# 3D Simulation Analysis of Transcranial Magnetic Stimulation

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*Abstract*— **This paper presents the results from a simulation of Transcranial Magnetic Stimulation using realistic brain model. The simulation found some interesting results regarding the distribution of the electric field induced in the cortex.**

*Keywords*— **Transcranial magnetic stimulation, coil position, bioelectromagnetism.**

## I. INTRODUCTION

Transcranial Magnetic Stimulation (TMS) allows direct initiation of cortical activity, adding a new dimension to studies of the human brain. In TMS, the cortical cells are stimulated non-invasively by strong magnetic field pulses that induce a flow of current in the tissue leading to membrane depolarization and thereby to neural excitation.

TMS is used in neurology to determine different conditions by evaluating the cortical-motor threshold or to assess the continuity of nervous pathways.

In recent years TMS has proven its capabilities in treating psychiatric conditions like depression or schizophrenia. There is also a lot of research under development for the treatment of other psychiatric conditions [1][2].

Because psychiatric treatments imply stimulation (or inhibition) of certain cortex gyrus, we designed a simulation to see the effects of a circular stimulation coil on a realistic model of the cortex.

## II. TMS – BASIC PRINCIPLES

The neurons are stimulated by applying a rapidly changing magnetic field. In TMS the excitation is obtained through a pulse current that drives a coil situated in the vicinity of the head (figure 1). The source of the activation of neurons is the electric field E induced in the tissue by the varying magnetic field (Faraday's Law) [3]:

$$\nabla \times E = -\frac{\partial B}{\partial t} \quad (1)$$

At cellular level the electric field E affects the transmembrane potential which may lead to local membrane depolarization and firing of the neuron (figure 2) [4].

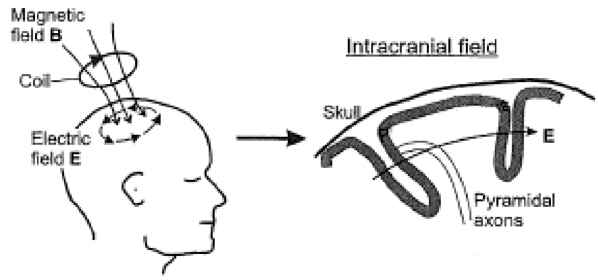


Fig. 1 TMS mechanism – macroscopic view [3]

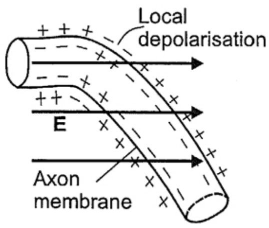


Fig. 2 TMS mechanism – cellular level [3]

## III. SIMULATION SETUP

Because the surface of the cortex is highly irregular, we wanted to view the effects of stimulation on a realistic brain model. To reach our goal we designed a double 70 mm copper circular coil placed in the vicinity of the brain. The brain is represented by an anatomically correct right side hemisphere. The simulation was performed using 3D Finite Element Modeling software.

The generally accepted time periods for TMS are 200-500 μs [5]. The coil is excited by a 1 kA current with a frequency of 2.5 kHz, which corresponds to duration of 400 μs for each pulse. This time period is similar to the one used by Magstim Rapid[2] magnetic stimulators.

The brain hemisphere was modeled as a 3D solid object composed of 261 faces (figure 3). It includes white and gray matter, modeled as a homogeneous volume. Conductivity of the brain was set according to recent research regarding brain conductivity. For body temperature and frequencies between 10 Hz-10 kHz the conductivity was set to 1.79 S/m [6].

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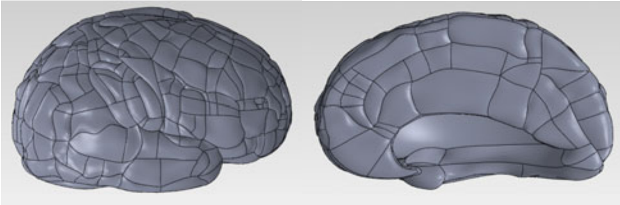


Fig. 3 Cortex views

The exterior diameter of the coil loops is 70 mm, and the interior 40 mm. The coil and cortex objects were included in a sphere containing air. This enclosure has the radius 10 times bigger than the radius of the coil loops. This allows us to set the Neumann condition on the exterior surface of the enclosure without important distortions to the magnetic field produced by the coils.

