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IBB Institute for Biomagnetism and Biosignalanalysis

Combined EEG/MEG source analysis for presurgical epilepsy diagnosis using calibrated realistic volume conductor model

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Philadelphia – Biomag
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Outline

- Introduction
- Combined EEG/MEG pipeline for presurgical epilepsy diagnosis
- Combined SEP/SEF versus single modality SEP or SEF
- Inter- subject skull conductivity variation
- Combined EEG/MEG source analysis and connectivity of an epilepsy case
- Summary

Introduction

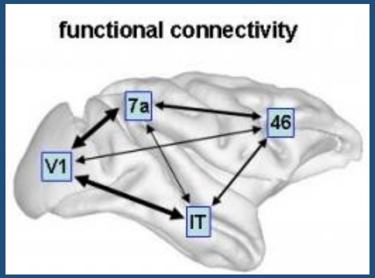
- Non-invasive combined EEG/MEG source analysis is a reliable tool for presurgical epilepsy diagnosis (previous talks)

- Realistically interpretation of not only source localization but also of source orientation of the underlying reconstructed source is also important (Salayev et al., 2006; Rullmann et al., 2009; Güllmar et al., 2010; Aydin et al., 2014).

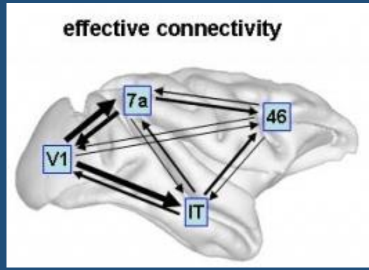
- Inter- subject skull conductivity variabilities might linear descend over the age (Hoekema et al., 2003).

- EEG/MEG have been widely used for connectivity analysis to identify networks of neuronal activities (Schoffelen and Gross, 2009; Castellanos et al., 2011; Palva and Palva, 2012; Dai et al., 2012; van Dellen et al., 2014; Nissen et al., 2016).

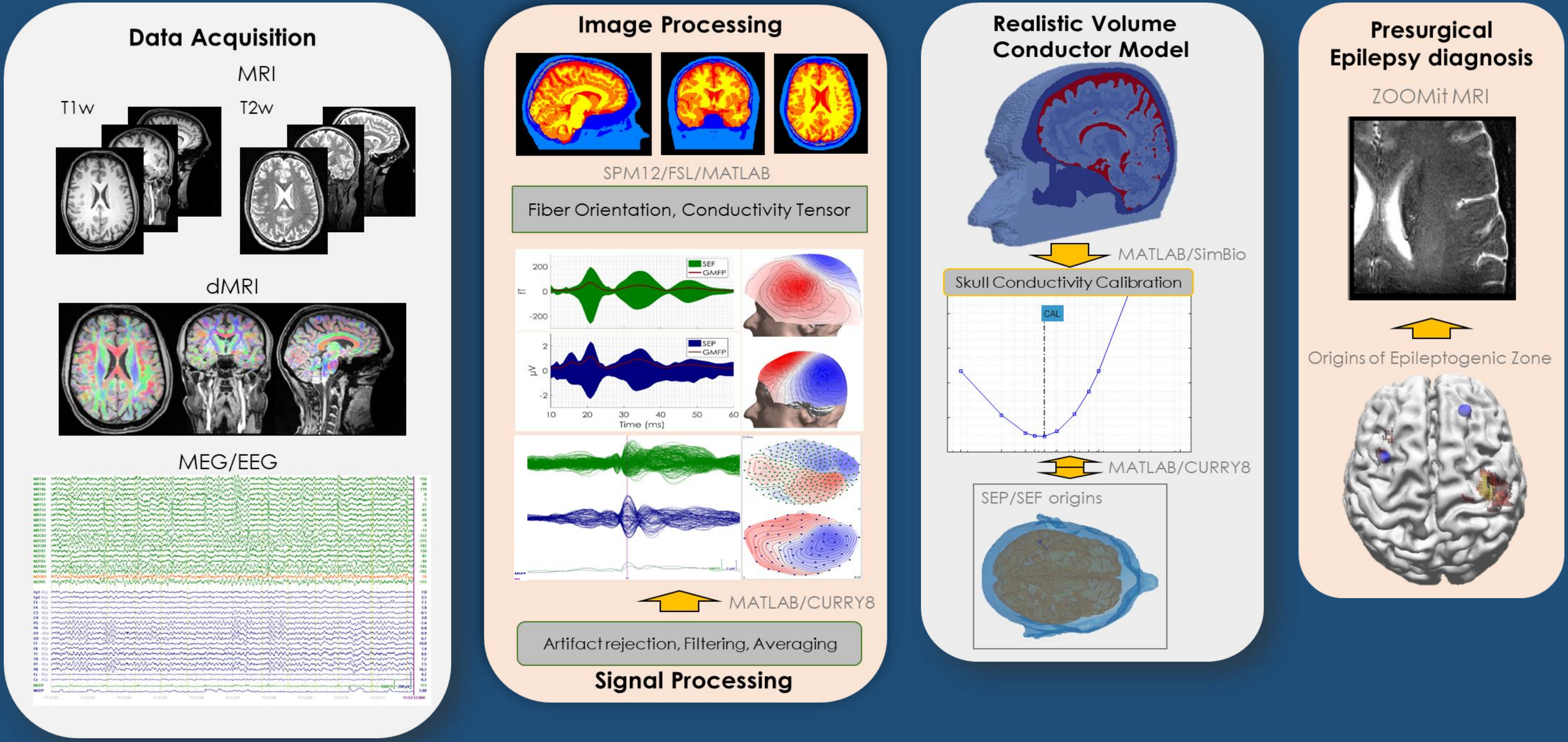
- The term '**connectivity**' can refer to different phenomena depending on context and purpose (Friston, 1994; Horwitz, 2003).



Sporns 2007, Scholarpedia

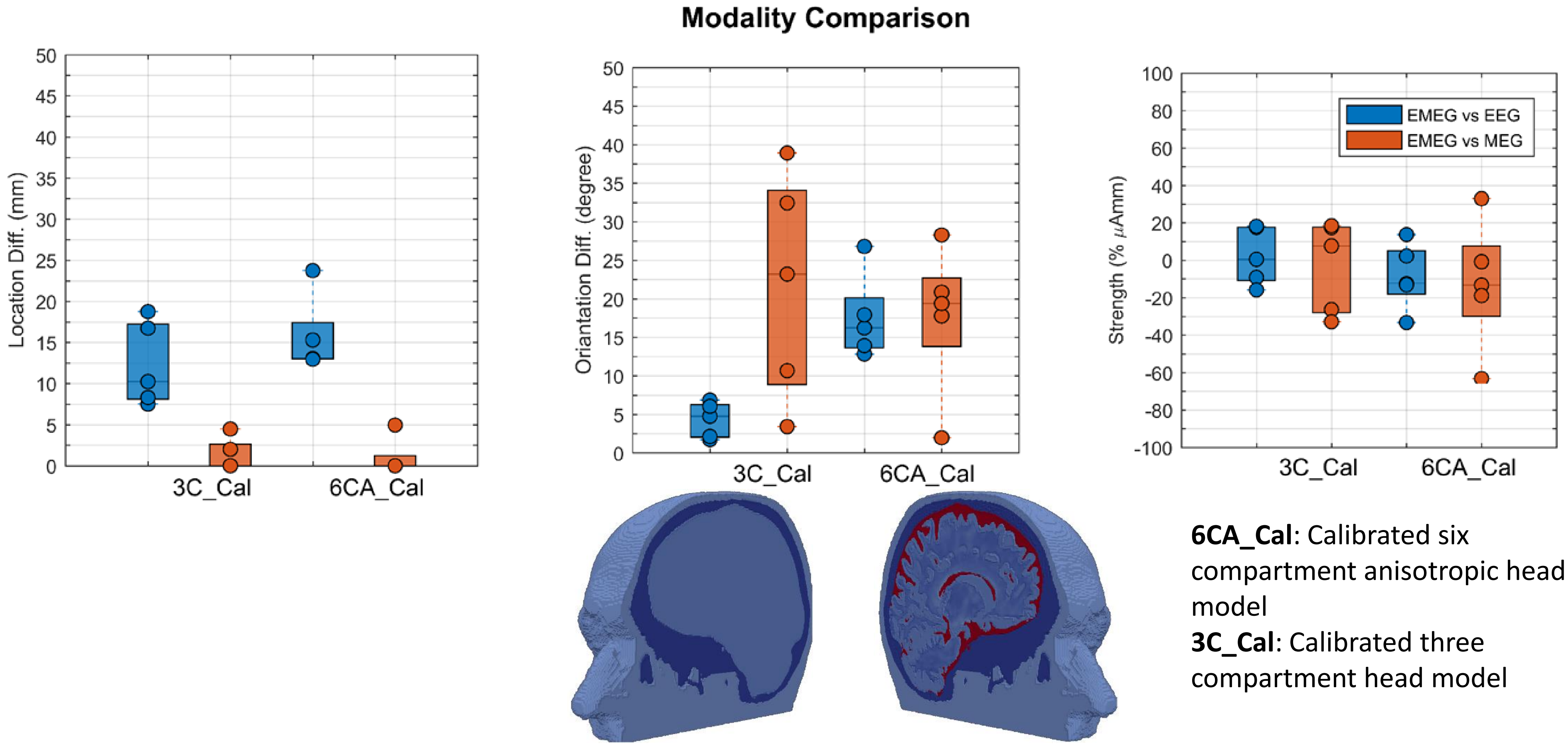


EMEG pipeline for presurgical epilepsy diagnosis



Combined SEP/SEF versus single modality SEP or SEF

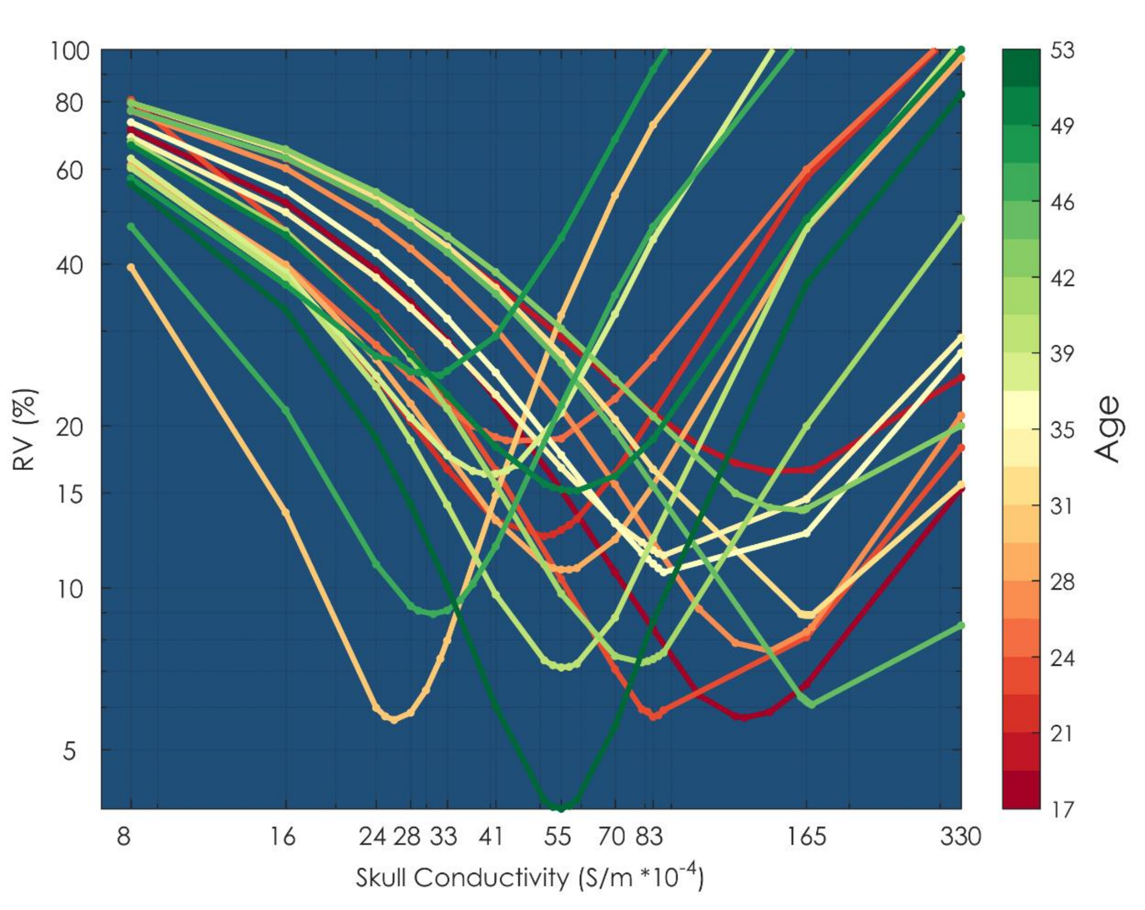
- Source reconstruction of the human somatosensory P20 component for **combined** EEG/MEG (EMEG) vs **single** modality EEG or MEG



