Presentation of two Brainstorm plugins: (1) Brain Entropy in space and time (BEst) for Maximum Entropy on the Mean source imaging (2) NIRSTORM plugin dedicated for fNIRS analysis

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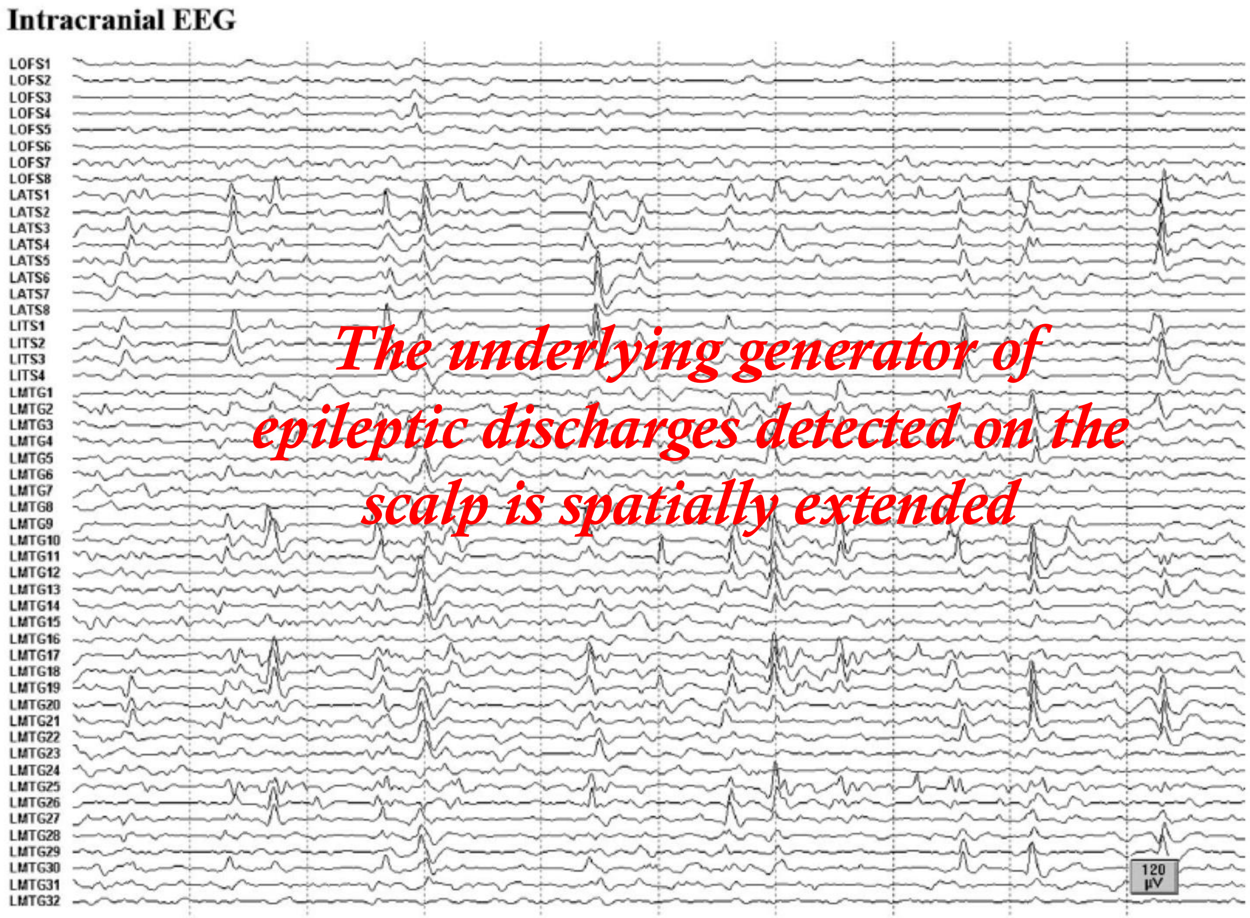
Part 1: EEG/MEG source imaging using Maximum Entropy on the Mean (MEM)

BEst

Brain Entropy in space and time

http://neuroimage.usc.edu/brainstorm/Tutorials/TutBEst

EEG recording of epileptic discharges



The underlying generator of epileptic discharges detected on the scalp is spatially extended

Tao et al Clin Neurophys 2007

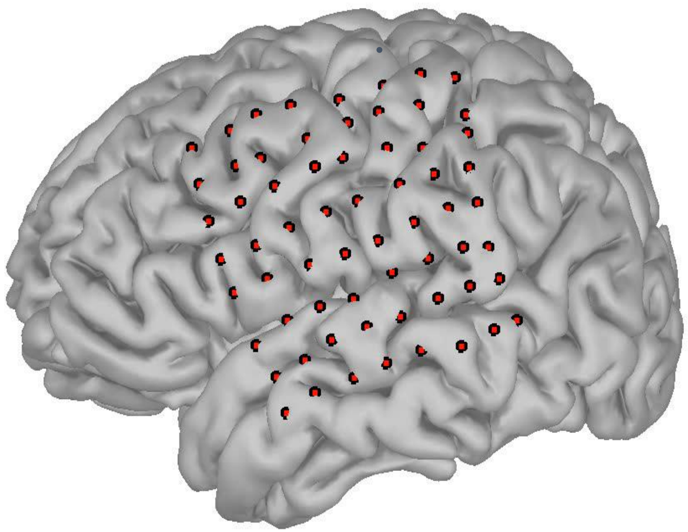
Should we have spatially extended generators to detect epileptic discharges from the scalp. What is the true underlying extent ?

Spike generators of 4 to 8 cm^2 can generate scalp EEG signals with good SNR

A minimum of 3-4 cm^2 can generate MEG signals with good SNR

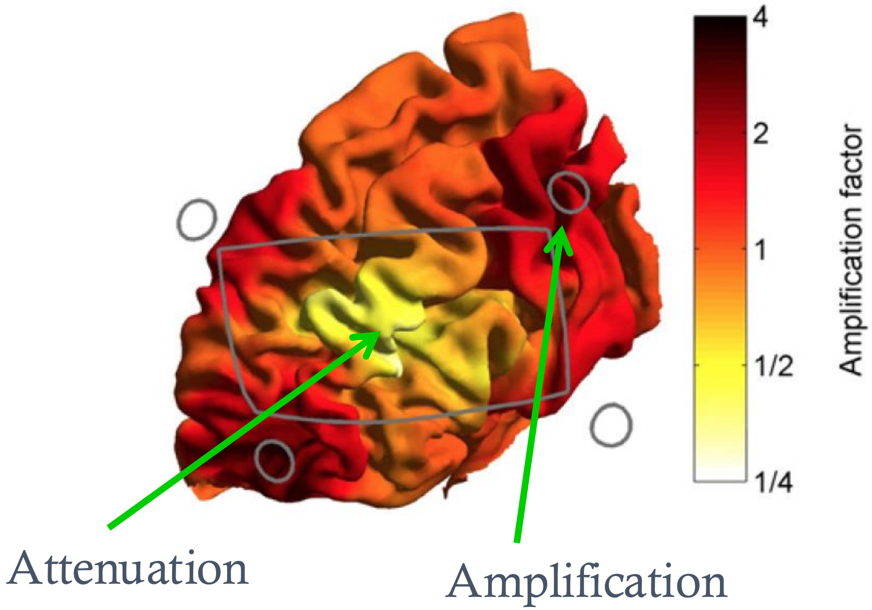
(Oishi et al Epilepsia 2002)

An ECoG grid is not covering the whole underlying surface



Courtesy of T. Hedrich

An ECoG grid is influencing local signal to noise ratio (SNR)



Von Ellenrieder Neuroimage 2014

EEG/MEG source imaging and estimation of the underlying spatial extent of the generators

EEG/MEG Source localization using Maximum Entropy on the Mean (MEM)

Recover the spatial extent of the source with good accuracy

Brainstorm
http://neuroimage.usc.edu/brainstorm

MEM plugin available in Brainstorm software

- **MEM in the time domain**: interesting spatial properties and the ability to recover the **spatial extent of the underlying sources**

- **Wavelet based MEM (wMEM):** MEM localization after time-frequency decomposition of the data using discrete wavelets. **Ideal to localize oscillations.**

- **Ridge MEM (rMEM):** localization of **synchronous** sources

Co-Developper / Main Collaborator

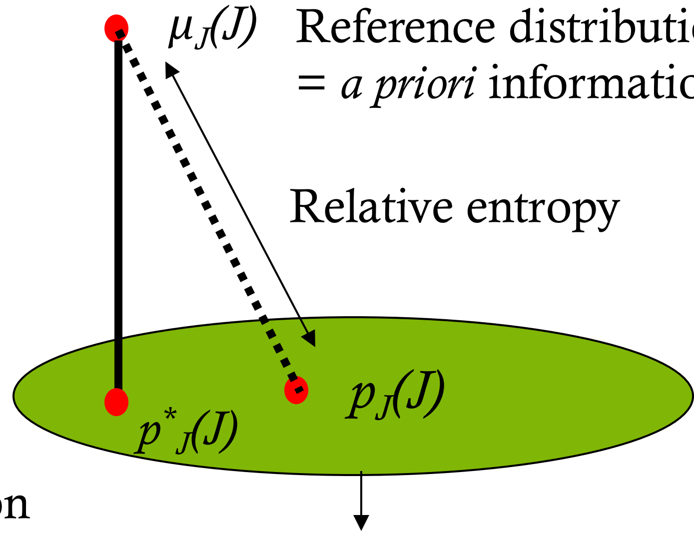
ÉTS
Le génie pour l'industrie

Jean-Marc Lina, PhD

Solving the EEG/MEG inverse problem: Maximum Entropy on the Mean (MEM) model

Maximum Entropy on the Mean (MEM)

Reference distribution = *a priori* information



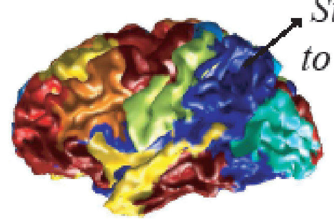
MEM solution

Data fit: set of all distributions $p_J(J)$ explaining the data on average

Prior information on J: Brain activity distributed over K cortical patches

$$d\mu(\mathbf{j}) = \Pi_{k=1}^{K} \left[(1-\alpha_k)\delta(\mathbf{j}_k) + \alpha_k \, \mathcal{N}(\mu_k, \Sigma_k)(\mathbf{j}_k)\right] d\mathbf{j}$$

Parcelling of the cortical surface in K parcels:



State variable (S_k = 0 or 1) associated to the activation of the k^{th} parcel

$$Prob(S_k = 1) = \alpha_k$$

Inactive parcel (Sk = 0) Dirac distribution

Active parcel (Sk = 1) Gaussian distribution

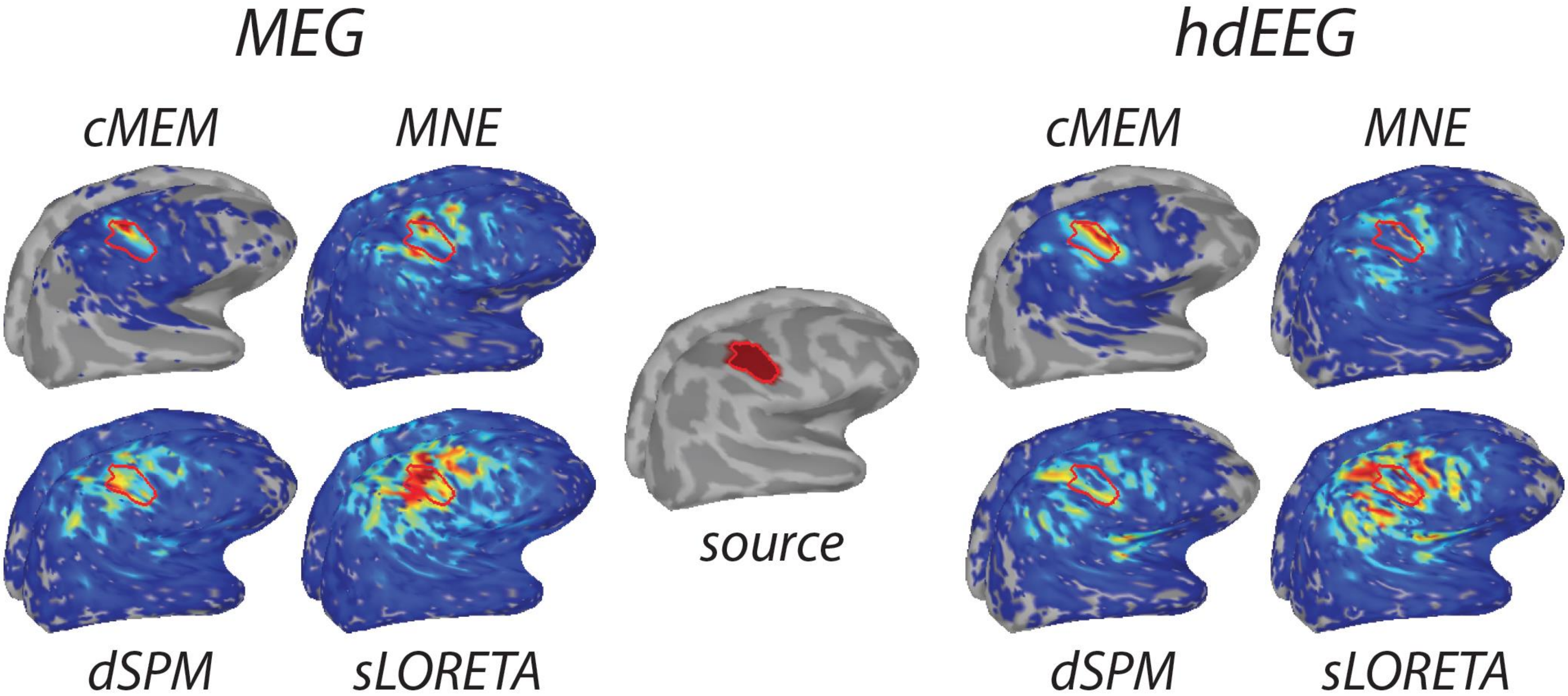
Grova et al, Neuroimage. 2006;29(3)

Amblard et al, IEEE BME. 2004;51(3)

Chowdhury et al, Neuroimage 2016; 43:175-195

Point Spread Function of an extended source
Resolution matrix study

Tanguy Hedrich

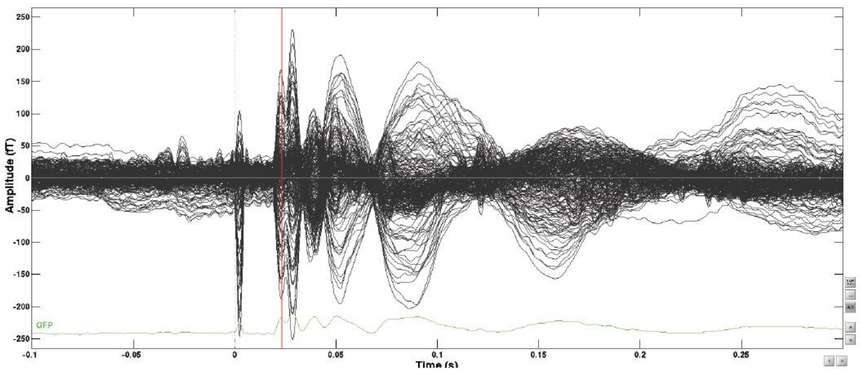


Hedrich et al, Neuroimage 2017

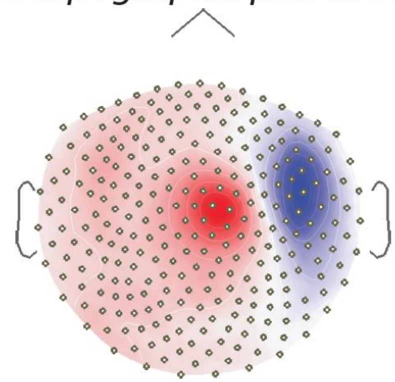
Electrical median nerve stimulation in 5 healthy controls in MEG

Tanguy Hedrich

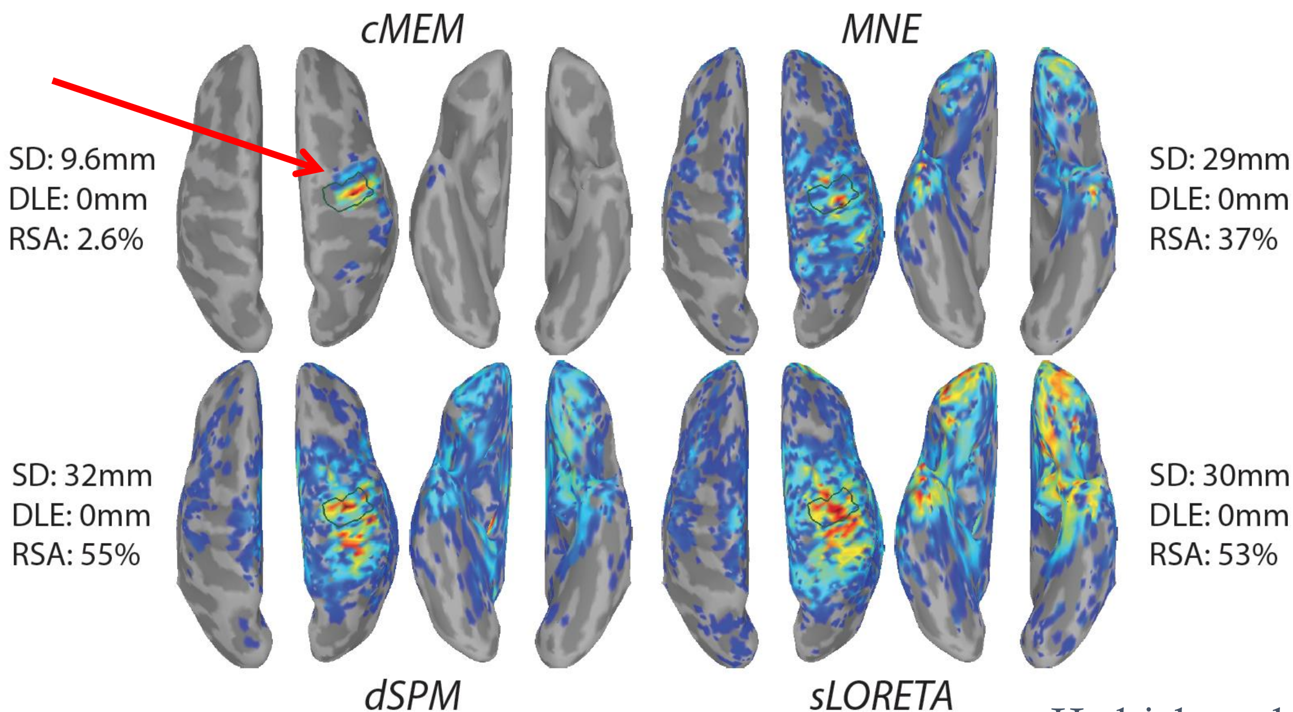
MEG butterfly plot



MEG topographic plot at 20ms



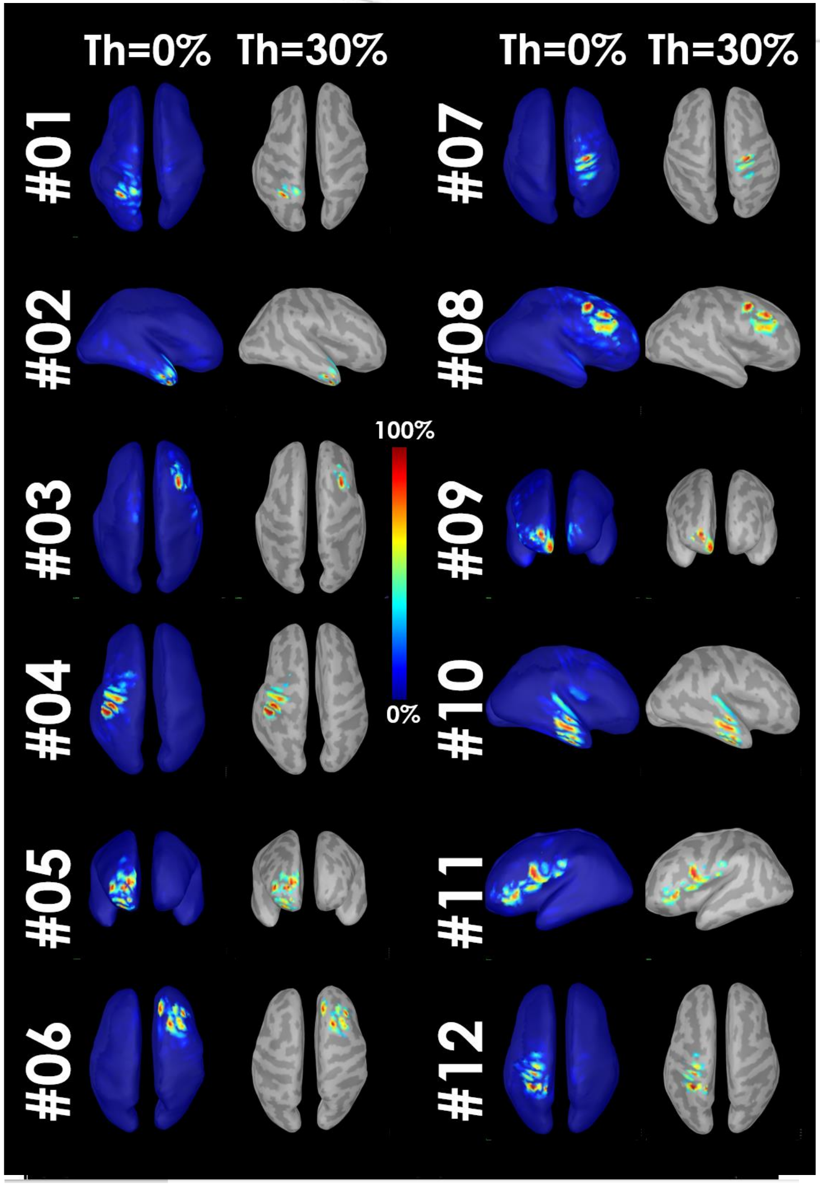
Reference:
Anatomical Landmark of S1



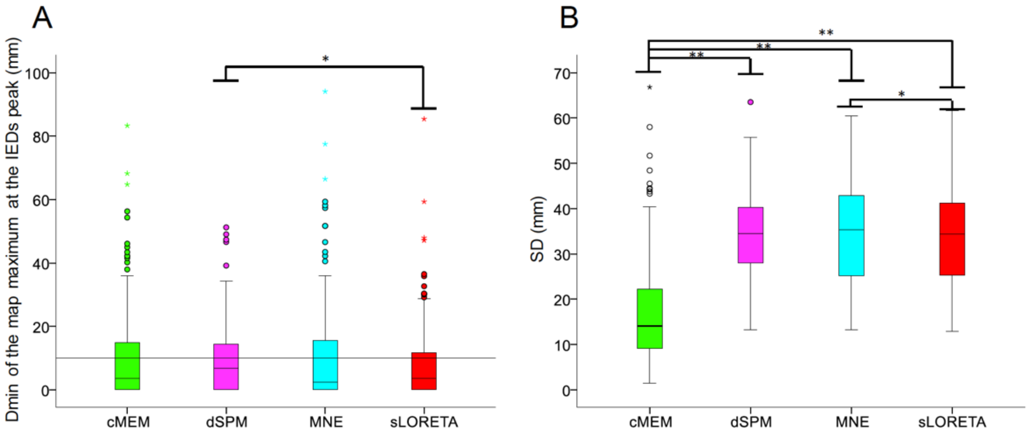
Hedrich et al, Neuroimage 2017

Clinical yield of MEG source localization using cMEM in epilepsy in 340 studies (49 patients)

Giovanni Pellegrino



Comparison of several distributed sources Localization methods: MEM, MNE, dSPM, sLORETA



Distance to the focus

Spatial spread around the focus

Pellegrino et al, HBM 2018, 2020

Outline

- Basic principle of source localization and imaging in EEG/MEG
- Validation of EEG/MEG source imaging with intracranial EEG
- EEG/MEG source imaging of oscillatory patterns
- EEG/MEG source imaging of deep activity
- EEG/MEG source imaging of resting state

RESEARCH ARTICLE

Clinical Yield of Electromagnetic Source Imaging and Hemodynamic Responses in Epilepsy

Validation With Intracerebral Data

Chifaou Abdallah, MD, Tanguy Hedrich, PhD, Andreas Koupparis, MD, PhD, Jawata Afnan, MSc, Jeffrey Alan Hall, MD, PhD, Jean Gotman, PhD, Francois Dubeau, MD, Nicolas von Ellenrieder, PhD, Birgit Frauscher, MD, PD, Eliane Kobayashi, MD, PhD, and Christophe Grova, PhD

