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APPLIED MATHEMATICS MÜNSTER

Hierarchical Fully-Bayesian Inference for Combined EEG/MEG Source Analysis of Evoked Responses: From Simulations to Real Data

F. Lucka[1,2,3], Ü. Aydin[2,3], J. Vorwerk[2,3], M. Burger[1,3], C.H. Wolters[2,3]

(1) Institute for Applied Mathematics (2) Institute for Biomagnetism and Biosignalanalysis (3) Cells in Motion Interfaculty Center. All: University of Münster, Germany

Background

The reconstruction of brain networks by means of EEG/MEG recordings is still a challenging task for most current density reconstruction (CDR) imaging approaches. Recently, hierarchical Bayesian modeling (HBM) emerged as a promising CDR framework. Our work examines the performance of fully-Bayesian inference methods for HBM for source configurations consisting of few, focal sources when used with realistic, high resolution Finite Element (FE) head models.

Data acquisition and Preprocessing

The following data was recorded from a healthy 25-year old male subject:

- Different MRI scans to build a realistic FE head model (see below)
- Somatosensory evoked potentials (SEP) and fields (SEF) by electrical stimulation of the medianus nerve (left/right hand, about 980 events each)
- Auditory evoked potentials (AEP) and fields (AEF) by 500 ms long pure sinusoidal tones with 350, 1400 and 5600 Hz (about 120 events each)

EEG/MEG preprocessing was performed using standard filtering and conservative channel and trial rejection. Results: SEP-N20(m) (SNR: 12.2), SEF-N20(m) (SNR: 9.1), AEP-N100(m) (SNR: 19,4), AEF-N100(m) (SNR: 19,0).

SEP/SEF N20(m)