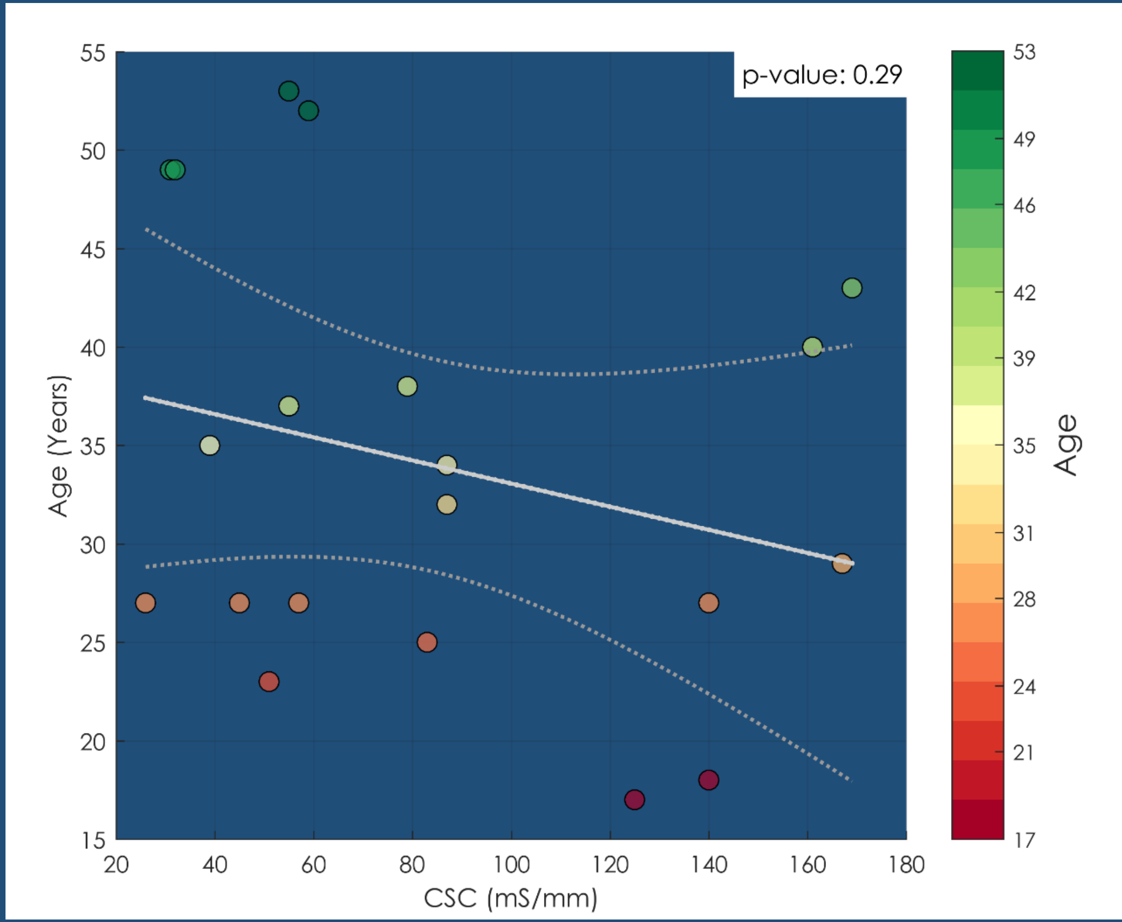
6CA_Cal: Calibrated six compartment anisotropic head model
3C_Cal: Calibrated three compartment head model

Antonakakis et al., BACI, 29.08 – 02.09.2017
Antonakakis et al., in preparation

Inter- subject skull conductivity variation



Calibration skull conductivity curves of 6CA model for **twenty** subjects (10 female) colored by subject's age.



Robust linear Regression model between age and calibrated skull conductivity (**CSC**).

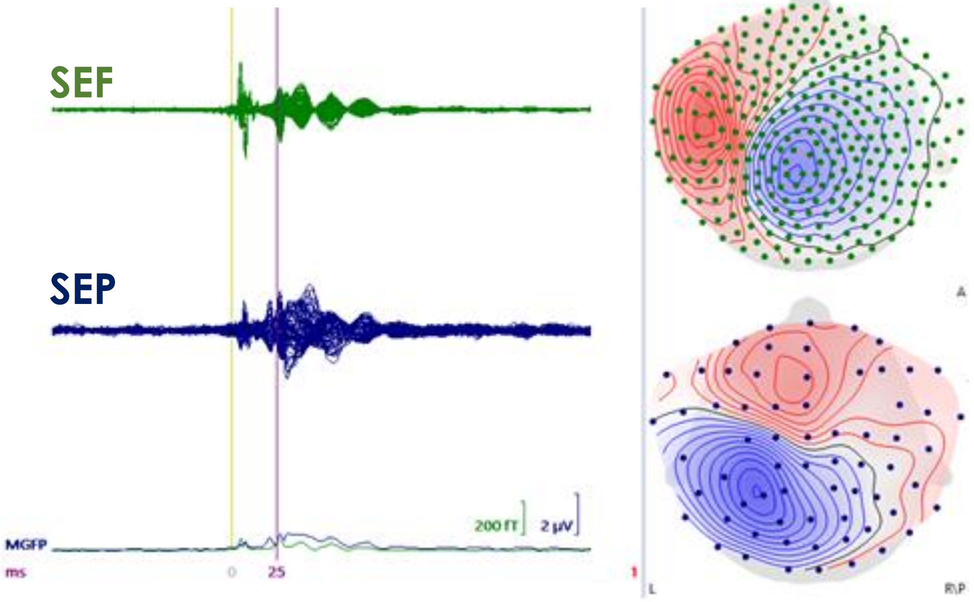
Antonakakis et al., 50years of MEG, 19 – 22.04.2018, best poster award (3rd)
Antonakakis et al., in preparation

Combined EEG/MEG source analysis of an epilepsy patient

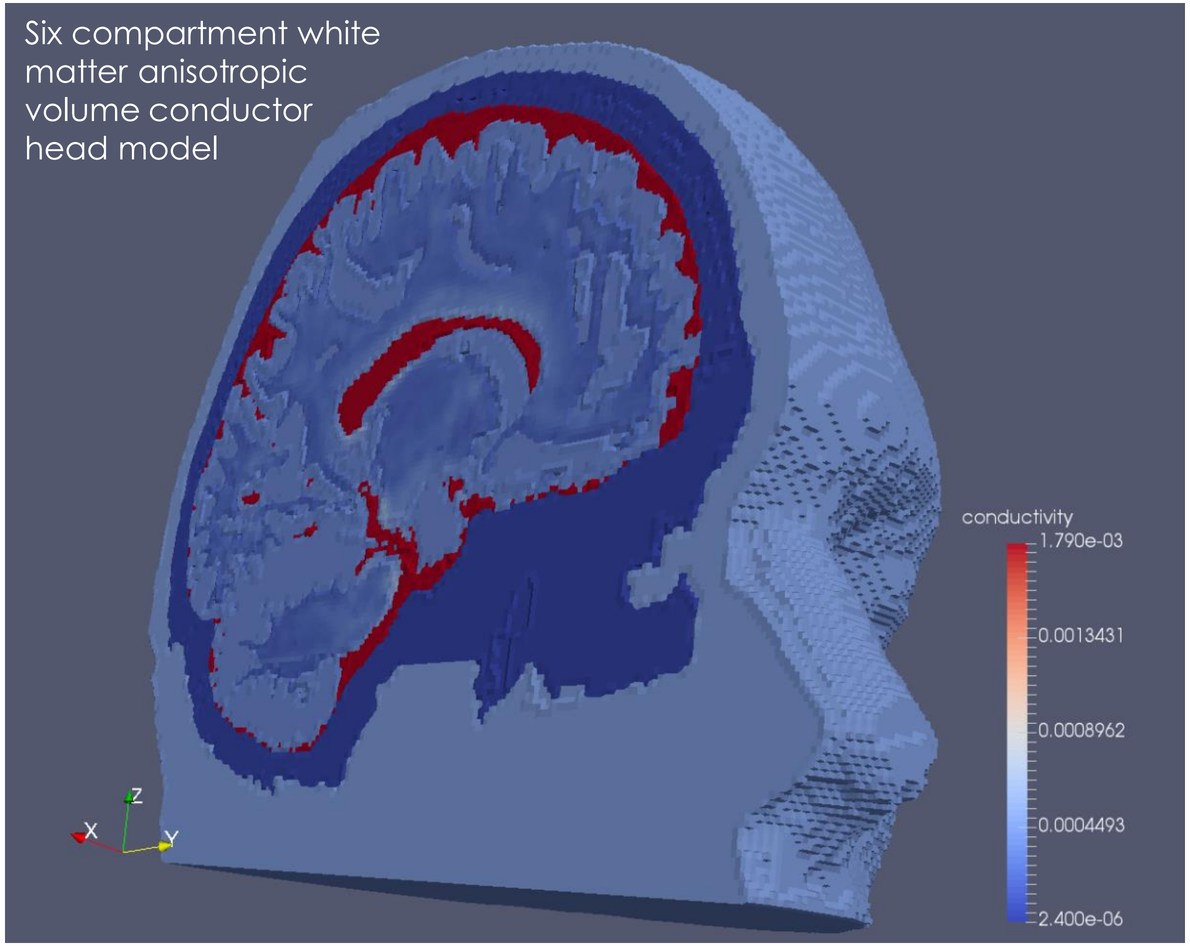
Patient

- Clinical history
  - ❑ 27 years old
  - ❑ Symptomatology: Tingling feeling and tonic movements in the left hand followed by tonic movements to the mouth (20 times per month)
  - ❑ Non-invasive electrophysiological recordings
    - o SEP/SEF data for calibration purposes
    - o Simultaneous EEG/MEG of epileptic activity
    - o Detection of 328 epileptic spikes by board-certified epileptologist

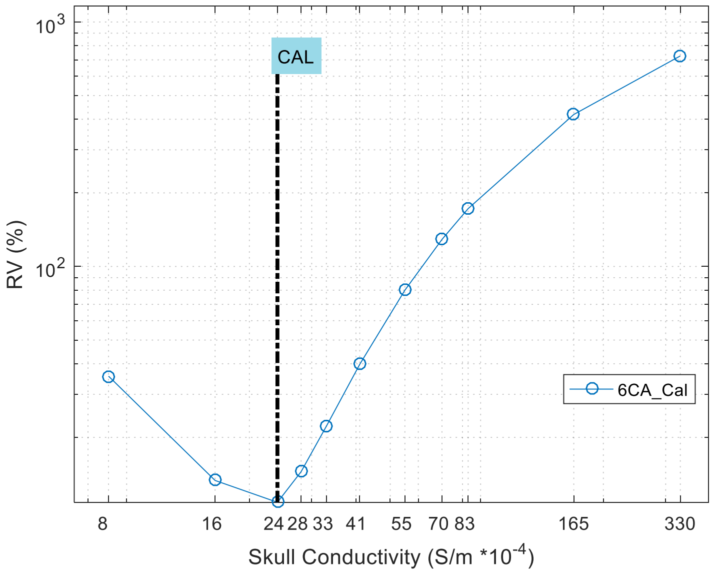
SEP/SEF data



Six compartment white matter anisotropic volume conductor head model

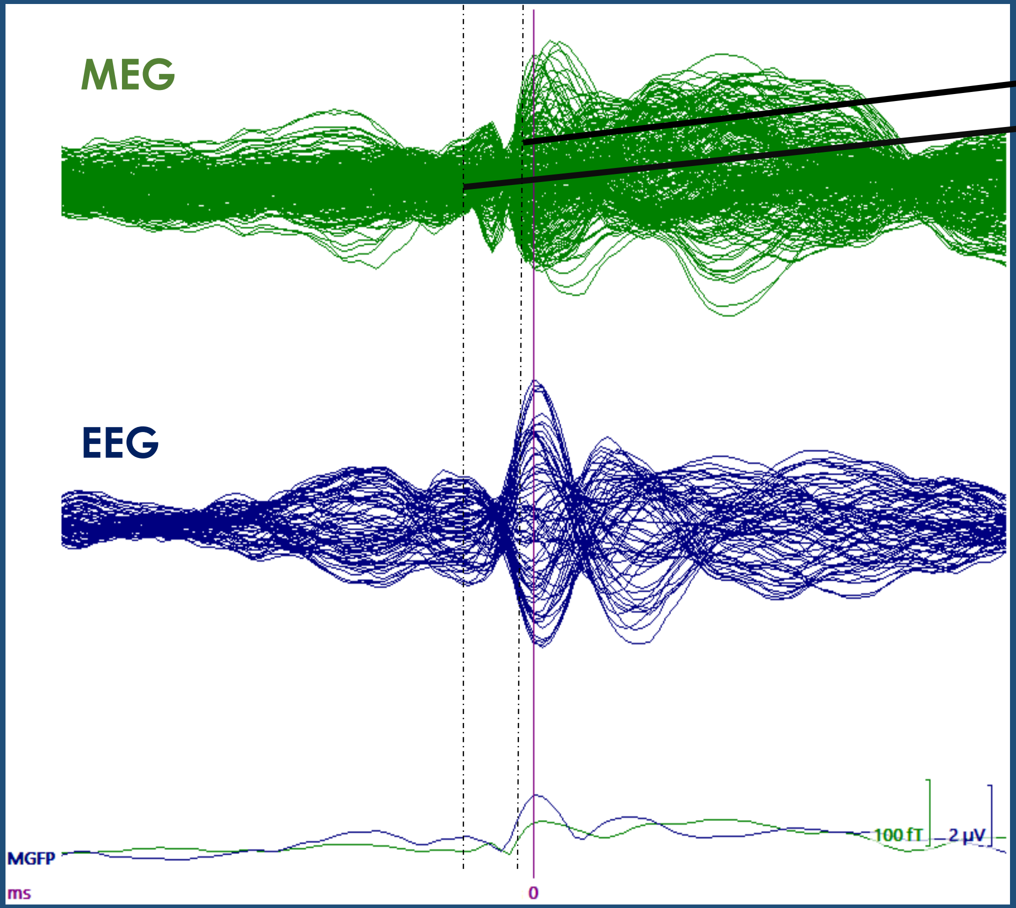


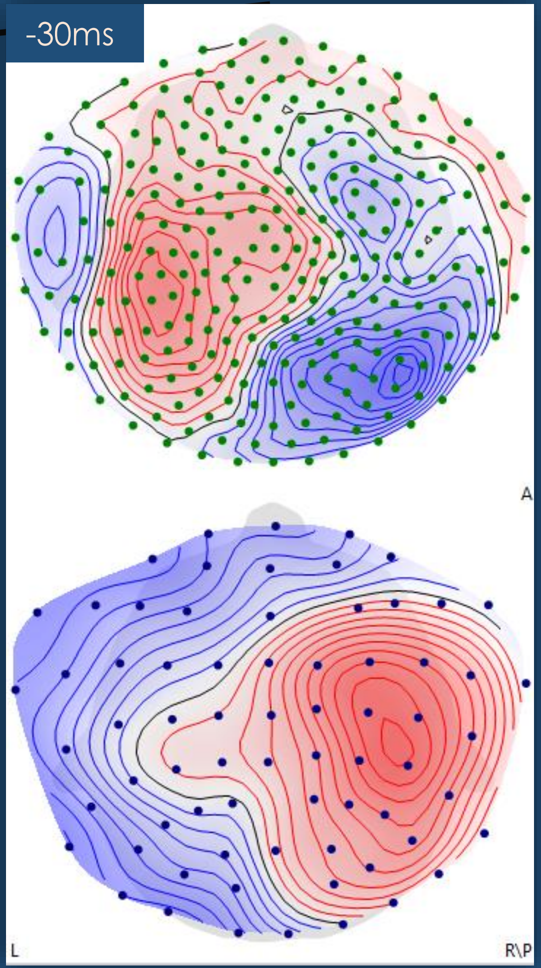
Calibrated skull conductivity at 0.0024 S/m

