Implicit Reference-Based Group Registration in Structural and Functional MRI Studies

X. Geng[1], H. Gu[1], T. J. Ross[1], and Y. Yang[1]

[1]Neuroimaging Research Branch, National Institute on Drug Abuse, National Institutes of Health, Baltimore, MD, United States

Introduction

Group analyses of structural and functional MR images provide opportunities to study brain morphometry and neural activity in different populations. Spatial normalization is essential for reducing inter-subject variations. Most current normalization techniques[1,2], especially in fMRI studies, follow a standard framework that utilizes a low order model, i.e., affine model, and register each data to a selected reference image. In this work, we propose an implicit reference-based group (IRG) registration method[3,4] with a high-dimensional elastic deformation model to align structural or functional images in groups. The IRG registration was compared with reference-based registration using T1-weighted MR images with pre-defined ROIs. It was also applied to an fMRI study with sensorimotor and visual tasks.

Methods

IRG registration and validation using structural MRI. The proposed IRG registration simultaneously maps each image to an implicit reference space under a small deformation elastic (SDE) model. It avoids reference-selection and generates unbiased results[3]. IRG registration estimates transformations using a multi-scale approach, parameterizes them with Fourier basis and allows them to have high degrees of freedom. To evaluate the performance, a population of 16 MR images from an evaluation package[5] was used with pre-defined 32 gray matter ROIs for each data set. Relative overlap of each ROI was computed. A Total of 16 reference-based registrations using the same SDE model, with each subject selected as the reference, were compared with IRG registration.

fMRI data acquisition. Twenty-nine different healthy controls were scanned using an EPI sequence on a 3T Siemens Allegra scanner. Acquisition parameters were: TE/TR=27/2000 ms; FOV=220x220 mm^2; image matrix=64x64; slice thickness/gap=4/0 mm; number of slices=39. A set T1-weighted MPRAGE images (1x1x1 mm^3) were also acquired. Subjects performed a block-design finger tapping task cued by a flashing checkerboard, which started with 20s "off" (watching a cross on the screen without moving fingers) and followed by 7 cycles of 20s "on" (watching a flashing checkerboard on the screen and moving fingers) and 20s "off" states.

fMRI data processing and group analysis. EPI data preprocessing included slice-timing correction, motion correction and linear detrending conducted in AFNI. All functional data were spatially normalized to the standard Talairach space using affine registration. Spatial smoothing with a 6-mm Gaussian kernel was performed afterwards. Both reference-based and IRG registrations were applied to further align the EPI data. For reference-based method, each subject was selected as the reference resulting in 29 reference-based registrations. The general linear model was exploited and the linear regression coefficient β maps were obtained. For each registration group, one-sample t-tests were applied on the maps. A threshold of $t > 5.3$ with a cluster size greater than 54 mm^3 (corrected $p<0.01$) was used to generate group functional activation maps. Four activated regions were selected as ROIs including visual cortex, left and right sensorimotor cortices and supplementary motor area (SMA). Average standard deviation (ASD) of image intensity, β weights and t-statistics in the four ROIs were computed and compared.

Results

Fig.1 plots the average relative overlap (ARO) over 32 ROIs using IRG and 16 reference-based registrations on T1-weighted MR images. The ARO by IRG is nearly always larger than the AROs generated from reference-based registrations. The performance of reference-based registrations is not consistent through different ROIs. Fig.2 shows results of IRG and one reference-based registration from randomly-selected 4 out of the 16 subjects. The average images of the 16 deformed data after both reference-based and IRG registration are much sharper compared to the average before nonlinear registration. The registered images are similar to the first image (reference) after reference registration and are similar to the average shape of the population after IRG registration. The functional activation maps are shown in Fig.3. Compared with affine approach, the elastic registrations provide larger β values in the left and right sensorimotor cortices and visual cortex. Fig.4(a) shows the ASD in the whole brain and in each ROI under different registration methods. The reference-based registrations reduced the ASD 30 percent on average compared to the affine method. IRG method further reduced the ASD approximately 2 percent compared to the average performance of reference-based registrations. Fig.4(b) and (c) show the average of β weights and t-statistics in the four ROIs under various methods. Compared with the affine approach, the elastic registrations increase the average β and the t-statistics in each ROI. The IRG further increased β values in right and left sensorimotor cortices and visual cortex, and the t-statistics in all ROIs compared with the reference-based registrations on average.