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Neurology® 2022;98:1-13. doi:10.1212/WNL.0000000000200337

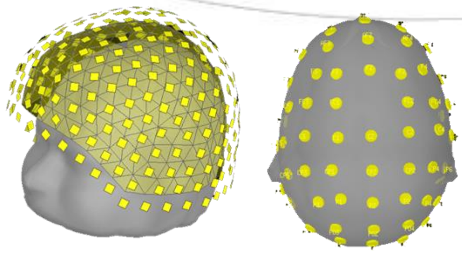
Chifaou Abdallah

Quantitative comparison between EEG/MEG fusion using MEM, EEG/fMRI and intracranial EEG

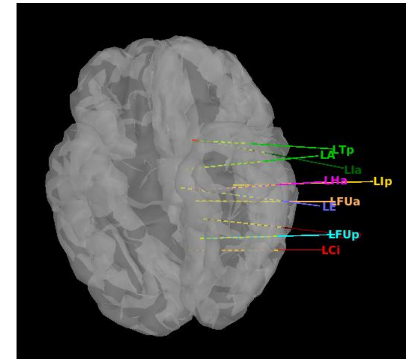
Abdallah et al. Neurology 2022

Abdallah et al. Neurology 2022

Clinical yield of electromagnetic source imaging and hemodynamic responses in epilepsy: validation with intracerebral data



brainproducts.com



MEG+EEG: ~300 MEG sensors ,
60 EEG electrodes
Sampling Rate: at least **1200Hz**,
About 1h recording, divided **in 6 min runs**

Simultaneous EEG/fMRI
+ Anatomical MRI (3T)
Head model, Hemodynamic response to epileptic spikes

Intracranial EEG (iEEG)
Gold Standard

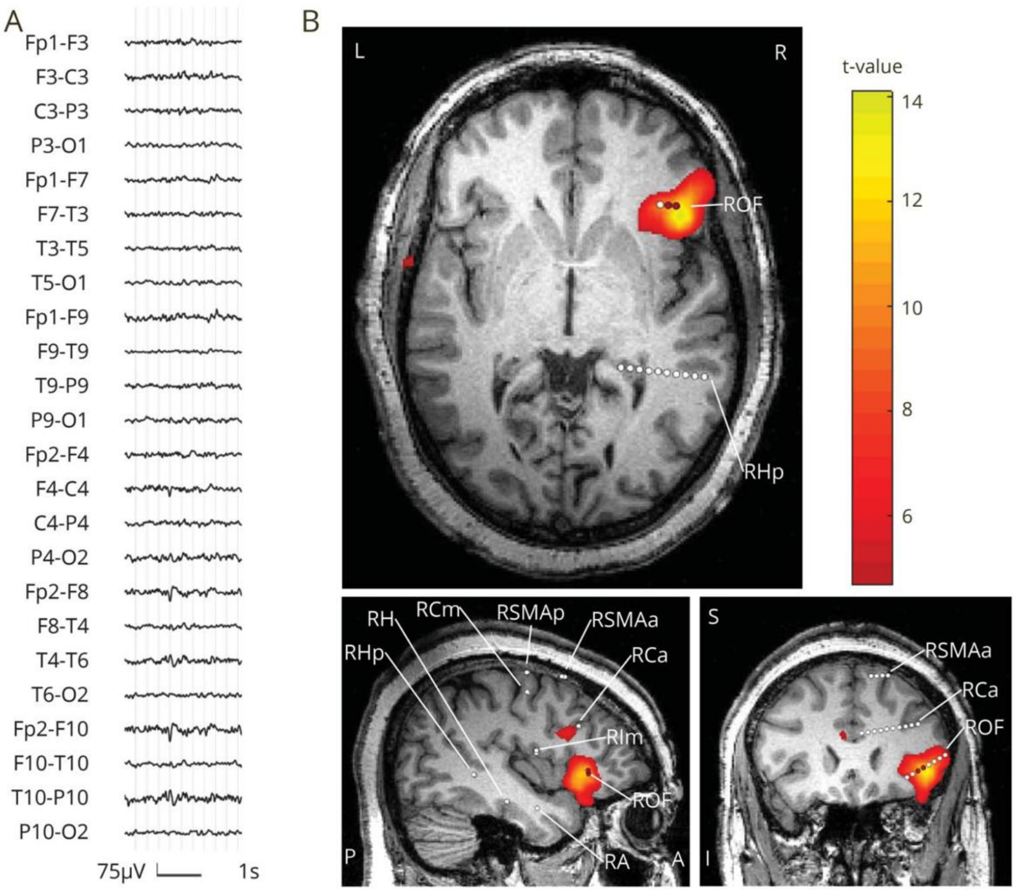
17 Patients who underwent EEG/MEG, EEG/fMRI and subsequent iEEG were included

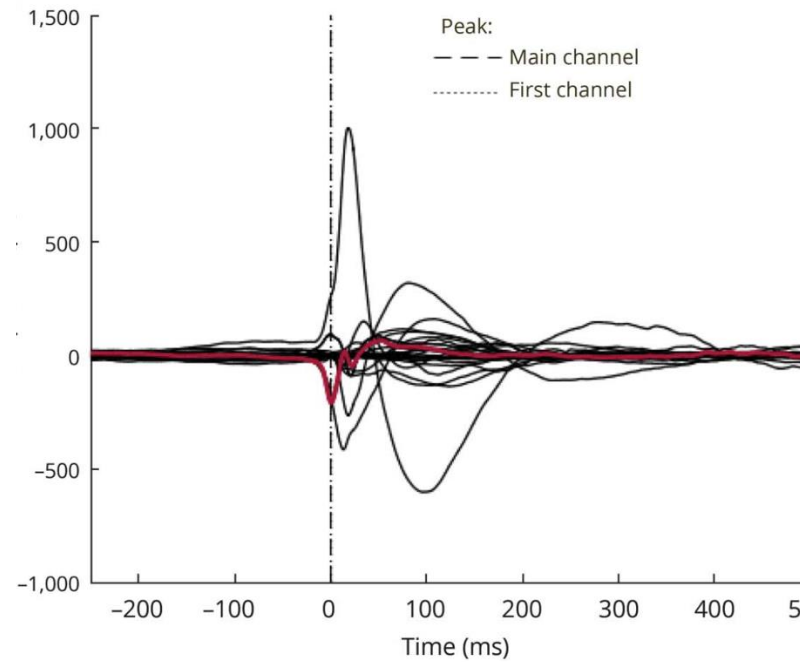
EEG/MEG fusion using MEM (Chowdhury et al HBM 2018) and **fMRI BOLD response** (Khoo et al Neurology 2018) to similar EEG epileptic spikes

Identification of the reference **SOZ** and **Primary Irritative Zone (PIZ)** from iEEG data

Quantitative analysis within the iEEG space: spatial overlap (ROC analysis) and distances

Simultaneous EEG-fMRI: The most significant BOLD response localizing the spike onset





Averaged interictal spike in SEEG

The most significant fMRI BOLD response (pos. or neg.) to interictal discharges delineates a subset of the irritative zone in concordance with the seizure onset zone

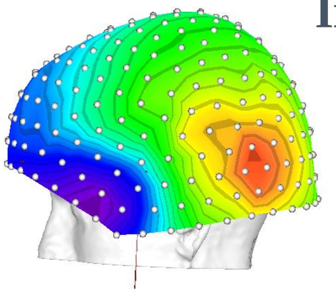
→ **Spike onset zone**

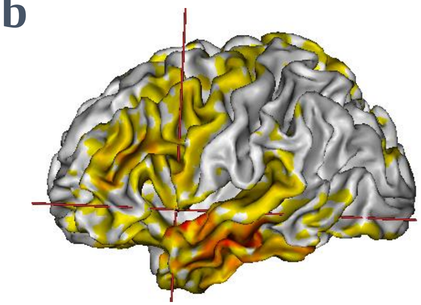
Khoo et al. Epilepsia 2017, Neurology 2018

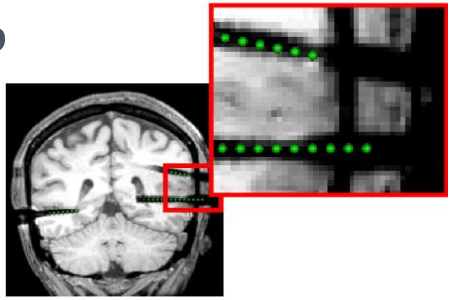
Quantitative correlation between EEG/MEG sources and iEEG

MEG/EEG
Inverse pb

iEEG
Forward pb







MEG scalp recordings (in pT)

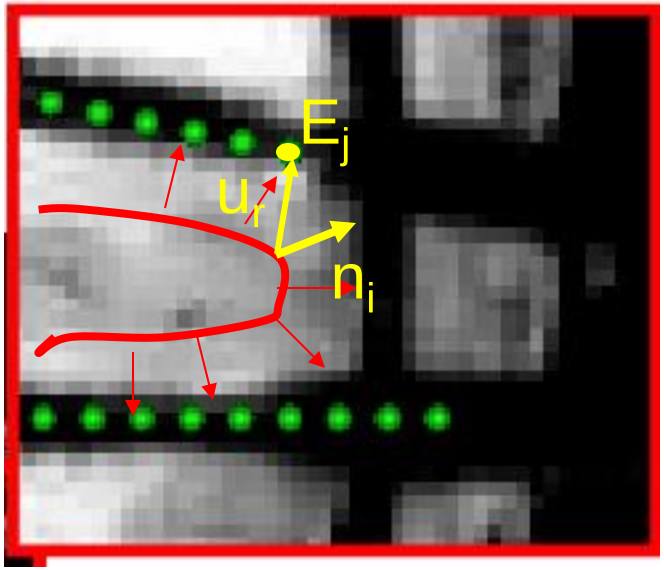
MEG/EEG Source loc (in nA.m)

iEEG potentials Simulated from scalp MEG or EEG data (in uV)

- One can compare **virtual MEG-estimated iEEG potentials** with **real iEEG potentials**
- Same physical entities: electrical potentials in V
- Spatial relationship between the cortical surface and iEEG contact: **iEEG forward model**

Grova et al, Human Brain Mapping 2016

iEEG forward model: infinite volume conductor model



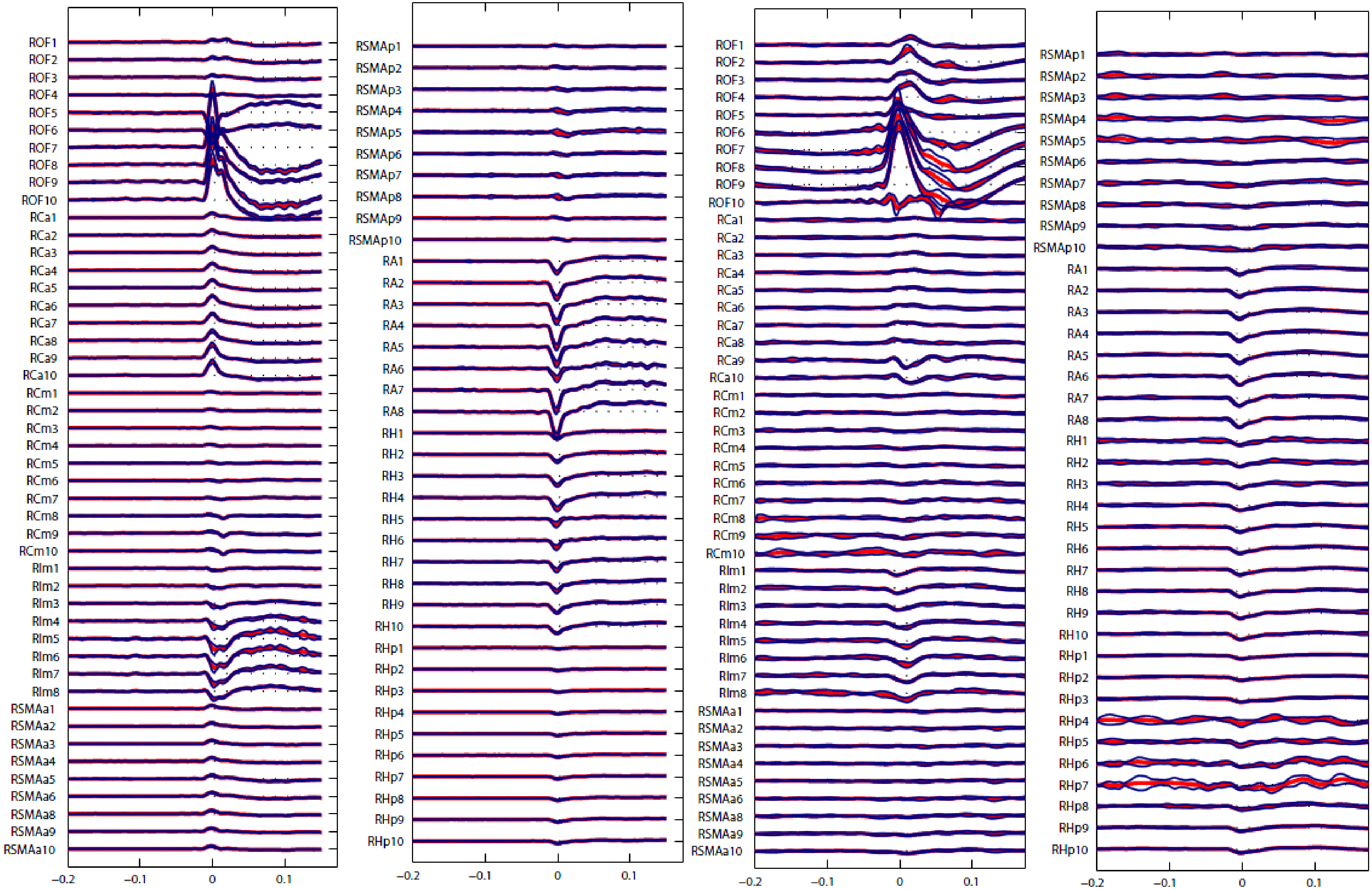
$$V\left(E_j\right) = \frac{\vec{n}_i \cdot \vec{u}_r}{4\pi\sigma r^2}$$

Electrical potential created by the ith dipolar source of the cortical surface on the jth iEEG electrode contact, located at a distance r from the source

Key parameters

Distance and source orientation

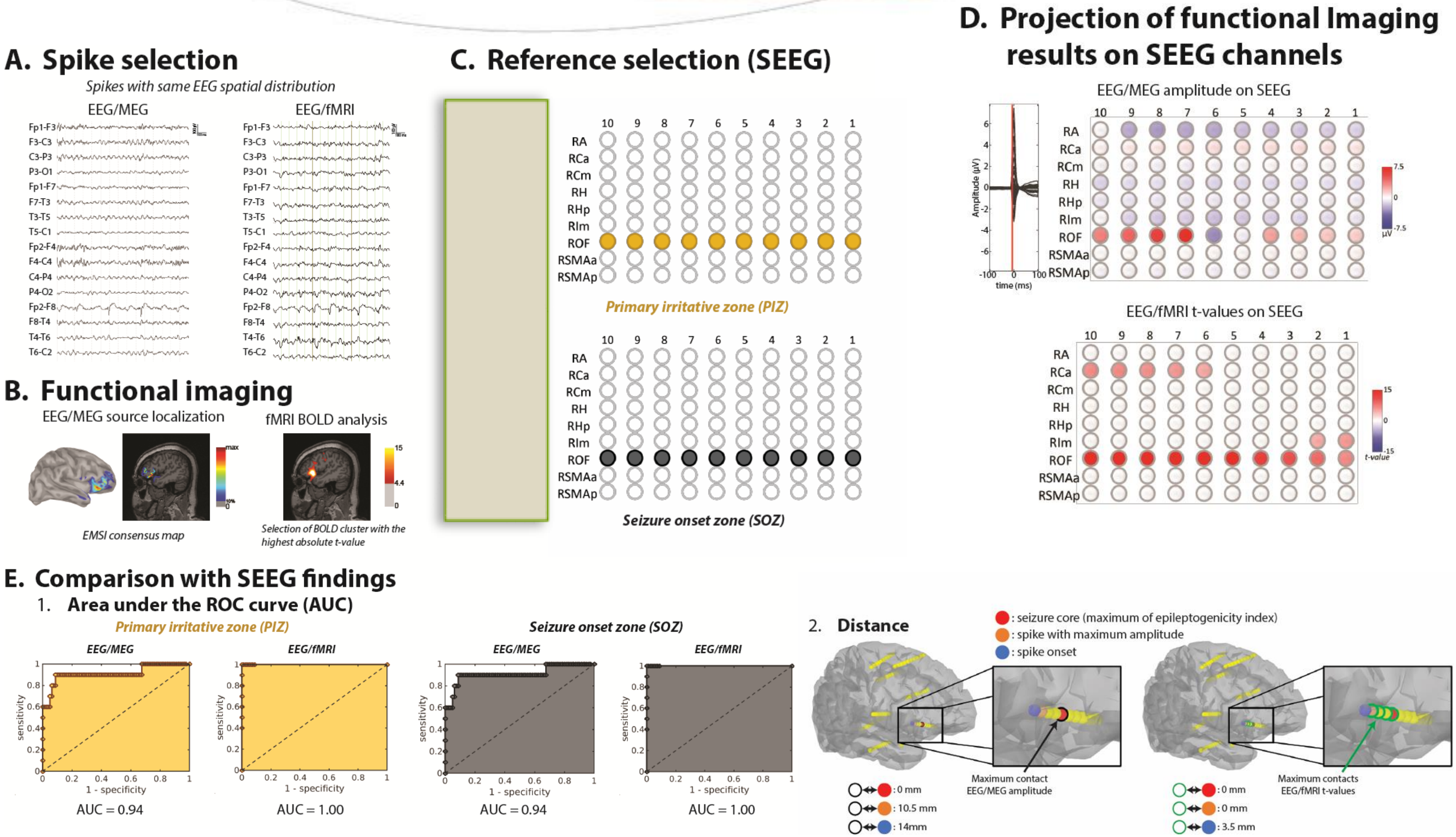
Grova et al, Human Brain Mapping 2016



(v) Simulated iEEG potentials from MEG sources V_{MEG}

(vi) Recorded iEEG potentials V_{iEEG}

Multimodal comparison involving EEG/MEG fusion, EEG/fMRI and intracranial EEG



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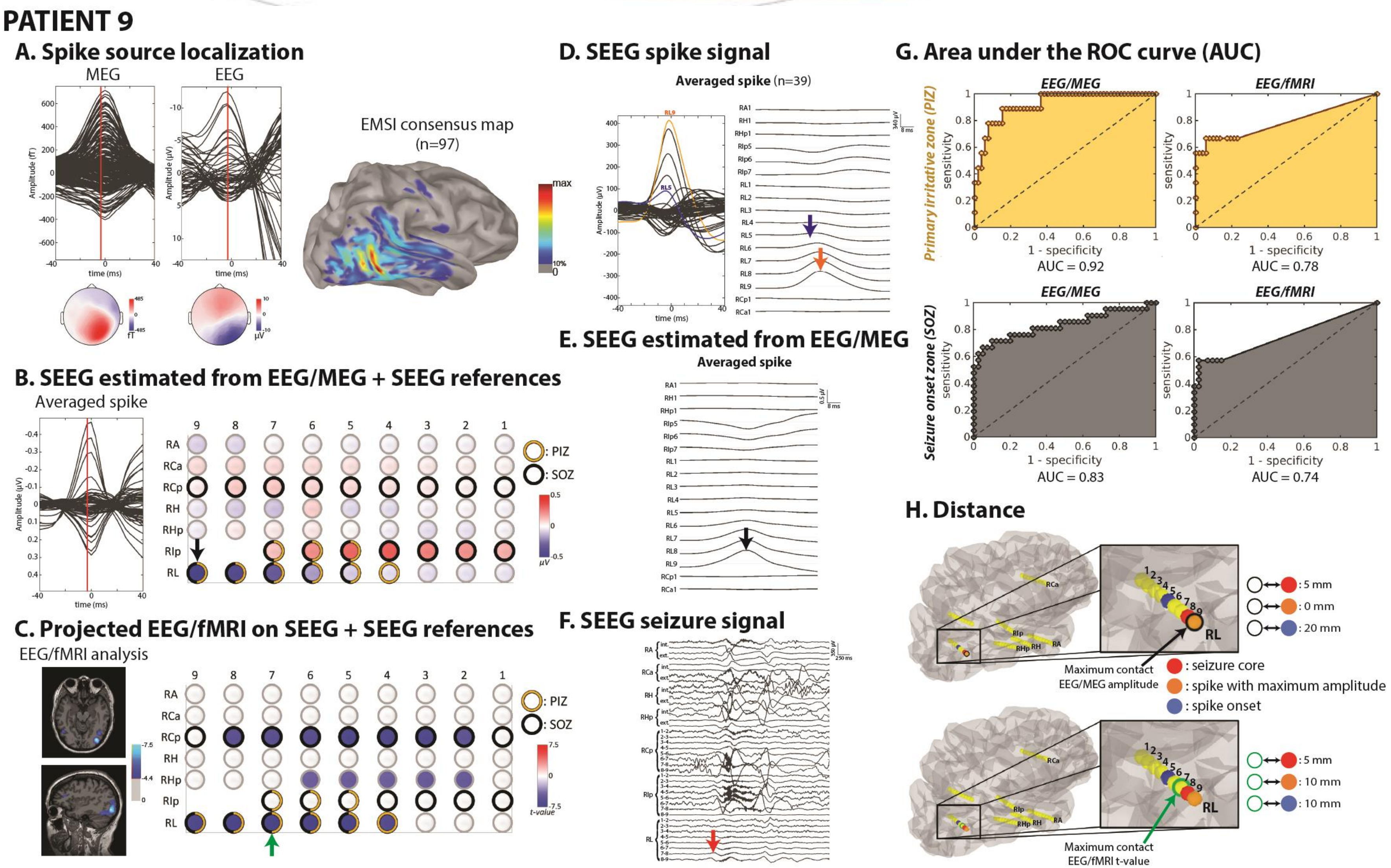
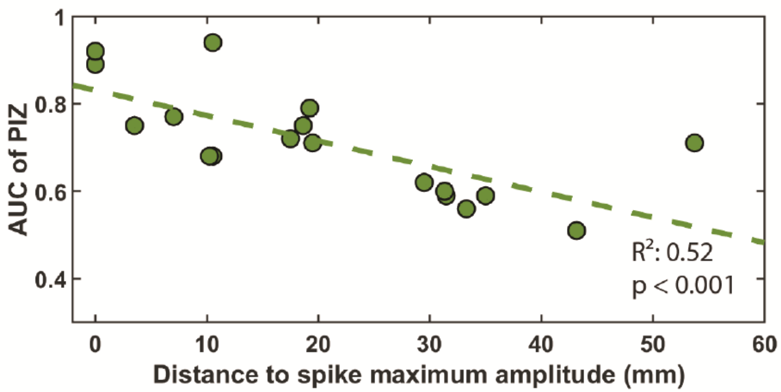


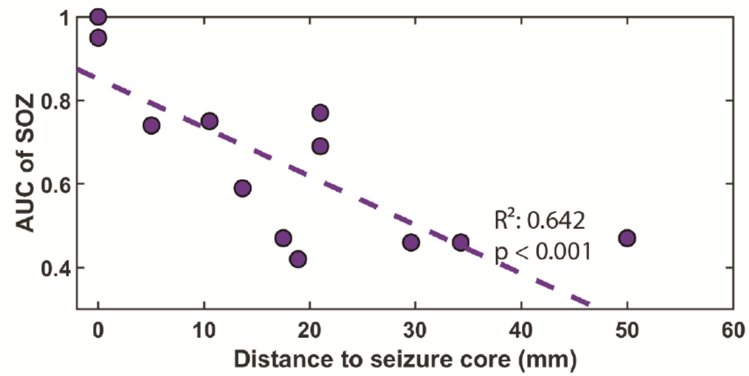
Multimodal comparison involving EEG/MEG fusion, EEG/fMRI and intracranial EEG