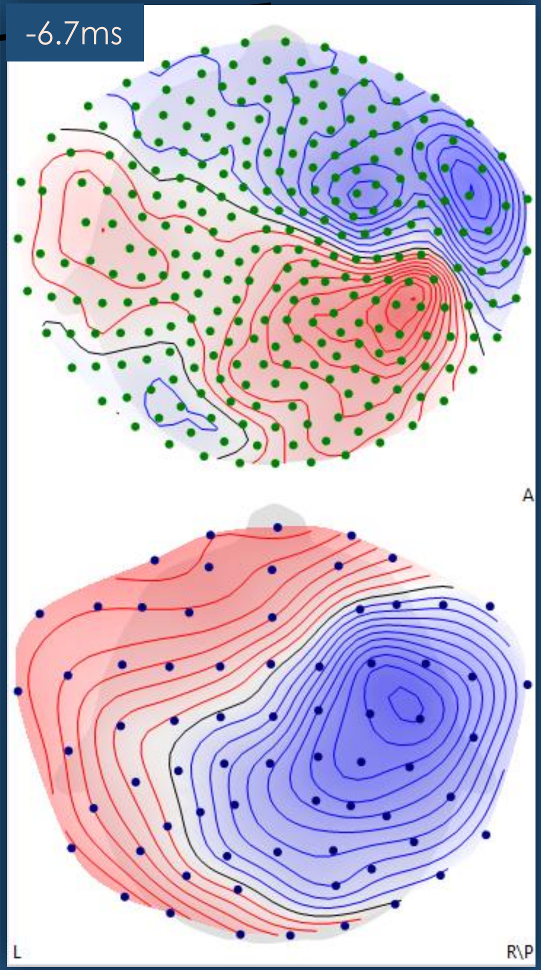


Averaged inter-ictal discharges

- Average of 328 artefact free spikes

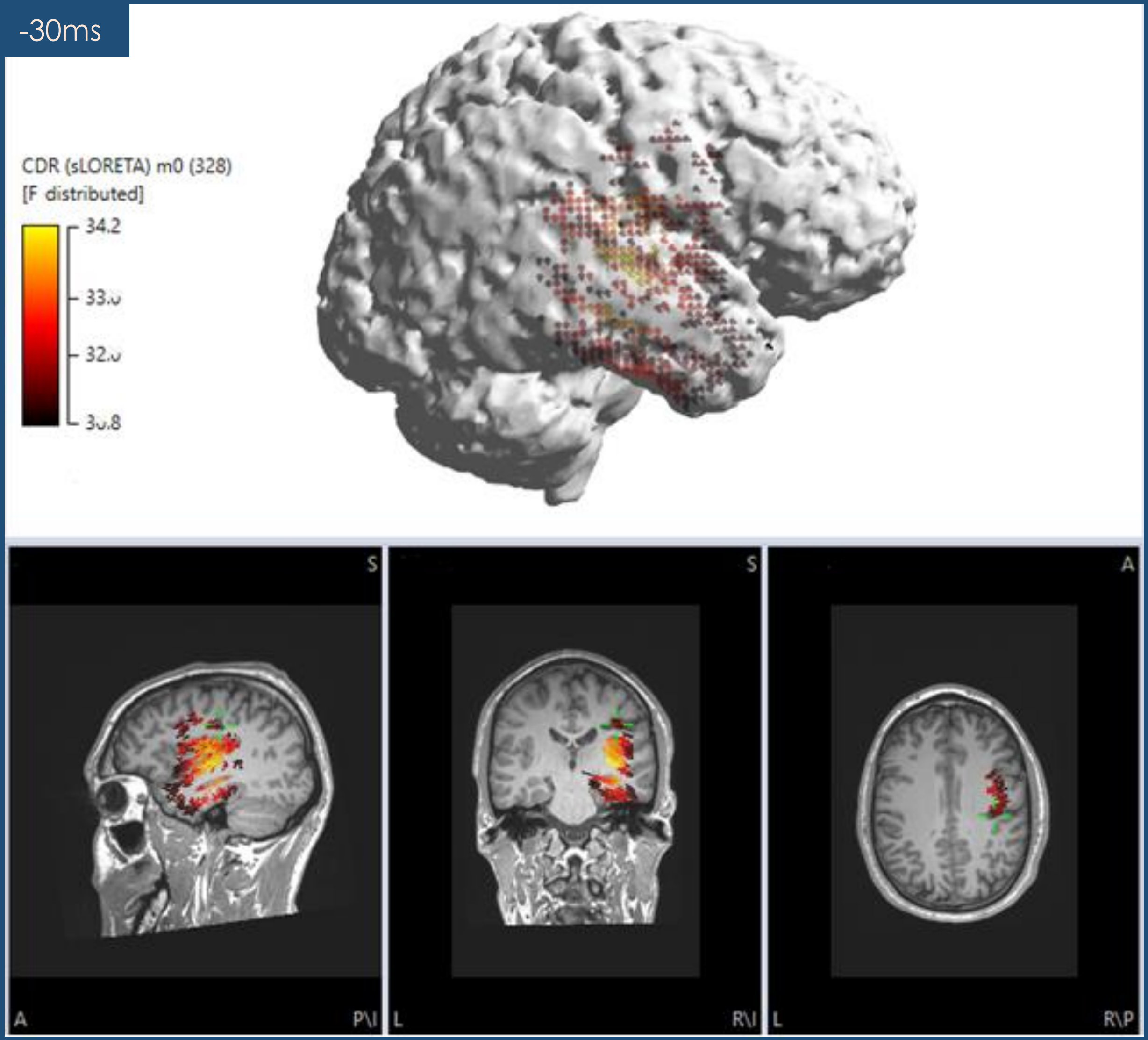


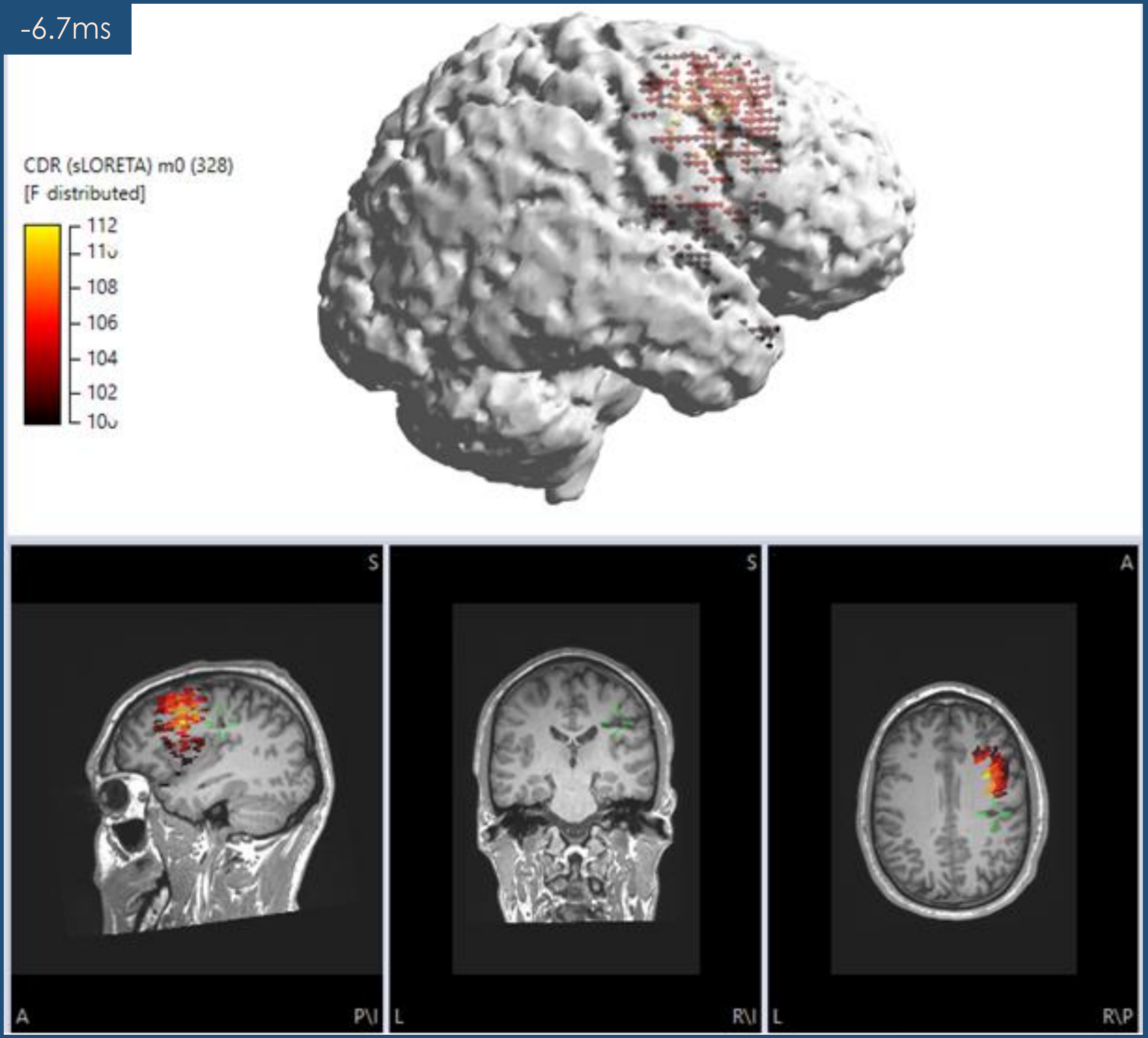




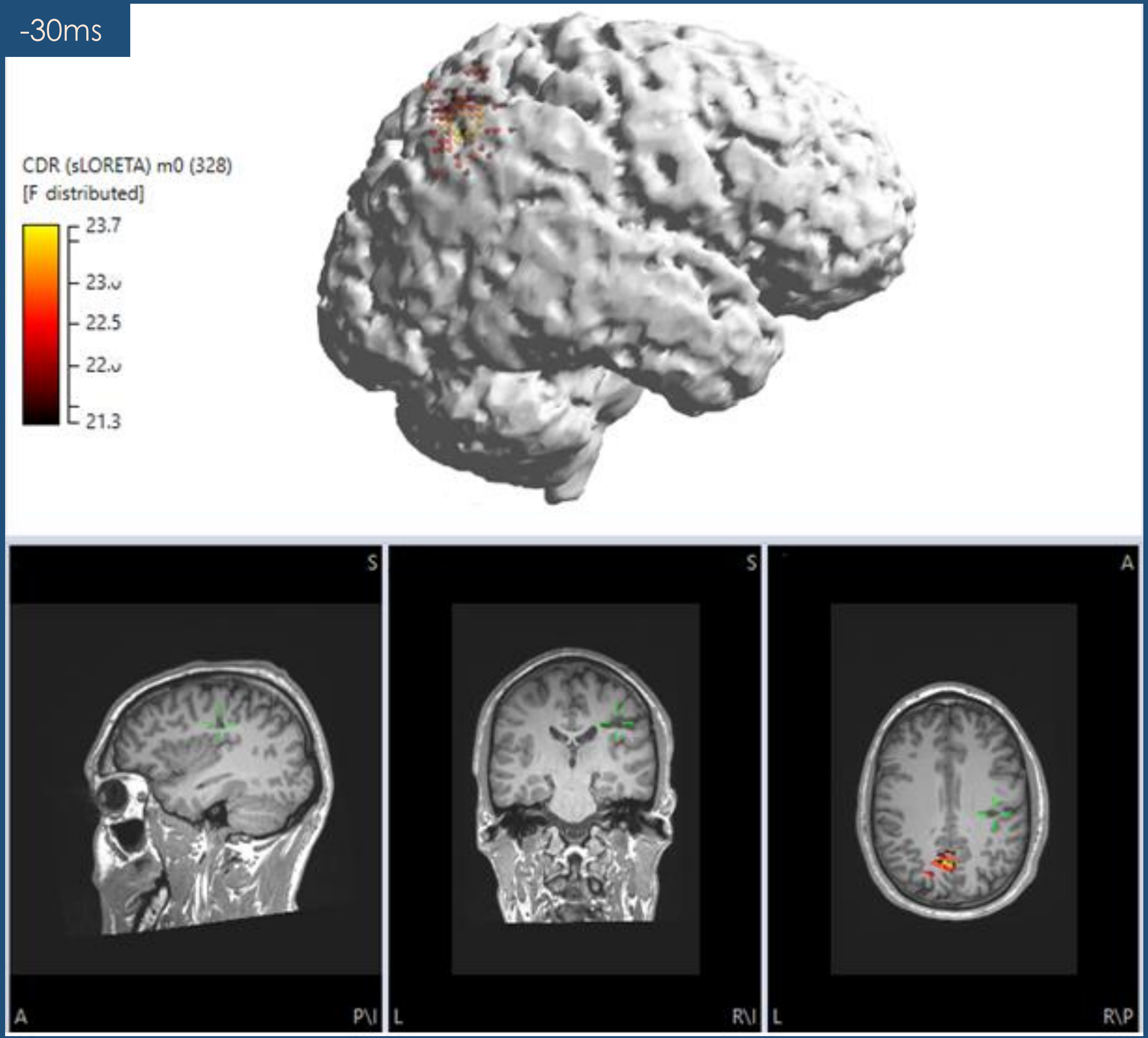
- Low SNR scenario (Aydin et al., 2017)
- Rising flank of the peak (Lantz et al., 2003)

