Introduction/Synopsis

Ultra-High Magnetic Fields offer large advantages, including higher image SNR, higher functional contrast and increased spatial specificity (i.e. accuracy) for T2-weighted fMRI [1]. Short transverse relaxation times, increased magnetic susceptibility effects, specific absorption rate (SAR) and B1 inhomogeneities [2,3], however, can all undermine these advantages. Here we present an integrated approach consisting of a T2-weighted sequence that reduces SAR significantly (SPIF-T2) [4], a large volume B1 shim to improve T2 contrast and either a 16 channel or a 30 channel transceiver array coil that enable and improve RF (B1) 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 T2 weight (SPIF-T2) [4] is used to provide the T2 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 B1 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 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- and the motor-cortex. The slab selective T2 magnetization preparation (Fig. 2), consisted of a (90° | 180°|-90°) 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 cm²; 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 T2 preparation module; this includes a 12.2 ms fat suppression module for each slice). Two B1 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 B1 shim target location. A 3D B1 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 B1 maps [8]. Those relative maps merged with the 3D B1 map yielded 16 magnitude and phase B1 maps for each channel [9]). A B1 shim solution was calculated for all targets using the optimization toolbox in matlab. 3D B1 maps were measured again with the two B1 shim settings to validate the predicted B1 alterations and efficiencies.

Results (B1-Shim)

B1-homogeneity was improved substantially in the visual cortex as well as in the motor cortex. T2-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 B1 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 B1 shim solution that sacrificed B1 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 B1 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-T2 (see Fig. 3 for the activation maps pre and post B1-shim in both areas of the brain acquired with the 16 channel coil). A dramatic improvement in contrast and activation in the B1 shimmed target areas can be observed for both coils. The number of activated pixels is substantially increased in all cases after B1 shim.

Discussion

A strong case has been made for an integrated, multi-component approach to address challenges for T2-weighted fMRI at Ultra-High fields. The low SAR T2-weighted sequence (SPIF-T2) together with a large volume B1 shim to improve T2 contrast and a 30 channel, z-shim enabling transceiver coil are a very efficient approach to sample T2 weighted contrast in large B1 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 T2-weighted fMRI with the double banded version of SPIF-T2 [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-T2.

Acknowledgements: