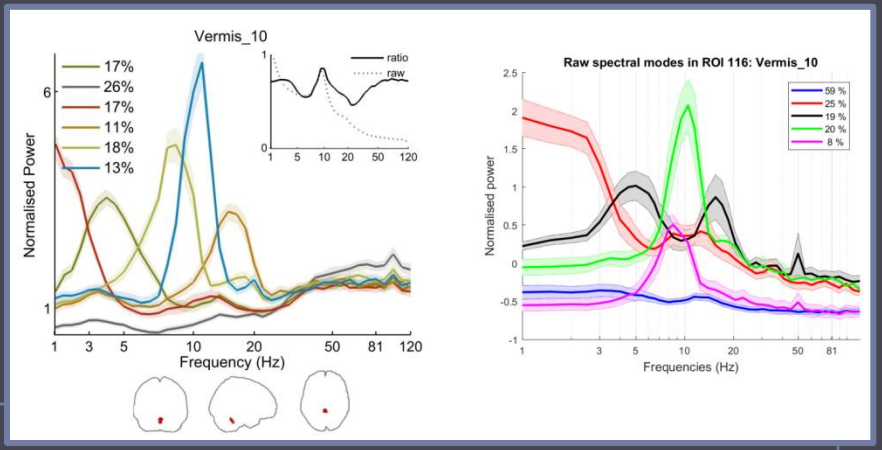


EEG Spectral Fingerprints

Michał Konrad Komorowski

michak@is.umk.pl

20.06.2018

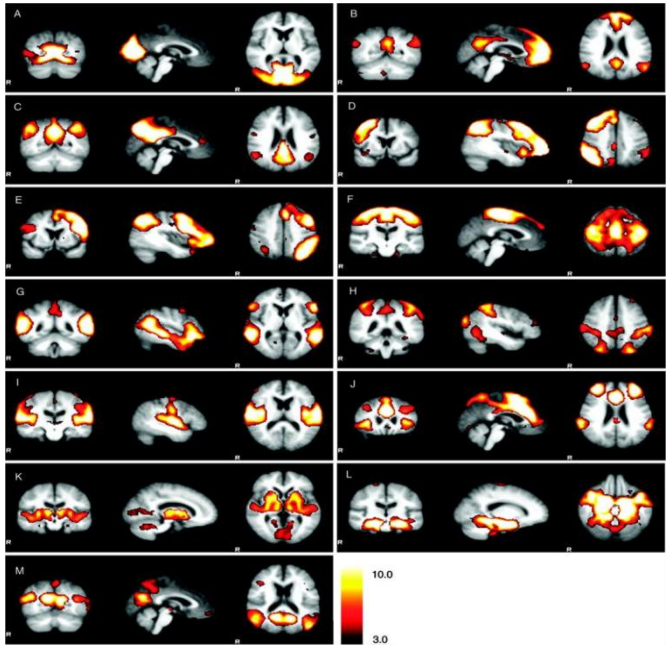
58th Cracow School of Theoretical Physics, Zakopane

Goal of the study

- We want to develop **a reliable method** which allow us to see activity of **deep sources** of human brain and **dynamics of the networks** from EEG:
  - **optimal representation of EEG signal** that expose information about brain networks and deep sources reliably
  - discovering **specific and stable features** of each brain structure
  - ability to model brain functions as **dynamic systems**
    (thanks to high time resolution of the EEG signal)

Support

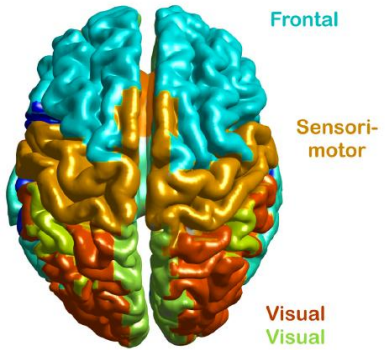
- Different stable **resting state networks** can be found in the human brain
  - Damoiseaux et al. 2008 *(Cerebral Cortex)*
- **Natural frequencies** exist for different brain regions
  - Rosanova et al. 2009 *(J. Neuroscience)*
- Patterns are stable and gathered across **core patterns**
  - Krienen et al. 2014 *(Phil. Trans. of the Royal Society B)*
- Feedforward and feedback **loops** in primates visual cortex (delta, alpha)
  - van Kerkoerle et al. 2014 *(PNAS Neuroscience)*
- Sensory or lower-to-higher order **hierarchy** in primates
  - Murray et al. 2014 *(Nature Neuroscience)*
- Human brain **does not follow** that hierarchy
  - Mellem et al. 2017 *(J. Neurophysiology: Neural Circuits)*
- **Gene expression** is correlated with functional brain networks
  - Richiardi et al. 2015 *(Science: Brain Networks)*

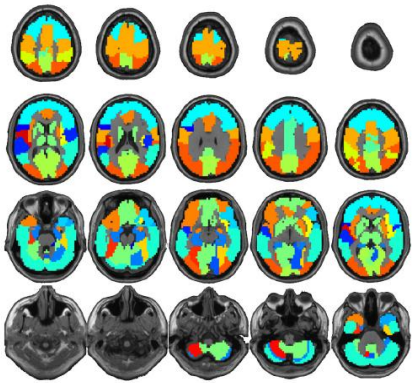


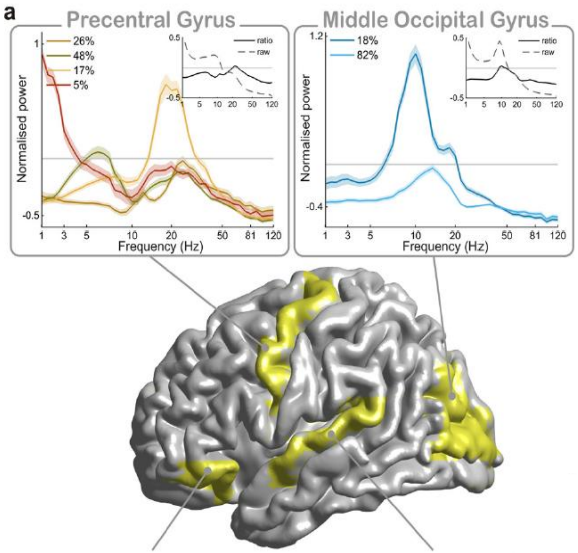
(Damoiseaux et al. 2008)

Brain Fingerprinting

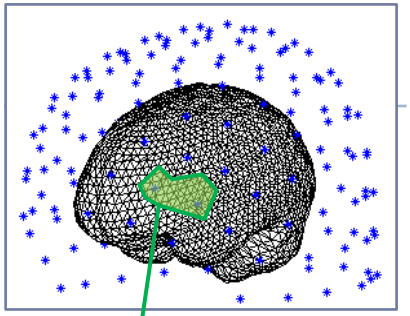
- Brain fingerprinting: spectral fingerprints based on approach in paper of A. Keitel i J. Gross, **„Individual human brain areas can be identified from their characteristic spectral activation fingerprints”**, *PLoS Biol*, t. 14, nr 6, s. e1002498, **2016**.
  - Model brain activity in each ROI as a **Gaussian Mixture Model** based on **spectral** content of MEG signal

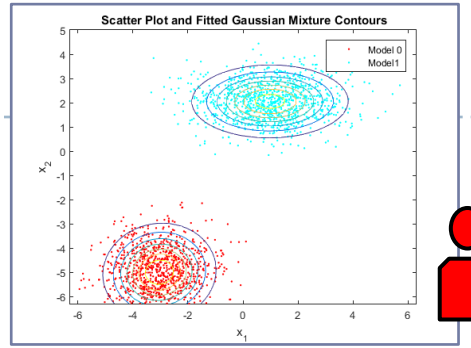




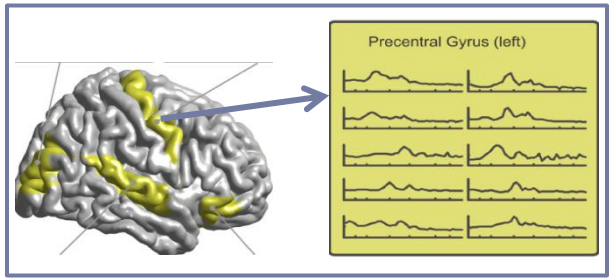


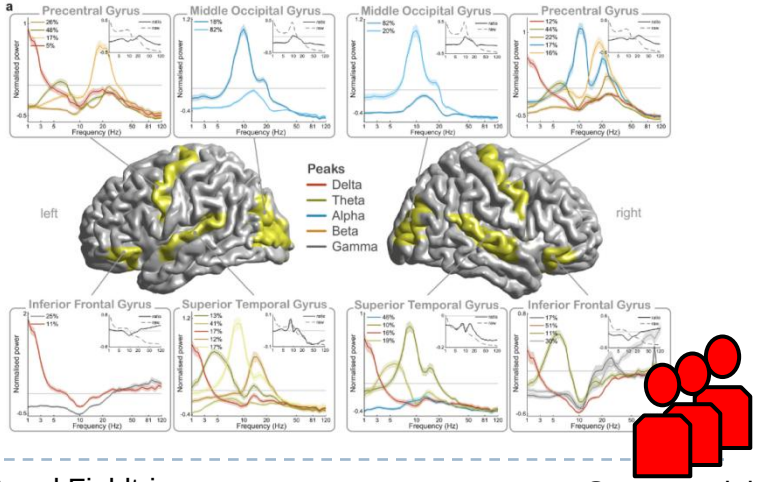
* Pictures from Keitel & Gross 2016





Single subject





Group model

* Pictures from Keitel & Gross 2016 and Fieldtrip beamforming tutorial

The Data

Datasets

	N	Spectral Fingerprints	Ranks	Opt. Number of modes	Networks
MEG reproduction	**22**	☑	☑	☑	☑
MEG - gamma	22	☑	☑	☑	☑
MEG – reduced number of trials (on average 279/466)	22	☑	☑	☑	☑
EEG Age-ility (RIKEN/worse coregister)	22	☑	☑	☑	☑
EEG Age-ility (fixed forward model)	22	☑	☑	☑	☑
EEG N=12 (data from Toruń)	12	☑	☑	☑	☑

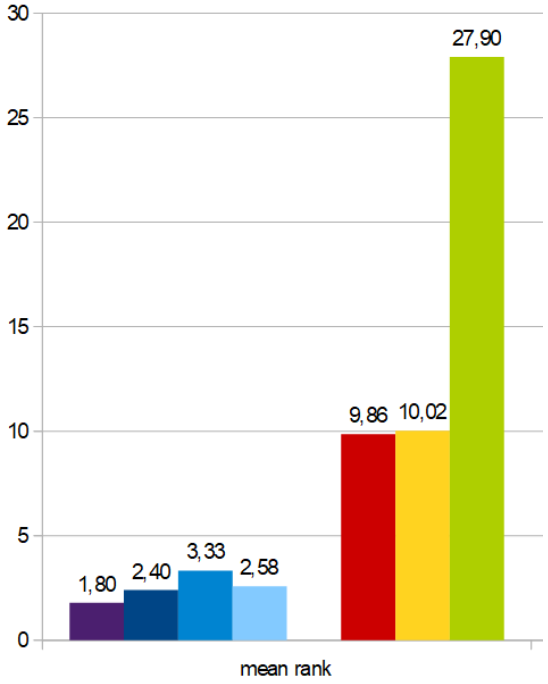
MEG : rest, 466 ± 20, eyes open, N=22, perfect coregistration

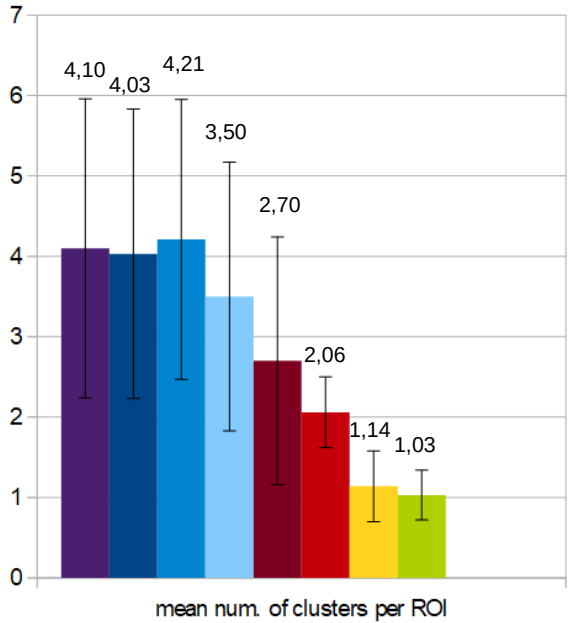
EEG Age-ility: rest, 118 ± 7 s, eyes closed, N=22, poor (manual) coregistration of EEG to MRI

EEG N=12: rest, 460 ± 32 s, eyes open, N=22, fair (< 1cm per electrode) coregistration of EEG to MRI

Comparison between main results

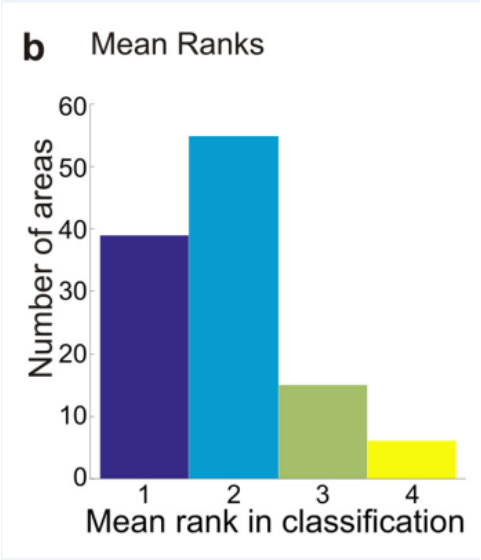
- MEG (orig)
- MEG (reprod.)
- MEG (-gamma)
- MEG (reduced trials)
- EEG N=7
- EEG N=12
- EEG Ageility N=22
- EEG Ageility N=22 (worse coregister)





