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
B1 heterogeneities are a major challenge at Ultra-High Field[1,2]. B1 shim techniques can mitigate those inhomogeneities but B1 Shimming solutions aiming at uniform B1 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 the T2* weighted sequence that was previously developed [4] in order to obtain multi-slice T2* fMRI at 7T with low levels of SAR. The critical T1 preparation of this sequence cannot be efficient if large B1 variations occur within a preparation slab. Here we demonstrate that a multi-region B1 Shim approach allows for improving T2* 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 T1 weight (SPIF-T1)) [4] is used to provide the T1 weighting for the more accurate Spin Echo (SE) fMRI [4-6], while reducing SAR significantly (~5 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 T2 prepared 120 mm slab going through the visual- or the motor-cortex. The slab selective T1 preparation of this sequence was efficient in the visual cortex as well as in the motor cortex. T1 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 T2* -weighting in the prepared case. Two B1 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 B1, varied only slowly along the Z direction, i.e. around those target slices. A 3D B1 Map of the whole brain was obtained with the AFI technique with a nominal flip angle of 70 degrees [8]. For each B1 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 B1 maps [3]. Those relative maps merged with the 3D B1 map yielded 16 magnitude and phase images for each channel [9]. A B1 shim solution was calculated for each target using the optimization toolbox in matlab. 3D B1 maps were measured again with the two B1 shim settings to validate the predicted B1 alterations. Note that only B1 phase modulation was utilized in the non linear optimization algorithm. RF power rescaling was performed in a second, optional step.

Results (B1-Shim)
B1-homogeneity was improved substantially in the visual cortex as well as in the motor cortex. T1-weighted contrast has been increased dramatically. The starting point for both areas was the standard phases and power calibration provided by the product sequences [9]. With B1 preparation module for each slice). For comparison, a similar dataset but without the T1 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 T2* -weighting in the prepared case. Two B1 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 B1, varied only slowly along the Z direction, i.e. around those target slices. A 3D B1 Map of the whole brain was obtained with the AFI technique with a nominal flip angle of 70 degrees [8]. For each B1 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 B1 maps [3]. Those relative maps merged with the 3D B1 map yielded 16 magnitude and phase images for each channel [9]. A B1 shim solution was calculated for each target using the optimization toolbox in matlab. 3D B1 maps were measured again with the two B1 shim settings to validate the predicted B1 alterations. Note that only B1 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 T1; w prepared multi slice EPI. One slice (out of ten) is shown in the visual cortex (left) and the motor cortex (right), before pre B1 shim (top) and after B1 shim (bottom). Voxels with p-values ≤ .001%, corresponding to 3.3e, and cluster size threshold of 12 are highlighted.](image1)

![Fig. 2: B1 maps in the visual cortex before (left) and after (right) B1 shim. The white contour defines the ROI in the occipital lobe where the B1 shim was calculated. The color bar is in degrees.](image2)

<table>
<thead>
<tr>
<th># of activated pixels in the Visual Cortex</th>
<th># of activated pixels in the Motor Cortex</th>
</tr>
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<tbody>
<tr>
<td>With T1 prep module</td>
<td>Without T1 prep module</td>
</tr>
<tr>
<td>Pre B1 Shim</td>
<td>2105</td>
</tr>
<tr>
<td>Post B1 Shim</td>
<td>3074</td>
</tr>
</tbody>
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Table 1: Total # of activated pixels w/ and w/o the T1 preparation module shown before and after B1 shim.

Discussion
A strong case has been made for the need to address B1 inhomogeneities for T2-weighted fMRI at Ultra-High fields. It has been demonstrated that a multi region B1 shim is a very efficient approach to sample T2-weighted contrast in the visual and motor cortices. In locations such as the occipital lobe for instance adjusting only B1 phases dramatically improved the regional B1 distribution without a need for increased RF power. This technique of using regional B1 shim sets in conjunction with T2-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 RR080879, P50 NS057091 and R01 EB000331. References: 1. Wang, J. et al., MRM 48:362-369 (2002); 2. Vaughan, JF. 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. Yarmykh, VL. et al., MRM 57:192-200 (2007); 9. Van de Moortele, P.-F. et al., ISMRM 1676 (2007);