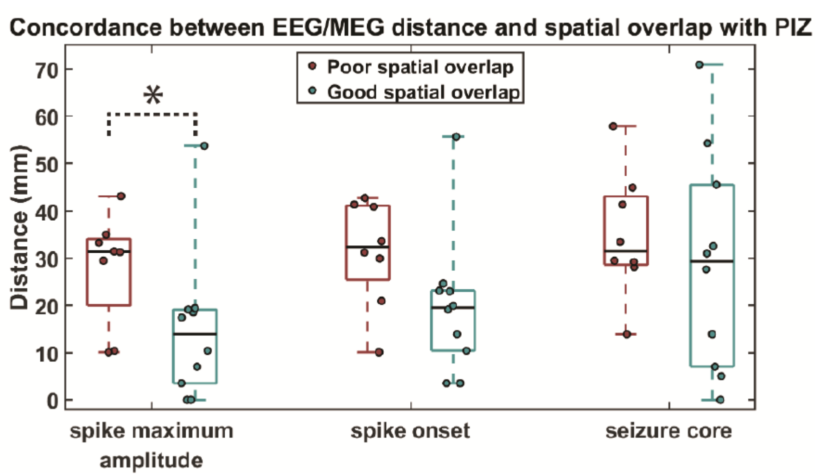
Chifaou Abdallah

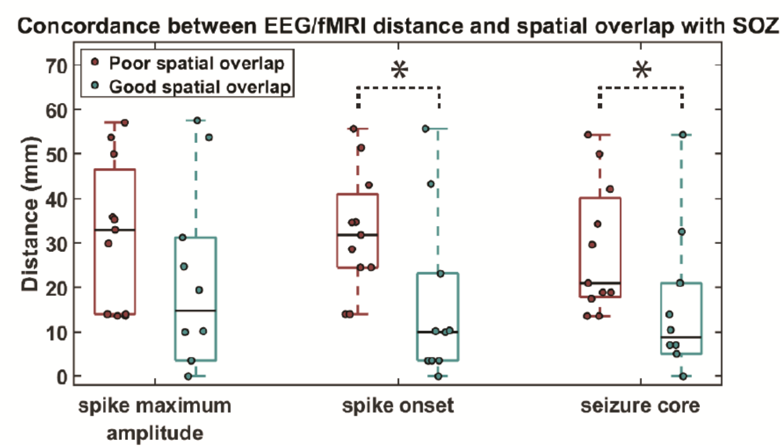
EEG/MEG source imaging vs PIZ



EEG/fMRI response vs SOZ







Importance of considering spatial overlap in quantitative evaluation

EEG/MEG localized accurately the Primary Irritative Zone (PIZ)

whereas fMRI response to similar spikes well localized the Seizure Onset Zone (SOZ)

Abdallah et al. Neurology 2022

EEG/MEG Source localization using Maximum Entropy on the Mean (MEM)

Recover the spatial extent of the source with good accuracy

Brainstorm

http://neuroimage.usc.edu/brainstorm

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Co-Developper / Main Collaborator

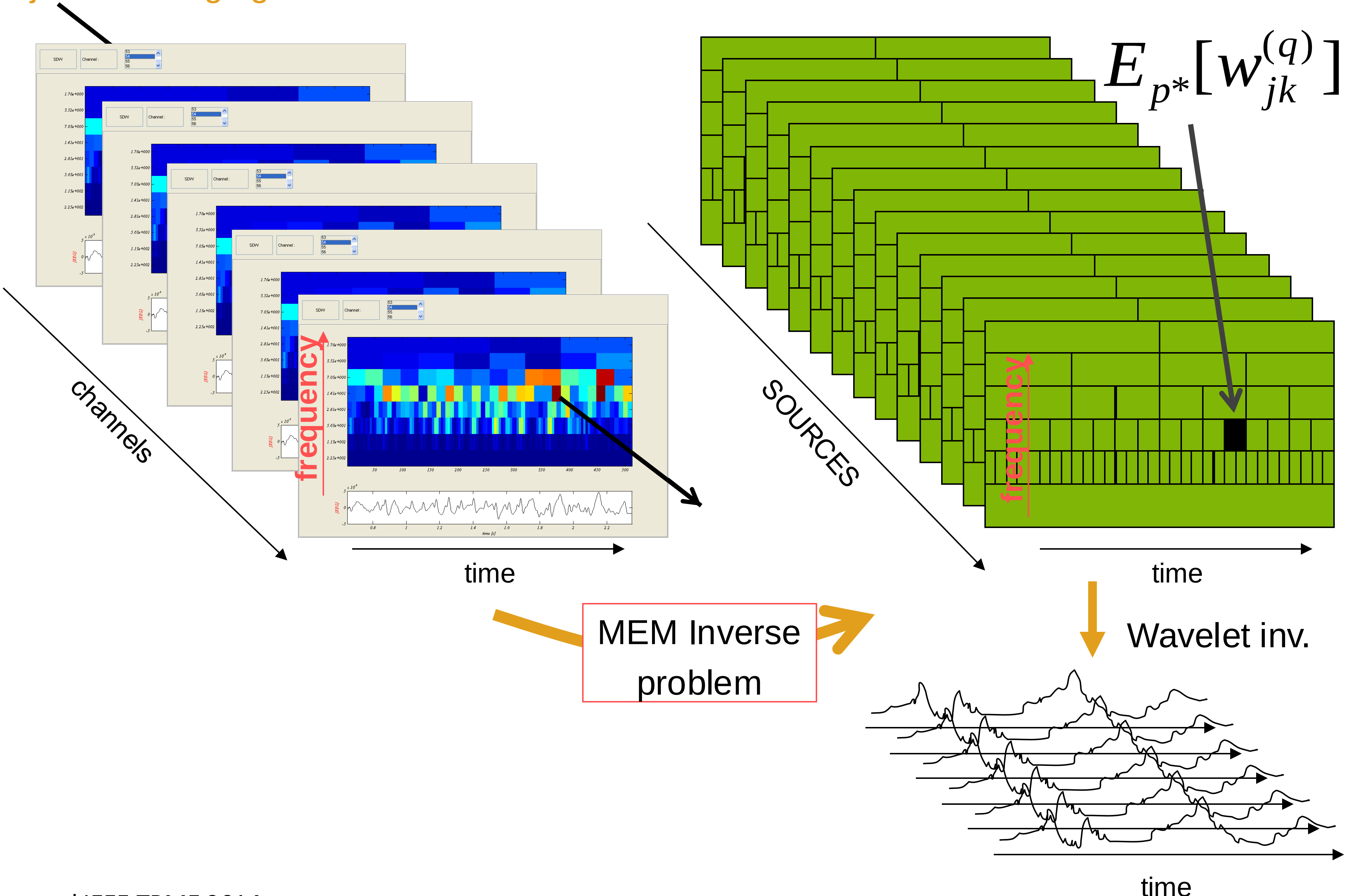
ÉTS

Le génie pour l'industrie

Jean-Marc Lina, PhD

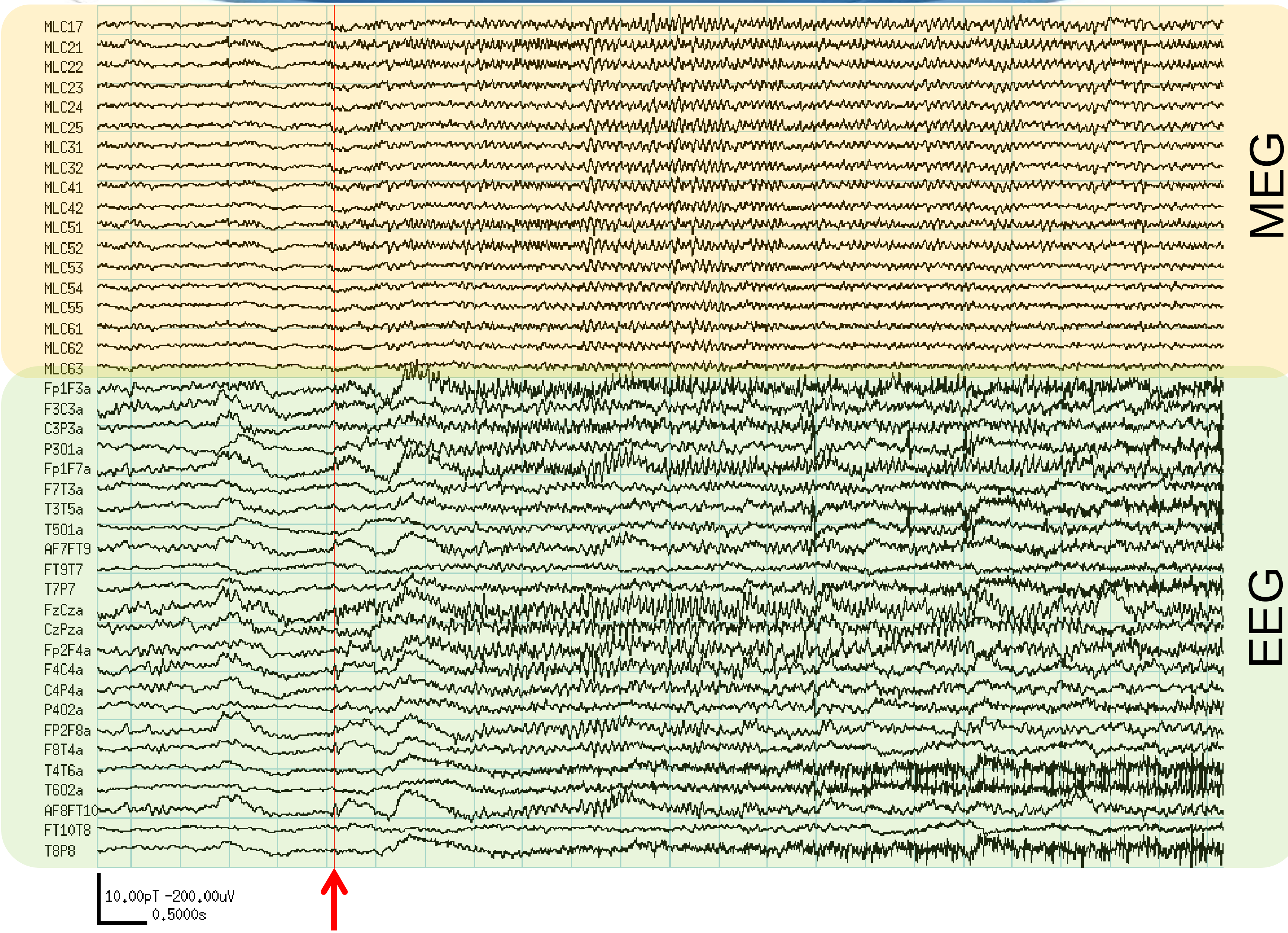
INVERSE PROBLEMS AND SPARSE (WAVELET) REPRESENTATIONS OF SIGNALS

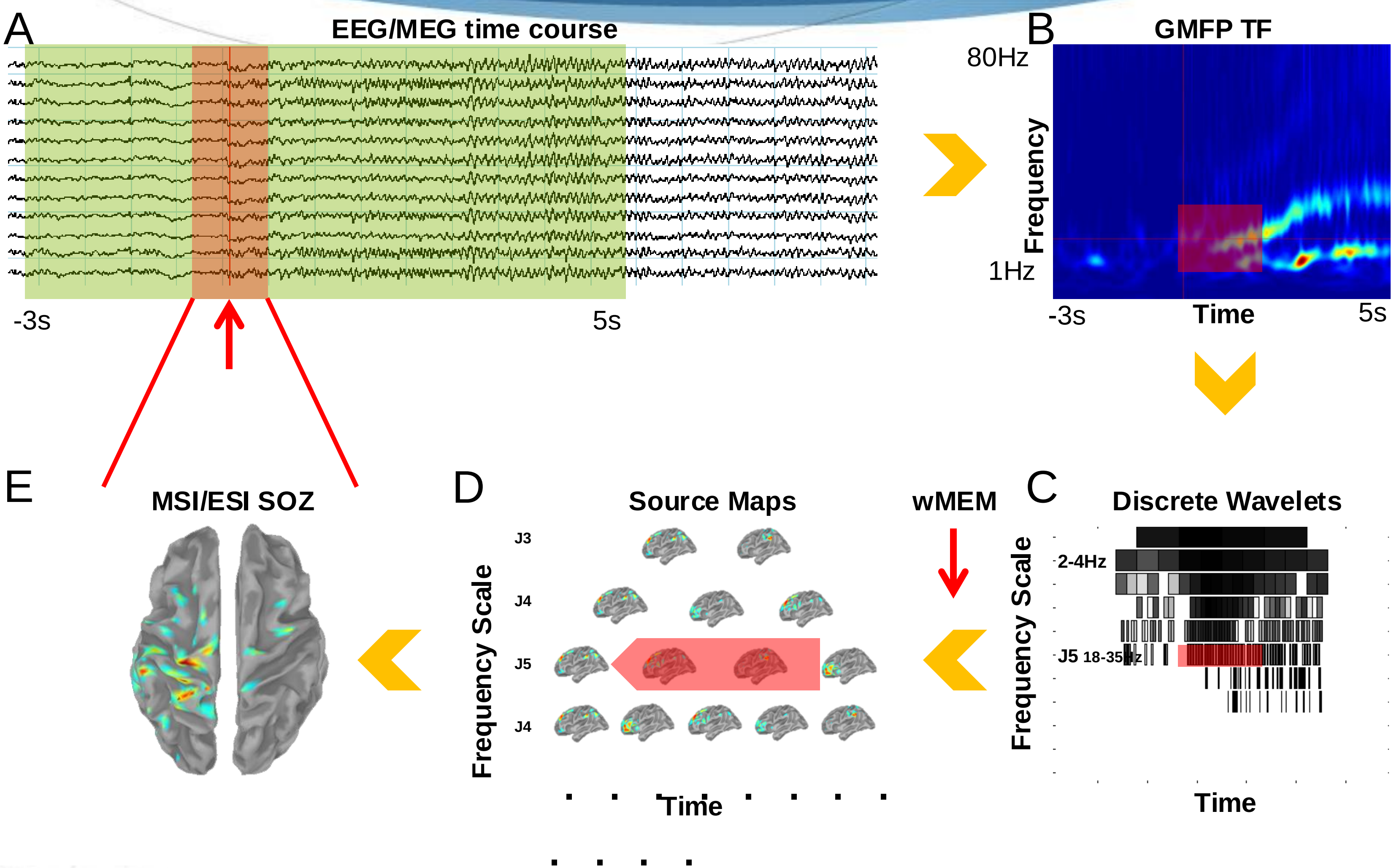
Objective: imaging the local oscillations from MEG/EEGs



Lina et al IEEE TBME 2014

Localization of the Seizure Onset Zone (SOZ) from ictal EEG/MEG data

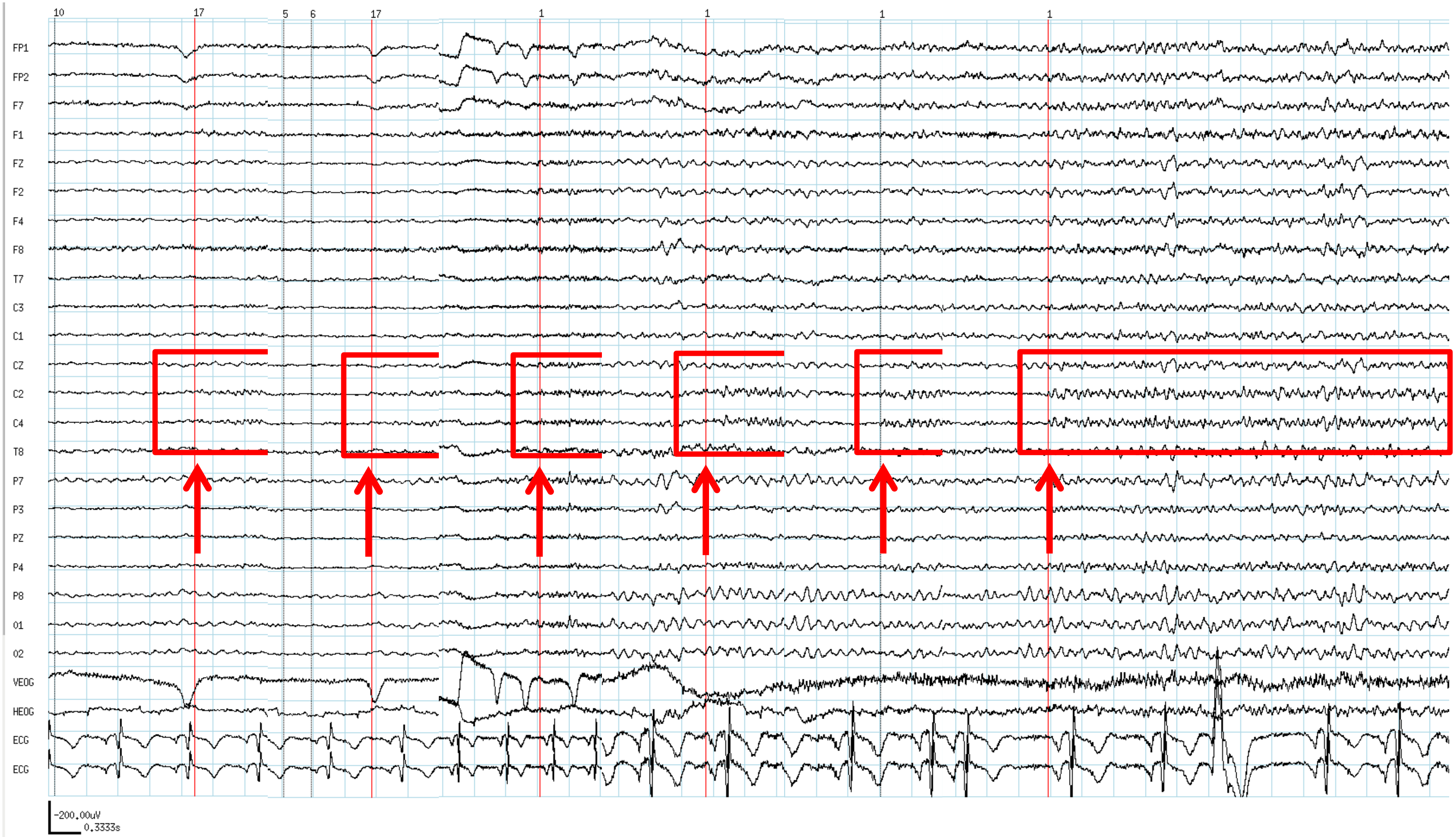




Wavelet-based Maximal Entropy on the Mean (wMEM): distributed inverse solution approach sensitive to the spatial extent of the epileptic generator (Lina et al., IEEE TBME 2014).

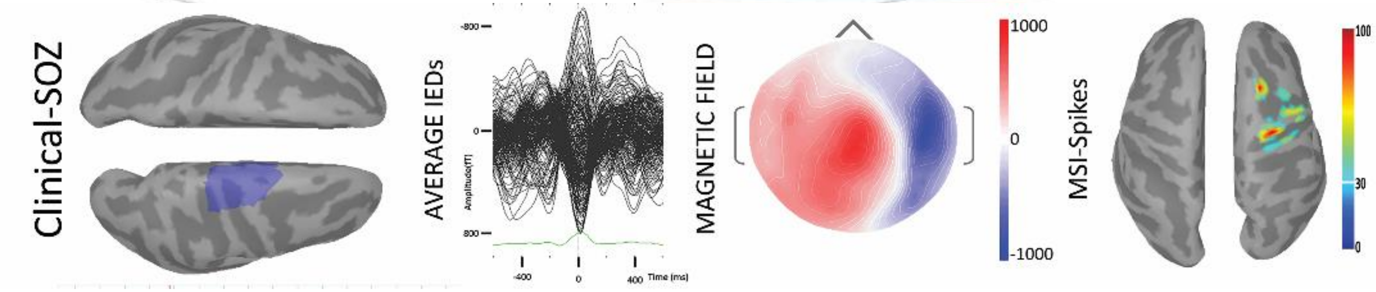
BEst Brain Entropy in space and time

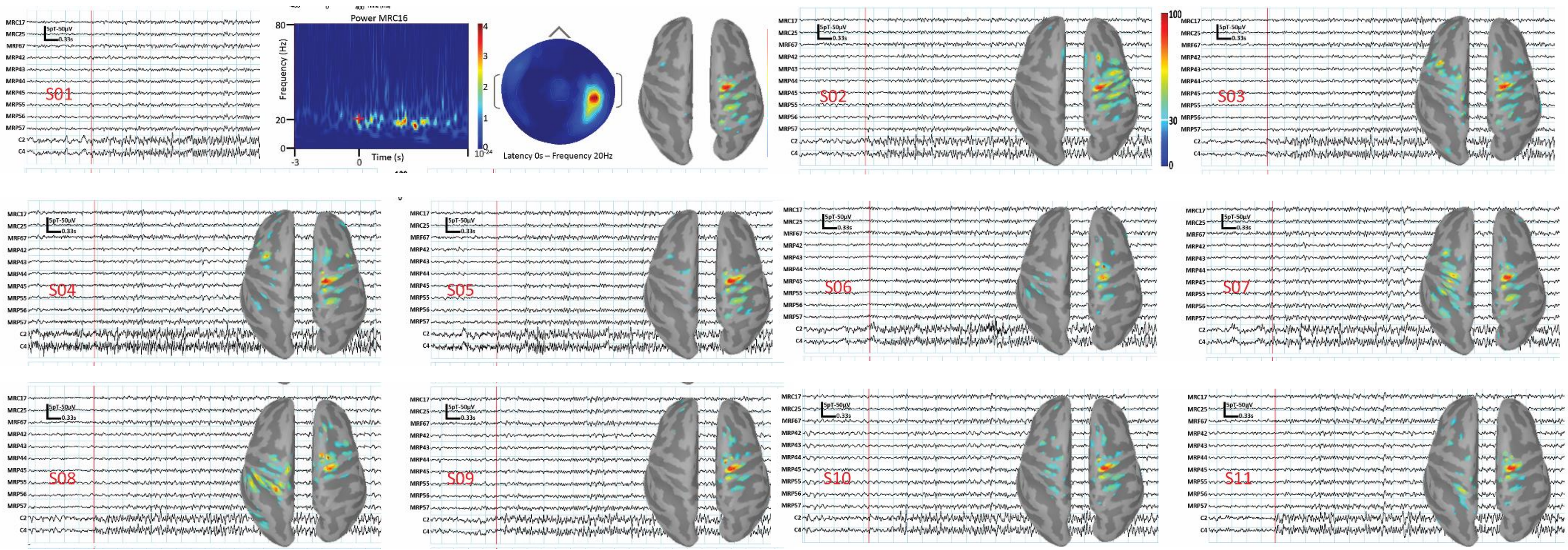
Seizure: 1 2 3 4 5 6 …



Localization of the Seizure Onset Zone (SOZ) from ictal EEG/MEG data, using MEM

Giovanni Pellegrino





Pellegrino et al, HBM 2016

MEG/EEG Localization of the SOZ versus Clinical-SOZ

Giovanni Pellegrino

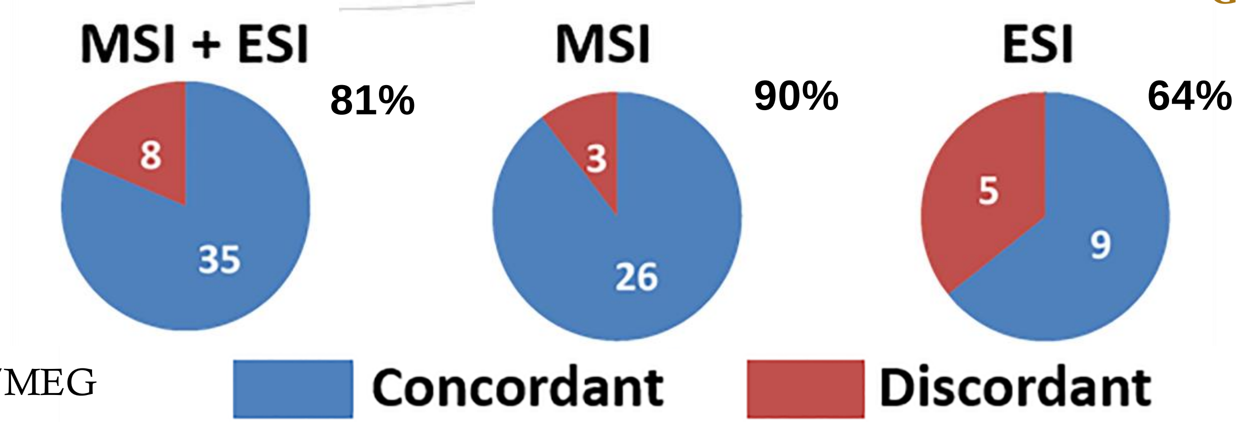
Qualitative analysis

13 Patients

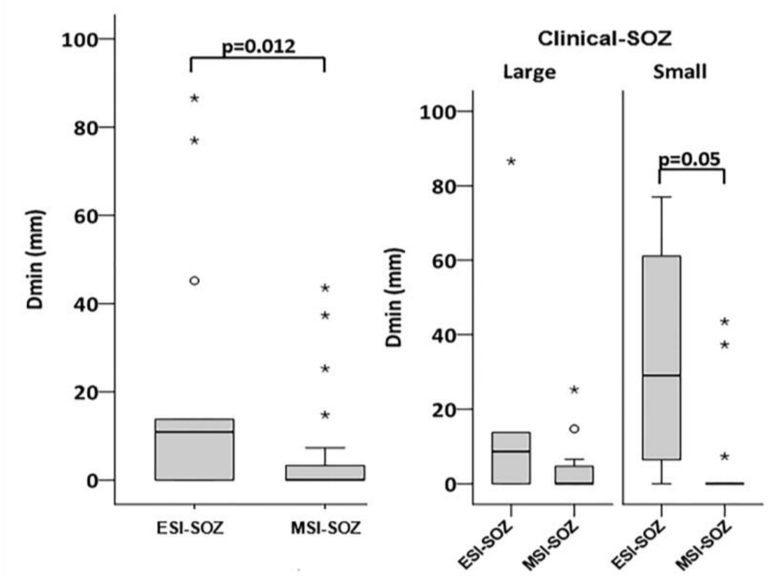
31 seizures:

15 simultaneous EEG/MEG

16 MEG only



Quantitative analysis



ESI: EEG Source Imaging

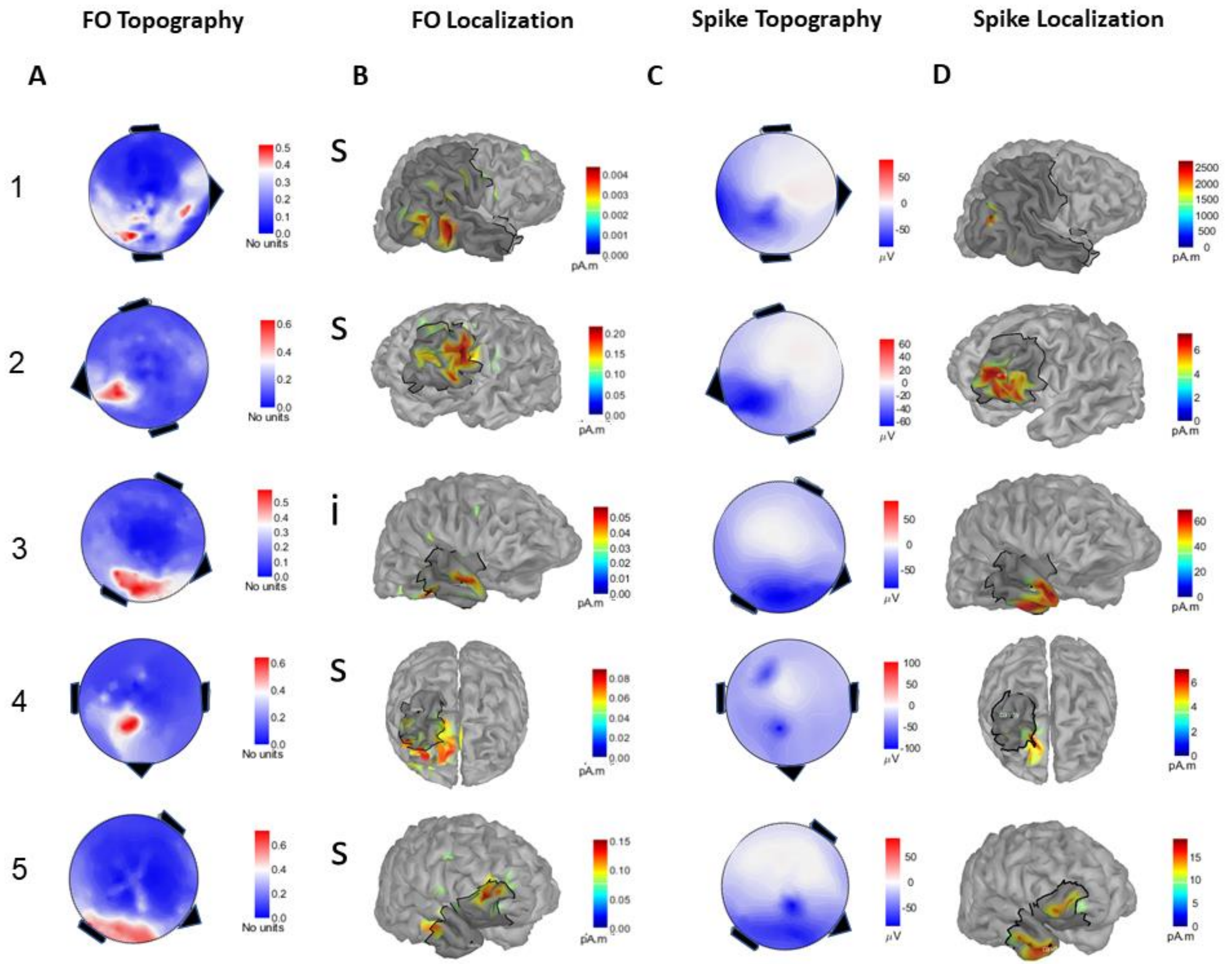
MSI: MEG Source Imaging

Pellegrino et al, Human Brain Mapping 2016

Localization of Fast Oscillations (FO 40-160 Hz) detected from high-density EEG


Tamir Avigdor


Birgit Frauscher



Avigdor et al, Clin Neurophys 2021

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- EEG/MEG source imaging of resting state

MEG localization of resting state oscillations
Validation with the iEEG atlas as ground truth

Jawata Afnan

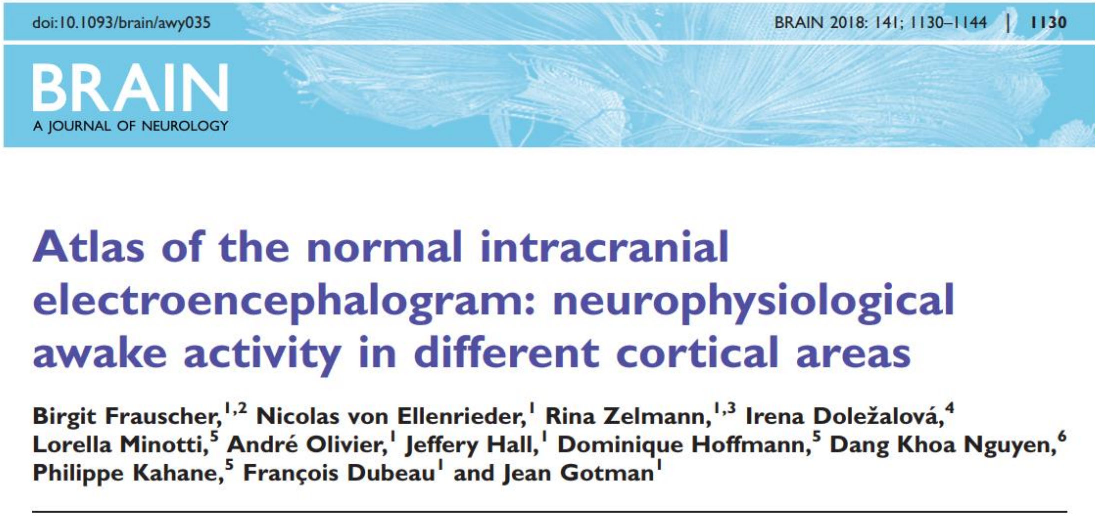
1. MEG source imaging of resting state oscillatory patterns in healthy subjects to be validated at the group level with the iEEG atlas

2. Evaluate the ability of wavelet-based MEM, to localize MEG resting state oscillatory sources in different frequency bands in healthy subjects

Ground truth: the iEEG atlas of normal resting state oscillations

Birgit Frauscher

- Frauscher et al (2018) proposed the first atlas of normal iEEG data
- Pulling together iEEG data from different patients, from different epilepsy centres, in healthy regions, eyes closed, during wakefulness, dense coverage of most brain regions
- Provides unique opportunity to study the spectral characteristics of normal brain oscillatory patterns at a group level

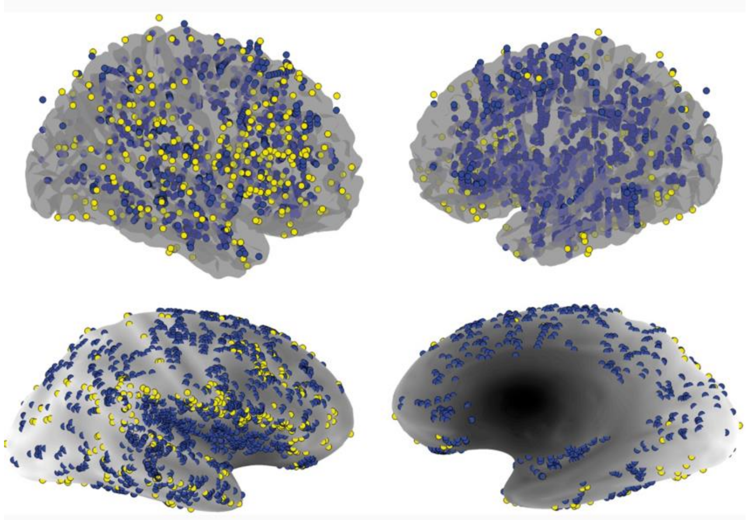


doi:10.1093/brain/awy035 BRAIN 2018: 141; 1130–1144 | 1130

BRAIN
A JOURNAL OF NEUROLOGY

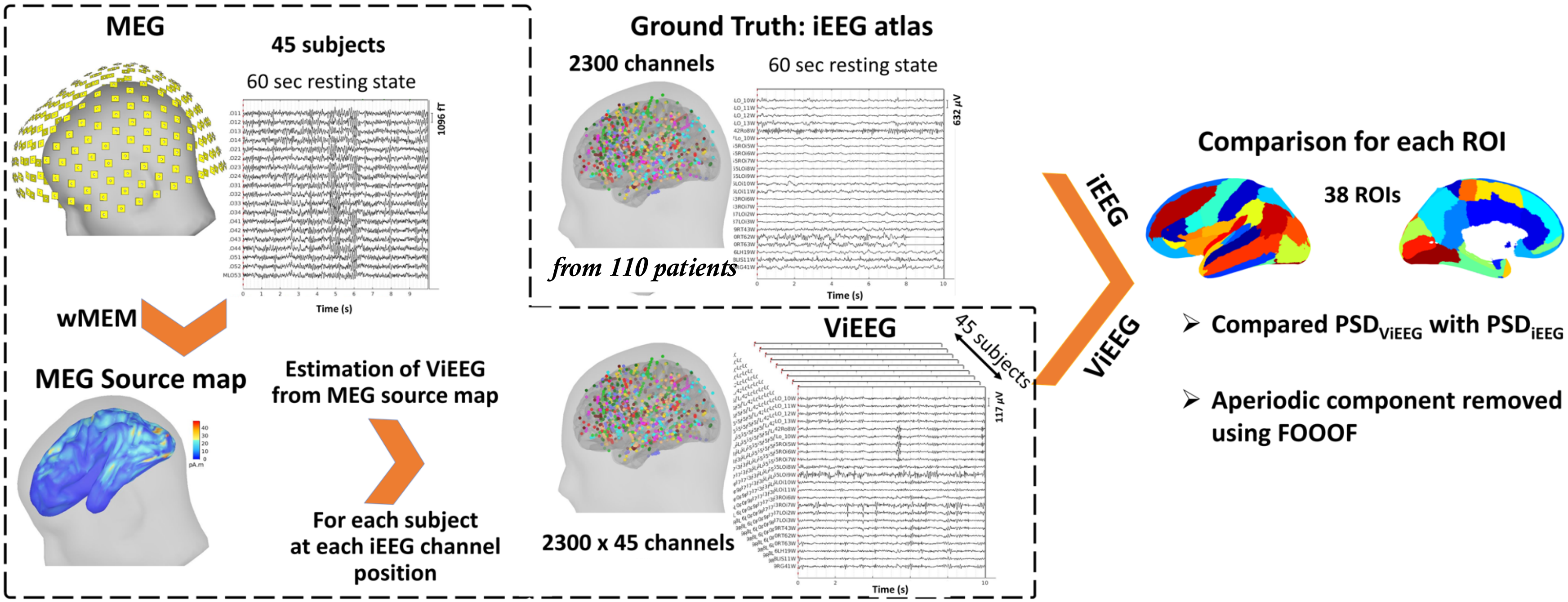
Atlas of the normal intracranial electroencephalogram: neurophysiological awake activity in different cortical areas

Birgit Frauscher,[1,2] Nicolas von Ellenrieder,[1] Rina Zelmann,[1,3] Irena Doležalová,[4] Lorella Minotti,[5] André Olivier,[1] Jeffery Hall,[1] Dominique Hoffmann,[5] Dang Khoa Nguyen,[6] Philippe Kahane,[5] François Dubeau[1] and Jean Gotman[1]



MEG localization of resting state oscillations
Validation with the iEEG atlas as ground truth

Jawata Afnan

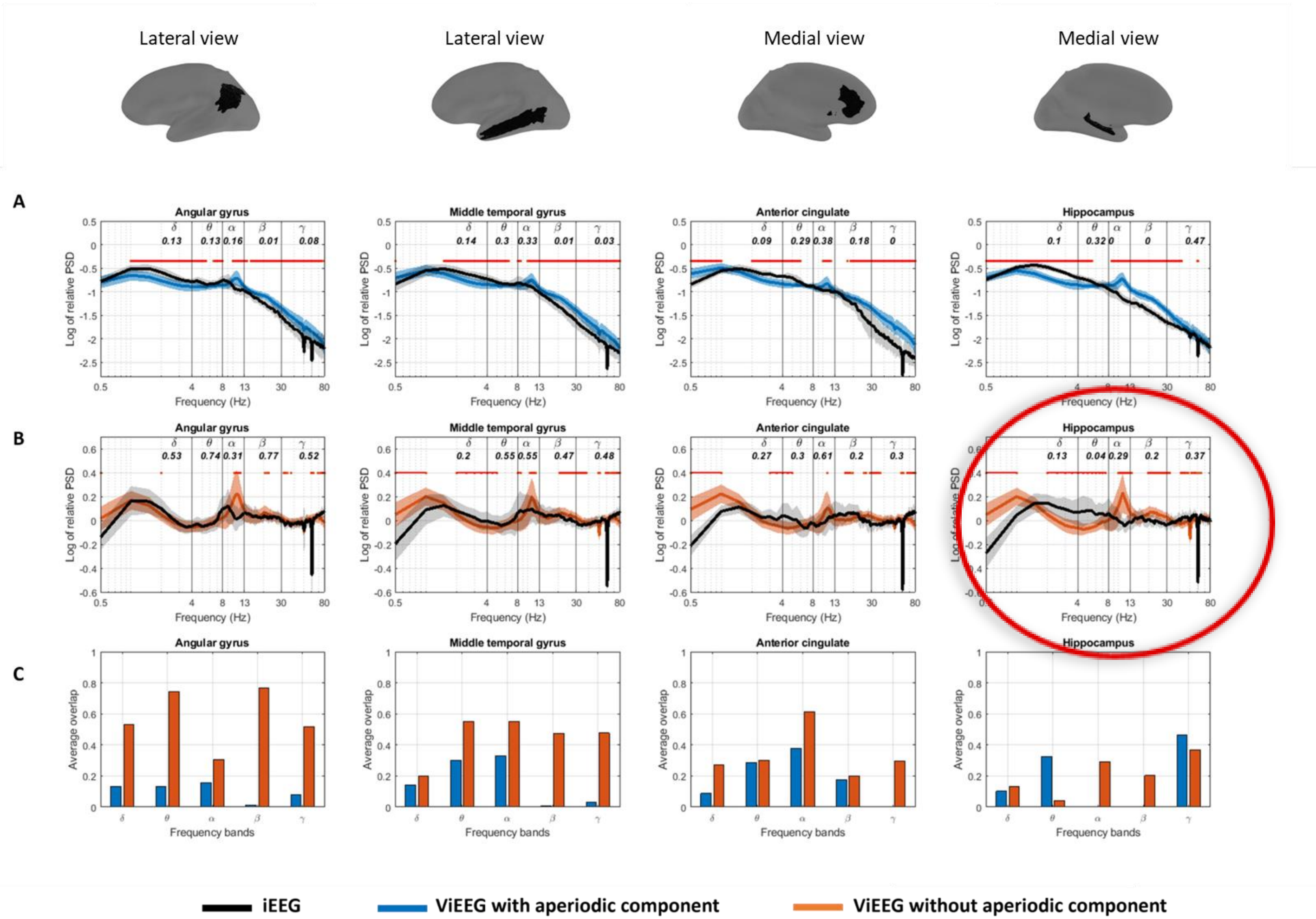


Afnan et al Neuroimage 2023

MEG localization of resting state oscillations
Validation with the iEEG atlas as ground truth

Jawata Afnan

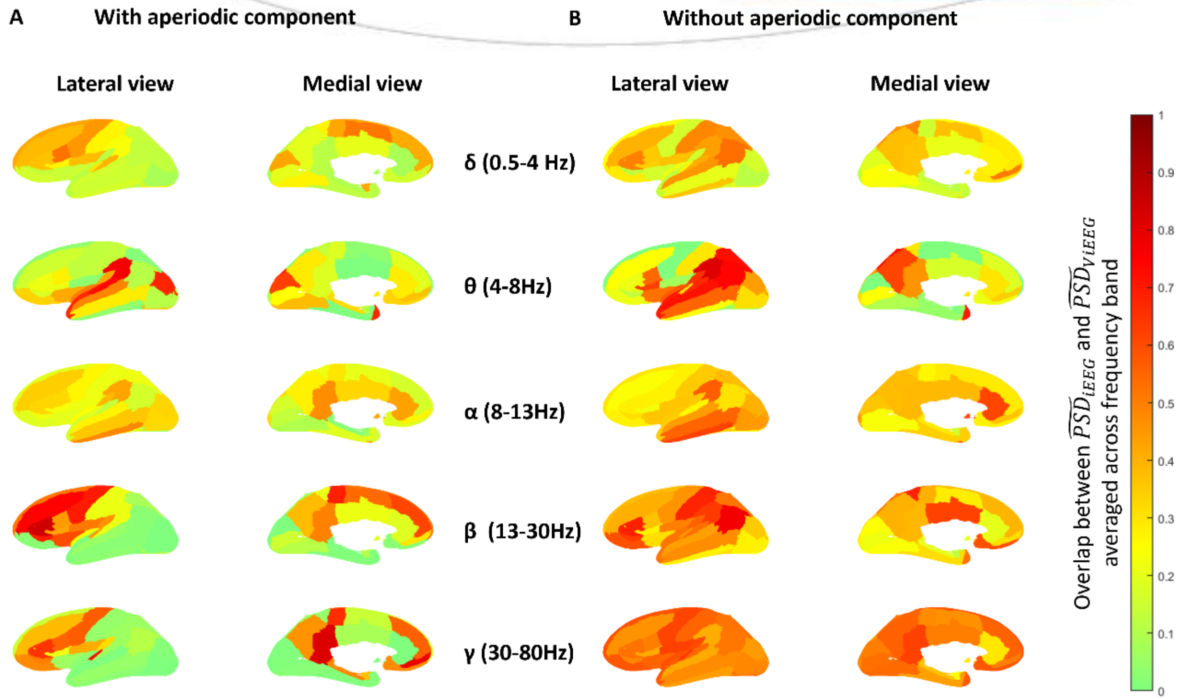
Comparison of MEG estimated spectra using wMEM with ground truth iEEG: selected ROIs



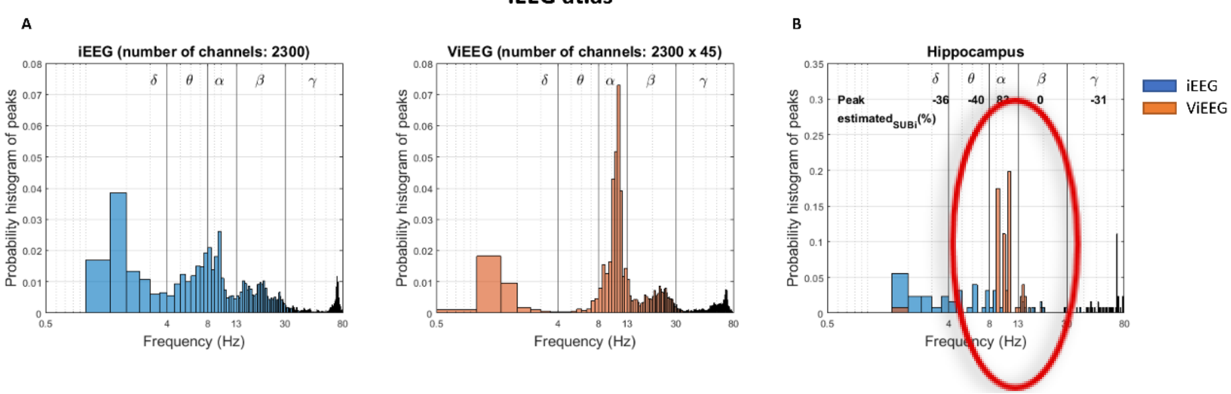
Afnan et al Neuroimage 2023

MEG localization of resting state oscillations
Validation with the iEEG atlas as ground truth

Jawata Afnan



Comparison of oscillatory peaks identified in MEG estimated spectra with MNI iEEG atlas



Overall we retrieved accurate MEG resting state oscillations in most cortical regions in different frequency bands

Results were more comparable with the iEEG atlas after removing aperiodic components

Localization in deeper structures was biased by source leakage, cf. widespread large alpha peak

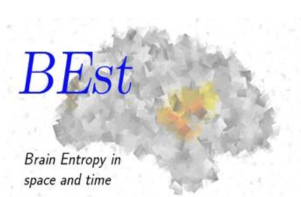
Similar findings when considering wMEM, MNE and Beamformer

Afnan et al Neuroimage 2023

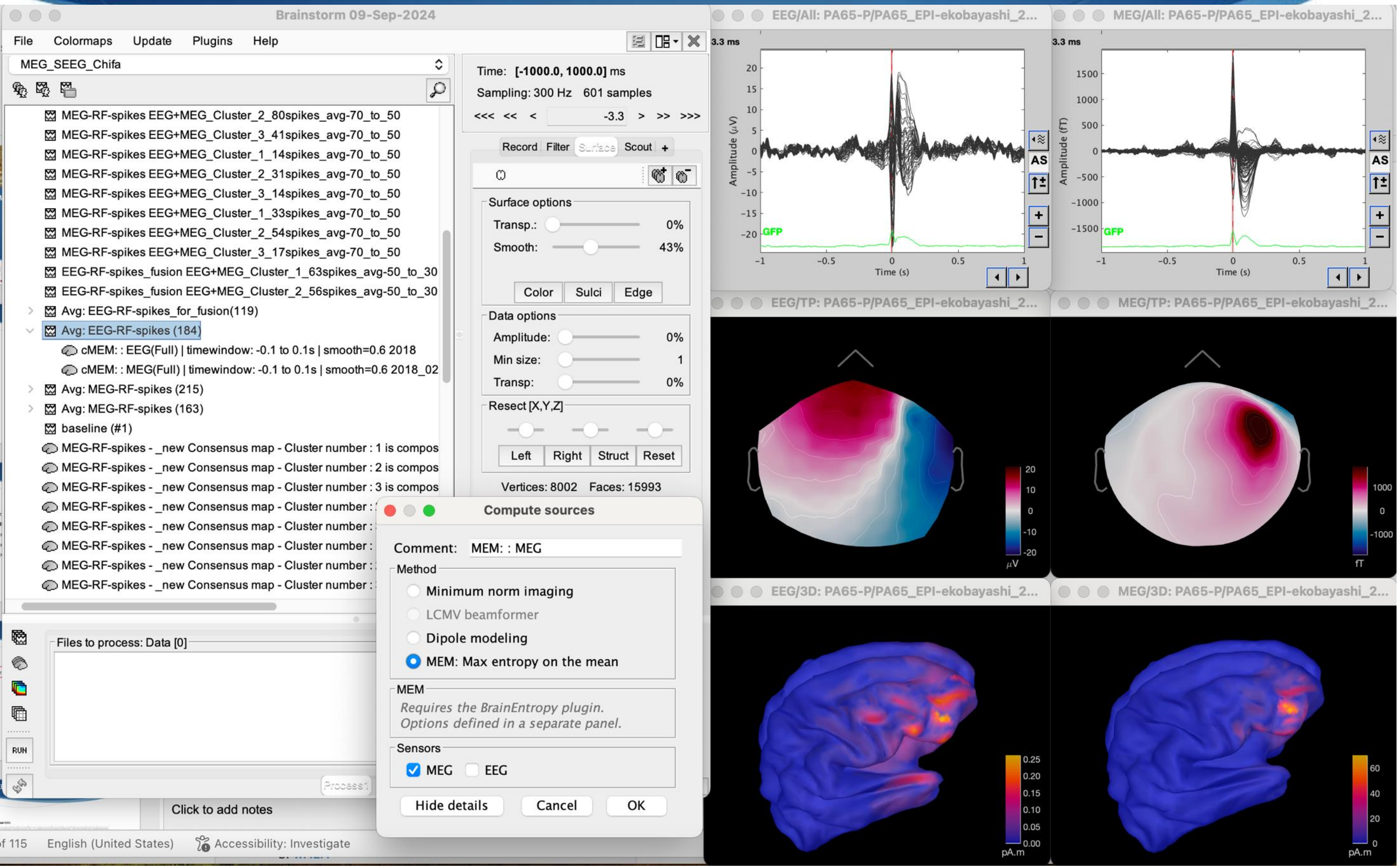
Take home messages

- Several hypotheses associated with each localization method
- From ***dipole fitting*** (requires excellent knowledge / expertise in electrophysiology) to ***source imaging*** (less parameters to tune, but be careful when interpretating)
- All methods are useful, some might be wrong, always assess compatibility with scalp topography, be aware of the methods' assumption when interpreting the data
- Comparison between localization methods is always a plus
- Complementarity between MEG and high-density EEG source imaging
- Localizing deep activity remains challenging, even more during resting state
- Estimation of the spatial extent: our plugin using ***Maximum Entropy on the Mean*** is available in Brainstorm software