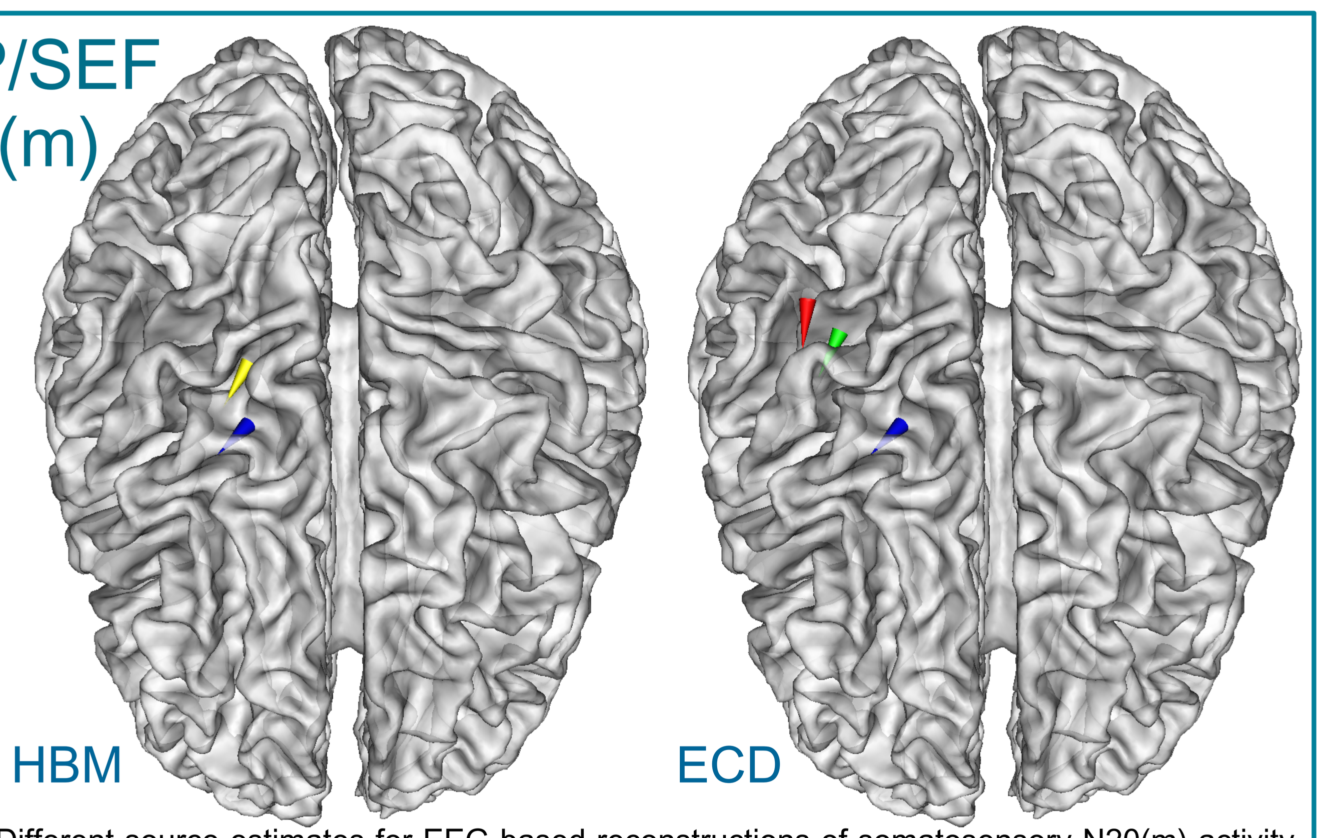


Figure 1: Different source estimates for EEG-based reconstructions of somatosensory N20(m) activity, visualized by colored cones plotted with the white matter surface. Left: HBM Full-NM (Near Mean) estimates (see Lucka et al., 2012a) using an iid or diagonal noise covariance model (yellow cone, estimates nearly coincide) or the full noise covariance (blue cone). Right: ECD fits using an iid (red cone), diagonal (green cone) or full (blue cone) noise covariance model.

The full noise covariance matrix is estimated from the pre-stimulus interval. For the reconstructions, three different noise models are build from it: The full covariance matrix, its diagonal and an iid approximation. In Figure 1 we compare HBM-based CDR to an Equivalent Current Dipole (ECD) fit (based on the same 6 mm source reconstruction grid) for all noise models. Both methods show the same result for the full covariance model which is assumed to be the most accurate one (note that CDR do not limit the number of active sources explicitly!). HBM does not seem to be more sensitive to covariance simplification than single ECD fits which are commonly regarded as a very robust source reconstruction technique. Extensive simulation studies using a similar design confirm this.

Conclusions

- Fully Bayesian inference for hierarchical Bayesian modeling can also give good source reconstruction results for real data and focal source scenarios.
- HBM is surprisingly robust against noise misspecification and residual background activity.

Motivation and Outline

In previous work (Lucka et al, 2012a, 2012b) we compared fully-Bayesian inference for HBM for EEG, MEG and EEG-MEG combination (EMEG) to established CDR methods by extensive simulation studies. Encouraged by the good results we proceeded to process first experimental data for simple, well-established source scenarios. We used somatosensory N20(m) to test our methods for a single, superficial and mainly tangential source, while auditory N100(m) was used to test our algorithm for a more difficult scenario (bi-lateral sources near planum temporale, Pantev and Lütkenhöner, 2000).

In contrast to our expectations, the first results were quite unsatisfactory. Other researchers reported similar findings. Consequently, we wanted to better understand and improve our results. We build our own preprocessing pipeline with fieldtrip (Oostenveld et al., 2011) to control and examine all steps involved:

- Noise estimation: Is HBM particularly sensitive to a misspecification or simplification of the noise covariance matrix?
- Unmixing: Is HBM particularly sensitive to residual background brain activity in the data?

We investigated these questions by real data analysis as well as by simulation studies.

Here, we present our current reconstructions and results concerning the issues raised above.

AEP/AEF N100(m)

In Figure 2, we compare EEG, MEG and EMEG reconstructions. Commonly, MEG-based reconstructions of the locations of auditory activity are regarded as more reliable than those of EEG-based reconstructions due to the better coverage of the characteristic magnetic field topographies in the sensor array (Pantev and Lütkenhöner, 2000). Note that this is not reflected in the SNRs of this single subject.

