Correcting for EPI distortion at very high field using the fieldmap method with multi-channel coils: effectiveness in presurgical planning fMRI at 7 T

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<u>Introduction:</u> Presurgical mapping of motor function in tumour patients with fMRI can benefit from the use of very high static magnetic field. Increased BOLD sensitivity can be used to improve the reliability of voxels identified as active, and/or the precision of localisation of eloquent tissue (by increasing resolution). Accurate localisation is critical for the avoidance of surgery-induced postoperative neurological deficits, but EPI distortions due to magnetic field inhomogeneity scale approximately linearly with field strength. Postprocessing with image registration techniques cannot adequately correct such distortions in pathological brains [1]. The most established method for correcting for distortions in EPI, field mapping [2], is not trivial with very high field systems because of the complex phase topologies encountered and – in the absence of a volume imaging coil – the need to combine phase images from a number of RF receivers which are subject to different, spatially varying, phase offsets. We have implemented a highly accelerated MGE sequence for field mapping with a computationally efficient combination of multi-channel RF phase data. Field maps are corrected for phase jumps between slices and echoes, reduced in noise, and thresholded for the maximum achievable voxel remapping. The effectiveness of distortion correction using these field maps is evaluated in presurgical fMRI of patients with brain tumours in the localisation of primary hand and face motor representations.

<u>Materials and Methods:</u> Four patients with a range of pathologies (left temporoparietal astrocytoma, left temporoinsular astrocytoma (relapse), right central space occupying lesion of unknown origin, right frontal low grade glioma) and who were scheduled for surgery were studied with a Siemens 7 T whole-body scanner with an 8 channel coil. Between 10 and 20 blocked-design functional runs of auditorily-cued motor tasks (either hand or chin) were performed. EPI was acquired with 34 slices of 3 mm thickness with a 128x128 matrix and a 230x230 mm FoV, TE/TR=22/2500 ms, GRAPPA factor=2 and RBW_PE=1220 Hz. Field maps were acquired with a triple-echo MGE sequence (TE=4.6, 9.3, 14.8 ms), GRAPPA factor 4, with slice prescriptions matching the EPI, saving phase and magnitude data from all channels separately (TA=27s).

<u>Analysis:</u> Phase images from the odd echoes were combined according to the complex conjugate method [3] (Fig 1, PD1), and unwrapped in 2D using the region-growing algorithm PHUN [4] (Fig 1, PD2), which is fast and reliable in regions of high field gradient. The combined phase difference data was converted to fieldmap values via $\Delta B_0=\Delta\theta/2\pi\gamma\Delta TE$ (Fig 1, FM1). Integer 2π phase jumps between slices were identified on the basis of mean phase values in each slice and removed (Fig 1, FM2) [5]. Out of brain values were masked using FSL's BET [6] and fieldmaps denoised using non-zero 3x3x3 median replacement of outliers. Regions in which fieldmaps implied local gradients in voxel remapping shifts in the PE direction (Fig 1, VSM) greater than 1 - where the correction would lead to signal pileup or crossover - were reduced to 0.8 (FM3) [5] and flagged. Unwarping was performed with FSL's FUGUE. Slice timing correction, but no other preprocessing, was applied to EPI time series both with and without prior distortion correction. Activated voxels were identified on a single patient basis with a fixed effects GLM analysis of single run responses, analysed using a canonical HRF (SPM5).

<u>Results:</u> Fieldmaps were free from artefacts (such as non-terminating fringe lines and n2π phase jumps) and low in noise. Close to tumours, there were no high frequency features and no regions in which the voxel gradient remapping criterion identified that distortion could not be fully removed. EPI distortions at 7 T (with moderate acceleration; GRAPPA factor 2) were at a similar level to those encountered with typical EPI parameters at 3-4 T without acceleration [5]; e.g. 7-9 mm in occipital areas (Fig 2, top row, 1st column - extract, at position of crosshair), and 9-14 mm in frontal areas (ACC bordering corpus callosum, Fig 2, top row, 3rd column - extract, at crosshairs). Distortions were effectively corrected with field maps, with no apparent residual signal mislocalisation (Fig 2, middle row) compared to a near distortion-free gradient-echo reference scan (Fig 2, bottom row). In functional results, without distortion correction, activation foci in motor areas were mislocalised along the PE axis by 5-7 mm to the posterior (assessed in the undistorted space). In the example in Fig 3, the distortion led to the appearance of a margin between the border of pathology (purple outline in enlargement) and the hand region (activation at yellow arrow in enlargement). It is clear from the distortion corrected data (and overlay on raw EPI, not shown) that activation in fact immediately borders the pathology.

Fig 1.

Fig 2.

Fig 3.
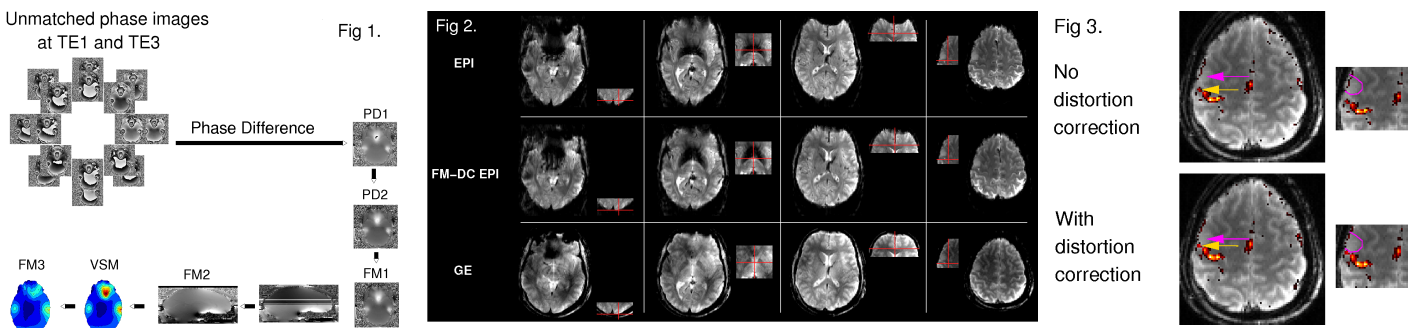
<u>Discussion and conclusion:</u> Even in primary motor cortex, which is generally considered to be well shimmable, deviations from B_0 were 380±40 radss^{-1}, and led to sizable distortions despite the use of parallel imaging. Activation in the hand area was mislocalised posteriorly in the space of structural (near distortion-free) gradient-echo scans, with the potential to lead to clinically relevant consequences in planning. No residual distortions were apparent after correction. This is the first study into the use of distortion correction in presurgical planning fMRI at 7 T, and demonstrates that it is possible to capitalise on the potential CNR benefits of ultra-high field for presurgical planning and effectively eliminate residual distortions. Transformation of fMRI results into a distortion-free space allows improved registration to high resolution structural scans and thereby reliable, automated integration of fMRI results into neurosurgical planning systems.

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