To mimic realistic stimulation conditions, the coil was positioned parallel to the scalp, rather than to the surface of the cortex. The center of the stimulator is positioned at coordinates (0, 0, 0), and the coils are parallel to the YZ plane (figure 4).

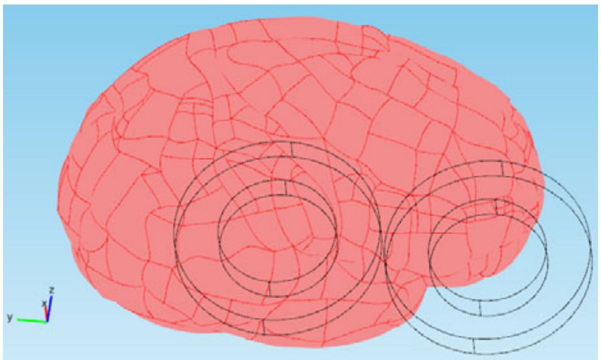


Fig. 4 Overview for the position of the coil relative to the brain

## IV. RESULTS AND DISCUSSIONS

The solution was solved for 753554 degrees of freedom. The overview of the results is in concordance with our expectations – the biggest values for induces electric field are located under the center of the stimulator. But the distribution is not uniform (figure 5).

Although one could expect bigger values for the electric field in the gyri, since they are closer to the coil, we find higher intensities along the channels (called sulci) between them.

For the vertical slices, their positions were chosen to include the center of the stimulator and the points under the inner margin of the left coil (figure 6).

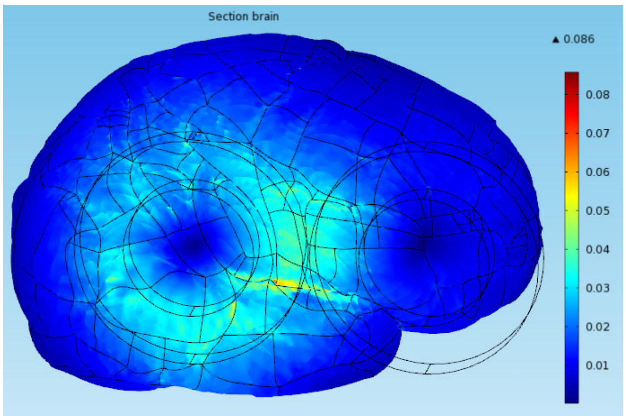
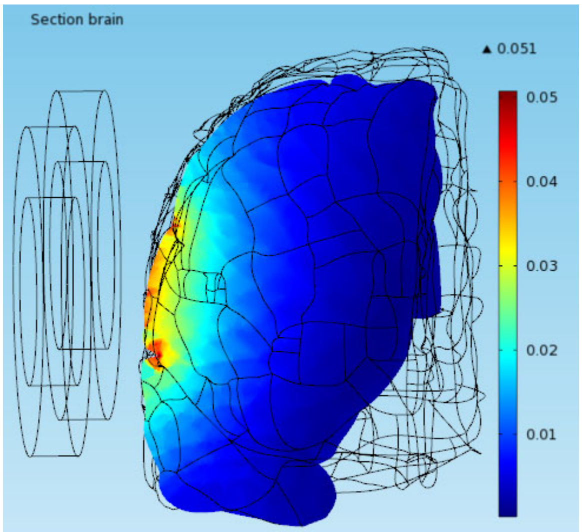
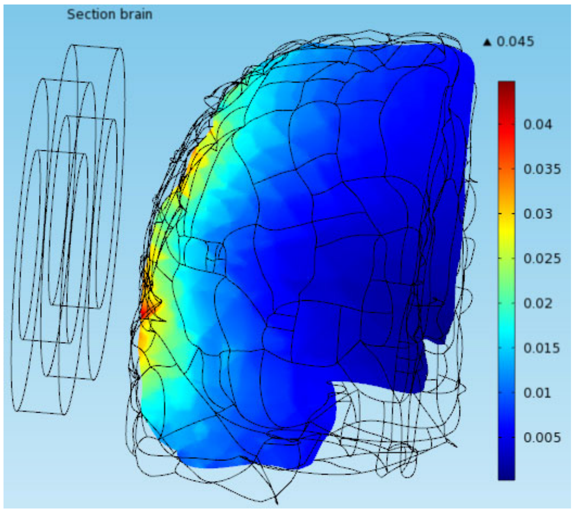



