Impact of Uncertain Transcranial Magnetic Stimulation Coil Position and Orientation in the Stimulation for a Motor Cortex
Congsheng Li*(1) Tongning Wu(1)

(1) China Academy of Information and Communications Technology, No.52, Huayuanbei Road, Haidian District, Beijing, China. 100191. congshengli@gmail.com toniwoo@gmail.com

Abstract

Transcranial magnetic stimulation (TMS) is a non-invasive brain stimulation technique to modify neural excitability. The effectiveness of TMS experiments critically depends on precise TMS coil position and orientation. There are many TMS coil positioning methods have been used to optimal TMS efficiency. But, sometimes these data are not always precise, and it will make the results uncertainty. To quantify the uncertainty of induced electric field (E-field) in human brain, multi-variate generalized polynomial chaos expansions of the model solutions are used based on uncertain TMS coil position and orientation. Sensitivity of the quantities of interest is investigated for the induced E-field. The results demonstrate that the position of TMS coil has much more effect on induced E-field in human brain than the effect by the orientation of TMS coil. But the effect of TMS coil rotation on Z axis cannot be neglected.

1. Introduction

Transcranial magnetic stimulation (TMS) [1] is a noninvasive brain interference technique that is widely used to investigate brain-behavior relationships in the healthy and diseased human brain. The effectiveness of TMS experiments critically depends on precise TMS coil position and orientation [2]. However, a major practical difficulty is the accurate and consistent positioning of TMS coil to stimulate an area of an individual’s brain cortex [3].

Different methods for TMS coil positioning have been develop in recent years [4-6]. Such as the immediate consequences [4, 5] of a single TMS pulse can be used as an index for effective stimulation. The international 10-20 coordinate system from EEG research [6], the individual anatomical and functional data [2] have been used as a popular method of TMS coil positioning. Although several procedures have been developed to optimally position a TMS coil over the desired targets, they all involve varying amounts of uncertainty that translate into uncertainty in the induced E-field distribution. At present, there are no satisfactory methods to estimate how uncertainty in TMS setup (e.g., coil position and orientation) affects uncertainty in the E-field.

The effects of uncertainties that affect TMS can be quantified via the generalized polynomial chaos expand (GPCE) technique [7] is applied. The GPCE of the quantities of interest can be used to compute their sensitivity on the uncertain TMS coil position and orientation as well as sensitivity arising out of their interactions. The global sensitivity analysis is carried out using Sobel’ indices, which describe the conditional variances of the quantities of interest [8].

This study aims at the uncertainty quantification of the induced E-field on human brain. Based on the uncertainty in TMS coil position and orientation, a multi-variate GPCE will be used to compute the stochastic measures and sensitivity of the quantities of interest.

2. Methods and Materials

2.1 Modeling transcranial magnetic stimulation

For this study, a voxel head model of 34-year-old male subject is generated from T2-wighted magnetic resonance images. Segmentation into tissue compartments skin, skull, cerebrospinal fluid, gray
matter, and white matter with a spatial resolution of 1 mm×1 mm is performed using in-house software [9].

Electric field (E-field) induced by the magnetic fields can be numerically evaluated by scalar potential finite-difference method, which was realized on the platform of SEMCAD X 14.8 (SPEAG AG, Zurich, Switzerland). The entire computational volume is discretized by 2 mm×2 mm×2 mm. The tissue dielectric properties are acquired from the existed database [10]. 8-shape coil are used in the simulations. The operating frequency of the 8-shape one-turn coil is 20 Hz and the current is 1000 A.

2.2 Uncertainty analysis for TMS coil position and orientation

Six parameters, govern the position and orientation of the TMS coil relatively to the head (figure 1). The support of the uniform distributions of these parameters are respectively [-10°, 10°], [-10°, 10°], [-10°, 10°], [-10 mm, 10 mm], [-10 mm, 10 mm], [-5 mm, 5 mm]. The mean E-field strength in a 10 mm×10 mm surface on the primary motor cortex is selected as the region of interest (ROI).

![Figure 1. Uncertainty analysis scenarios](image)

The LHS method was used to sample the position and orientation of TMS coil. Legendre polynomials were used as orthogonal polynomials due to the uniform distributions of input variables. Since the GPCE inputs in case of Legendre polynomials [7] must be [-1,1] an iso-probabilist transform should be used to link the six parameters. The Sobol’s indices [8] was used to find out which uncertain model parameters contribute in which manner to the induced E-field on ROI.

3. Results

The calculated E-field distribution on brain surface induced by TMS coil with different position and orientation are shown in figure 2.

![Figure 2. TMS coil position and orientation, and E-field distribution on brain. 0 dB = 0.01 V/m](image)

The effect of the TMS coil position and orientation on the average E-field on ROI was determined (figure 3).

![Figure 3. Effect of each uncertain variables on average strength of E-field on ROI](image)

4. Discussions

The objective of this study was to investigate the influence of E-field induced by TMS coil with varying positions and orientations. According to this study, the average E-field on RIO varied more than 3 times and the filed distribution on brain also varied observably due to the different TMS coil position and orientation.

A multi-variate GPCE was used and sensitivity of the quantities of interest were investigated. The LOOCV was used to evaluate sufficient accuracy in the investigated quantities of interest. In the present
research, a LOOCV (1-Q^2) [11] accuracy of 1% is obtained with a 3^rd order and the 0.1% accuracy is obtained with a 4^th order.

The SOL01 indices (figure 3) showed that the four most important parameters are X, Z, Y axis translation and Z axis rotation. The most important are X axis and Z axis translation. According to Ilkka’s research [12] support that the cortex is most sensitive to fields oriented perpendicular to the cortical layers. In this study, the translation on X axis is perpendicular to the ROI cortical layers, while translation direction on Y axis is parallel to the ROI cortical layers. So, the effect of X axis is much higher than Y axis translation. The E-field varied obviously while the translation on Z axis due to the variation of the distance between the TMS coil and ROI. The rotation around Z axis also change the angle between the angle between the field and the ROI cortical layers. It means that much more attention should be payed to the position and Z axis rotation of the TMS coil while we study on the location of TMS coil.

5. Conclusion

In this study, the influence of varying position and orientation of TMS coil on induced E-field defined ROI in human brain as well as the sensitivity of the TMS coil position and orientation was investigated by a multi-variate GPCE. the results demonstrated that, the position of TMS coil has much more effect on E-field induced in human brain than the effect by the orientation of TMS coil. The effect of TMS coil rotation on Z axis cannot be ignored. It should be done in the further investigation that the induced E-field on the other region of whole brain effected by varied TMS coil position and orientation due to the human brain complex structure.

6. Acknowledgements

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7. References


