Influence of interior cerebrospinal fluid compartments on EEG source analysis

Benjamin Lanfer[1,2], Isa Paul-Jordanov[2], Michael Scherg[2], Carsten H. Wolters[1]

1 Institut für Biomagnetismus und Biosignalanalyse, Westfälische Wilhelms-Universität Münster, Germany
2 BESA GmbH, Gräfelfing, Germany

I INTRODUCTION

Advanced numerical methods, for example, the finite element method (FEM) [1], allow solving the EEG forward problem in individual, realistic volume conductor models. In practice, a minimum of three tissues (scalp, skull, brain) are differentiated in these models. Adding the cerebrospinal fluid (CSF) as a fourth tissue is known to add further precision for EEG source analysis [2]. CSF filled spaces in the human head can be found in the ventricles and between the brain surface and the inner skull, as well as in the sulci. The presence of these CSF filled spaces does have an influence on the space of allowed sources. Incorporating the interior CSF spaces, like the ventricles or deep sulci, will result in a complicated, fragmented source space.
A fragmented source space can cause problems for inverse methods. The dipole fit approach, for example, might get "stuck" due to the holes and concavities in the source space. To alleviate these problems a simplified head model can be used in which deep interior CSF compartments are ignored. Our simulation study will investigate the EEG source analysis errors introduced by this simplified CSF model. A second test model completely ignoring the CSF is included in our study for comparison.

II MATERIALS and METHODS

Study design

- Anatomically plausible and detailed head model as a **reference** (Fig. 1)
- Test models with **partially (TM B)** or **completely ignored CSF (TM A)**
- Simulation of **reference data** in reference volume conductor model
- Direct comparison of forward simulations performed in test models
- Source reconstruction of reference data using the test models to perform the associated forward simulations
- **Probe sources** for forward and inverse simulation were distributed on regular 4mm, respectively, 10mm grid
- **81 electrodes** distributed according to international **10-10-system**
- Source reconstruction using **goal function scan** on 1mm scanning grid

Reference and test model construction

- **Construction of reference model** from two T1w and a T2w MRI of the same subject
  - **Segmentation** in a **semi-automatic way** incorporating thresholding, morphological operations and automatic classification methods
- **Test models** derived from reference model (Fig. 1)
  - **TM A**: all CSF spaces relabeled as brain
  - **TM B**: interior CSF spaces (ventricle, deep sulci) relabeled as brain
- High-resolution 1mm³ geometry-adapted hexahedral FE meshes [3]

Error measures [4]

$$\mathrm{RDM} = \left\| \frac{\phi^{\mathrm{ref}}}{\|\phi^{\mathrm{ref}}\|} - \frac{\phi^{\mathrm{test}}}{\|\phi^{\mathrm{test}}\|} \right\| \qquad \mathrm{MAG} = \frac{\|\phi^{\mathrm{test}}\|}{\|\phi^{\mathrm{ref}}\|} \qquad \text{Localization error} = \|\mathbf{x}^{\mathrm{test}} - \mathbf{x}^{\mathrm{ref}}\|$$