MEM is available as a Brainstorm Toolbox



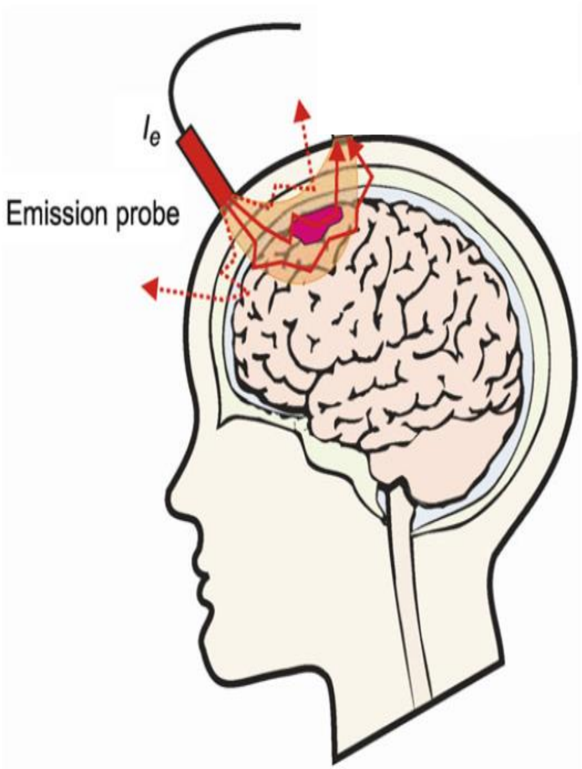
Brainstorm BEst Tutorial
http://neuroimage.usc.edu/brainstorm/Tutorials/TutBEst


Brainstorm 09-Sep-2024
File
Colormaps
Update
Plugins
Help
MEG_SEEG_Chifa
MEG-RF-spikes EEG+MEG_Cluster_2_80spikes_avg-70_to_50
MEG-RF-spikes EEG+MEG_Cluster_3_41spikes_avg-70_to_50
MEG-RF-spikes EEG+MEG_Cluster_1_14spikes_avg-70_to_50
MEG-RF-spikes EEG+MEG_Cluster_2_31spikes_avg-70_to_50
MEG-RF-spikes EEG+MEG_Cluster_3_14spikes_avg-70_to_50
MEG-RF-spikes EEG+MEG_Cluster_1_33spikes_avg-70_to_50
MEG-RF-spikes EEG+MEG_Cluster_2_54spikes_avg-70_to_50
MEG-RF-spikes EEG+MEG_Cluster_3_17spikes_avg-70_to_50
EEG-RF-spikes_fusion EEG+MEG_Cluster_1_63spikes_avg-50_to_30
EEG-RF-spikes_fusion EEG+MEG_Cluster_2_56spikes_avg-50_to_30
Avg: EEG-RF-spikes_for_fusion(119)
Avg: EEG-RF-spikes (184)
cMEM: : EEG(Full) | timewindow: -0.1 to 0.1s | smooth=0.6 2018
cMEM: : MEG(Full) | timewindow: -0.1 to 0.1s | smooth=0.6 2018_02
Avg: MEG-RF-spikes (215)
Avg: MEG-RF-spikes (163)
baseline (#1)
MEG-RF-spikes - _new Consensus map - Cluster number : 1 is compos
MEG-RF-spikes - _new Consensus map - Cluster number : 2 is compos
MEG-RF-spikes - _new Consensus map - Cluster number : 3 is compos
Files to process: Data [0]
RUN
Process1
Time: [-1000.0, 1000.0] ms
Sampling: 300 Hz 601 samples
-3.3
Record
Filter
Surface
Scout
Surface options
Transp.: 0%
Smooth: 43%
Color
Sulci
Edge
Data options
Amplitude: 0%
Min size: 1
Transp: 0%
Resect [X,Y,Z]
Left
Right
Struct
Reset
Vertices: 8002 Faces: 15993
Compute sources
Comment: MEM: : MEG
Method
Minimum norm imaging
LCMV beamformer
Dipole modeling
MEM: Max entropy on the mean
MEM
Requires the BrainEntropy plugin.
Options defined in a separate panel.
Sensors
MEG
EEG
Hide details
Cancel
OK
Click to add notes
English (United States)
Accessibility: Investigate
EEG/All: PA65-P/PA65_EPI-ekobayashi_2...
MEG/All: PA65-P/PA65_EPI-ekobayashi_2...
3.3 ms
Amplitude (μV)
Amplitude (fT)
GFP
Time (s)
AS
EEG/TP: PA65-P/PA65_EPI-ekobayashi_2...
MEG/TP: PA65-P/PA65_EPI-ekobayashi_2...
μV
fT
EEG/3D: PA65-P/PA65_EPI-ekobayashi_2...
MEG/3D: PA65-P/PA65_EPI-ekobayashi_2...
pA.m

Part 2: NIRSTORM analysis of fNIRS data from optimal probe design to 3D reconstruction

What is functional Near Infra-Red Spectroscopy (fNIRS)?

- fNIRS measures non-invasively fluctuations of both oxygenated and deoxygenated hemoglobin (HbO and HbR) in the brain with high temporal resolution
- How does it work?

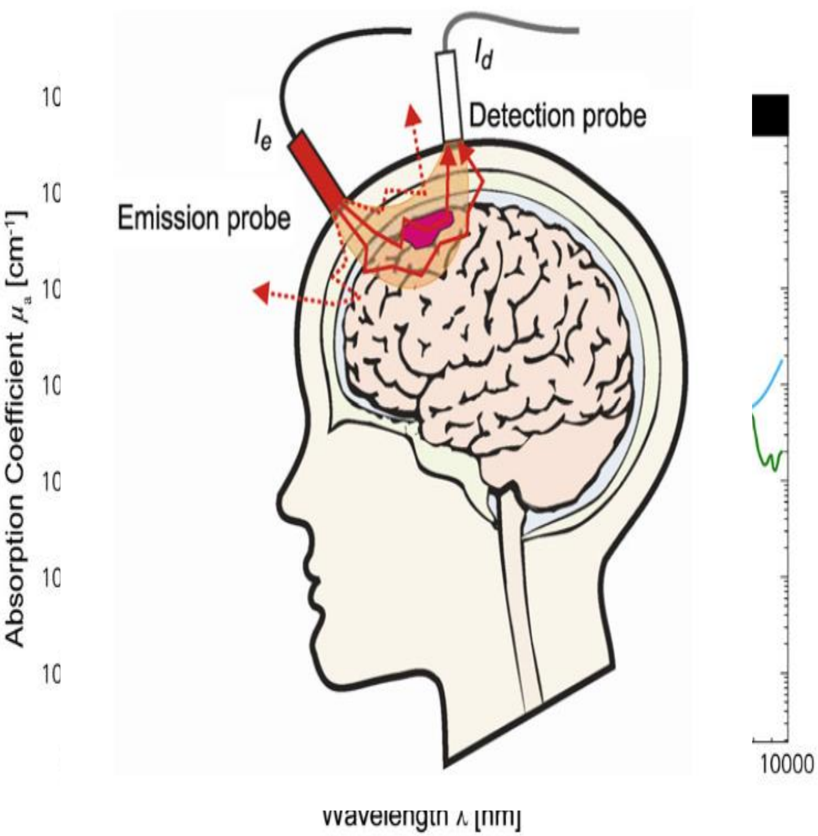


Scholkmann et al., Neuroimage 2014

- Emit light into the head
- Light propagates everywhere
- Put a detector 3cm away from source
- Light path is a "banana" shape
- The bottom of the "banana" could reach cortex

What is functional Near Infra-Red Spectroscopy (fNIRS)?

- fNIRS measures non-invasively fluctuations of both oxygenated and deoxygenated hemoglobin (HbO and HbR) in the brain with high temporal resolution
- How does it work?



Scholkmann et al., Neuroimage 2014

Hemoglobin absorbs the light

↓

If hemoglobin concentration changes

↓

Light intensity will change

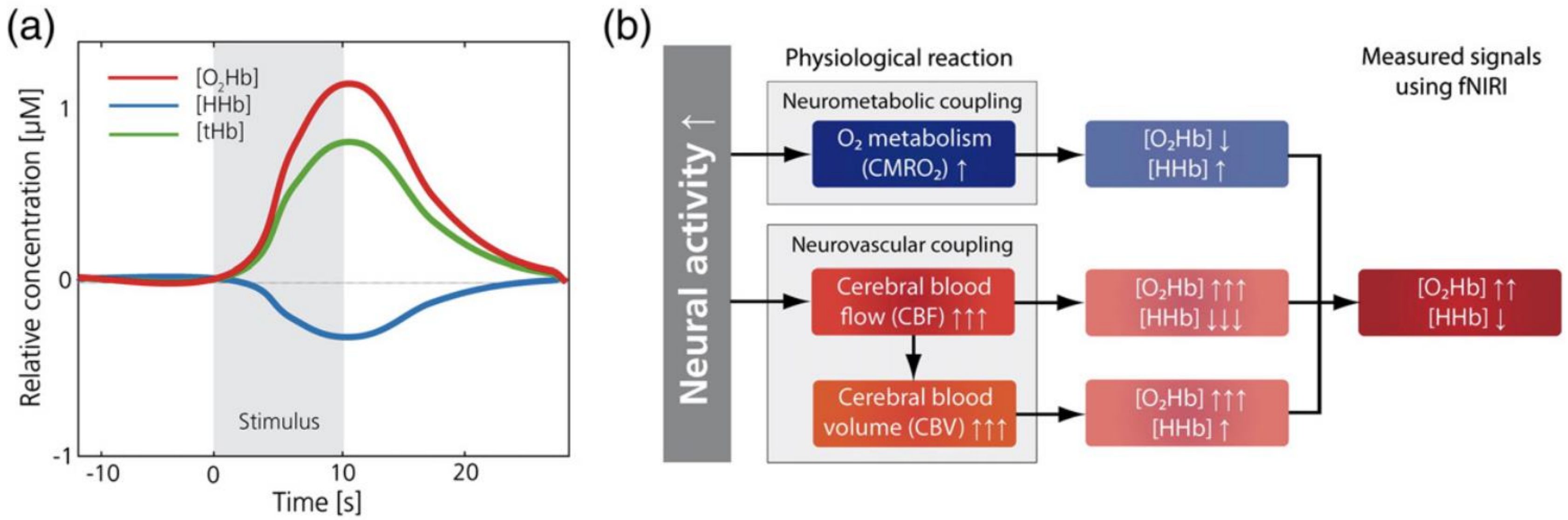
↓

HbO/HbR at least 2 wavelengths

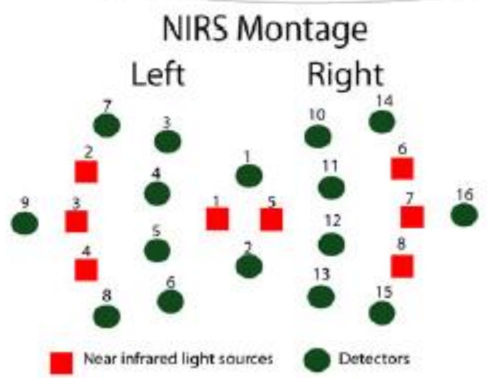
↓

2 equations
modified Beer–Lambert law
with 2 unknowns
problem solved

Origins of fNIRS signals



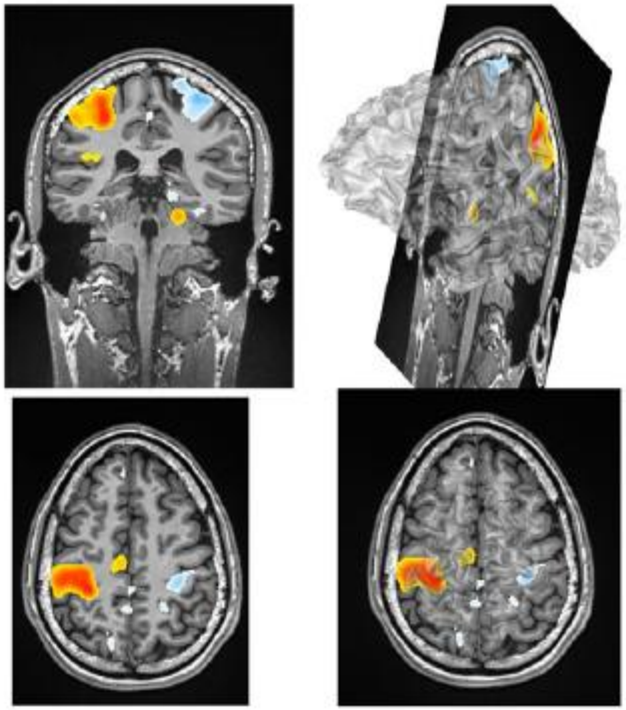
Finger opposition task in fMRI and NIRS



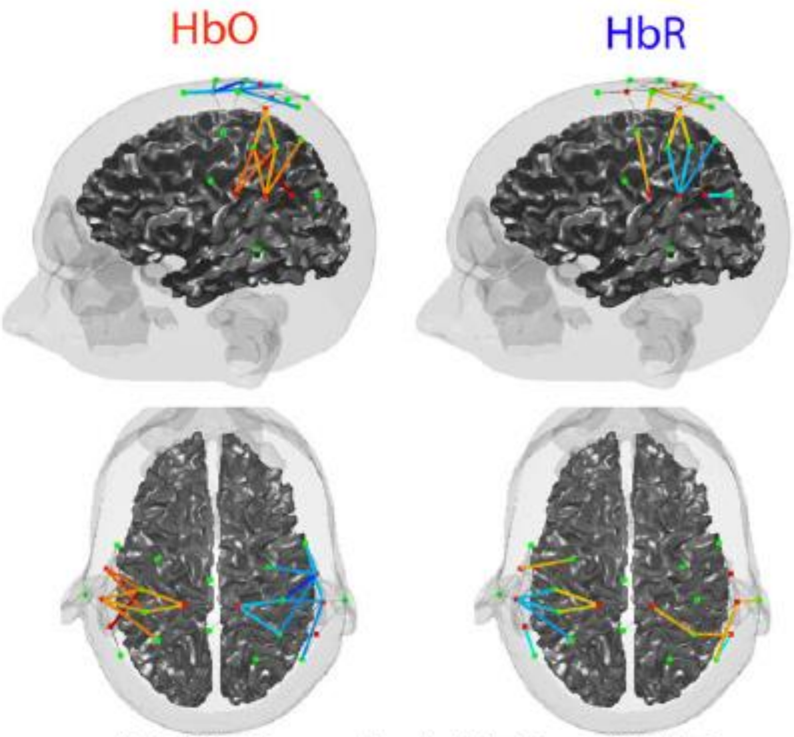
(i) NIRS montage using 8 sources at 690 nm, 8 sources at 830 nm (red squares) an 16 detectors (green circles)

(ii) Installation of Brainsight fibers equipped with low profile prisms on the EEG/NIRS cap

Finger opposition task in fMRI and NIRS

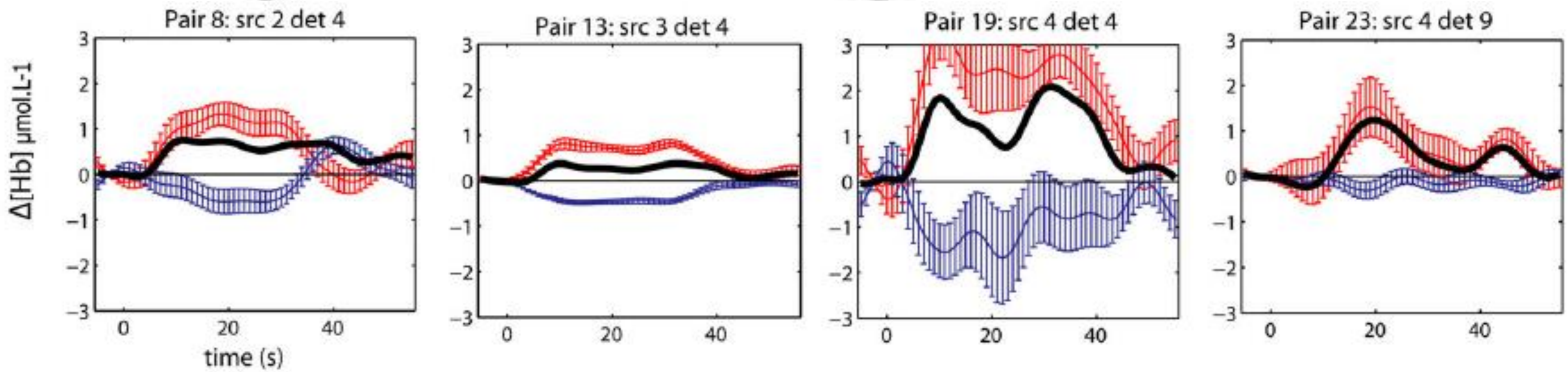


(iii) BOLD response: t-map superimposed on anatomical MRI (cortical surface in transparency)

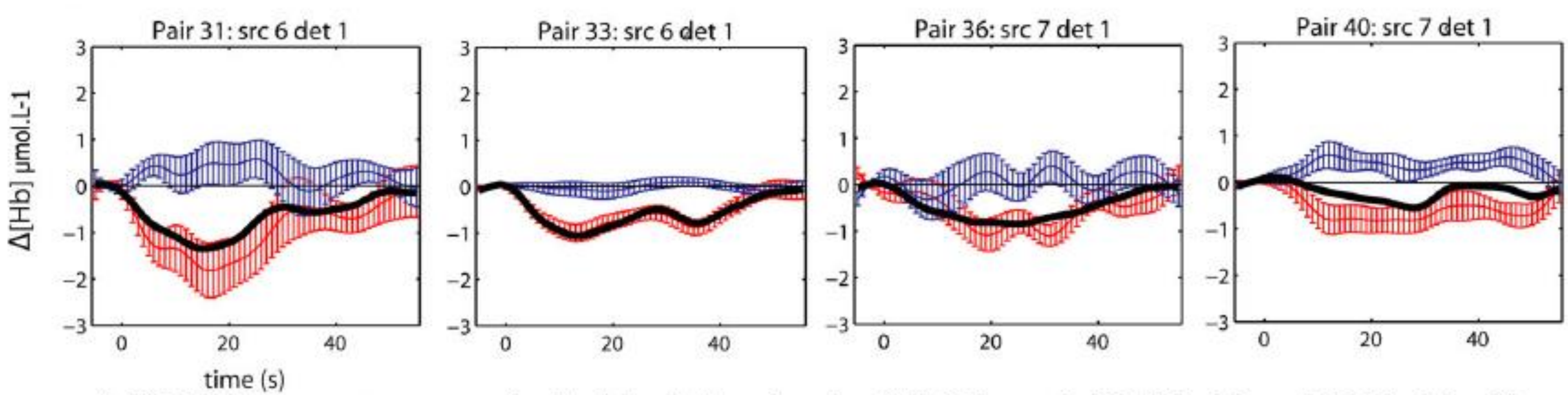


(iv) NIRS results in HbO and HbR over the cortical surface of the subject. For each channel: t-values in color

Finger opposition task in fMRI and NIRS



(v) NIRS response on selected contralateral pairs (HbO in red, HbR in blue, HbT in black)



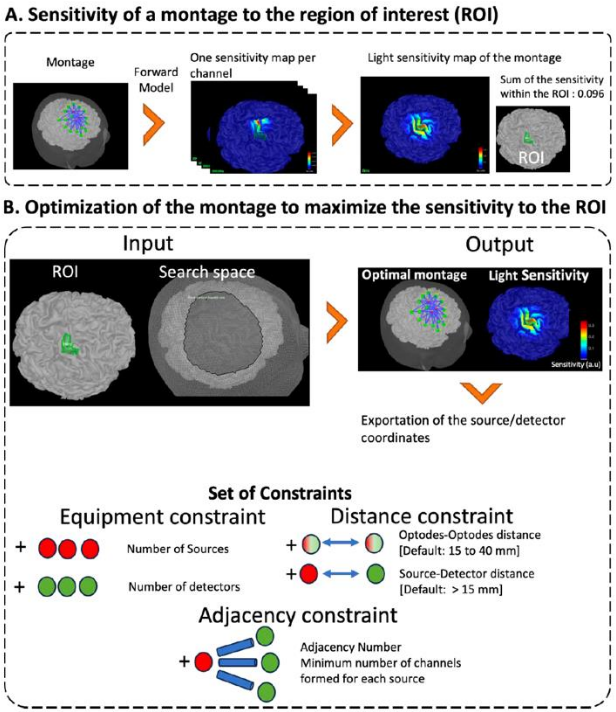
(vi) NIRS response on selected ipsilateral pairs (HbO in red, HbR in blue, HbT in black)

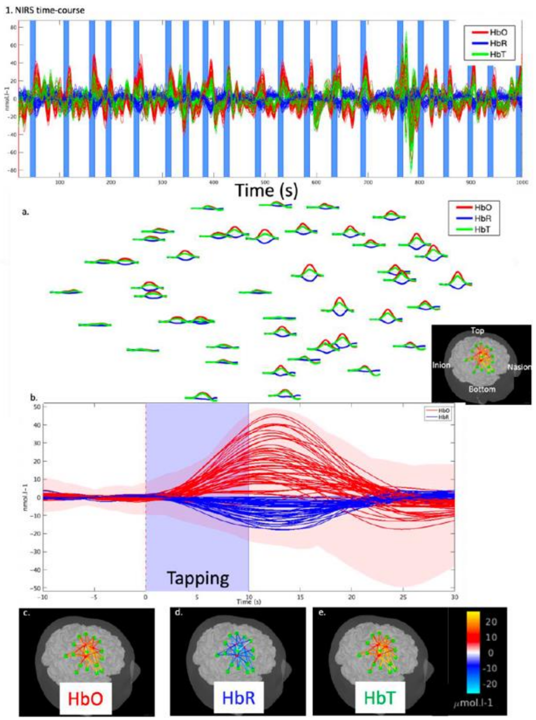
bioRxiv
THE PREPRINT SERVER FOR BIOLOGY

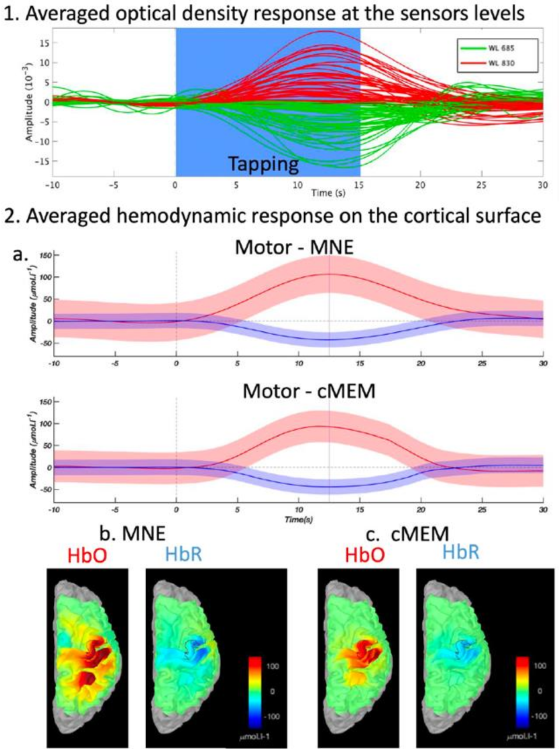
NIRSTORM: a Brainstorm extension dedicated to functional Near Infrared Spectroscopy (fNIRS) data analysis, advanced 3D reconstructions, and optimal probe design

