Central European Institute of Technology
BRNO | CZECH REPUBLIC

Simultaneous EEG-fMRI
Aplications

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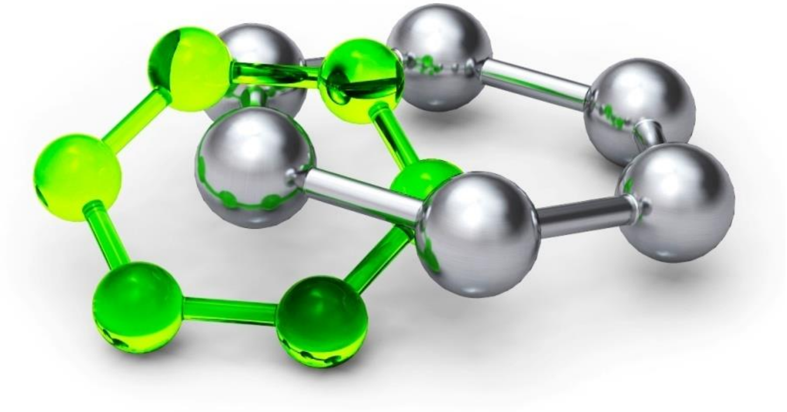
Brno, November 15th 2016



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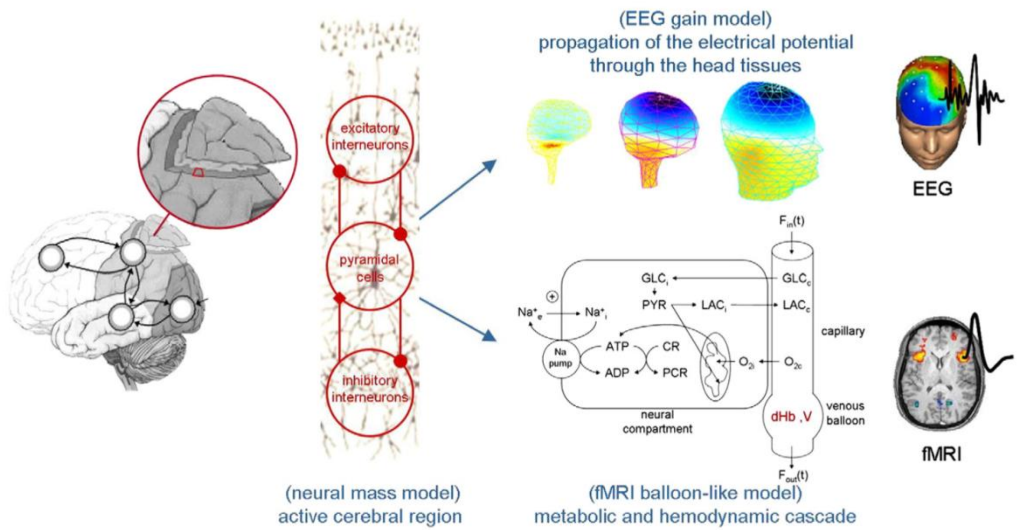
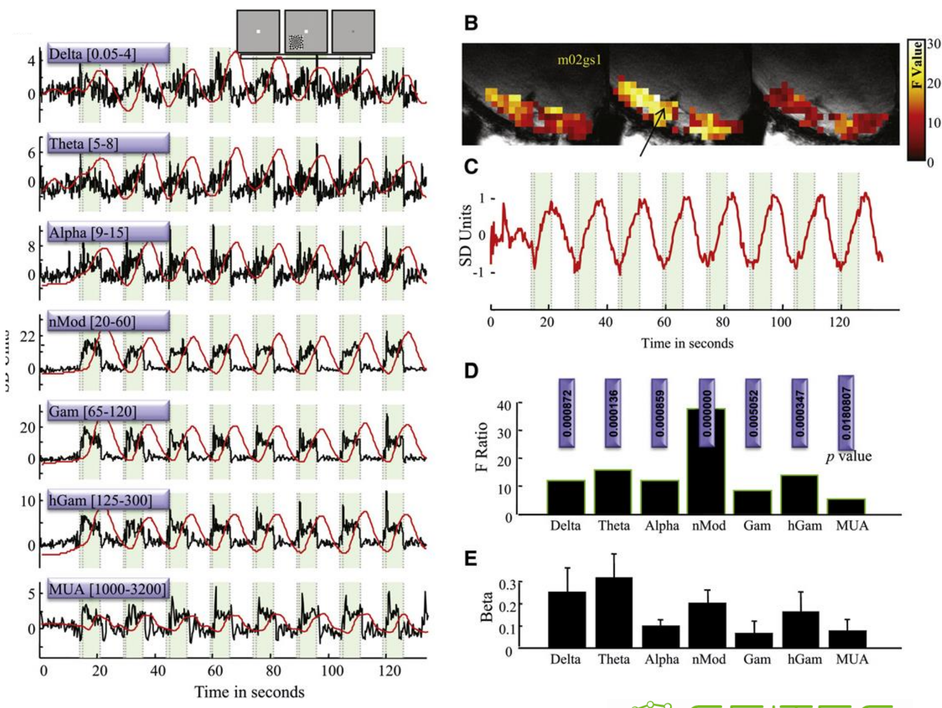
INTRODUCTION



- both modalities capture neuronal activity in an indirect way
- BOLD correlates with fluctuations of local field potentials
- common driver – postsynaptic potentials