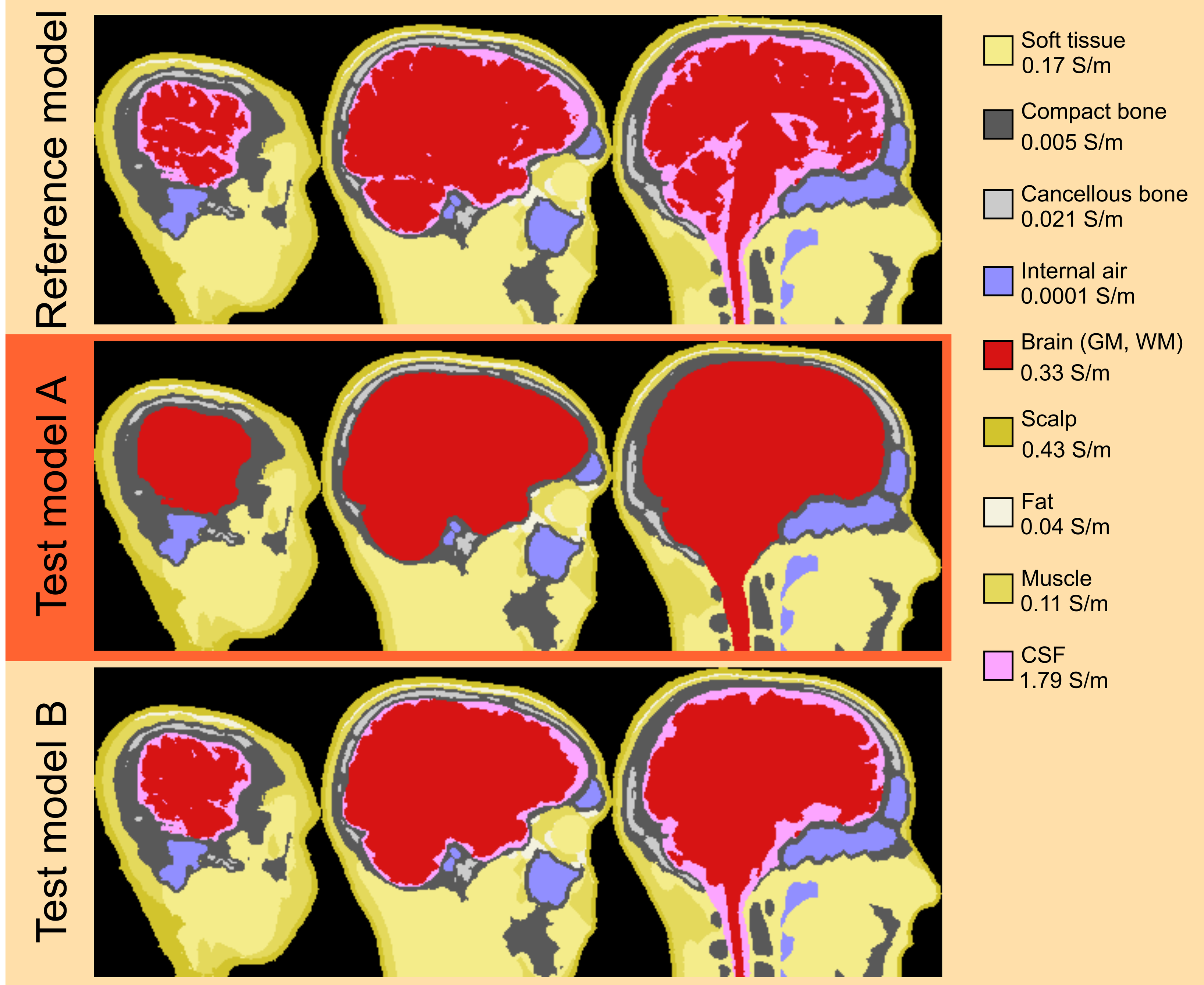

Fig. 1 Sagittal slices of the reference model and the test models.

III RESULTS

Forward simulations

- Large RDMs (> 0.1) in TM A for superficial sources and sources close to ventricles
- In TM B non-negligible RDMs only for few sources close to ventricles and deep sulci
- Average RDM for TM B clearly smaller than for TM A
- EEG potentials strongly overestimated in TM A for sources throughout the source space
- Slight tendency for overestimation also in TM B
- Average MAGs in TM B closer to optimal value of 1 than average MAGs in TM A

Source reconstruction

- Non-negligible localization errors (> 5mm) in TM A mainly for superficial and frontal sources
- Localization errors negligible (< 2mm) in TM B for nearly all sources
- Sources in TM A by tendency mislocalized towards positions deeper in the brain

