Towards Whole Brain T2-Weighted fMRI at Ultra-High Fields using an Integrated Approach

J. Ritter[1], P-F. Van de Moortele[1], G. Adriany[1], and K. Ugurbil[1]
[1]CMRR/University of Minnesota, Minneapolis, MN, United States

Introduction/Synopsis Ultra-High Magnetic Fields offer large advantages, including higher image SNR, higher functional contrast and increased spatial specificity (i.e. accuracy) for T_2-weighted fMRI [1]. Short transverse relaxation times, increased magnetic susceptibility effects, specific absorption rate (SAR) and B_1 inhomogeneities [2,3], however, can all undermine these advantages. Here we present an integrated approach consisting of a T_2 weighted sequence that reduces SAR significantly (SPIF-T_2) [4], a large volume B_1 shim to improve T_2 contrast and either a 16 channel or a 30 channel transceiver array coil that enable and improve RF (B_1) shimming for large volumes of the human brain. Robust activation is demonstrated in both the visual and motor areas of the human brain.

Methods A slab wise magnetization Preparation for Functional Imaging with a T_2 weight (SPIF-T_2) [4] is used to provide the T_2 weighting for the more accurate Spin Echo (SE) fMRI [1,4,5], while reducing SAR significantly (~3 fold for 10 slices when compared to a standard multi slice Spin Echo (SE) sequence). Ten slices were positioned to go through either the visual- or the motor-cortex. This technique is used in conjunction with Parallel Imaging with X4 acceleration (1D) and a half-Fourier technique (5/8) to allow for whole brain coverage while maintaining short acquisition times necessary to keep Gradient Echo (GE) contributions small.

Two normal subject of similar physiology, one for each coil, participated in this study. A 16 channel [6] and a 30 channel transceiver array coil (Fig. 1) were used. The 30 channel coil consisted of two concentric rings (14 and 16 elements respectively) of short (8 cm) line elements to cover the superior and inferior part of the human head, allowing for efficient B_1 manipulation along the z-direction. Two elements have been omitted from the lower ring to allow for task presentation. 16 channels, distributed among the two rings in an approximately interleaved fashion were used for transmit and receive.

Experiments were performed on a 7T system (Siemens). The motor (finger tapping) and visual (flashing red checker board) paradigms consisted of 10 blocks of 30s stimulus and 30s rest with a total duration of about 10 minutes. Each 30s period consisted of 5 acquisitions. Each acquisition consisted of the same T_2 prepared 120 mm slab going through the visual- and the motor-cortex. The slab selective T_2 magnetization preparation (Fig. 2), consisted of a (90º |180º|-90º) RF sequence to flip back the magnetization along the z axis, followed by 10, interleaved GE EPI slices of 2 mm thickness each. (FOV = 19.2 x 19.2 cm^2; matrix = 128 x 128, single shot; α=90°); TE for the preparation slab was 55 ms; TE for the EPI readout with half-Fourier was 5.9 ms. TR in the multi slice EPI train was ~ 25 ms per slice leading to 250 ms for the 10 slice acquisition following each T_2 preparation module; this includes a 12.2 ms fat suppression module for each slice).

Two B_1 shim targets within one large volume were defined based on three axial slices positioned in each of the two slabs chosen for the subsequent fMRI series (one in the visual cortex, one in the motor cortex). Within each of these six (2*3) axial reference slices an ROI was drawn defining the B_1 shim target location. A 3D B_1 Map of the whole brain was obtained with the AFI technique with a nominal flip angle of 70 degrees [7]. A series of 18 GE images was obtained with a small flip angle (16 images one channel transmitting at a time, one image all coils transmitting, one image without pulsing RF) to produce relative B_1 maps [8]. Those relative maps merged with the 3D B_1 map yielded 16 magnitude and phase B_1 maps for each channel [9]). A B_1 shim solution was calculated for all targets using the optimization toolbox in matlab. 3D B_1 maps were measured again with the two B_1 shim settings to validate the predicted B_1 alterations and efficiencies.

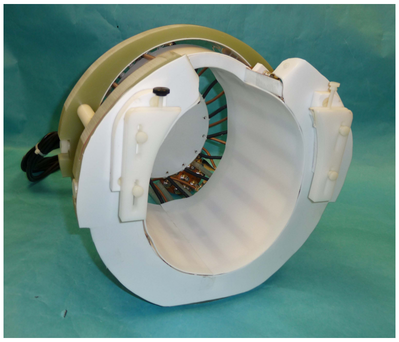

Fig. 1: The 30 channel transceiver coil is shown with the opening on top to allow for task presentation.