The MEG-based HBM reconstruction shows the expected bi-lateral sources in areas considered to contribute to auditory processing, a result similar to classical ECD fits. Interestingly, for this considered subject, the EEG-based HBM re-construction is not too different from the MEG-based one aside from a slight shift in location and orientation. The EMEG-based HBM reconstruction resembles the MEG-based one, a result consistent with the simulation studies we performed in Lucka et al, 2012b: If the reconstruction based on one modality is significantly weaker than the other, a combined reconstruction manly follows the stronger modality.

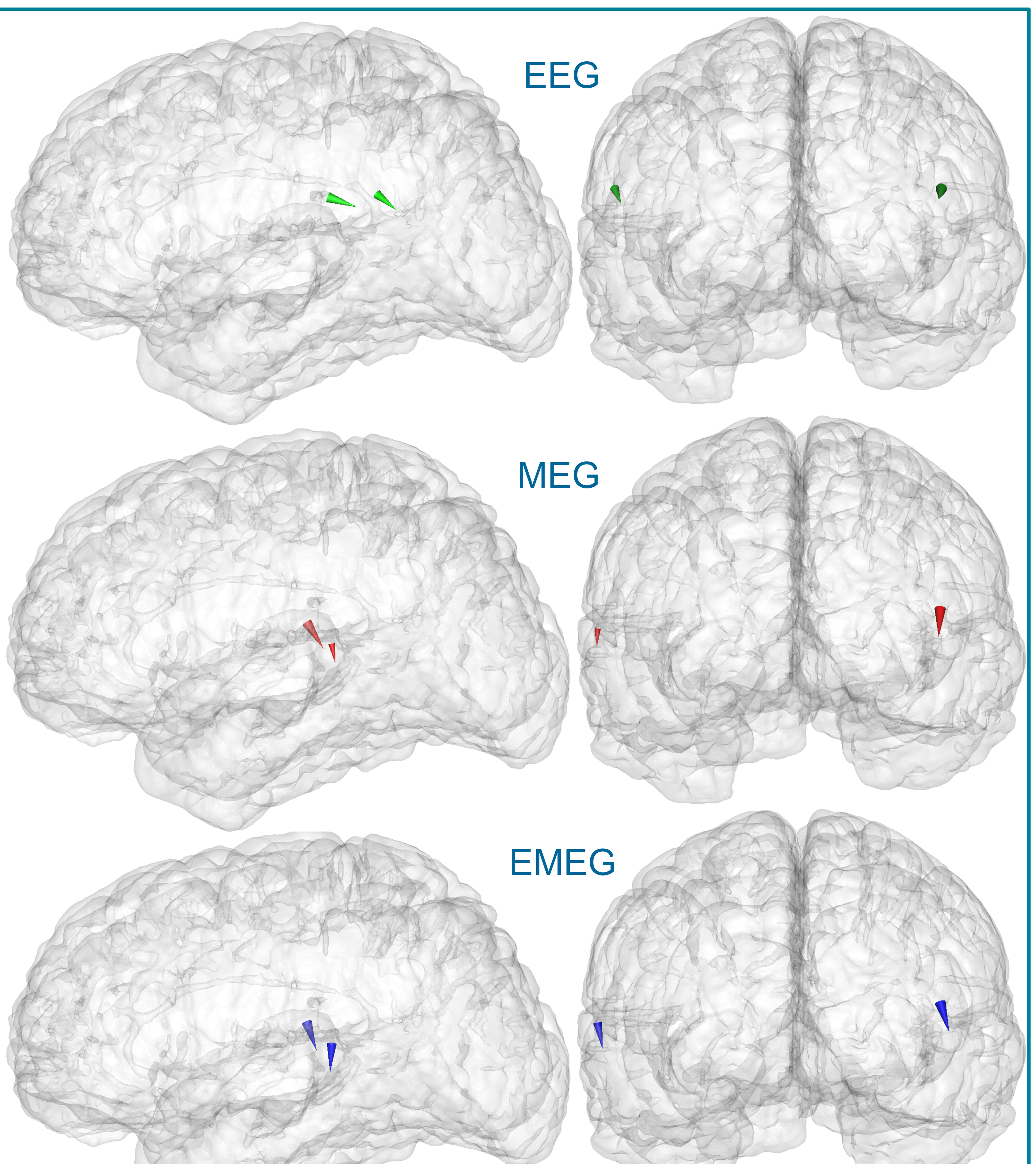
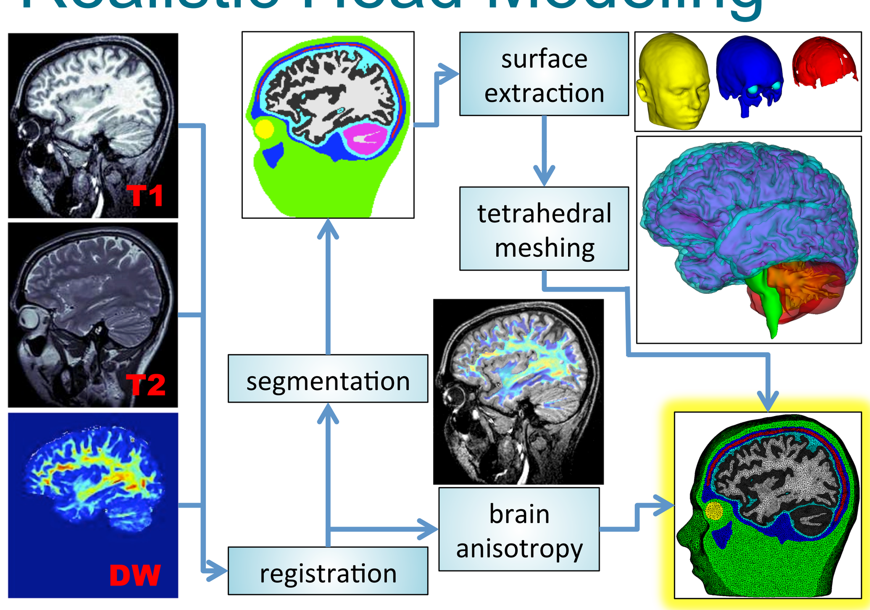


