Whole brain field homogenization with localized electrical coils

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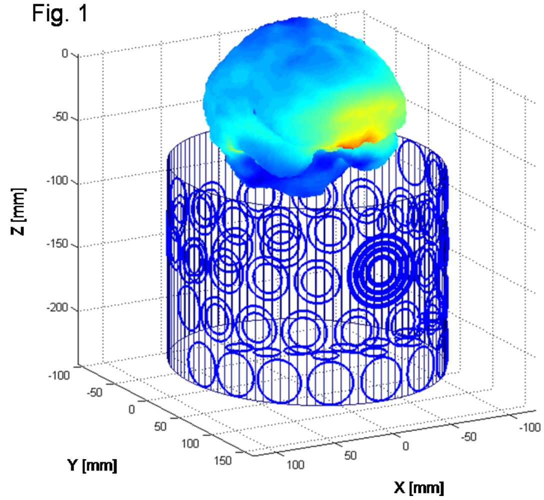
INTRODUCTION: The orbital prefrontal cortex and the medial temporal lobes are common target structures in the study of cognitive function and are relevant in pathologies like temporal lobe epilepsy. Excellent magnetic field homogeneity in these areas is essential for meaningful NMR experiments. The strong field distortions created by largely varying magnetic susceptibility conditions at tissue/bone and air interfaces in the human head, however, pose a major limitation for studying these brain areas as they hamper whole brain imaging and spectroscopy. To improve the homogeneity in the brain the field distribution is typically measured and compensated by a set of low-order spherical harmonic shim functions. Spherical harmonic shimming is able to eliminate shallow field gradients, but becomes useless in these areas of localized, high amplitude distortions. Passive shimming has been applied for whole brain homogenization of magnetic field distribution [1]. The results are promising, but the method is extremely labor-intensive and inflexible and, therefore, not suitable on a subject-by-subject basis. Based on experimental experiences with an 8 coil setup (additional abstract), field simulations of a set of 100 circular electrical coils were used to show that high quality whole brain shimming can be achieved.

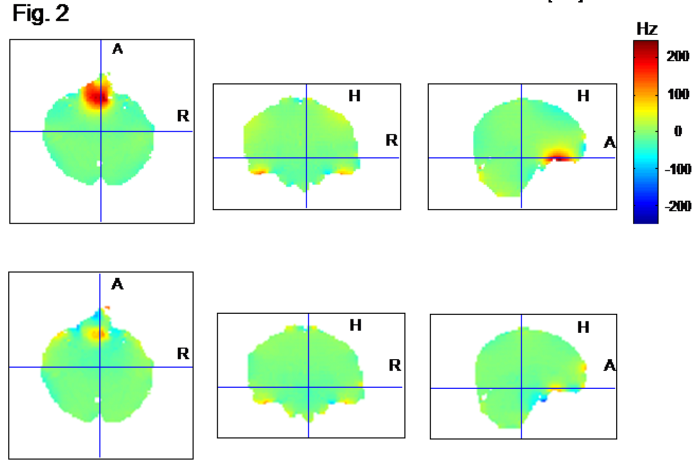
METHODS: A setup consisting of 100 circular electrical coils was derived and optimized on the basis of 15 experimental brain maps acquired from adult volunteers of mixed gender and race at 4 Tesla. Coils with 100 turns and 20-55 mm diameters were placed on the surface of a virtual, elliptical mask with 20/23 cm axis diameters, which can accommodate a human head (Fig 1.). Notably, all coils were positioned below the nose of the subject. Whole brain field distributions were decomposed into a combination of the 100 independent coil fields plus zero-to-second order spherical harmonics. Particular emphasis was placed on the experimental feasibility of the theoretical setup, which included the dimensioning and positioning of the coils as well as assuming a current limit of 1 A per channel. All data processing, analysis and field simulations were done with customized software.

Fig. 1



RESULTS: A setup of 100 independent coils has been developed that allowed us to remove virtually all macroscopic field distortions of the 15 experimental brain maps. The distortions in the prefrontal cortex as well as the distortions above the ears and in hippocampus that could not be addressed by zero-to-second order shimming (Fig. 2, first row), but were almost entirely eliminated with the multi-coil approach (Fig. 2, second row). Residual standard deviations over the entire brain in the range of 10-15 Hz were observed, which is 2-3 times better than after zero-to-second order spherical harmonic shimming only.

Fig. 2



DISCUSSION: The presented methodology and setup promises a major improvement in field homogenization over the entire human brain. The shim fields that are generated with a large set of localized coils are no longer restricted to the shallowness of low order spherical harmonic functions. In fact, shim fields can be generated whose strength and complexity far exceeds the capabilities of the former, not problem-oriented mathematical functions. Active localized shimming with the presented approach will require only a single placement of the subject within the NMR scanner, as is the case for spherical harmonic shimming. Shim fields will be easily adjustable with high accuracy simply by switching the appropriate coil currents. Well-defined placement of the proposed shim device with respect to the brain and an exact knowledge of the produced shim fields will be the key for reproducible, high quality results. Since all coils are placed below the nose, risks and discomfort to the subject are minimized as well as potential interferences with other modalities, e.g. visual stimulation devices for fMRI. Future implementations can be made by integrating RF and shim coils into one assembly.

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[1] US Patent 6,294,972 B1 (2001)