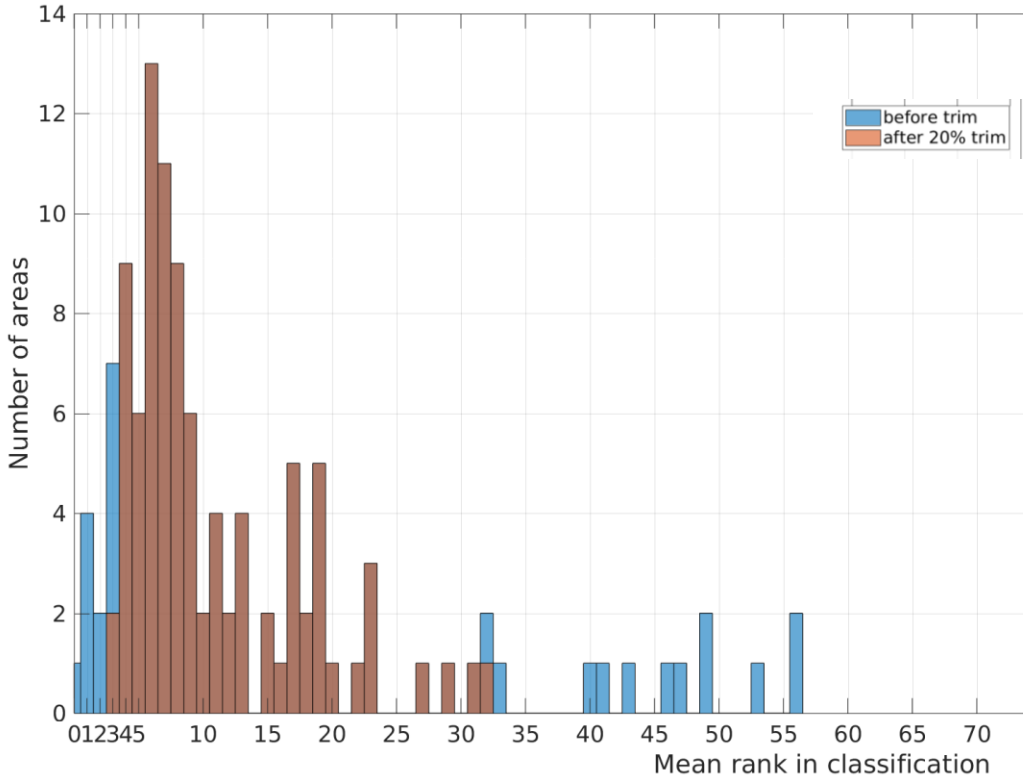
EEG Age-ility (N=22, fixed forward model)

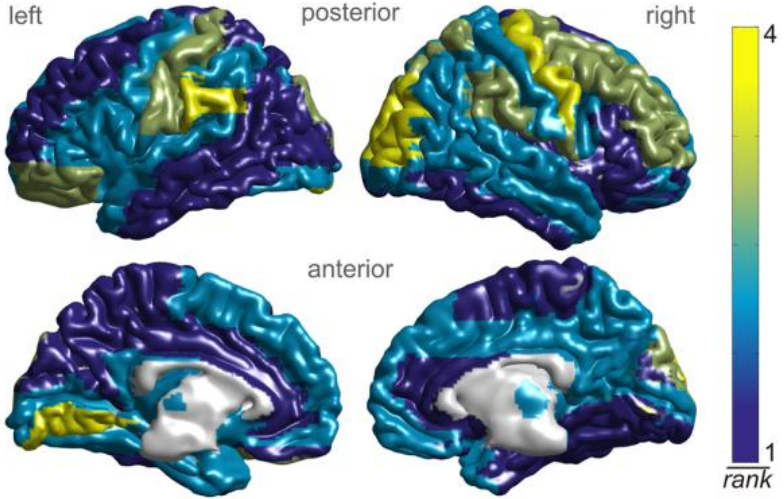
Left: Keitel & Gross
(GoodGrid, GoodFixCINum).
Mean rank = 1.8

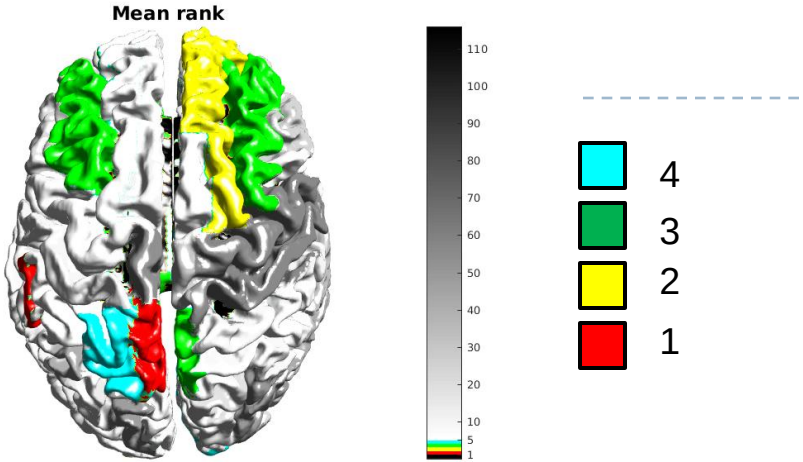


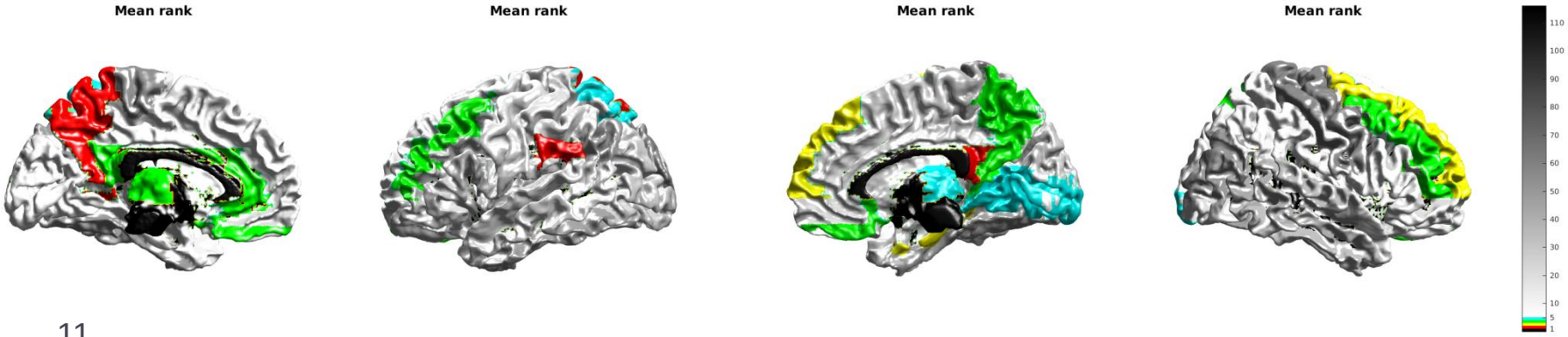
Right: EEG N=22 Agility

Mean rank = 10.02

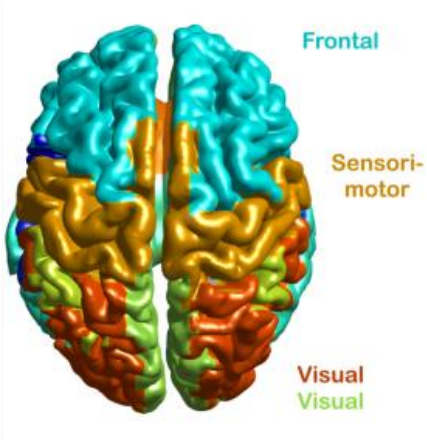


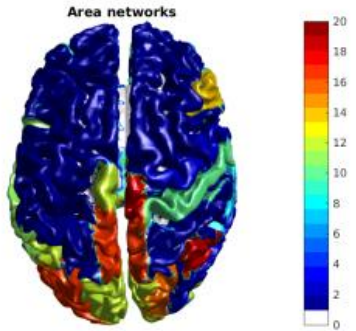

left
posterior
right
anterior
4
1
rank

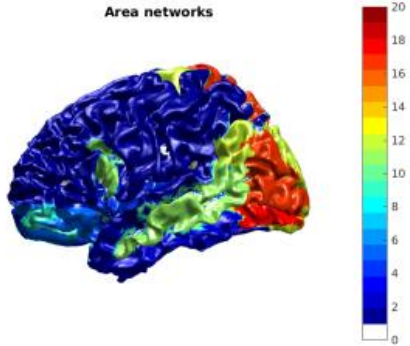

Mean rank
110
100
90
80
70
60
50
40
30
20
10
5
1
4
3
2
1

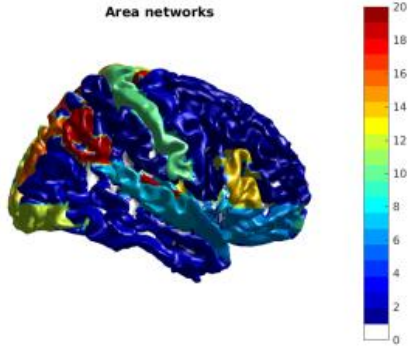

Mean rank
Mean rank
Mean rank
Mean rank
110
100
90
80
70
60
50
40
30
20
10
5
1

Left-up: Keitel & Gross, other figures: EEG N=22 Agility (GoodGrid, GoodFixCINum).



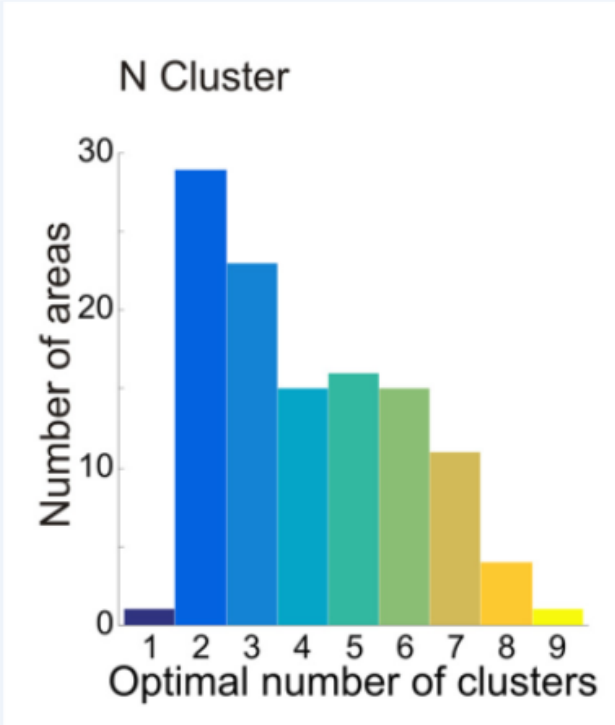


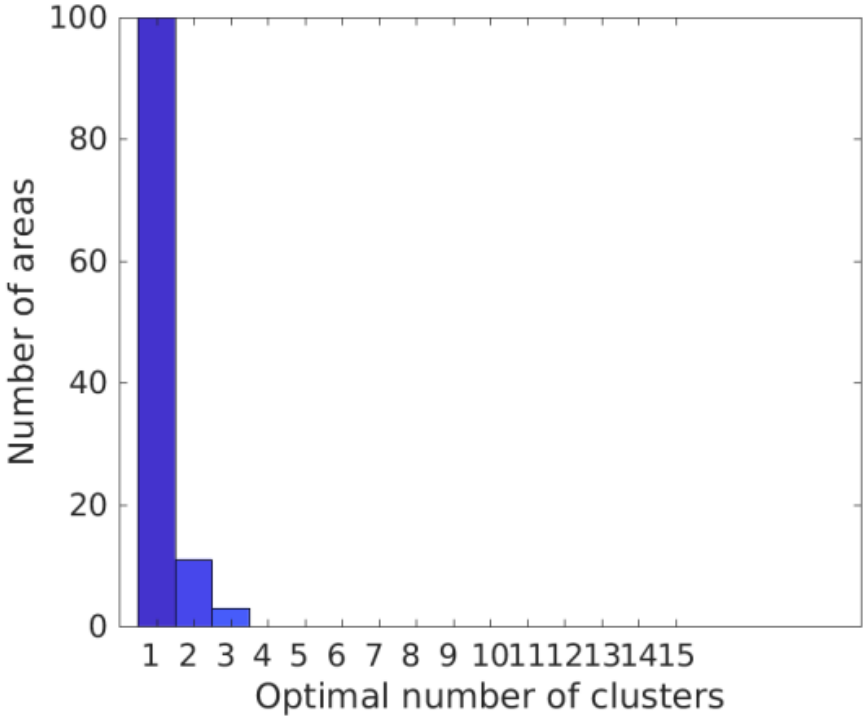




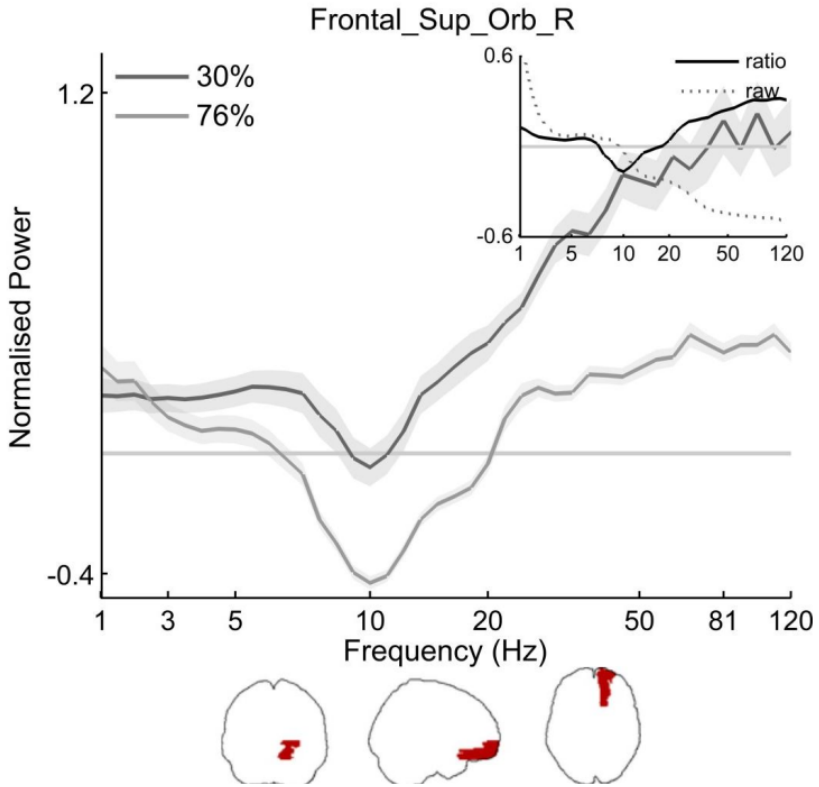
Left: Keitel & Gross
Agility(GoodGrid, GoodFixCINum).
Avg. num. of clusters = 4.10 ± 1.86

