Sensitivity of EEG and MEG to cortical and subcortical sources in the human brain

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This study investigates the sensitivity of EEG and MEG to cortical and subcortical sources in the human brain. We use finite element method (FEM) forward simulations in a realistic multi-compartment anisotropic head volume conductor model and measured EEG and MEG noise levels. Previous studies have been conducted, e.g., by [1] and [2], where sensitivity maps have been created using a boundary element method in a three compartment head model and cortical sources. In this work, we extended previous work by using FEM in 3 different head models and by considering cortical and subcortical sources.

SNR maps

$$SNR^i \overset{(1)}{=} 10 log_{10}\left[\frac{(a^i)^2}{N}\sum_{k=1}^{N}\frac{(b_k^i)^2}{s_k^2}\right] \qquad D^i \overset{(2)}{=} SNR^i_{MEG} - SNR^i_{EEG}$$

For each dipole i, the i-th Signal-to-Noise-Ratio (1) and the i-th differential SNR (2) are computed (following [1]), where:

- a^i is the source amplitude (10nAm)
- N is the number of sensors (71 and 271, EEG and MEG, resp.)
- b_k^i is the signal at the sensor k (i.e. forward problem solution)
- s_k^2 is the noise variance of the sensor k

data acquisition

- T1w, T2w and DTI data
- simultaneous EEG and MEG data from a somato-sensory evoked potential (SEP) and field (SEF) experiment (medianus nerve electrical stimulation)
- one 49yo male volunteer healthy subject

noise estimation

- pre-processing of SEP and SEF data
- computation of variance over the pre-stimulus interval for each channel V_k
- computation of median over channels of $(V_k)_k$

forward problem solution evaluation

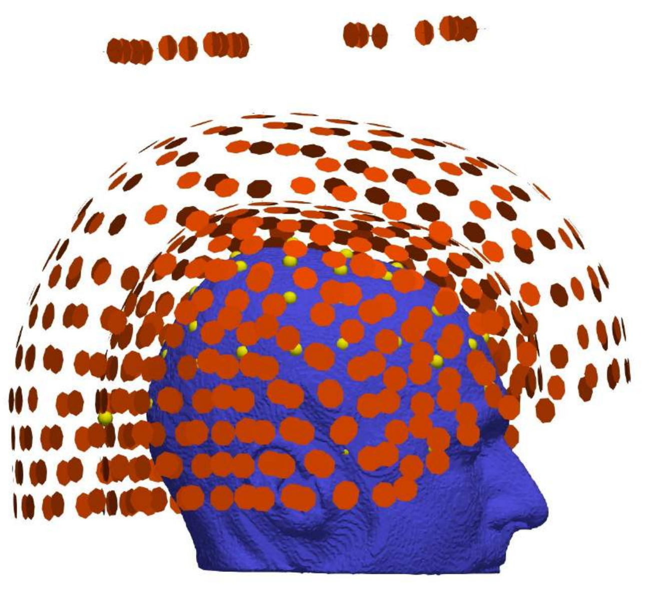

Fig1: 80 EEG (in yellow) and 275 MEG (in red) sensor configurations.

