Radio frequency (B1) field mapping at 7T using 3D SE/STE EPI technique

A. Lutti[1], C. Hutton[1], J. Stadler[2], O. Josephs[1], O. Speck[3], C. Tempelmann[4], J. Bernarding[5], and N. Weiskopf[1]

[1]Wellcome Trust Centre for Neuroimaging, Institute of Neurology, University College London, London, United Kingdom, [2]Special Lab Non-Invasive Brain Imaging, Leibniz Institute for Neurobiology, Magdeburg, Germany, [3]Dept. Biomedical Magnetic Resonance, Institute for Experimental Physics, Otto-von-Guericke University, Magdeburg, Germany, [4]Department of Neurology, Otto-von-Guericke University, Magdeburg, Germany, [5]Institute for Biometry and Medical Informatics, Faculty of Medicine, Otto-von-Guericke-University, Magdeburg, Germany

Introduction Spatial inhomogeneities in the radio-frequency (RF) field (B_1) increase with field strength affecting quantification and contrast of images. For correction of B_1 inhomogeneities, fast and robust whole-brain B_1 mapping methods are essential and are intensively studied for ultra high fields. Following optimization previously implemented at 3T [1], we further optimize the spin-echo/stimulated echo (SE/STE) 3D EPI method introduced by Jiru and Klose [2] for whole-brain B_1 mapping at 7T. The optimization addresses severe off-resonance effects leading to image distortion and variations in the effective flip angle, B_1 inhomogeneities and refocusing of coherence pathways.

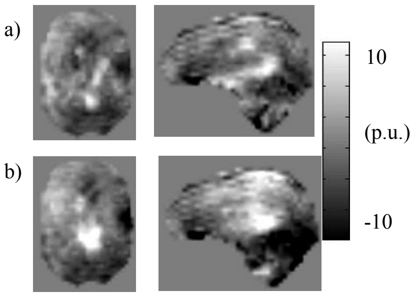

Figure 1: Difference between B_1 maps acquired using the AFI and EPI methods with (a) and without (b) permutation of the crusher gradient polarities.

Methods Image acquisition: 3D EPI data were acquired on two subjects on a 7T whole-body system (Siemens Medical Solutions, Germany), operated with head-only CP transmit and 24-channel receive coils (Nova Medical, Inc., Wilmington MA) with the following parameters: matrix size 48x64x48, 4x4x4 mm^3 resolution, acquisition time 3min 48s. Distributions of B_1 fields were calculated from the ratio of STE (nominal flip angle α) and SE (nominal flip angle 2α) images for different values of α [2]. To speed up acquisition and reduce spatial distortion, 2D GRAPPA parallel imaging was implemented with acceleration of 2 along the phase and partition directions. The reference lines for the calculation of the GRAPPA kernel were acquired as a separate fully encoded image (48s acquisition time). The echo times were 35.9 ms and 67.55 ms for the SE and STE images respectively. The readout time was 12.96 ms for a bandwidth of 2298 Hz/Px. An additional B_0 map was acquired for correction of residual image distortion (acquisition time of 2 mins). Hamming-filtered sinc SE and STE pulses (time-bandwidth product of 6) were used. In order to minimize off-resonance effects, the minimal RF pulse duration was used for each nominal α, maximizing the RF voltage and effective B_1 amplitude. Accurate B_1 estimation requires high signal intensity in the SE image, i.e., $\alpha_{local} \approx 90^o$ at every voxel location, to avoid excessive noise and bias. To fulfil this requirement under the large B_1 deviations present in the human head at 7T (~50%), 15 image volumes were acquired with nominal α ranging from 240^o to 100^o by steps of 10^o. Each volume was acquired in 12s for a repetition time TR of 500ms. The polarity of the crusher gradients was inverted along the read, phase and slice directions successively (*permutation*) to avoid the refocusing of undesired magnetization coherence pathways across excitations at this short TR value. In order to assess the accuracy of the method, we also acquired B_1 maps with the widely used AFI method [4]. **Image post-processing:** Artefactual voxel displacements along the phase encode direction (R->L) were corrected by B_0 fieldmap-based *unwarping* [3]. For each voxel, 6 data points with maximum intensity in the SE image were selected out of the 15 repetitions. Local flip angles were estimated by a linear regression of nominal versus local flip angles. The standard deviation of the result (SD) was used as a measure of the goodness of fit. Voxels with SD > 5 p.u. were masked out of the images and the missing values were estimated by averaging those of the remaining neighbouring voxels (*padding*). In order to illustrate the accuracy of the technique, the estimated 3D EPI B_1 maps were used to correct for flip angle inhomogeneities in T_1 maps acquired at 7T using a dual angle 3D FLASH acquisition [5].