Right: EEG N=22
Avg. num. of clusters = 1.14 ± 0.44

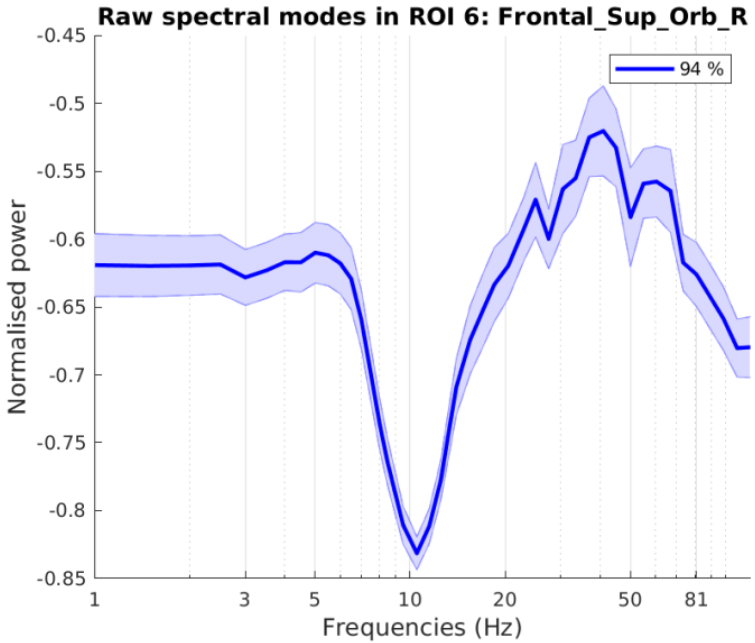




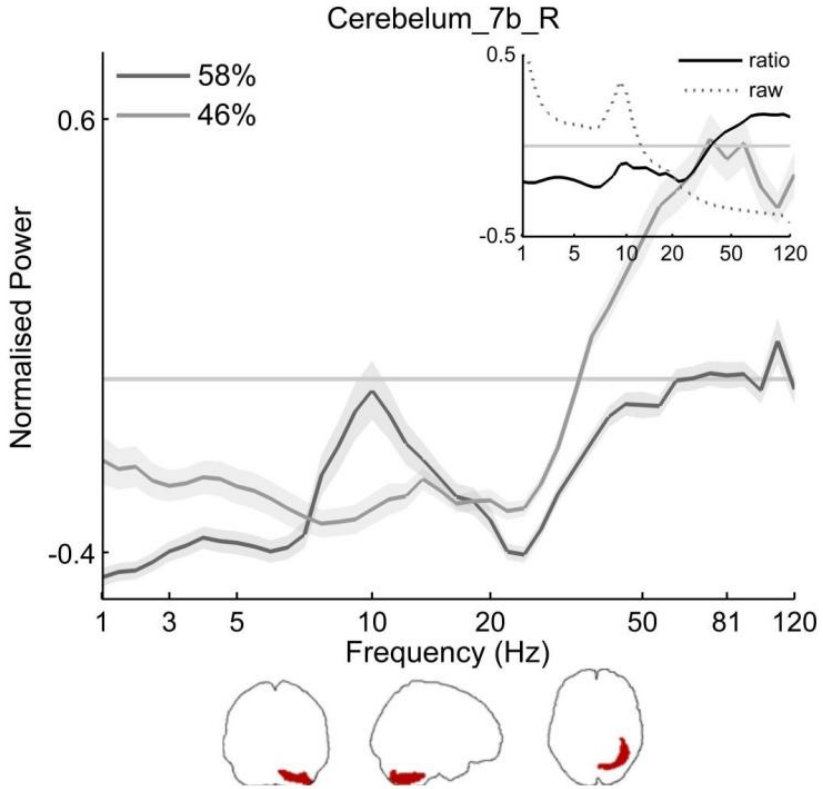
Keitel & Gross, 2016



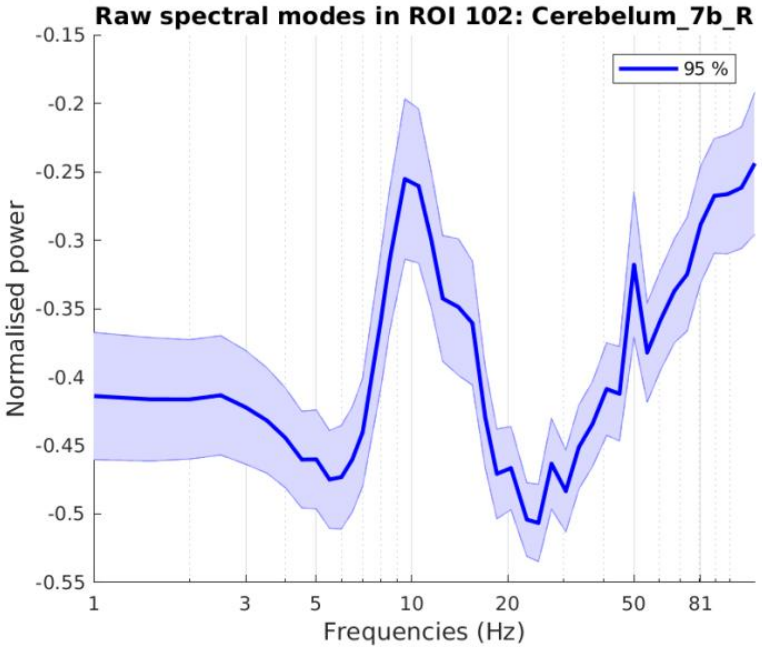
EEG Age-ility



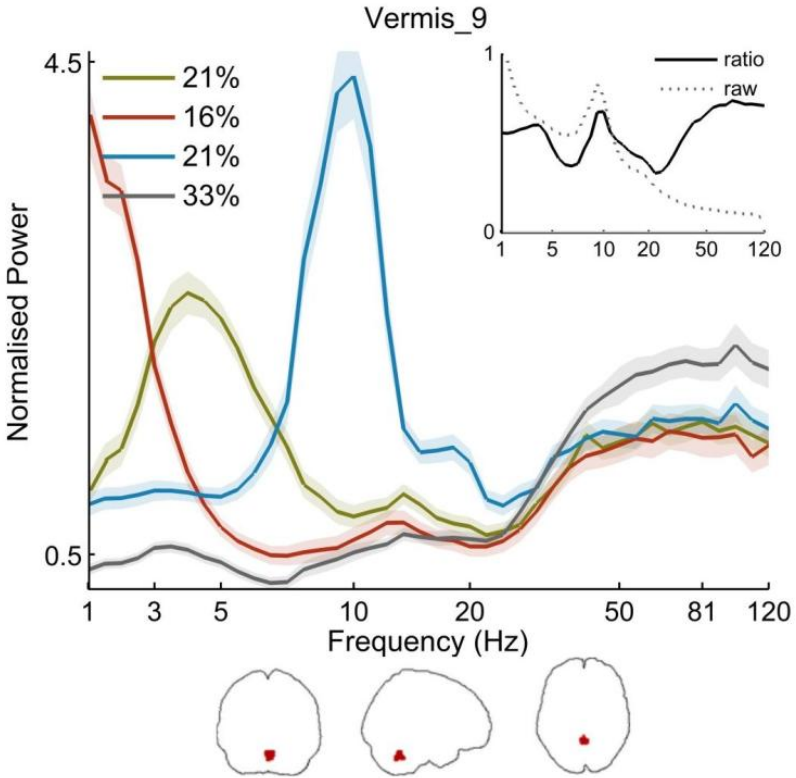
Keitel & Gross, 2016



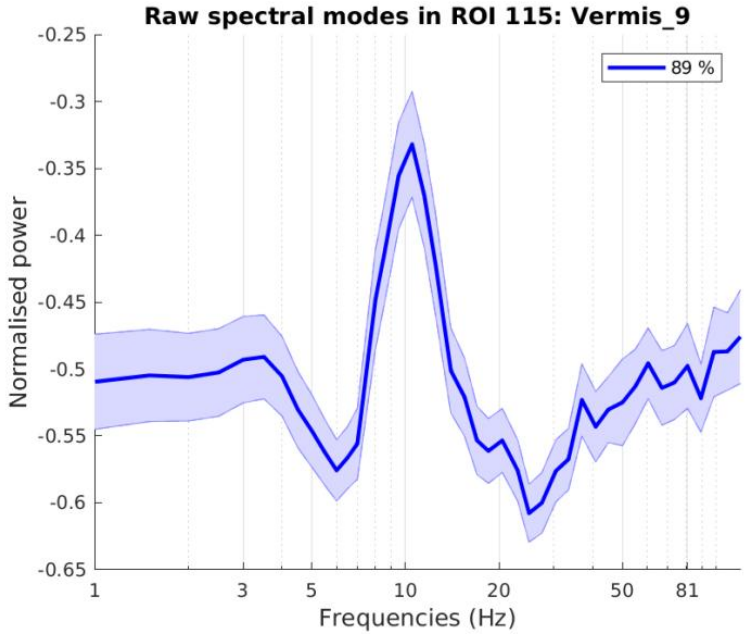
EEG Age-ility



Keitel & Gross, 2016

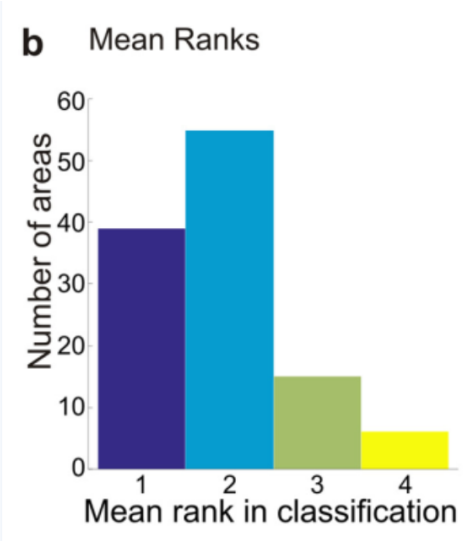


EEG Age-ility

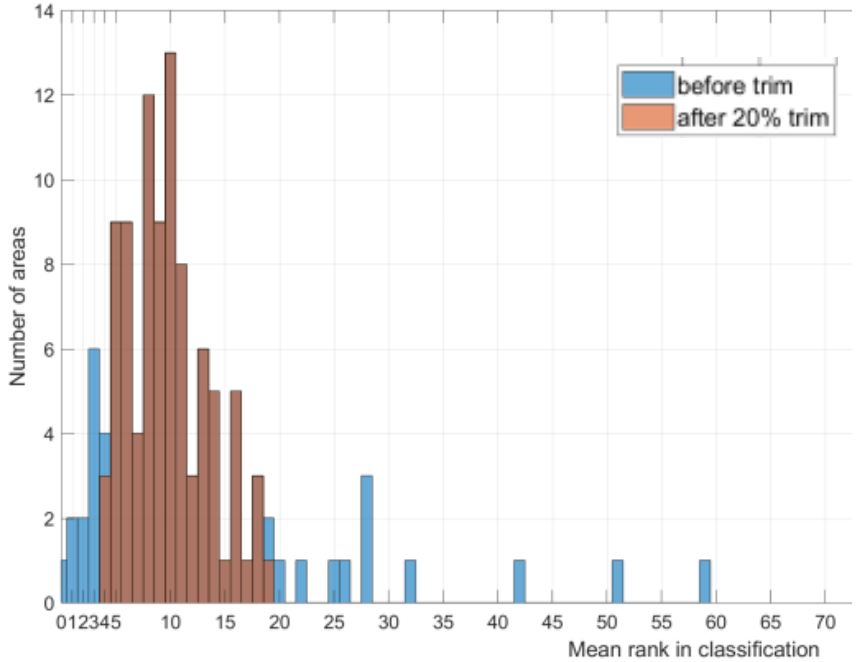


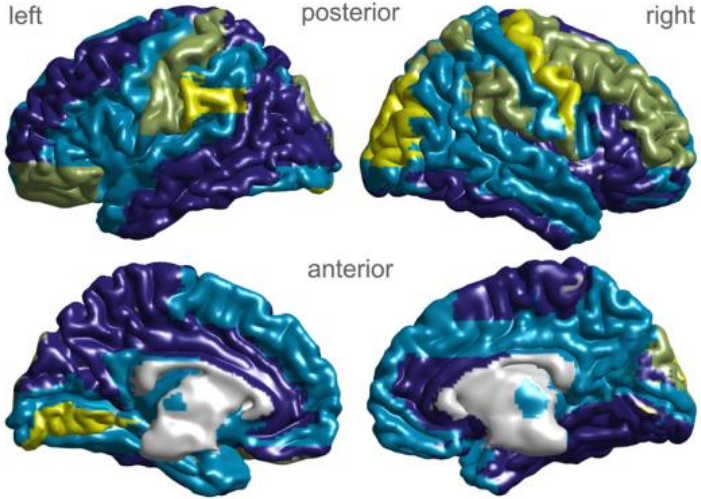
EEG N=12 (Toruń)

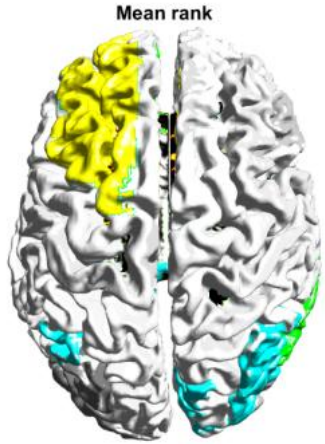
Left: Keitel & Gross
Mean rank = 1.8

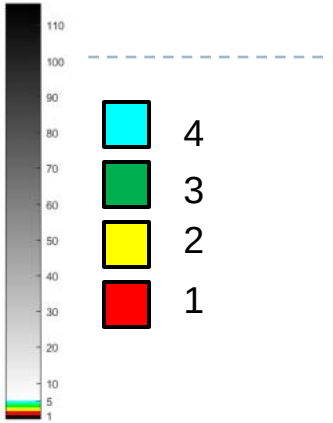


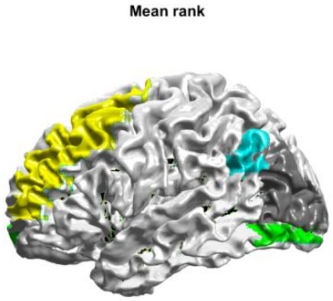
Right: EEG N=12 Torun.
Mean rank = 9.86

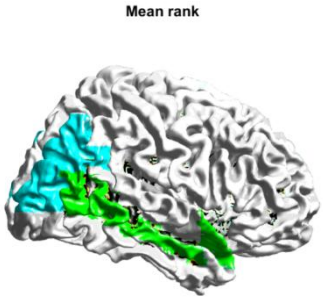


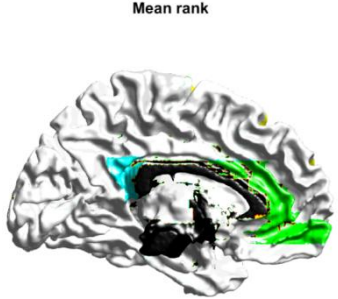

left
posterior
right
anterior
4
1
rank

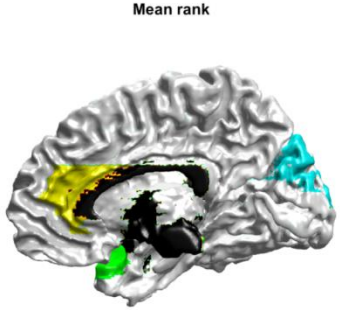

Mean rank

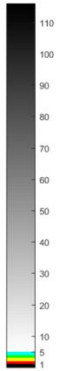

110
100
90
80
70
60
50
40
30
20
10
5
1
4
3
2
1


Mean rank

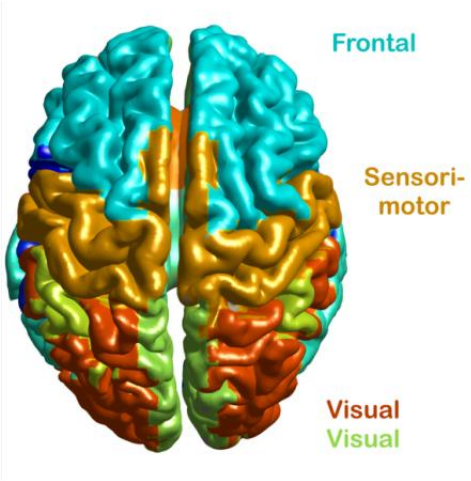

Mean rank

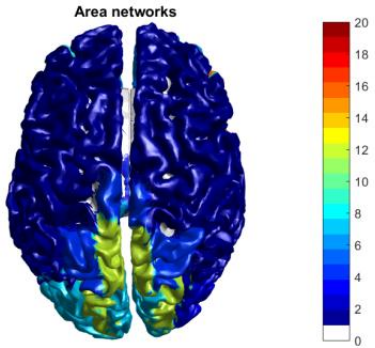

Mean rank

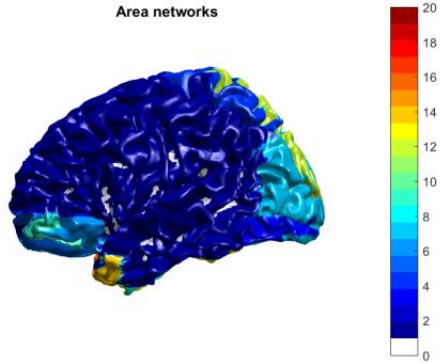

Mean rank

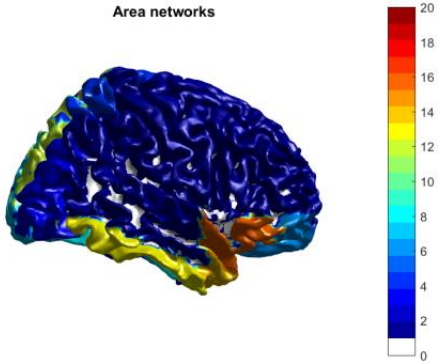

110
100
90
80
70
60
50
40
30
20
10
5
1

Left-up: Keitel & Gross, other figures: EEG N=12 Torun

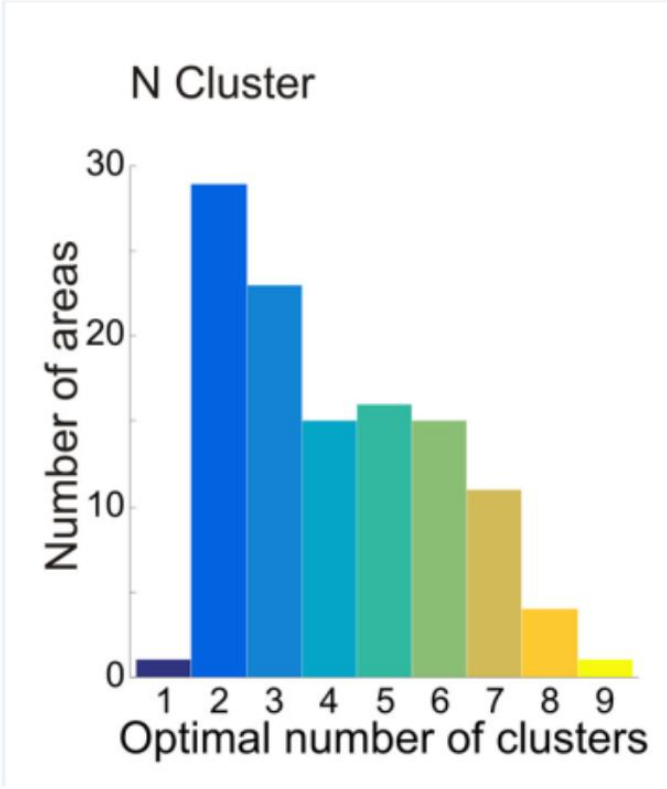




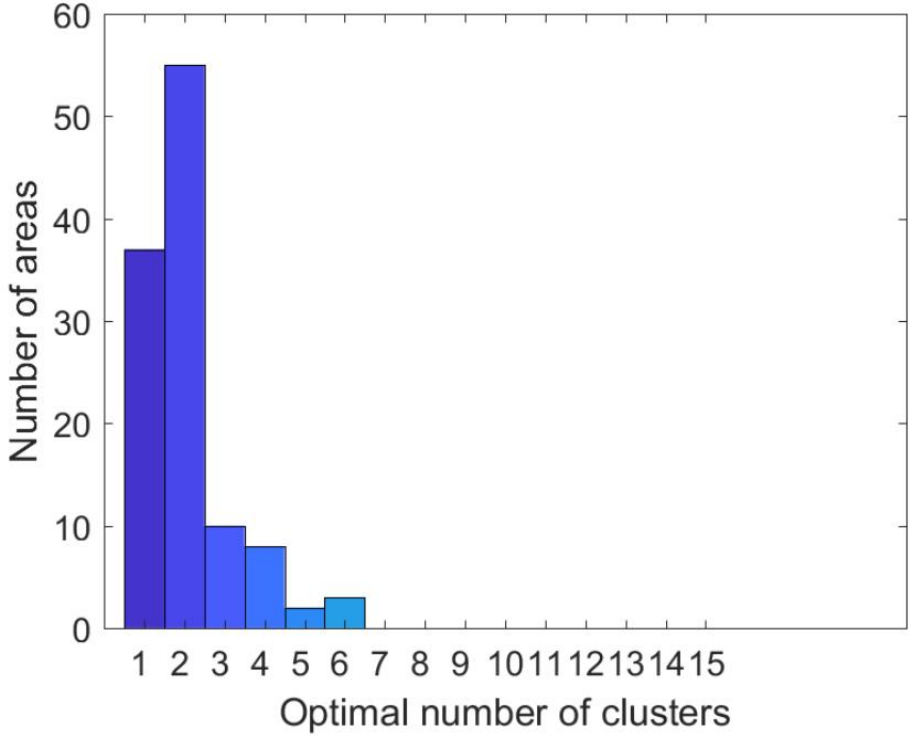




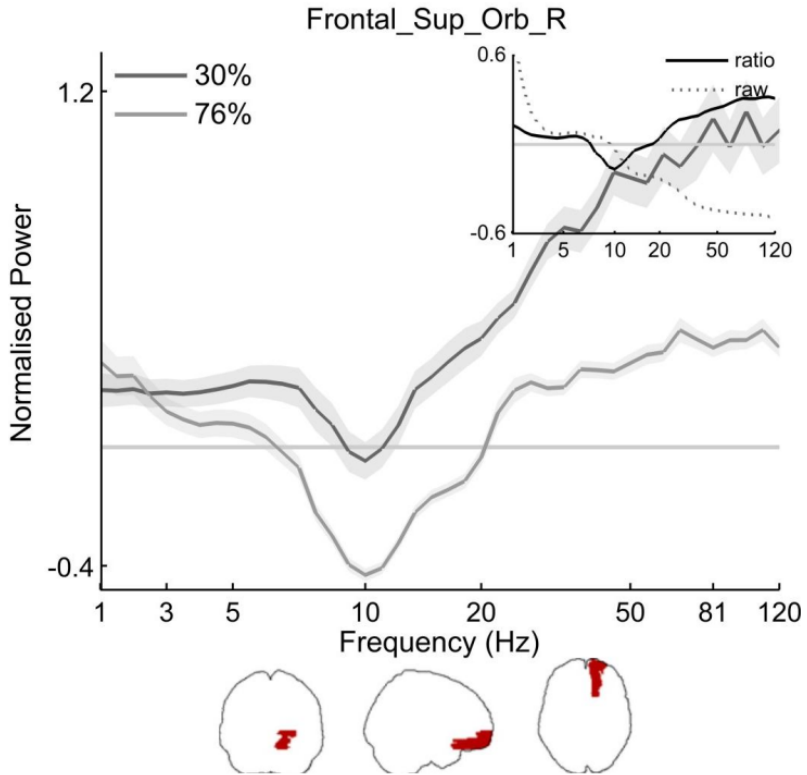
Left: Keitel & Gross
Avg. num. of clusters = 4.10 $\pm$ 1.86



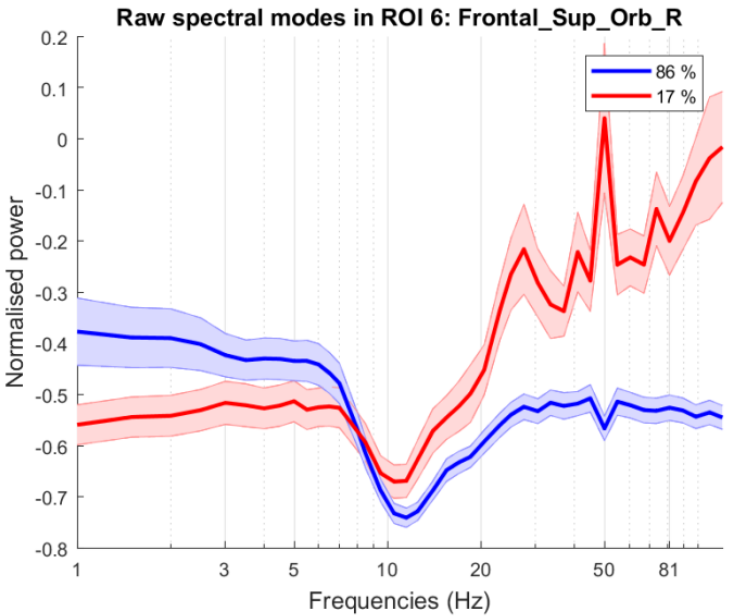
Right: EEG N=12 Torun.
Avg. num. of clusters = 2.06 $\pm$ 1.13



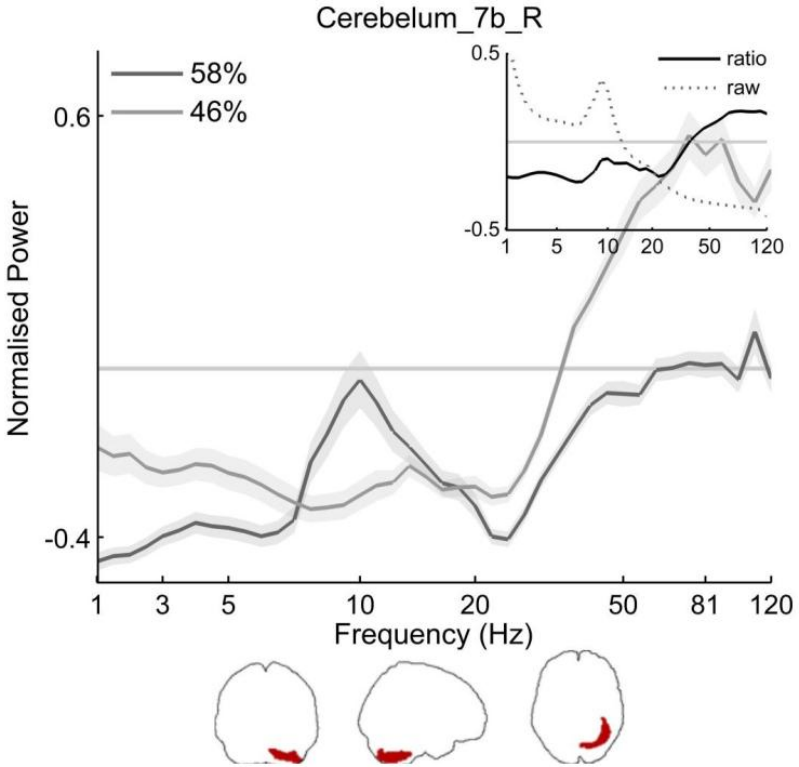
Keitel & Gross, 2016



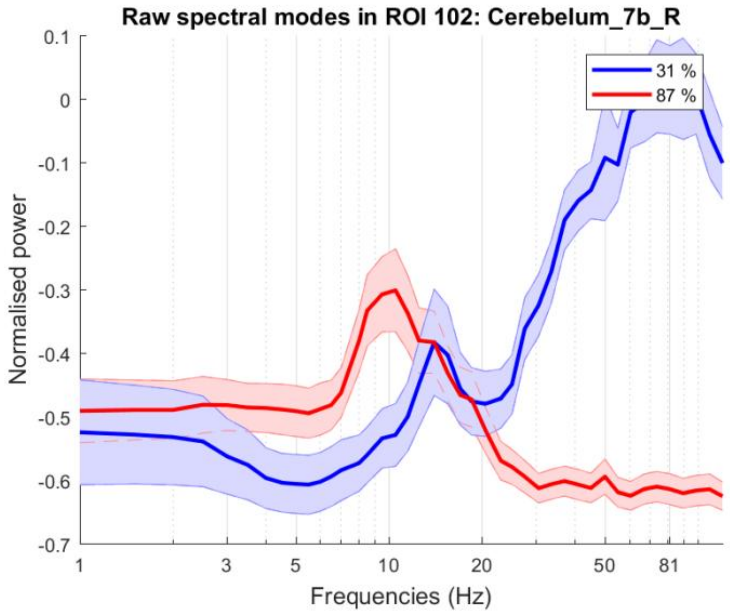
EEG (Toruń)