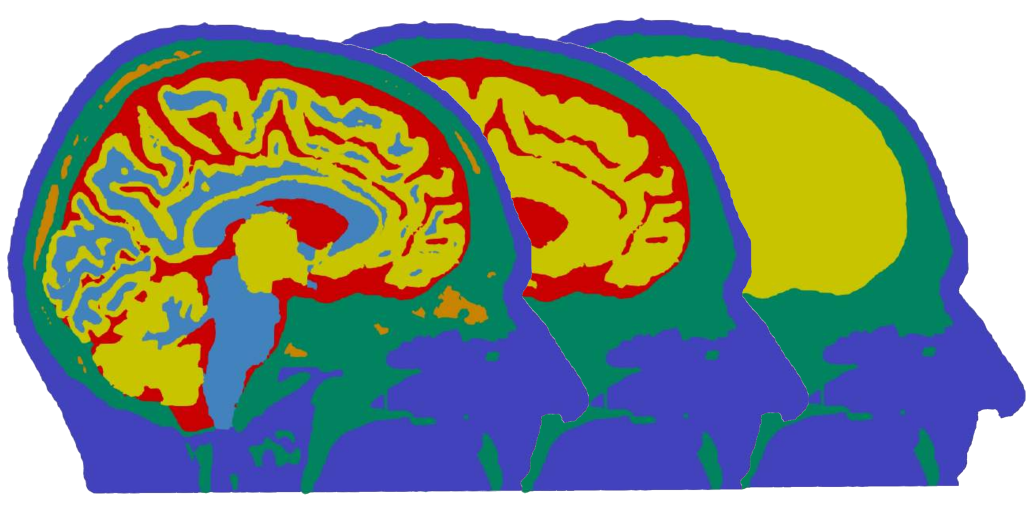

Fig2: three head models: isotropic 3 compartment (skin, skull, brain) on the right; isotropic 4 compartment (+ CSF) in the middle; 6 compartment with anisotropic white matter (+ skull spongiosa + gray matter + white matter) on the left. One unique tetrahedral mesh with 5,335,615 elements and 885,214 nodes is generated.

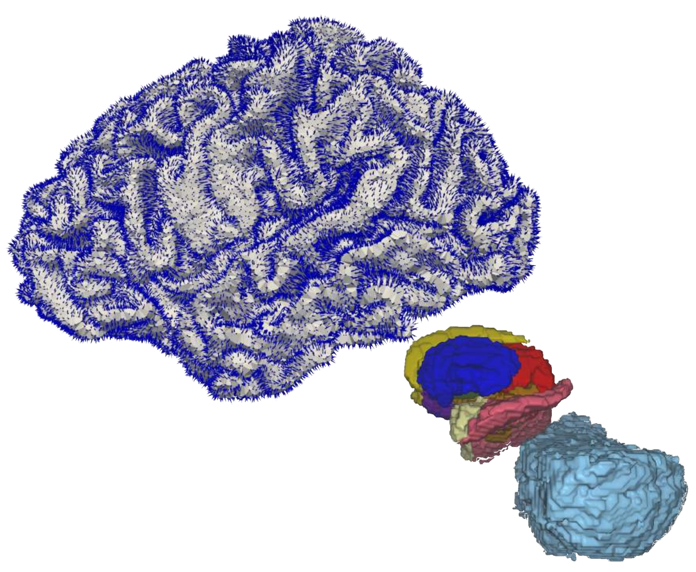

Fig3: 278,621 cortical sources with moment normal to the white matter surface (up); 111,903 subcortical sources with Cartesian moment orientations (down).

Dune http://dune-project.org/ duneuro http://duneuro.org/

- standard Lagrangian FEM used for the computation of the EEG and MEG forward problem solutions using the *duneuro* module python interface
- transfer matrix approach used for both EEG and MEG in combination with a partial integration approach for the discretization of the source term

