A Comparison Between an A-V and V Formulation in Transcranial Magnetic Stimulation

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Introduction: Transcranial Magnetic Stimulation (TMS) is a non-invasive method to stimulate the human brain by inducing eddy currents using strong and rapidly changing magnetic fields. In order to gain better understanding of all underlying procedures to identify unwanted effects it may cause, it is possible to run numerical simulations without any risk for the patient. The focus of this study is to compare **A**-*V* and *V* formulations of the given electromagnetic field problem, where **A** and *V* are the magnetic vector and the electric scalar potential, respectively.

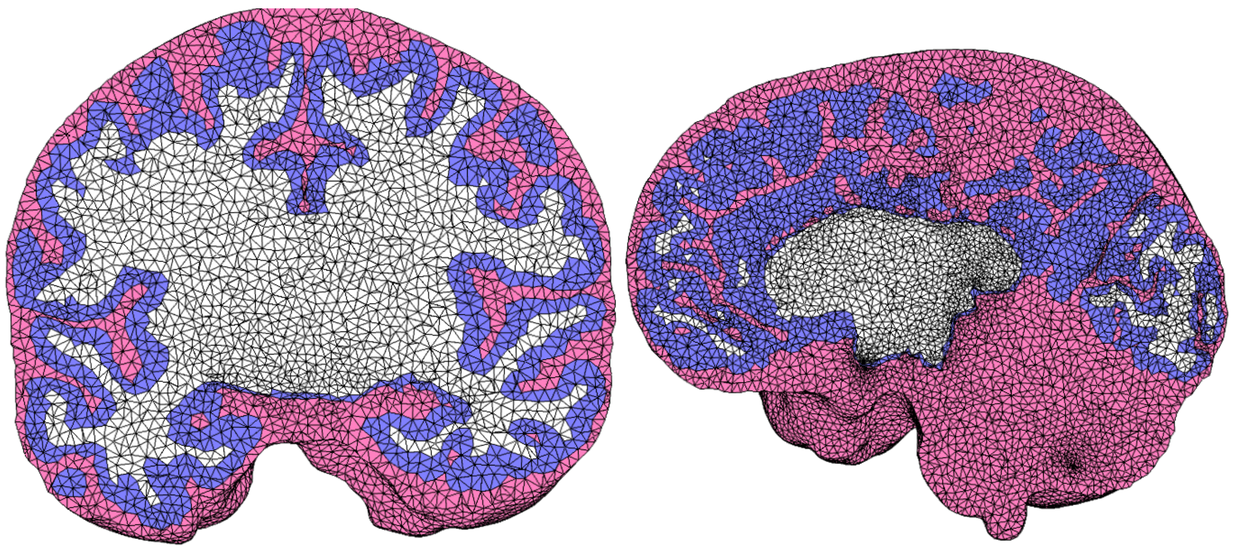

Figure 2. Coronal (left) and sagittal (right) view of the finite element mesh generated out of MRI data and imported into COMSOL.

Computational Methods: The **A**-*V* formulation is a standard modeling approach, where the head model is surrounded with an air region and the calculation of the induced electric field is achieved numerically by solving the respective differential equations for magnetic vector (**A**) and electric scalar (*V*) potential. In case of the *V* formulation only the head region is considered and the magnetic field has to be calculated analytically in advance to include the magnetic excitation.

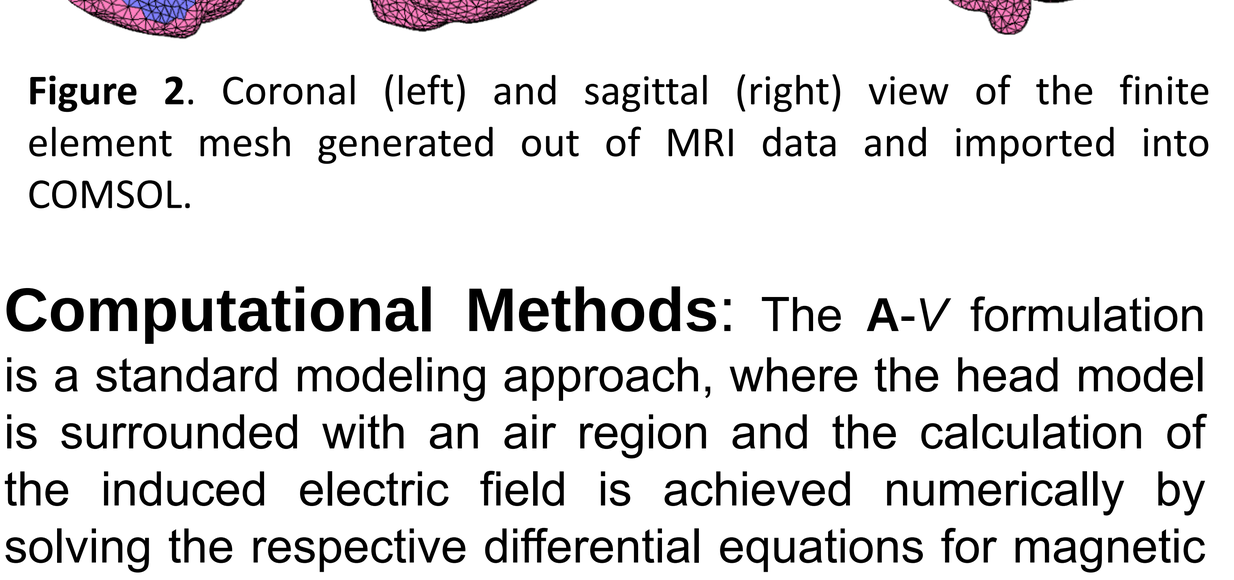

Figure 1. Physical interpretation of domains, subdomains, and boundaries included in the **A**-*V* formulation (left) and *V* formulation (right).

