An Evaluation of Single Dipole Solutions to Extended Sources in EEG and MEG

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***Abstract*—Interictal spikes as observed in epilepsy patients are assumed to be generated by relatively large patches of activated cortex. In order to check the validity of single dipole solutions to such spikes in EEG and MEG a simulation study is performed in a realistically shaped cortical model. It is shown that both in EEG and MEG the center of activated cortex can be misrepresented by single dipole solutions by more then 1 cm. The geometry of sulci and gyri determines where, for which modality, this effect is larger.**

Keywords-EEG, MEG, dipole, epilepsy, source modeling, interictal spikes.

I. INTRODUCTION

The localization of the generators of interictal spikes in epilepsy patients is an important application of noninvasive functional source imaging techniques. Removal of cortical areas that show interictal spikes are related to better outcome when epilepsy surgery is performed in patients for which seizures cannot be controlled by medication. In the clinical setting methods based on the single equivalent dipole model are most often used for noninvasive localization, both for EEG and for MEG.

In the pre-surgical evaluation of such patients often electrocorticography (ECoG) is performed using intracranial grid electrodes. From these ECoG data it is clear that single interictal spikes often extend over relatively large (> 20 cm^2) cortical areas [1]. This finding challenges the validity of using the single dipole model for source localization. In an interesting study Kobayashi *et al.* indeed showed that for EEG, dipole modeling of interictal spikes can result in misleading localizations, in spite of a low residual difference for the fitted data [2] .

In a previous study in a group of epilepsy patients we showed that EEG based dipole modeling localized the source consistently deeper (0.7 cm) and with more scatter in depth than MEG based modeling [3]. As a likely explanation of this observation inter-individual variability of skull conductivity was proposed. However, an alternative hypothesis would be that dipole localization of extended sources behaves differently for EEG and MEG.

In this study we investigate whether single dipole solutions for extended sources as a model for interictal spikes represent the source better for MEG than for EEG, and whether there is a geometrical bias in the misrepresentation.

II. METHODS

A high resolution triangular tessellation of cortex (left hemisphere only) containing 19554 nodes was generated based on the high quality MRI as available in the distribution of the MRICRON software [4]. The average node area was 6 mm^2. A corresponding realistic head model containing a skin, skull and brain compartment was constructed and from this a boundary element model (BEM) for forward computation of EEG and MEG was set up using CurryV3.0. Conductivity ratios chosen for skin/skull/brain were 1/20/1. Realistic 85 channel cap electrode positions and 151 MEG helmet gradiometer positions were defined. The geometry of this forward model is shown in figure 1.

For this configuration transfer functions were computed for a distributed dipole layer with assumed uniform strength. In the uniform distributed dipole layer model the basic elements are not dipoles but true elementary patches for which the field strength is proportional to the solid angle of the patch with respect to an observation point [5]. It can be considered a proper model for a cortical layer with homogeneous density of pyramidal cells and it does not show the singular behavior that the dipole model shows with respect to the observation point.

Centered on each elementary patch larger patches were set up extending to neighboring nodes with an average area of 25 cm^2. An example of a patch is shown highlighted in figure 2 for a node in the frontal superior gyrus. Note that the patch extends over sulci with opposite orientation. For both elementary and extended patches the EEG and MEG fields were computed. Field strengths were ordered in RMS magnitude and patches in the lower 1/3 of this distribution, either for EEG or for MEG, (mostly deeper, non-cortical sources) were not used for subsequent analysis.

A fixed amount of uniform noise was added to each simulated field, consisting of 10% of the RMS value of the field for all sensors and all patches. For these simulated EEGs and MEGs single dipole solutions were obtained. For each resulting dipole the position was computed with respect to the centered elementary patch. Differences for EEG and MEG for the same patch were evaluated with respect to cortical geometry. In order

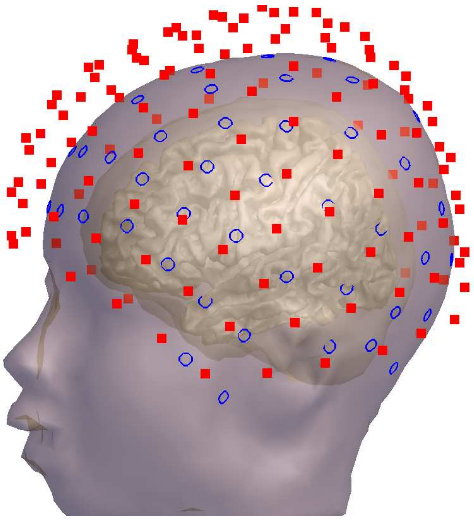

Figure 1. BEM geometry used. Shown are the skin and inner skull compartment, and the cortical geometry. Red squares: MEG sensors, blue circles: EEG electrodes.

