

EEG source explorer: an interactive browser tool, and how accurate source reconstruction really is

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Live tool: dircksen47.space/neuro · built with MNE-Python, three.js and AI-assisted programming (Claude Code)

Abstract. I built a single-page web application that simulates cortical activity on the FreeSurfer template brain, projects it to 128 scalp electrodes through a three-shell boundary-element head model and reconstructs the sources live in the browser with four linear inverse methods (MNE, dSPM, sLORETA, eLORETA). To quantify what such reconstructions can show, I ran a resolution analysis over all 5124 cortical sources for six electrode montages (8–128 channels), with and without a head-model error, plus a Monte Carlo simulation with sensor noise. Without noise, sLORETA and eLORETA localise every point source exactly; with realistic noise their accuracy depends strongly on sensor density (median error ≈ 0.5 cm at 64 channels, ≈ 3.5 cm at 8), and spatial blurring of ≈ 4 –6 cm remains for every method. The underdetermination of the inverse problem makes every source image partly a picture of its modelling assumptions.

01 The tool

The forward model follows the standard MNE-Python pipeline: fsaverage cortex, an ico4 source space (5124 dipoles normal to the cortical surface), a three-layer BEM (scalp, skull, brain; 0.33 / 0.0066 / 0.33 S/m) and 128 electrodes of the 10-05 system. The lead field G (128×5124) is embedded in the page in compressed form; a web worker computes the inverse kernels for any montage, method, regularisation and head model.

```
b = G q + n
MNE: K = R GT (G R GT + λ2 C)-1 , λ2 = 1/SNR2
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dSPM normalises the MNE estimate by its noise variance, sLORETA standardises it with the resolution matrix, and eLORETA iterates source weights so that point sources are localised exactly in the noise-free case. Twenty simulated activities (e.g. eyes closed: occipital alpha; hand movement: contralateral mu) are rendered as band-power maps on a 160 000-point cortex, side by side with the true sources. Users can switch electrodes on and off, add noise, change regularisation and depth weighting, and generate the EEG with a deliberately wrong head model (electrodes shifted ≈ 6 mm, skull conductivity 1/25 instead of 1/50, coarser BEM).

02 Mini study: methods

For every montage and method I computed the resolution matrix $R = K G$ (Hauk et al., 2022). Its columns are point-spread functions; from them I derived the **peak localisation error** (distance between the true source and the maximum of its reconstruction) and the **spatial dispersion**. Because the resolution matrix ignores noise, I added a Monte Carlo simulation: 400 random sources $\times$ 10 draws of white sensor noise at SNR 1, 3 and 10 (signal RMS over noise RMS), identical noise across conditions. $\lambda^2 = 1/9$; depth weighting 0.8 for MNE/dSPM. The head-model error changes the lead field by 15 % (relative Frobenius norm).

03 Results

- **Noise-free:** sLORETA and eLORETA have zero localisation error at every channel count, their known theoretical property. MNE is off by a median of 2.0–4.0 cm (pull towards superficial sources), dSPM by 3.2–4.5 cm.
- **With noise (SNR 3):** sensor density matters. sLORETA/eLORETA reach ≈ 0 –0.5 cm at 64–128 channels, 1.1–1.9 cm at 16–32 and ≈ 3.5 cm at 8 channels. At SNR 1 every method lands at 3–7 cm, and dSPM is the most robust.
- **Blurring:** spatial dispersion only falls from ≈ 6.3 cm (8 channels) to ≈ 4 cm (128 channels), similarly for all methods.

- **Head model:** this particular perturbation barely changes the metrics, so it is a mild error;

differences between a template and an individual head can be larger.

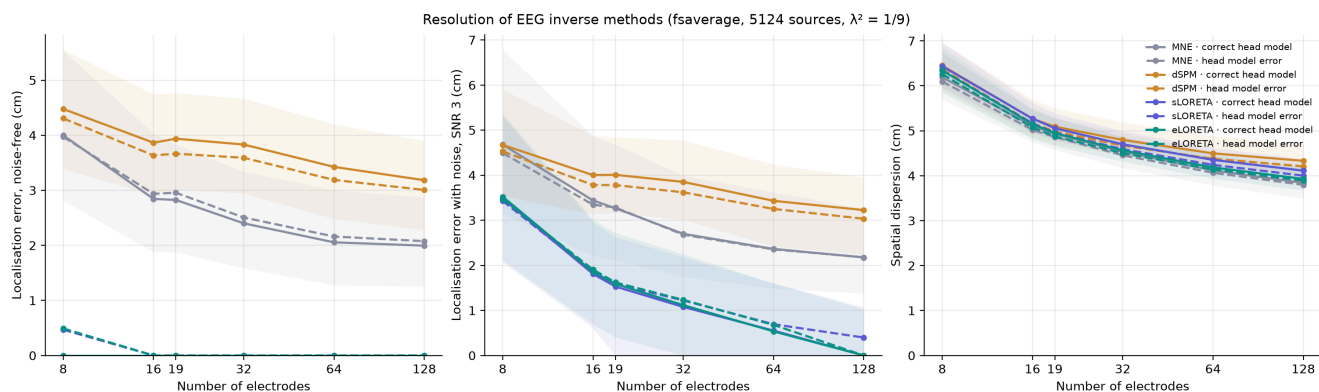


Figure 1. Median over 5124 sources (left, right) or 4000 noisy trials (middle) by number of electrodes; solid: correct head model, dashed: head model error; shaded: interquartile range. Computed with MNE-Python 1.13 (studie/aufloesung.py).

04 Discussion: what can we know from EEG?

The EEG inverse problem is underdetermined: infinitely many source distributions produce the same scalp potentials (Helmholtz, 1853). Each method selects one solution by a criterion that does not come from the data: minimum norm, noise normalisation, standardisation, exact point localisation. The study shows where these priors pay off and where they do not. sLORETA's exactness is real but conditional; under noise, accuracy is bought with sensors, and the irreducible blur of several centimetres means that a "hot spot" is a statistical summary, not a location. For neuroscience this is a methodological caution; for philosophy of science it is a clean case of model-dependent observation, where what counts as seeing activity in the brain depends on the assumptions built into the instrument.

05 Limitations and next steps

Template head and standard electrode positions; point sources and white noise; simulated activities are didactic simplifications. Next steps: coloured noise and extended sources, and an individual head model.

06 Real data

A "real data" mode shows group maps from the open PhysioNet EEG Motor Movement/Imagery dataset (40 subjects, 64 channels): log band-power ratios projected with the same head model. Eyes closed vs. open (alpha) peaks in left lateral occipital cortex, and 98 % of the top 5 % of sources lie in occipital or parietal areas. Imagined left-hand movement shows mu desynchronisation over right post-central cortex (positive lateralisation in 75 % of subjects, 93 % in beta), and the right hand shows the mirror image.

07 References

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