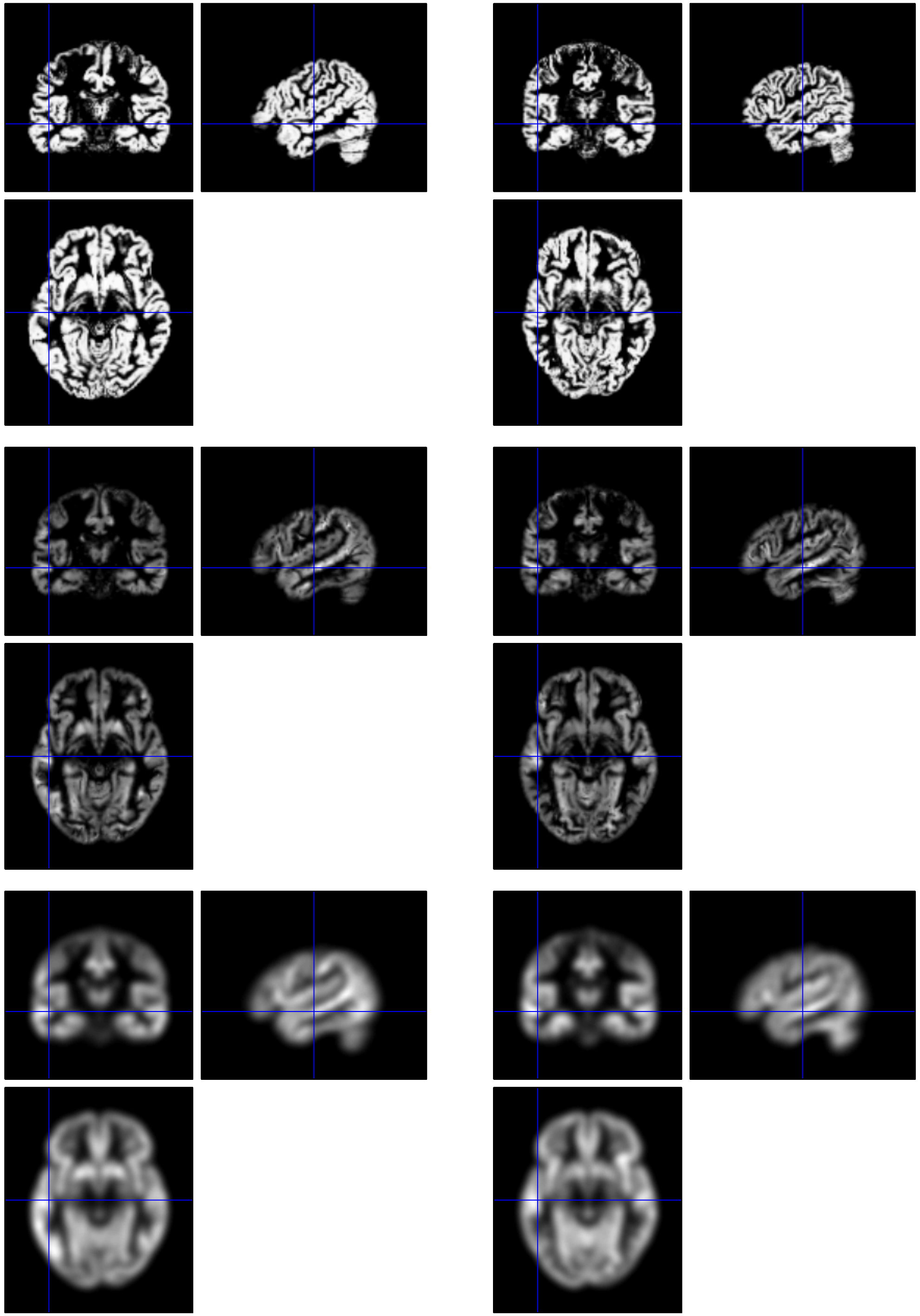


Convolved with a Gaussian



VBM Pre-processing

* Use Segment button for characterising intensity distributions of tissue classes.
* DARTEL import, to generate rigidly aligned grey and white matter maps.
* DARTEL warping to generate “modulated” warped grey matter.
* Smooth.
* Statistics.



References

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* Ashburner. *A Fast Diffeomorphic Image Registration Algorithm*. NeuroImage 38:95-113 (2007).
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