Stochastic Co-Registration of Functional And Anatomical Data Improves the Spatial Resolution of fMRI

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Abstract. Accurate co-registration of functional and anatomical data from individual subjects is critical for the precise mapping of function on the cortical surface using functional magnetic resonance imaging (fMRI). Because of minor head movements a different spatial sampling of functional activations is inevitably obtained from successive functional images gathered during an experiment. It is generally thought that minor movements interfere with the precision of functional mapping. Here a stochastic co-registration method is described wherein low-resolution functional images are re-sampled and co-registered individually with the reference brain in high-resolution anatomical brain space. Counter intuitively, small movements significantly improve spatial mapping precision when stochastic co-registration is used, as demonstrated in both simulations and fMRI experimental results.

Introduction. Accurate co-registration of functional data to anatomical images is critical for the precise mapping of cortical activations visualized with fMRI. A key source of potential variability is the projection of functional data from its native low-resolution image space to the high-resolution space used for anatomical imaging. Traditionally, activation maps are created from averaged functional image that have been realigned to a common low-resolution functional image (the reference image, typically 64x64 or 128x128 voxels x 5 mm slice thickness). Then, the mean functional image is co-registered with a higher resolution anatomical template (typically 256x256x256 voxels). As a result, choosing different functional reference images from set can produces different functional maps even when the same data are analyzed in a single subject (see Fig. 4, below). Here we test stochastic co-registration (SC), where functional images are re-sampled and individually co-registered into the high-resolution anatomical brain space. In SC, each functional image provides an independent sample of the relationship between functional data and anatomical space. Both simulation and experimental results demonstrate that SC improves the reproducibility and accuracy of functional maps.

Methods. fMRI experiments were performed on a 1.5T Philips Eclipse. To test the functional reproducibility, four complete experiments were performed on the same scanner on four separate days spaced over a 6-week interval. Anatomical images were first re-sliced to images with a voxel size of 1x1x1 mm, and then inflated to the cortical surface using FreeSurfer[1]. Local maps of human auditory cortex area were cut and flattened from the inflated surfaces. An average map of auditory cortex curvature was obtained from 10 subjects using a local landmark-based co-registration method[2] (LLM). Functional activations were generated from images realigned and co-registered using either the traditional alignment method or the SC method described above. In the traditional method, functional images were aligned and re-sliced to a reference functional image (usually the first image in the data set). Then the mean functional image was co-registered to the anatomical image in order to map functional data into anatomical space. In the SC method, each functional image was co-registered and independently re-sliced into anatomical image space. Then, average functional data were computed in reference-anatomical space. All the calculations for realignment for both methods were performed using SPM99[3]. To simulate the effects of the two methods, a set of single voxel activations was imposed on the mean anatomical map as shown in Figure 1. Voxels in all the functional images that contained the selected anatomical points on the mean flat map had a constant intensity and all the other voxels had zero values. The final functional maps were smeared regions around those selected anatomical points because (1) the voxels in the functional images are bigger than the pixels on the flat map, and (2) the head motion effects during the scan increase the dispersion of the functional data. "Dispersion radii", defined as the mean distance of all the activated functional points to their center-of-mass point, were used to compare mapping precision. Finally, functional activations in human auditory cortex area were displayed on auditory cortical flat maps to show possible auditory cortical fields[4] (ACFs) and to compare the accuracy and reproducibility of activations within an experiment.

Results. Figure 1 shows the mean anatomical flat map of auditory cortex curvature using LLM. Figure 2 shows mean functional maps from 10 subjects of selected gyral and sulcal points generated by traditional method (a) and the SC method (b). The activation on the superior temporal gyrus is enlarged in panels (c) and (d) to show the increased dispersion produced by the traditional method. In each subject and hemisphere (i.e., 20 comparisons), mean dispersion radii were smaller with the SC than traditional methods (mean, 6.3 mm vs. 5.7 mm). Figure 3 shows the functional maps of one subject generated by the traditional method (a) and SC methods (b). A single point of activation gives rise to a smooth and contiguous functional map using the SC method, but an apparently multifocal activation using the traditional method. Figure 4 shows the variability in the analysis of the same data set that is introduced by the choice of different functional reference frames using the traditional method. Even greater variation is evident across experimental sessions. Figure 4c shows the clearer and more focal activations revealed by the SC method.

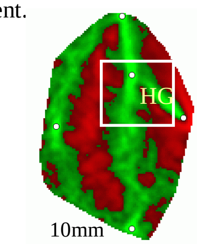
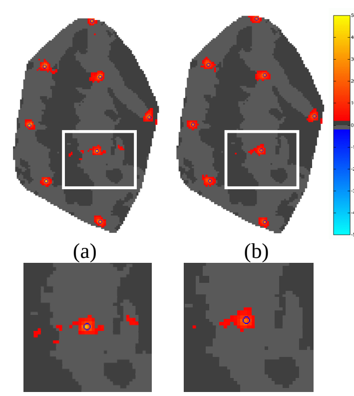
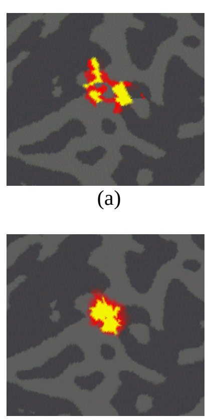


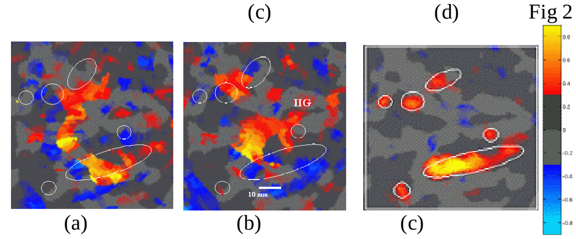
Fig 1
HG – Heschl's Gyrus



(a) (b) (c) (d) Fig 2



(a) (b)
Fig 3



(a) (b) (c)
Fig 4

<u>Conclusions</u> The stochastic co-registration method improves the spatial precision of functional maps and results in higher reliability and reproducibility. The method appears to be a promising technique for fMRI studies of cortical fields in the human brain.

References

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