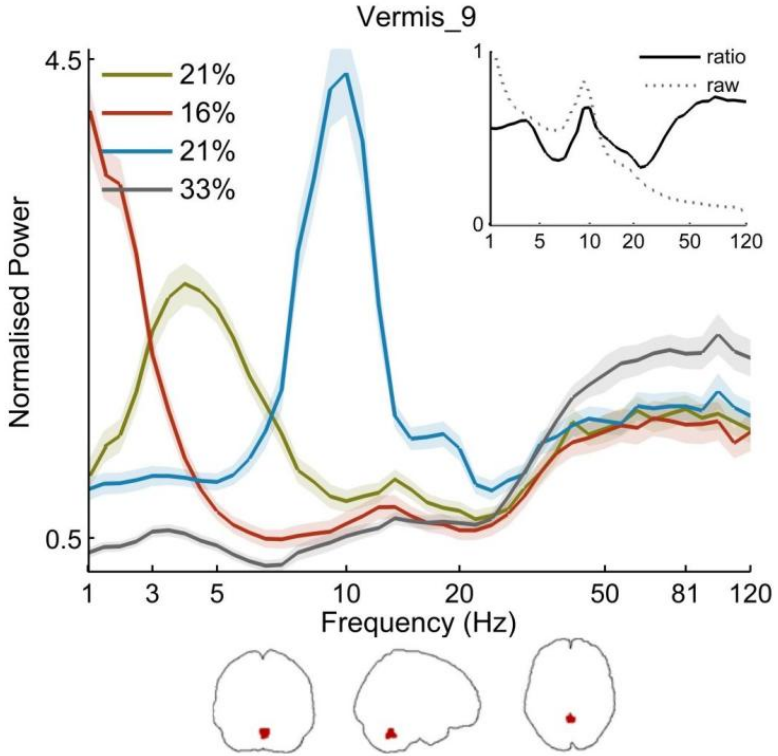
Keitel & Gross, 2016



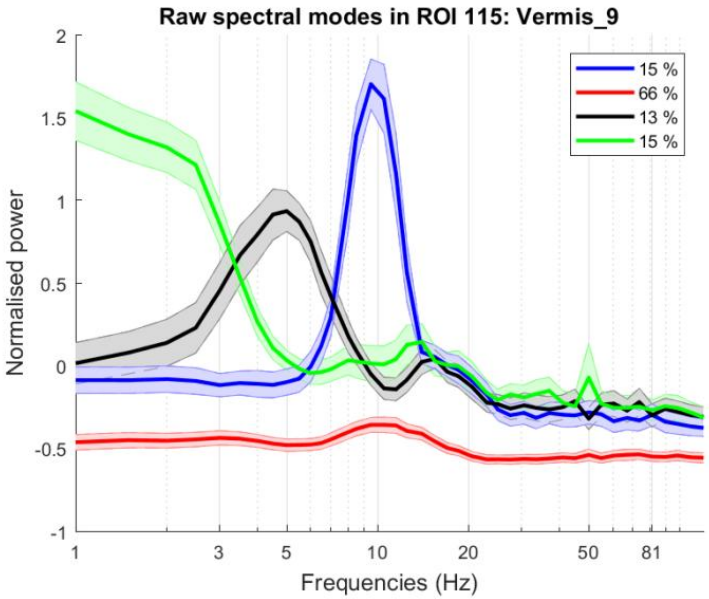
EEG (Toruń)



Keitel & Gross, 2016



EEG (Toruń)

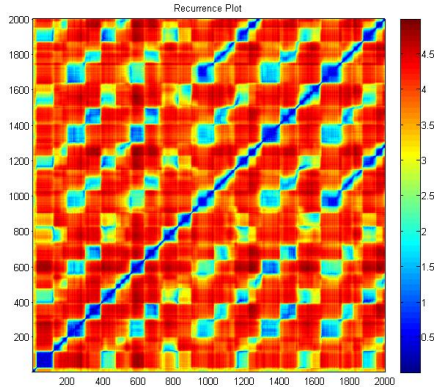


Conclusions

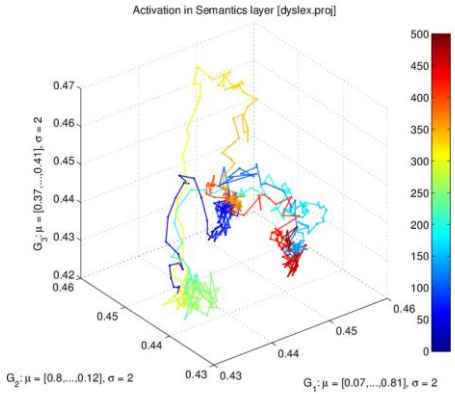
- **Spectral fingerprinting** is a procedure that allows to discover spectral dynamics of each ROI from functional data (MEG, EEG)
- Distant **homologue areas** are connected together
  (similarity is not an artifact caused by short distance similarity and source mixing)
- **MEG**: ROI spectral fingerprints are specific so we can classify them
- **EEG**: ROI recognition accuracy basing on its spectral fingerprint is well above chance level (but still some improvement is needed)

Plans for the future

- Prove that EEG spectral fingerprints :
  - Are specific for each brain region and stable across participants
  - Can be used to differentiate ROIs (classification, ranks)



- Calculate spectral fingerprints on **resting-state EEG N=22** or more
- Spectral fingerprints from EEG recording with **128 electrodes or more**
- Improve inverse problem solution with MV-PURE approach
  (Piotrowski, Nikadon, Gutierrez **arXiv:1712.02997** **[eess.SP])**
- Check wheter spectral fingerprints exhibit **attractor structure**
- Study **trajectories in higher-dimensional spaces**



Pictures from http://www.is.umk.pl/~kdobosz/visertoolbox/
K. Dobosz, W. Duch

Contributions

- **prof. Włodzisław Duch**, dr Joanna Dreszer
  - for finding an idea and setting Spectral Fingerprints as one of the direction of research
- Jakub Wojciechowski
  - ongoing help with analysis of the methods and results from Keitel & Gross 2016 paper, preprocessing of EEG datasets
- Jan Nikadon and dr Tomasz Piotrowski
  - help with generating forward model for source reconstruction
- **prof. Andrzej Cichocki**
  - substantial part of work was done during the internship in RIKEN, BSI, Japan under professor's supervision and inspiration
- **Dr Anne Keitel & prof. Joachim Gross**
  - For providing access to the data and advices on know-how

- **Nicolaus Copernicus University** in Poland
  - Faculty of Physics, Astronomy and Informatics
    - Department of Informatics
      (pol. Katedra Informatyki Stosowanej)

NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ
Faculty of Physics, Astronomy and Informatics

Katedra Informatyki Stosowanej

Neurocognitive Laboratory

Centre for Modern Interdisciplinary Technologies in Toruń, Poland

FACULTY OF PHYSICS, ASTRONOMY AND INFORMATICS

CENTRE FOR MODERN INTERDISCIPLINARY TECHNOLOGIES

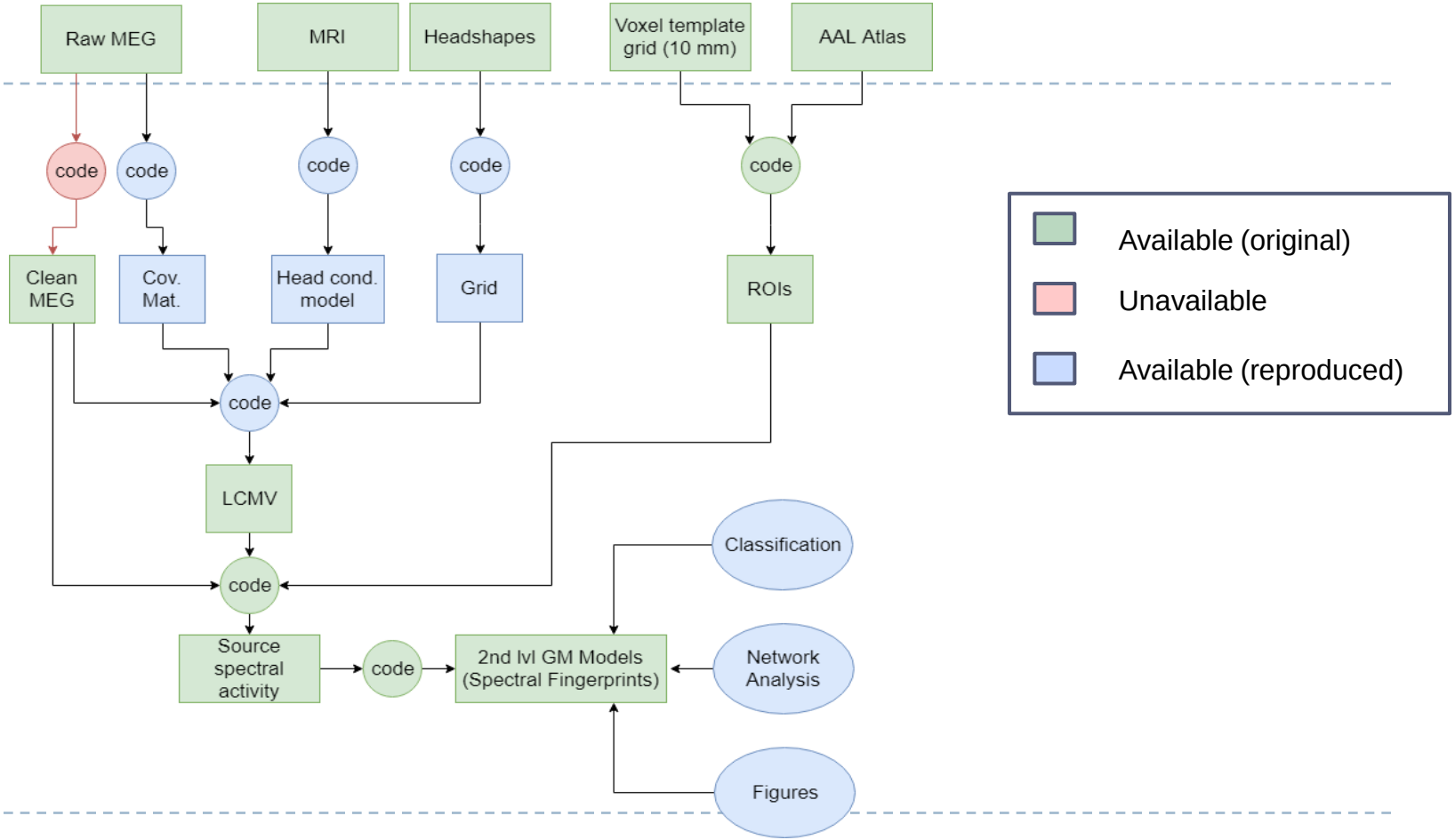
INSTITUTE OF PHYSIOLOGY AND PATHOLOGY OF HEARING

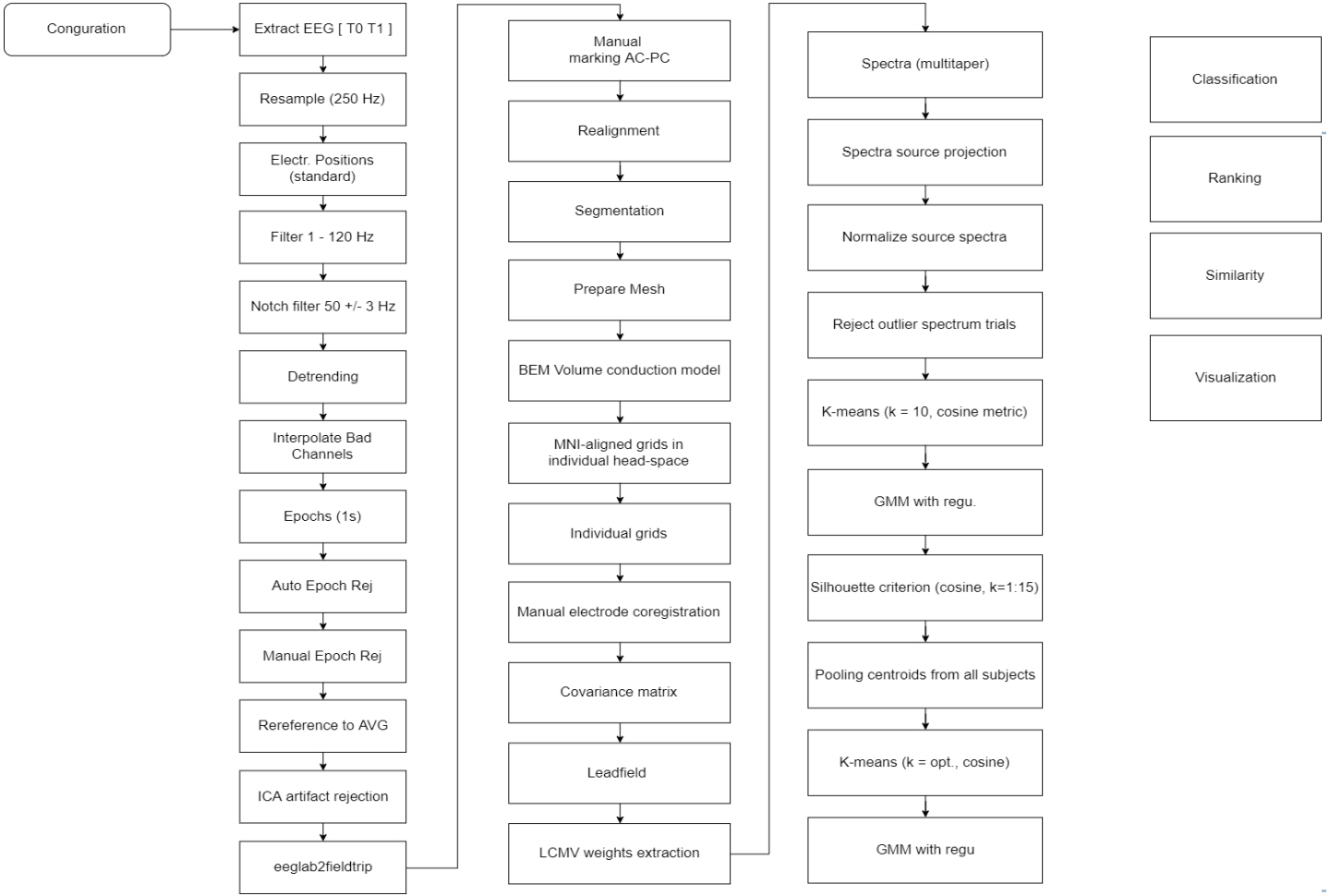
nencki institute of experimental biology

„In search of the sources of brain's cognitive activity".
This study was **supported by the National Science Center Poland (UMO-2016/20/W/NZ4/00354) grant** awarded to Prof. dr hab. Andrzej Cichocki.

