Investigation Of Distortion-Correction Procedures For A Double Inversion-Recovery Sequence With An Echo-Planar Imaging Readout

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Introduction

The sensitivity to detect brain activation in functional magnetic resonance imaging (fMRI) would be improved by restricting the search volume of the statistical analysis to the grey matter only. It has previously been shown that this can be achieved by using a double inversion-recovery (DIR) sequence with an echo-planar imaging (EPI) readout to image selectively the grey matter at the point of acquisition, and by making use of this information in the fMRI analysis(1). It must be ensured, however, that the images obtained using the DIR sequence match the geometry of the functional data set. This means that if a procedure were to be implemented to remove the distortions that are inherent in the EPI-based fMRI data(2, 3, 4), then a similar technique would have to be applied to the DIR-EPI image also. A comparison is therefore presented of candidate methodologies for correcting distortions in DIR-EPI images, to allow more robust segmentation of grey matter for fMRI analysis.

Methods

Distortion correction was performed using a dual phase-encode traversal technique that has previously been described(4). In the case of a DIR-EPI image, there are two possible ways of applying such a correction. The first, which will be referred to here as Method A, would involve the acquisition of two DIR-EPI images with *k*-space traversal in opposite directions, and these images would be used to calculate the required pixel-shift information. Method B would involve the additional acquisition of two EPI images (without inversion pulses but with all other key imaging parameters identical) with opposite direction *k*-space traversal, and the pixel shifts calculated from those EPI images would then be applied to the DIR-EPI data. Each of these has potential disadvantages, and so they were both assessed. Images of a normal volunteer were obtained with a Philips Achieva 3-T MR system (Philips Medical Systems, Best, The Netherlands), using the body coil to transmit and an 8-channel phased-array head coil to receive the signal. Two DIR-EPI images (with a spin-echo EPI readout) were acquired, one with the phase-encoding direction set to be right-left and the other with the phase-encoding direction set to be left-right. The imaging parameters used were a repetition time of 6000 ms, an echo time of 75 ms, inversion times of TI_1 = 2405 ms and TI_2 = 495 ms, a number of signal averages of 2, an excitation flip angle of 90°, a field of view of 23 cm × 23 cm, a slice thickness of 5 mm with no gap, a number of slices of 25 and a matrix size of 96 × 96 reconstructed to 128 × 128. The scanning time was 10 min per data set. Two spin-echo EPI images were also obtained with no inversion pulses, again with the phase-encoding in opposite directions. Each of these consisted of 8 dynamic acquisitions, using the same imaging parameters as above (except with a repetition time of 1000 ms and a number of signal averages of 1), and the scanning time was 40 s per data set. Distortion correction was then carried out on the resulting images, using both Method A and Method B.

Results

Figures 1(*a*) and 1(*b*) show example slices (corresponding to the same region of the anatomy) that were extracted from the two DIR-EPI images, with the phase-encoding in opposite directions. The geometric distortions inherent in the images are immediately apparent. Figures 2 and 3 show the results obtained on this image slice after applying the distortion-correction procedure, using Method A and Method B respectively. For comparison, Figure 4 shows the same slice extracted from the distortion-corrected EPI image. The outline of the brain was defined on Figure 4 (the red contour), and that same contour has been overlaid on all of the other Figures; it should be noted that the EPI images were not registered to the DIR-EPI images, and so some slight discrepancies in these outlines might be expected, although the amount of subject movement between the scans was minimal. It can be seen in Figures 2 and 3 that both Method A and Method B effectively recover the undistorted shape of the brain: the outlines of the brain agree well with the red contours. Differences between the two methods can however be seen when looking at the interior of the brain. It was found that Method A was not able to cope very well with the large regions of low signal intensity in the DIR-EPI images, corresponding to the nulled white matter. The result of this was that spurious areas of signal were generated within the white matter in the distortion-corrected image, as indicated by the yellow arrows in Figure 2. In contrast, Method B does not suffer from this problem, as seen in Figure 3.

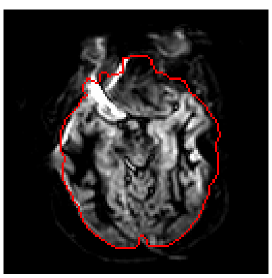

Figure 1(*a*)

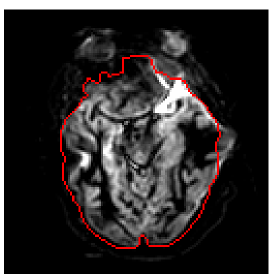

Figure 1(*b*)

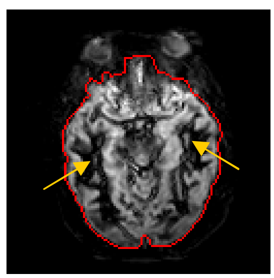

Figure 2

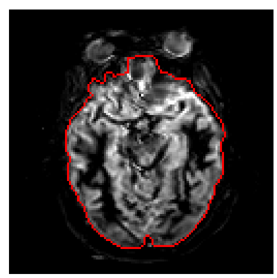

Figure 3

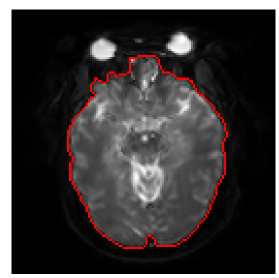

Figure 4

Conclusions

The results show that the optimal method for carrying out distortion correction on DIR-EPI images is to make use of pixel-shift information calculated from EPI images acquired using the same imaging parameters, but with no inversion pulses (which was described here as Method B). It appears that to use only two DIR-EPI images to derive the pixel shifts (Method A) creates problems, due to the lack of information provided by the large areas of nulled signal intensity. It should be noted that the images acquired here deliberately did not use parallel imaging, and so they demonstrate an extreme degree of distortion; these results therefore represent the performance of the two methods in a situation that was far worse than would actually be experienced in practice. The present work has discussed only the application of a DIR-EPI image to fMRI, but future developments will involve the use of anatomical information from a (white matter-selective) DIR-EPI image to improve the results from diffusion MRI, which would also require an adequate method for distortion correction to be applied. Furthermore this is also, to the best of our knowledge, the first report of the implementation of a DIR-EPI sequence at a magnetic field strength of 3 tesla.

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