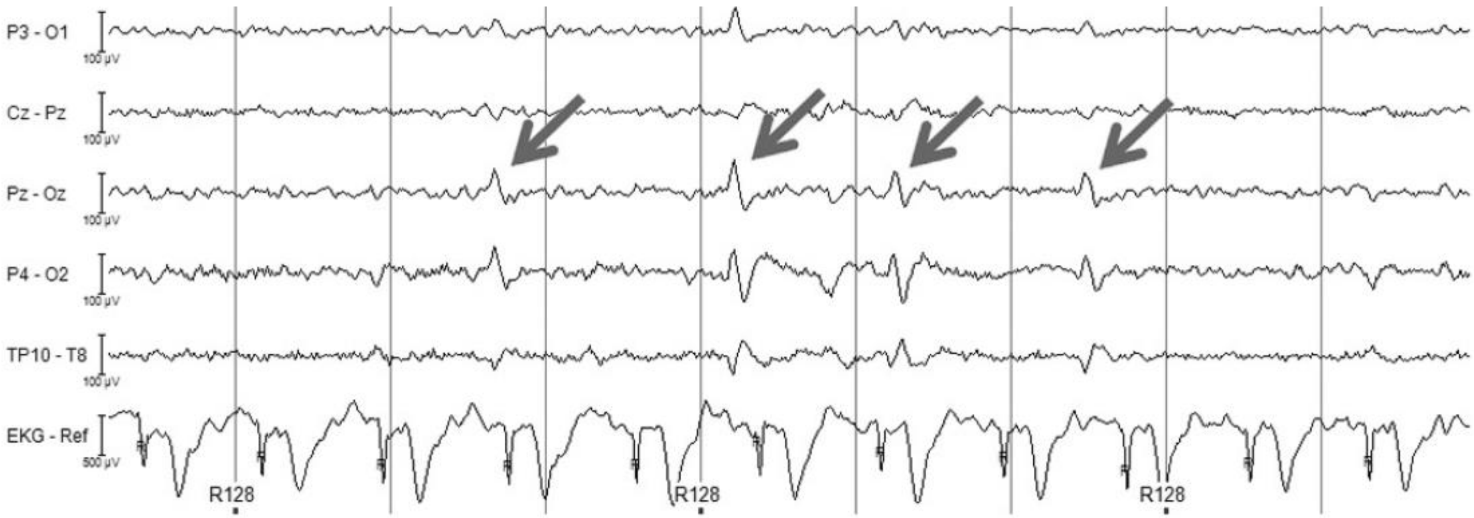
OUTLINE

- EEG – fMRI as a clinical tool in epilepsy
- EEG – fMRI as a tool for studying large scale brain networks
- other applications

EEG-fMRI in epilepsy principles

- a presence of interictal epileptiform discharges (IEDs) in scalp EEG shows that the neural activity and consequently perfusion and hemodynamic fluctuations are affected during interictal periods

- the data may help to localize epileptogenic focus – the potential target for resection treatment of pharmacorezistant epilepsy

