Quantitative Comparison of Neuroimage Registration for fMRI Analyses by AIR, SPM, and a Fully Deformable Model

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Introduction

Accurate region identification is critical for inter-subject comparisons of functional brain images, particularly in comparisons across groups. Atlas-based segmentation identifies regions of interest (ROI) for the individual brain image by geometrically aligning the template brain image to the subject brain image and using the resulting spatial transformation to warp the atlas labels into the individual brain space. Typical packages used for co-registration of neuroimages in functional image analyses are Automated Image Registration (AIR)[1] and Statistical Parametric Mapping (SPM)[2]. However both methods have limited-dimension deformation models, AIR uses a polynomial transformation model with limited coefficients, while SPM uses the linear combination of coordinates and three-dimensional discrete cosine transform (DCT). A fully deformable registration technique, which combines the piecewise linear registration for coarse alignment with the demons registration [3] for finer tuning, allows a higher degree of deformation, and enables a more accurate spatial deformation field. This leads to a more accurate co-localization of the functional imaging signal from different subjects and, therefore produces a more reliable group average signal. In this study, we quantitatively compare the performance of AIR, SPM and the fully deformable model through a series of experiments. We found that the fully deformable model is consistently and significantly more accurate than AIR and SPM.

Methods

Ten subjects (7 male; mean age 24.4, range 20-32 years; right-handed) were scanned using a 1.5T GE CVi scanner with 3DSPGR (TE/TR=5/25; flip angle = 40; FOV 24×18cm, slice thickness 1.5mm, 256×192 matrix). The standard MNI brain image colin27 was used as the template. Functional imaging data was available on 8 of the 10 subjects. Functional scanning was performed using a one-shot spiral sequence (TR/TE = 35/2000; flip angle = 70; FOV = 24; slice thickness = 3.8mm; 64×64×26 matrix). Subjects performed 8 blocks of a learning task in which they responded to the location of a stimulus on the screen by pressing a corresponding key as fast and accurately as possible. Stimuli appeared once every 2 seconds for 40 seconds, followed by 20 seconds of fixation. Previous work has suggested that dorsal anterior cingulate region (dACC) plays a role in performance monitoring [4], so we expected to see in dACC a significant difference between signal extracted from trials when subject pressed the correct key versus the signal from trials when an error happened, i.e., the incorrect key was pressed.

The fully deformable model was provided in the registration library in Insight Segmentation and Registration Toolkit (ITK) [5]. A series of experiments were performed to evaluate the relative accuracies of the three methods, including 1. a quantitative comparison of atlas-based segmented regions to manually-drawn regions, in which the automatically segmented left hippocampus and left anterior cingulate cortex (ACC) of each subject was compared to the manually-drawn regions to obtain the overlap ratio for each subject and the mean overlap ratios across all the subjects are then calculated for each registration method, 2. a visual inspection and quantitative evaluation of the sharpness (contrast) of the mean brain image from warping the 10 very different subjects to the template colin27, and 3. a group analysis of the resulting functional image signal on segmented dACC using the three different approaches.

Results

In the first experiment, the mean overlap ratios across all the subjects for left hippocampus and ACC are shown in table (1) #1. For both regions, the fully deformable model gives a higher mean overlap ratio than AIR or SPM, 7.3% higher for ACC and 15.6% higher for left hippocampus. A paired two-tailed t-test of the overlap ratios of the deformable model versus SPM was highly significant at $t(9) = -5.182$, $p = 0.00058$ (ACC) and $t(9) = -6.372$, $p = 0.00013$ (left hippocampus); similarly the t-test of the overlap ratios of the deformable model against AIR at $t(9) = -3.819$, $p = 0.0041$ (ACC) and $t(9) = -3.8782$, $p = 0.0037$(left hippocampus). There is no significant difference in mean overlap ratios between AIR and SPM at $t(9) = 0.0494$, $p = 0.962$ (ACC) and $t(9) = 0.1853$, $p = 0.857$ (left hippocampus).

The second experiment demonstrated the improved performance of the fully deformable method over AIR or SPM, with a sharper average brain image, as shown in Fig.1. The template image colin27 is also displayed for comparison. The smoothness of these average brain images as measured with AFNI using 3dFWHM is presented in table (1) #2. The filter width reported is the estimation of the width of the filter needed to produce current smoothness, so wider filter width means more smoothness and indicates more inter-subject misalignment. As shown in Table (1), the average brain image from the fully deformable model has much smaller filter width in all three dimensions, which means that the fully deformable model introduces much less inter-subject registration error than AIR or SPM.

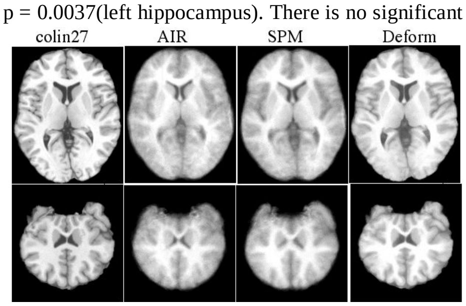

Fig. 1 Average brain image from AIR, SPM, the full deformable model. Colin27 is the template.

In the third experiment, the functional signal was extracted from a dorsal anterior cingulate region previously identified as relevant for conflict and error processing [4]. This region was automatically segmented using atlas-based segmentation by each method. The subjects' fMRI signal on a reaction-time task was compared on trials in which they answered correctly versus when they made errors. As predicted there was a greater fMRI signal on the error trials than the correct trials regardless of how the region was segmented (i.e., AIR, SPM, or the fully deformable model). However, as can be seen in Table (1) #3, the results were more reliable with the fully deformable method, thus suggesting a more reliable extraction of the functional imaging signal.

Method\Experiment	#1 mean Overlap ratio		#2 Smoothness of the average brain image (Sigma : FWHM)			#3 Functional Signal	
	Left-ACC	Left-Hippo	Sigmax : FWHMx	Sigmay : FWHMy	Sigmaz: FWHMz	t(7)	P value
AIR	40.0%	42.0%	(47.77 112.49)	(54.42 128.16)	(51.80 121.98)	-2.7269	0.0295
SPM	40.0%	42.3%	(51.46 121.17)	(61.09 143.85)	(58.11 136.84)	-2.1681	0.0668
Fully Deform	47.3%	57.9%	(2.52 5.92)	(2.79 6.57)	(2.69 6.33)	-4.3499	0.0034

Table 1 the results from all the three experiments in AIR, SPM and the fully deformable model

Conclusion

The fully deformable model produces higher overlap ratios for the atlas-based segmentation, sharper average brain image and more reliable functional MRI signals; hence it shows consistently and significantly better performance over AIR and SPM.

Reference

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