Thank you !

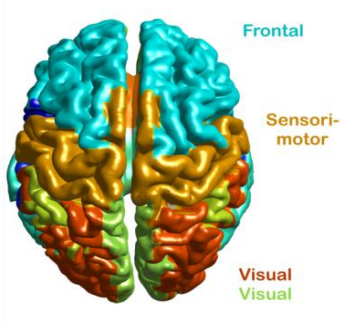
Diagram of code availability (updated 24.01.2018)

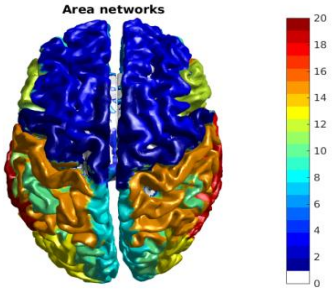


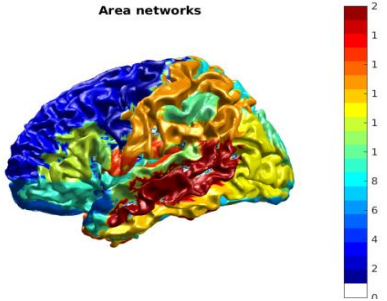

Conguration
Extract EEG [T0 T1]
Resample (250 Hz)
Electr. Positions (standard)
Filter 1 - 120 Hz
Notch filter 50 +/- 3 Hz
Detrending
Interpolate Bad Channels
Epochs (1s)
Auto Epoch Rej
Manual Epoch Rej
Rereference to AVG
ICA artifact rejection
eeglab2fieldtrip
Manual marking AC-PC
Realignment
Segmentation
Prepare Mesh
BEM Volume conduction model
MNI-aligned grids in individual head-space
Individual grids
Manual electrode coregistration
Covariance matrix
Leadfield
LCMV weights extraction
Spectra (multitaper)
Spectra source projection
Normalize source spectra
Reject outlier spectrum trials
K-means (k = 10, cosine metric)
GMM with regu.
Silhouette criterion (cosine, k=1:15)
Pooling centroids from all subjects
K-means (k = opt., cosine)
GMM with regu
Classification
Ranking
Similarity
Visualization

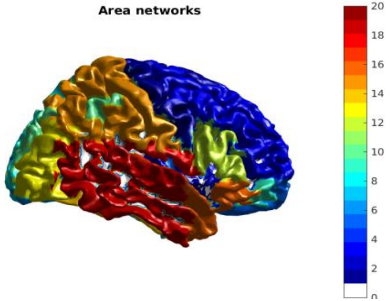
MEG reproduction results – ROI similarity (network analysis)

Left-up: Keitel & Gross, other figures: Reproduction.



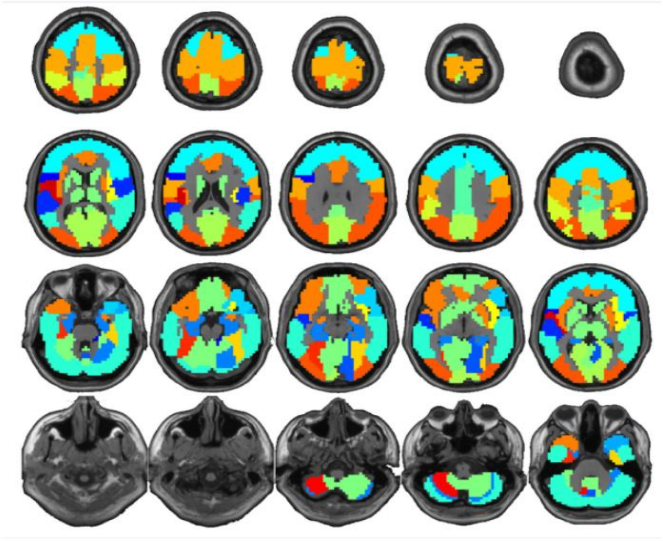




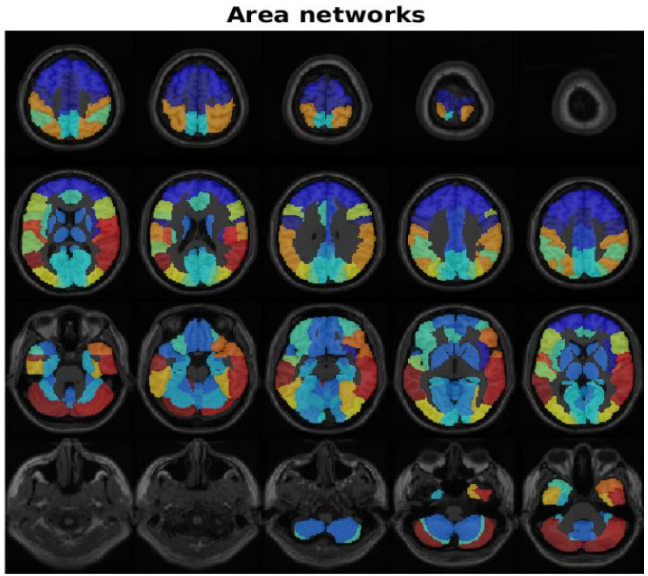


MEG reproduction results – ROI similarity (network analysis)

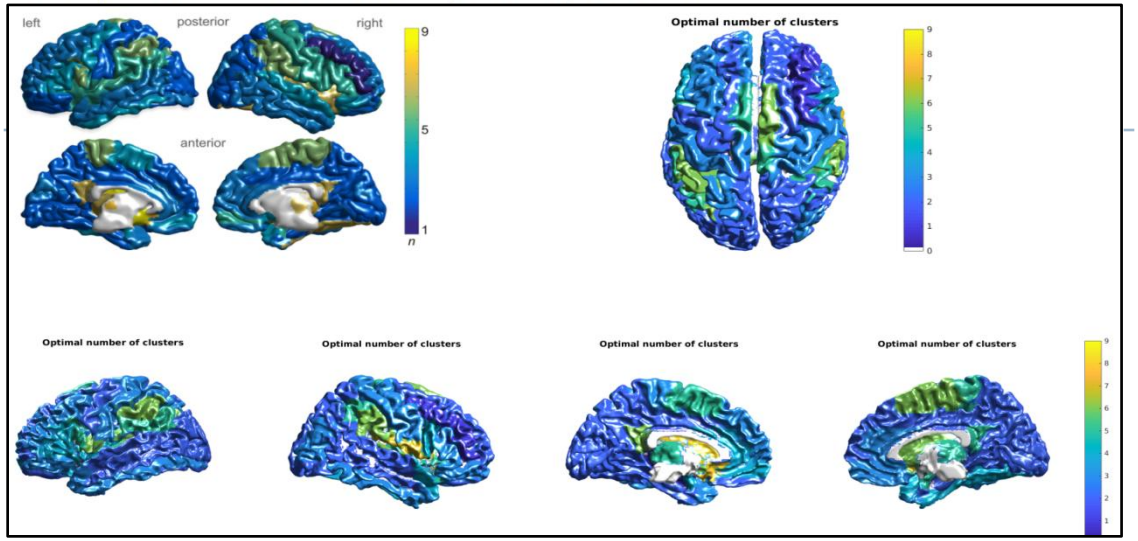
Left: Keitel & Gross



Right: Reproduction.

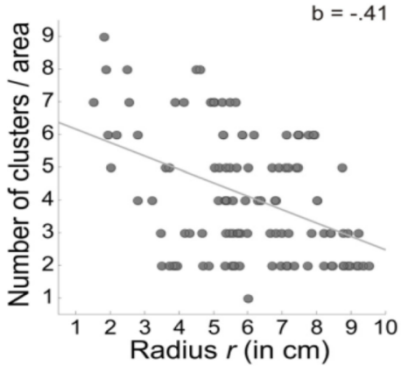


Left-up: Keitel & Gross, other figures: Reproduction.



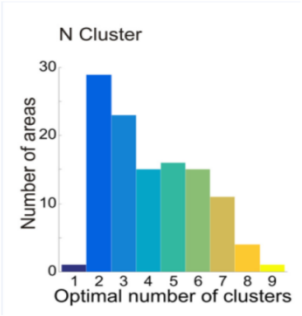
ft: Keitel & Gross

$R^2 = 0.18, F = 24.15, p < 0.001$



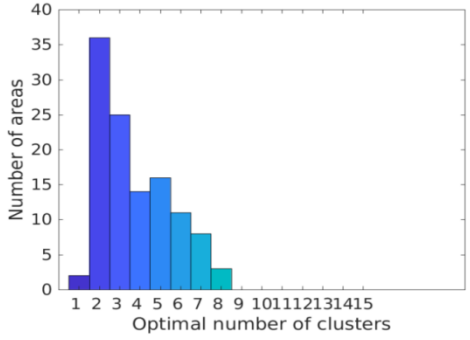
Left: Keitel & Gross

Avg. num. of clusters = 4.10 ± 1.86



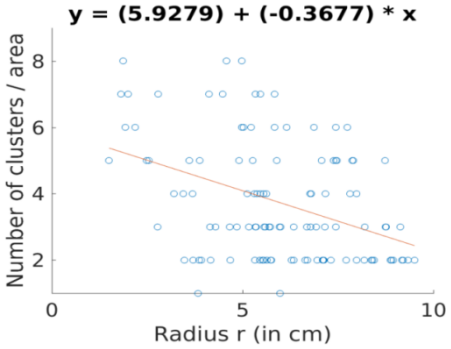
Right: Reproduction.

Avg. num. of clusters = 3.75 ± 1.78

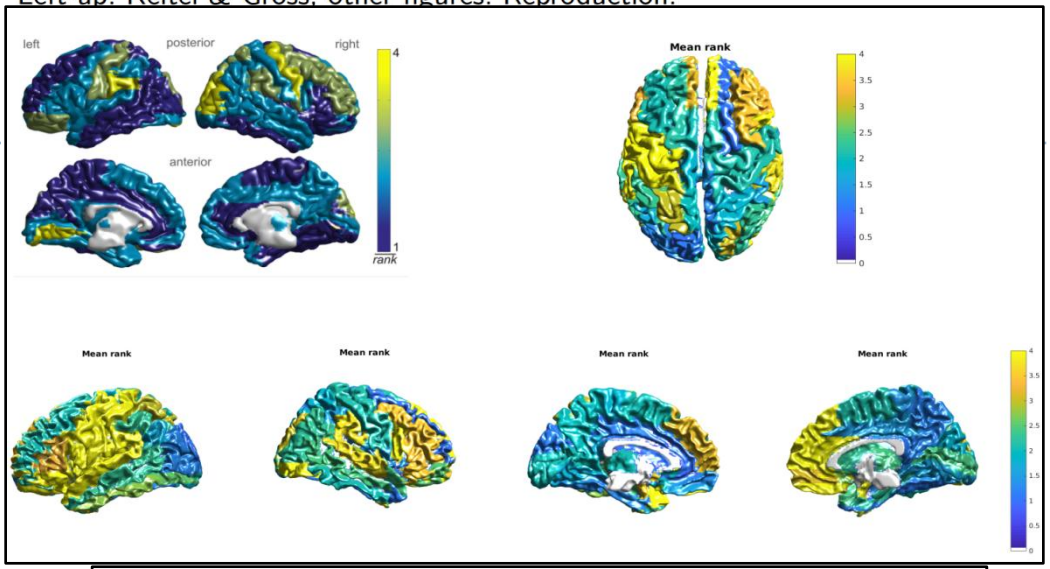


t: Reproduction.

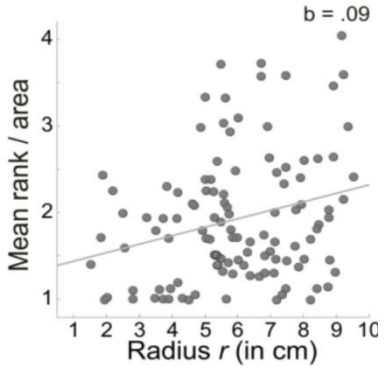
$R^2 = 0.16, F = 21.75, p < 0.001$



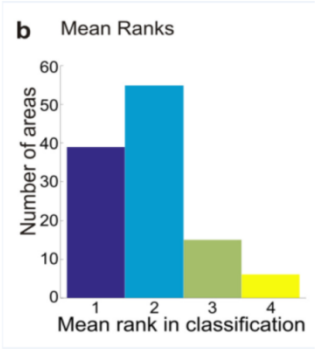
Left-up: Keitel & Gross, other figures: Reproduction.