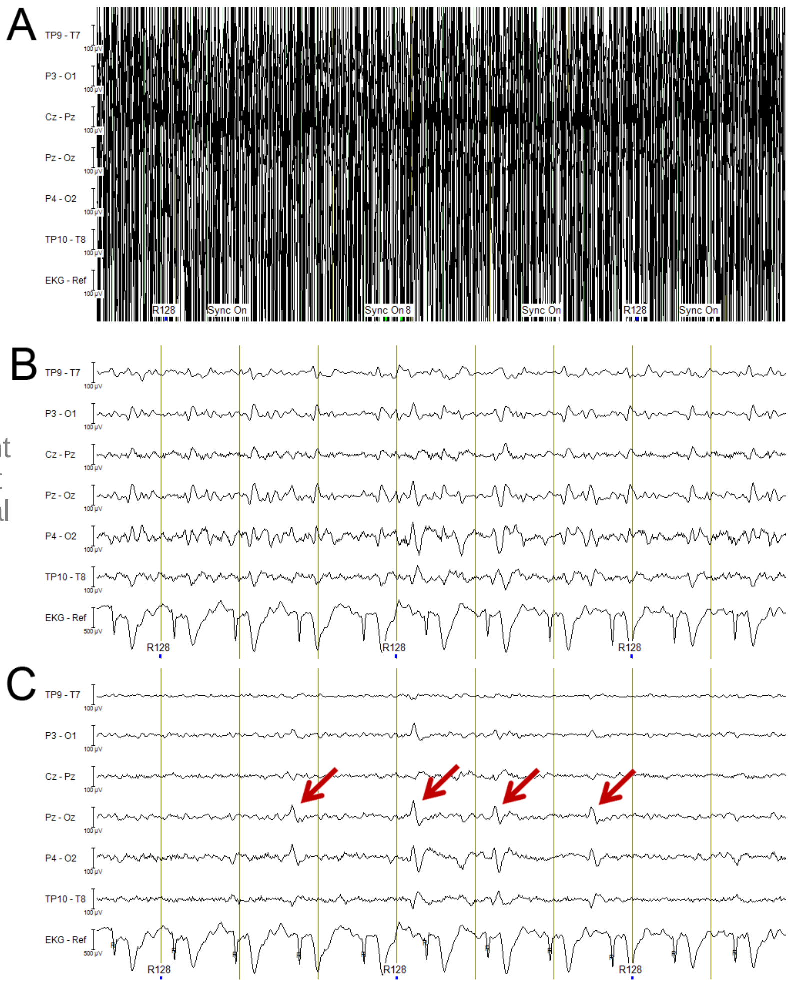


EEG-fMRI in epilepsy principles

raw data

gradient artifact removal

"clean" EEG



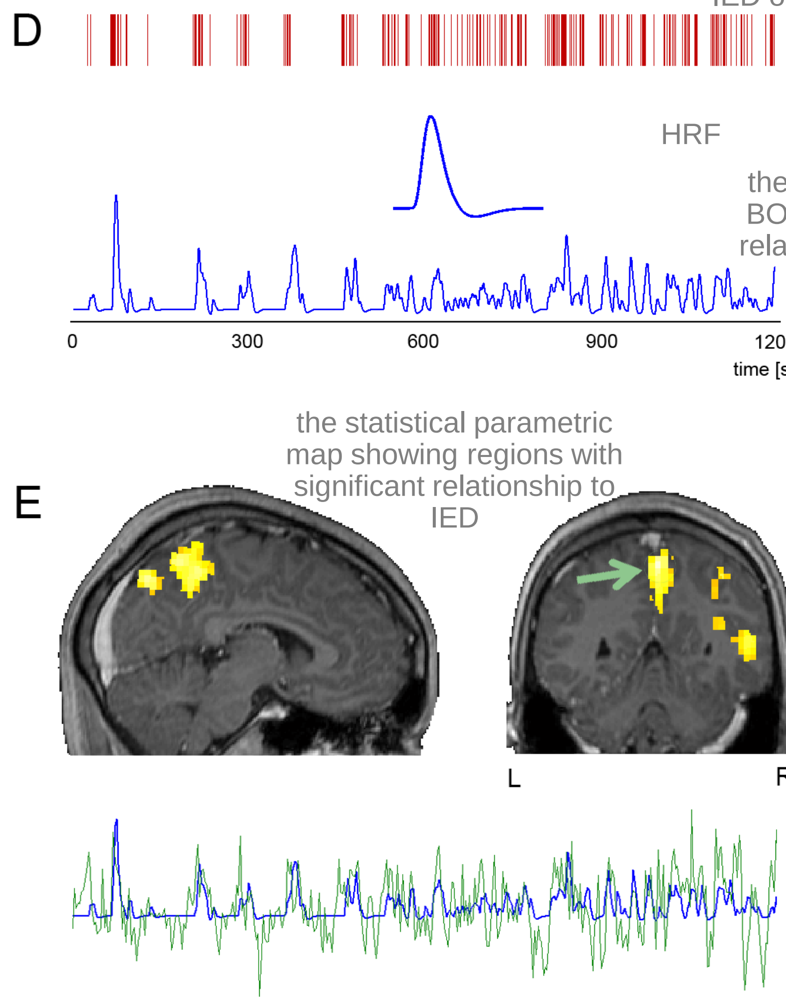
„spike informed" GLM

time-seriers of IED occurence

HRF

the model of BOLD signal related to IED

the statistical parametric map showing regions with significant relationship to IED



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EEG-fMRI in epilepsy
methodological aspects – IED identification

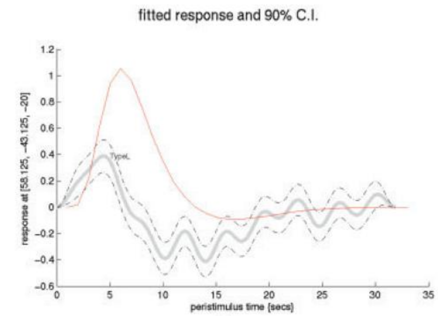
- accurate identification of IED is crucial
  - ideally, all IED should be identified
  - the statistical power depends on the number of IEDs (to many / to few….)
  - it is highly subjective
  - can be all IEDs seen on scalp EEG recordings?

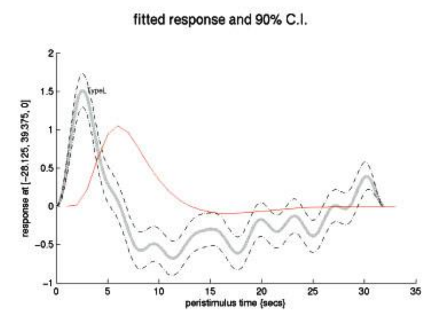
- sorting of IEDs

- no identifiable IEDs in EEG for ~30% of cases, despite the fact, that clinical EEG does contain IEDs

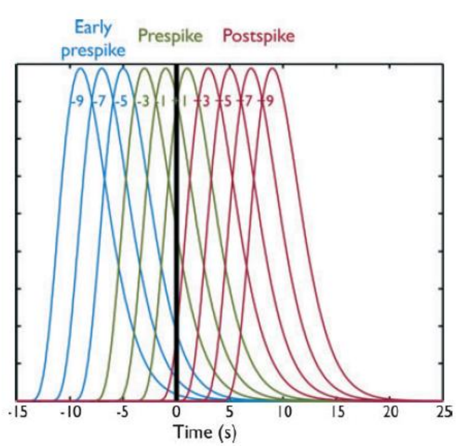
EEG-fMRI in epilepsy methodological aspects – HRF

- senzitivity depends on prior asumptions made about shape and timing of HRF
- canonical HRF??
- allow for slight variability in shape and timing of HRF
  - various basis sets for HRF
  - e.g. several time-shifted HRFs
  - e.g. including HRF derivatives (“SPM” approach)
  - resonable in cases with the hemodynamic system strongly affected by structural or ischemic lesions





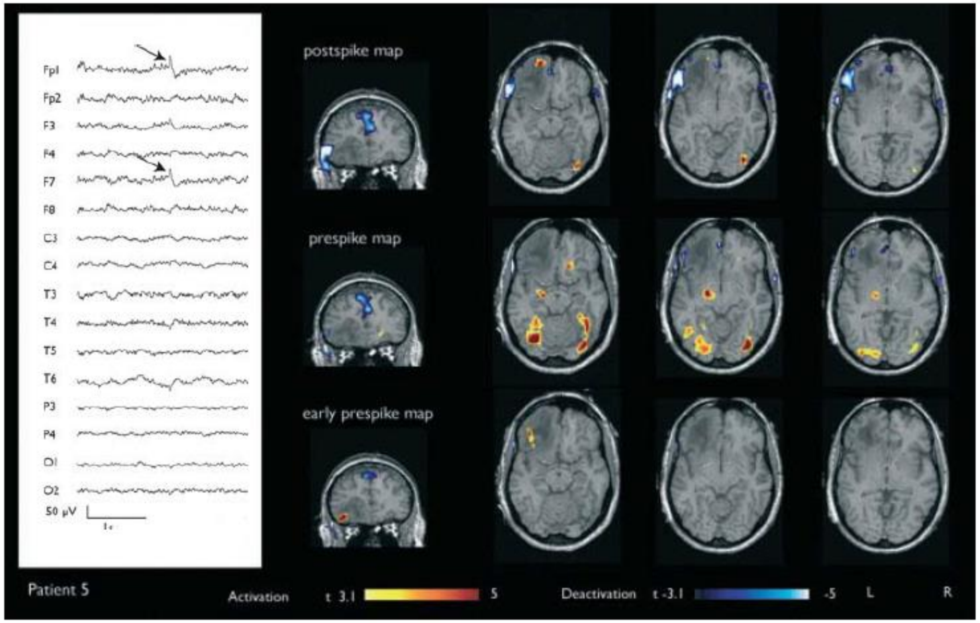
Lemieux et al. 2008



Bagshaw et al.,2004; Rathakrishan et al. 2010

EEG-fMRI in epilepsy
methodological aspects – negative BOLD

- positive BOLD response
  - sources and propagations of IED



Rathakrishan et al. 2010

- negative BOLD response
  - ??
  - resting state networks, which decrease their activity during pathological; “internal” stimuli (Laufs 2007)
  - anti-ictogenic role – inhibition in local and distant regions (Chaudhary 2011; Gotman BACI2013)
  - specific to slow wave discharges ?? (Gotman BACI2013)

