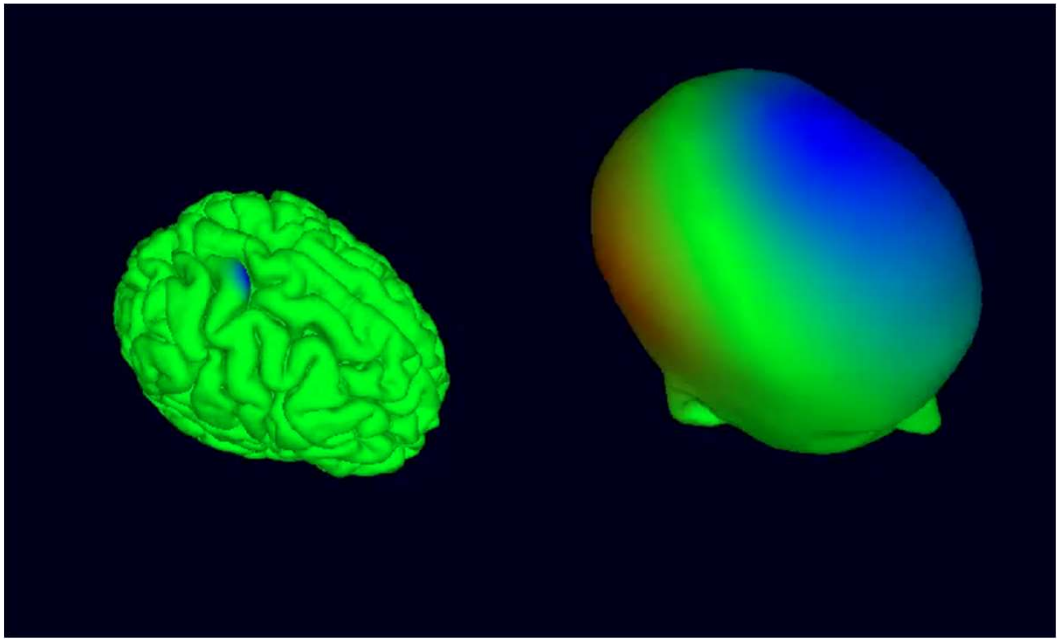
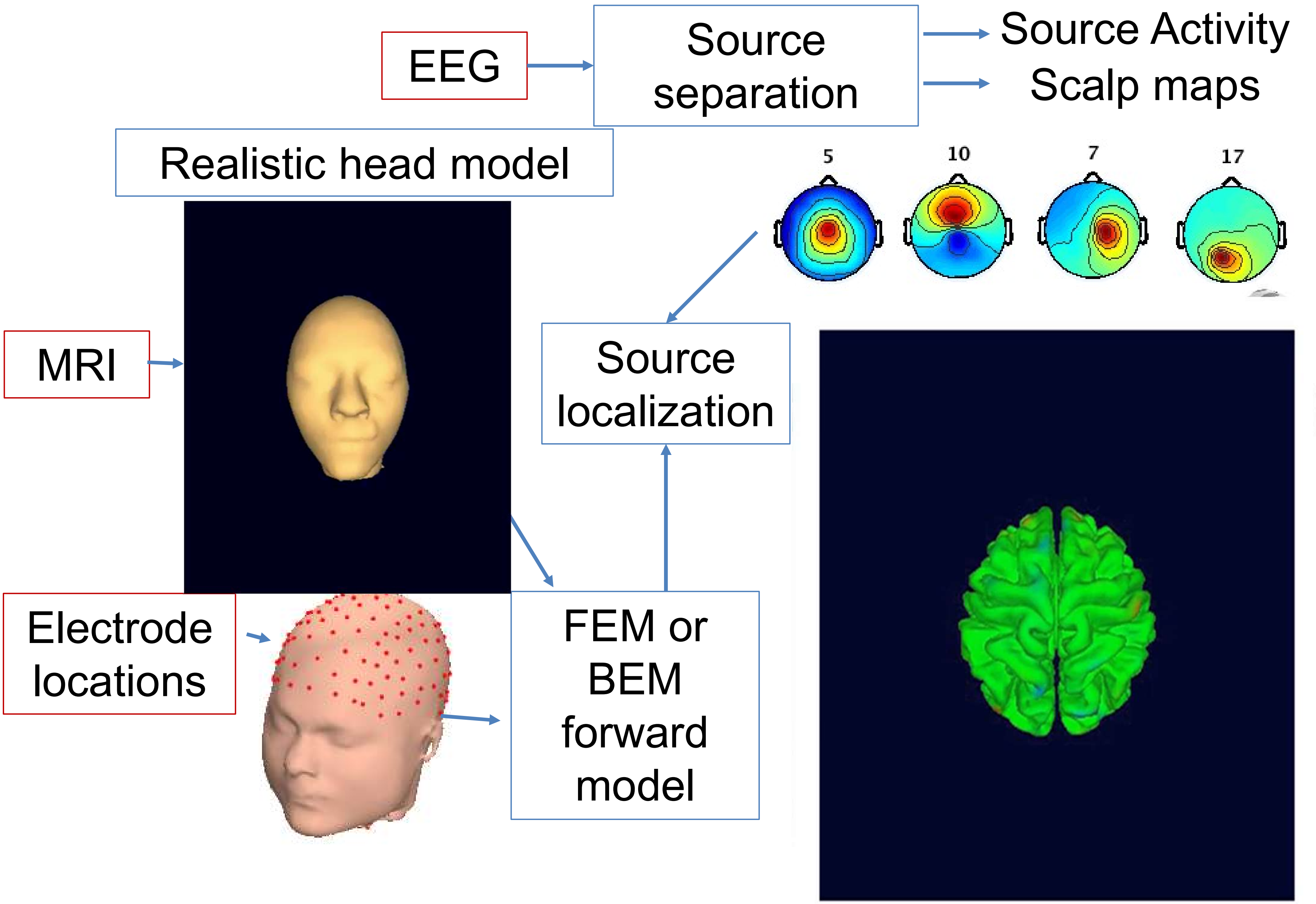


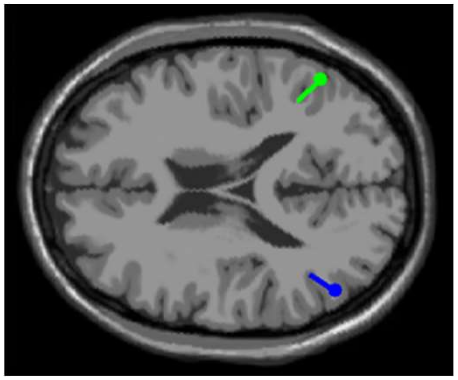
High-Resolution Forward Head Modeling and Source Localization

Zeynep AKALIN ACAR

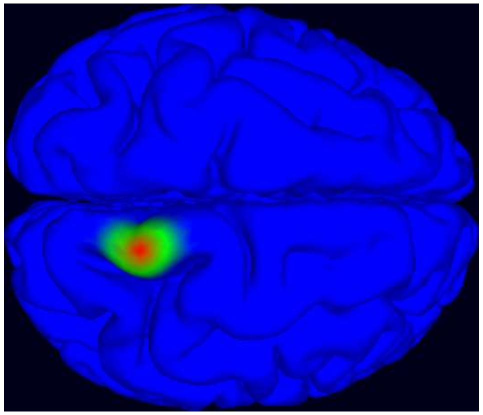
Swartz Center for Computational Neuroscience

EEGLAB workshop, 2021


EEG
Source separation
Source Activity
Scalp maps
Realistic head model
5
10
7
17
MRI
Source localization
Electrode locations
FEM or BEM forward model



Inverse Problem Approaches



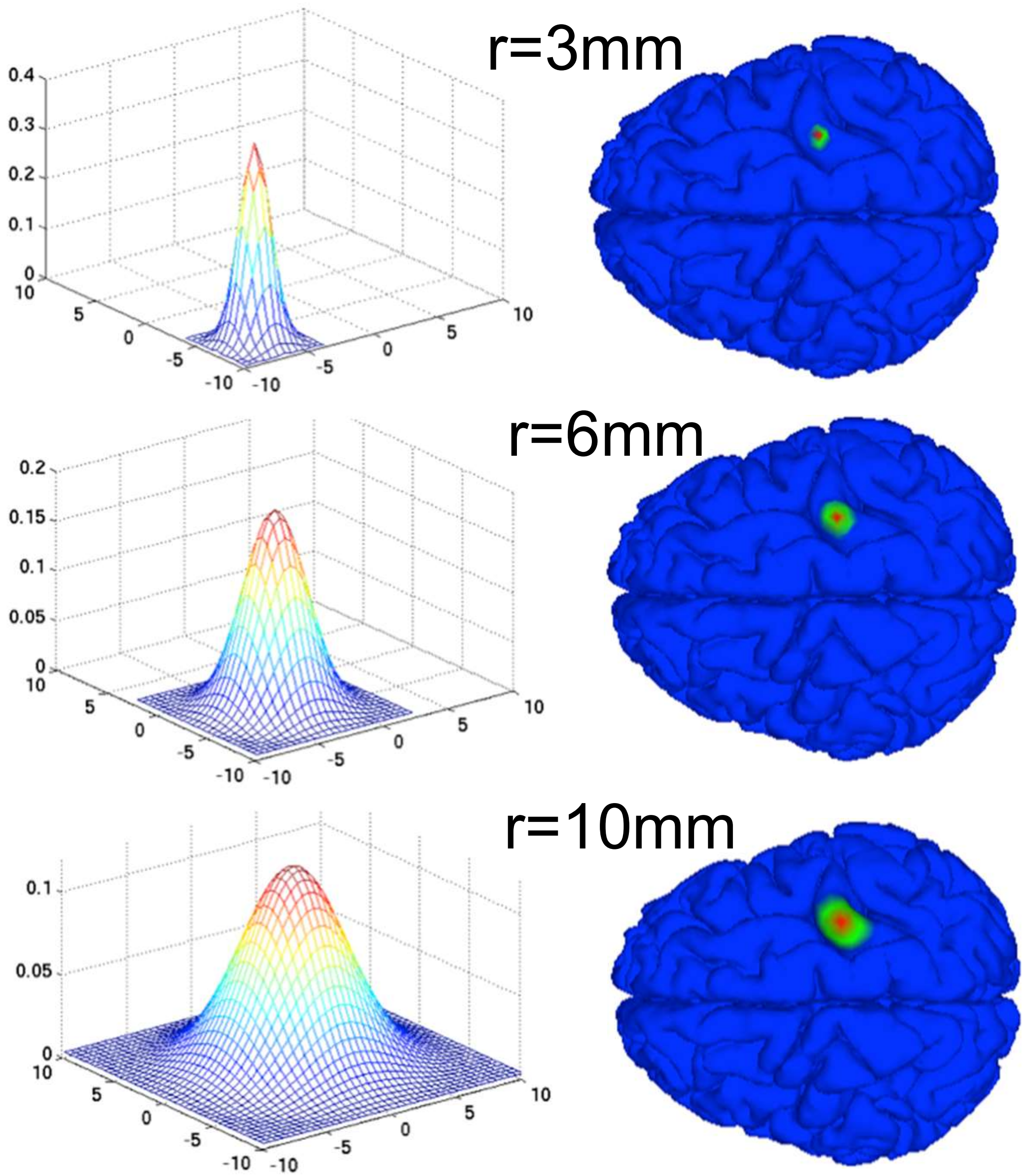
Equivalent dipole Methods

- Overdetermined
- Searches for parameters of a number of dipoles
- Nonlinear optimization techniques
- May converge to local minima
- Non-linear least squares, beamforming, MUSIC, simulated annealing, genetic algorithms, etc.

Linear distributed Methods

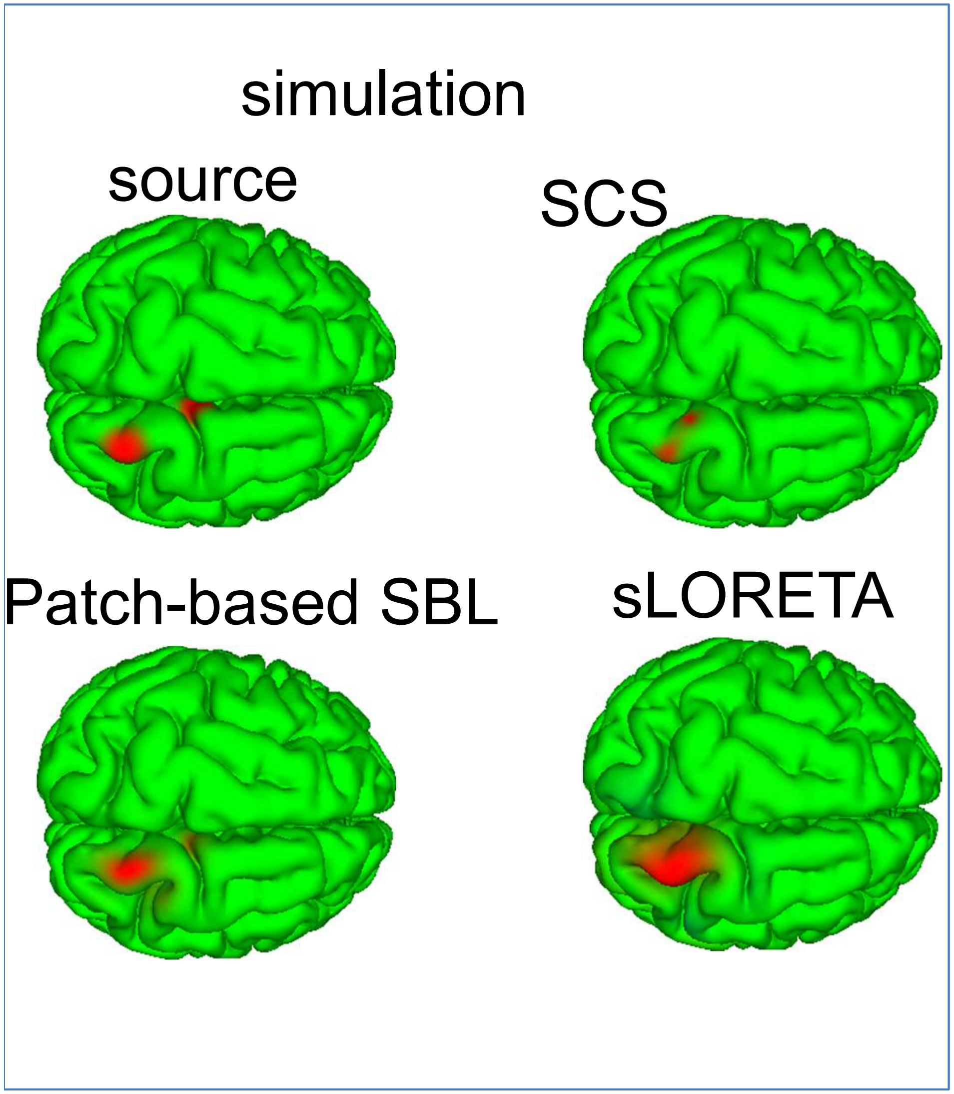
- Underdetermined
- Searches for activation in given locations.
- Linear optimization techniques
- Needs additional constraints
- Bayesian methods, MNE, LORETA, LAURA, etc.

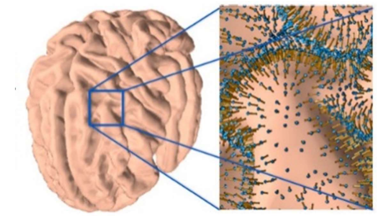
Localization of cortical patch sources



- Source space: patches tangent to the cortex.
- 80,000 dipole elements using tessellated FreeSurfer gray matter surface.
- For each dipole element: three gaussian-tapered cortical patches of sizes with geodesic radii of 10 mm, 6 mm, and 3 mm.

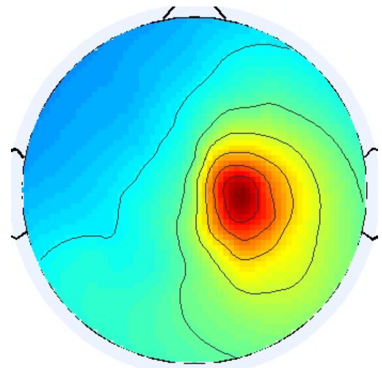
Comparison of methods



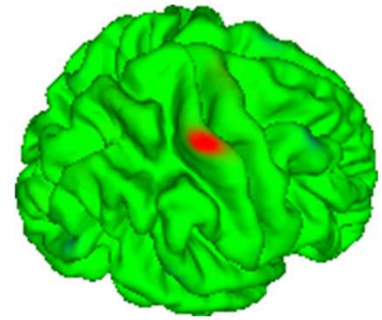


Source space

Scalp map

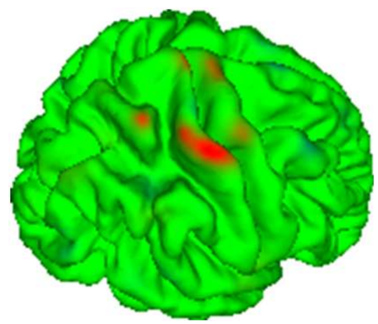


SCS

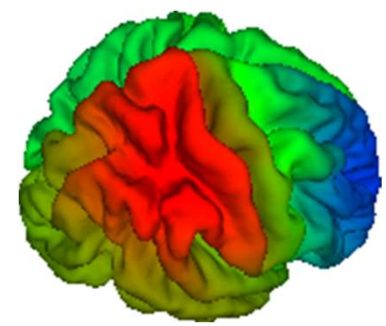


Cheng Cao, 2012

Patch-based SBL



sLORETA



Inverse Problem with SCS

- Sparse Compact Smooth (Cao et al. 2012)
  - Generates spatially sparse and maximally compact source distributions.
  - Neurophysiologically plausible for near-dipolar ICs

- Masking-off low-magnitude voxels reduces the goodness of fit significantly
  - Residual Variance (RV) where RV=0 is perfect fit.
  - Due to default "identity" noise model.

Akalin Acar, Makeig, 2020, BIBE

Estimating Noise Characteristics of ICs

- Spatial noise covariance matrix can be computed from EEG channel recordings.

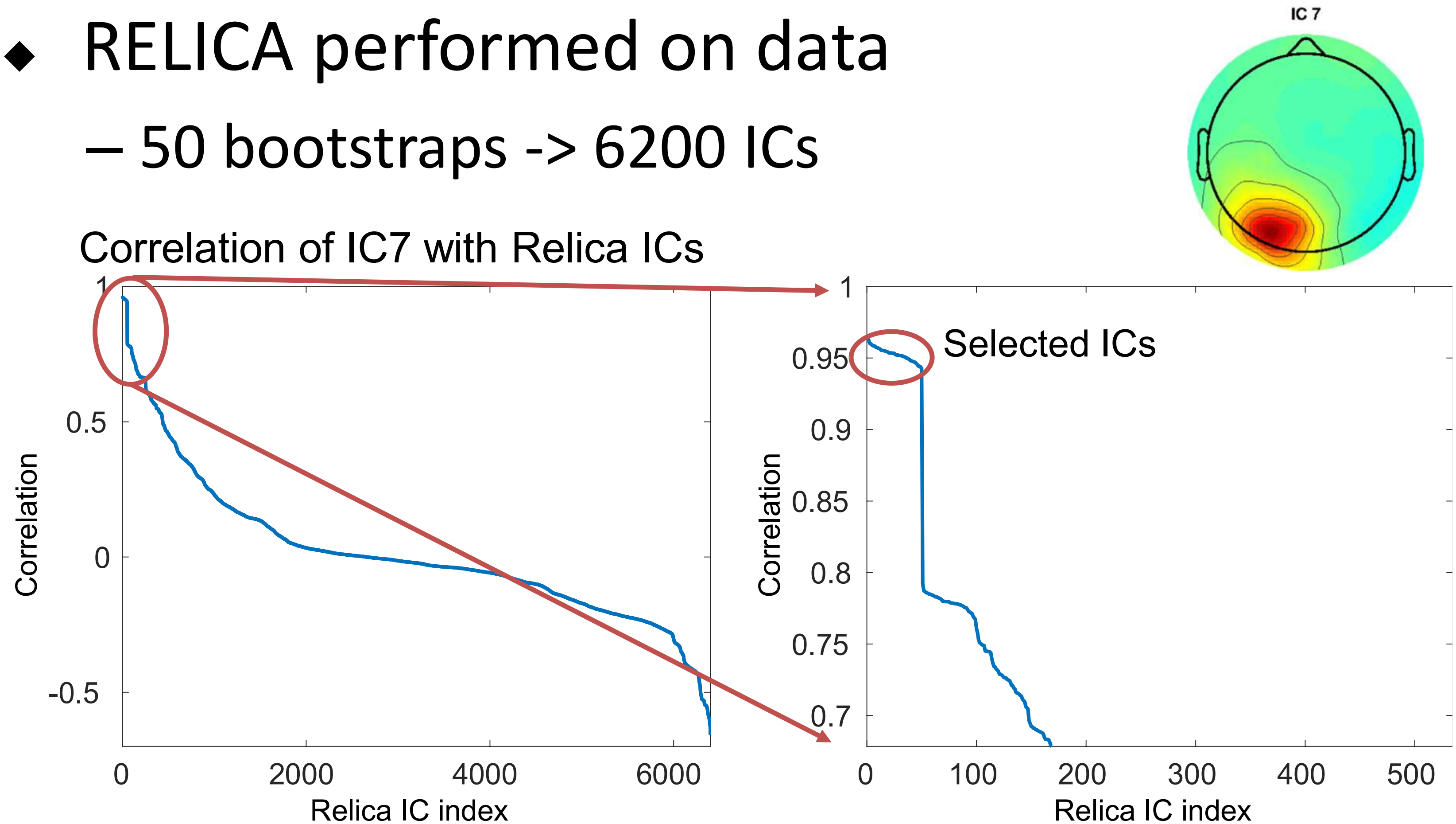
- However, we run SCS on IC scalp maps.
  - How can we model noise for individual IC maps?
  - Need more data to generate variability statistics.

- We use RELICA (bootstrap-ICA)
  - 50 bootstrap decompositions of same data
  - Cluster similar IC maps to compute channel statistics.

Akalin Acar, Makeig, 2020, BIBE

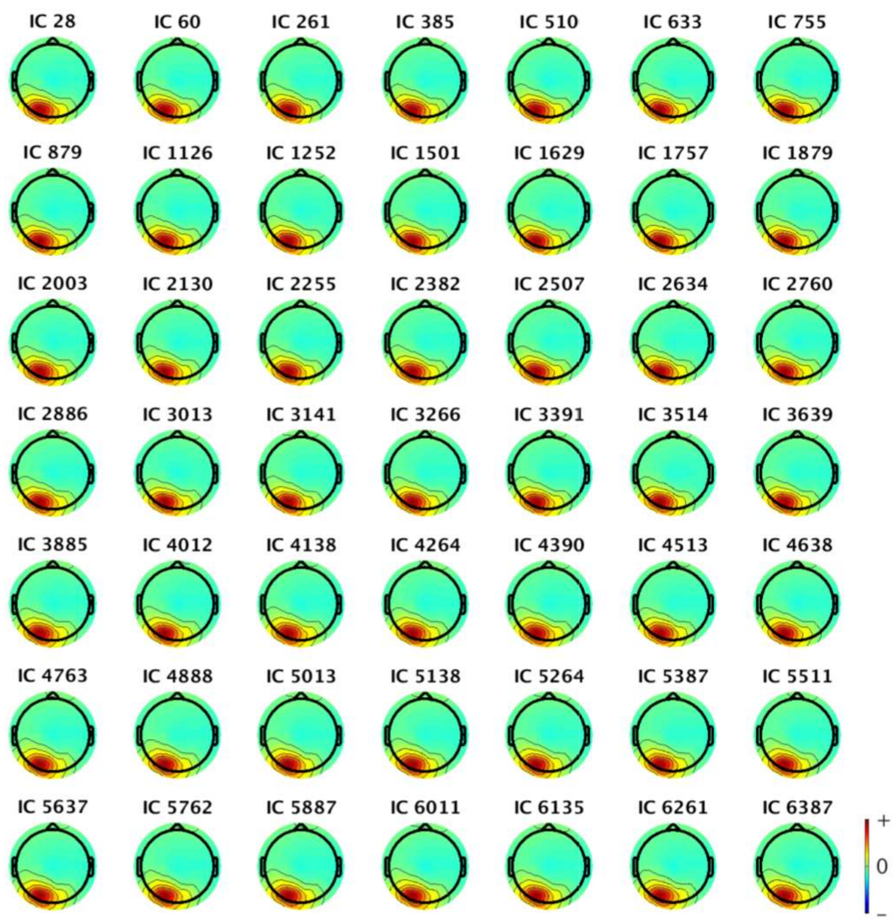
Estimating Noise Characteristics of ICs

- Brain ICs obtained from multimodal AMICA
- RELICA performed on data
  - 50 bootstraps -> 6200 ICs

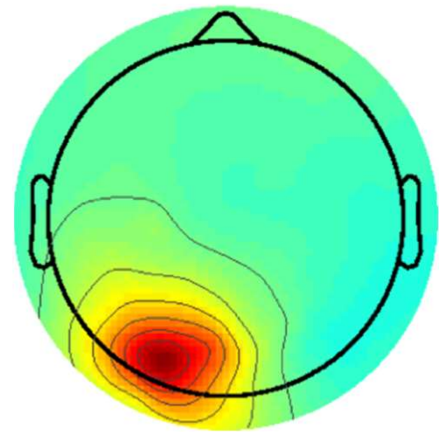


Akalin Acar, Makeig, 2020, BIBE

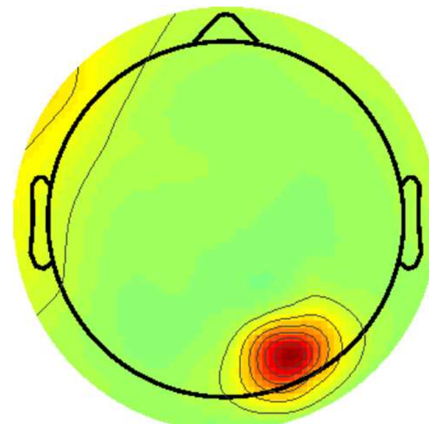
Estimating Noise Characteristics of ICs



Selected RELICA ICs similar to IC7



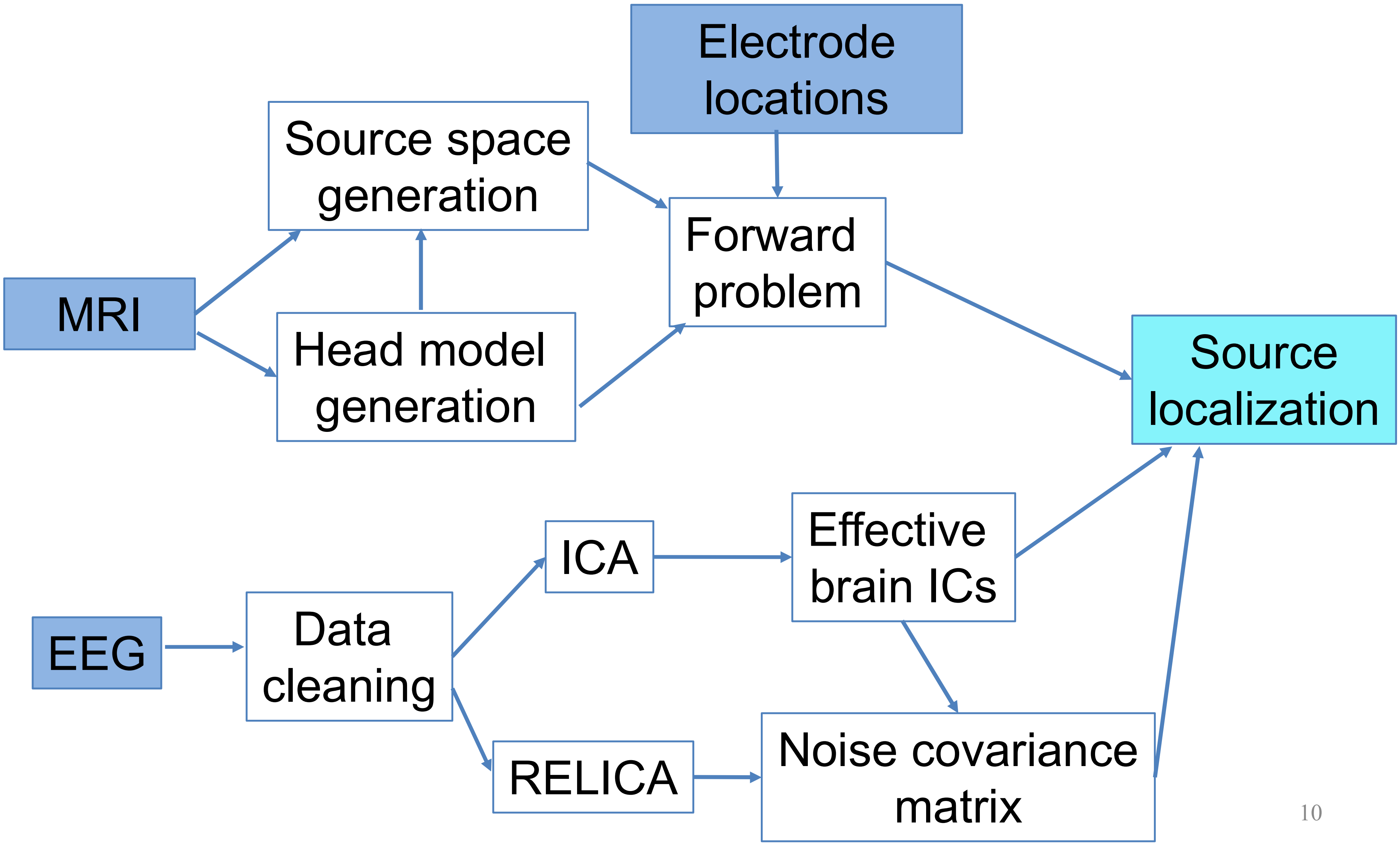
Scalp map of IC7



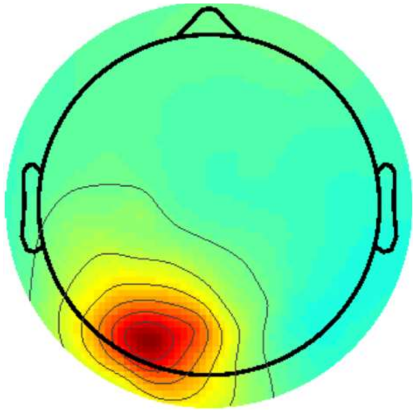
Variance of the
selected RELICA ICs

Akalin Acar, Makeig, 2020, BIBE

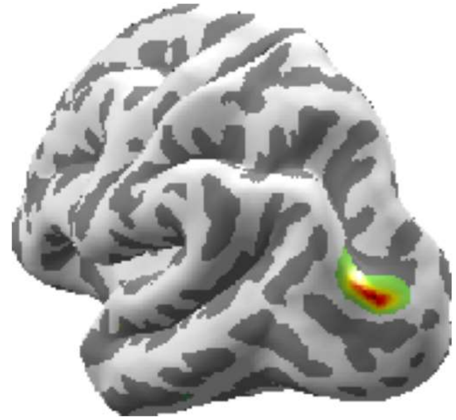
Source localization flowchart

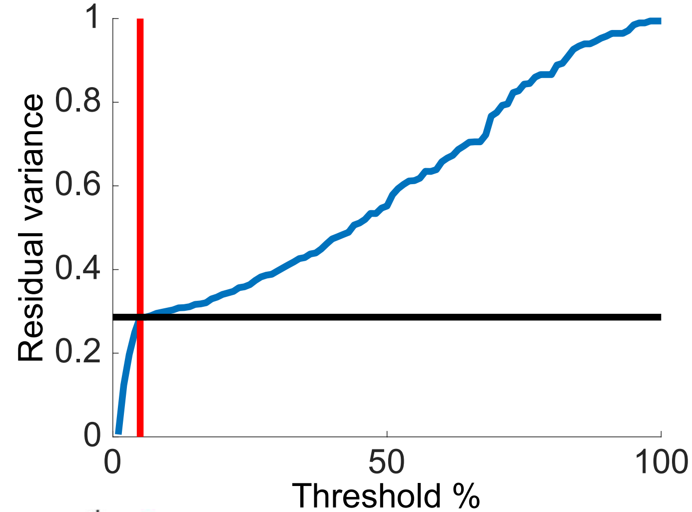


Scalp map for IC=7

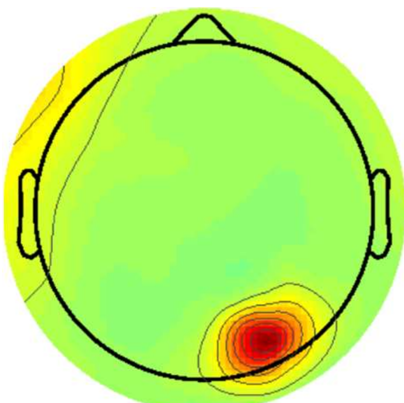


SCS solution

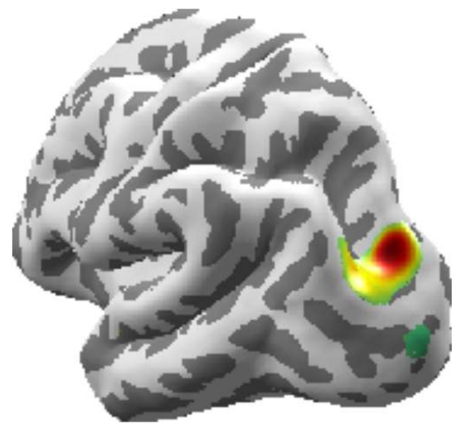


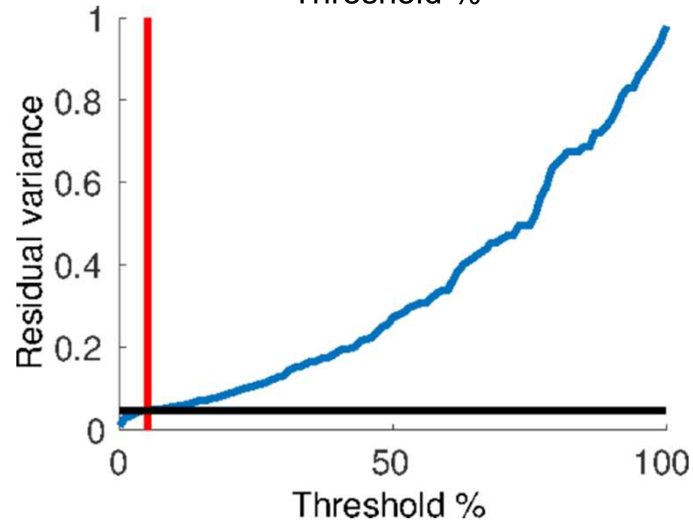


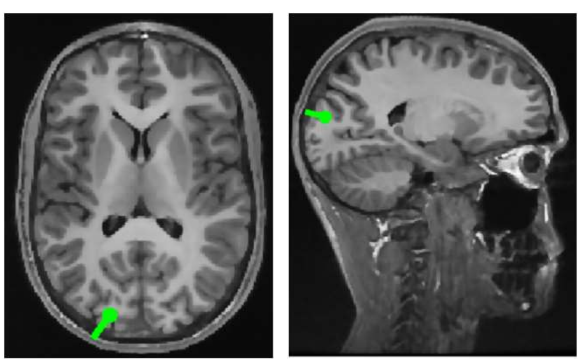
Variance of the selected Relica ICs



Updated SCS solution





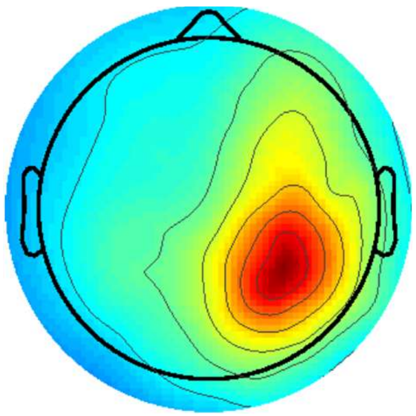


Equivalent dipole
r.v. = 1.7%

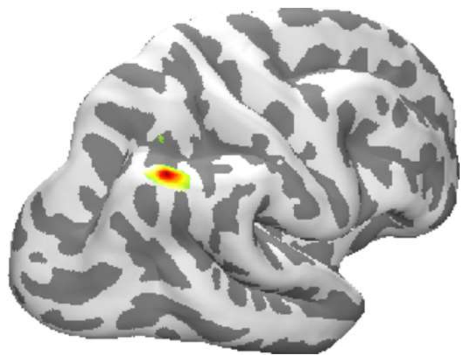
SBL solution

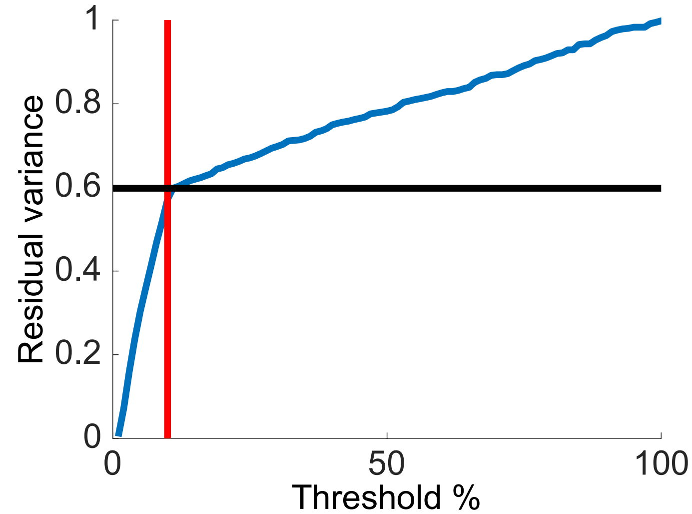
Akalin Acar, Makeig, 2020, BIBE

Scalp map for IC=13