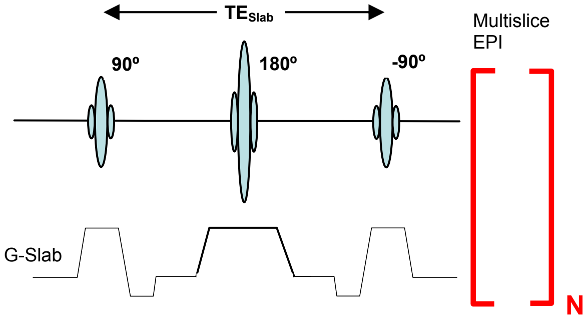

Fig.2 A schematic view of the slab selective T_2 magnetization preparation (SPIF-T_2), consisting of a 90º pulse followed by a refocusing 180º pulse and a -90º to flip back the magnetization along the z axis. Then N slice selective excitation pulses are applied, each followed by EPI readout

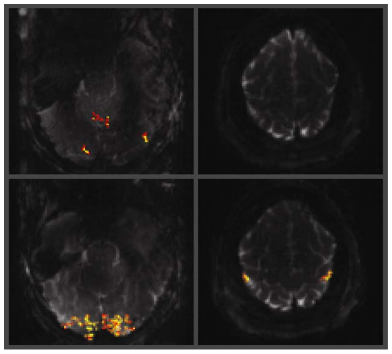

Fig. 3: Activation maps using SPIF-T_2 show one slice (out of ten) in the visual cortex (left) and the motor cortex (right), before B_1 shim (top) and after B_1 shim (bottom). Voxels with p-values $\leq$ .001%, corresponding to 3.3σ, and cluster size threshold of 9 are highlighted.

Results ***(B_1-Shim)*** B_1-homogeneity was improved substantially in the visual cortex as well as in the motor cortex. T_2-weighted contrast has been increased dramatically (see Fig. 3). The starting point was the standard phases and power calibration provided by the product sequences. Efficiency for the B_1 shim solution, however, varied greatly between the two different coils. That for the 16 channel coil called for a substantial increase in power to reach the nominal 70 degree flip angle that was well above SAR limitations. Therefore a B_1 shim solution that sacrificed B_1 homogeneity in favor of efficiency was applied. The still dramatically improved activation results are shown in Fig. 3. For the 30 channel z-shim coil such a tradeoff was not required. Its power requirements are substantially lower and stayed well within SAR limitations (~50%). This indicates that a coil with segmentation along z offers substantially improved B_1 shim capability for applications involving volumes with large extension along z. ***(fMRI)*** Significant BOLD responses were detected in the visual- and motor-cortex (including primary sensorimotor cortex and supplementary motor area) using SPIF-T_2 (see Fig. 3 for the activation maps pre and post B_1-shim in both areas of the brain acquired with the 16 channel coil). A dramatic improvement in contrast and activation in the B_1 shimmed target areas can be observed for both coils. The number of activated pixels is substantially increased in all cases after B_1 shim.

Discussion A strong case has been made for an integrated, multi-component approach to address challenges for T_2-weighted fMRI at Ultra-High fields.

The low SAR T_2-weighted sequence (SPIF-T_2) together with a large volume B_1 shim to improve T_2 contrast and a 30 channel, z-shim enabling transceiver coil are a very efficient approach to sample T_2 weighted contrast in large B_1 shimmed volumes of the human brain.

Moreover, the segmentation of the 30 channel coil in z provides additional encoding along that axis. It should be ideally suited to acquire T_2-weighted fMRI with the double banded version of SPIF-T_2 [10]. Data acquisition speed will be increased by an additional factor of two, as two slices will be acquired at a time. The incurred penalty in SAR for double-banded pulses is expected to be more than compensated for by the low SAR feature of SPIF-T_2.

Acknowledgements: The authors would like to thank P. Anderson, E. Auerbach, S. Schmitter and J. Strupp for helpful discussions, software and hardware support. This work was supported by WM Keck Foundation, BTRR - P41 RR008079, P30 NS057091 and R01 EB000331.

References: 1. Yacoub, E. *et al*., MRM 49:655-664 (2003); 2. Wang, J. *et al*., MRM 48:362-369 (2002); 3. Vaughan, JT. *et al*., MRM 46:24-30 (2001); 4. Ritter, J. *et al.*,ISMRM 662 (2006), Ritter, J. *et al.*,ISMRM 1953 (2007) 5. Ogawa, S. *et al*., Proc Nat'l Acad Sci USA, 1990; 6. Adriany, G. *et al.* MRM 59: 590-7(2008); 7. Yarnykh, VL. *et al.* MRM 57:192-200 (2007); 8. Van de Moortele, P.-F. *et al*., MRM 54:1503-18 (2005); 9. Van de Moortele, P.-F. *et al*., ISMRM 1676 (2007); 10. Ritter, J. *et al.*,ISMRM 2374 (2008),