Multiple Area B1 Shimming: An efficient, low SAR approach for T2-weighted fMRI acquired in the Visual and Motor Cortices of the Human Brain at Ultra-High Field

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Introduction/Synopsis B_1 heterogeneities are a major challenge at Ultra-High Field[1,2]. B_1 shim techniques can mitigate those inhomogeneities but B_1 Shim solutions aiming at uniform B_1 over the whole brain generally result in poor RF efficiency because of large destructive interferences [3]. This translates into higher RF power, thus higher SAR levels. Less constraining tradeoffs can be obtained, sacrificing to some degree on B1 homogeneity, but some sequences are especially sensitive to flip angle variations. This is the case for a T_2 weighted sequence that was previously developed [4] in order to obtain multi-slice T_2w fMRI at 7T with low levels of SAR. The critical T_2 preparation of this sequence cannot be efficient if large B_1 variations occur within a preparation slab. Here we demonstrate that a multi-region B_1 Shim approach allows for improving T_2 contrast in different regions of the human brain (visual and motor cortices) with better homogeneity and lower RF power.

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 [4-6], 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 to allow for whole brain coverage while maintaining short acquisition times necessary to keep Gradient Echo (GE) contributions small.
One normal subject participated in this study. Experiments were performed on a 7T system (Siemens, Magnex). 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- or the motor-cortex. The slab selective T_2 magnetization preparation, 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 2mm thickness each. (FOV=19.2x19.2cm^2; matrix=128x128, 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). For comparison, a similar dataset but without the T_2 preparation module was obtained. Identical readout was played in prepared and non-prepared acquisitions except for a smaller flip angle in the non prepared case to account for the reduced SNR due to the T_2-weighing in the prepared case.
Two B_1 shim targets were defined based on two axial slices positioned in the center of the two slabs chosen for the subsequent fMRI series (one in the visual cortex, one in the motor cortex). Within each of these two axial reference slices an ROI was drawn defining the B1 shim target location. It was sufficient to utilize the center slice as transmit B_1 varied only slowly along the Z direction, i.e. around those target slices. A 3D B_1 Map of the whole brain was obtained with the AFI technique with a nominal flip angle of 70 degrees [8]. For each B_1 shim target a series of 18 GE images were 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 [3]. 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 each target 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. Note that only B_1 phase modulation was utilized in the non linear optimization algorithm. RF power rescaling was performed in a second, optional step.

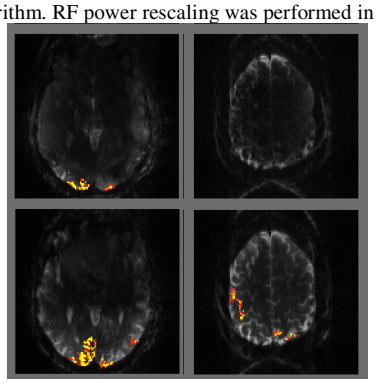

Fig. 1: Activation maps using T_2 w prepared multi slice EPI. One slice (out of ten) is shown in the visual cortex (left) and the motor cortex (right), before pre B_1 shim (top) and after B_1 shim (bottom). Voxels with p-values ≤ .001%, corresponding to 3.3σ, and cluster size threshold of 12 are highlighted.

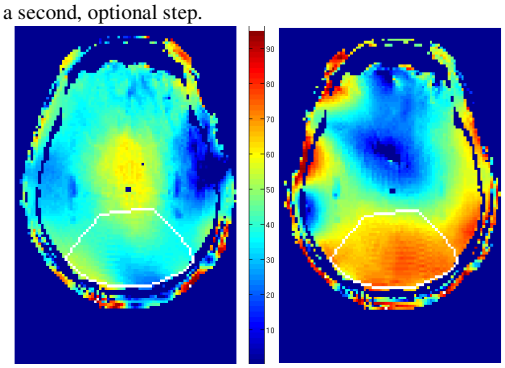

Fig. 2: B_1 maps in the visual cortex before (left) and after (right) B1 shim. The white contour defines the ROI in the occipital lobe where the B_1 shim was calculated. The color bar is in degrees.

	# of activated pixels in the Visual Cortex		# of activated pixels in the Motor Cortex
	With T_2 prep module	Without T_2 prep module	With T_2 prep module
Pre B_1 Shim	2105	1998	990
Post B_1 Shim	3074	3846	3756

Table 1: Total # of activated pixels w/ and w/o the T_2 preparation module shown before and after B_1 shim.

Results ***(B1-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. The starting point for both areas was the standard phases and power calibration provided by the product sequences. In the visual area B_1 phase shim was sufficient to considerably improve B_1 efficiency and overcome the loss in B_1 due to the phase cancellations predominant in this area [3]. In order to obtain a 180° flip angle in this area without B_1 shim the RF would have to double, translating in a 4 times increase in RF power and SAR. Furthermore, the B_1 shim solution greatly improved B_1 homogeneity, thus T_2 contrast was homogeneous through the ROI. As expected, B1 destructive interferences were less pronounced in the motor cortex, which is located closer to the center of the coil in the xy-plane [6]. However, this area being closer to the end of the RF coil along Z experienced lower available B_1. Here it was then necessary to multiply the RF amplitude by a factor 1.75. This emphasizes the variational needs for RF amplitude and phase modulation in different areas of the human brain.***(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. 1 for the activation maps pre and post B_1-shim in both areas of the brain). A dramatic improvement in contrast and activation in the B_1–shimmed target areas can be observed. The number of activated pixels is substantially increased in all cases after B_1-shim (see Table 1). The implementation of SPIF-T_2 with parallel imaging techniques for two distinct areas of the human brain in conjunction with B_1-shim has been demonstrated.

Discussion A strong case has been made for the need to address B_1 inhomogeneities for T_2-weighted fMRI at Ultra-High fields. It has been demonstrated that a multi region B_1 shim is a very efficient approach to sample T_2-weighted contrast in the visual and motor cortices. In locations such as the occipital lobe for instance adjusting only B_1 phases dramatically improved the regional B_1 distribution without a need for increased RF power. This technique of using regional B_1 shim sets in conjunction with T_2-weighted fMRI can now be extended and applied towards cognitive paradigms corresponding to regions of the brain not previously studied at 7T.

Acknowledgements: The authors would like to thank P. Anderson, G. Adriany and J. Strupp for helpful discussions and hardware support. This work was supported by WM Keck Foundation, BTRR - P41 RR008079, P30 NS057091 and R01 EB000331. **References**: 1. Wang, J. *et al.*, MRM 48:362-369 (2002); 2. Vaughan, JT. *et al.*, MRM 46:24-30 (2001); 3. Van de Moortele, P.-F. *et al.*, MRM 54:1503-1518 (2005); 4. Ritter, J. *et al.*,ISMRM 662 (2006), Ritter, J. *et al.*,ISMRM 1953 (2007) 5. Yacoub, E. *et al.*, MRM 49:655-664 (2003); 6. Ogawa, S. *et al.*, Proc Nat'l Acad Sci USA, 1990; 7. Adriany, G. *et al.* ISMRM 673 (2004); 8. Yarnykh, VL. *et al.* MRM 57:192-200 (2007); 9. Van de Moortele, P.-F. *et al.*, ISMRM 1676 (2007);