Fig. 5 Overview of induced electric field (V/m)




(a)




(b)

Fig. 6 XZ plane slices for induced electric field (V/m). Slice position: (a) 0 mm; (b) +55 mm

Figure 7 contains vertical slices through the center of each coil. The difference between the maximum values in the two slices is due to the distance between each coil and the brain.

For the horizontal slices, their positions were chosen so that they include the points under the center of the stimulator (figure 8 a), or the points under the inner margin of the coils (figure 8 b and c).

If we look at different slices through the cortex, we realize that the biggest values for the electric field are not necessarily in the closest vicinity of the coil, but rather in the tight sulci (depressions or fissures in the surface of the brain). This means that stimulation can occur at rather smaller power levels in sulci (figure 6, 7 and 8).

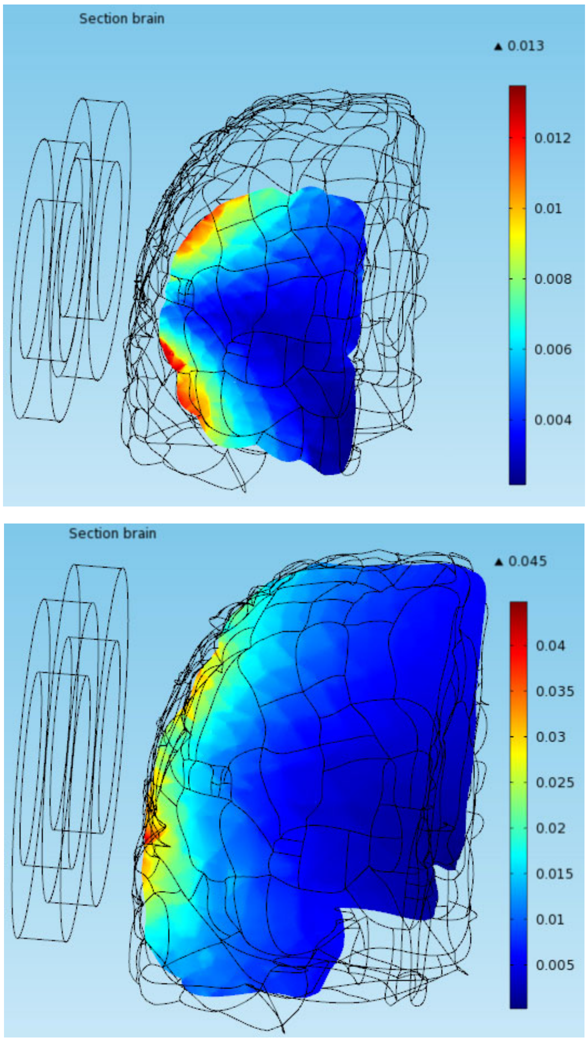



Fig. 7 XZ plane slices for induced electric field (V/m). Slice position: (a) -36 mm; (b) +36 mm

