Assessment of SPM5's brain registration performance using landmark points

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Introduction

The performance of registration algorithms is known to be one of the limiting factors of automated morphology methods. One such technique is voxel based morphometry (VBM), which is used to detect structural changes in diseased cohorts by contrasting them with healthy subjects [1] – this is highly dependent on the performance of the registration step [2]. The goal is to quantify the misregistration of datasets using standard software tools in both normal and diseased cohorts.

Methods

10 controls,10 patients with mild Alzheimer's disease (AD), 10 subjects with Semantic Dementia (SD) and 10 subjects with Frontotemporal Dementia (FTD) were used in this study. Magnetic Resonance (MR) images were acquired with a 1.5 T GE Signa MRI scanner (GE Medical Systems, Milwaukee, WI). Volumetric T1-weighted images were coronally acquired using a spoiled gradient-echo technique (pixel dimension 0.86mm^2, slice thickness 1.5 or 1.8mm). All manual landmarks were placed using Analyze version 7.0 (Biomedical Imaging Resource, Mayo Clinic, Rochester, MN, USA). The MRI images were first interpolated to give cubic voxels (0.86x0.86x0.86mm) and manually re-aligned along the anterior commissure-posterior commissure line. The anterior and posterior commissure points were defined and placed. We refer to this alignment as "native space". A further 18 points were placed in anatomically relevant locations, as seen in the table below. Scans were registered through SPM5's (http://www.fil.ion.ucl.ac.uk/spm/) unified segmentation process [3], and the resulting deformation field was used in Matlab7 (Mathworks Inc., Natick, MA, USA) to transform the fiducial coordinates from native space to standard space. Within each cohort, similar fiducials were clustered together and the standard deviation of their locations was calculated as a measure of dispersion. We have also assessed the improvements provided by the DARTEL registration algorithm (Diffeomorphic Anatomical Registration Through Exponentiated Lie algebra) [4]. Other preprocessing methods (SPM Pre), with prior skull stripping and bias correction, were also tested in order to assess their ability to improve the registration results of the standard SPM approach as suggested by Acosta-Cabronero et al [5].

Results

The results for controls and AD are summarised in the figure below, which depicts the localisation of the used landmarks and their respective measures of spatial dispersion before and after the different registration methods. Other results for the SD and FTD cohorts are not shown as they follow a similar trend.