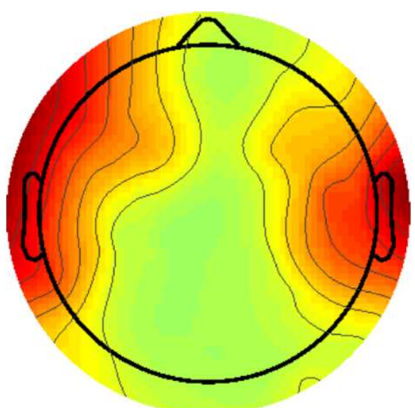


SCS solution

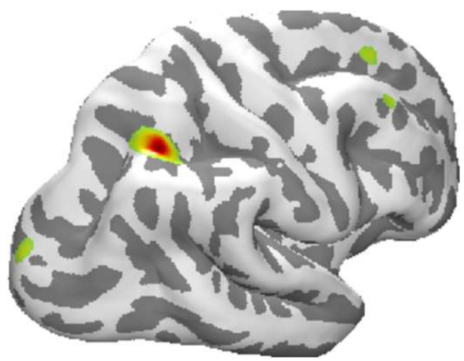


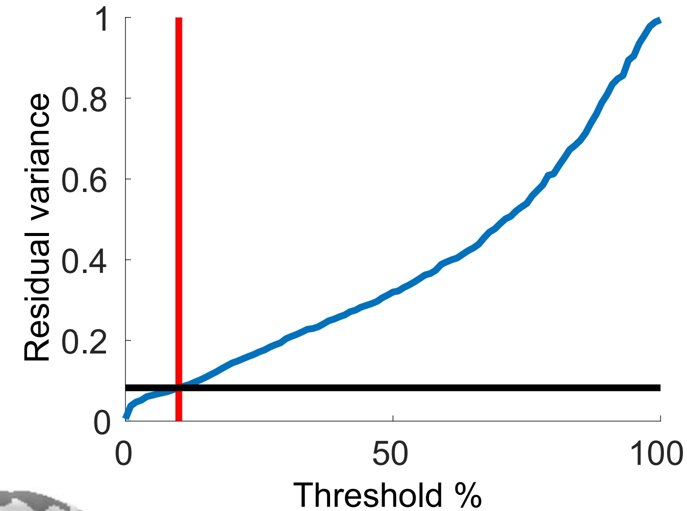


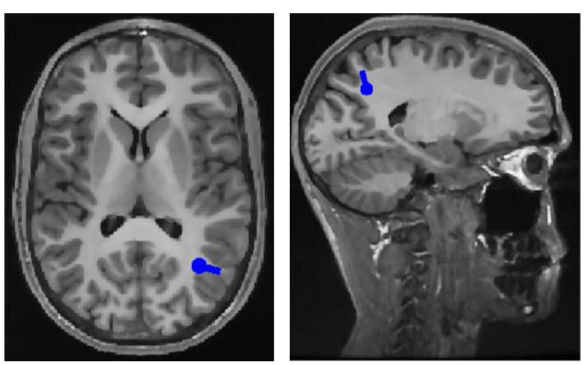
Variance of the selected Relica ICs



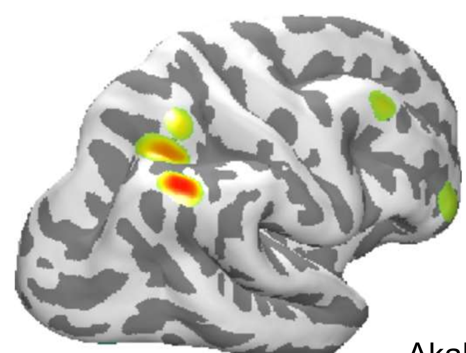
Updated SCS solution







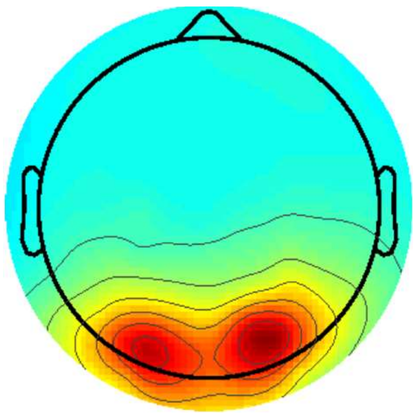
Equivalent dipole r.v. = 5.7%



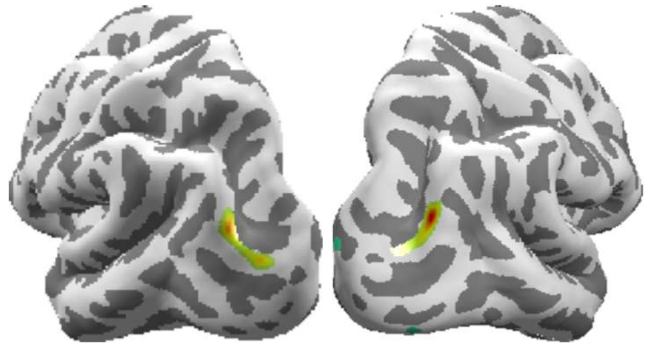
SBL solution

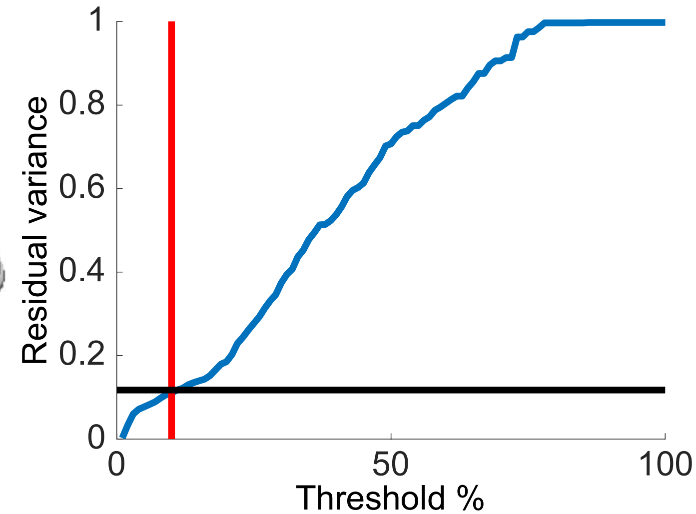
Akalin Acar, Makeig, 2020, BIBE

Scalp map for IC=17

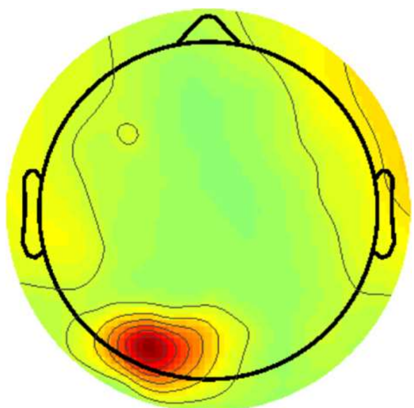


SCS solution

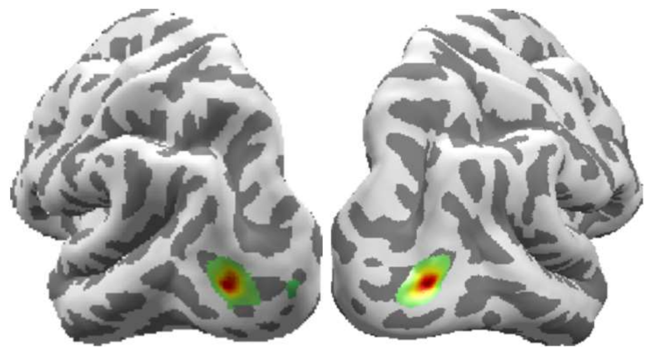


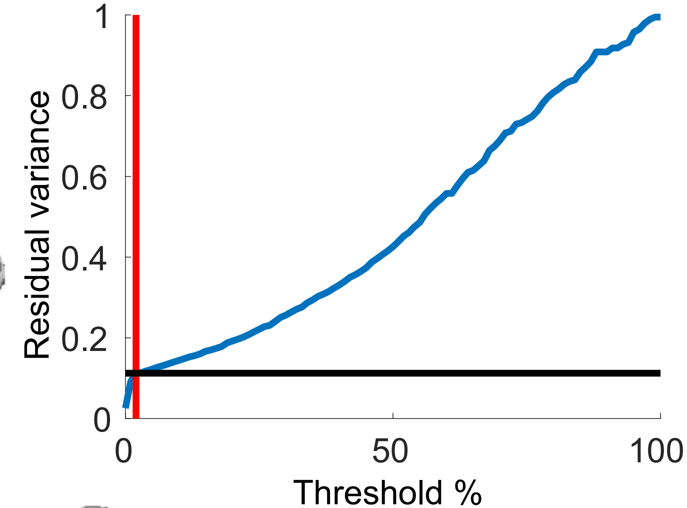


Variance of the selected Relica ICs

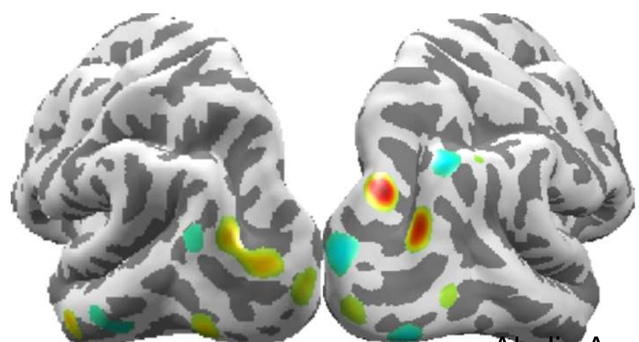


Updated SCS solution





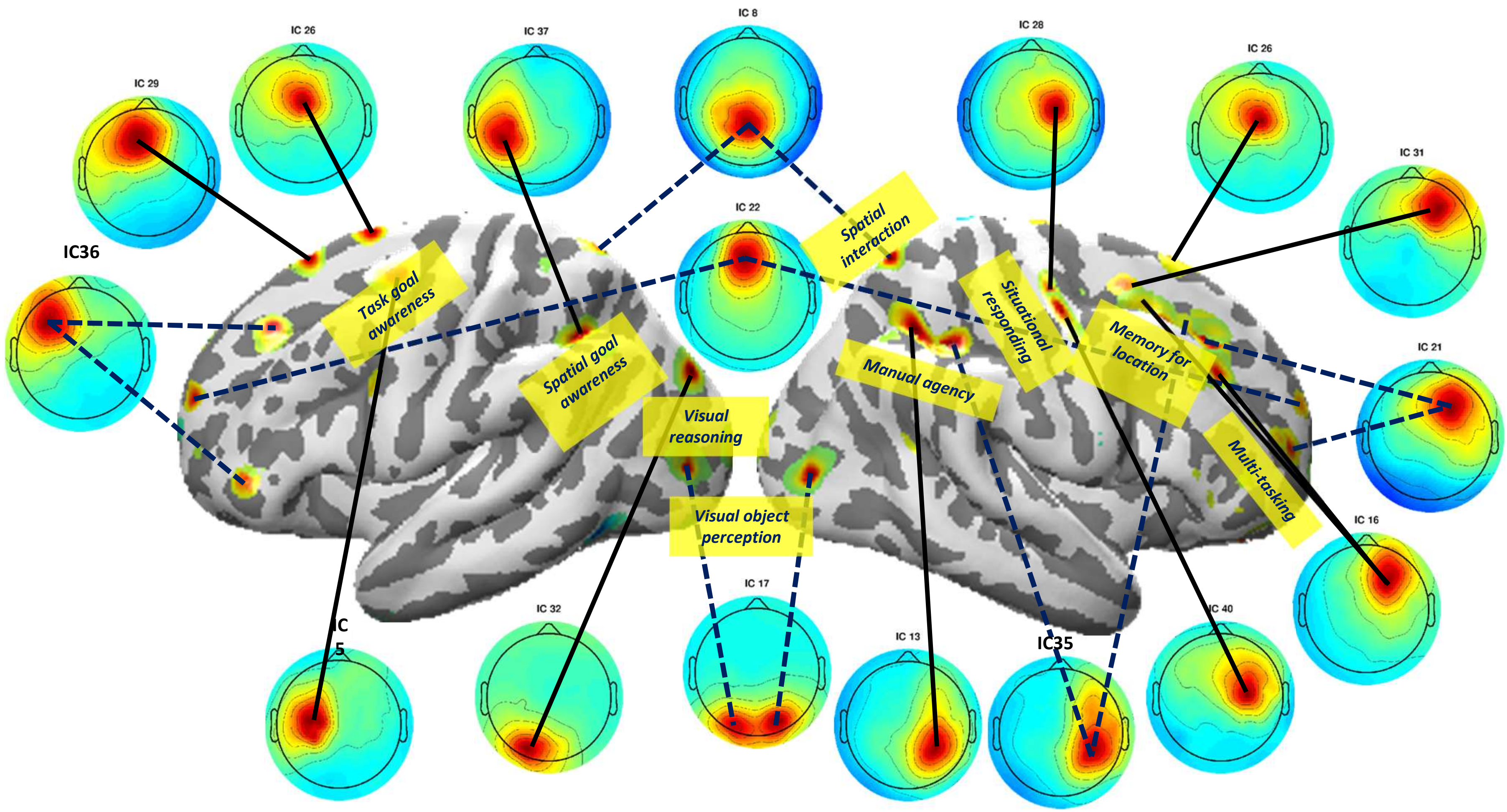
Equivalent dipole
r.v. = 1.3%



SBL solution

Akalin Acar, Makeig, 2020, BIBE

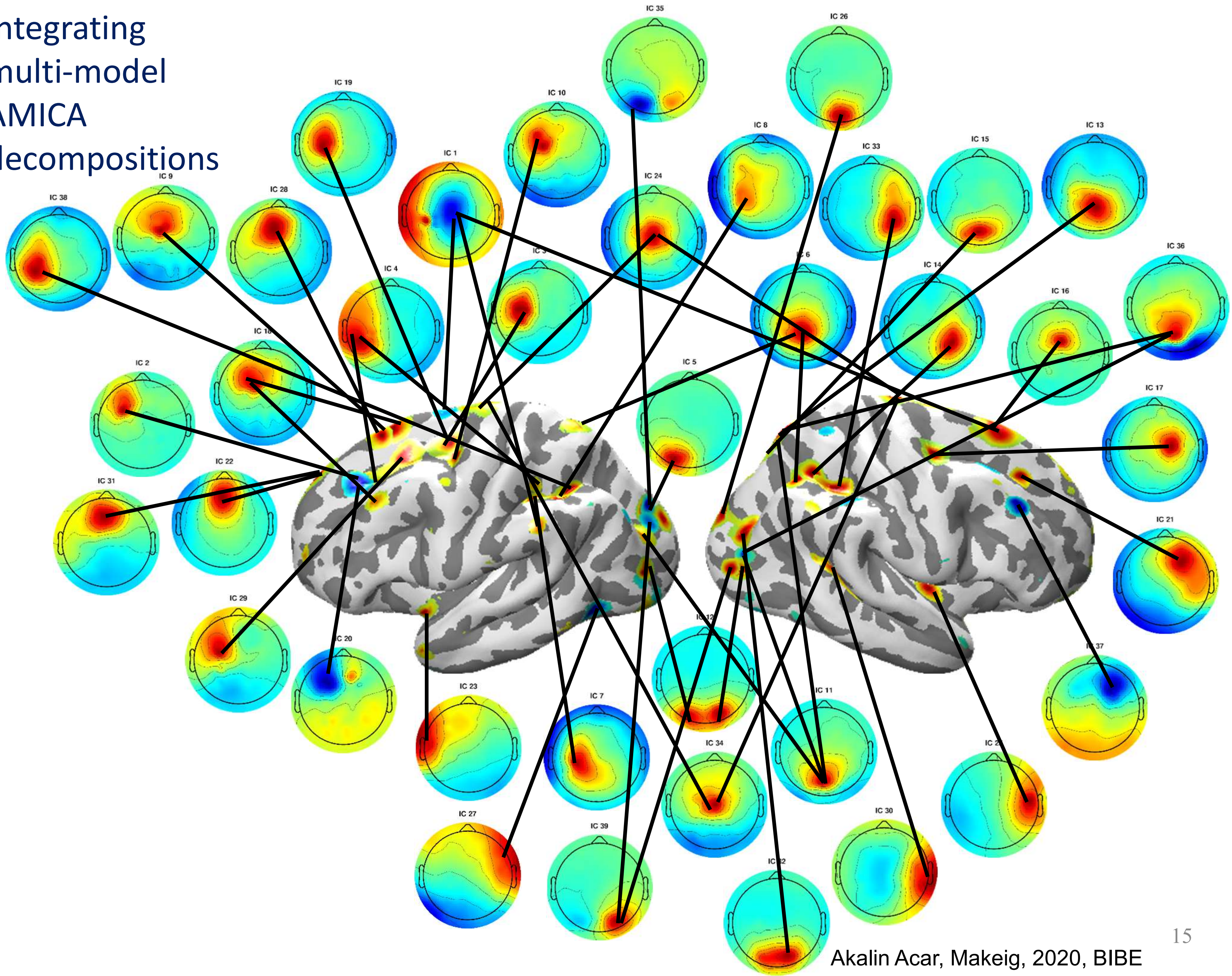
ICA effective source distributions localized by SCALE