Édouard Delaire, Thomas Vincent, Zhengchen Cai, Alexis Machado, Laurent Hugueville, Denis Schwartz, Francois Tadel, Raymundo Cassani, Louis Bherer, Jean-Marc Lina, Mélanie Pélégrini-Issac, Christophe Grova

doi: https://doi.org/10.1101/2024.09.05.611463





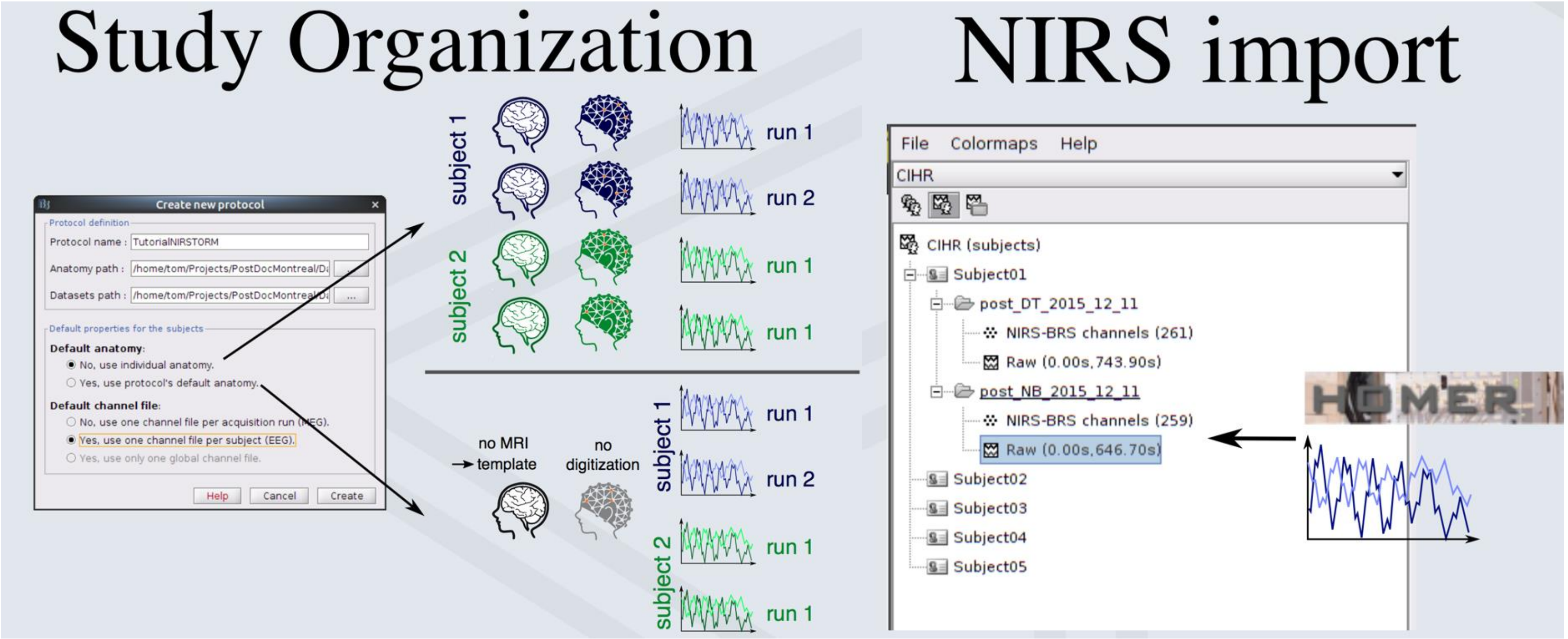


NIRSTORM

Delaire et al under rev, Bioarxiv 2024

1. fNIRS standard sensor level analysis

Data organization / Data input



Input Data format:

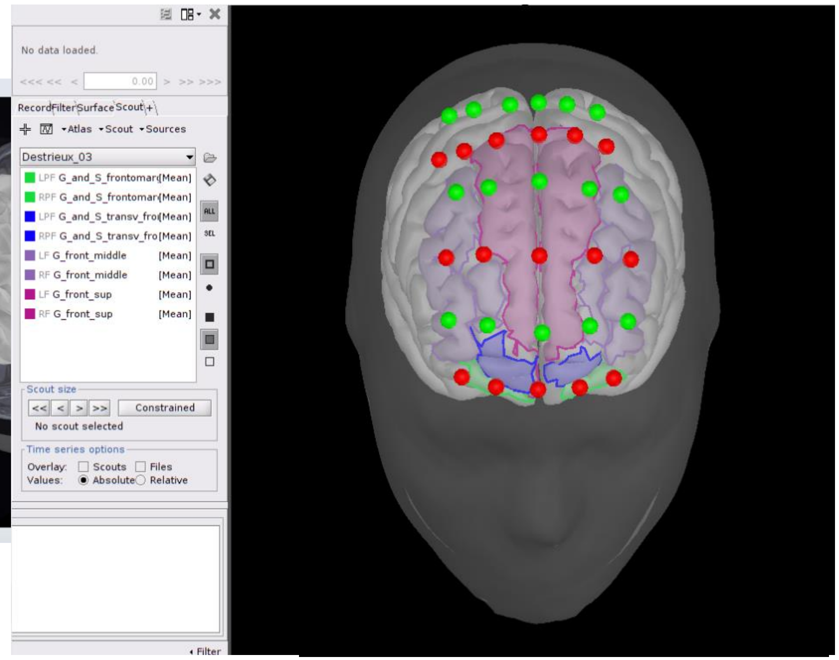
.nirs as in Homer

.snirf file

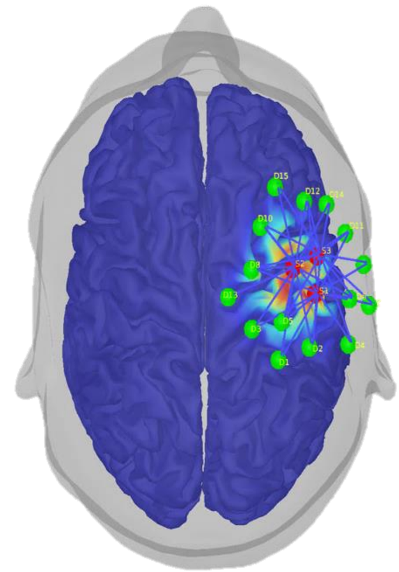
…

Standard NIRS data analysis in the sensor space
Visualization features

Anatomical Model
subject specific or Template



Overlay on anatomical atlases



Optimal fNIRS montage
targeting the right hand knob

Standard fNIRS data analysis in the sensor space
Typical preprocessing pipeline

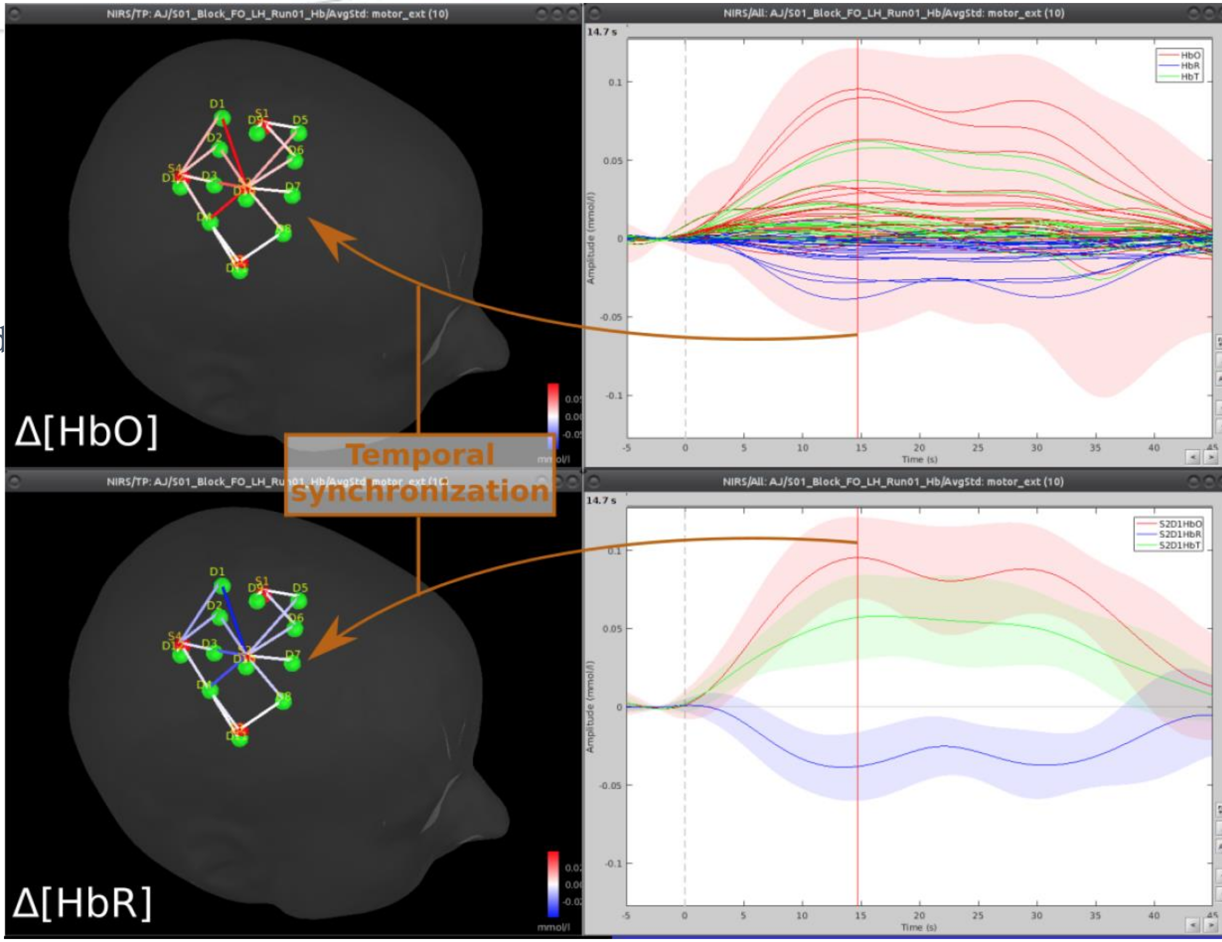
1. Importing data and trigger exploration, verification, removal of bad channels

2. Motion Detection / Correction

3. Conversion in HbO/HbR Modified Beer Lambert Law

4. Band Pass Filtering (0.005-0.08Hz), short distance channel regression

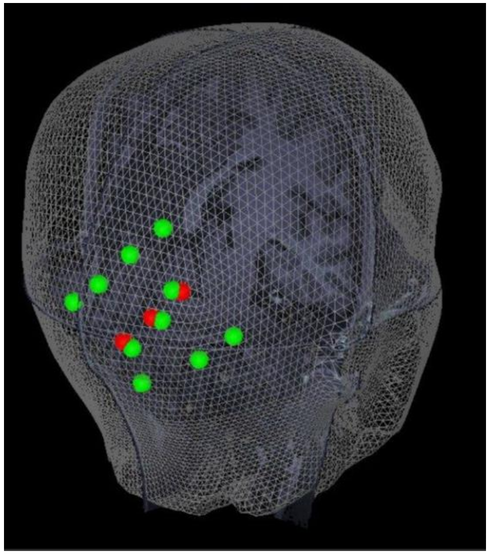
5. Signal averaging and interaction with the data

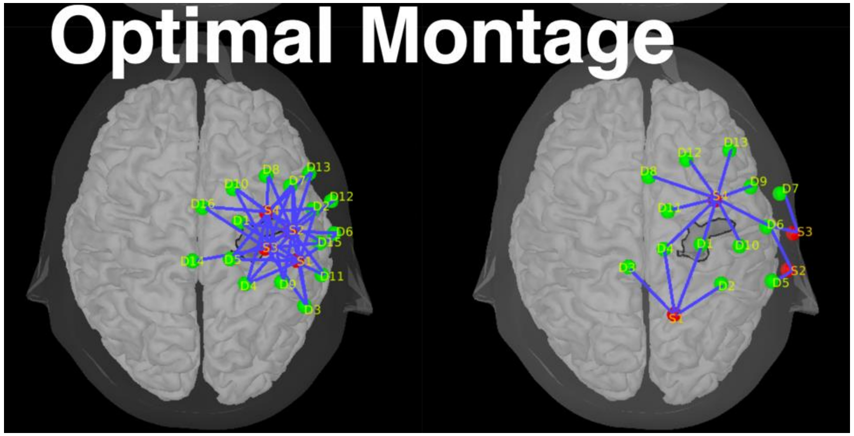


Taking benefit from Brainstorm
EEG/MEG developments: filtering, PCA, ICA, SSP, Wavelets, connectivity measures …

Personalized fNIRS:

Optimal Montage Design

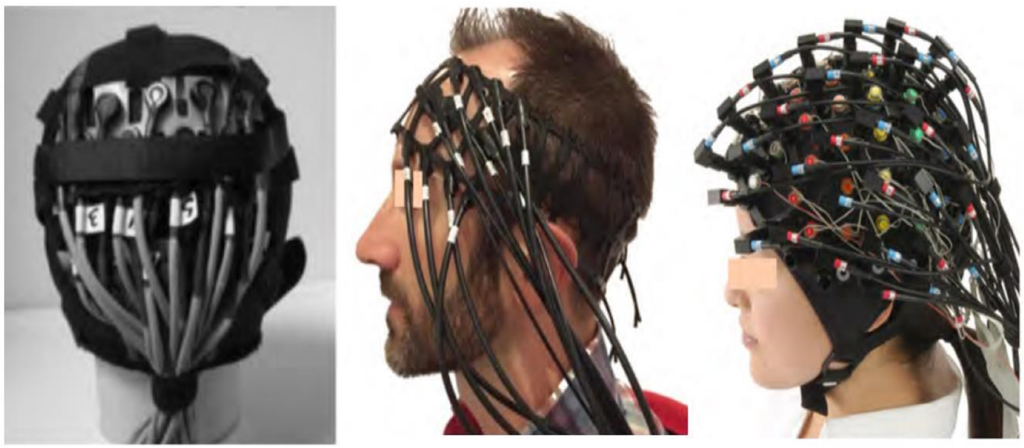




Optimal Montage Design: motivations

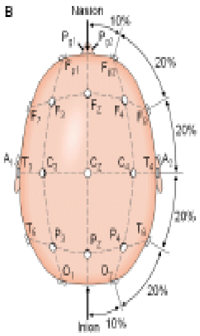
- No standard procedures: Many different probe designs proposed

Velcro patches   Elastic nets   Semi rigid



- Difficulty to assess the cortical area being illuminated
- Difficult to maintain optode contact for long periods
- Difficulty to integrate montages with an EEG positioning system

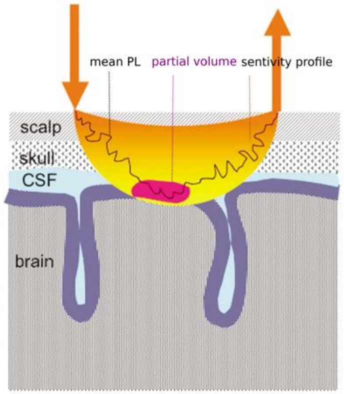
EEG 10-20 international system



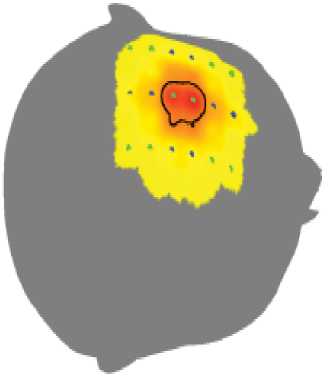
Development of personalized "Optimal NIRS montages"

Alexis Machado

Light sensitivity profile



Δ[HbO] interpolation on the scalp



- How to ensure that the target area is well illuminated ?

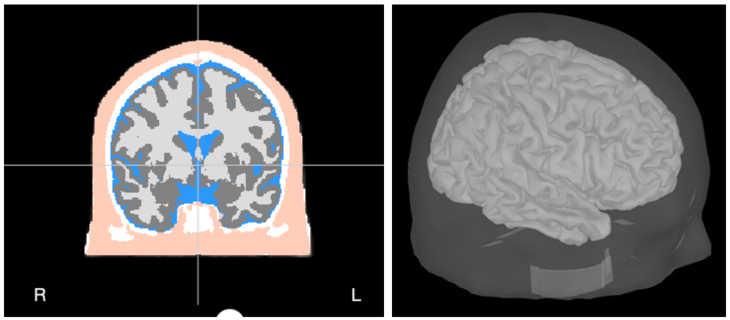
Methodology to find the best optode positions over target brain regions

Machado et al. 2014, Journal of Biomedical Optics

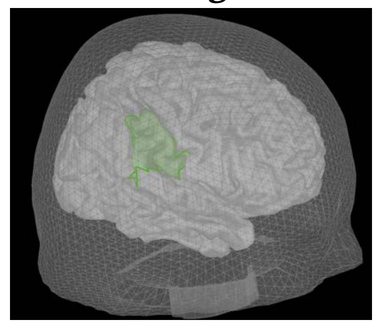
Machado et al, 2018, JNS – Methods

Development of personalized "Optimal fNIRS montages"

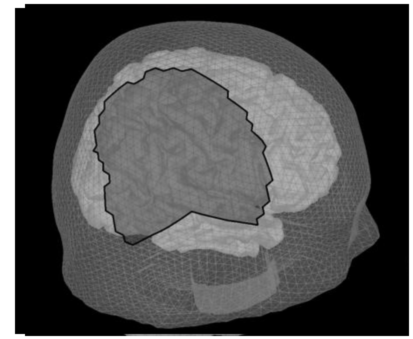
Anatomical Information
Head model for light propagation modeling



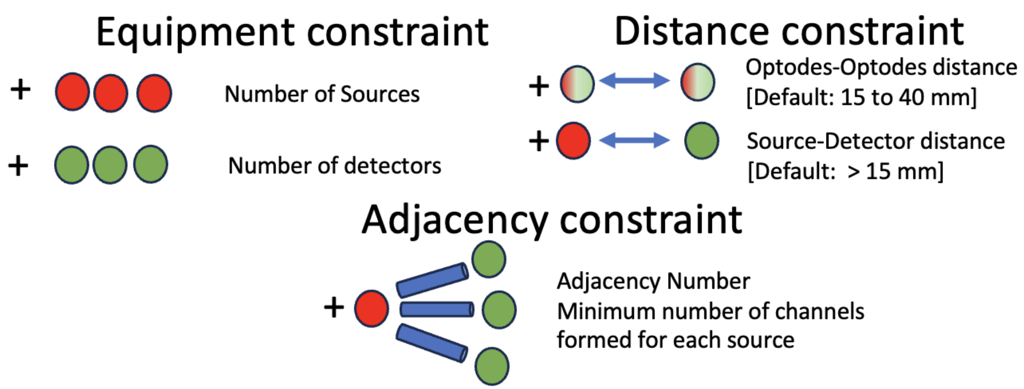
Region of Interest
To target



Optodes possible locations on the skin (search space)



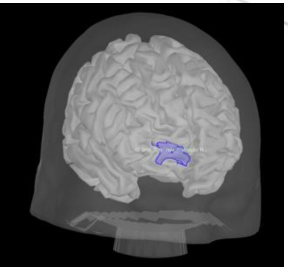
Definition of the constraints to search for an Optimal Montage



Machado et al. 2014, Journal of Biomedical Optics

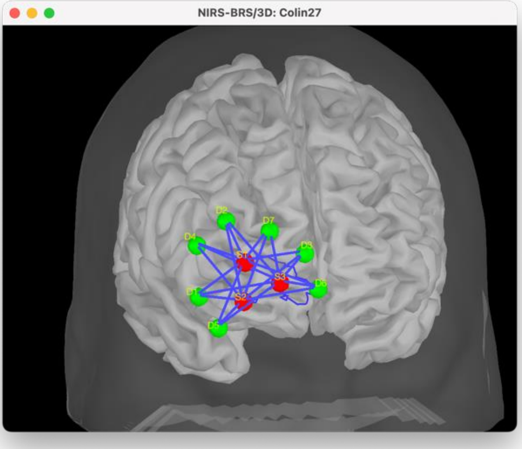
Machado et al, 2018, JNS – Methods

Development of personalized "Optimal fNIRS montages"

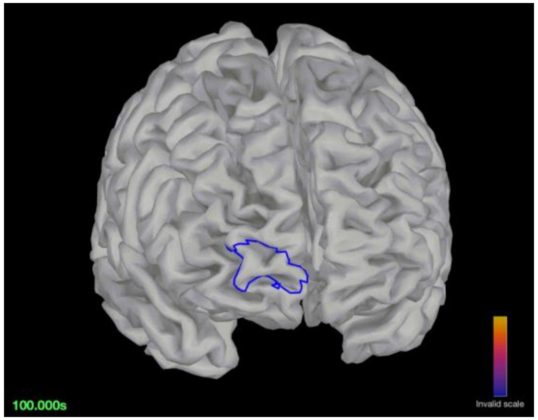


Targeted right
Fronto polar region

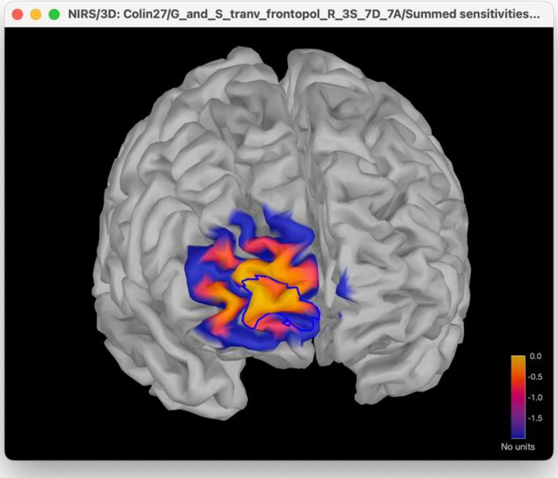
fNIRS montage



Light sensitivity map



Summed Light sensitivity map

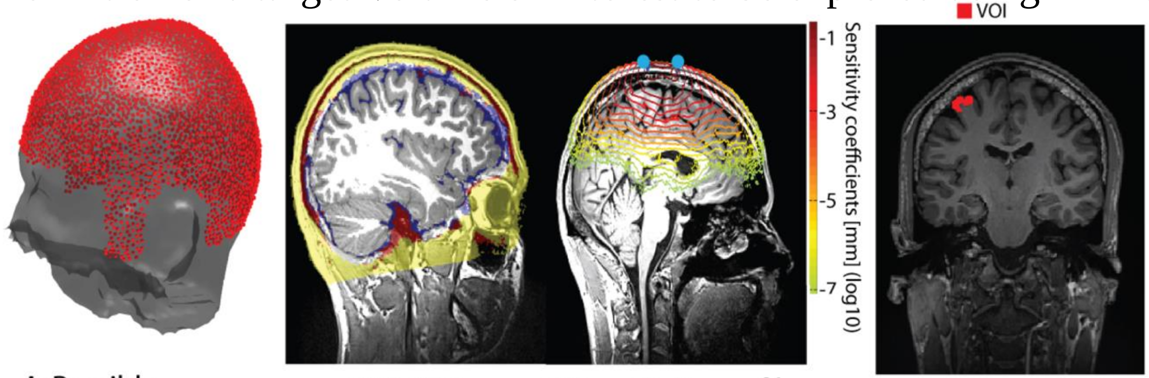


Machado et al. 2014, Journal of Biomedical Optics
Machado et al, 2018, JNS – Methods

Personalized NIRS using "Optimal NIRS montages"

Alexis Machado

Definition of a target Volume of Interest to be explored using fNIRS



A: Possible optode positions

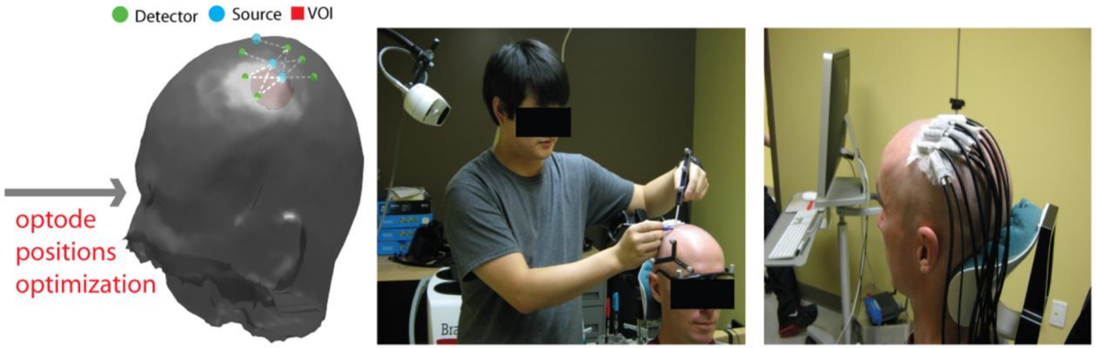
B: T1 MRI

C: Sensitivity profile for one couple of vertices

D: Target VOI

Maximizing a priori light sensitivity to the target and spatial overlap between channels

