Dynamic distortion correction with standard single-echo EPI: development of the method for multi-channel coils at 7T and accuracy in the presence of substantial motion.

Barbara Dymerska[1], Benedikt Poser[2], Markus Barth[3], Siegfried Trattnig[1], and Simon Daniel Robinson[1]

[1]High Field MR Center, Department of Biomedical Imaging and Image-guided Therapy, Medical University of Vienna, Vienna, Vienna, Austria, [2]Department of Psychology and Neuroscience, Cognitive Neuroscience, Maastricht University, Maastricht, Netherlands, [3]Centre for Advanced Imaging, The University of Queensland, Brisbane, Australia

Introduction:

Local variations in B_0 lead to geometric distortions in EPI, particularly at high field. The "static" remedy is to remap voxels on the basis of a single field map (FM)[1]. Errors arise, however, when there are changes in B_0 after the reference scan (e.g. due to motion). In "dynamic" distortion correction, an FM is calculated for each EPI volume[2,3,4]. In DOCMA[2], for instance, an FM is calculated from the phase difference between echoes in each volume of multi-echo EPI. An alternative dynamic approach, for single-echo EPI[3,4], is to calculate the echo-time-independent contribution to the EPI phase (the "offset", or Φ_{off}) from reference EPI measurements made prior to the fMRI time series with two different echo times. This Φ_{off} is removed from the phase of the EPI time series to yield a series of field maps, $FM_{\Phi off}$. This avoids the spatio-temporal resolution restrictions associated with multi-echo EPI but is dependent on Φ_{off} remaining nearly constant in the presence of motion. The stability of Φ_{off} has only been tested with very modest movement (up to 0.2° rotation[3] or 3mm translation[4]) at 1.5T and 3T, where receiver offsets vary slowly in space. There is potential for larger errors with more realistic motion at 7T, particularly because the RF wavelength is shorter (~12cm @ 7T c.f. ~30cm @ 3T). Previous studies were performed with a volume coil. In this study we extend the method to work with multi-channel coils, each element of which is subject to a different offset, and to use a dual echo GE reference scan instead of EPI to yield a higher SNR estimate of Φ_{off}. Using DOCMA as a reference, we quantify the errors encountered with both $FM_{\Phi off}$ and the static approach for large motion (up to 10° rotation).

Methods and Analysis:

Measurements were carried out with a 7T Siemens scanner and a 32 channel head coil on one volunteer. In **Exp. 1**, motion-related errors in $FM_{\Phi off}$ (due to changes in Φ_{off}) and FM_{GE} (due to changes in B_0) were quantified with respect to DOCMA. The volunteer rotated their head slowly about the left-right axis during acquisition of dual-echo EPI with TE=[11,31]ms, TR=1.2s, 3.3x3.3x4.4mm^3 voxel size and 50 volumes. In **Exp. 2** the effectiveness of the distortion correction with dynamic $FM_{\Phi off}$ and static FM_{GE} was qualitatively compared for single-echo EPI (TE=20ms, TR=1.2s and 1.6x1.6x4.4 mm^3 voxel size) where there was motion of the head between the GE and EPI scans. Dual echo Gradient Echo scans with TE=[5,11]ms and the same geometry as EPI were acquired prior to both experiments for Φ_{off} and FM_{GE} calculation.

The static FM_{GE} was calculated with a separate channel approach[5]. The Hermitian inner product method[6] was used for DOCMA. Φ_{off} was calculated following Ref [7] both from the reference GE scan, for $FM_{\Phi off}$, and from dual-echo EPI (in Exp. 1) to assess the motion-dependence of Φ_{off}. The FM_{GE} and the GE-based Φ_{off} were warped to the EPI distorted space. The GE-based Φ_{off} were subtracted from phase data, channel-wise, and the angle of the complex sum was taken. $FM_{\Phi off}$ was obtained by division of this offset-free combined phase by the corresponding T_E (11ms in Exp. 1 and 20ms in Exp. 2). FMs were converted into Voxel Shift Maps (VSM)[5]. In Exp. 1, a voxel-wise difference between FM_{GE} or $FM_{\Phi off}$ VSMs and DOCMA VSMs was calculated and, for selected ROI, plotted as a function of time (Fig.1-d). Root-mean-square (rms) error maps were calculated from VSM differences (Fig.1-b and c).

