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

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Introduction

For accurate EEG source analysis, it is necessary to solve the forward problem of EEG as exact as possible. Multiple studies have investigated the effect of the modeling of different conductive compartments of the human head on EEG forward and inverse solutions (see [1] for an overview). However, these studies did not take the uncertainty inherent to the conductivity values into account. It was previously shown that for example the skull conductivity has a strong influence on EEG forward and inverse problem [2], while it strongly varies with age and disease state [3]. The goal of this study is to assess and quantify the influence of varying conductivity values on EEG forward and inverse solutions.

Objective

We investigate the influence of the uncertainty with regard to the conductivity values of the different conductive compartments of the human head on the EEG forward and inverse problem. The goal is to identify for which of these compartments varying conductivity values have the strongest influence, so that these conductivitiy values can be individually calibrated in future studies [4].

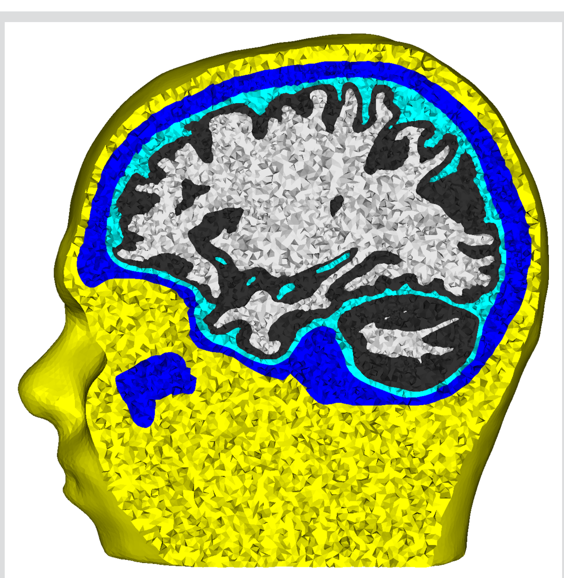

Figure 1: Realistic five compartment (skin, skull, CSF, gray matter, white matter) finite element head model.

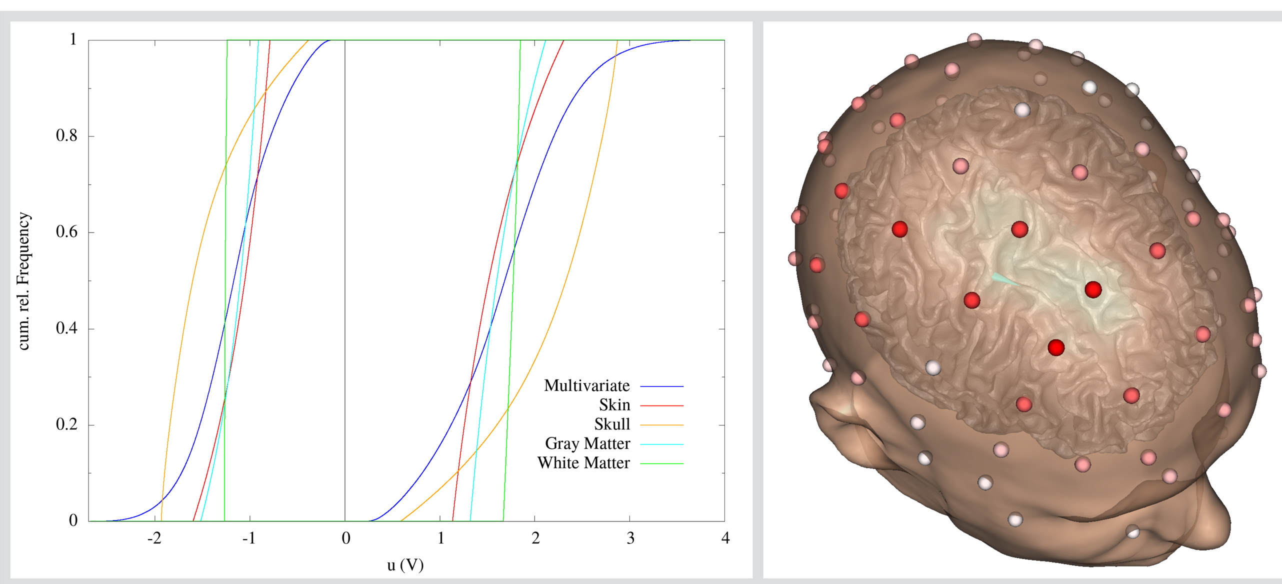

Figure 2: Cumulative relative frequencies ($P(u \leq x)$) of electrode potential for most negative (left lines) and most positive (right line) electrode for varying conductivity values (left); standard deviation of potential for each electrode for multivariate conductivity distribution (right).

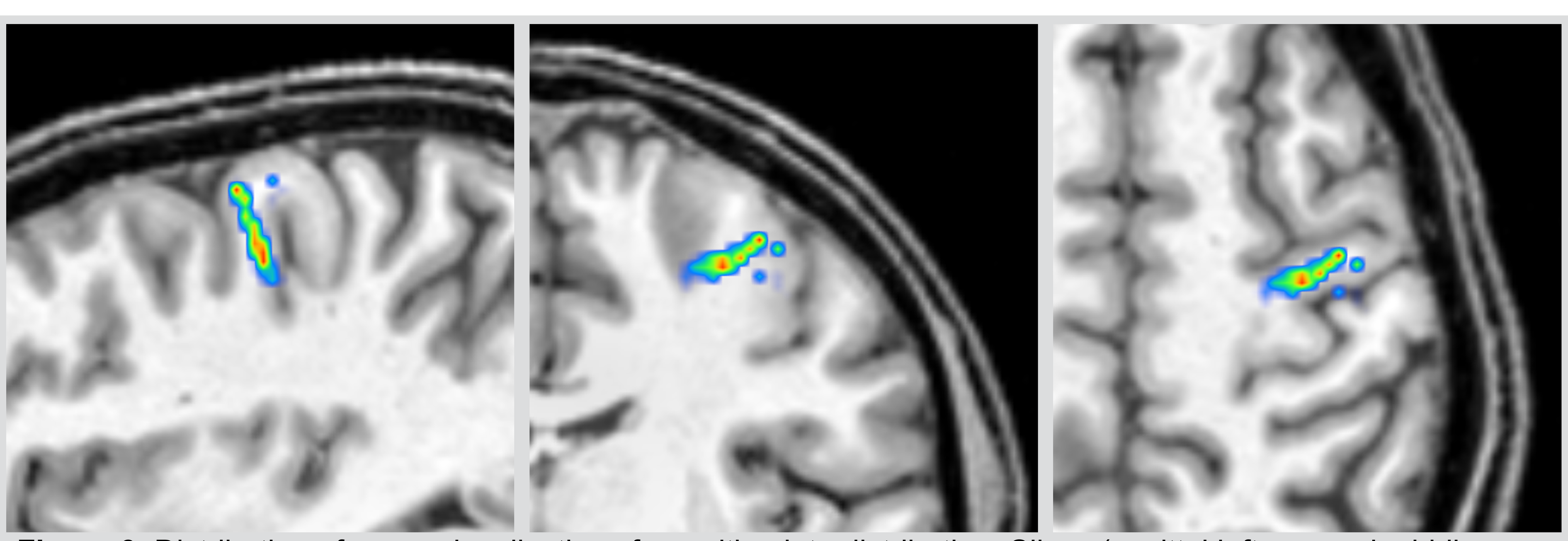

Figure 3: Distribution of source localizations for multivariate distribution. Slices (sagittal left, coronal middle, axial right) taken through the center of gravity of source locations; locations projected into the plane.

Methods

- Somatosensory evoked potentials (left hand median nerve stimulation) of a healthy human subject were measured using a 74 channel EEG cap (10-10 system)
- A highly-realistic five-compartment (skin, skull, CSF, gray, and white matter) finite element (FE) head model was generated based on MRI data (**Fig. 1**, [1])
- An initial source analysis based on FE simulations was performed assuming common conductivity values (cf. [1] for exact values and further references)
- Sources were distributed around this source location on a grid (width 1.5 mm)
- Multi- and univariate generalized polynomial chaos (gPC) expansions were computed using FE forward solutions and UQLab [5]; the conductivities of skin, skull, gray and white matter were assumed to be varying, the CSF conductivity was fixed
- A uniform distribution was assumed for each conductivity; the range was chosen following [6]:

  Skin 280.0 - 870.0 mS/m; skull 1.6 - 33.0 mS/m;
  gray matter 220.0 - 445.0 mS/m; white matter 90.0 - 290.0 mS/m
- 10,000 samples were evaluated for each gPC expansion
- To visualize the influence on the EEG forward problem, electrode voltages and variances for a source fixed at the initial source position were evaluated (**Fig. 2**)
- To investigate the influence on the EEG inverse problem, a goal function scan was performed for each sample, and changes of both source position and goodness of fit (GoF) where analyzed (**Fig. 3-5**)

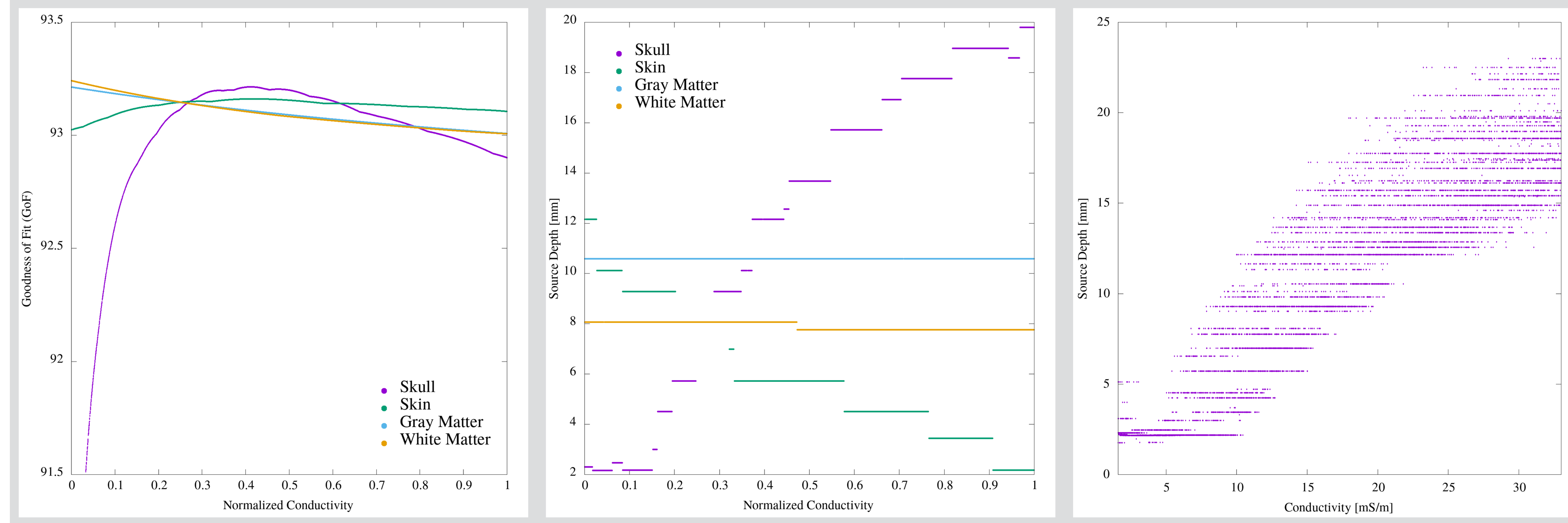

Figure 4: Scatter plot of GoF (left) and source depth (distance to inner skull surface, middle) against normalized conductivity for univariate distribution. Source depth against skull conductivity for multivariate distribution (right).