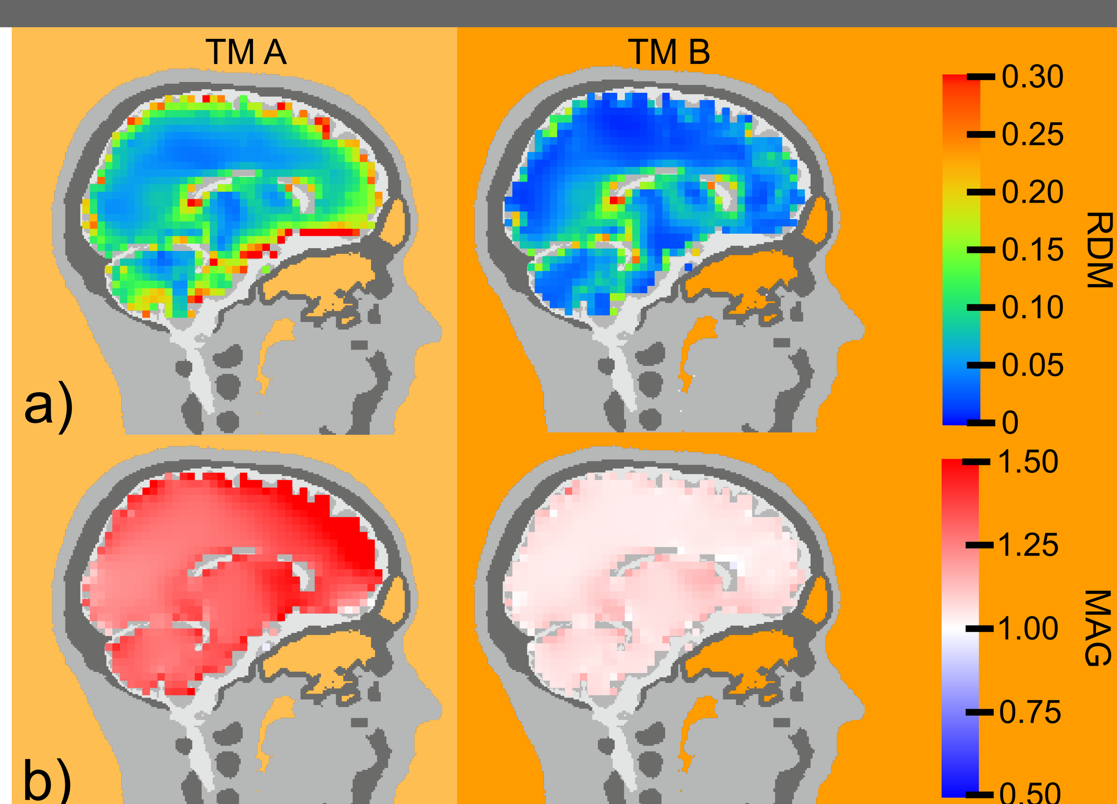

Fig. 2 RDM and MAG error maps.

