Automated Online EPI Distortion Correction for fMRI Applications

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Synopsis

Geometric distortions are a well-recognised problem in echo-planar imaging (EPI), the technique most commonly used for functional imaging. This limits the accuracy of the registration between the reconstructed functional maps and high-resolution anatomical images, thus complicating the results interpretation. Increased availability of high-field imagers, where distortions are more pronounced, and high-performance gradient systems, which afford EPI with higher spatial resolution, requires the development of robust operator-independent correction techniques. Presented here is a simple and efficient fully-automated distortion correction protocol, which is based on the point-spread function mapping technique. Application of the distortion correction to a functional experiment is demonstrated.

Introduction

The presence of geometric distortions in EPI and their sources are known and well understood.[1-4] Manifold approaches have been developed to provide robust correction of EPI distortions, varying in complexity and required amounts of computation. Nevertheless, in majority of currently performed fMRI studies the existence of distortions in functional data remains overlooked. Here we present an uncomplicated automated distortion correction protocol and demonstrate it's performance in a simple fMRI experiment in order to draw the attention of the fMRI community to the importance of distortion correction, particularly at higher field strengths.

Methods

Distortion correction was based on the point-spread function (PSF) mapping approach,[2,3] which was further developed by us. The PSF mapping sequence consisted of the EPI readout module with a modified phase pre-winder, which was varied as the sequence was repeated multiple times. Post-processing included the application of a Hanning filter and FFT in the additional phase-encode direction (PSF-direction). The dataset thus contained both distorted image, if integrated along original phase-encode direction and undistorted image, if integrated along PSF direction. In the undistorted image space the original phase-encode direction represented the PSFs for each image pixel. The dataset was then phase-corrected in order to make the undistorted image purely real, and then the real part of the PSFs was used to determine the peak position of each image pixel in undistorted coordinates. These positions were defined by parabolic 3-point interpolation of the maxima positions, which appeared to be more robust against noise than the centre-of-mass approach used in the original publications.[2,3] The shift maps were than used to create noiseless, delta-function-like PSFs, which were used thereafter to correct distortions in the subsequently acquired EPI images. No intensity correction was applied.

Measurements were performed in healthy volunteers on Siemens Magnetom Trio 3T scanner. Informed consent was acquired prior to the measurement. The protocol consisted of a T_1-weighted anatomical scan, the PSF mapping sequence and a functional EPI run. The readout parameters were set exactly identical for the PSFM and EPI sequences: FoV=192mm, 128^2 matrix, 16 slices, 3mm slice thickness, 1mm gap; readout bandwidth 1.4kHz/pix, echo spacing 800µs, TE=33ms, TR=3s. The PSF mapping sequence used 32 additional phase-encode steps, which resulted in 1min 36s acquisition time. Both, the reconstruction of the distortion maps and the correction of the EPI images acquired later were performed online on the scanner in a fully-automated manner.

The fMRI paradigm was a simple block-design finger-tapping consisting of 4 cycles of 30s of activity followed by 30s rest periods. The paradigm was preceded by 4 dummy scans, which were then discarded. Both uncorrected and corrected EPI images were saved and analysed separately. The images were motion corrected and statistically analyzed using SPM99 (no smoothing or normalization).

Results

The efficiency of the correction algorithm is demonstrated in Fig. 1. Here, slices drawn from the 16-slice volume dataset are presented overlaid with contours produced from the anatomical T_1-weighted scan. In both cases EPI volume data were realigned to the T_1-weighted scan. Considerable distortions in Fig. 1(a) in vertical (phase-encode) direction are seen. Improved registration between the anatomical data and EPI images is obvious in Fig 1(b). In order to make distortions more apparent the high-order shims were deliberately detuned.

Results of a finger-tapping experiment are shown in Fig.2. Here, the same paradigm was repeated twice with optimal and detuned shims. The two raw datasets were then reconstructed in two ways, with and without correction. Thereafter, the four datasets were processed with SPM as described in Methods. Good correspondence between distorted-and-corrected (b) and undistorted (c) conditions is to be noted.

Discussion

The PSF mapping approach,[2,3] employed in this work, appears to be robust. It does not require intensive or unstable computations like matrix inversion or phase unwrapping, and is able to produce low-noise high-resolution distortion maps.

The recovery of activated area locations with accuracy, better than expected in repeated fMRI experiments, has been shown; the variation of locations of centres-of-mass of activations in Fig.2(b) and (c) lies by far within the deviations introduced by realignment. This is also supported by the phantom data, not presented here, where the method has demonstrated sub-pixel correction accuracy.

In this work, due to the current lack of stimulation equipment, we could not demonstrate the correction of the activation locations in the more strongly distorted brain areas, e.g. the parietal or occipital lobe, while the motor cortex only experiences mild distortions, even with detuned shims. However, the correct activation positions are expected to be recovered in more severe cases of geometric distortions.

References

[1] Jezzard P, Clare S. HBM 1999; 8:80-85 [2] Robson MD, Gore JC, Constable RT, MRM 1997; 38:733-740 [3] Zeng H, Constable RT, MRM 2002; 48:137-146 [4] Hutton C, Bork A, Josephs O, Deichmann R, Ashburner J, Turner R. Neuroimage 2002, 16:217-240

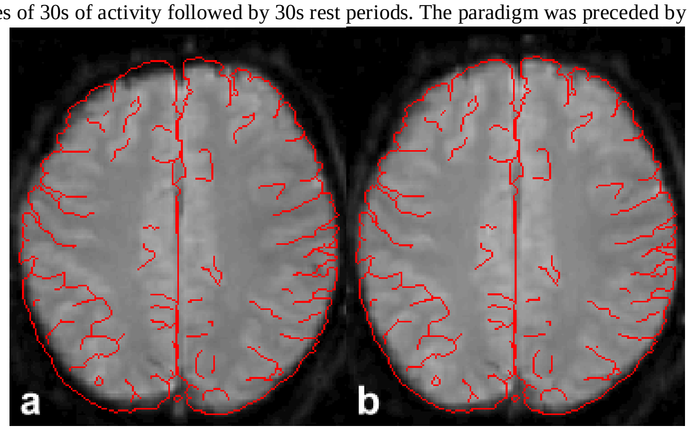

Fig. 1. Uncorrected (a) and corrected (b) EPI images, reconstructed from the same raw data, overlaid with the anatomy contour derived from the T_1-weighed scan. Images are motion-corrected. In order to cause additional distortions the second-order shims were deliberately detuned.

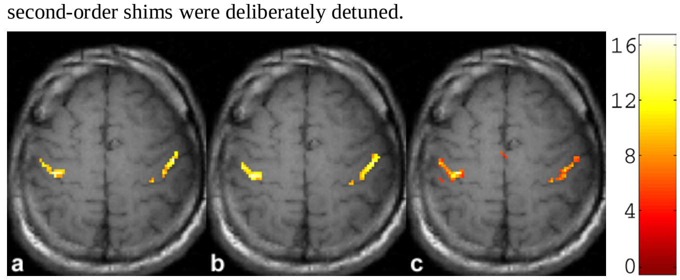

Fig. 2. fMRI activation areas in a finger-tapping experiment overlaid on T_1-weighted images; (a) offset shims, no correction, (b) offset shims, with correction, (c) optimal shimming conditions. Note that source images for (a) and (b) are reconstructed from the same raw data, while (c) is a different experiment. Positions of the centre-of mass of activated regions are identical in (b) and (c), while in (a) are they are shifted by 3mm and 2mm posterior for left and right activations respectively.