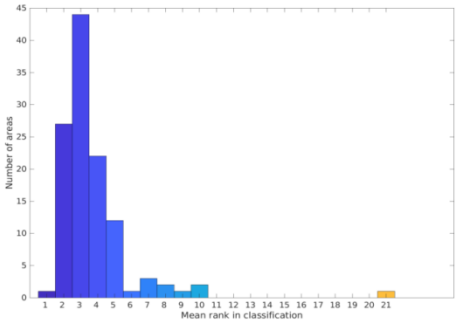
eft: Keitel & Gross
$R^2 = 0.07, F = 8.15, p = 0.04$



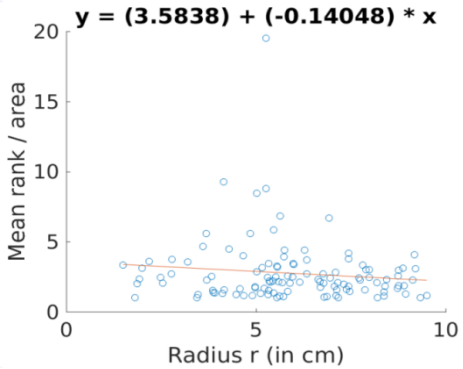
Left: Keitel & Gross
Mean rank = 1.8



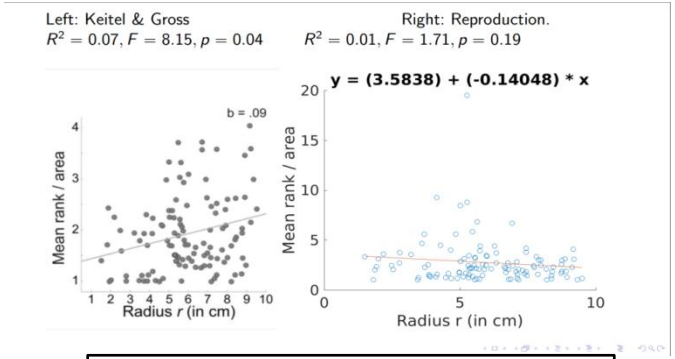
Right: Reproduction.
Mean rank = 2.28

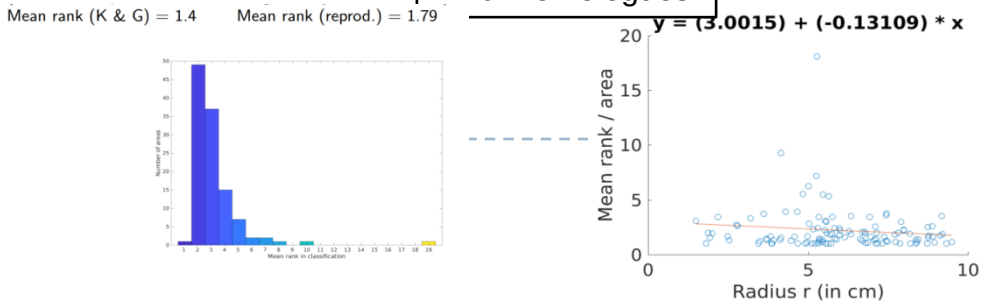


: Reproduction.
$R^2 = 0.01, F = 1.71, p = 0.19$

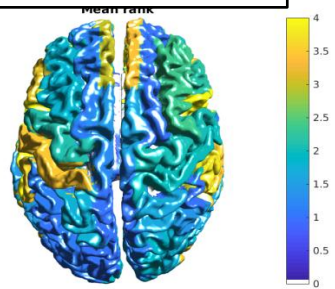


With homologues

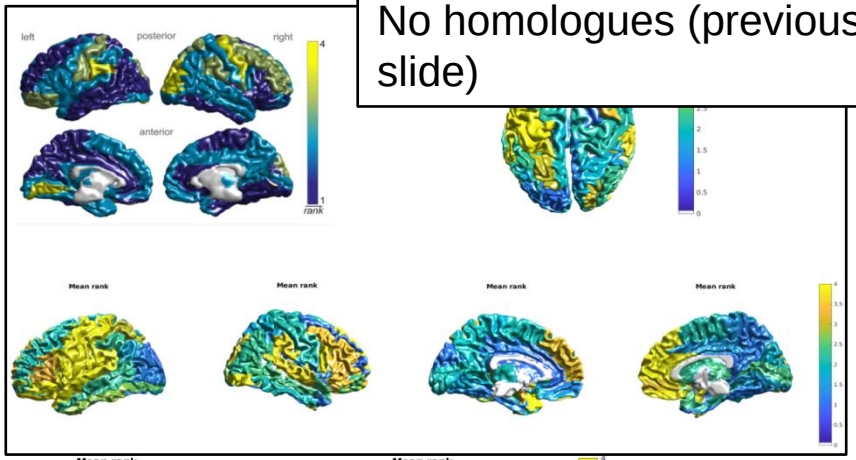


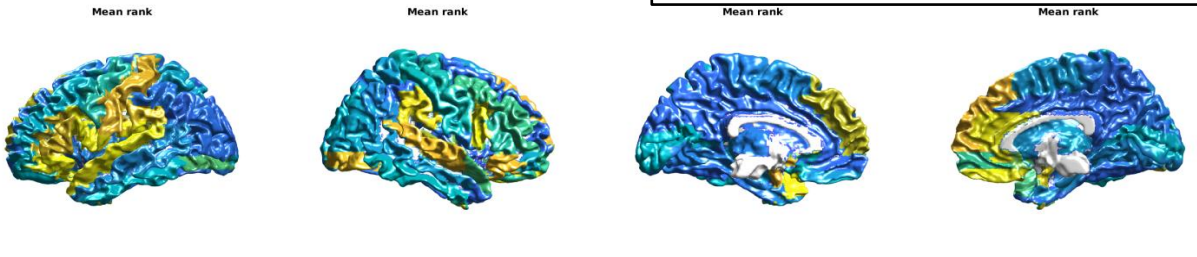


With homologues

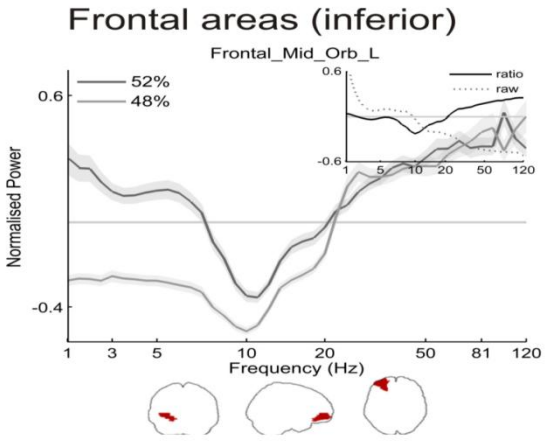


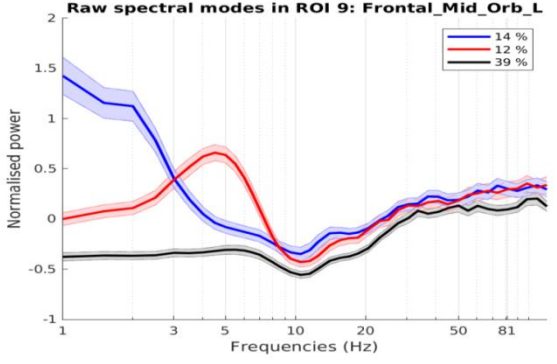
No homologues (previous slide)

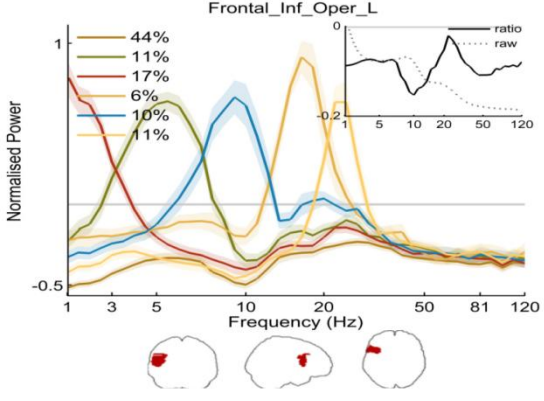


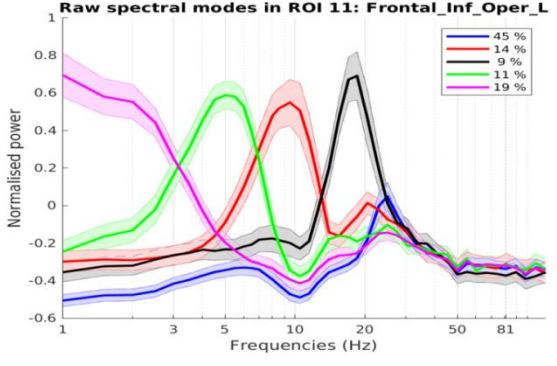


MEG reproduction results – ROI spectral fingerprints

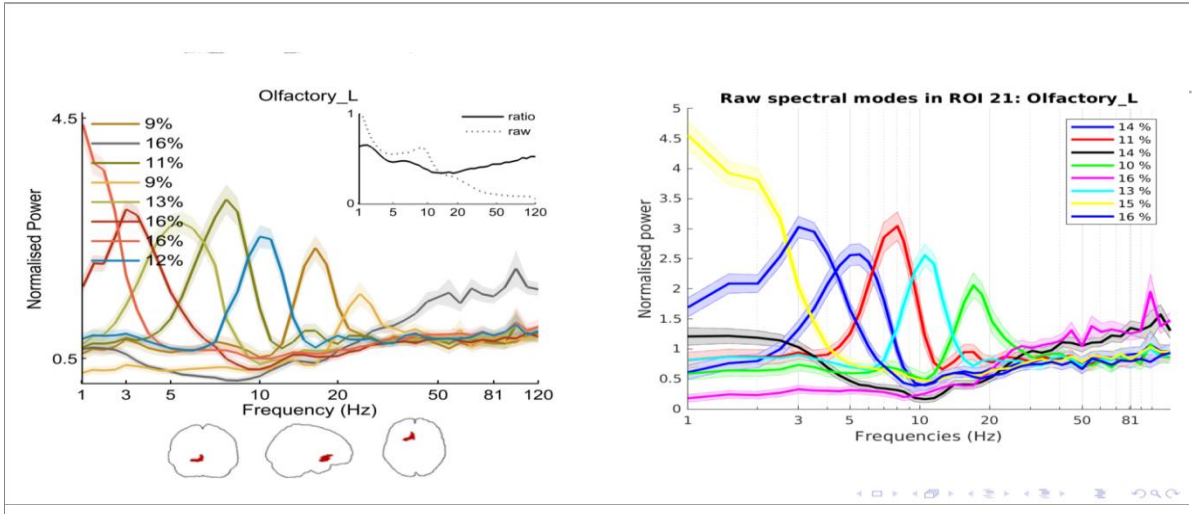


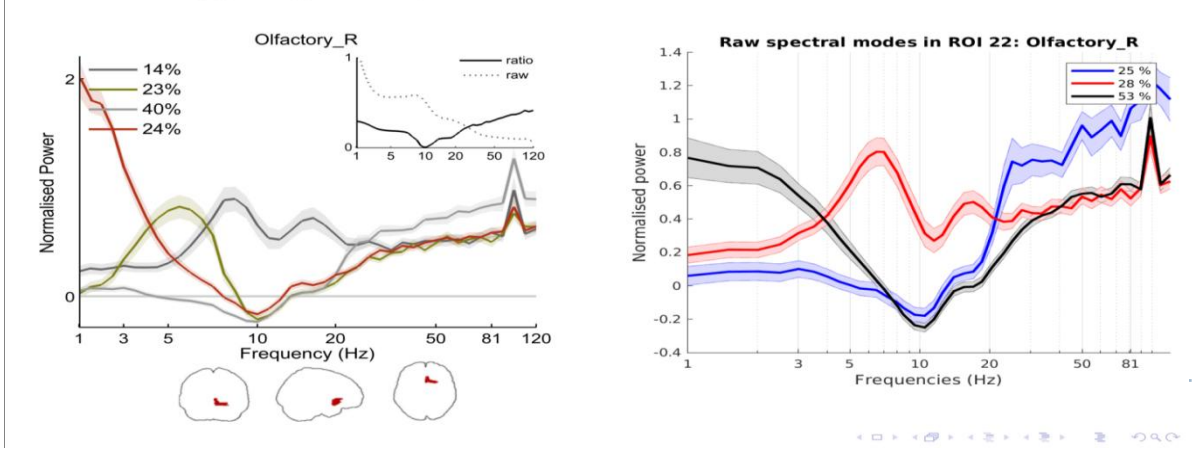




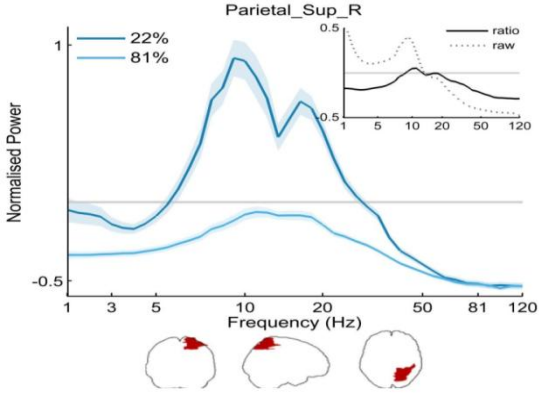


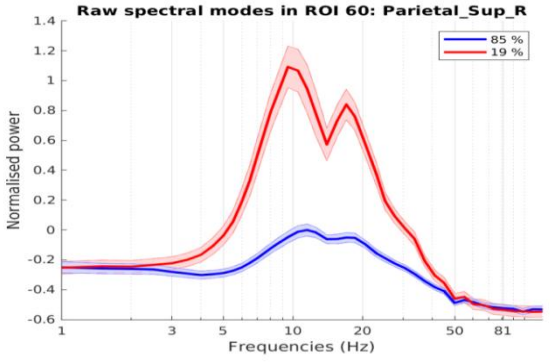
MEG reproduction results – ROI spectral fingerprints