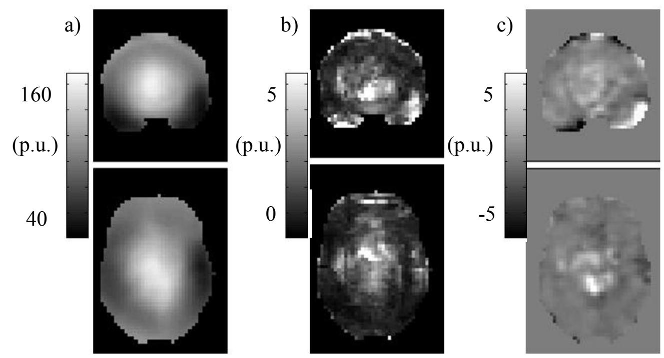

Figure 2: a) Flip angle map obtained using the 3D EPI method. b) Map of SD of the flip angle calculations. c) Scan-rescan stability as difference between two successive acquisitions.

Results All flip angle maps shown here are normalized to the nominal flip angle (= 100 p.u.). Figure 1 represents differences in measured flip angles between the 3D EPI and AFI methods with (a) and without (b) permuting crusher gradients. When crushers were permuted, the B_1 maps agreed within a 5 p.u. margin with the AFI method [4] over most brain regions (see figure 1 a). The main areas of improved spoiling were the ventricles probably due to the long T_2 times of cerebrospinal fluid and the temporal lobes and cerebellum probably due to the low B_1 field. However, significant discrepancies remained in the latter regions due to low signal levels for both AFI and EPI methods. Minimizing the RF pulse duration for each nominal flip angle value reduced off-resonance effects in the orbital frontal cortex where high B_0 gradients are present, leading to changes up to 30 p.u. in the measured flip angles (not shown). Figures 2 a) and 2 b) show a typical B_1 map and its associated error SD map (goodness of fit). Significant SD values (>5%) were observed in the temporal lobes and cerebellum as well as in the ventricular system. Figure 2 c) shows scan-rescan differences between two B_1 maps acquired successively. Regions of large SD corresponded with regions of large instabilities. Figure 3 shows T_1 maps and whole-brain histograms acquired at 7T based on dual angle 3D FLASH acquisition before (a) and after (b) correction with the EPI B_1 map [5]. The severe inhomogeneities in T_1 values due to B_1 variations were removed, particularly in the central and peripheral brain regions (note that the wide scaling of the histogram in figure 3 b) does not allow to distinguish between grey matter and white matter T_1 values). Only some residual bias in the inferior parts of the temporal lobes and cerebellum remained, corroborating the high accuracy and precision of the B_1 map.

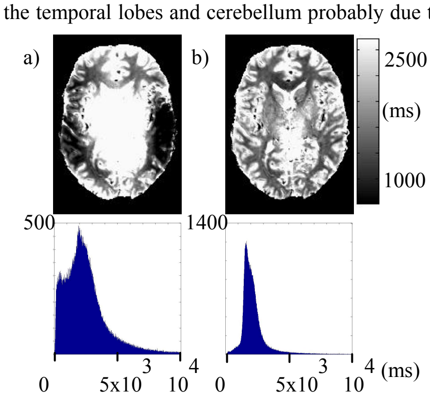

Figure 3: Maps and whole-brain histograms of T_1 values uncorrected (a) and corrected (b) for flip angle bias. After correction, the T_1 values are found highly homogeneous throughout the brain, illustrating the accuracy of the B_1 mapping method.

Conclusion We have optimized the SE/STE 3D EPI method for fast, accurate and precise whole-brain B_1 mapping at 7T. The improvements resulted in a method robust against the severe B_0 and B_1 inhomogeneities encountered at ultra high field. Permutation of the crusher gradients led to a reduced sensitivity of the method to transverse coherence effects, an important feature at all field strengths. At field strength <7T, the number of nominal values can be reduced due to smaller B_1 inhomogeneities, leading to a significant reduction in scan time.

References [1] A. Lutti *et al*, MRM, under revision. [2] F. Jiru and U. Klose, MRM **56**:1375-1379 (2006). [3] C. Hutton *et al*, NeuroImage **16**:217-240 (2002). [4] V.L. Yarnykh, MRM **57**: 192-200 (2007). [5] G. Helms *et al*, MRM, **59**:667-672 (2008).

Acknowledgments Funded by the Wellcome Trust[1], BMBF grant 13N9208 and 01 EQ0605[3]