Participant P6: STRUM videogame playing task

Akalin Acar, Makeig, 2020, BIBE

Integrating multi-model AMICA decompositions



Akalin Acar, Makeig, 2020, BIBE

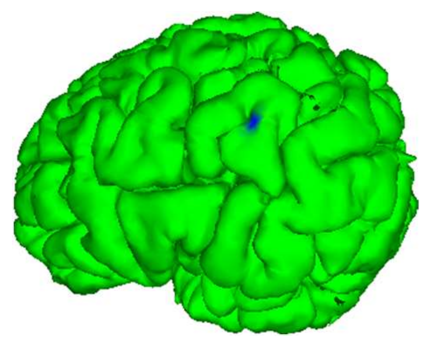
Skull conductivity estimation

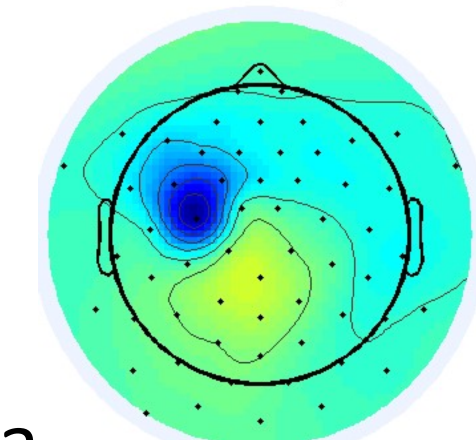
- We propose a skull conductivity estimation method using independent EEG brain sources.
- Patch-based source localization measures:

  \- Source compactness

  \- Source projection

  goodness of fit





- Linearize the forward problem around a conductivity distribution.

Linearization of the potentials around a conductivity distribution

If we perturb the conductivity values by $\Delta\sigma$

$$\sigma = \sigma_0 + \Delta\sigma \qquad \Rightarrow \qquad \Phi = \Phi_0 + \Delta\Phi$$

For a discretization with N nodes and M elements:

$$A(\sigma)\Phi = b$$

Φ: Nx1 vector of unknown node potentials
σ: Mx1 vector of layer conductivities
A: sparse, symmetric NxN matrix containing geometry and conductivity information
b: Nx1 primary current density

Linearization of the potentials around a conductivity distribution

Changes in the potentials at the electrode locations:

$$\Delta\Phi_s = -DA(\sigma_0)^{-1} \left.\frac{\delta A(\sigma)}{\delta\sigma}\right|_{(\sigma=\sigma_0)} \Phi_0 \Delta\sigma$$

$$\Delta\Phi_s = S_\Phi \Delta\sigma$$

S: mxM sensitivity matrix

Gencer and Acar, 2004

Iterative procedure

1. Generate a head model - **NFT**
2. Calculate the forward model using initial conductivity distribution - **NFT**
3. Estimate source distribution (for P number of near-dipolar ICA sources) - **NIST**
4. Calculate the sensitivity matrix.
5. Estimate the change in the conductivity values
6. Update the conductivity, repeat 2, 3, 4, and 5.

Conductivity estimation

Estimate the conductivity change by minimizing the topological difference between EEG and calculated potential:

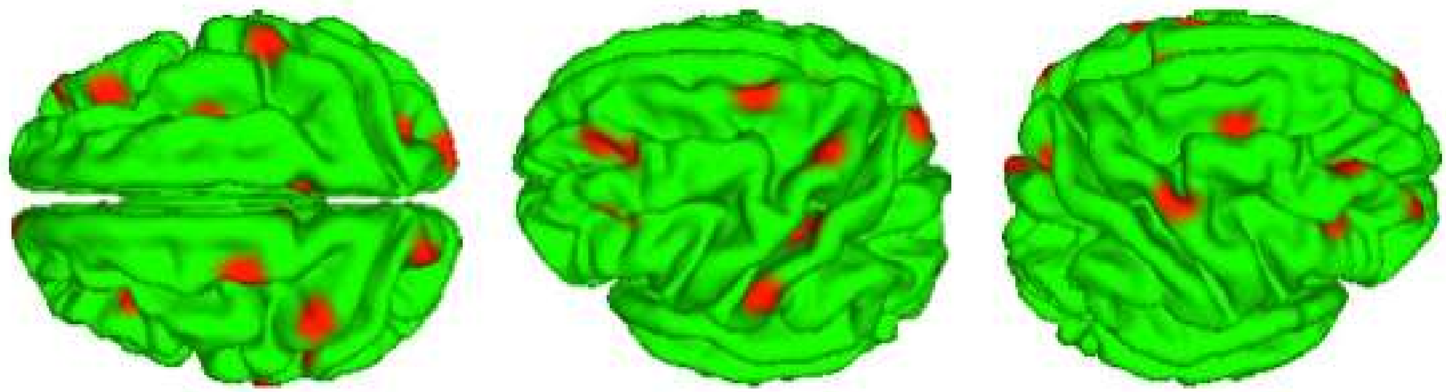
$$\Delta\hat{\sigma}_i = \min_{\Delta\sigma} RDM(\Phi_{EEG}, \Phi_i)$$

Since: $\Phi_i = S_i \Delta\sigma_i + \Phi_{i-1}$

$$\Delta\hat{\sigma}_i = \min_{\Delta\sigma} RDM(\Phi_{EEG}, S_i \Delta\sigma_i + \Phi_i)$$

Simulation study

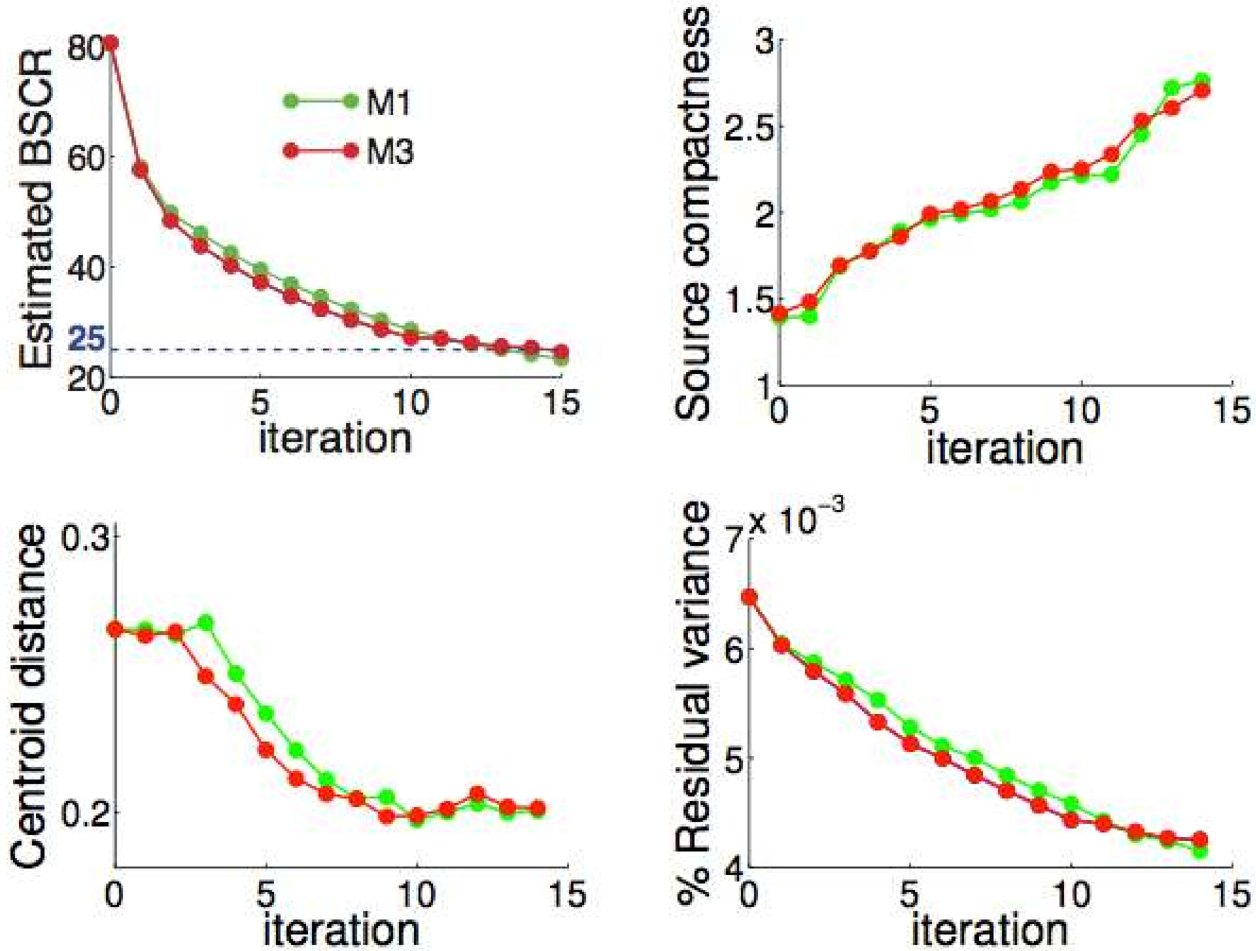
20 cortical Gaussian patch sources used in the simulations.