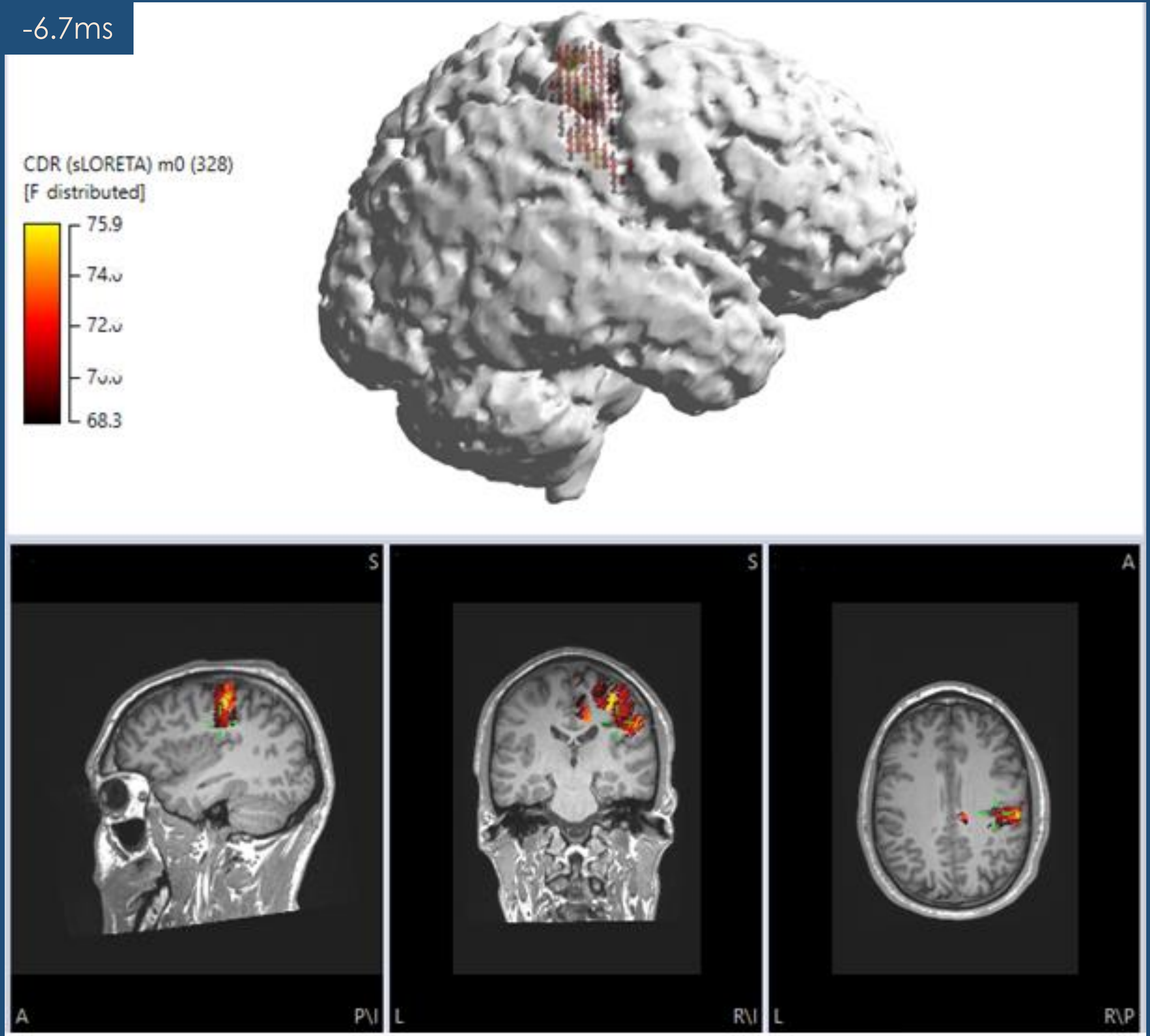
Source analysis result (EEG)



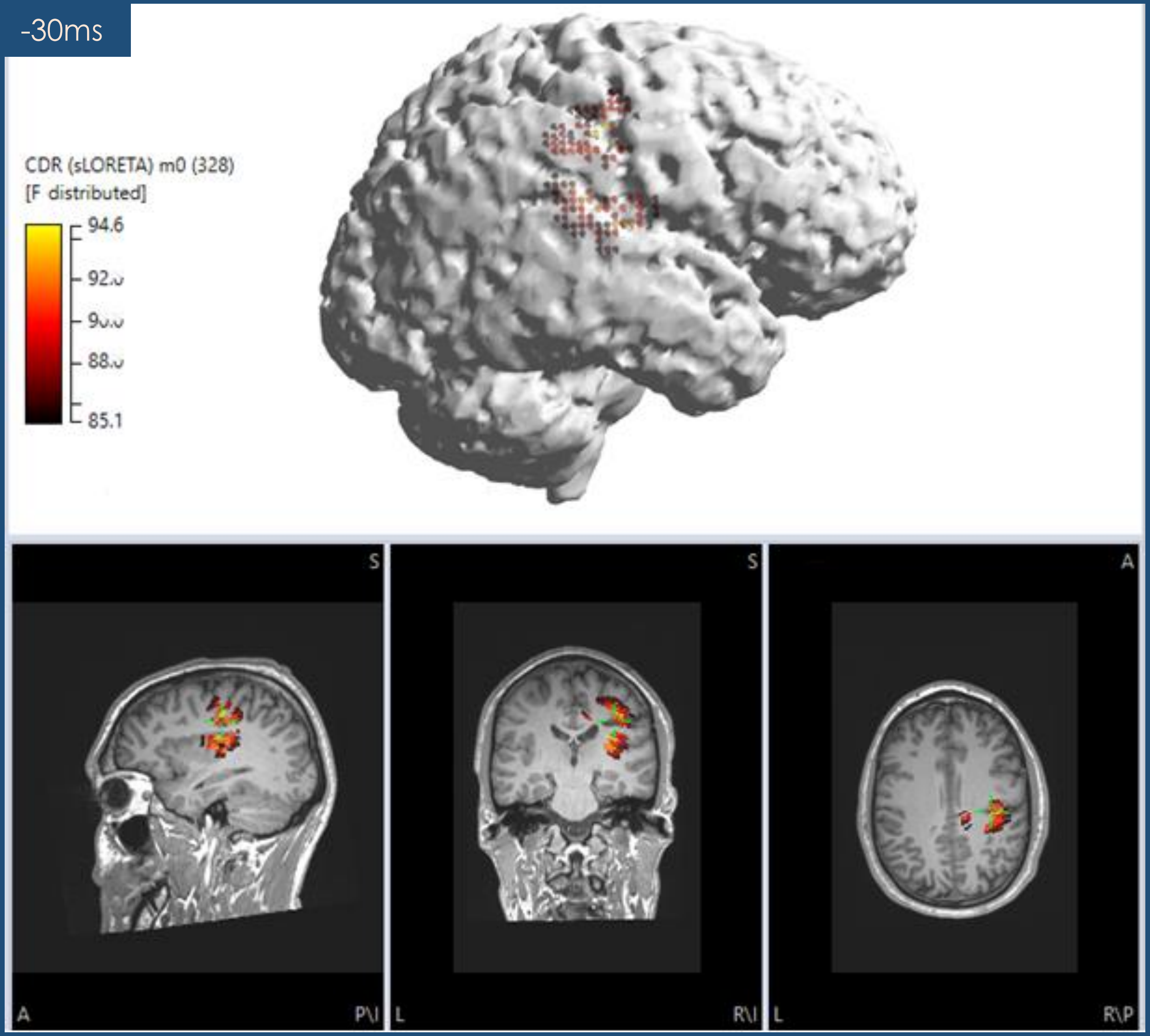


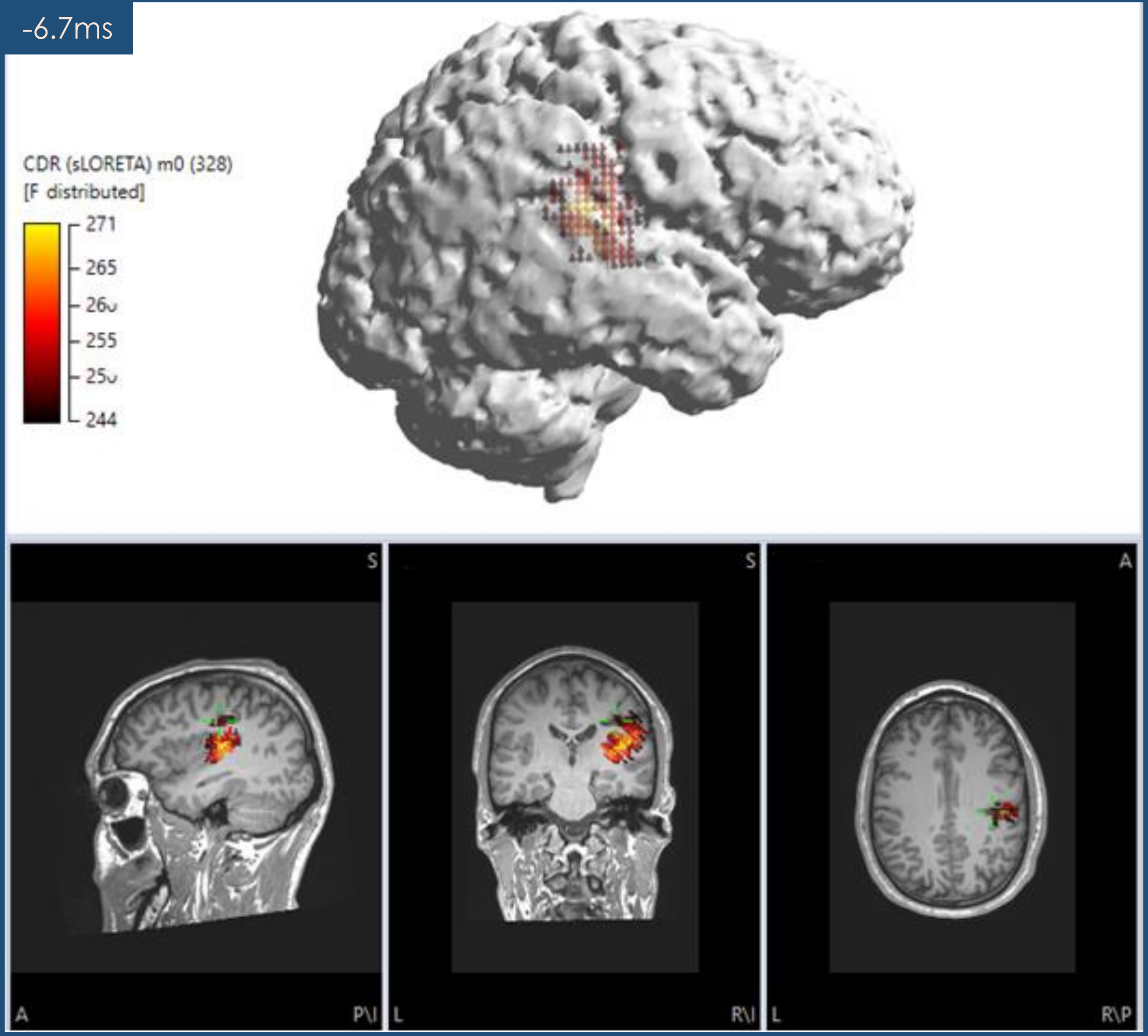
Source analysis result (MEG)





Source analysis result (EMEG)