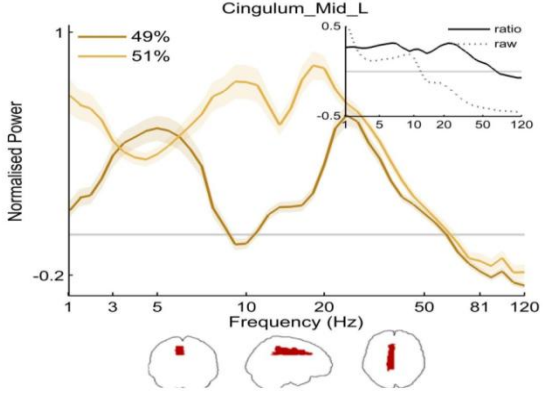


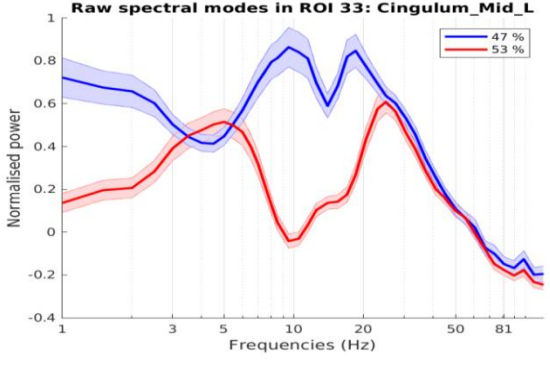


MEG reproduction results – ROI spectral fingerprints

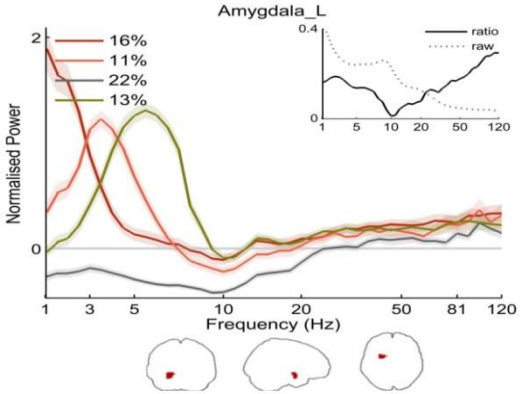


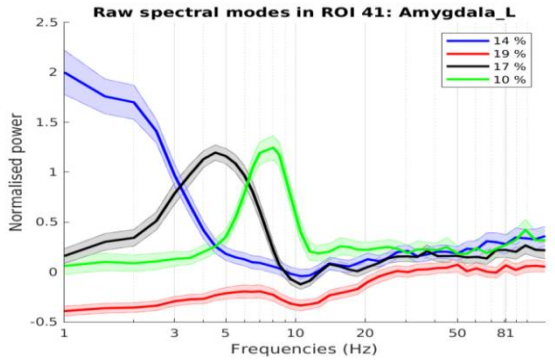


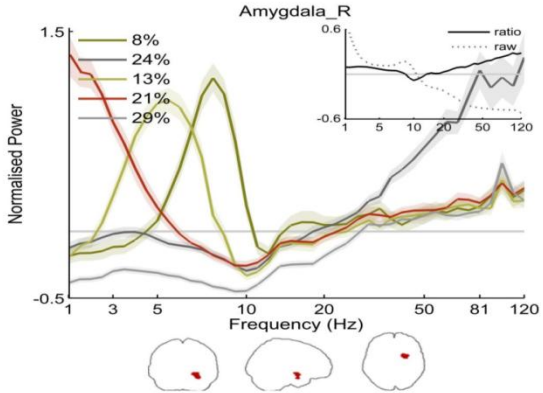


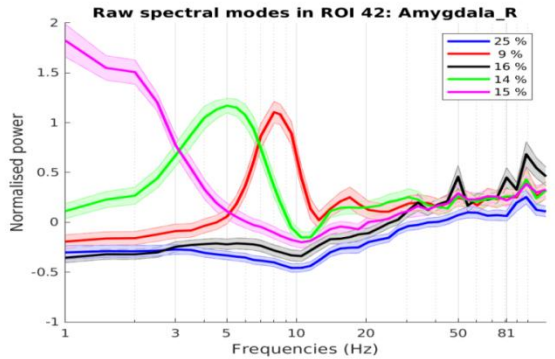


MEG reproduction results – ROI spectral fingerprints

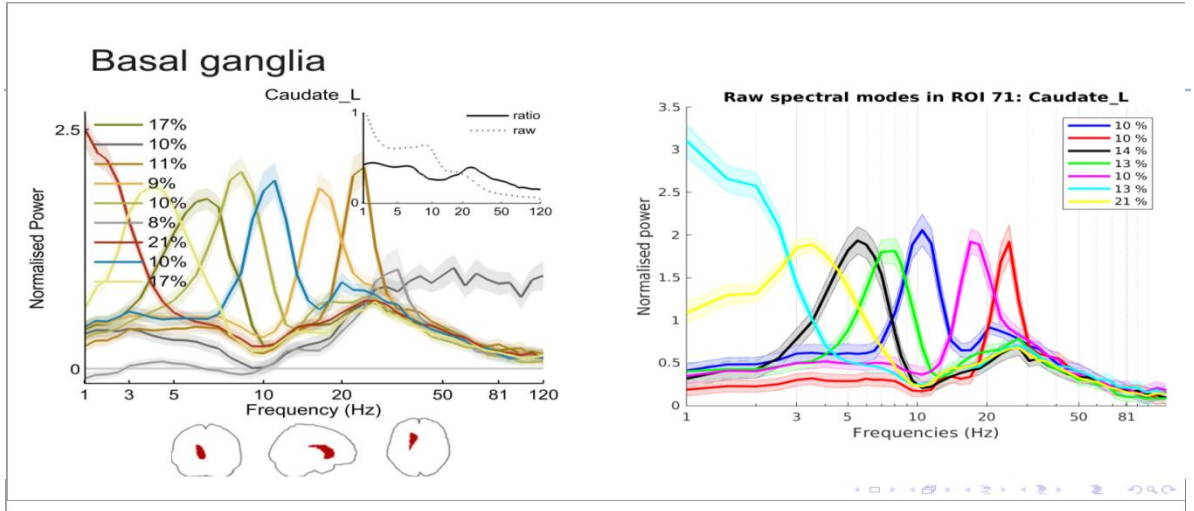


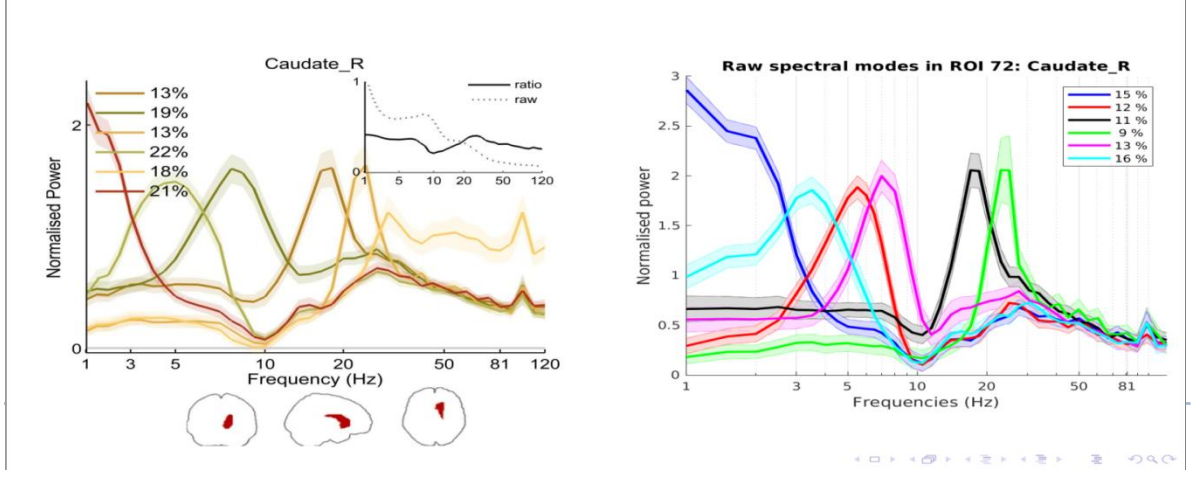




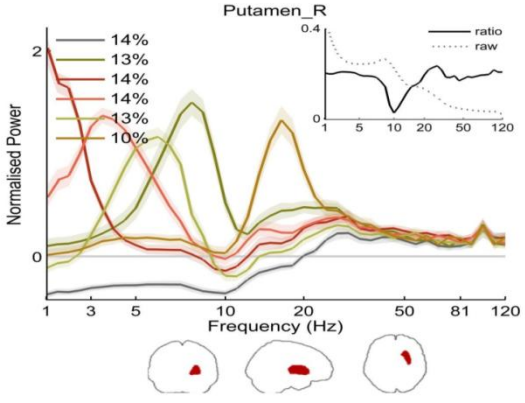


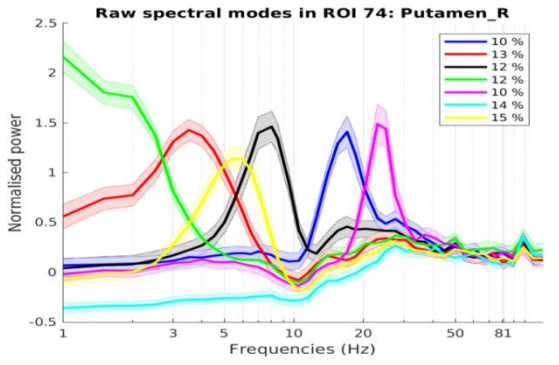
MEG reproduction results – ROI spectral fingerprints



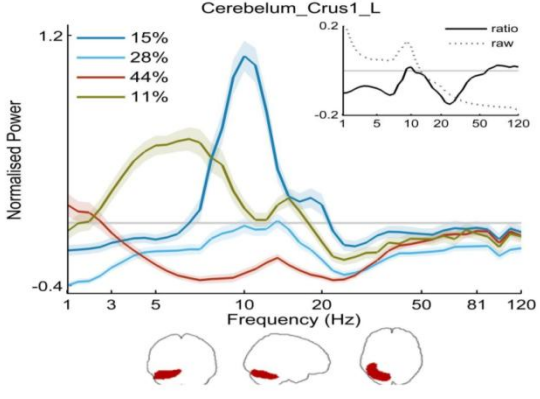


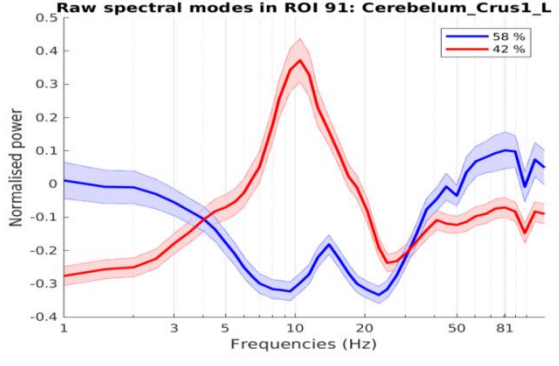
MEG reproduction results – ROI spectral fingerprints



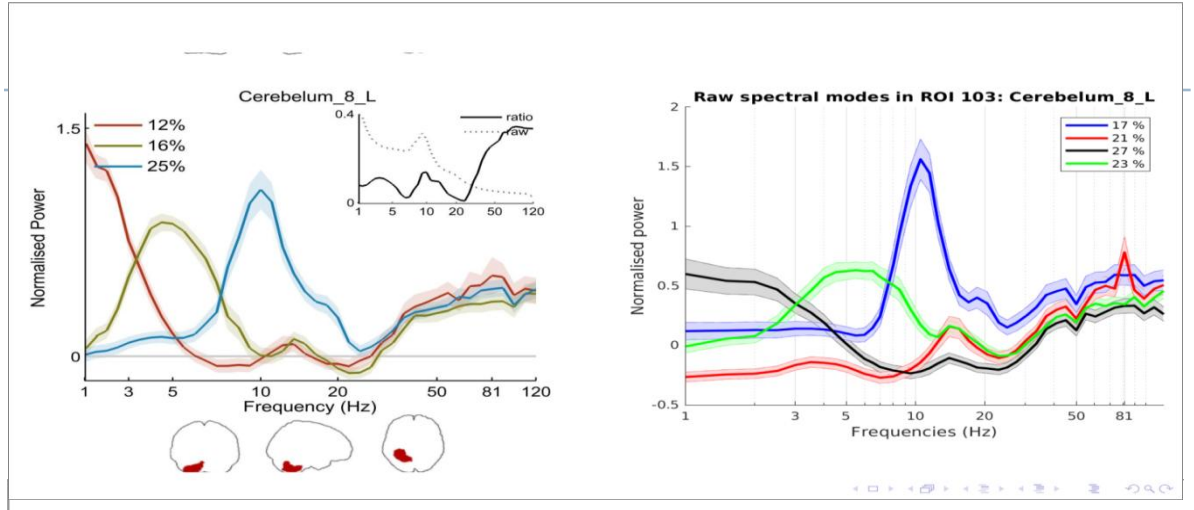


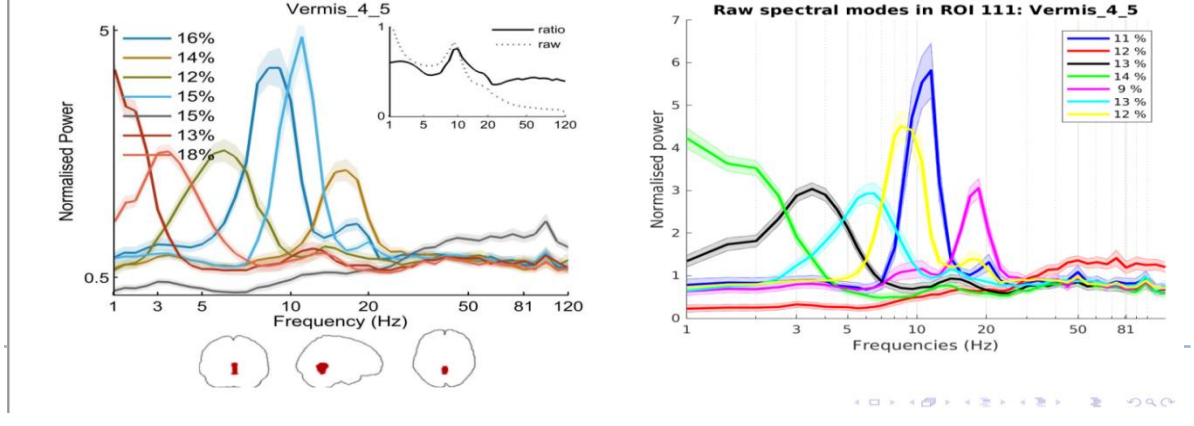
Cerebellum





MEG reproduction results – ROI spectral fingerprints





MEG reproduction results – ROI spectral fingerprints