Influence of Uncertainties in the Head Tissue Conductivities on the EEG Forward Problem

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Introduction

For accurate EEG/MEG source analysis it is necessary to solve the forward problem of EEG as exact as possible. Recent studies have investigated the effects of the modeling of different conductive compartments of the human head on the accuracy of the EEG forward and inverse solution (Vorwerk et al., 2014; Cho et al. 2015). These studies showed that the modeling of white matter, gray matter, and cerebrospinal fluid (CSF) is of high importance, while it is well-known since a longer time that correctly modeling the low-conducting skull compartment is especially important for the EEG (Dannhauer et al., 2011). However, these studies did not take the uncertainty inherent to the assumed conductivity values into account. These uncertainties arise as the conductivity values cannot easily be measured for the individual subject, so that literature values have to be used. Therefore, it is of high importance to also investigate the influence of the uncertainty of the tissue conductivities on the EEG forward problem. Generalized polynomial chaos (gPC) has recently been used to access the uncertainty caused by varying conductivity values in the forward solution of transcranial direct current and deep brain stimulation (tDCS, DBS) (Schmidt et al., 2013, 2015). In this study, we use gPC to access and quantify the uncertainty caused by varying conductivities in the field of EEG source analysis.

Methods

A highly realistic six-compartment finite element head model was created based on MRI recordings. We assumed the conductivities of the compartments gray matter, white matter, skull, and skin to be variable. A uniform distribution was assumed and the parameters of the distributions for each compartment were chosen based on literature values (cf. Schmidt et al., 2015). The conductivity of the CSF was fixed, since it was shown to have a low inter-individual variance (Baumann et al. 1997). Based on the assumed conductivity distributions, the finite element method was used to calculate the EEG forward solutions that were necessary to set up (multi- and univariate) gPC expansions of EEG forward solutions and to allow for a rapid calculation for randomly drawn samples of conductivity values. Based on numerous evaluations of forward solutions using the gPC expansions for random samples of the conductivity values, the probability distributions that resulted for source analysis of somatosensory evoked potentials (SEP), e.g., of electrode potentials (cf. Figure 1) or source locations, were estimated.

Results

The results show that the EEG forward solution and, in consequence, also the inverse solution are strongly influenced by the uncertainty in the conductivity profiles. In our scenario of a somatosensory, and thereby quasi-tangential source, the strongest absolute variation is caused by the skull conductivity, while the white matter conductivity leads to the smallest changes (cf. Figure 1). However, this effect is relativized, when considering the relative variance of the input data instead (cf. Schmidt et al., 2015). Comparing the influence on the different electrodes, the highest variance is found for those electrodes with the strongest signal (cf. Figure 2).

Conclusion

The results obtained in this study show that the results of EEG source analysis are strongly influenced by variations of the conductivity values for the investigated four compartments. These results underline the importance of determining the individual conductivity values for each subject as exact as possible and motivate the further development of approaches for in-vivo conductivity estimation. Approaches based on simultaneous EEG and MEG recordings were shown to achieve good results when fitting the conductivity of a single compartment, but the simultaneous reconstruction of multiple conductivities has turned out to be unstable (Lew et al., 2009; Aydin et al., 2014). Therefore, we hope that our results encourage further development in the area of conductivity calibration methods.

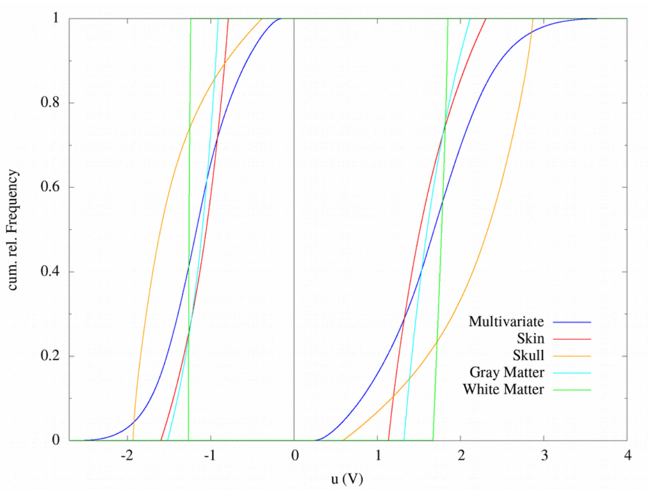

Figure 1: Cumulative relative frequencies (P(u ≤ x)) of distribution of electrode potentials for varying conductivity values (multi- and univariate distributions) for the electrode with most negative (left lines) and most positive (right lines) values, respectively. A steeper increase of a curve corresponds to a narrower distribution and smaller variance, a flatter increase to a wider distribution and higher variance.

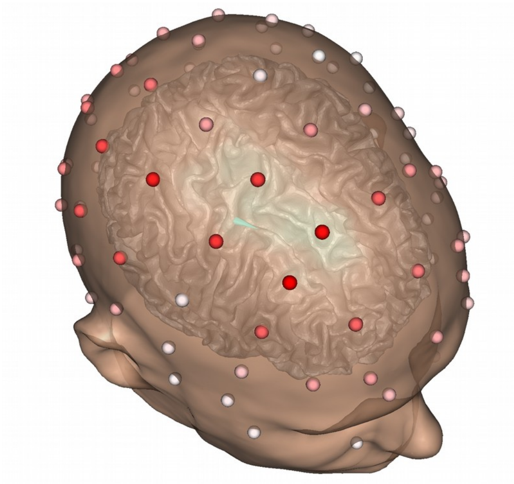

Figure 2: Standard deviation for each electrode for multivariate conductivity distribution and a dipole in the somatosensory cortex (turquoise cone)

Aydin, Ü. (2014), 'Combining EEG and MEG for the Reconstruction of Epileptic Activity using a calibrated realistic volume conductor model', PloS one, vol. 9, no. 3, pp. e93154

Baumann, S.B. (2013), 'The Electrical Conductivity of Human Cerebrospinal Fluid at Body Temperature', IEEE Transactions on Biomedical Engineering, vol. 44, no. 3, pp. 220-223

Cho, J.-H. (2015), 'Influence of the Head Model on EEG and MEG Source Connectivity Analysis', vo. 110, pp. 60-77

Dannhauer, M. (2011), 'Modeling of the Human Skull in EEG Source Analysis', Human Brain Mapping, vol. 32, no. 9, pp. 1383-1399

Lew, S. (2009), 'Improved EEG source analysis using low-resolution conductivity estimation in a four-compartment finite element head model', Human Brain Mapping, vol. 30, no. 9, pp. 2862-2878

Schmidt, C. (2013), 'Influence of Uncertainties in the Material Properties of Brain Tissue on the Probabilistic Volume of Tissue Activated', IEEE Transactions on Biomedical Engineering, vol. 60, no. 5, pp. 1378-1387

Schmidt, C. (2015), 'Impact of Uncertain Head Tissue Conductivity in the Optimization of Transcranial

Direct Current Stimulation for an Auditory Target', Journal of Neural Engineering, vol. 12, no. 4, 046028 (11p)
Vorwerk, J. (2014), 'A Guideline for Head Volume Conductor Modeling in EEG and MEG', NeuroImage, vol. 100, pp. 590-607