Results:

Exp. 1: motion-related errors were much higher for FM_{GE} than $FM_{\Phi off}$ (Fig.1-b and c), especially at the boundaries of the brain (Fig.1-b, arrows). FM_{GE} values diverged dramatically from DOCMA (Fig.1-d, blue line) with rotation of the head (Fig.1-d, black line) while $FM_{\Phi off}$ consistently agreed with DOCMA (Fig.1-d, red line). There was little variation in Φ_{off} despite motion; the temporal standard deviation of the EPI-based phase offsets was ≈ 0.6 rad (corresponding to ~0.2 voxel in VSM units) on average throughout the brain. **Exp. 2**: when there was motion between FM_{GE} and EPI (sum rotation ≈10°), FM_{GE} caused unwarping errors of up to 11mm in the occipital lobe (Fig. 2-c) instead of correcting distortions. No residual distortions were apparent in the EPI corrected with $FM_{\Phi off}$ (Fig. 2-d).

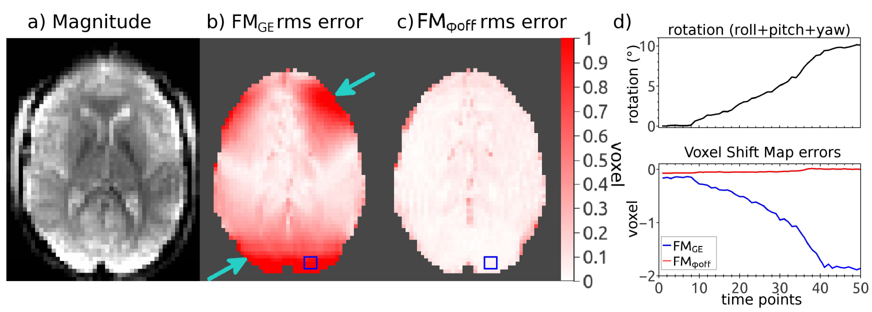

Fig.1: *Quantification of FM_{GE} and $FM_{\Phi off}$ errors during head rotation. a) Original EPI magnitude, b) c) root-mean-square (rms) error maps, d) top: SPM8 rotation estimates, bottom: FM_{GE} and $FM_{\Phi off}$ VSM differences from DOCMA in selected ROIs (a,b,c blue squares) as a function of time.*

Discussion and Conclusion:

We describe the development of a method for dynamic distortion correction using single-echo EPI[3,4] and multi-channel coils, and the testing of this in the presence of large motion at 7 T. Visual inspection of phase offsets generated from GE reference scans show no gross errors, whereas those generated from EPI reference, as in the original implementation[3,4], show unwrapping errors due to low SNR, especially in the ventral brain. Those bottom slices were excluded from the temporal standard deviation of the Φ_{off} in order to focus on motion effects. We show that rotations as large as 10° introduce only small variations in the phase offset (0.6 rad). As a result, the proposed method, $FM_{\Phi off}$ with subtraction of GE-based Φ_{off}, leads to an accurate distortion correction with negligible errors.

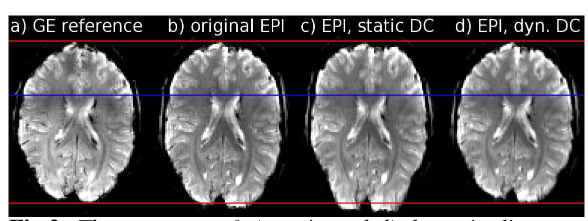

Fig.2: *The accuracy of c) static and d) dynamic dist. corr. (DC) in comparison with a) distortion-free reference.*

Acknowledgment: This study was funded by a DOC fellowship of the Austrian Academy of Science and the Austrian Science Fund (FWF KLI 264).

References: [1] Jezzard P and Balaban RS (1995) *MRM* 34:65–73. [2] Visser E, et al. (2012) *MRM* 68:1247–1254. [3] Lamberton, et al. (2007) *MRM* 26:747-755. [4] Marques JP and Bowtell RW (2005) Proc. of ISMRM 2014, #510. [5] Robinson S and Jovicich J (2011) *MRM* 66:976-988. [6] Bernstein MA, et al. (1994) *MRM* 32:330–334. [7] Robinson S, et al. (2011) 65:1638-1648.