Geometric distortion correction in echo volumar imaging

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Introduction: Echo volumar imaging (EVI) is a 3D extension of echo-planar imaging (EPI) that allows data from an entire volume to be acquired following a single excitation. However, only a few studies to date have applied EVI to functional MRI (fMRI) due to its high sensitivity to field-inhomogeneity induced distortions. In this study, we extend two EPI distortion correction techniques to EVI: correction using a field inhomogeneity map [1] and via PSF mapping [2].

Methods: A modified EVI sequence incorporating rewind gradients in the phase encoding direction [3] was used in this study. This has the advantage of avoiding Nyquist ghost artefacts in the slice encoding direction. Similar to the EPI distortion correction method in [1], we first obtained a field inhomogeneity map from two 3D gradient echo images acquired with different TE-values. This field map is then used to estimate the pixel shift, based on which pixel intensity at a distorted location is interpolated and then multiplied by an operator based on the local pixel shift gradient to recover the accurate intensity.

In the other approach, we extended the correction by PSF mapping [2] from EPI to EVI. Compared to a normal EVI sequence, the pre-excursion gradient pulse in the slice direction is replaced with a PSF encoding loop as shown in Figure 1. This loop adds a distortion-free constant-time encoding in the slice direction. Fourier transformation with respect to this additional encoding yields the PSF in the slice direction for each location in the object. There are two ways to correct the distorted EVI data based on the PSF map: (1) to measure the pixel shift and then apply the correction method in [2]; (2) to deconvolve the EVI data using the PSF.
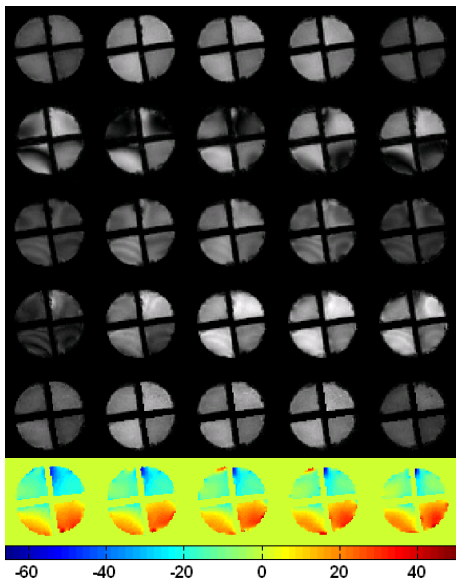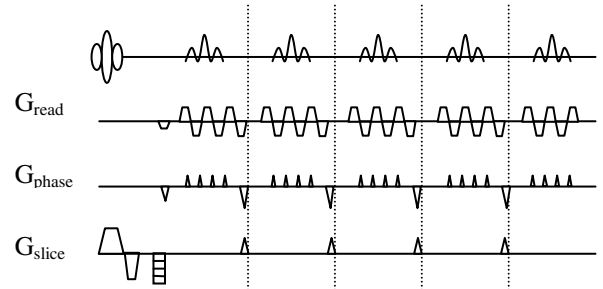

Figure 1 Timing diagram of PSF mapping sequence

Experiments were carried on a Philips Achieva 3T using an 8-channel head receiver coil. The following imaging parameters were used: acquisition matrix 64×64×5 and voxel size 3 x 3 x 3 mm^3, TR = 2s. In addition, SENSE [4, 5] was used to reduce the minimum echo time and maximise the bandwidth per pixel in the slice direction, which took a value of ~15 Hz when a SENSE reduction factor of 3 was applied in the phase encoding direction. Initial experiments were carried out on a 4-segment spherical phantom containing doped agar with different concentrations of Gd-DTPA in each segment. Subsequently brain images were obtained, including an fMRI study involving visual stimulation with an on period of 5s and an off period of 15s for 20 cycles. fMRI data was processed using FSL [6].

Results: Figure 2 shows the results obtained on the phantom using the different correction methods, Figure 3 shows results obtained from the human brain using an axial slice orientation, while Figure 4 shows coronal slice data spanning visual cortex from the fMRI study.

Figure 2 Results on phantom; top to bottom: 1. 3D EPI; 2. distorted EVI; 3–5. distortion-corrected images by (3) a field map, (4) PSF using pixel shift and (5) PSF using deconvolution; 6. field map (Hz)
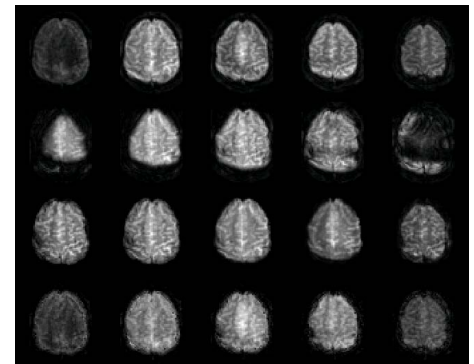

Figure 3 Results on human brain in axial slice orientation, top to bottom rows: 1. 3D EPI; 2. distorted EVI; 3-4. distortion-corrected image by (3) a field map and (4) PSF using deconvolution.
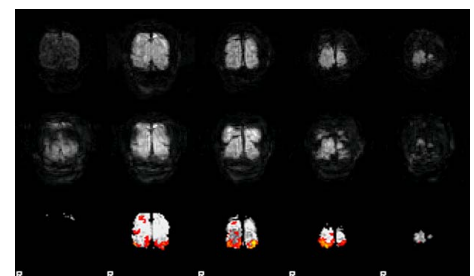

Figure 4 Results on human brain in coronal slices spanning visual cortex, top to bottom: 1. 3D-EPI; 2. distorted EVI; 3. distortion-corrected image by PSF using deconvolution, overlaid with fMRI result.

Discussion and Conclusion: Figure 2 shows that distortion correction by PSF using pixel shifts is not very effective for EVI data. This is due to the fact that the pixel shift representation of distortion does not take into consideration the spreading of PSF peaks due to eddy currents and signal decay over the long echo train. Similarly, correction using a field map is relatively ineffective. In particular, the pixel shift representation of distortion could not solve the case where two pixels overlap with each other in slice direction. This is often the case in EVI as distortion in end slices will wrap around to the other end of the excited slab. These experiments show that with a total of 5 pixels in the slice direction, unwrapping the distortion via pixel shifting is not promising when the shift is ~ 3 pixels in magnitude. Thus in our study, the correction was done through deconvolution of the distorted EVI with PSF mapping. Tikhonov regularization was used in the deconvolution process to control the noise amplification. The result shows that this implementation of EVI distortion correction by PSF mapping is robust and stable. In addition, this correction technique is also compatible with parallel imaging using SENSE [5].

Reference: [1] Jezzard P *et al.* (1995), *MRM* 34:65-73. [2] Zaitsev M *et al.* (2004), *MRM* 52:1156-1213. [3] van der Zwaag W *et al.* (2006), *MRM* 56:1320–1327. [4] Pruessmann KP *et al.* (1999), *MRM* 42:952–962. [5] Rabrait C *et al.* (2008), *JMRI*, 27:744–753. [6] http://www.fmrib.ox.ac.uk/fsl/.