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A numerical study on TMS and tDCS: Influence of skin conductivity and anatomical head model

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Transcranial Magnetic Stimulation (TMS) and Transcranial Direct Current Stimulation (tDCS) are noninvasive brain stimulation techniques used in neuronal investigation studies as well as in the treatment of neurological disorders and psychiatric diseases [1]. TMS employs a high intensity pulsed magnetic field delivered through the scalp to induce an electric field responsible for the neurostimulatory and neuromodulatory effects on the brain. Conversely, tDCS is a purely neuromodulatory technique that injects a low intensity (260 μA – 2 mA) direct current by means of electrodes placed on the scalp of the patient. To optimize efficacy during the treatment, an accurate knowledge of the E field distribution inside the brain is necessary. Thus, understanding the reliability of numerical estimations coming from modeling becomes key factor. At the same time, assignment of the correct electric properties to different tissues is still an open issue. Particularly, there is no consensus in the literature on the conductivity value to be used for the skin, as it is highly variable with hydration level, corneum layer thickness, healthy or ill status, subject age and gender [2]. Thus, we herein numerically investigated the variability of electric field induced inside the brain by a TMS coil and by tDCS electrodes, over changes in the head anatomy and skin conductivity. Electromagnetic simulations were performed with the EM software Sim4Life (V4.4, Zurich MedTec, Zurich) on the 29-year-old female head model MIDA [3] and on the 34-year-old male whole body model Duke [4]. Four values of σ_{skin} were studied: 0.0002 S/m, 0.08 S/m, 0.17 S/m and 0.465 S/m. For TMS stimulation, the Magstim coil MAG-9925-00 was considered and placed over the motor area M1. tDCS electrodes, i.e. anode and cathode, were modeled as two rectangular pads of 5 cm x 7 cm that consisted of a metallic contact (PEC) and a saline soaked sponge (σ = 1.4 S/m). Cathode was placed over the contralateral supraorbital region and anode was placed over the primary motor cortex (M1). To evaluate local differences caused by σ_{skin} in the electric field induced inside the head by the TMS coil and tDCS electrodes, we computed the Symmetric Mean Absolute Percentage Error (SMAPE):

$$\text{SMAPE} = \frac{\left|\text{E}_{\sigma_1} - \text{E2}_{\sigma_2}\right|}{\frac{\text{E}_{\sigma_1} - \text{E2}_{\sigma_2}}{2}} * 100. \quad (1)$$

For tDCS, intersubject variability is up to 10 % in the grey matter (GM) and 12 % in the white matter (WM), while SMAPE values can be up to 70 %, with maximum differences concentrated in the region below the anode. For TMS, intersubject variability is up to 11 % in the GM and 3 %. SMAPE is up to 20% in the skin and in the region of the neck and the jaw. In conclusion, results of this study showed that, in tDCS applications, changes in the σ_{skin} determined local differences in the E field induced in the brain up to 70%. These differences are due to the capacitive coupling between the tDCS electrodes and the tissues. For TMS, SMAPE revealed variations up to 20% not only inside the skin but also in deeper regions. Such differences are caused by the secondary field created by accumulation of charges at the interface between different material and that depends on each tissue conductivity.

References

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