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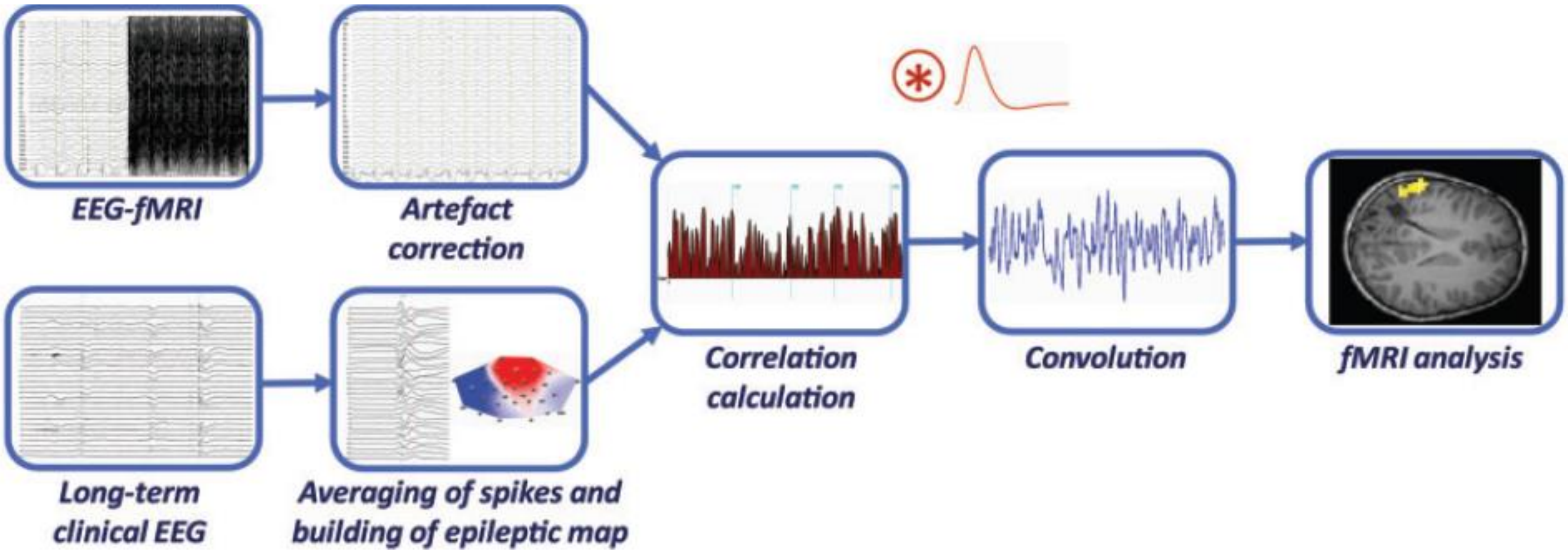
EEG-fMRI in epilepsy clinical implications

- IEDs generated in irritative zone
  - may be or may not be concordant with seizure onset zone

- considerable portion of subjects with “nonactive” EEG



- Grouiller et al. 2011
  - interesting way how to analyze nonactive EEG

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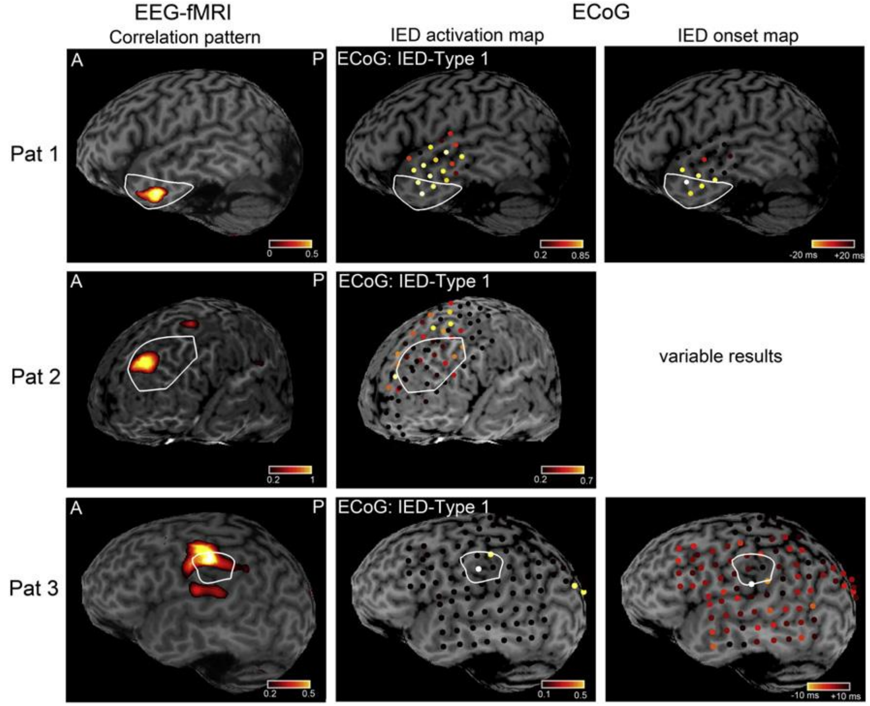
EEG-fMRI in epilepsy
clinical implications - senzitivity

- Pittau et al. 2012
  - 14 patients
  - in 12 concordance of BOLD response localization with intracerebral electrodes / MR lesion

- Van Houdt et al. 2013
  - in all 16 patients at least one IED-related BOLD response concordant to the interictally active ECoG



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EEG-fMRI in epilepsy
clinical implications - reproducibility