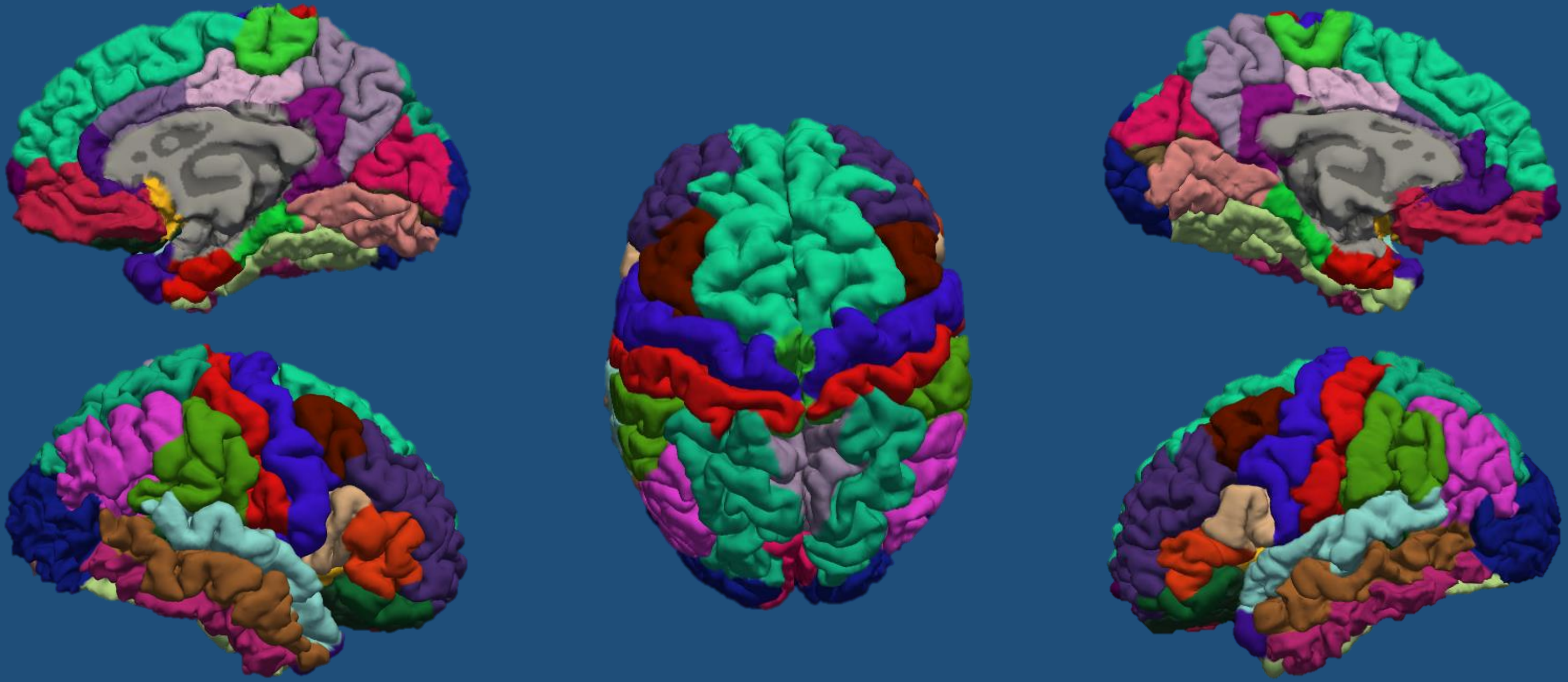


Connectivity in source space using EMEG

Connectivity in source space using EMEG

- Combined EEG/MEG sLORETA for every time point of the averaged spikes
  - sLORETA *shows good localization properties for* ***single*** *dipoles but it deficits to yield good reconstructions in the presence of more focal sources (Lucka et al., 2012)*.
- Determination of basic anatomical areas and their corresponding source signals based on the freesurfer segmented model and the registration upon the Desikan-Killiany (DTK) atlas

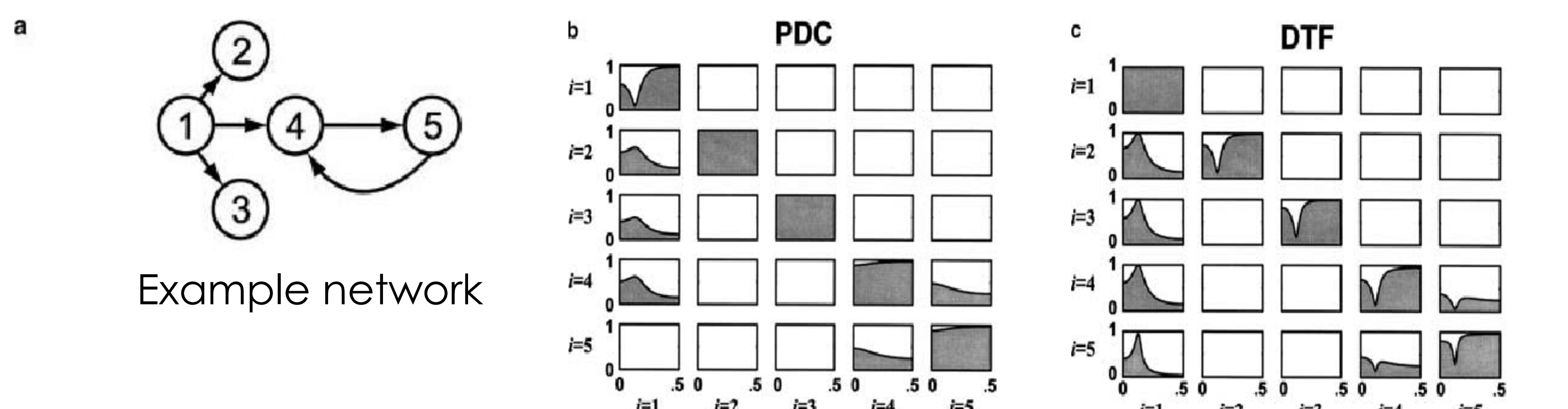
The anatomical Desikan-Killiany (DTK) atlas



101 labeled brain images and a consistent human cortical labeling protocol
Arno Klein, Jason Tourville. Frontiers in Brain Imaging Methods. 2012. 6:171.
(https://surfer.nmr.mgh.harvard.edu/fswiki/CorticalParcellation)

Connectivity in source space using EMEG

- Combined EEG/MEG sLORETA for every time point of the averaged spikes
- Determination of basic anatomical areas and their corresponding source signals based on the freesurfer segmented model and the registration upon the Desikan-Killiany (DTK) atlas
- Perform effective connectivity by means of **generalized** Partial Directed Coherence – gPDC (Baccalá and de Medicina, 2007; Omidvarnia et al., 2013) that reflects the influenced effects (PDC) and shows the influencing effects (DTF)



Baccalá and Sameshima, 2001

Connectivity in source space using EMEG

- Combined EEG/MEG sLORETA for every time point of the averaged spikes
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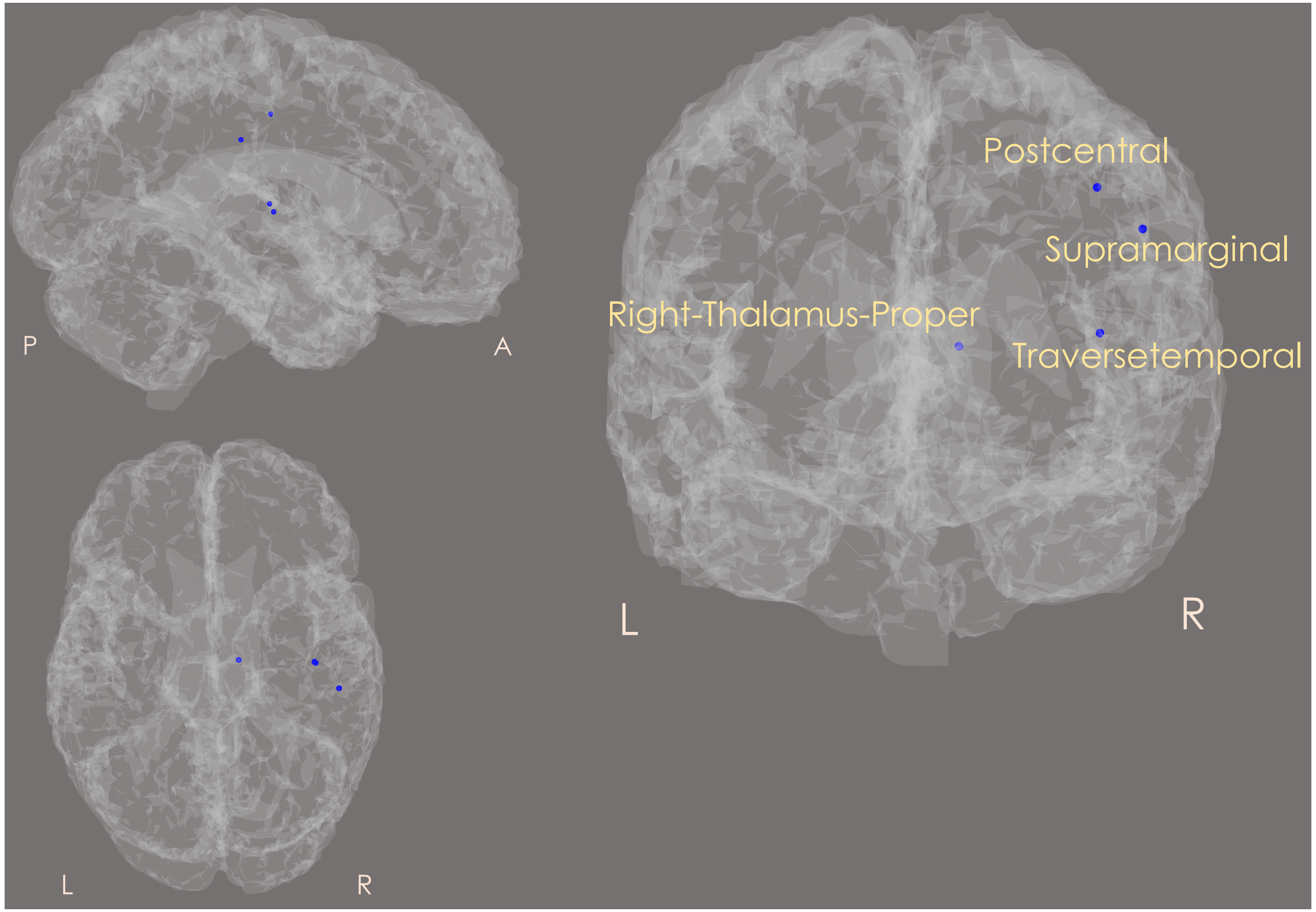
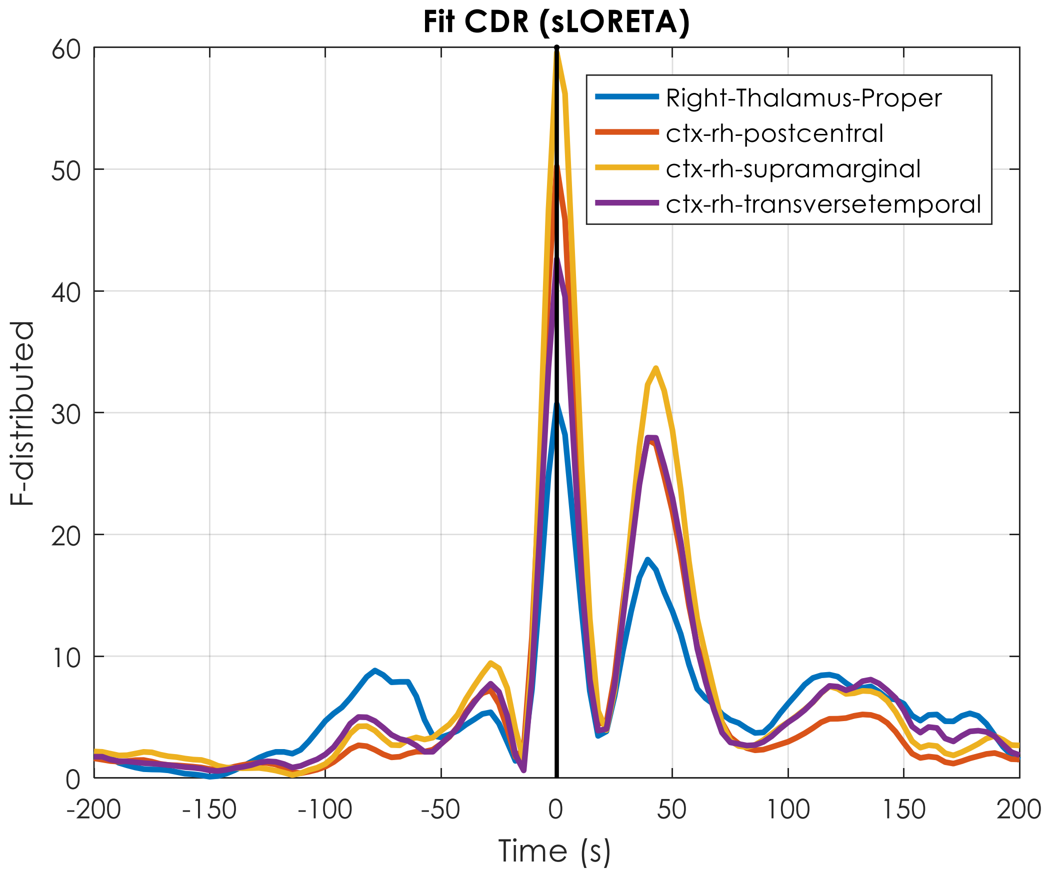
- Perform effective connectivity by means of **generalized** Partial Directed Coherence – gPDC (Baccalá and de Medicina, 2007; Omidvarnia et al., 2013) that shows the influencing effects (DTF) and reflects the influenced effects (PDC)
- Selection of the most dominant anatomical areas

