

Probabilistic Approach for Localizing the Activation Site of Transcranial Magnetic Stimulation of the Primary Motor Cortex

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Transcranial magnetic stimulation (TMS) can non-invasively activate the motor cortex, evoking measurable muscle responses; this is useful for investigating the function of the motor cortex and its descending pathways for both research and clinical applications. The drawback of TMS, because it is delivered externally at some distance from the targeted neurons, is that the location and/or other characteristics of the activated neurons are difficult to identify. A long-standing question concerns which neurons are actually affected by TMS. In recent years, several approaches to localize the sites activated by TMS have been proposed [1, 2, 3]. These approaches make use of individualized computational models of induced electric fields to find the cortical site where the induced electric fields give the best agreement with the measured electrophysiological responses. However, they still lack robustly defined confidence bounds, which makes the interpretation of the results difficult.

In this study, we developed a new systematic method to determine the parameters of TMS-evoked activation, namely, the location, direction, and threshold of activation. In contrast to previous approaches, we use Bayesian modelling to find not only the parameters of interest but also their probability distributions.

We have conducted pilot experiments in five subjects. We first acquired the T1 and T2-weighted magnetic resonance (MR) images of each subject using a 3 T MRI scanner. The images were then segmented to a high-resolution anatomical model of each subject. We then performed TMS experiments using a figure-8 magnetic coil connected to a monophasic magnetic stimulator (Magstim 200², Magstim Ltd, UK). The location of the magnetic coil was tracked using a neuronavigation system, and the active motor thresholds were measured in two hand muscles using up to 9 different coil locations/directions. Finally, the induced electric field was calculated for each of the coil locations using the finite element method, and the electric field data were analyzed with the Bayesian model to determine the probability distributions of the activation sites and preferred directions. Figure 1 visualizes the results in a single exemplary subject.



Figure 1. Visualization of volumes where the activation related to first dorsal interosseous muscle occurs at 95% probability. From left to right: axial, coronal, and sagittal planes, surface rendering of white and gray matters including the 95% probability volume and the preferred direction. Dashed line depicts the central sulcus.

The proposed method is used to infer the a-posteriori model parameter probability distributions from the measured stimulation thresholds. The major benefits of the method are that the uncertainty associated with measured thresholds is modelled, the posterior density of the activation location is provided and, finally, we present a quantity that estimates the likelihood of the measurements assuming the model is correct. We shall discuss on the problem-specific computational approaches taken to evaluate the model statistics and we shall present exemplary measurements to highlight the methods utility as a cortical mapping tool.

References

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