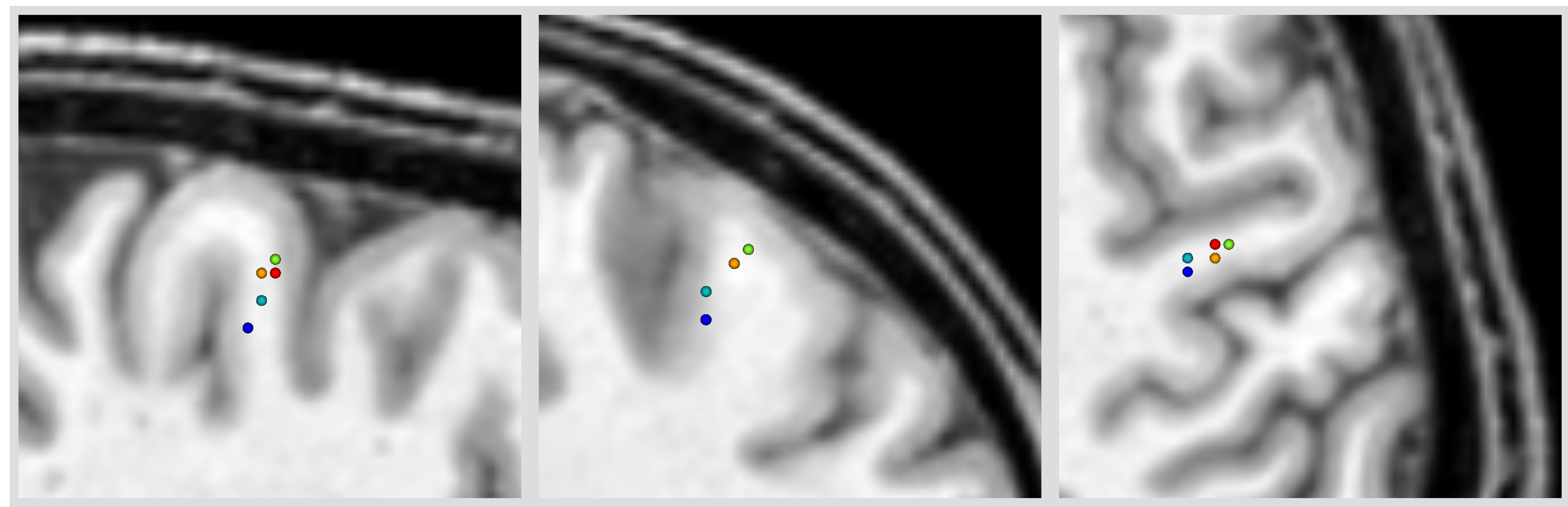

Figure 5: Source locations with optimal GoF for multi- and univariate distributions (multivariate blue, skin green, skull tourquois, gray matter orange, white matter red) on MRI (sagittal left, coronal middle, axial right).

Results

Forward Problem

- **Fig. 2, left** shows that changes in the skull conductivity lead to the strongest variations in electrode potentials. Changes in gray and white matter conductivities cause the smallest variations.
- The potentials for electrodes directly above the source show the strongest variations, while more distant electrodes are less affected (**Fig. 2, right**).

Inverse Problem

- **Fig. 3** shows the distribution of source localizations for the multivariate distribution
- **Fig. 4** shows that variations in GoF are mainly driven by the skull conductivity (left), while for the source depth also an influence of the skin conductivity is visible (middle). However, the dominance of the skull conductivity is clear (right)
- While in all cases, also without varying the skull conductivity, high GoFs are achieved (*max. GoF: Multivariate 93.70, Skull 93.21, Skin 93.16, GM 93.21, WM 93.24),* **Fig. 5** shows that the thereby obtained source locations vary clearly and tend to be more superficial if the skull conductivity is not varied

Discussion and Conclusion

The presented results underline the strong influence of variations of the conductivity values chosen for the conductive head compartments on EEG forward and inverse solutions.

- For the investigated source in the somatosensory cortex, the skull conductivity clearly has the strongest influence, while white and gray matter conductivities have a very low influence
- If possible, an individual calibration of the skull conductivity should therefore be performed
- The feasibility of a calibration of further conductivity values based on SEPs is questionable given the dominance of the skull conductivity
- The results for gray and white matter allow the assumption that the conductivity range chosen based on the literature might be too narrow

This study shows that besides the geometrical modeling of the conductive compartments of the human head, also the conductivity values assumed for these compartments have a strong influence in EEG soure localization.

Therefore, if possible, an individual conductivity calibration should be performed as demonstrated in [4].

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