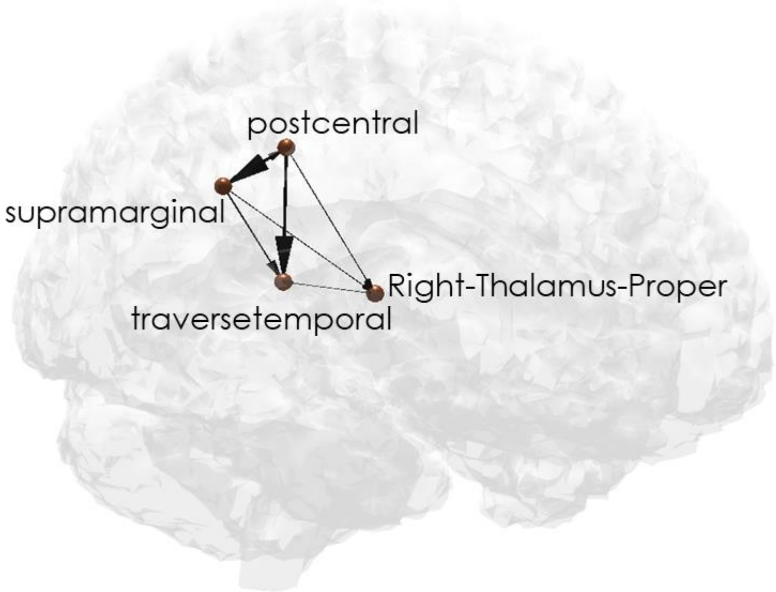
Selected anatomical areas

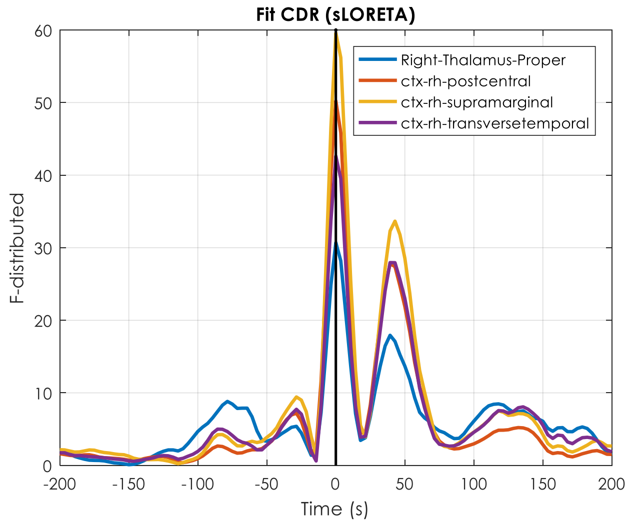
- $mean(s_i) > mean(\boldsymbol{S}) + std(S)\ for\ i = 1, \ldots, 101\ a.a.$
  where $\boldsymbol{S}$ is the reconstructed source time series array of (101 a.a. x 120 timepoints) and s_i row vector of $\boldsymbol{S}$