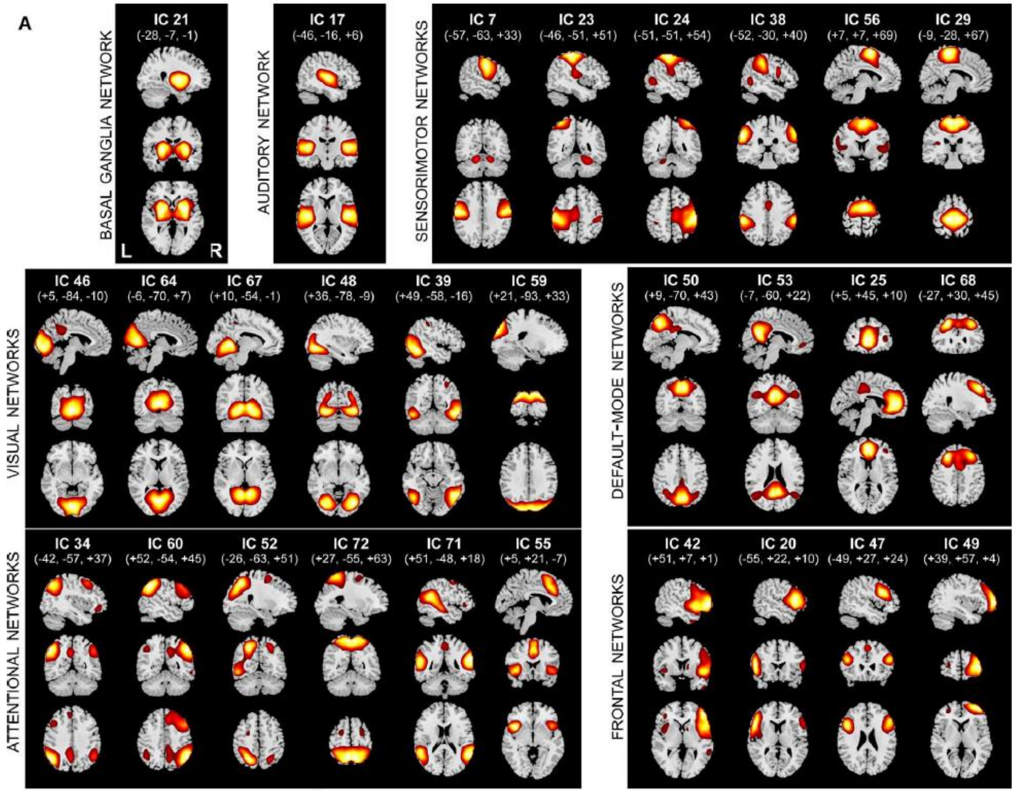
- Gholipour et al. 2011
  - 15 patients recorded twice (1.5T/3T in 8 cases; 3T/3T in 7 cases)
  - in 12 reasonable reproducibility of results
  - in 4 patients results from 3T more significant than in from 1.5T

EEG-fMRI in epilepsy conclusion

- nowadays widely used in presurgical patient evaluation being complementary to the traditional methods for focus localization, e.g., scalp EEG description or more recently proposed IED Source Imaging
- precise identifying of IEDs is crucial
- can not be viewed as a stand-alone modality for EPI focus localization
- brings valuable information to the process of EPI surgery planning

Brain rhythms

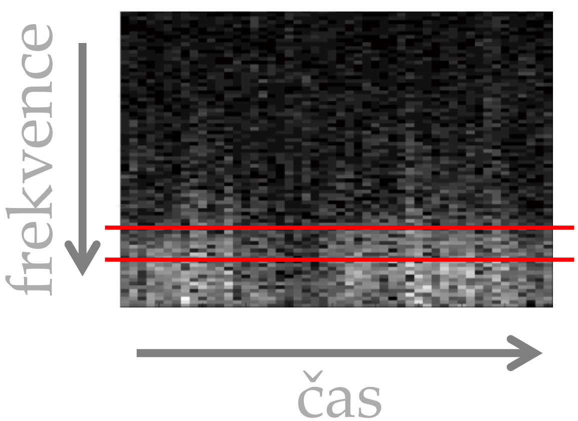
- the functional connectivity studies show, that human brain is organized into the large scale brain networks
- are there any markers of these networks in EEG data??



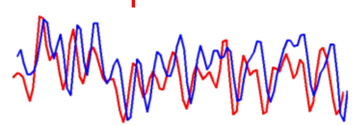
Allen et al., 2011

Brain rhythms

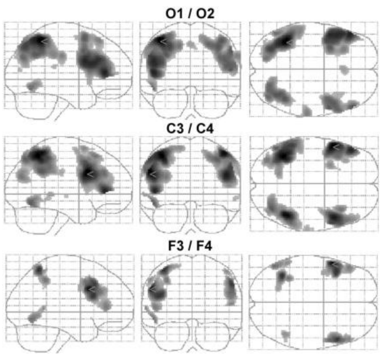
- examination of relationships between EEG activity and large scale brain networks



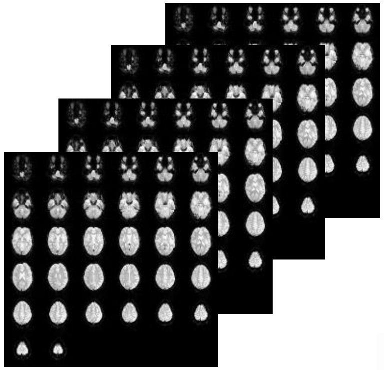
fluctuations in power within alpha band



hemodynamic fluctuations



H. Laufs et al., 2003

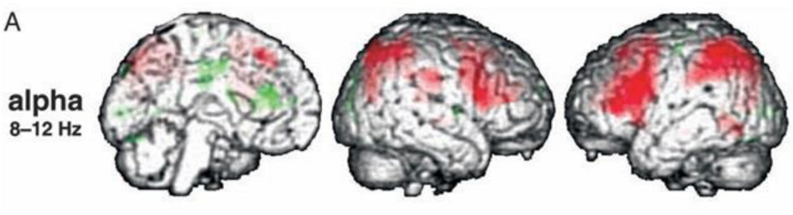


Brain rhythms

Laufs et al., 2003

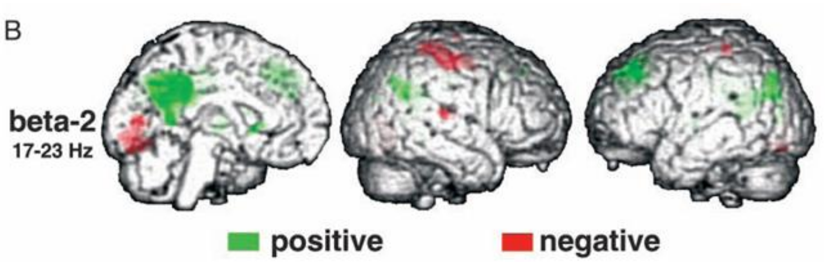
ALFA

- desynchronization when attentional network goes on
- positive correlation with hemodynamic fluctuation in thalamus, negative in fronto-parietal regions (attentional network)



