EPI DISTORTION CORRECTION BY CONSTRAINED NONLINEAR COREGISTRATION IMPROVES GROUP FMRI

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Introduction

Because of its short volume acquisition time, echo planar imaging (EPI) has remained the method of choice for most fMRI studies. A well-known problem with EPI are geometric distortions caused by magnetic susceptibility inhomogeneities in the field of view. Especially in the frontal part of the brain, this can cause activation to appear at an offset along the phase encoding (PE) direction from its true location. Additionally, as the distortions tend to vary in severity between subjects and interfere with affine coregistration, activation at the group level can suffer from the resultant registration errors. We show that unwarping the EPI images to match a distortion-free anatomical image using a method similar to [1] can reduce these problems and improve the sensitivity of the statistical analysis.

Methods

Susceptibility gradients cause undesired phase evolution during the EPI read-out train. Due to this phase evaluation, the tissue where the signal originates is shifted along the PE direction in the reconstructed image. As shown in [1], this knowledge can be used to describe a distortion model that is more restricted than more general non-linear registration methods. The model used here is very similar and described by the map

$$T : (x, y, z) \mapsto (x, y + d(x, y, z), z)$$

where *d(x, y, z)* is the displacement field and phase encoding is along the *y*-direction. The displacement field is parameterised as

$$d(x, y, z) = \sum_{i,j,k} a_{ijk} X_i(x) Y_j(y) Z_k(z)$$

where X_i, Y_j and Z_k are the basis functions of the discrete cosine transform up to a certain order. This reduces the number of parameters to be estimated and ensures smoothness of the displacement field. The coefficients a_{ijk} are found by minimization of the normalized mutual information [2] of the transformed EPI image and an undistorted target image, that has been coregistered with a rigid body transformation. As the method is applied to gradient echo EPI images, the physical constraint that the integral of signal intensity along a line in the PE-direction is conserved does not hold. Therefore no effort is made to correct intensities for compression and stretching. Instead, the Jacobian determinant of *d(x, y, z)* is added as a regularisation term to prevent excessive or unnecessary deformation, for example if the contrast contains insufficient information to otherwise constrain the displacement field.

To evaluate the benefit of including the described procedure in a group fMRI study, we re-evaluated data of 22 subjects from a previous working memory study [3]. In the study, an N-back task was used. Analysis was performed using SPM8 (http://www.fil.ion.ucl.ac.uk/spm/). To compare results, the same analysis was run twice; once including the proposed distortion correction scheme (with X_i and Z_i up to 8th order, Y_i up to 12th order) and once without. Functional EPI volumes were motion corrected and coregistered with the subject's structural image. Optionally, a displacement field was then estimated for the mean EPI volume and applied to all motion corrected volumes. The functional images were then normalised to standard space and smoothed with a 6mm FWHM Gaussian kernel using DARTEL [3].

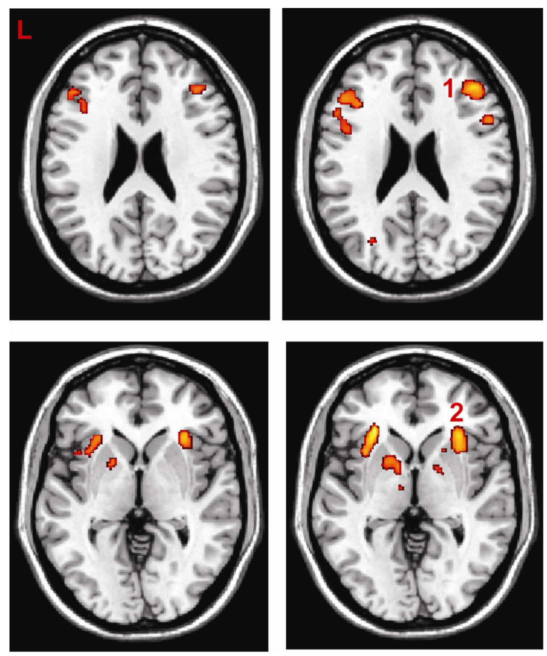

Figure 1. Dorsolateral (top) and inferior (bottom) prefrontal areas involved in working memory (p<0.05, FWE). Left: Without distortion correction. Right: With distortion correction.

Results

We will only consider the 2-back vs. 0-back contrast, representing areas involved in working memory. Frontal areas where this contrast was significantly positive are shown in Figure 1. Statistics for selected clusters are shown in Table 1. In general, clusters appeared larger and less fragmented when using distortion correction.

		No distortion correction		Distortion correction	
Cluster		k_E	T	k_E	T
1	Left	143	8.52	941[a]	10.55
	Right	138	9.19	539	10.86
2	Left	222	8.57	459	12.65
	Right	320	11.08	636	11.26

Table 1. Cluster size in voxels k_E and peak T-statistic for corresponding clusters in Figure 1. [a] Cluster was not separate from a more caudal region, also visible in Figure 1.

Discussion

Our results strongly suggest that incorporating a distortion correction scheme in the analysis pipeline can significantly improve group results. By directly estimating deformations from alignment with the structural image that is in many cases already used in the normalisation procedure, this improvement is essentially free. With recent improvements, like DARTEL, in standard space normalisation, the benefit of better alignment of functional to structural data may have increased as well.

References

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