Figure 2 (right): HBM Full-NM of auditory N100(m) activity. Source estimates for EEG, MEG and EMEG-based reconstructions are visualized by colored cones plotted with the gray matter surface.

Outlook

- Comparing source reconstructions to atlas-based cortical segmentation
- Evaluating datasets from different subjects and for different source scenarios.
- Test stability of HBM reconstructions against SNR: Reconstruction of sub-sampled trial averages, comparison to all-trial averages.
- Data pooling to generate semi-artificial multiple-source scenarios.
- Develop automatic parameter choice rules for HBM.
- EEG/MEG combination requires a calibration of the head model conductivities, see Wolters et al., 2010.

Realistic Head Modeling



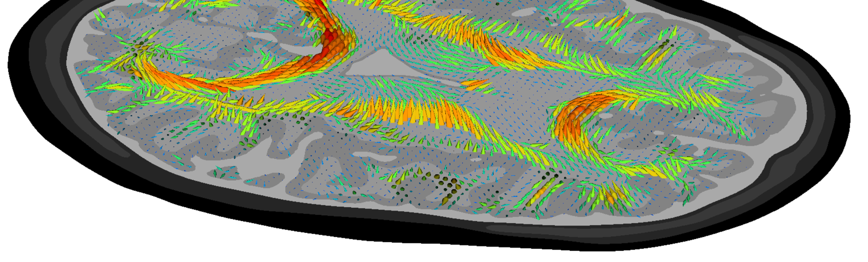


Figure 3 (above): The first eigenvector of the conductivity tensor scaled by the corresponding fractional anisotropy (FA). Figure 4 (left): Procedure to build an individual, realistic, anisotropic finite element (FE) head model. Compartments: Skin, eyes, skull compacta, skull spongiosa, csf, gray and white matter of both cerebrum and cerebellum and brain stem. For gray and white matter, anisotropic conductivities are used, which have been computed from diffusion weighted MRI (DW-MRI) scans. A detailed description is given in Janssen et al. 2013.

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Corresponding author:

Felix Lucka

✉ felix.lucka@wwu.de