BETA

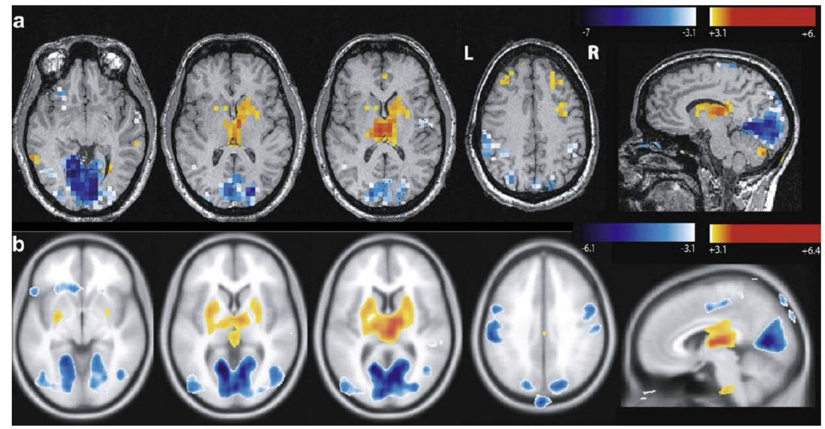
- positive correlation with hemodynamic fluctuations in default mode network



Brain rhythms

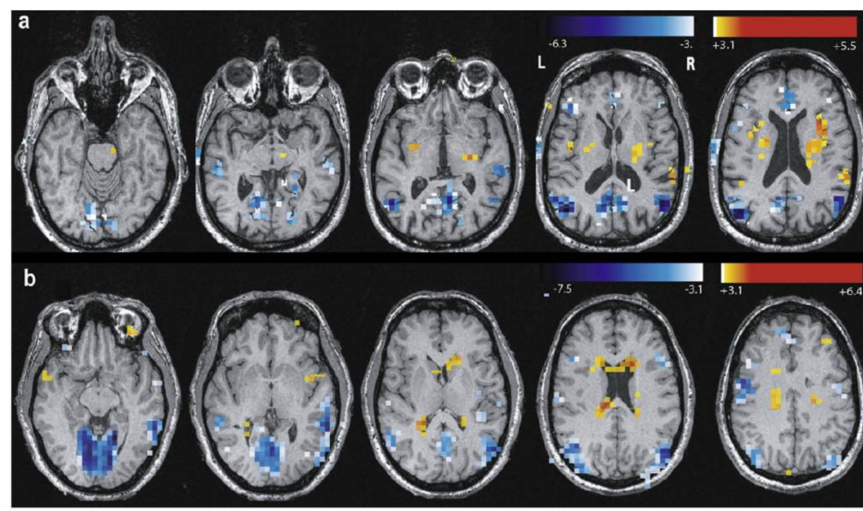
Tyvaert et al., 2008

L. Tyvaert et al. / Clinical Neurophysiology 119 (2008) 2762–2774



ALFA

- positive correlation with hemodynamic fluctuation in thalamus
- the rhythmic thalamic activity related to cortico-cortical component that contributes to the generation of a cortical domain of alpha and its propagation over the cortex



