Dynamic unwarping of multi echo EPI data

E. Visser[1,2], B. A. Poser[3], M. Barth[1,4], and M. P. Zwiers[1,2]

[1]Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen, Nijmegen, Netherlands, [2]Department of Cognitive Neuroscience, Radboud University Nijmegen Medical Centre, Nijmegen, Netherlands, [3]Department of Medicine, Queen's Medical Center, Honolulu, Hawaii, United States, [4]Erwin L. Hahn Institute for Magnetic Resonance Imaging, University Duisburg-Essen, Essen, Germany

Introduction

Geometric distortion caused by inhomogeneities of the B_0 field is a well known problem with echo-planar imaging (EPI) [1]. Although parallel imaging can reduce their impact, local distortions remain apparent and continue to cause problems where accurate registration to distortion free data is required. We propose to use the phase information provided by a multi echo EPI (ME-EPI) acquisition [2-4] to obtain a B_0 field map for each volume and use this map to perform dynamic distortion correction. This eliminates the need for a separately acquired field map and sidesteps any possible problems resulting from the motion-distortion interaction which may invalidate field maps acquired in a prescan even after the application of motion correction. [5]. Dynamic multi-echo single-shot distortion correction using the fMRI timecourse data itself has previously been suggested with the gradient reversal technique [6], but the use of dynamically extracted ME-EPI field maps has not been investigated.

Methods

It is well known for EPI sequences that the local displacement d_y along the phase encoding (PE) direction is given by $d_y = N \cdot ESP \cdot \gamma \cdot \Delta B_0 = N \cdot ESP \cdot \Delta\omega$, where N is the number of PE steps, ESP is the echo spacing and $\Delta\omega$ is the angular velocity of the undesired (i.e. non-gradient) phase evaluation. We calculate the $\Delta\omega$ map, which is proportional to the ΔB_0 map, directly from the phase components φ_1 and φ_2 of the first two echoes of the reconstructed ME-EPI images as $\Delta\omega = (\varphi_2 - \varphi_1)/\Delta TE$, where ΔTE is the echo time difference between the first and the second echo. The phase difference maps are unwrapped using the SPM8 FieldMap toolbox. The actual per-volume unwarping operation was integrated into the SPM realignment procedure to remove the need to resample prior to realignment.

Two series of ME-EPI volumes were acquired: 1.) 2.5 x 2.5 mm^2 in-plane resolution, matrix size 88 x 88, GRAPPA x3, 6/8 PF, slice thickness 2.5 mm with 0.5 mm gap, TR = 2400 ms, TE1 = 11.00 ms, TE2 = 24.63 ms, TE3 = 38.26 ms. Siemens 7T system with 32 channel head coil. 2.) 3.5 x 3.5 mm^2 in-plane resolution, matrix size 74 x 74, GRAPPA x3, 6/8 PF, slice thickness 3.2 mm with 0.3 mm gap, TR = 2640 ms, TE1 = 7.70 ms, TE2 = 18.87 ms, TE3 = 30.04 ms, TE4 = 41.21 ms. Siemens Trio 3T system with 32 channel head coil. Additionally, a field map was measured on the 3T system using a conventional dual gradient echo sequence with 3.5 x 3.5 x 3.0 mm^3 resolution, TE1 = 10.00 ms and TE2 = 12.46 ms.

Results

Figure 1 shows the difference between the original and corrected images in two adjacent slices of the 7T dataset. The top row of images clearly shows displacements of several voxels in frontal areas, despite the use of factor-3 acceleration. The bottom row shows the improved co-registaration to an undistorted T1-weighted volume, which is particularly apparent near the frontal part of the ventricles.

Results for the 3T dataset were compared with those obtained using a conventional dual gradient echo field mapping approach. The volumes corrected using the two methods appear very similar (not shown). The spatially-averaged (brain mask) temporal SNR (tSNR) over 140 volumes was comparable for the uncorrected volumes (tSNR = 13.6) and those corrected using either method (tSNR = 14.1 for both), confirming that the dynamically obtained field maps do not introduce unwanted malign fluctuations into the fMRI data to which they are applied. Field maps obtained using both methods are displayed in figure 2.

Discussion

From these results, we conclude that dynamic unwarping is likely to be a robust and practical alternative to traditional field map based unwarping. Our results also demonstrate that distortion correction allows considerable improvements in image quality even when the distortion is "relatively low" due to the use of high acceleration factors, such as a.f. 3, adding further benefits to group analyses [7]. One aspect that may need further investigation is the method's performance in areas where signal drop-out at TE2 compromises calculation of the field maps. In practice however, this is unlikely to be a limitation, since the BOLD signal, which is typically observed at TE2 and the later echoes, would be lost anyway (TE1 is too short to provide BOLD contrast) .

References

[1] Jezzard and Clare (1999), HBM 8:80-85. [2] Speck and Hennig (1998), MRM 40:243-248. [3] Posse et al. (1999), MRM 42:87-97. [4] Poser et al. (2006), MRM 55:1227-1235. [5] Hutton et al. (2002), NeuroImage 16:217-240. [6] Weiskopf et al. (2005), NeuroImage 24:1068-1079. [7] Cusack et al. (2003), NeuroImage 18:127-142.

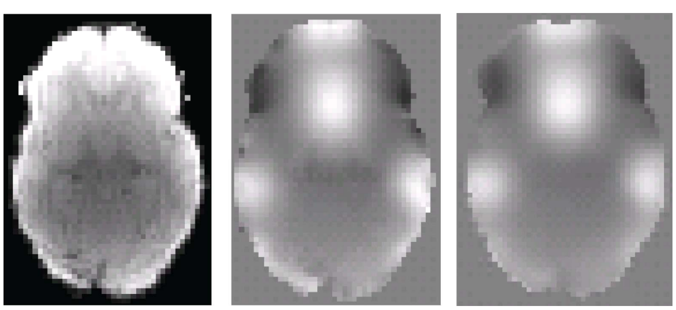

Figure 2. Magnitude image of echo 1 (left), dynamic field map (middle), conventional field map (right). Note that the dynamic field map is itself distorted, while the conventional one is not.

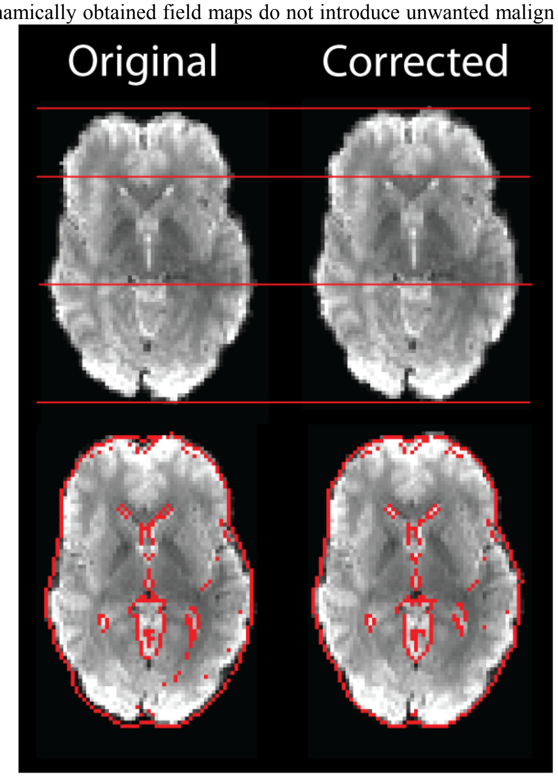

Figure 1. Distorted and corrected images at 7T. In the bottom row, contours of a registered T1 volume are shown in red.