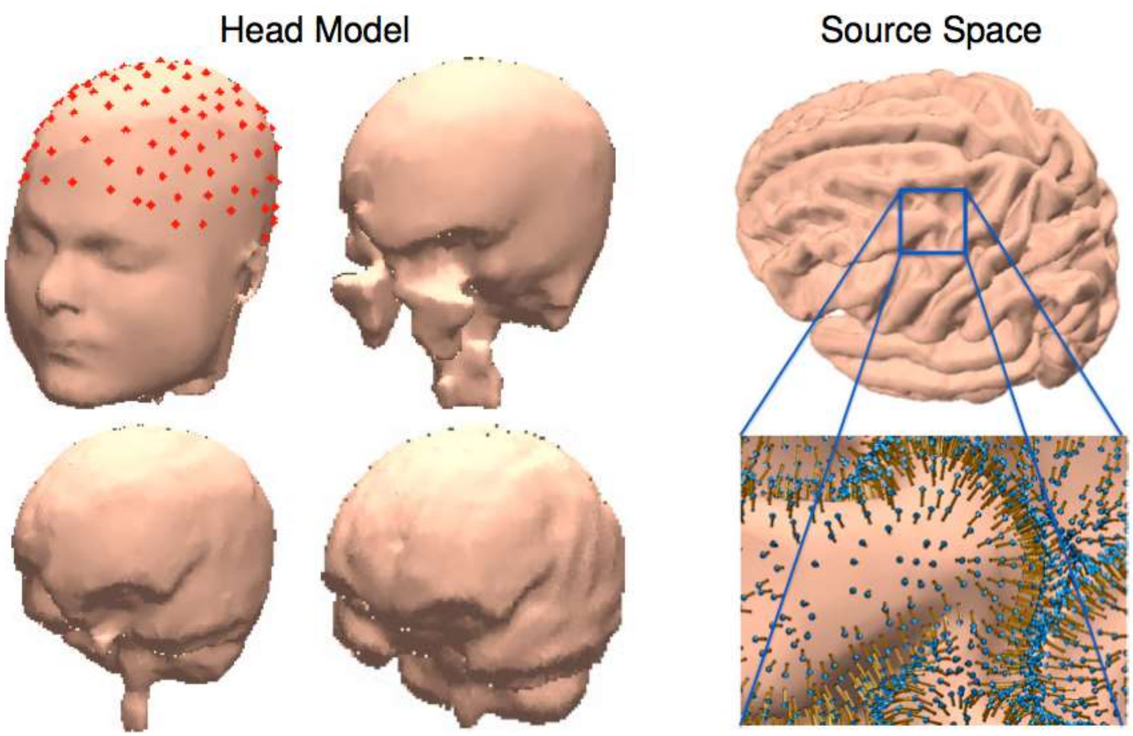
10 mm radius, 3.33 mm std., 128 electrode locations

Simulated EEG: BSCR=25
SCALE initialized at BSCR=80.

Simulation results



Real EEG study



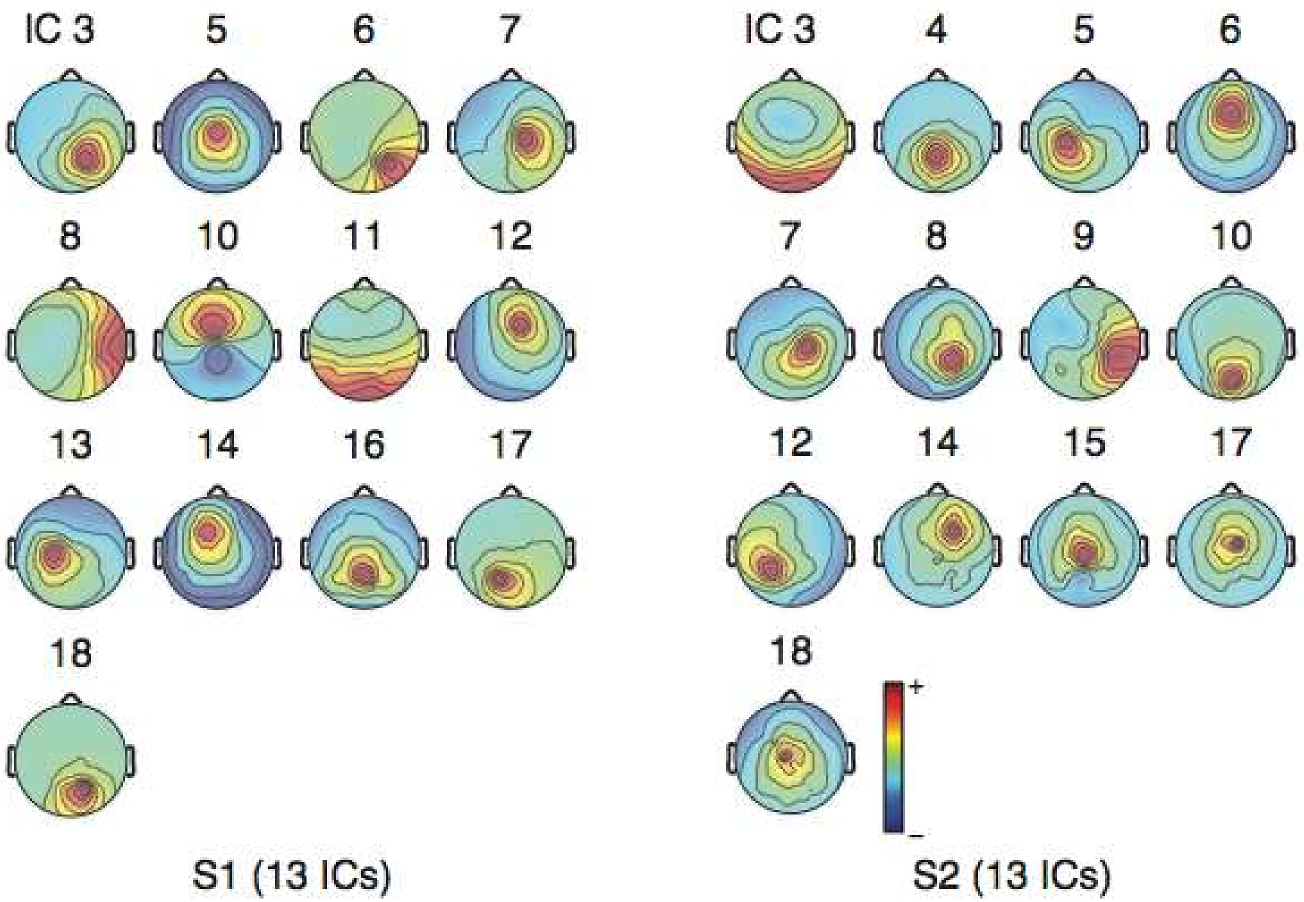
Subjects: 2 male subjects, ages: 20, 23

MRI data: GE 3T whole head MRI with 1 mm^3 resolution.

EEG data: 128 scalp EEG, (256-Hz sampling rate) collected using a Biosemi Active Two system during an arrow flanker task.

Head modeling: NFT is used to generate 4-layer FEM head models. Freesurfer is used to generate cortical source spaces.

Independent Components

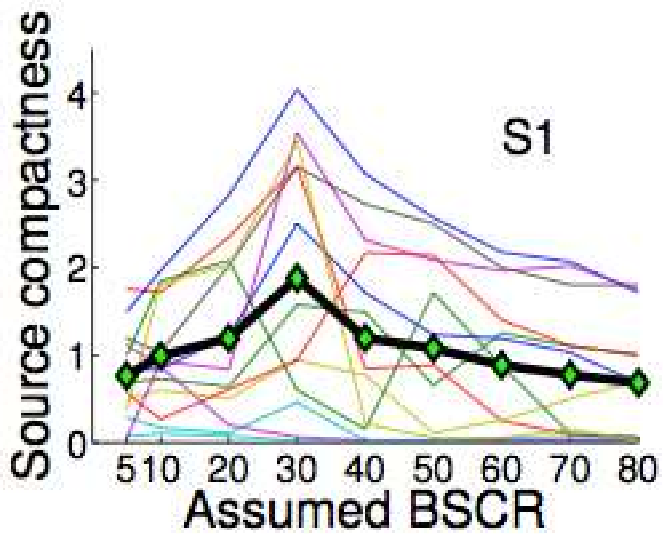


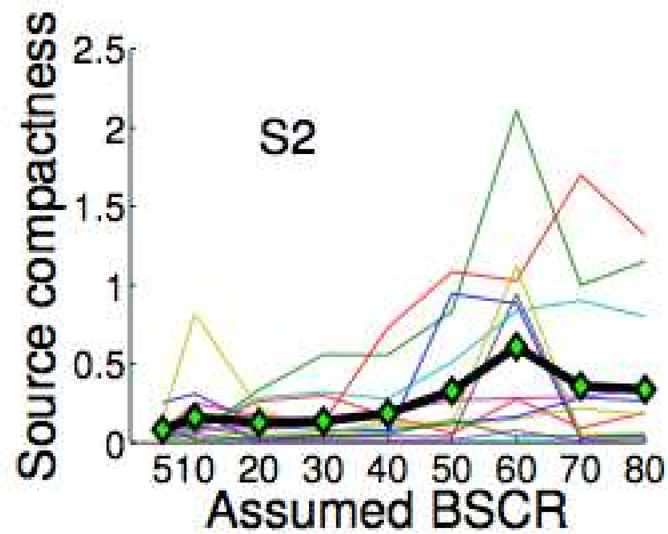
1-model Amica is applied, 13 near-dipolar Ics are selected.

EEG pre-processing: high-pass filter the continuous EEG data above 1 Hz, remove artifacts by initial likelihood-based rejection of time points (5%- 10% of data)

Source Compactness

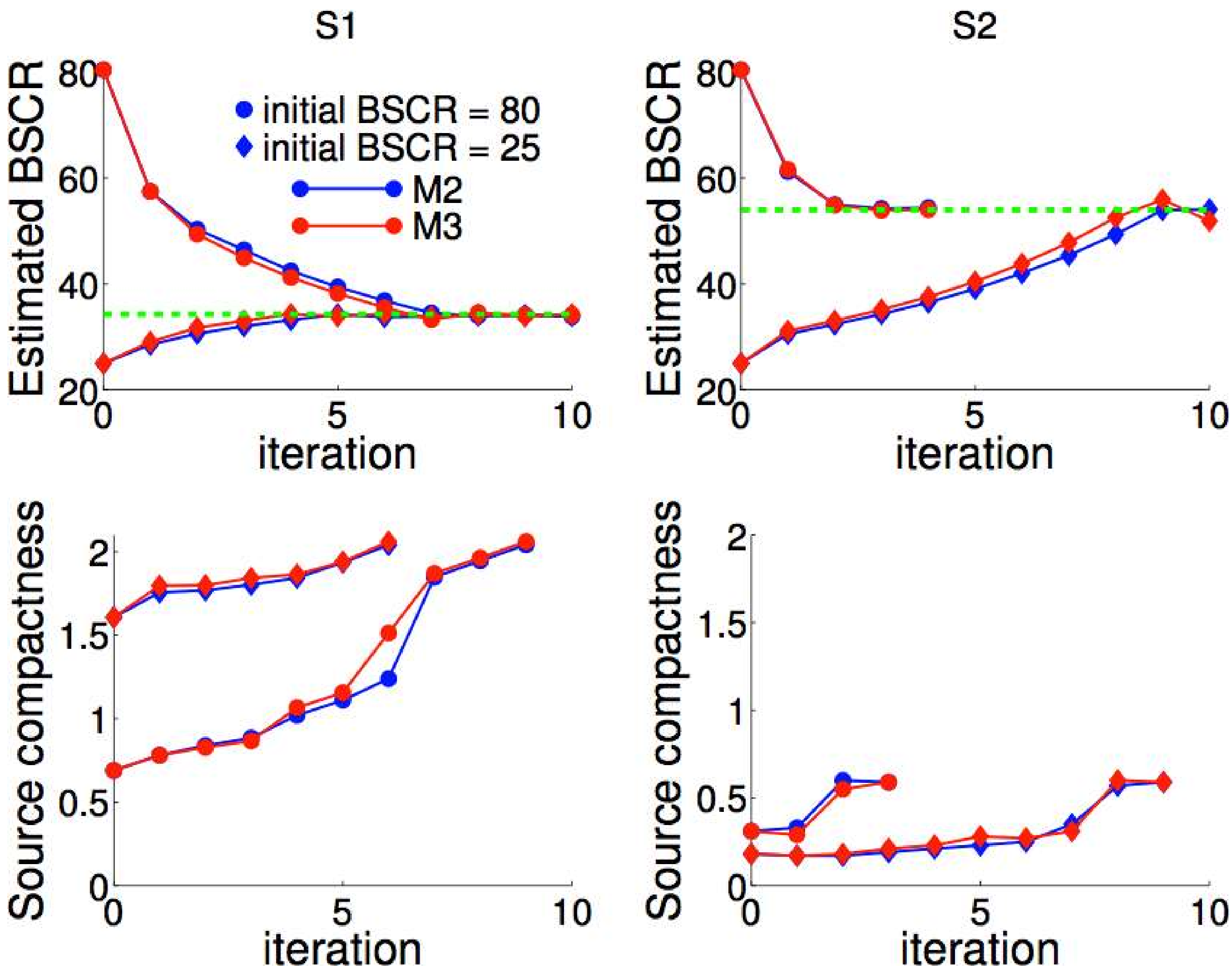
• Generate 9 electrical forward models with BSCR=5, 10, 20, 30, 40, 50, 60, 70, 80
• Estimate source distributions for the 13 ICs for each subject.
• Compute compactness.