Results: Both formulations were tested several times on the same computer (Intel i5, 16GB RAM) using the same set of parameters in order to acquire an appropriate set of simulation times. Data acquired during testing is shown in Table 1. The time values represent mean values from the different runs. Peak memory allocation represents the largest amount of memory allocated by COMSOL during the simulation.

Category	**A**-*V* **formulation**	*V* **formulation**
Time	595 s	74 s
Peak memory allocation	28 GB	4 GB
Number of elements	1 106 239	889 478
Degrees of freedom	8 487 402	1 217 556

Table 1. Comparison of computational resources between an **A**-*V* and *V* formulation in TMS.

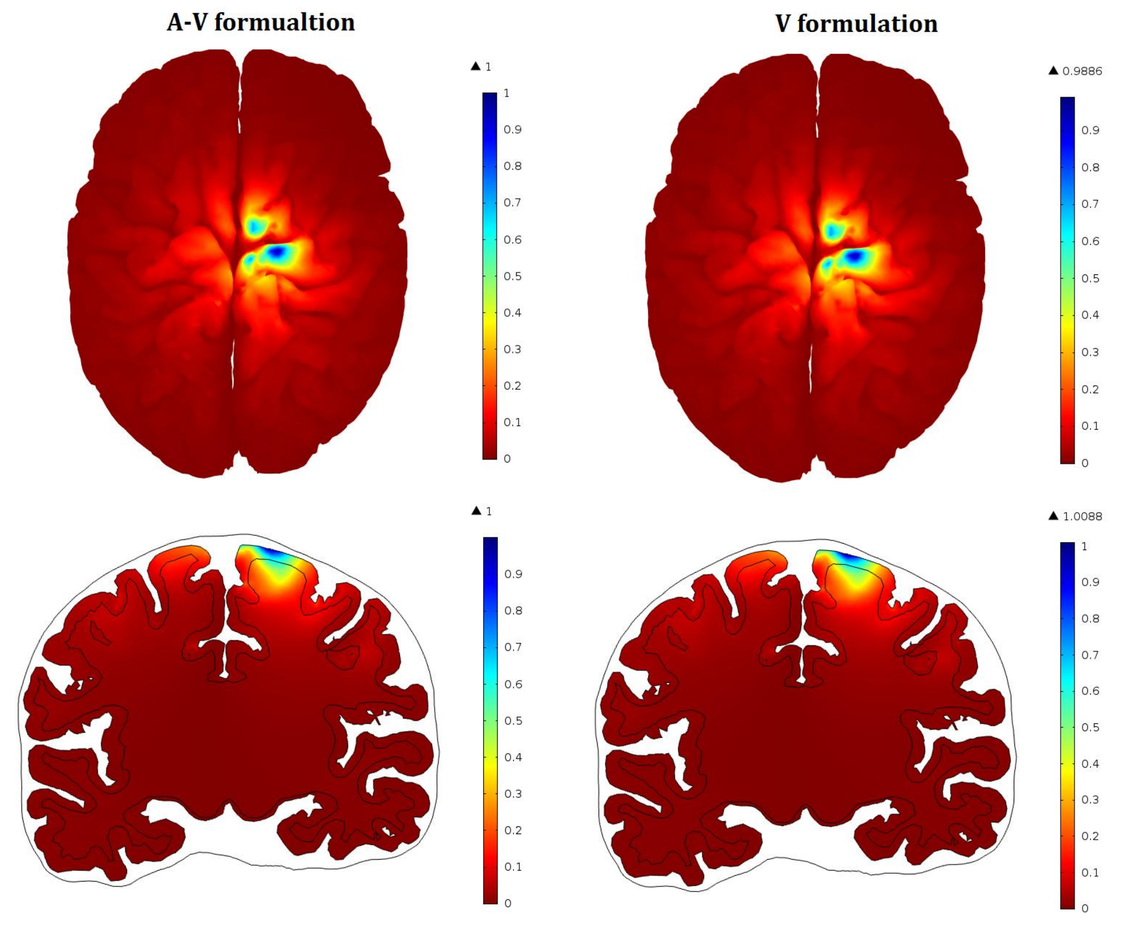

Figure 3. Induced electric field distribution in grey matter obtained by **A**-*V* and *V* formulations: transverse view (upper row) and coronal view (bottom row).

Conclusions: Considering the time necessary to run the simulations it can be noticed that the *V* formulation is approximately eight times faster compared to the **A**-*V* formulation. The magnitude of the induced electric field shows differences lower than 3%. It can be concluded that using a *V* formulation does reduce computation time significantly, while maintaining a satisfactory level of accuracy.

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