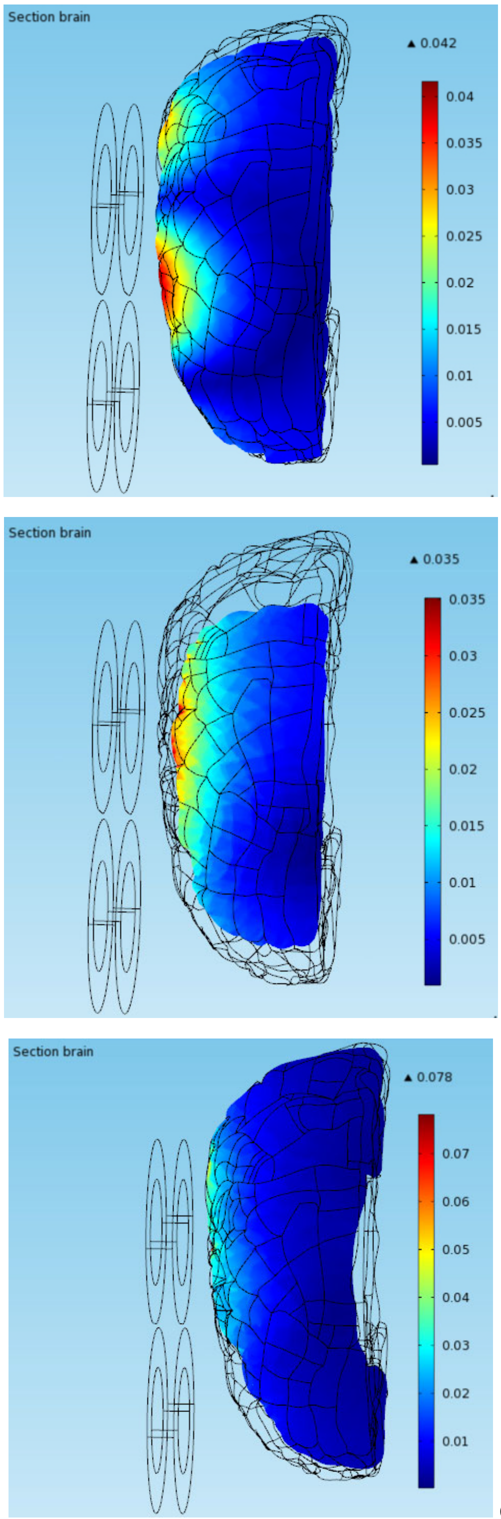



Fig. 8 XY plane slices for induced electric field (V/m). Slice position: (a) 0 mm; (b) +23 mm; (c) -23 mm

The highest value for the induced electric field is 86 mV/m and is located in the lateral sulcus (also called Sylvian fissure). Electric field values in the gyri are smaller than 50 mV/m.

Analyzing the results obtained we see that the electric field intensity is at least 20-30% higher in the sulci then in the gyri (figure 6, 7 and 8). Also, the highest values of the electric field are found in the lateral sulcus, despite the fact that the it is not perfectly under the center of the stimulator. The maximum value in that sulcus is almost double the value in the gyri located under the center of the stimulator (figure 5 and figure 6a).

## V. Conclusions

Our results show that the shape of the targeted area of the cortex greatly influences the distribution of the induced electric field during TMS. This effect has a big impact on the locus of stimulation, and should be taken into consideration by physicians when applying TMS.

More studies are needed to confirm our findings, including more complete models that contain the scalp, skull, cerebrospinal fluid and the cortex.

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## References

1. Pascual-Leone A, Rubio B, Pallardo F, Catala MD. Rapid-rate transcranial magnetic stimulation of the left dorsolateral prefrontal cortex in drug-resistant depression. Lancet. 1996;348:233-237.
2. Fitzgerald PB, Daskalakis ZJ. A. Review of Repetitive Transcranial Magnetic Stimulation Use in the Treatment of Schizophrenia. Arch Gen Psychiatry. 2003;60:1002-1008.
3. Risto J. Ilmoniemi, Jarmo Ruohonen, Jari Karhu, Transcranial magnetic stimulation – A new tool for functional imaging of the brain, Critical reviews in Biomedical Engineering, 27(3-5) 1999, 241-284
4. Jarmo Ruohonen, Transcranial Magnetic Stimulation: Modeling and New Techniques, PhD Thesis, Espoo, Finland,1998.
5. Eric Wassermann, Charles Epstein and Ulf Ziemann, Oxford Handbook of Transcranial Stimulation, Oxford University Press, 2008
6. Baumann S.B., Wozny D.R., Kelly S.K., Meno, F.M., The Electrical Conductivity of Human Cerebrospinal Fluid at Body Temperature, IEEE Trans. on Biomedical Engineering, Vol. 44, No. 3, March 1997, pp. 220-223

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