Magnetic field homogenization of the human prefrontal cortex with a set of localized electrical coils

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INTRODUCTION: The prefrontal cortex is of major neuroscientific and clinical interest due to its role in perception and memory. Large differences in magnetic susceptibility between the air-filled sinuses and the tissue/bone in the frontal part of the human head result in strong and highly localized field distortions in the prefrontal cortex, which cannot be addressed by low-order spherical harmonic shimming. As a result, image distortion and signal dropout are observed in MR imaging. Attempts have been made to minimize these artifacts with diamagnetic pieces [1] or correct them with electrical coils [2]. Both attempts, however, require the incorporation of devices into the mouth of the subject. Here we show that the distortion can be significantly reduced with a limited set of external coils when combined with the regular first and second order spherical harmonic shimming. To this end, a fixed coil configuration has been developed to provide a localized and high amplitude shim field in the prefrontal cortex with minimum impact on the rest of the brain. The experimental realization enabled us to strongly minimize or even eliminate signal dropout for gradient-echo images and settings typically used in fMRI.

METHODS: A setup consisting of 8 circular coils was numerically optimized with respect to shim requirements of 15 adult brains of mixed gender and race in a 4 Tesla field. The majority of the total shim field was created by one coil while the other coils determined the exact shape and position of the field focus. For subject-specific fine tuning the 8 coils were driven by 6 independent channels of a Bruker shim power supply with currents <2 A. The coils have diameters of 3-5 cm, 70-200 turns and were mounted on the surface of an oval facial mask (diameter 20/23 cm) as well as at 5-8cm away from the mask surface (Fig. 1). The mask was located inside the RF coil and the subjects were placed into the mask. The shim method was applied on 10 subjects of mixed gender and race. Multi-echo FLASH images were acquired on a 4 Tesla Bruker BioSpec system (TE 6.0/6.3/7.0/9.0 ms, FOV 20x24x10 cm^3, matrix 80x96x40) and coil currents and spherical harmonic contributions were calculated from a single whole brain field map. Multiple temperature probes provided close temperature monitoring and minimized potential heat related risks to the subjects. Gradient echo imaging at settings typically used in fMRI studies of the human brain was done to evaluate the impact of the method (FOV 24x24x10 cm^3, matrix 120x120x20, TE 30 ms, TR 1 s). Coil simulations and optimizations, image and field map processing as well as the current adjustments were done with home-built software.

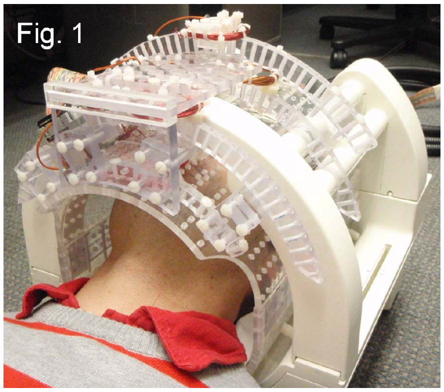
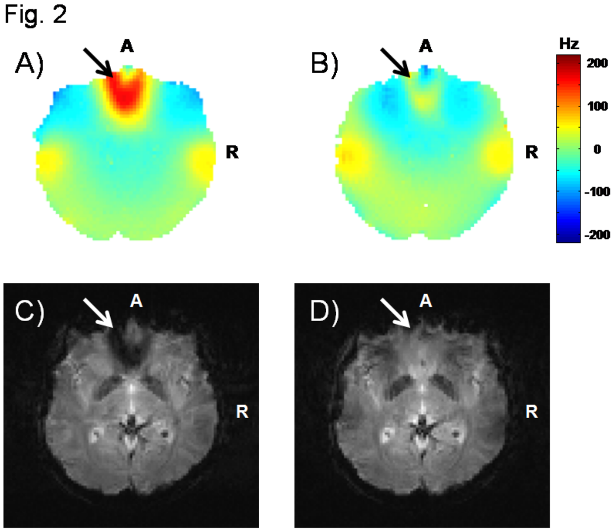


Fig. 2



RESULTS: In all cases focal field artifacts in the prefrontal cortex which were regularly observed after first and second order spherical harmonic shimming only (Fig. 2A) were strongly reduced with the combined shimming method (Fig. 2B). As a consequence, with the localized coil shimming image distortions and signal dropout in gradient echo images of the prefrontal cortex could be strongly reduced (Fig. 2D) as compared to spherical harmonic shimming (Fig. 2C).

DISCUSSION: It has been shown that most of the field and image distortions observed in the human prefrontal cortex can be removed with a limited set of external shim coils with minimum hardware requirements. Single scan field mapping was sufficient for the determination of all coil and spherical harmonic shim terms. The method is sufficiently flexible to account for inter-subject variability and based on the fixed setup, experiment-specific calibrations as described in [2] are not necessary. Minimization of coil currents, as well as total experiment time, limited coil heating such that the temperature on the inside of the shim mask never exceeded body temperature. No artifacts were observed which could be related to the placement of constant current coils inside the magnet bore or inside the RF coil. We expect that the presented proof of principle can be readily extended to the whole brain.

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[1] JL Wilson et al., MRM 48:906 (2002), [2] J-J Hsu et al., MRM 53:243 (2005)