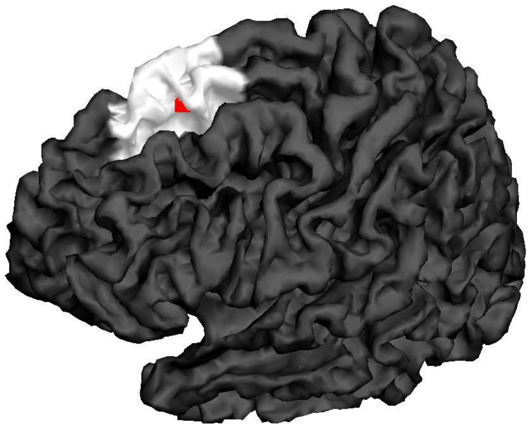

Figure 2. Cortical geometry showing activity on the frontal superior gyrus in white. Red square: center point of the patch.

to allow analysis in term of depth bias, difference vectors were reoriented in such a way that the positive z-axis was pointing in the direction from the source towards the nearest point on the scalp [3].

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III. Results

The average distance between the central point and the estimated dipole position was 0.12 cm for EEG and 0.55 cm for MEG when fields were simulated for elementary patches. The maximum distance observed was 0.59 cm for EEG and 1.58 cm for MEG. There was no directional bias. The average residual differences were 5.7 % and 6.1 % respectively.

For the extended patches the average distance between the central point of the patch and the estimated dipole position was 0.80 cm for EEG and 0.98 cm for MEG. Maximum distances were 2.66 cm and 4.61 cm respectively. For EEG there was an average depth bias of 0.47cm (compared to 0.37 cm in orthogonal directions), for MEG this was 0.58 cm (0.44 in orthogonal directions). The average residual differences were 7.9 % and 8.9 % respectively.

Figure 3 shows, in blue, areas where differences in EEG dipole localizations with respect to the central point exceeded 1 cm , in figure 4 this is shown, in red, for MEG. Note that these areas overlap in certain locations, but are different in others. In figure 5, in blue, areas are shown for which difference for EEG were larger than for MEG, in red those for which MEG differences were larger. Both a left lateral and a right view revealing the inter-hemispheric region are shown. Note that these areas are distinct and depend on sulcal and gyral geometry.

IV. Discussion

The hypothesis that MEG dipole localization is less affected by assumption of a focal source when actually the source has a relatively large extent has to be discarded. In this study it is shown that MEG dipole misrepresentation of the center of a patch of activity on average is larger than for EEG dipoles. Yet this is not true when specific cortical locations are considered. As is shown in figure 5, larger discrepancies are found for EEG in, *e.g.,* the inferior frontal gyrus, the cuneus, inter-hemispheric aspects of the pre- and post-central gyrus and part of the cingulate. Both for EEG and MEG a slight depth bias exists for these misrepresentations. Although this was not analyzed for specific locations, these results cannot account for the observed depth bias of 0.7 cm for EEG as opposed to MEG as described in [3].

The conclusion of the study by Kobayashi *et al.,* that for EEG “dipole modeling of epileptic spikes can be misleading of accurate” is confirmed, and it is shown that this is also the case for MEG. Residual variances also show that these cannot be used to determine whether the single dipole model is appropriate or not.

These results might not have any practical, clinical implications when EEG of MEG dipole localization is used for pre-surgical planning of ECoG subdural grid implantation. However, if functional imaging based on EEG or MEG is expected to accurately delineate epileptogenic cortex, *i.e.* the cortical extent of an interictal spike, dipole modeling does not suffice. Given the ill-posed nature of the inverse problem, estimating source extent from bio-electromagnetic data remains challenging, although promising attempts are being made [6] .