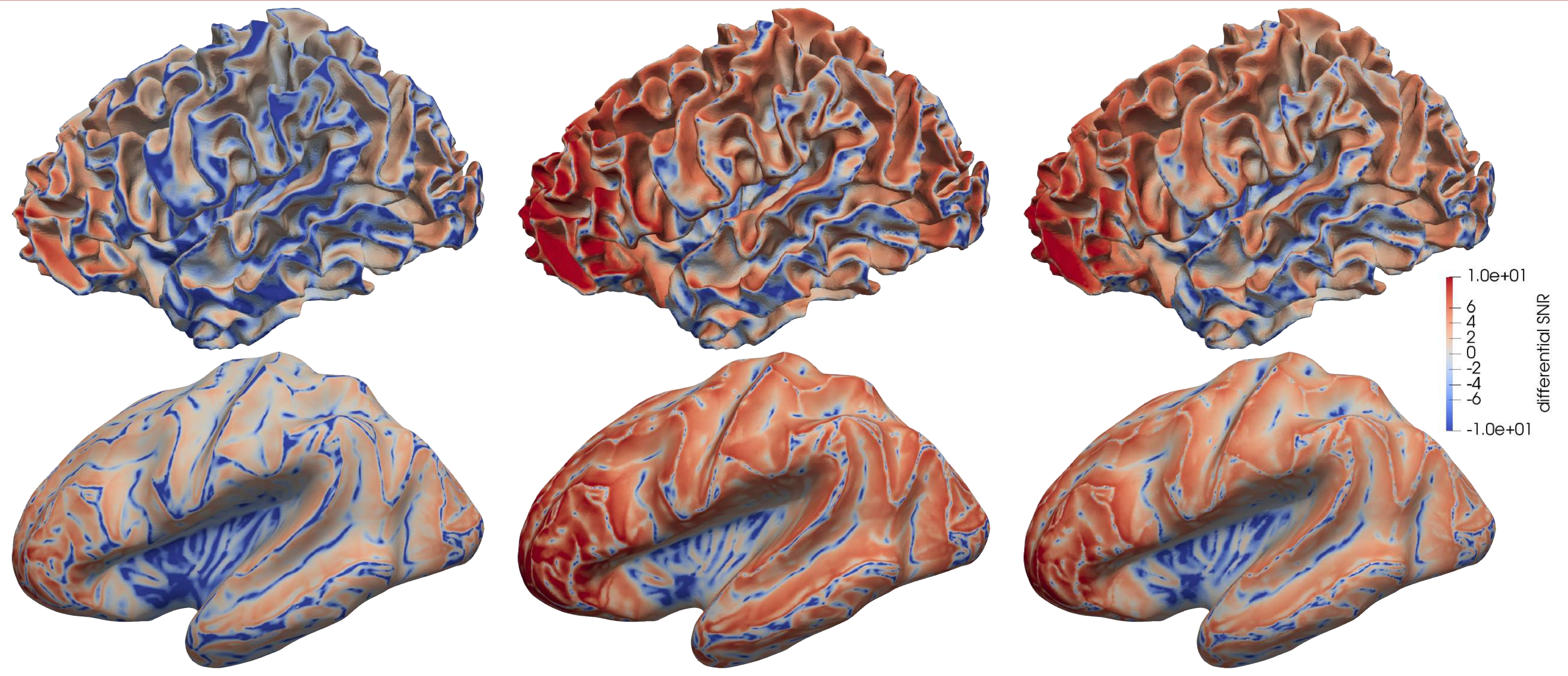

Fig4 (cortical dipoles): differential SNR (2) for 3comp (left), 4comp (middle) and 6comp (right) head model simulations visualized on white matter (upper row) and inflated white matter (lower row) surfaces.