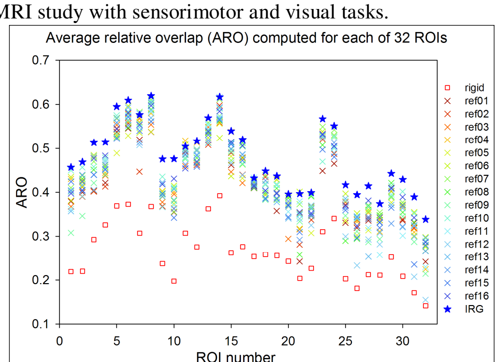

Fig.1 Comparison of IRG and 16 reference–based registrations using the ARO metric in each ROI.

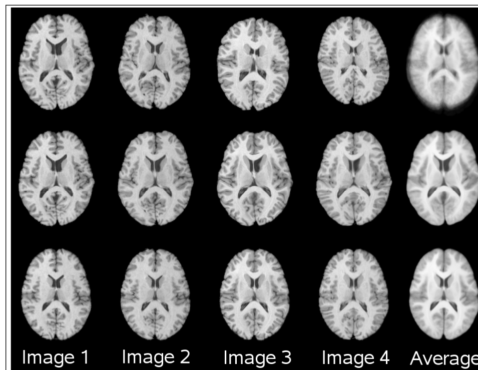

Fig.2 Registration results on structural MR images. Top row: 4 out of 16 original images and the average. Middle & bottom rows: the 4 images and average after reference-based & IRG registrations.

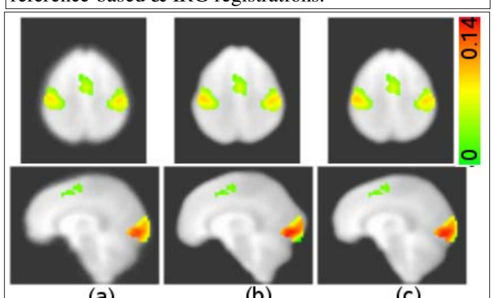

Fig.3 Functional activation maps with (a) affine, (b) reference-based, (c) IRG registration methods. All maps are overlaid on the average of all deformed EPI using IRG and color coded by β values.

Discussion and Conclusion

The proposed implicit reference-based group registration was validated using structural MR images with pre-defined ROIs and compared to reference-based methods. IRG produced better registration performance in terms of higher relative overlaps. IRG registration was also applied to group analyses of fMRI data sets. The elastic registration improves the statistical detection power compared to affine approach. Since fMRI data sets have lower resolution and less structural information compared to T1-weighted images, the improvement of IRG registration over reference-based method in fMRI studies is smaller than that in structural images.

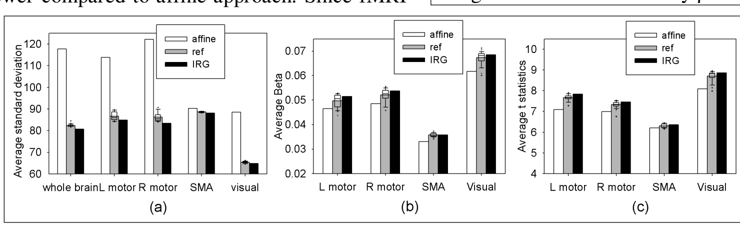

Fig.4 Comparison of (a) intensity ASD, (b) β and (c) t statistics in ROIs with various methods.

References 1.Anticevic et al. *Neuroimage.* 2008. 2.Fan et al. *Neuroimage.* 2007. 3.Geng et al. *ISMRM* 2008. 4.Joshi et al. *Neuroimage.* 2004. 5.Christensen et al.*WBIR*2006.