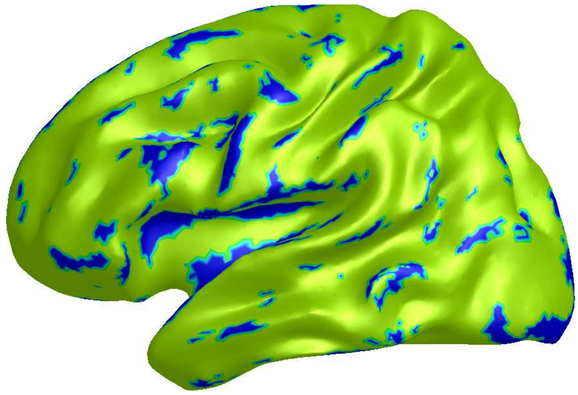

Figure 3. Locations (in blue) for which the distance between the central point and EEG dipole exceeds 1 cm. The cortical surface is partly unfolded in order to show data in sulci..

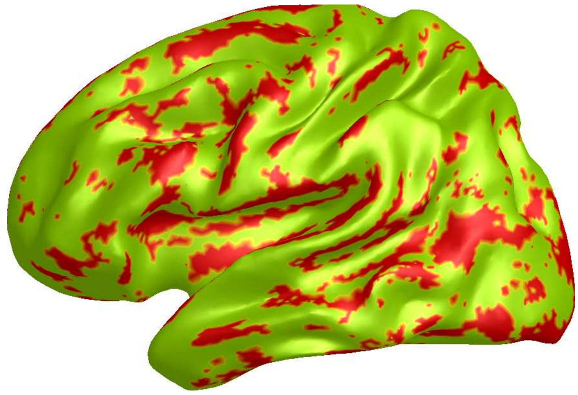

Figure 4. Locations (in red) for which the distance between the central point and MEG dipole exceeds 1 cm. Cortical surface is partly unfolded in order to show data in sulci.

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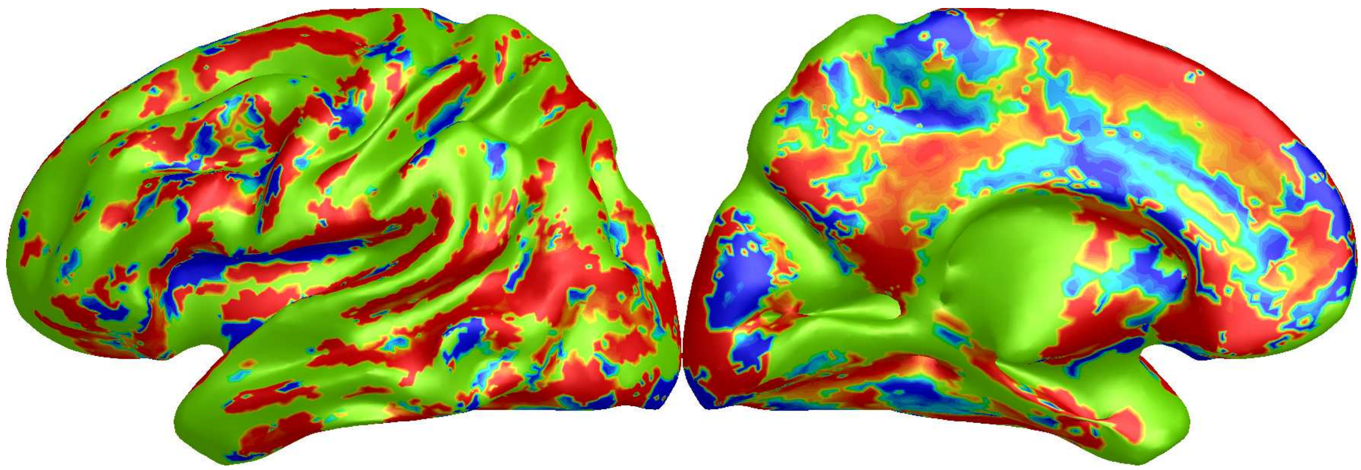

Figure 5. Areas for which misrepresentation is largest for EEG (blue) and for MEG (red). Partly unfolded cortical geometry. Left panel shows left lateral view, right panel shows a right view on the inter-hemispheric area.