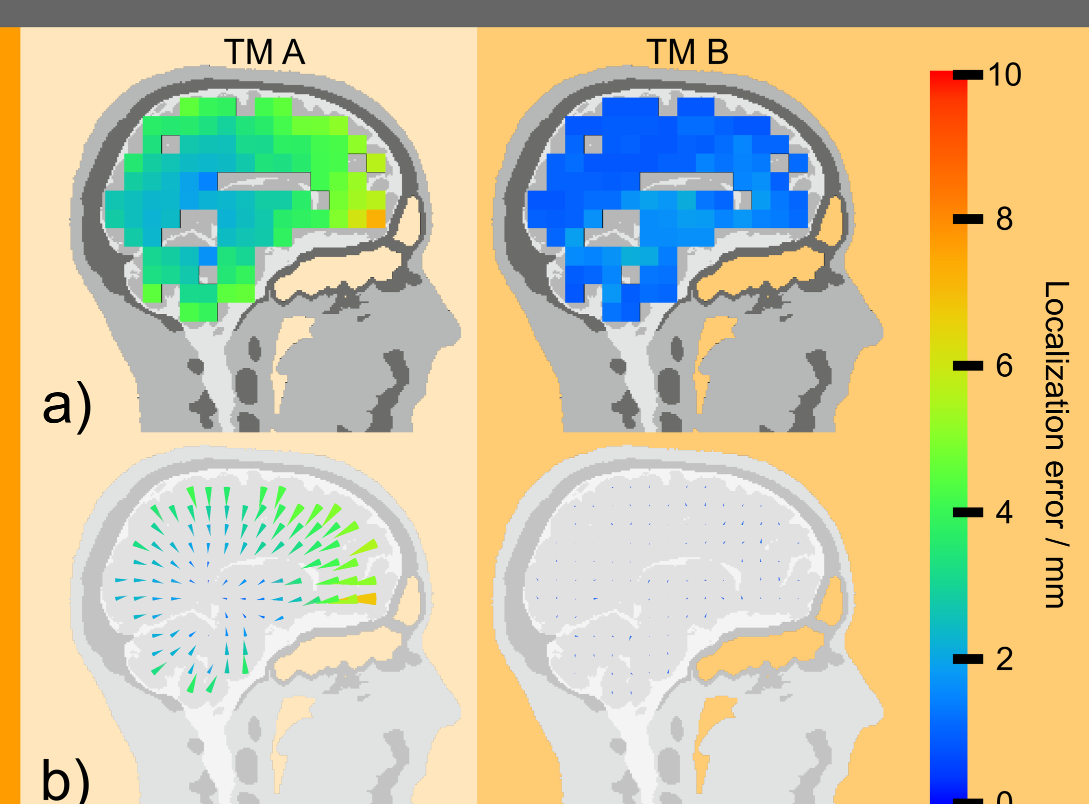

Fig. 3 Maps of localization errors and mislocalization tendencies.

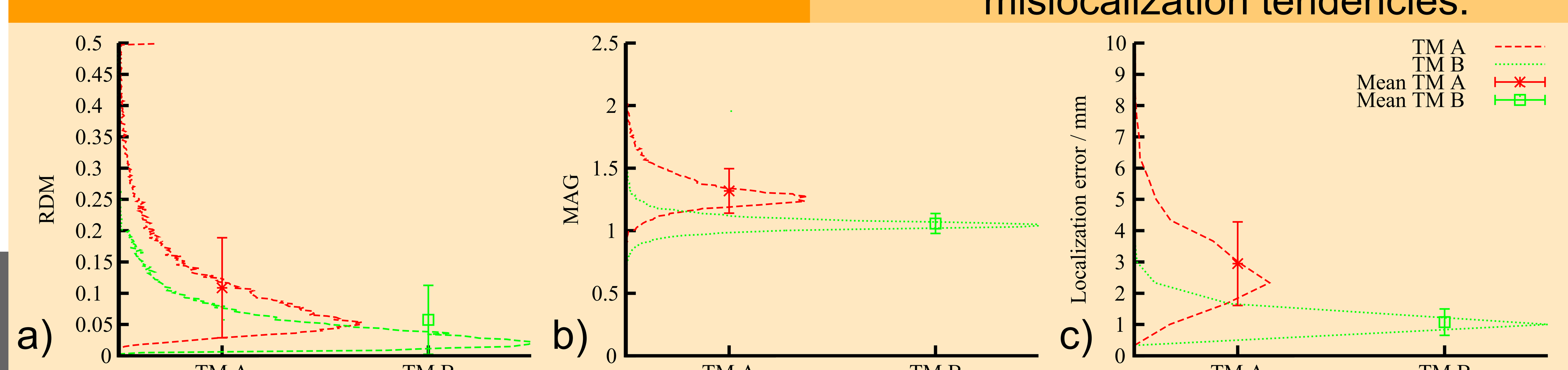

Fig. 4 Histograms of the RDM, MAG and localization errors.

IV CONCLUSION and OUTLOOK

Large errors were found for forward simulations and source reconstruction when completely ignoring the CSF. In contrast, ignoring only the interior CSF spaces (i.e., ventricles and deep sulci) caused smaller and more local errors. This was especially evident in the source reconstruction results. Source reconstruction errors for the partial CSF model were so low that we regard them as negligible for most applications. The influence of completely ignoring the CSF was also investigated by Ramon et al. [2] who find localization errors of 2-3mm for sources in the motor cortex. In our study, similar localization errors are found in some brain areas (e.g., the motor cortex or occipital cortices). In other areas, however, (e.g., the frontal lobe) larger localization errors above 5mm were observed. This difference might be explained by the larger amount of CSF in the vicinity of the frontal lobe as compared to the area of the motor cortex. From the observed negligible reconstruction errors when ignoring interior CSF spaces we finally conclude that a simplified CSF model comparable to TM B can be employed to avoid the problems which a complicated source space geometry causes for some inverse methods.

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Corresponding author:
Benjamin Lanfer (benjamin.lanfer@uni-muenster.de)
Münster, Germany