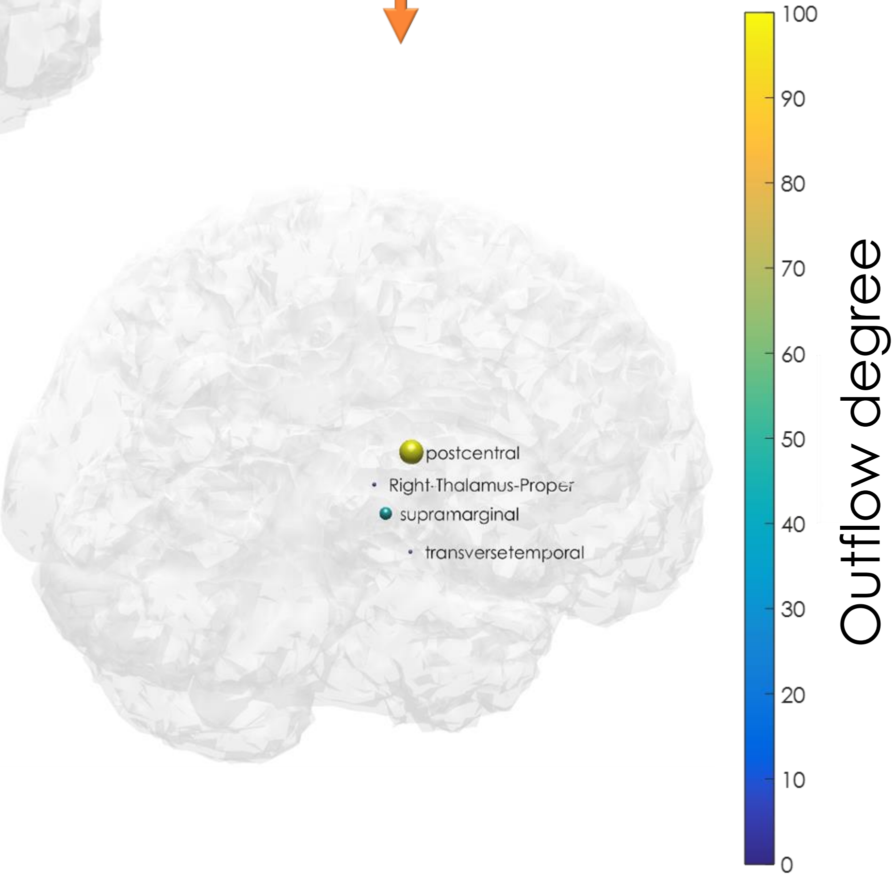


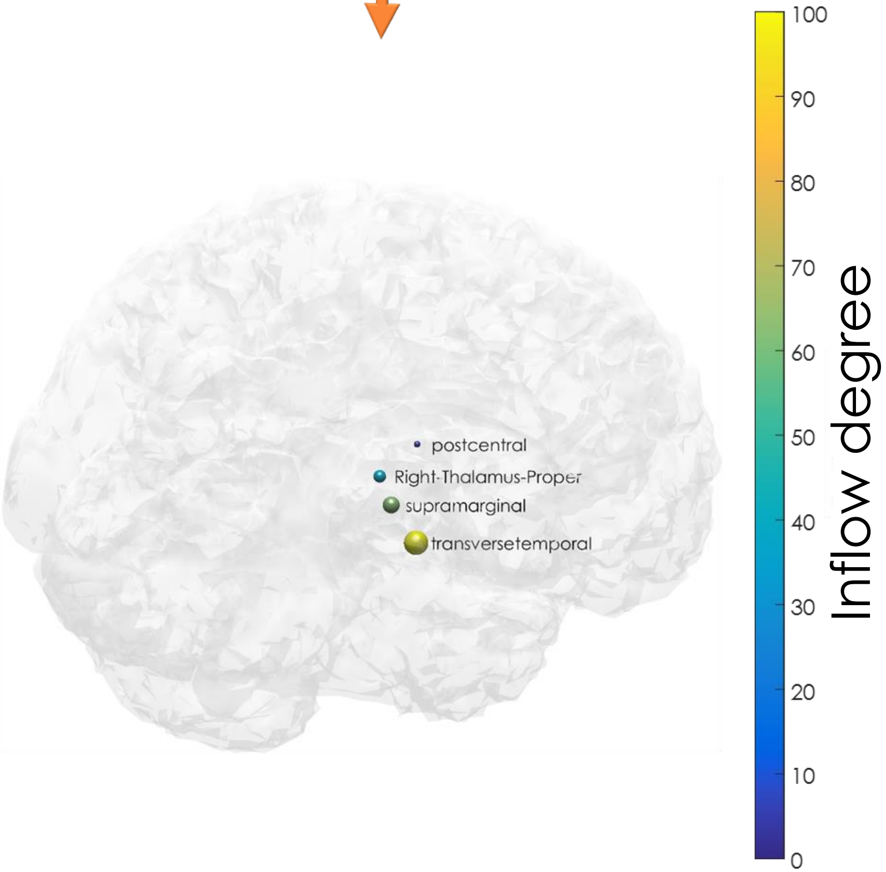


Time-Invariant gPDC: network state





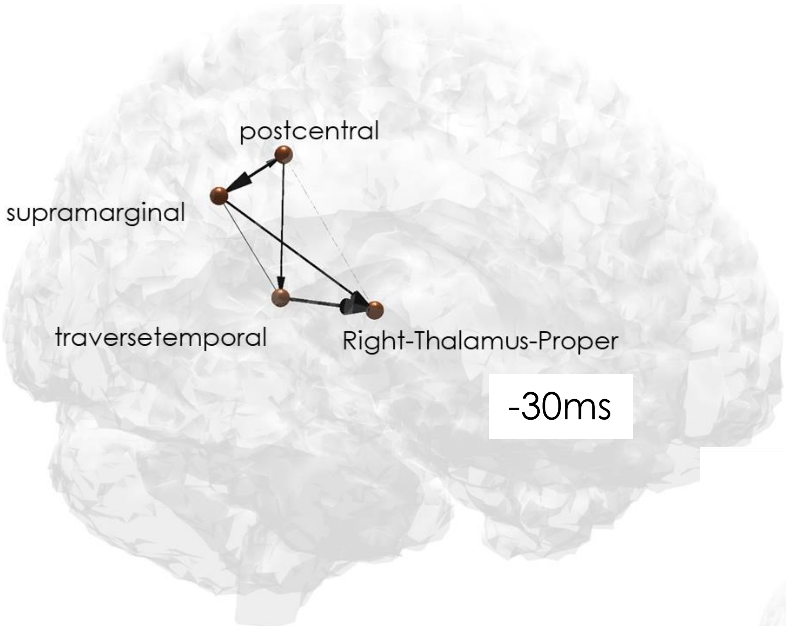


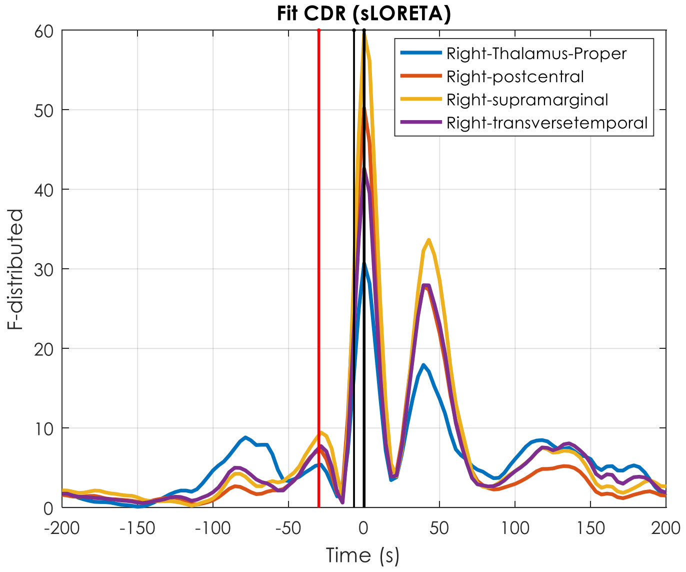


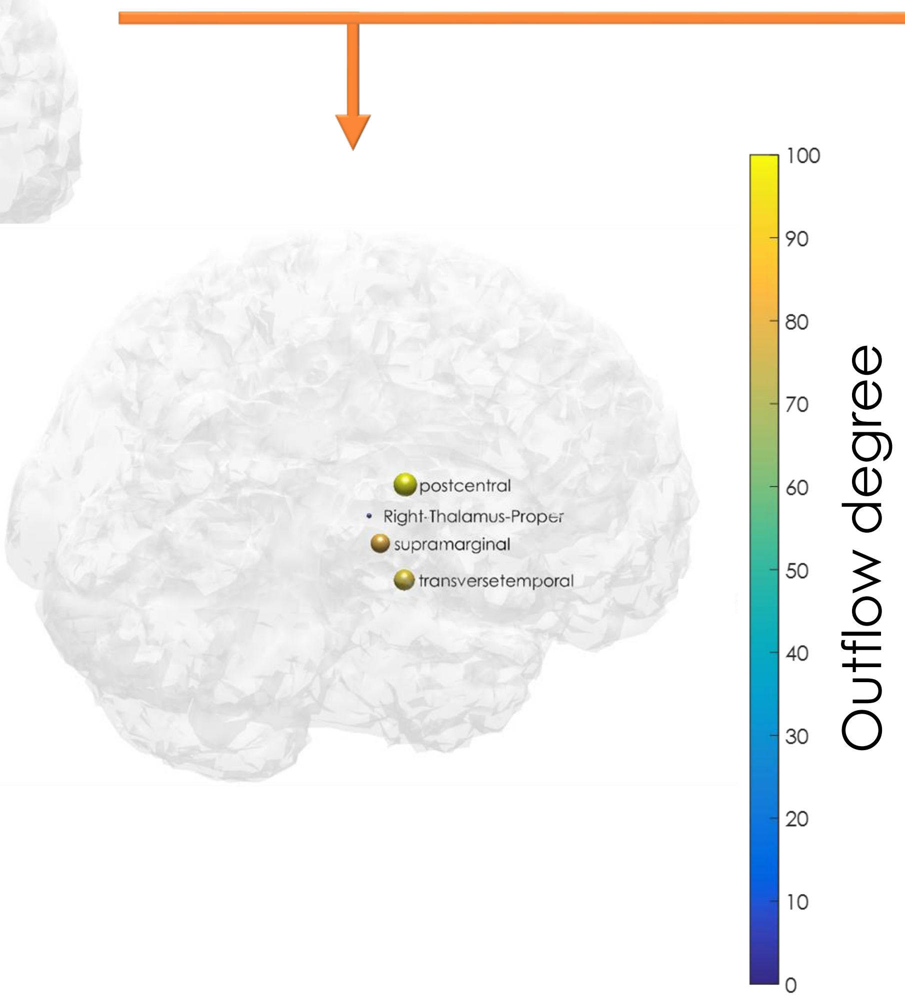
Connectivity in source space using EMEG

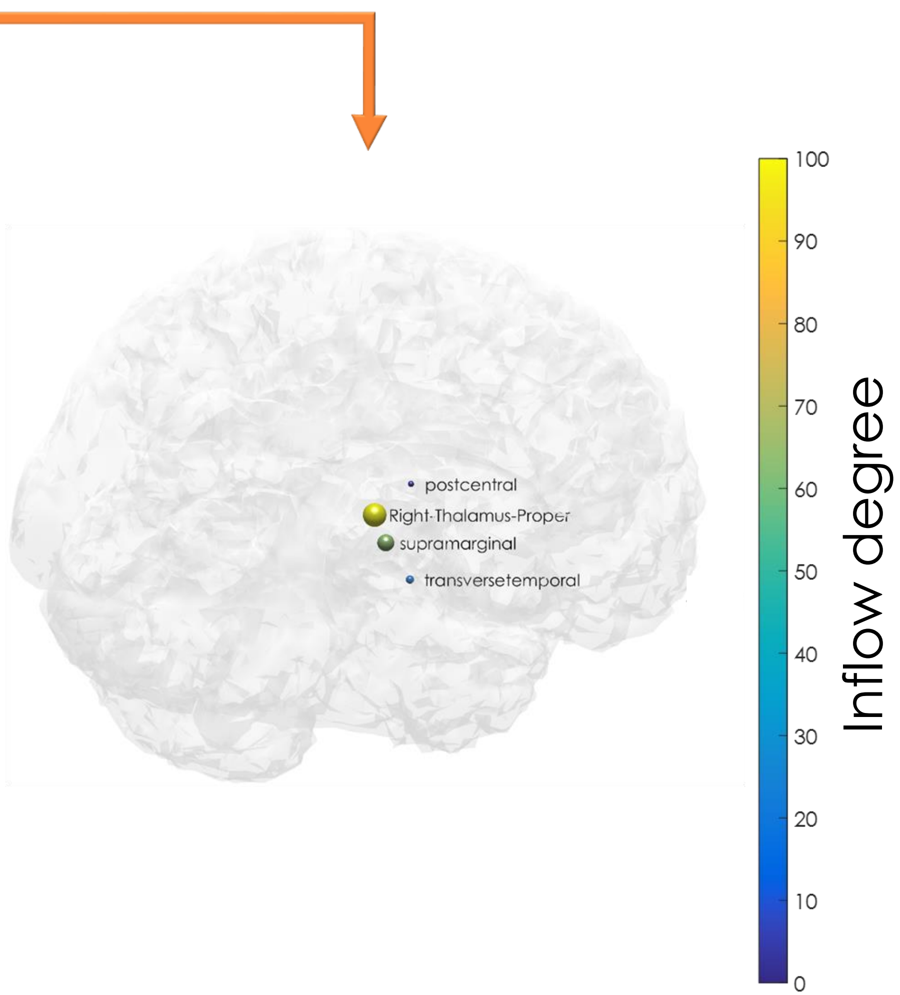
- Combined EEG/MEG sLORETA for every time point of the averaged spikes
- Determination of basic anatomical areas and their corresponding source signals based on the freesurfer segmented model and the registration upon the Desikan-Killiany (DTK) atlas
- Perform effective connectivity by means of **generalized** Partial Directed Coherence – gPDC (Baccalá and de Medicina, 2007; Omidvarnia et al., 2013) that shows the influencing effects (DTF) and reflects the influenced effects (PDC)
- Selection of the most dominant anatomical areas
- Dual extended Kalman filter (DEKF)-based time-varying gPDC connectivity analysis