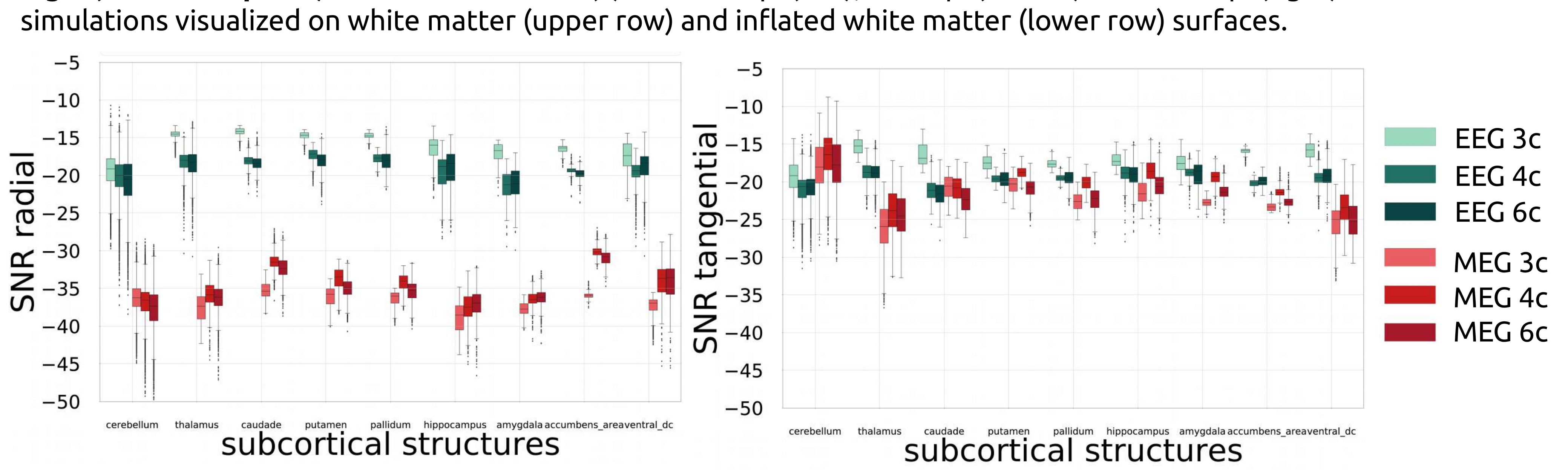

Fig5 (subcortical dipoles): boxplots of (1) for radial (left) and for tangential (right) subcortical sources. EEG and MEG SNR values are evaluated for the three different head models. The orientations are extrapolated via SVD analysis of MEG forward solutions.

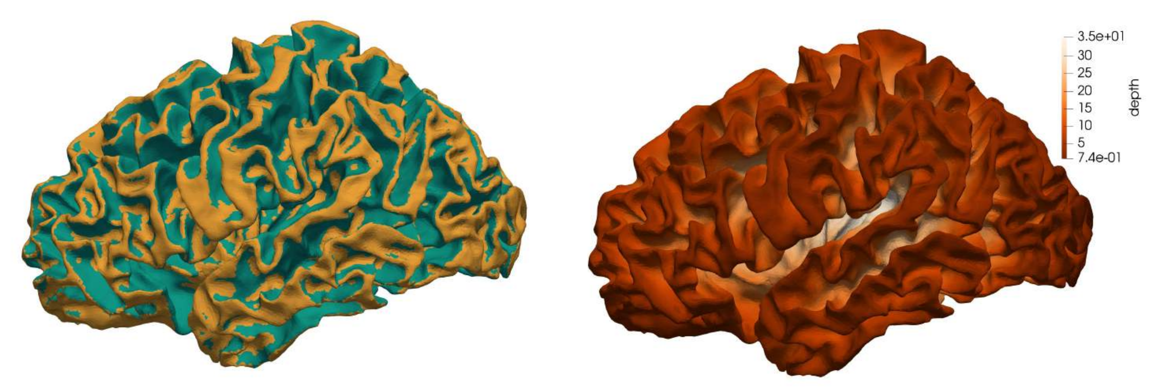

Fig6: orientation of cortical dipoles w.r.t. inner skull surface (left): radial dipoles in orange and tangential dipoles in green. Dipole depth w.r.t. inner skull surface (right).