Mixed integer linear programming problem (CPLEX, IBM)



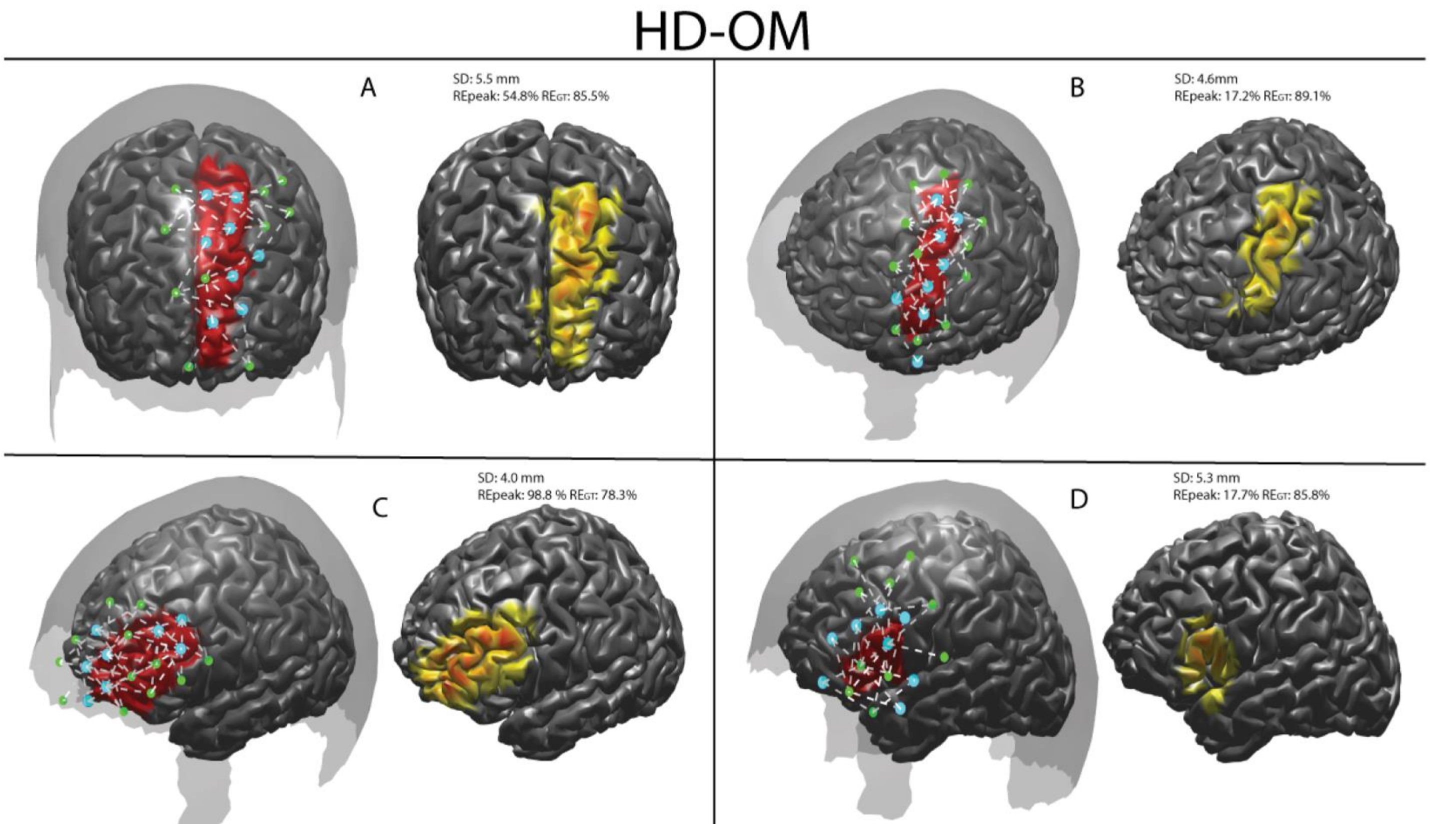
E : Resulting optimal montage

F : Neuronavigation

G : Installation using collodion

Personalized NIRS using “Optimal NIRS montages”

Alexis Machado



Machado et al, J Biomed Optic 2014, JNS – Methods, 2018, Sci. Report 2021

Personalized fNIRS using optimal montage: dataset considered for NIRSTORM webinar

Personalized fNIRS channel layout design using anatomical head MRI

- Optical head model using a Monte Carlo photon simulator (Fang and Boas, 2009)
- Personalized optimal montage targeting the right hand knob (Machado et al., 2018)

What is optimal montage?

- Maximization of spatial sensitivity of fNIRS measurements targeting a specific brain region, and maximizing spatial overlap between sensors

  - Hand knob 16.7 cm^2 (black profile)

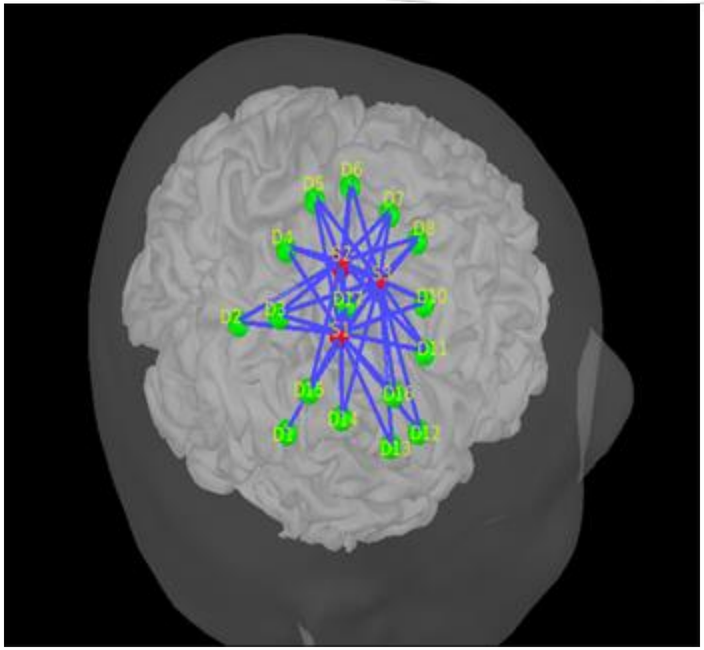
- Pre-set # of sources, detectors and the density of channels

  - 3 Sources, 15 Detectors, at least 13 Detectors seeing each source , source-detector separation 1.5~4cm

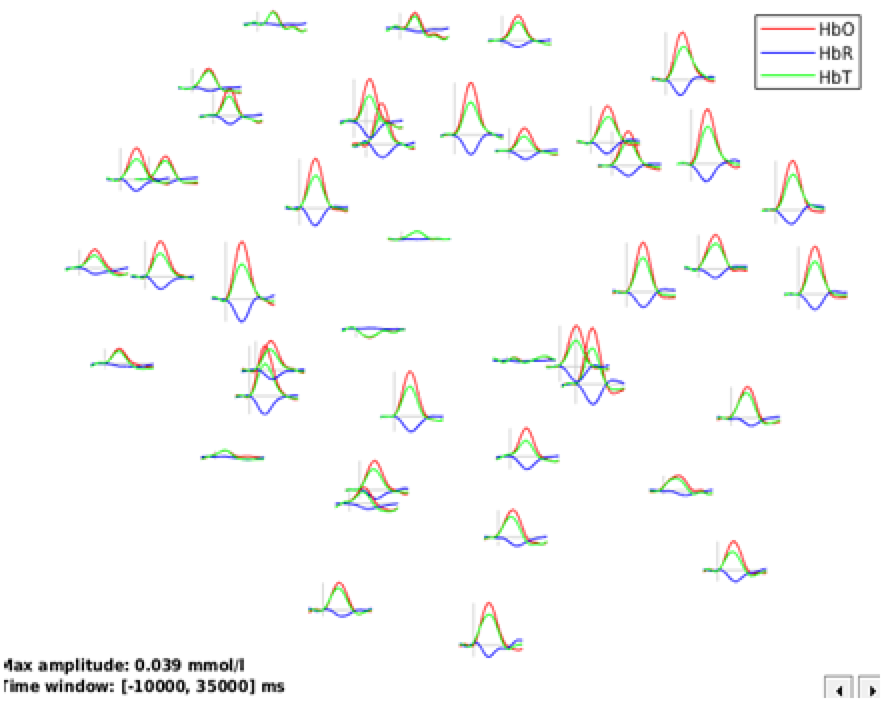
- Use of collodion to glue optodes on the scalp, ensuring good optical contact for prolonged investigations (Yücel et al., Neuroimage, 2014; Pellegrino et al., Frontiers Neurosc, 2016)

- Finger opposition task at 2Hz, 20 Blocks of 10s with an inter-stimulus period ranging from 30 to 60s, Brainsight fNIRS device (Rogue-Research Inc, Montreal)

Standard NIRS data analysis on data measured using the optimal montage

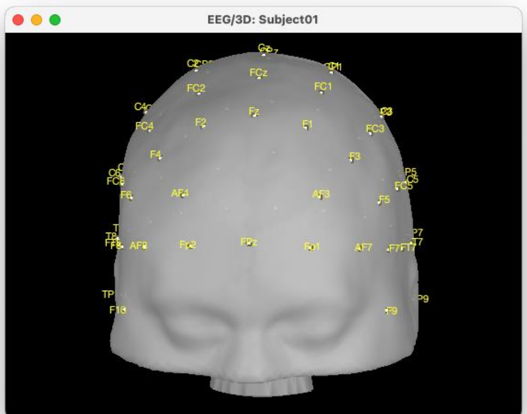


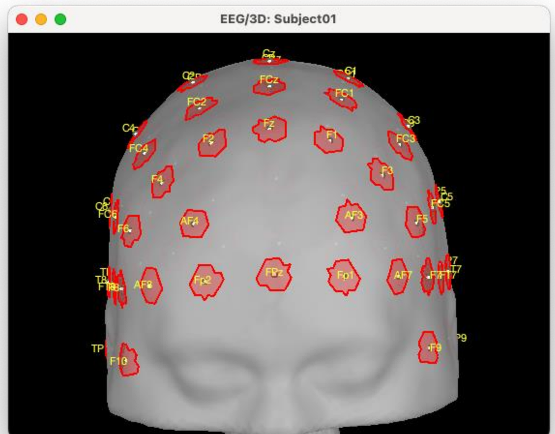
Optimal Montage targeting
the right hand knob region
+ 1 additional detector
between the three sources
To obtain three short distance channels



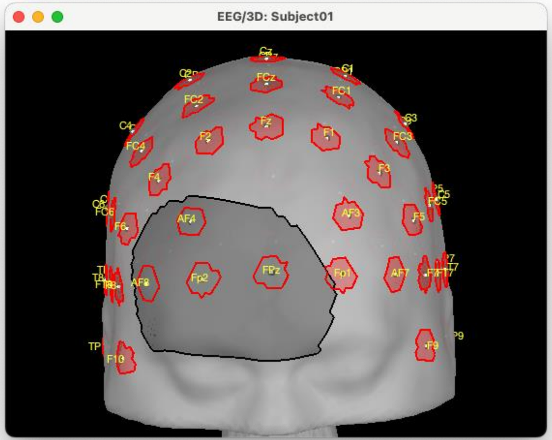
Average response
Band pass filter 0.005 – 0.08Hz
+ Short distance channel regression

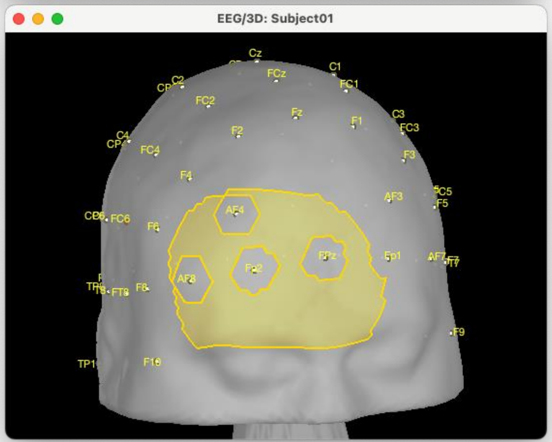
Optimal fNIRS montage, taking into account EEG position constraints





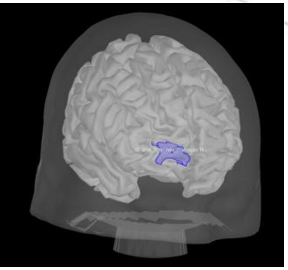
Avoiding the positions of an EEG cap





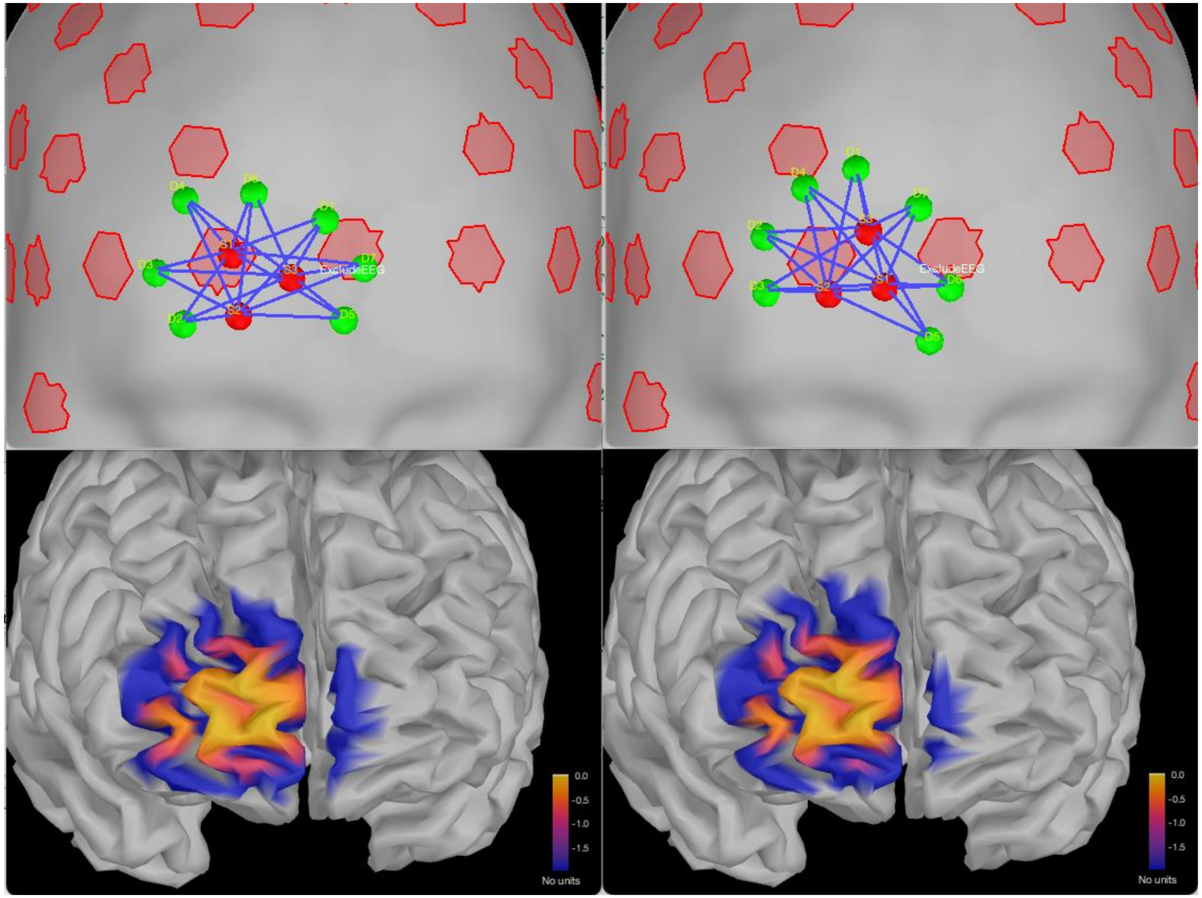
Updating the search space

Optimal fNIRS montage, taking into account EEG position constraints



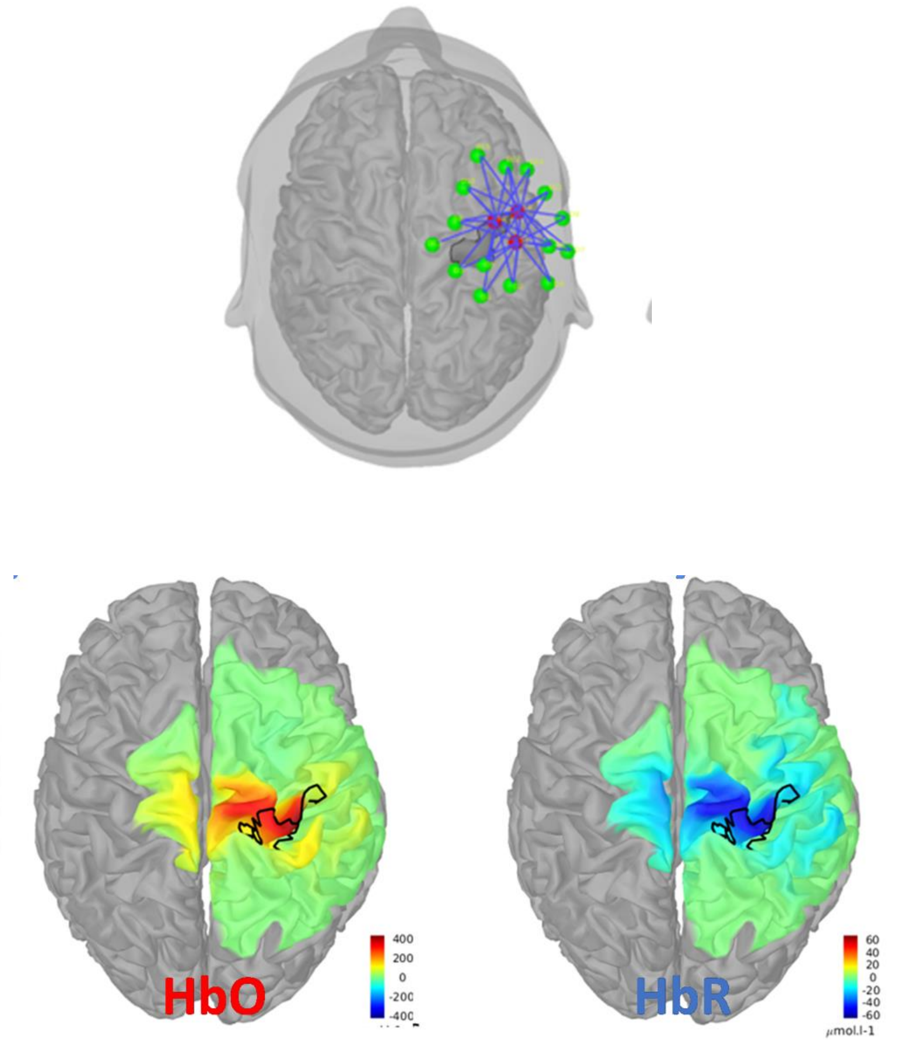
Targeted right

Fronto polar region



fNIRS 3D Reconstructions

Diffuse Optical Tomography (DOT)

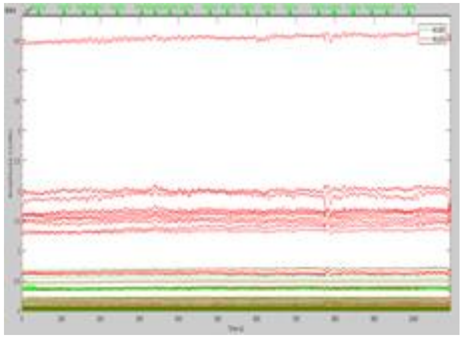


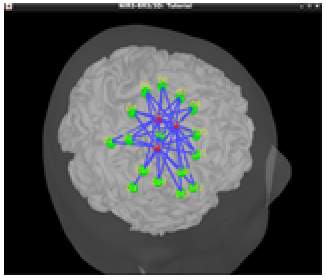
fNIRS 3D reconstruction
Solving an ill-posed inverse problem

$$Y = AX + e$$

Noise

Optical Density data at specific wavelengths
(685, 830 nm)





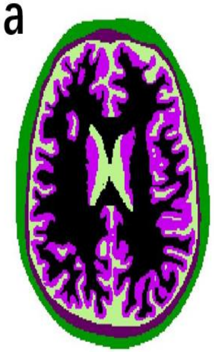
fNIRS forward model

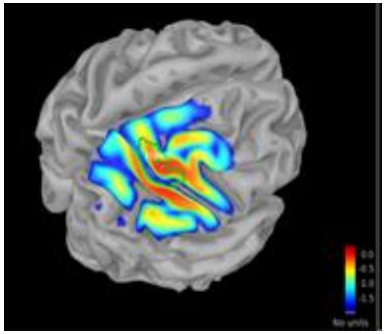
Light sensitivity maps estimated using Monte Carlo simulations

MCXLab

(Fang and Boas 2009)

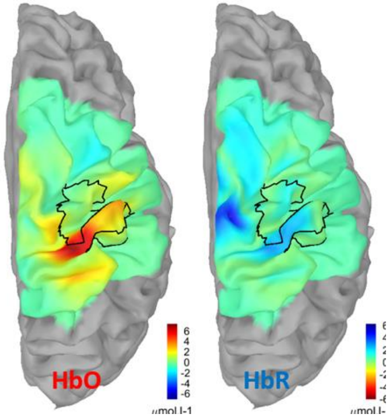
a





fNIRS 3D reconstruction along the cortical surface

1. Minimum Norm Estimate (MNE)
2. Maximum Entropy on the Mean (MEM)



fNIRS 3D reconstruction
Solving the forward Problem A

$$Y = AX + e$$

fNIRS forward model

Light sensitivity maps estimated using Monte Carlo simulations

MCXLab

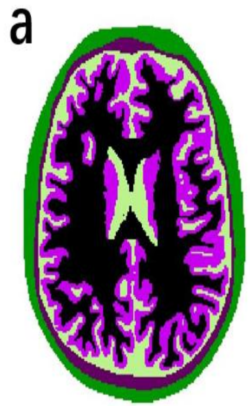
(Fang and Boas 2009)

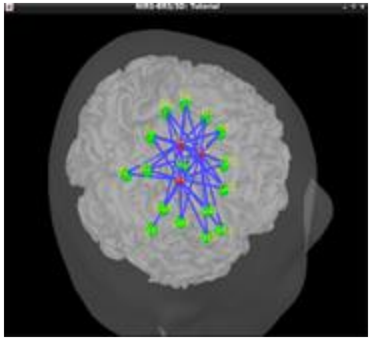
Subject Specific

(or template base)

Head Modeling in 5 tissues

(Freesurfer, SPM)

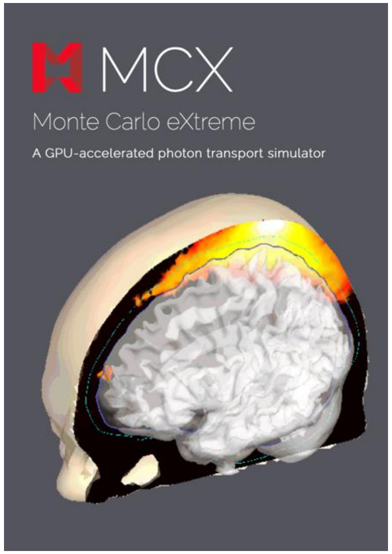




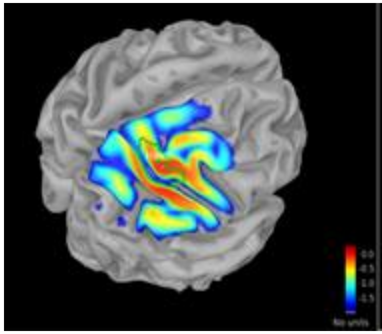
Integration of MCXLab, Monte Carlo Simulation of light transport on GPU

(Fang and Boas 2009)

http://mcx.space



Light sensitivity map on the cortical surface,



fNIRS 3D reconstruction
Solving the DOT inverse problem

Zhengchen Cai

$$Y = AX + e$$

Minimum Norm Estimate (MNE)

