MRI based measurement of magnetic field distribution generated by transcranial magnetic stimulation coils

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Introduction

Transcranial magnetic stimulation (TMS) has great potential as a research and therapeutic tool (1,2,3). The technique suffers from poor spatial localization and specificity, and recent research has focused on improving these characteristics via stimulation coil design. The design of a stimulation coil necessitates models of the electromagnetic fields induced by the coil and experimental validation of such models. Numerous field models have been developed with varying degrees of detail, some using MR images to build realistic head models (4,5) but to the best of our knowledge a straightforward experimental method for model validation does not yet exist. In this work, we propose an MRI-based method to measure the magnetic field distribution in the head, and present phantom data to demonstrate the measurement.

Methods

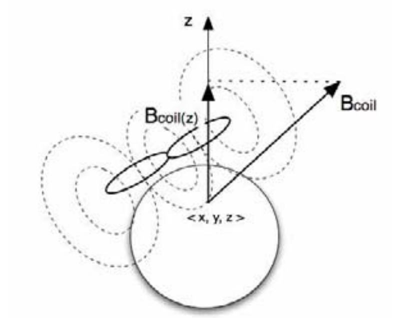

Figure 1. TMS coil positioned over object. Only, the projection of $\vec{B}_{coil}$ onto the Bo axis is observed.

TMS pulses are typically low frequency (< 1KHz) and thus the generated magnetic field's spatial *distribution*, $\mathbf{B_{coil}}$, can be approximated as DC. A small figure-eight coil mimicking a standard TMS probe was connected to a 9mA current source and fixed on the surface of a spherical phantom filled with copper sulfate solution, as illustrated in figure 1. Inside the phantom, three vessels containing different concentrations of copper sulfate were fixed in order to provide a heterogeneous "anatomical" structure. $\mathbf{B_0}$ field maps were measured (6) as proportional to the phase difference between two images with slightly different echo times in a gradient echo sequence (GE 3T scanner, spiral acquisition, 16 interleaves, TE=7ms, TR=9s, 1mm slice thickness, 24cm FOV). Maps were collected with both zero current and a small direct current (9mA) running through the coil. Subsequent subtraction of the resulting maps yielded the projection of the magnetic field produced by the current in the TMS coil, $\vec{B}_{coil} = (B_{coil,x}, B_{coil,y}, B_{coil,z})$, onto the $\vec{B}_0$ direction. The phantom and coil assembly was rotated along two orthogonal axes to produce a total of three setup positions. Rotation angles were less than 30 degrees from the reference position. The images and field maps were realigned using SPM2's realignment tool (7) in order to measure the exact 3D rotation and translation parameters at each position relative to the reference position. Given the measured $B^n_{coil,z}$'s at three positions (n=1,2,3), and the estimated rotation matrices M_1, M_2, M_3, we calculated the three components of the $\vec{B}_{coil}$ by solving a simple linear system for $B_{coil,x}$ and $B_{coil,y}$:

$$\vec{B}^1_{coil} = M_1 \cdot \vec{B}_{coil} \qquad \vec{B}^2_{coil} = M_2 \cdot \vec{B}_{coil} \qquad \vec{B}^3_{coil} = M_3 \cdot \vec{B}_{coil}$$

Results and discussion

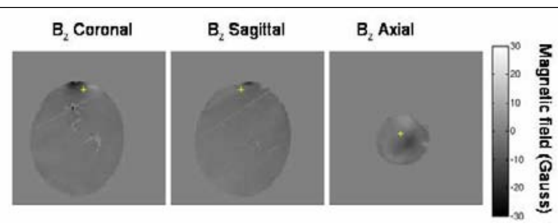

Figure 2 . Orthogonal views of the Z component of the TMS field

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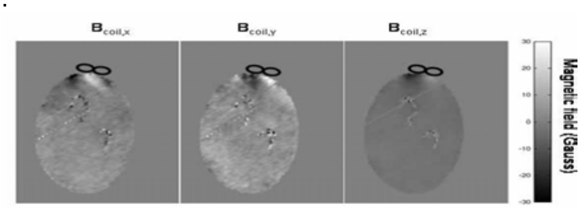

Figure 3. Coronal views of the vector field generated by the TMS coil. Note the coil plane is perpendicular to the image plane.

The choice of acquisition parameters kept image distortion (through-plane dephasing, in-plane pile-up artifact) from the TMS coil current to a minimum, while still allowing us to measure field maps effectively. A typical orthogonal view of $B_{coil,z}$ map can be seen in figure 2. Images of the x,y,z components of $\vec{B}_{coil}$ in a single slice are shown in figure 3. At DC, the magnitude of the electric field generated by the coil is directly proportional to the magnitude of the magnetic field, so the distribution of the electric fields generated by the TMS coil can be readily inferred from these maps. This procedure can be easily applied to real TMS coils on human heads by replacing the stimulator's power supply by a small DC current with minimal risk to the subject.

References:

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