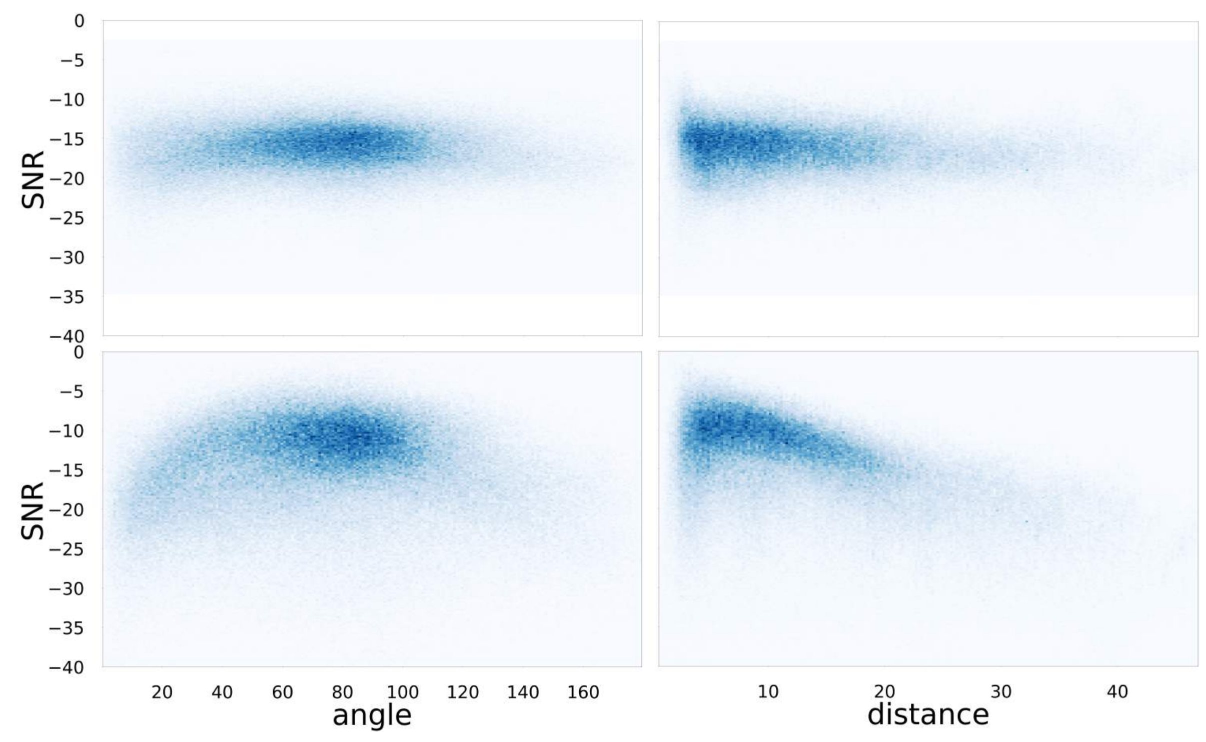

Fig7: heatmaps of EEG (upper row) and MEG (lower row) 6comp SNR values in dependency of angle (left) and distance (right) from the inner skull surface. Weak modulation of angle and distance for EEG SNR values. Slow SNR decrease for increasing distances. Sinusoidal behavior of MEG SNR values when the angle varies. MEG SNR values are low for radial sources, reach the maximum in the top of sulci walls and decrease for deeper sources. Cortical sources analyzed only.

- Complementarity of EEG and MEG measures: radial dipoles are more visible for EEG and tangential dipoles are more visible for MEG.
- Inclusion of CSF compartment strongly alters the sensitivity map of the EEG, so that ignoring the CSF in the classical 3 compartment head model leads to an overestimation of the EEG SNR.
- Due to the higher distance from source to sensor, SNR values for subcortical sources are smaller than for cortical sources.
- MEG SNR values show stronger dependency from angles and distances to inner skull compartment when compared with EEG SNR values.

References: [1] Goldenholz, Daniel M., et al. "Mapping the signal-to-noise-ratios of cortical sources in magnetoencephalography and electroencephalography." Human brain mapping 30.4 (2009): 1077-1086.
[2] Hunold, A., et al. "EEG and MEG: sensitivity to epileptic spike activity as function of source orientation and depth." Physiological measurement 37.7 (2016): 1146.

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