	Controls				AD subjects			
Fiducial Description	**Native Space**	**SPM**	**SPM Pre**	**DARTEL**	**Native Space**	**SPM**	**SPM Pre**	**DARTEL**
Right Temporal Pole	(3.9 3.6 4.9)	(1.4 0.9 1.3)	(1.4 0.6 0.8)	(1.4 0.8 1.2)	(4.5 9.0 2.6)	(1.6 1.0 1.6)	(1.7 1.3 1.7)	(2.1 1.5 1.8)
Left Temporal Pole	(3.9 4.3 5.6)	(1.5 0.8 1.6)	(1.5 0.6 1.7)	(1.6 1.1 1.5)	(4.5 8.6 2.6)	(1.7 0.7 0.8)	(1.6 0.8 1.1)	(1.4 0.9 1.3)
Right Amygdala	(2.4 4.0 4.8)	(0.6 0.8 1.8)	(0.7 0.7 2.0)	(0.7 1.0 1.6)	(2.6 8.9 2.1)	(1.2 0.8 1.2)	(1.2 0.7 1.3)	(1.0 0.9 1.0)
Left Amygdala	(2.3 4.0 4.5)	(0.8 0.8 1.4)	(0.8 0.7 1.4)	(0.9 1.0 1.2)	(3.4 8.9 2.3)	(1.3 1.3 1.3)	(1.2 1.0 1.5)	(1.0 1.2 0.7)
Left Hippocampal Head	(2.9 4.1 3.2)	(1.2 0.8 1.0)	(1.3 0.7 0.9)	(0.8 0.7 0.7)	(3.7 8.7 1.9)	(1.3 1.0 0.9)	(0.8 1.0 0.9)	(0.8 1.3 1.0)
Right Hippocampal Head	(2.2 4.1 3.8)	(0.4 0.7 1.1)	(0.5 0.7 1.3)	(0.7 0.9 0.9)	(4.1 8.7 2.6)	(1.5 0.7 0.7)	(1.4 0.8 0.8)	(1.3 1.2 1.0)
Anterior Commissure (AC)	(1.1 3.9 1.3)	(0.4 0.3 0.8)	(0.3 0.4 0.7)	(0.3 0.5 0.5)	(1.2 8.9 1.1)	(0.3 0.5 0.6)	(0.0 0.5 0.8)	(0.5 0.3 0.6)
Posterior Commissure (PC)	(1.1 4.1 1.3)	(0.5 0.4 0.5)	(0.4 0.5 0.5)	(0.5 0.3 0.5)	(1.2 8.5 1.1)	(0.4 0.6 0.5)	(0.3 0.6 0.5)	(0.5 0.5 0.6)
Left Convexity	(3.2 4.1 1.3)	(0.5 0.8 1.3)	(0.6 0.7 0.9)	(0.7 0.7 0.9)	(3.5 8.5 1.1)	(0.7 1.3 *1.9*)	(0.5 1.3 *1.8*)	(0.7 1.3 *1.8*)
Frontal Convexity	(1.1 4.7 1.3)	(0.8 0.9 *3.5*)	(0.8 0.9 *3.2*)	(0.9 1.2 *3.0*)	(1.2 8.0 1.1)	(0.7 0.8 *2.5*)	(0.7 0.7 *2.6*)	(1.0 1.0 *2.8*)
Occipital Convexity	(1.1 6.0 1.3)	(1.7 0.7 *2.1*)	(1.4 1.0 *2.0*)	(*Irretrievable*)	(1.2 10.5 1.1)	(*2.5* 0.9 *2.8*)	(*2.4* 1.1 *3.0*)	(*3.1* 1.5 *2.4*)
Right Convexity	(3.1 4.1 1.3)	(0.5 1.2 *1.4*)	(0.5 1.2 1.1)	(0.4 1.3 1.1)	(4.7 8.5 1.1)	(1.0 1.8 1.1)	(0.6 1.8 1.0)	(1.1 1.5 *1.2*)
Left Putamen	(2.8 5.9 1.3)	(0.6 1.4 0.9)	(0.6 1.4 1.0)	(0.4 1.5 1.3)	(3.1 8.0 1.3)	(0.5 1.1 1.3)	(0.5 1.0 1.1)	(0.7 0.9 1.1)
Left Caudate	(2.0 5.5 1.3)	(0.5 1.2 1.2)	(0.5 1.1 *1.4*)	(0.5 1.2 1.2)	(2.9 9.2 1.3)	(0.4 1.2 1.2)	(0.4 1.2 1.1)	(0.6 1.2 0.8)
Right Caudate	(2.8 3.9 1.3)	(0.6 1.1 1.3)	(0.6 1.0 *1.4*)	(0.3 1.0 1.3)	(3.0 9.0 1.3)	(0.5 0.9 1.0)	(0.5 0.8 1.1)	(0.6 0.8 1.0)
Right Putamen	(2.4 4.5 1.3)	(0.5 1.6 1.2)	(0.5 1.6 1.1)	(0.5 1.5 *1.4*)	(3.0 8.1 1.3)	(0.7 1.2 0.8)	(0.6 1.2 1.0)	(0.7 1.2 1.0)
Genu C. Callosum	(1.1 2.1 1.3)	(0.4 1.3 *2.1*)	(0.4 1.2 *1.9*)	(0.5 1.3 *2.1*)	(1.2 9.1 1.3)	(0.6 1.4 *1.4*)	(0.6 1.4 1.3)	(0.7 1.3 *1.5*)
Splenium C. Callosum	(1.1 3.7 1.3)	(0.5 1.2 1.0)	(0.5 1.2 1.0)	(0.7 0.9 *1.4*)	(1.2 10.0 1.3)	(0.5 0.9 1.3)	(0.5 1.0 1.3)	(0.9 0.7 *1.4*)
C. Callosum at AC level	(1.1 4.0 3.8)	(0.4 1.2 0.4)	(0.0 1.2 0.6)	(0.5 1.0 0.5)	(1.2 8.9 3.0)	(0.5 1.4 0.6)	(0.3 1.4 0.6)	(0.5 1.2 0.4)
C. Callosum at PC level	(1.1 4.1 2.6)	(0.5 1.2 0.6)	(0.5 1.3 0.7)	(0.5 1.3 0.4)	(1.2 8.5 3.2)	(0.7 1.1 0.7)	(0.7 1.1 0.5)	(0.5 1.3 0.6)

Table: Standard deviations in voxels in x,y, and z for each method, for the Controls and AD cohorts. *Red* values indicate a worsening relative to native space.

Discussion

As expected, initial dispersion was greater for AD subjects than for controls, and SPM registration presented a significant ($p<0.05$, one tail t-test) improvement in co-localisation across the 3 coordinates when compared to the native space results on all cohorts, especially on the *y* coordinate (anterior-posterior). There were no significant differences between tested algorithms, with some points presenting a systematic worsening of dispersion, notably points in the convexities and the genu and splenium of the corpus callosum. It can be hypothesised that a maximum bound on anatomically meaningful registration performance is being attained, with more complex methods (e.g. DARTEL) achieving greater similarity between images, which does not translate into a physical reality useful for VBM purposes.

References

[1] J. Ashburner et al, Neuroimage 2000; **11**: 805–821; [2] F. Bookstein, NeuroImage 2001, **14**: 1454–1462; [3] J. Ashburner, NeuroImage 2005; **15**: 839–851; [4] J. Ashburner, NeuroImage 2007, **38**: 95–113; [5] Acosta-Cabronero et al, Neuroimage 2008, **39**: 1654–1665