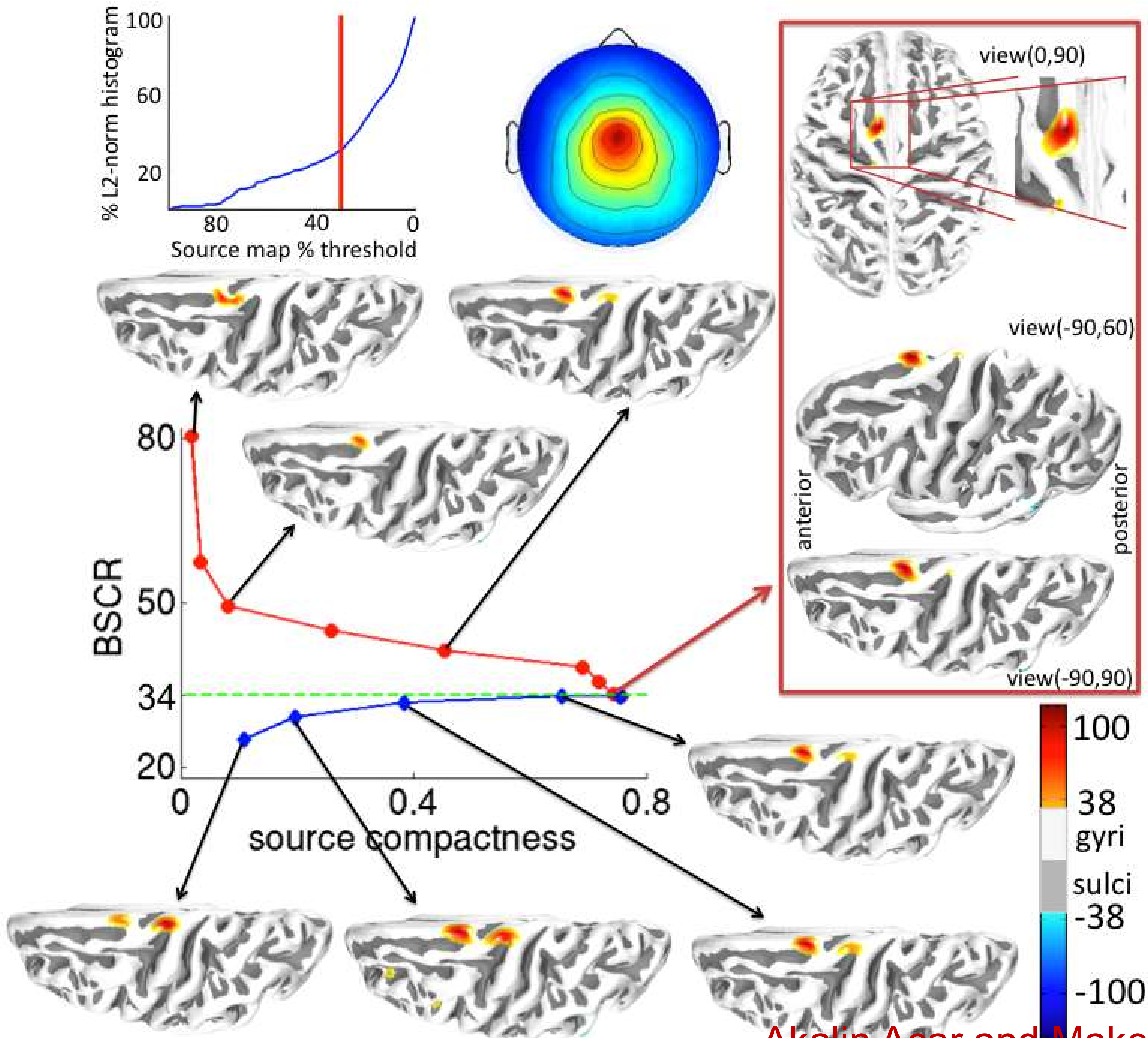


Maximum compactness occurred at BCSR = 30 for S1 and BSCR = 60 for S2.

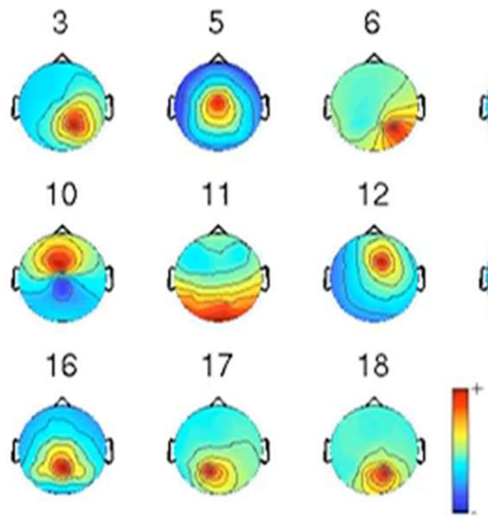
SCALE BSCR convergence

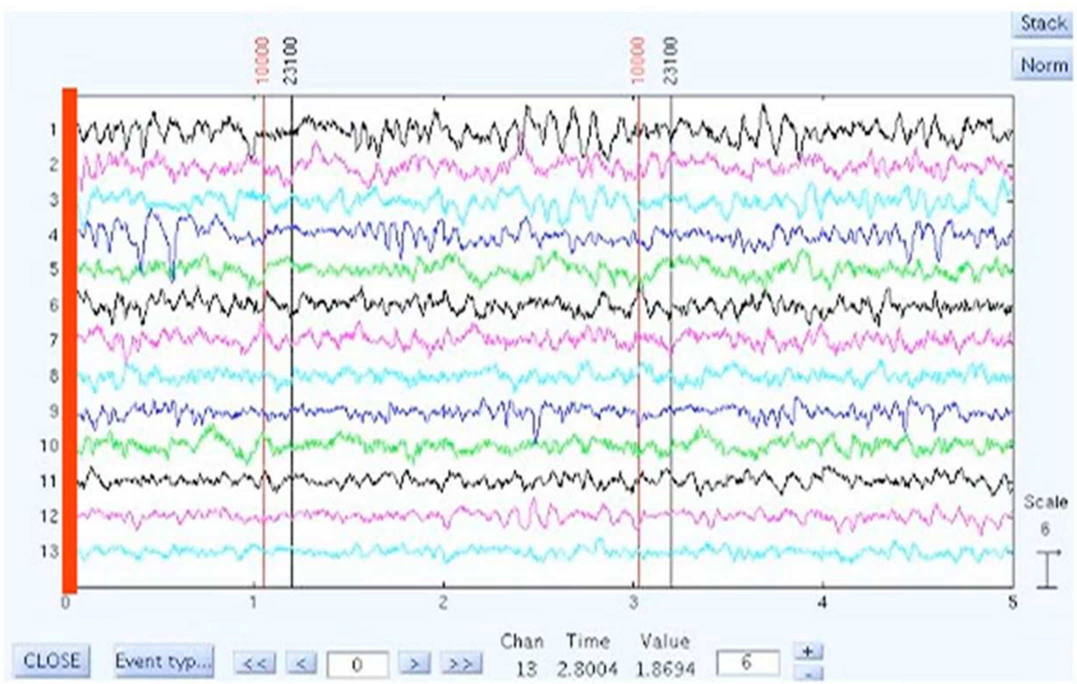


Akalin Acar and Makeig, 2016

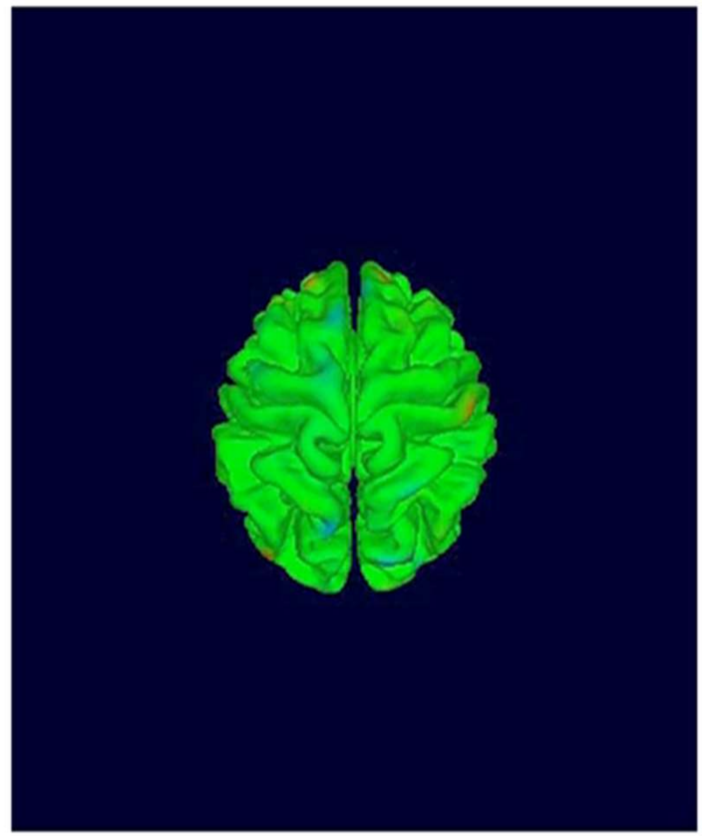


Akalin Acar and Makeig, 2016





13 component activity on the subject's cortical surface



NFT code

https://github.com/sccn/NFT

Demo folders:

NFTplugin_demo_dipole
NFTplugin_demo_cortical

https://rdl-share.ucsd.edu/message/U7F0uMivgbGZJur64TXDac

zeynep@sccn.ucsd.edu