Hamalainen and Illmoniemi 1994, Zeff et al 2007, Dehghani et al 2009, Eggebrecht et al 2014

$$\hat{X}_{MNE} = argmin\left(||(Y - AX)||^2_{\Sigma_d} + \lambda ||X||^2_{\Sigma_s}\right)$$

$$= (A^T \Sigma_d A + \lambda \Sigma_s)^{-1} A^T \Sigma_d Y$$

Noise covariance

Hyperparameter of regularization (L-curve)

Prior on source covariance (Identity)

Depth Weighted MNE

Lin et al 2006, Cai et al Submitted

$$\hat{X}_{dMNE} = argmin\left(||(Y - AX)||^2_{\Sigma_d} + \lambda ||X||^2_{\Sigma_s}\right)$$

$$= (A^T \Sigma_d A + \lambda (\Lambda \Lambda^t)^{-1})^{-1} A^T \Sigma_d Y$$

$$diag(\Lambda) = \frac{1}{diag\left((A^T \Sigma_d A)\right)^{\omega}}$$

Depth weighting parameter

Maximum Entropy on the Mean (MEM)

Amblard et al 2004, Grova et al 2006, Chowdhury et al 2013, Cai et al Sci Rep 2021

Non linear probabilistic approach

Relative entropy with a prior distribution

$$S_v(dp(x)) = -\int_x log\left(\frac{dp(x)}{d\nu(x)}\right) dp(x)$$

Data Fit term

$$Y - [A|I_q]\begin{bmatrix} E_{dp}[x] \\ e \end{bmatrix} = 0, \qquad dp \in C_m$$

Regularization using entropy

$$dp^*(x) = argmax_{dp(x) \in C_m}\left(S_v(dp(x))\right)$$

Flexible framework to define the prior distribution (reference)

Recent implementation of depth weighting within MEM

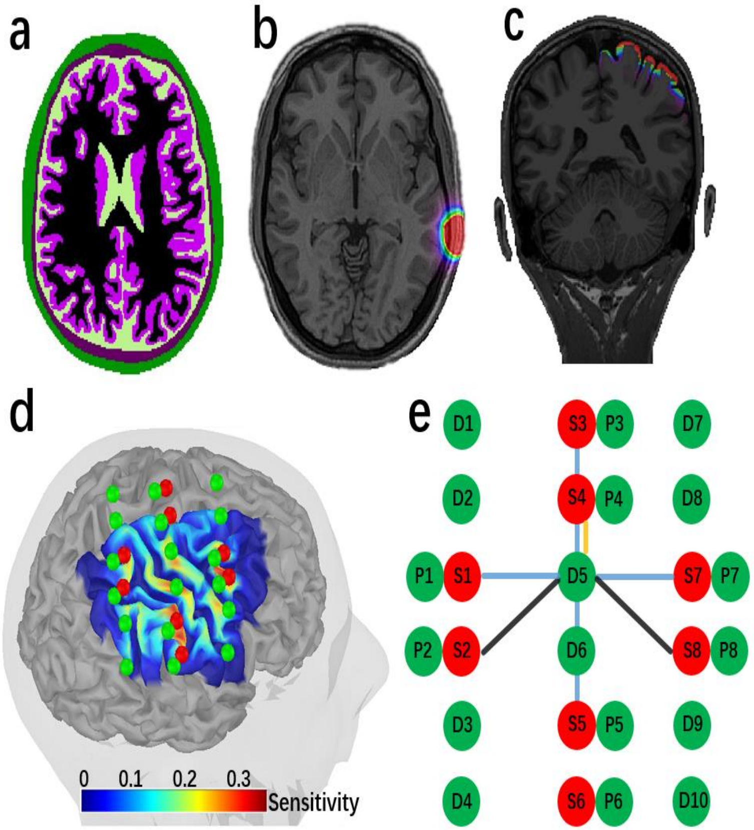
fNIRS 3D reconstruction using the MEM framework originally developed for EEG/MEG source imaging versus MNE

1. Evaluation using realistic simulations

Zhengchen Cai

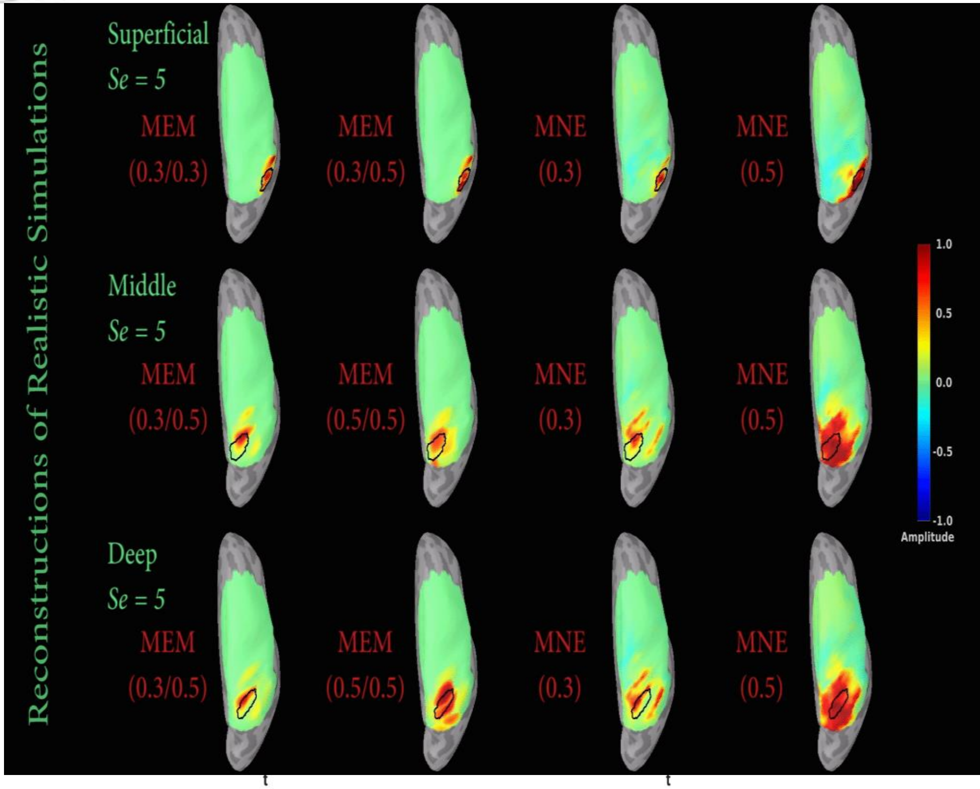
fNIRS probe and forward model

(Monte Carlo simulations)



fNIRS realistic simulations

at different SNR

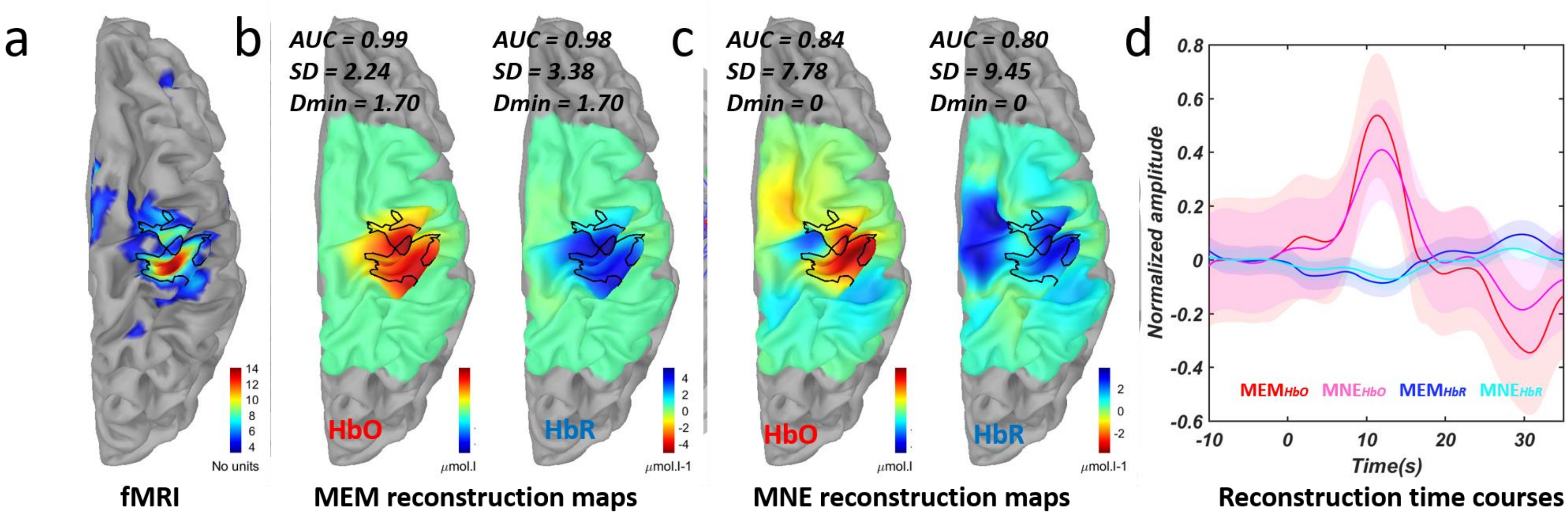


Cai et al Sci. Report 2022

fNIRS 3D reconstruction using the MEM framework originally developed for EEG/MEG source imaging versus MNE

2. Comparison with finger tapping fMRI in 10 healthy controls

Personalized fNIRS: optimal montage targeting the right hand knob



Cai et al HBM 2021

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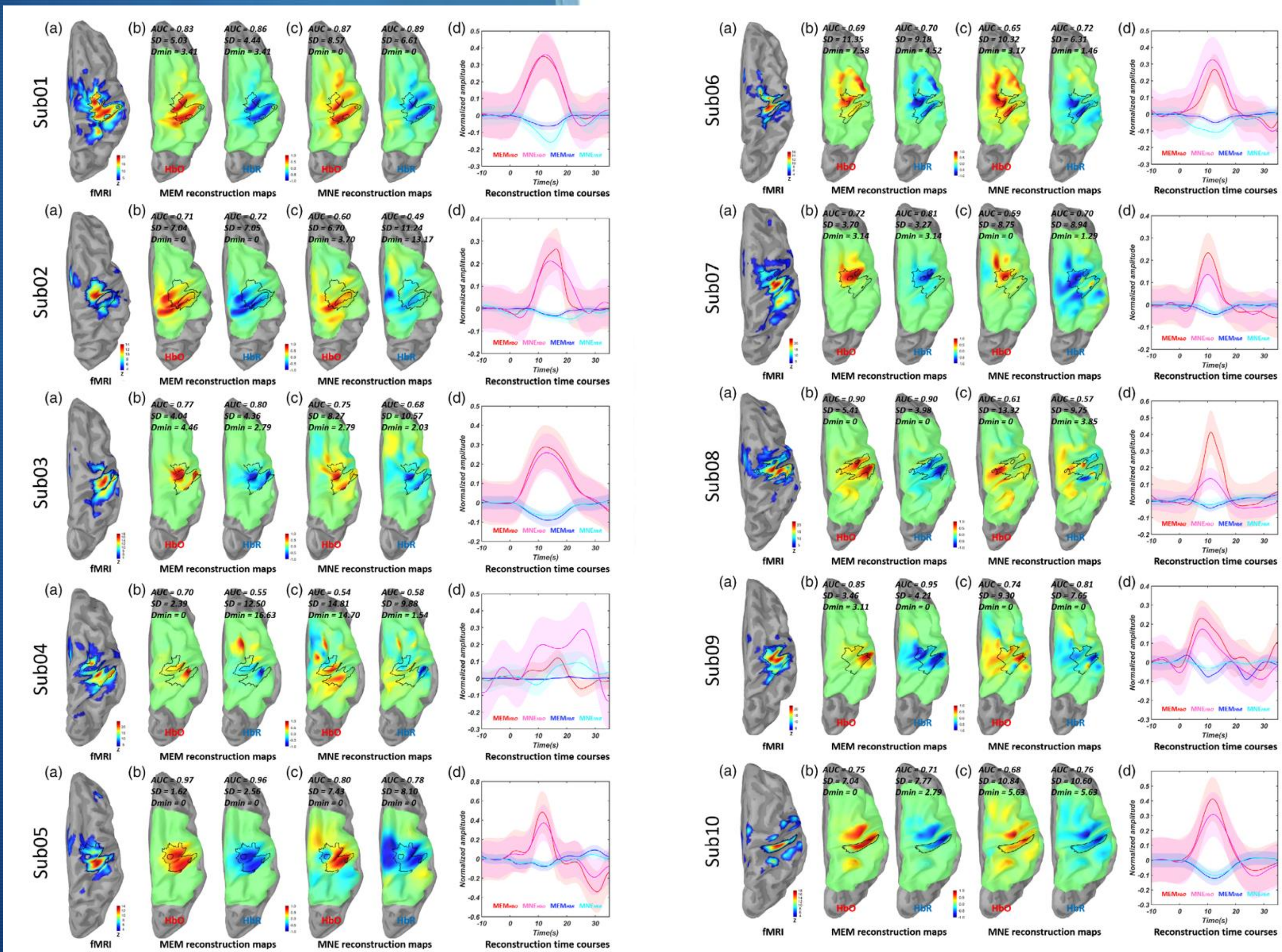
Evaluation of a personalized functional near infra-red optical tomography workflow using maximum entropy on the mean

Zhengchen Cai, Makoto Uji, Ümit Aydin, Giovanni Pellegrino, Amanda Spilkin, Édouard Delaire, Chifaou Abdallah, Jean-Marc Lina, Christophe Grova

First published: 03 August 2021 | https://doi.org/10.1002/hbm.25566 | Citations: 4

Zhengchen Cai



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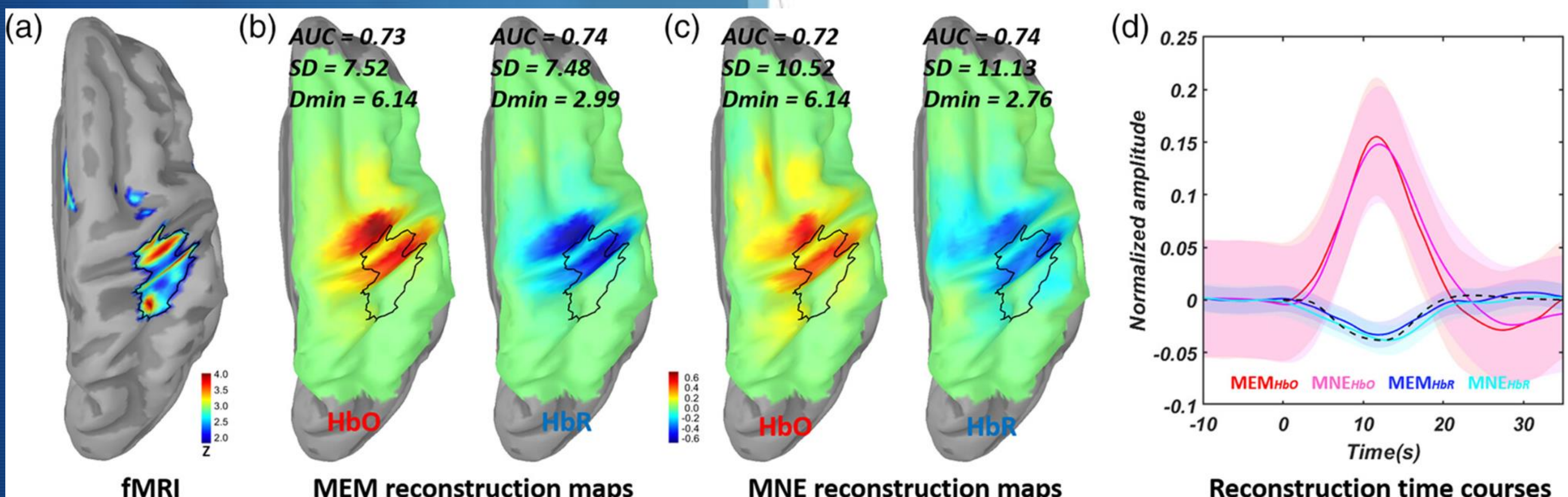
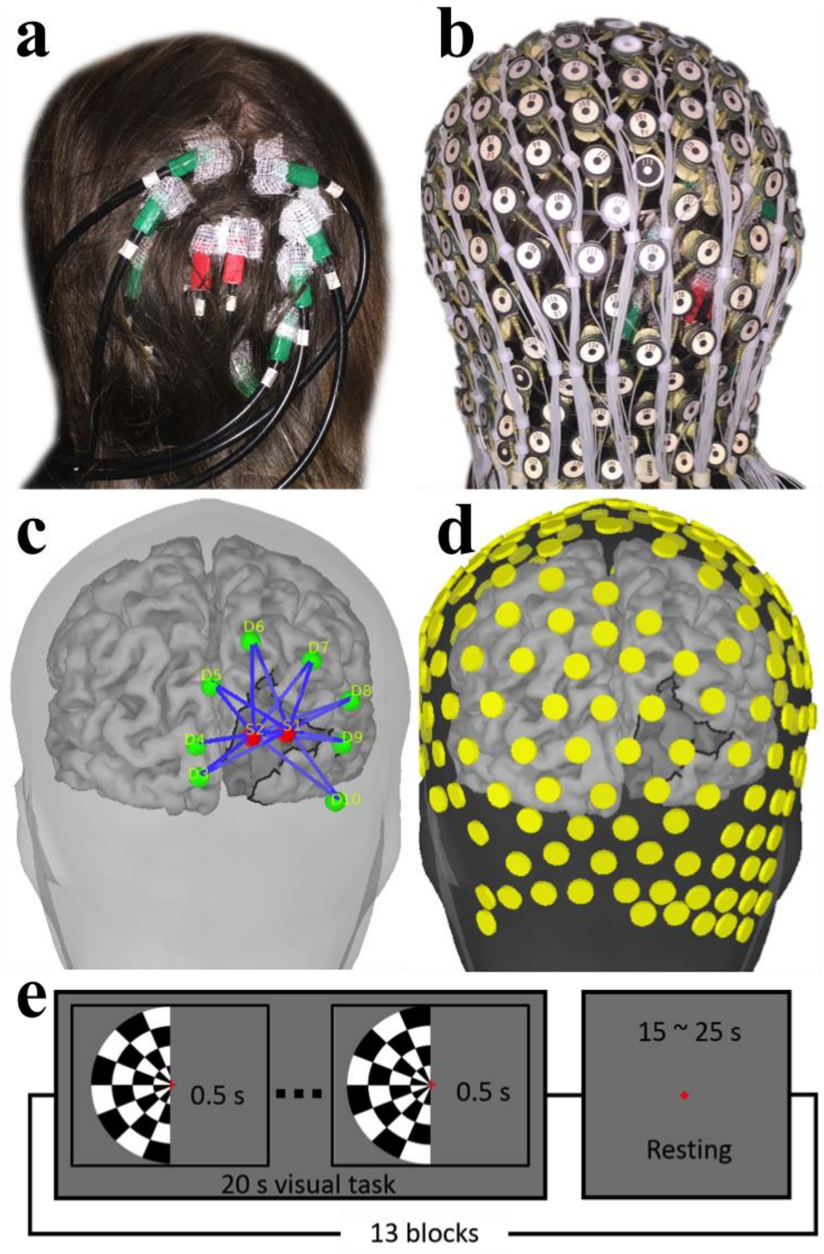
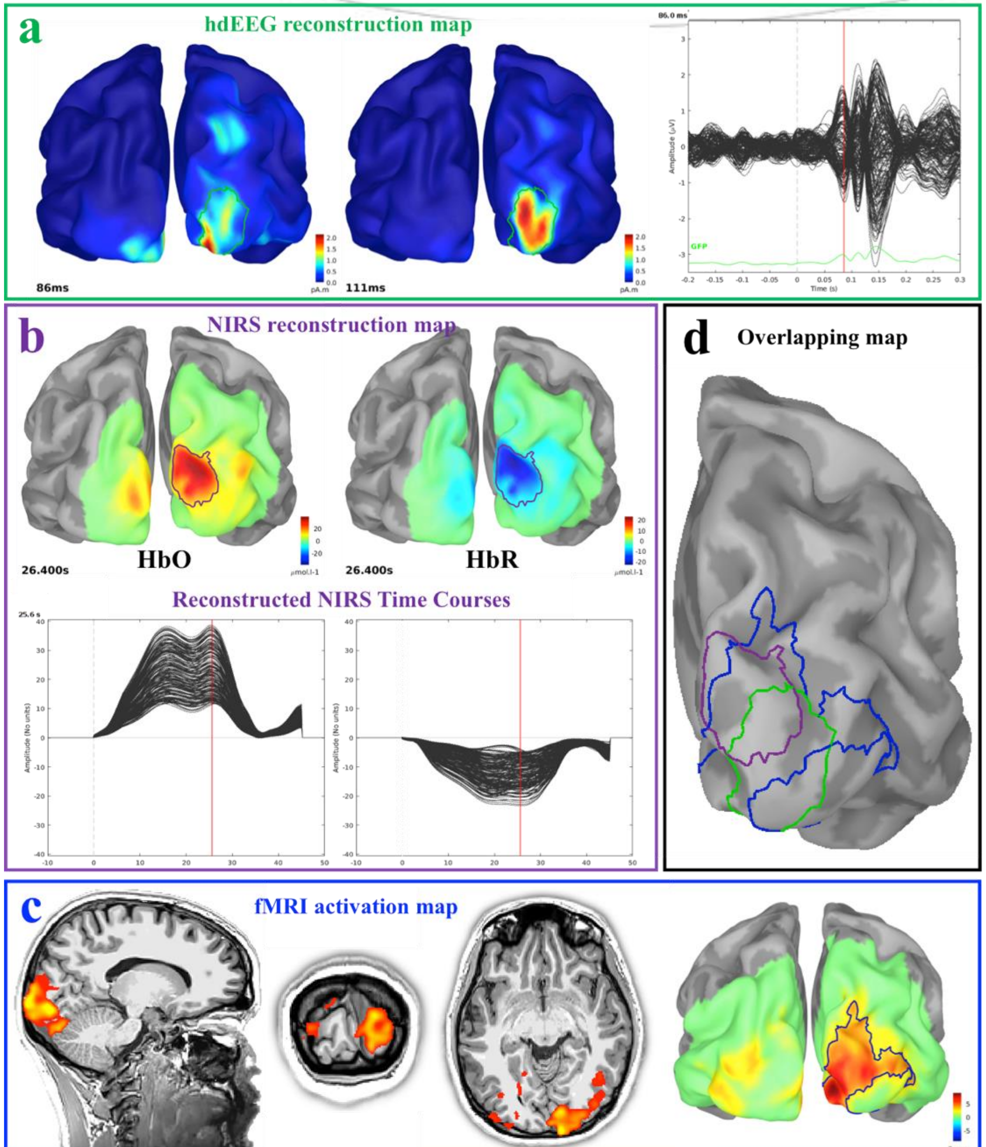


An example of complete multimodal investigation using: fMRI, high density EEG and NIRS



Full multimodal investigation (hdEEG, fMRI, NIRS) during a visual stimulation task



EEG and NIRS 3D Reconstruction using
Maximum Entropy on the Mean (MEM)
Amblard et al IEEE TBME 2004
Pellegrino et al HBM 2018, 2020
Abdallah et al Neurology 2022
Afnan et al HBM 2024

NIRSTORM

MEM in fNIRS:
Cai et al, HBM 2021
Cai et al Sci. Report 2021
Cai et al HBM 2023
Delaire et al Bioarxiv 2024

BEst
Brain Entropy in space and time

Brainstorm BEst Tutorial
http://neuroimage.usc.edu/brainstorm/Tutorials/TutBEst

NIRSTORM
https://github.com/Nirstorm/nirstorm

Acknowledgments

Multimodal functional Imaging Lab (Concordia and McGill)

MULTIFUNKIM
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Université Concordia University
Centre PERFORM Centre

Chifaou Abdallah, Jawata Afnan, Tamir Avigdor, Shahla Bakian Dogaheh, Arielle Dascal, Niels De Joode, Edouard Delaire, Maëva Laquitaine, Mahdi Mobark Abadi, Helia Mirabi, Mathilde Reyt

***Alumni**: Ümit Aydin, Zhengchen Cai, Rasheeda Chowdhury, Tanguy Hedrich, Hassan Khajehpoor, Kangjoo Lee, Giovanni Pellegrino, Amanda Spilkin, Makoto Uji, Yimeng Wang*

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ÉTS Le génie pour l'industrie

Birgit Frauscher

Jean Gotman

François Dubeau

Nicolas von Ellenrieder

Eliane Kobayashi

Jean-Marc Lina

Financial support

CIHR IRSC
Canadian Institutes of Health Research / Instituts de recherche en santé du Canada

NSERC CRSNG

Fonds de recherche sur la nature et les technologies Québec

QBIN Quebec Bio-Imaging Network

SAVOY Fondation • Foundation Épilepsie • Epilepsy

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