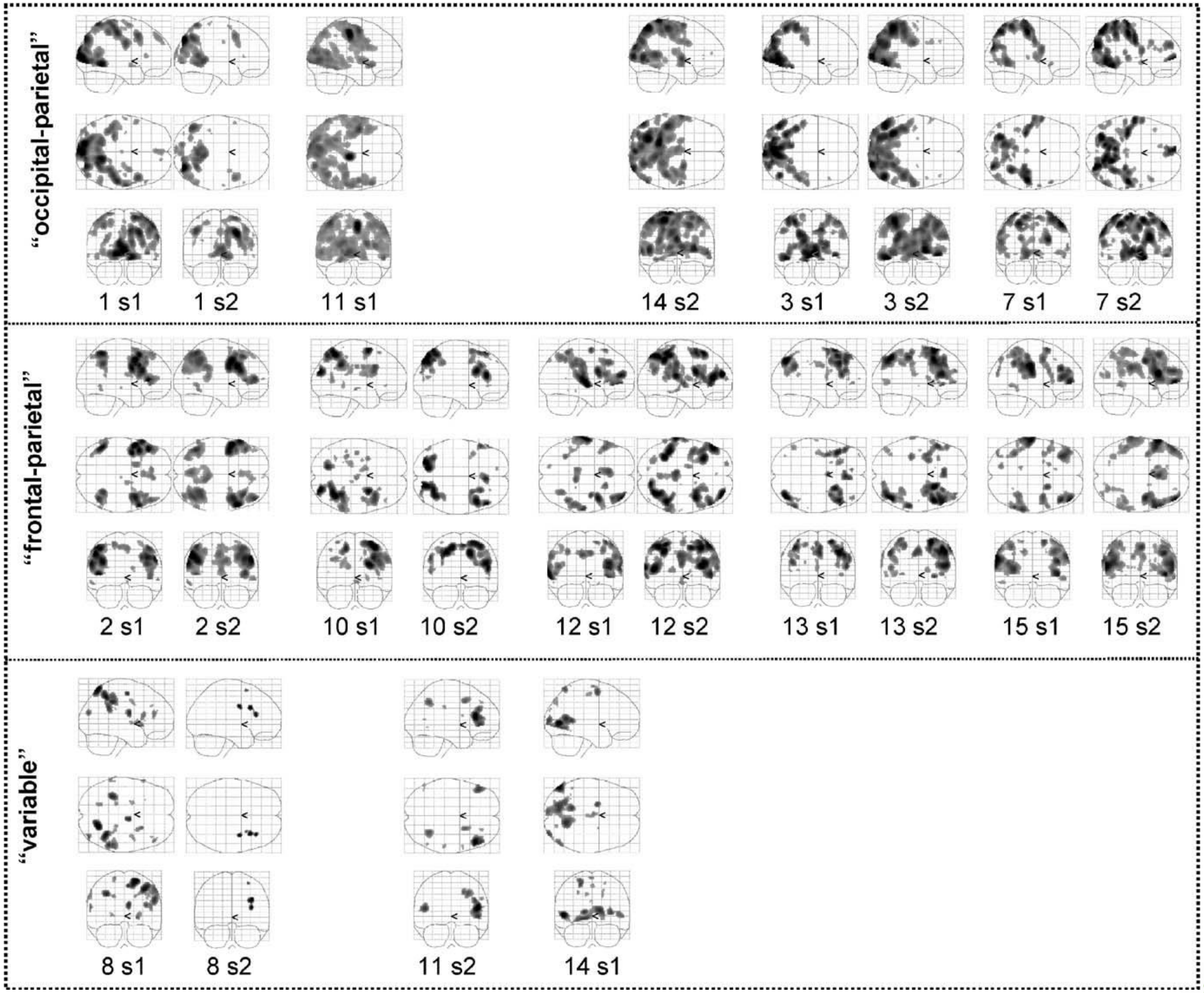
THETA

- theta seems related to default mode network

Brain rhythms

ALFA

Laufs et al., 2006



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Brain rhythms

In general, there is a consensus that a distinct fMRI network may correlate with multiple brain rhythms and, conversely, distinct brain rhythm may correlate with multiple fMRI networks.

de Munck et al. 2009; Laufs 2008

WHY??

probably due to strict constrains in the stage of EEG preprocessing

- preselected subgroups of electrodes
- averaging the signal across electrodes
- preselected frequency band of interest
- unknown shape and timing of hemodynamic response

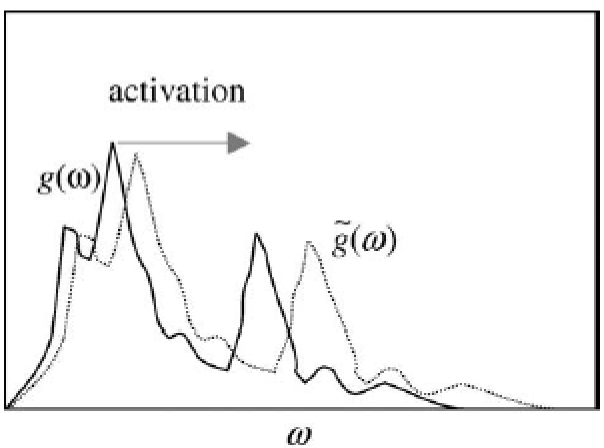
employ data-driven methods without any prior constraints applied to the spatial and temporal dimensions or to the shape of a frequency band of interest when seeking information hidden in the structure of EEG activity

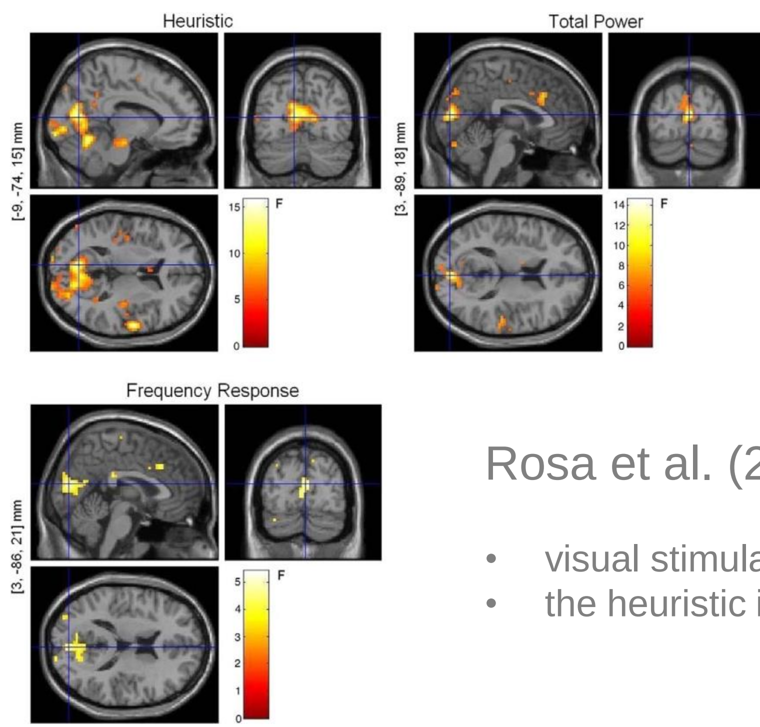
Brain rhythms

Kilner et al. (2005)

- theoretical neurophysiology model (“Heuristic”)
- activation causes:
  - increased energy dissipation
  - decreased effective membrane time constants
  - increased effective coupling among neuronal ensembles
  - a shift in the EEG spectral profile to higher frequencies

$$\left[\frac{\tilde{b}}{b}\right]^2 \propto (1+\alpha)^2 \propto \frac{\int \omega^2 \tilde{p}(\omega)d\omega}{\int \omega^2 p(\omega)d\omega}$$

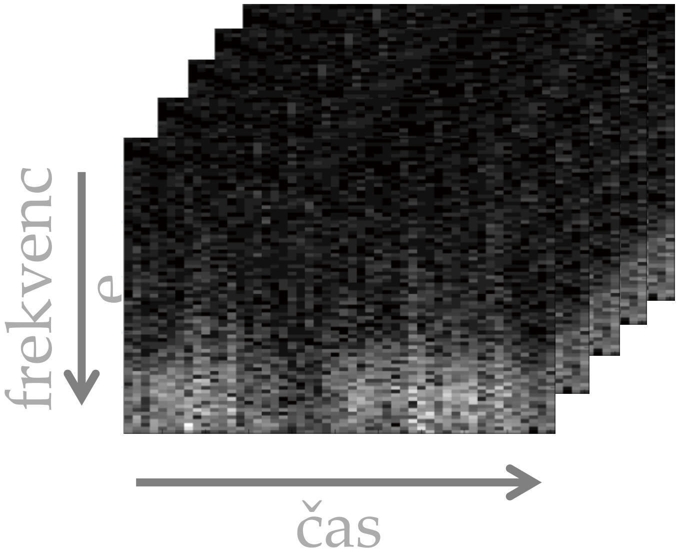




Rosa et al. (2005)