Time-Varying gPDC: network state at -30ms

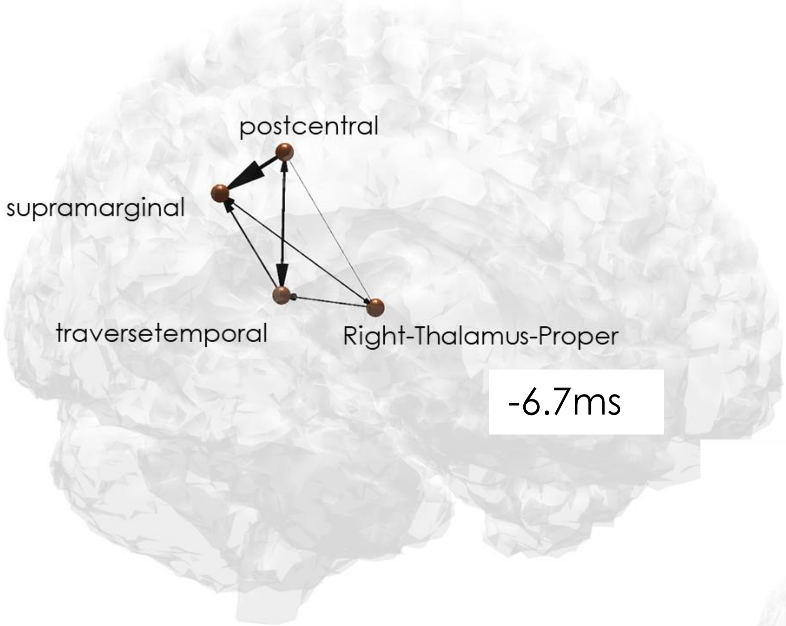


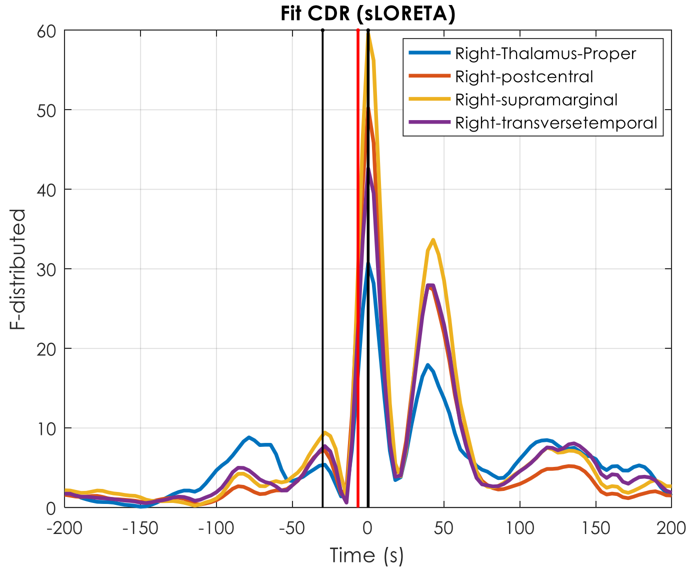


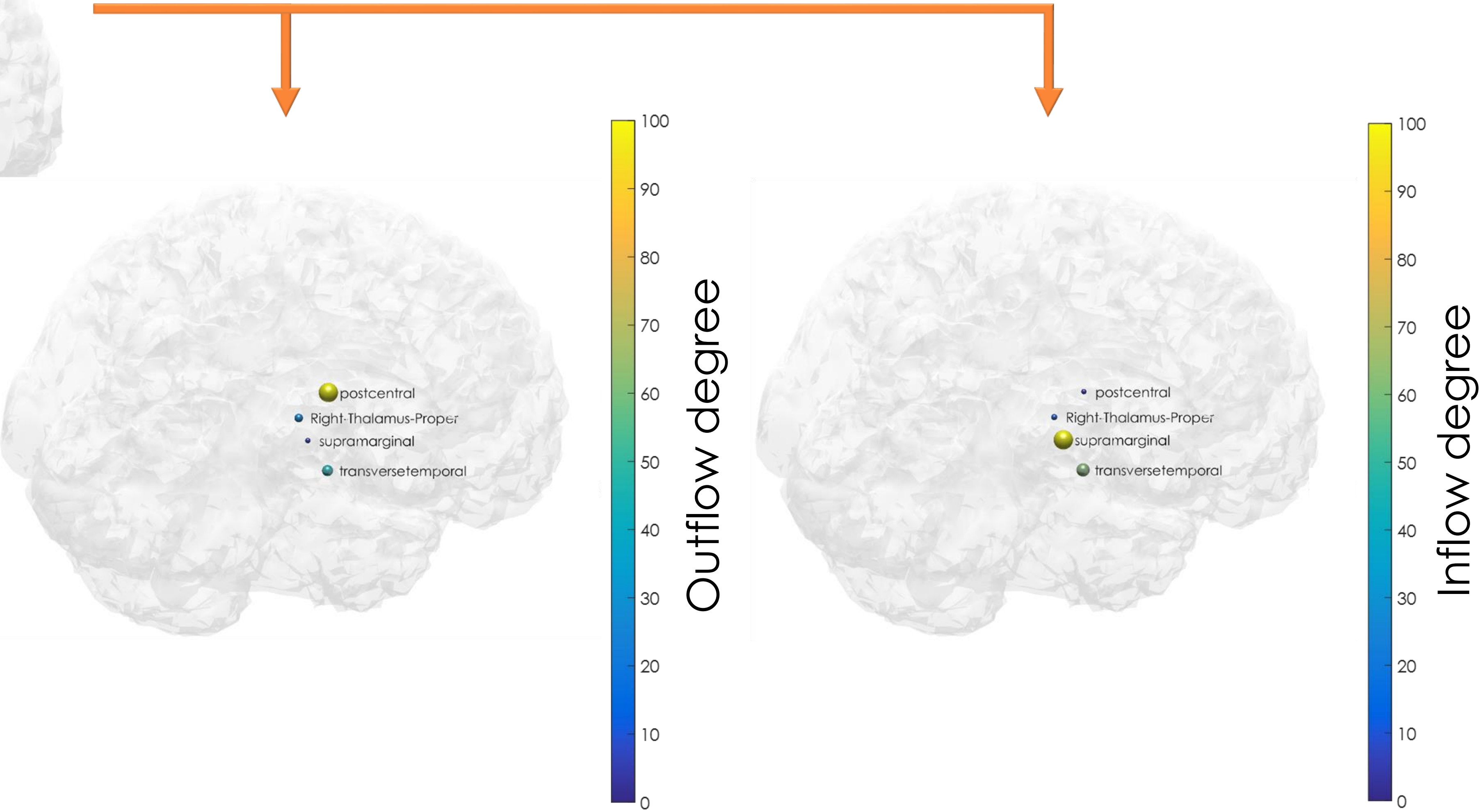




Time-Varying gPDC: network state at -6.7ms

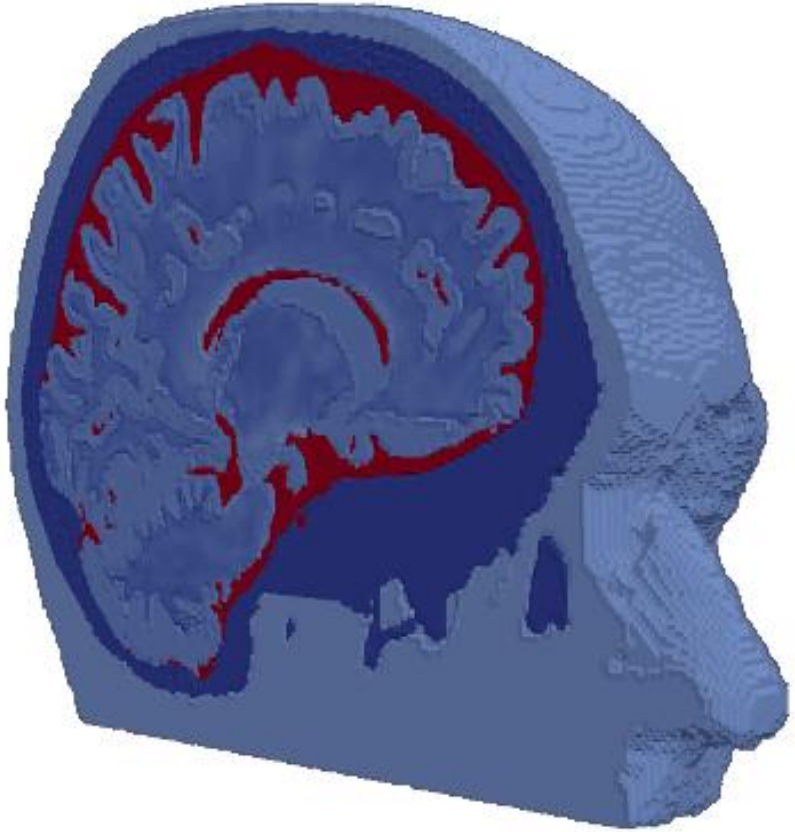




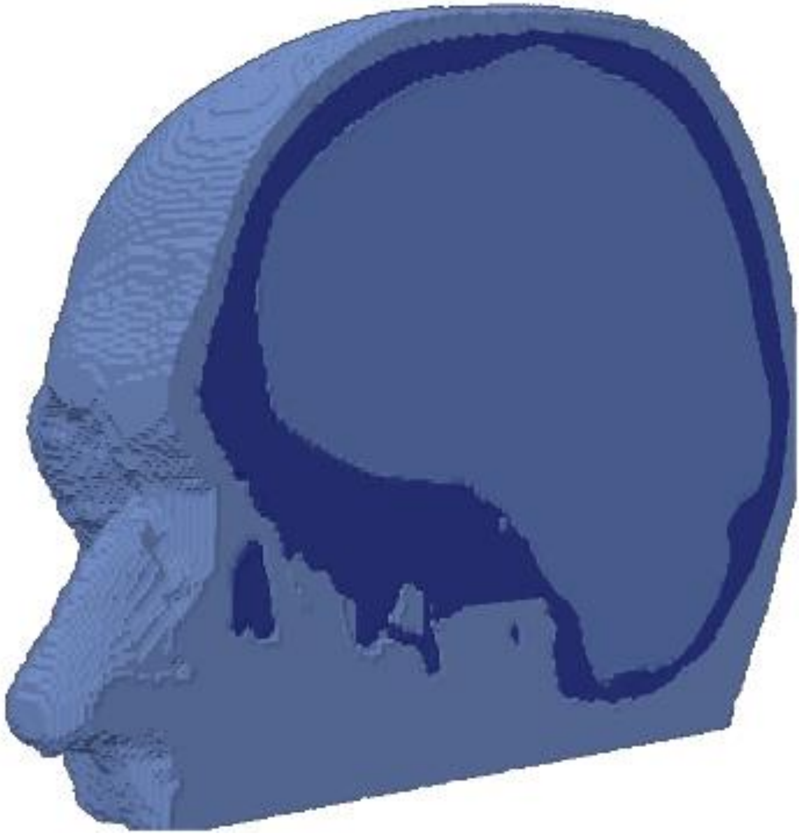


Simplification of the model from 6CA to 3C

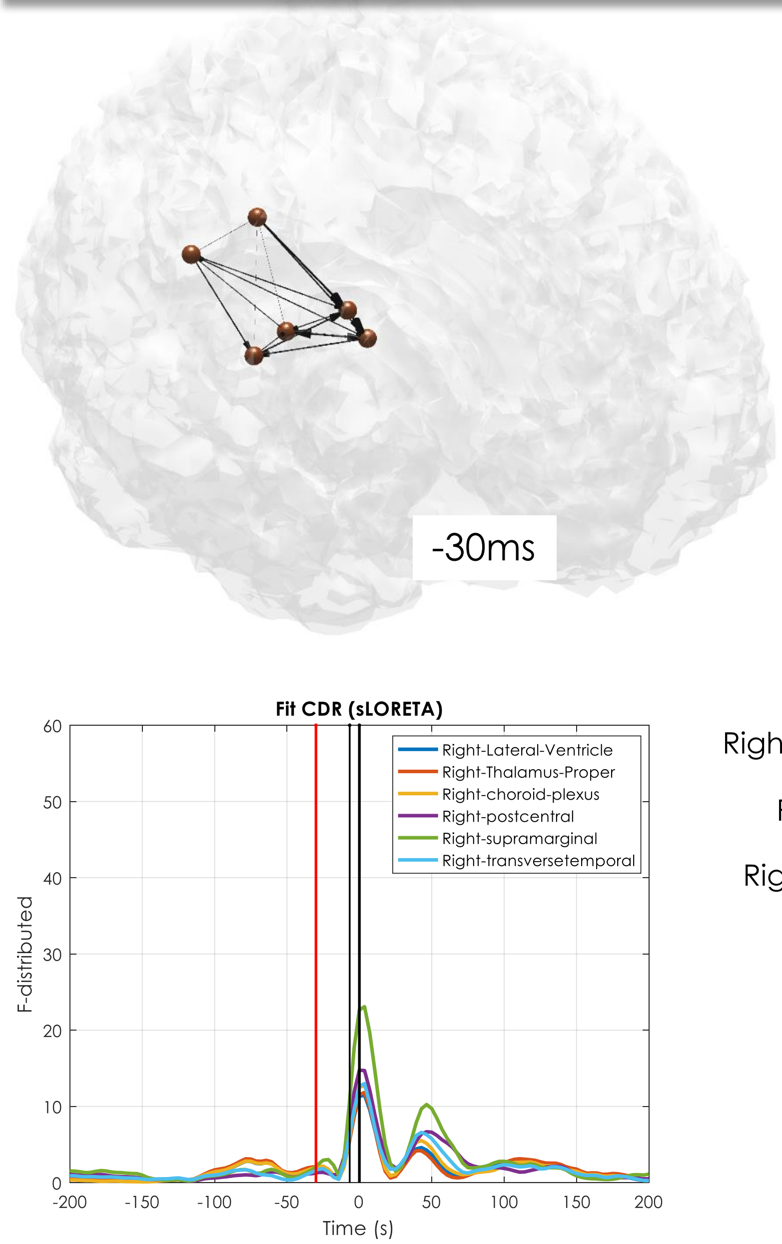
Changes in the forward model change the source analysis result and thereby the connectivity analysis (Cho et al., 2015)

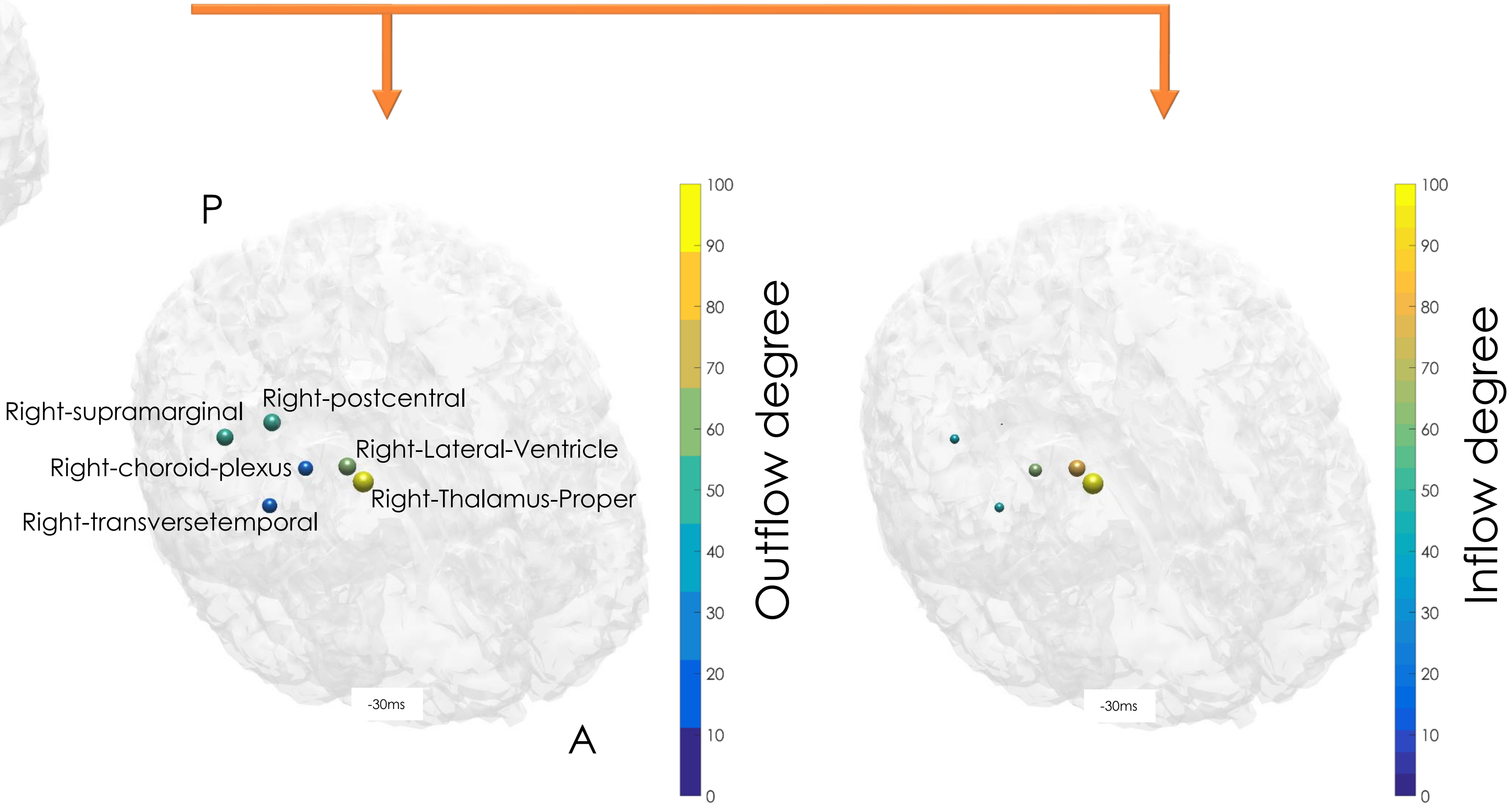


Homogenization of Spongiosa and Compacta into **Skull** and of CSF, GM and WM into **Brain**



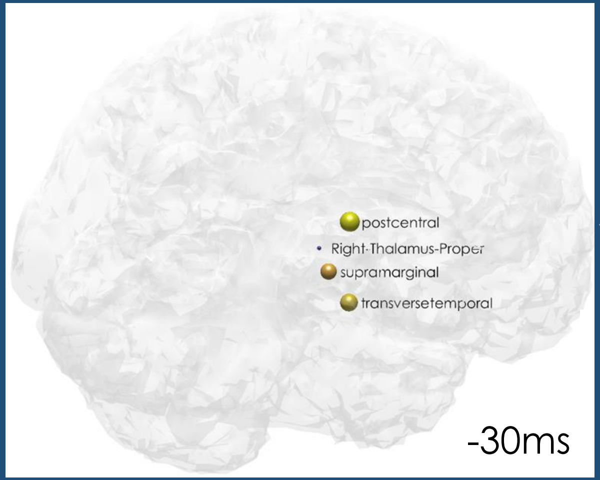
Time-Varying gPDC: network state for 3C at -30ms





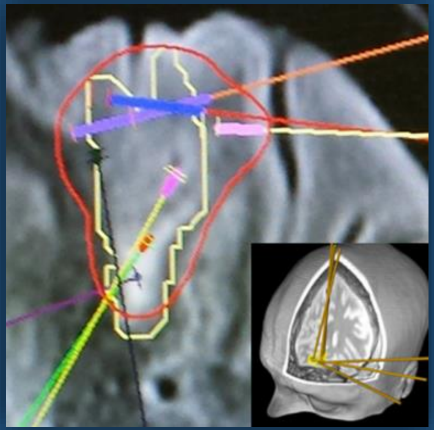
Diagnosis

- FCD type IIB in the right postcentral gyrus



<u>Symptomatology</u>
Left hand -> left mouth

- ✓ *Radio-frequency thermo-coagulation* (RFTC)
- ✓ Engel Outcome: **ID** (Generalized convulsions with antiepileptic drug withdrawal only)



Wellmer et al., 2014

Steps for presurgical epilepsy diagnosis

- Preprocessing of EEG/MEG data
- Segmentation into six (or seven) head tissues
- Preprocessing of dMRI
- Build of a geometrically-adapted hexahedral head model with anisotropy
- Calibration of skull conductivity
- Source analysis of every single modality (EEG or MEG) and combined EEG/MEG
- Determination and selection of the most dominant anatomical areas
- Perform combined EEG/MEG connectivity analysis in source space
- Visual inspection of FLAIR MRIs / ZOOMit MRIs on the suspected areas

Summary

- Realistically shaped volume conduction head models are important for source analysis leading to less modelling errors

- Individual calibration procedure is necessary
  - ❑ to stabilize the uncertainty of skull conductivity variation
  - ❑ to enable EMEG source analysis

- EMEG source analysis leads to more reliable results for low SNR scenarios

- Time-varying EC revealed temporal detailed directed paths of information flow among anatomical areas suspected brain region

- The more realistically shaped head volume conductor model (6CA_Cal) came close to the symptomatology

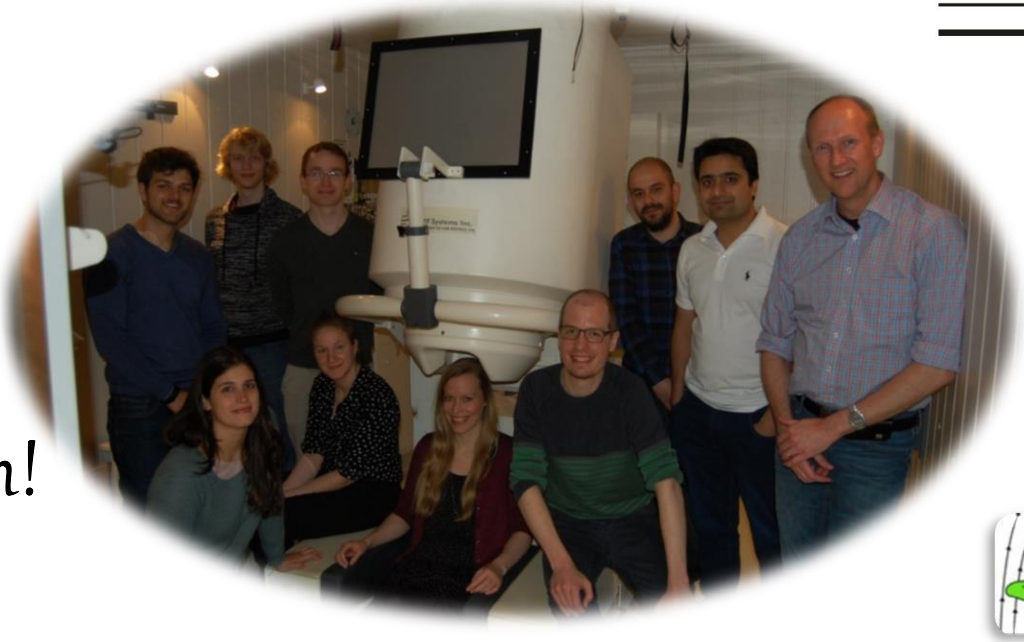
Current funding

MARIE CURIE ACTIONS

ChildBrain

ADVANCING BRAIN RESEARCH IN CHILDREN'S DEVELOPMENTAL NEUROCOGNITIVE DISORDERS

Westfälische Wilhelms-Universität Münster



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SimNeuro Group

Thank you for your attention!

questions ?

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