EPI distortion corrections at 4T: multi-channel field mapping and a comparison with the point-spread function method

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Introduction. The distortions in EPI which arise from local variations in the static magnetic field are roughly proportional to field strength, and can be in excess of 10mm at 4T. These may be corrected for via the field mapping (FM) [1] and point-spread function (PSF) [2] methods. Although the use of multi-channel coils is advantageous at high field, phase images – required for the generation of field maps – may not be generated by the combination of phase images from single channels, or non-physical discontinuities result due to arbitrary phase offsets. We show how high quality field maps may be generated from separate channel data and the consistency between channels used to identify unreliable voxels. The performance of distortion correction with these field maps is compared with the point-spread function correction over a wide range of distortions and subject head sizes. These methods have previously only been compared with much lesser distortions at 1.5 T with a single-channel coil [2].

Materials and Methods. Six subject were studied with a 4T Bruker Medspec scanner and an 8-channel head coil (USA instruments). Field maps were acquired with a dual echo (5ms, 10ms) gradient-echo sequence. Separate channel information was stored. A high bandwidth GE scan was acquired as a reference, with the same echo time as the EPI to yield similar contrast and signal loss, but no phase-encode direction distortion. For the PSF correction, EPI was acquired with a PSF-encoding loop, as implemented in the Siemens Distortion Correction WIP Version 2.5 [3]. To test the two methods over a range of distortions, EPI was acquired with pixels bandwidths in the phase encoding direction in the range of 1055Hz to 2170 Hz in 20 intervals (128x128 matrix, 20*2 mm thick axial slices, TE=39 ms, and 75% of phase-encoding steps).

Analysis. Phase images from each channel and echo were unwrapped using FSL's Prelude [4]. Field maps were generated for each channel from echo pairs. Inconsistencies in field maps may arise from phase images at the two echo times being unwrapped from seed regions on either side of a phase wrap. These were identified automatically on a slice-by-slice basis by comparison with a median field map over all channels (see Figure 1, label 3), and the relevant corrections to the single-channel field maps made. A combined field map was calculated from the mean of these. The effectiveness of field mapping is easily compromised by voxels with erroneous values on the periphery. These were identified via the standard deviation over channels, and excluded. The resultant fieldmap was despeckled (values being replace with the mean of surrounding, reliable voxels), expanded and smoothed with a 2mm kernel. FSL's Fugue was used to unwarp EPIs in the phase-encode direction. The PSF correction of EPIs was applied via a Siemens EVA application as described in Ref [3]. Uncorrected EPIs, FM-corrected EPIs and PSF-corrected EPIs were registered (with FLIRT) to the reference and brain-extracted mask created. These allowed analysis of residual distortions via the fraction of voxels incongruent with a mask of the anatomical reference.

Results. The method described yielded fieldmaps without phase jumps or wraps, or spurious edge values without intervention. Whilst blurring of the border of the brain and asymmetries are the most noticeable effects of field variations in uncorrected EPI, Figure 2 shows also the severity of mislocation of signal in the image interior, particular of the anterior extent of the ventricles and frontal grey matter (10 mm at the site of the arrows). Registration to the reference image shows that whilst distortion of the brain boundary is reduced, the mislocation of signal in the interior is exacerbated (14 mm at the same location). No residual distortions are apparent in either the FM or PSF images in the same slice. FM and PSF corrections can be seen to be equally effective in eliminating boundary distortions over a range of bandwidths/distortions (Figure 3, average values for 6 six subjects).

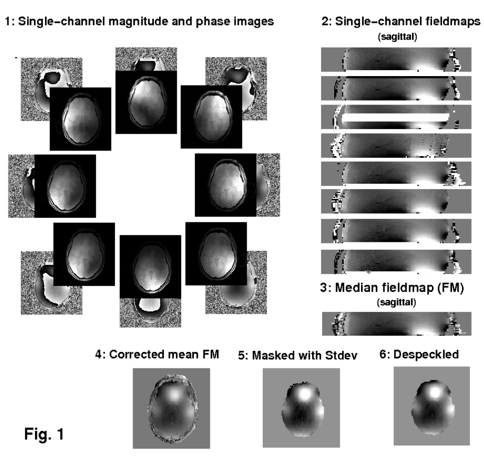
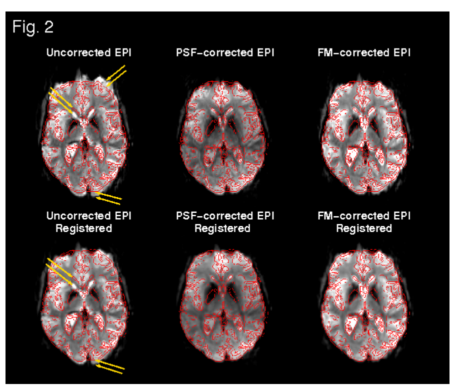
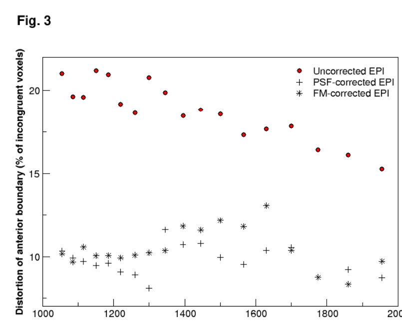


Fig. 1





Discussion and conclusion. High SNR data from multi-channel coils with the exclusion of unreliable voxels remedies many of the shortcomings of field mapping identified in an earlier comparison at lower field and with a birdcage coil [2]. Carefully implemented, both FM and PSF methods are effective in correcting for severe distortions in 4T EPI.

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