A Comparison Between a-V and V Formulations in Transcranial Magnetic Stimulation

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Abstract

Introduction:
Transcranial Magnetic Stimulation (TMS) is a non-invasive method of stimulating brain by inducing eddy currents using a strong rapidly changing magnetic field. It is being used in neurosciences as a research tool as well as a diagnostic and treatment tool for various neurological and psychiatric disorders. The main problem of TMS is to predict the exact location and intensity of the electric field induced in the brain due to its complex geometry and vaguely material properties.

The main aim of this study is to compare A-V and V formulations in FEM simulations, where A and V are the magnetic vector and the electric scalar potentials, respectively. It has to be quantified whether the V formulation enables a significant reduction of computational costs while maintaining a satisfactory level of accuracy.

Use of COMSOL Multiphysics®:
In the scope of this project COMSOL Multiphysics® is used as the main software tool to calculate the induced eddy current distribution during TMS on imported brain models. Different brain tissues were segmented from magnetic resonance images (MRI) using SimNIBS, the free available software tool for the simulation of non-invasive brain stimulation created at the Max-Planck Institute for Biological Cybernetics (Tuebingen, Germany) [1]. The brain model was generated and meshed by means of Gmsh, a free 3D finite element grid generator [2]. Subsequently, physics settings and all calculations have been performed using COMSOL Multiphysics®.

For the A-V formulation, the COMSOL Multiphysics® Magnetic and Electric Fields interface is used to set up the physics. The brain is surrounded with an air region and calculation of the induced electric field is achieved numerically by solving the respective differential equations for the magnetic vector potential A and the electric scalar potential V.

In case of V formulation the Electric Currents interface is used. However, only the brain region is considered and appropriate boundary conditions are set to include the magnetic excitation. The magnetic vector potential is calculated analytically, while the calculation of the electric scalar potential is realized numerically by means of COMSOL's integrated solver.

Results:
Simulations have shown significant improvements in terms of computation time. Time necessary for obtaining results using the V formulation is approximately 6-7 times shorter compared to the A-V formulation. Differences in induced electric field were less than 1%. The results obtained by both formulations are shown in Figure 1.

Conclusion:
A significant reduction of computational time while maintaining acceptable precision was observed using V formulation. This is necessary for example in optimization studies when running a large number of simulations. Furthermore, these results are useful in determining the best coil position to stimulate a certain part of the brain's cortical region as well as in studies on the neural system in general. The generation of a precise 3D brain model of the subject from MRI is useful for minimizing effects that could occur due to stimulation of undesired cortical regions. The full paper will describe the modeling procedure as well as the use of COMSOL Multiphysics® in details and provides a full list of reference.

Reference

1.Mirko Windhoff et al., Electric field calculations in brain stimulation based on finite elements: An optimized processing pipeline for the generation and usage of accurate individual head models, Human Brain Mapping, 34, 923-935 (2013)

2.Christophe Geuzaine et al., Gmsh: A 3-D finite element mesh generator with built-in pre- and post-processing facilities, International Journal for Numerical Methods in Engineering, 79, 1309-1331 (2009)

Figures used in the abstract

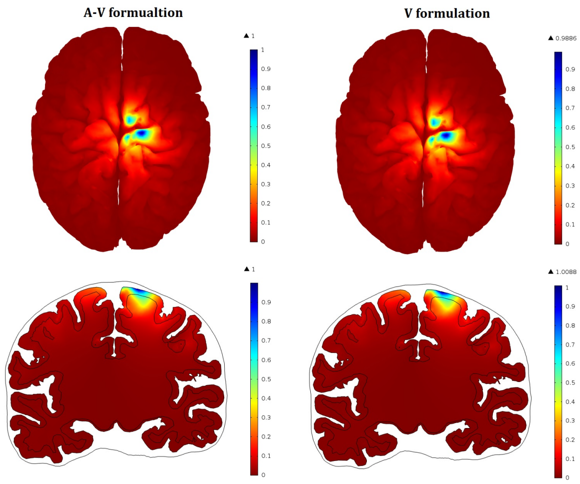

Figure 1: Induced electric field distribution in grey matter obtained by A-V and V formulations: transverse view (upper row) and coronal view (bottom row)