Comparison of Image Registration Algorithms for fMRI

E. E. Gualtieri[1], K. Ruparel[1], R. A. Pratiwadi[1], J. Hulvershorn[2], R. Gur[1], M. A. Elliott[2]

[1]Department of Psychiatry, University of Pennsylvania, Philadelphia, PA, United States, [2]Department of Radiology, University of Pennsylvania, Philadelphia, PA, United States

Introduction

A common goal in the analysis of functional images of the brain is co-registration with images containing more detailed anatomical information of the same subject, thereby aligning the functional activity with a specific brain region. There are several image-processing algorithms available that can perform this image registration. However, evaluation of these algorithms is difficult because the true amount of motion between the two images is not known, and because the quality of the registration is reported in terms of an optimization metric that has no clear physical interpretation. This paper describes a method for quantitatively evaluating the performance of registration algorithms using synthetic data and simulated motion. We also report the results of a comparison between several registration packages that use automated registration technique (SPM99 [1], SPM2 [1], and FSL-FLIRT [2]), and one package that uses a "hat-on-head" technique [3] which relies on manually drawn contours of the volume (MEDx, Medical Numerics, Sterling Virginia) .

Materials and Methods

Simulated T1- and T2-weighted images of a single brain were generated using the BrainWeb database from the Montreal Neurologic Institute [4]. Both volumes were initially composed of 181x217x181 1 mm voxels and were perfectly aligned. In order to make the T2-weighted image resemble a functional EPI scan, we applied a skull-stripping algorithm and used frequency-space cropping to blur and down-sample to a 3 mm voxel size (60x72x52). Gaussian noise was also added to the image to produce a signal-to-noise ratio of 30:1. We then generated a set of nine random, rigid-body transformations with translations and rotations constrained to ±4 mm and ±4 degrees, respectively. We applied these transforms, along with an identity transform, to the simulated EPI image to create ten resampled copies of the same volume, each with a different, but known, amount of motion. The ten images were then aligned with the original T1-weighted images using the registration programs listed above, and the resultant transforms were extracted for comparison with the known forward transform. For SPM99, SPM2, and FSL, the optimization criterion used was mutual information (MI), and if necessary the routines were constrained to find only rigid-body transforms. For MEDx, contours were drawn on the images by a skilled user of the software. A contour was placed on every slice of the 3 mm EPI image, and on every third, corresponding slice of the 1 mm images. We chose two representations of the realignment error as expressed by the following equations:

(1) $E_{avg} = 1/N \sum_{i=1}^{N} |\mathbf{a}_i - \mathbf{T} \bullet \mathbf{b}_i|$, and (2) $E_{\max} = \max(|\mathbf{a}_i - \mathbf{T} \bullet \mathbf{b}_i|)$, where

$\mathbf{a}_i$ is the original vector location of the ith voxel, $\mathbf{b}_i$ is the location of that voxel after the forward transform was applied, **T** is the reverse transform found by a registration algorithm, and N is the number of voxels. **Equation (1)** then, represents the average, absolute, vector displacement of each voxel in the image from its original position, and **Equation (2)** represents the maximum displacement of all voxels in the volume. Differences in the coordinate systems and representations of the transforms used by the various algorithms were accounted for in the analysis.

Results

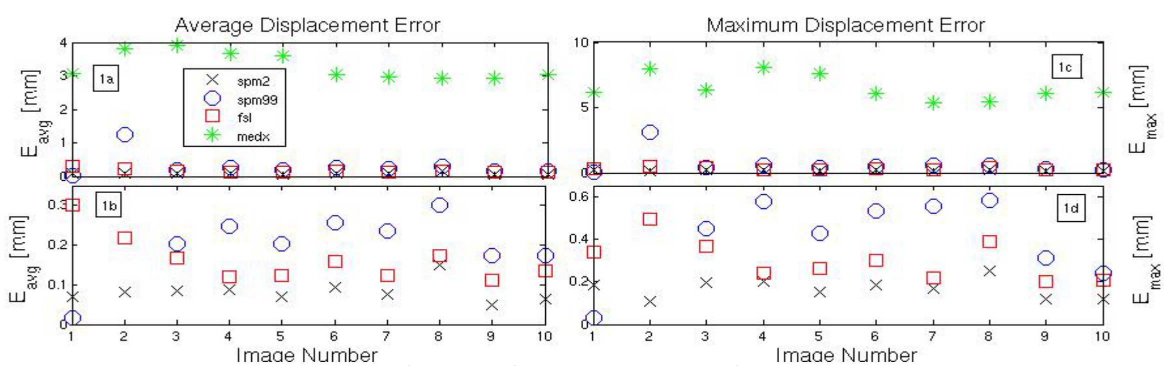

Figure 1a shows the average displacement error for each of the ten images and four registration algorithms. The automated MI registration algorithms significantly outperformed the hat-on-head method (MEDx). **Figure 1b** magnifies the scale of Figure 1 and reveals that SPM2 performed most consistently and in almost every case performed better than SPM99 and FSL, albeit by a typical margin of only 0.1 mm. **Figure 1c** shows the maximum displacement error for the same test case. The maximum error for the MI methods is slightly greater than the average error, but it remains below 1 mm. The maximum error for the hat-on-head algorithm, however is approximately double its average error. This reveals that rotational misregistration is a significant problem for this method, as translational misregistration would lead to identical maximum and average errors. **Figure 1d** again shows that SPM2 is the best of the three MI algorithms.

Conclusion/Discussion

We have described a method for the evaluation of the performance of image registration techniques that is quantitative and has a clear physical interpretation. The application of this method to several common registration packages shows that the automated MI techniques available in SPM and FSL significantly outperform the manual method in MEDx. Of the MI techniques, SPM2 had the best overall performance.

References

1. Friston K, Ashburner J, Frith C, Poline J, Heather J, Frackowiak R. Human Brain Mapping 1995, 2:165-189.
2. Jenkinson, M., Bannister, P., Brady, J. M., Smith, S. M. NeuroImage 2002, 17(2):825-841.
3. Pelizzari, C.A.; Chen, G.T.Y.; Spelbring, D.R.; Weichselbaum, R.R.; Chin-Tu Chen,. JCAT 1989, 13(1):20-26.
4. http://www.bic.mni.mcgill.ca/brainweb/

This work was supported by NIH grants RR02035 and MH64045-02.