- visual stimulation
- the heuristic is the best

Brain rhythms



=> 3D spectrogram

PARAFAC

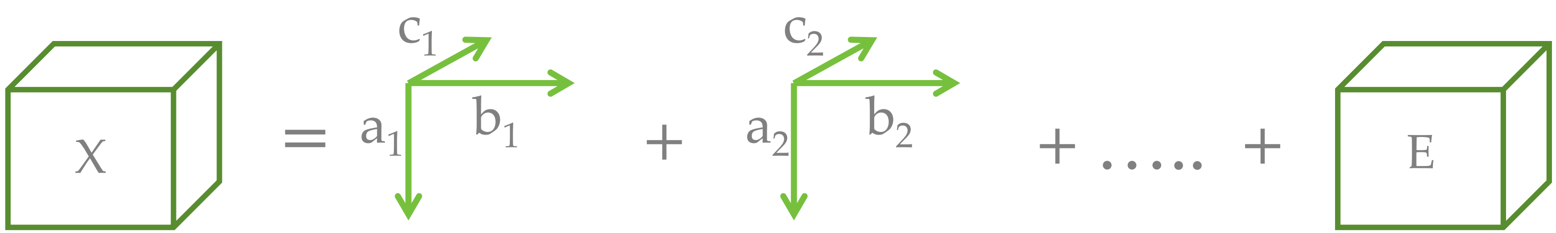
- blind decomposition of 3D data (in general N-dimensional)
- a kind of analogy of PCA to higher dimensions

Brain rhytms

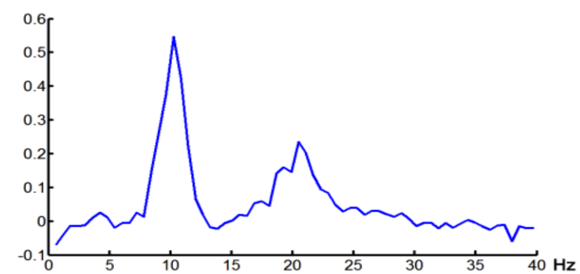
Parafac model

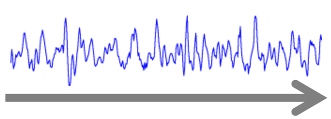
$$x_{ijk} = \sum_{f=1}^{F} a_{if}\, b_{jf} c_{kf} + e_{ijk}$$

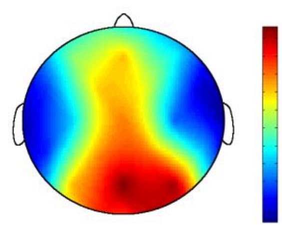
- decomposition of 3D matrix into components



- each component has 3 signatures
  - spectral pattern
  - scalp topography
  - time-series of power fluctuations



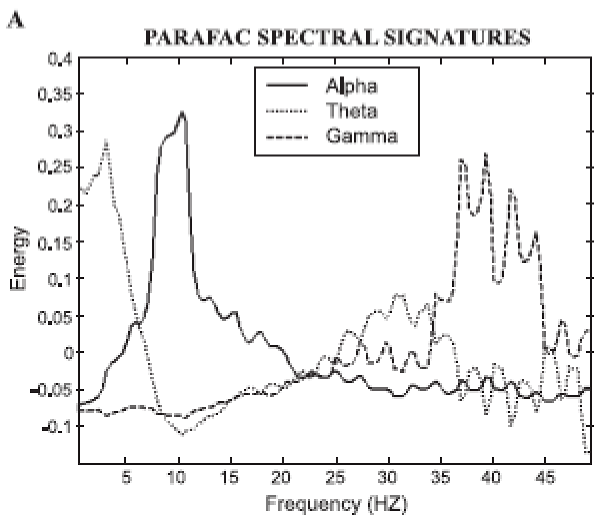


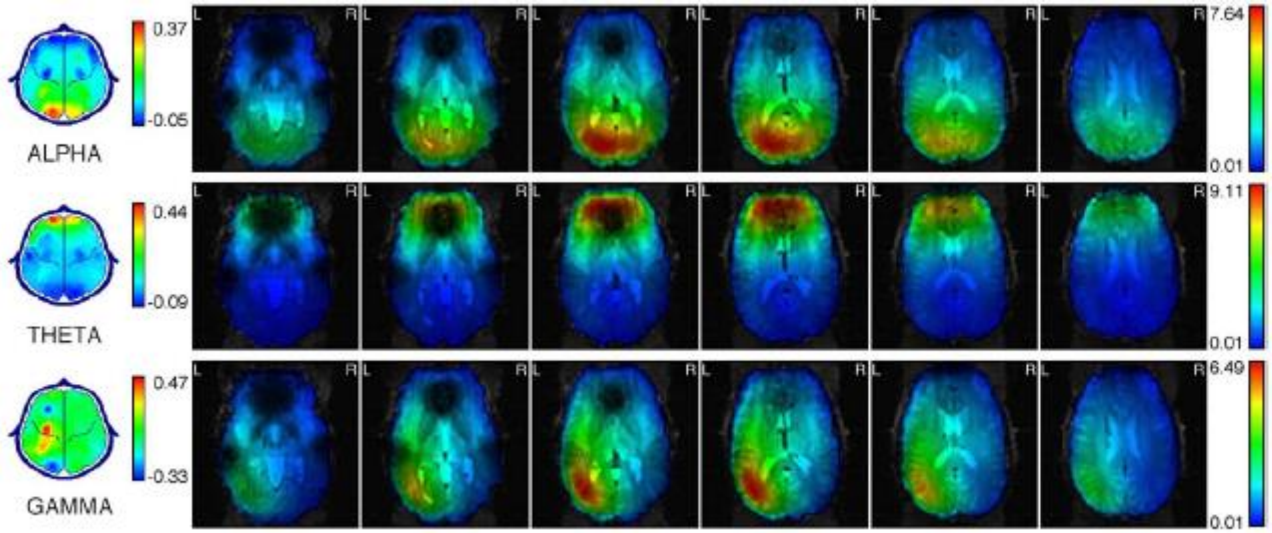


Brain rhythms

Martinez-Montes et al., 2004

- EEG-fMRI data
- resting state
- identified 3 components in EEG (atoms)
- time-series signaters used as a regressors for fMRI analysis





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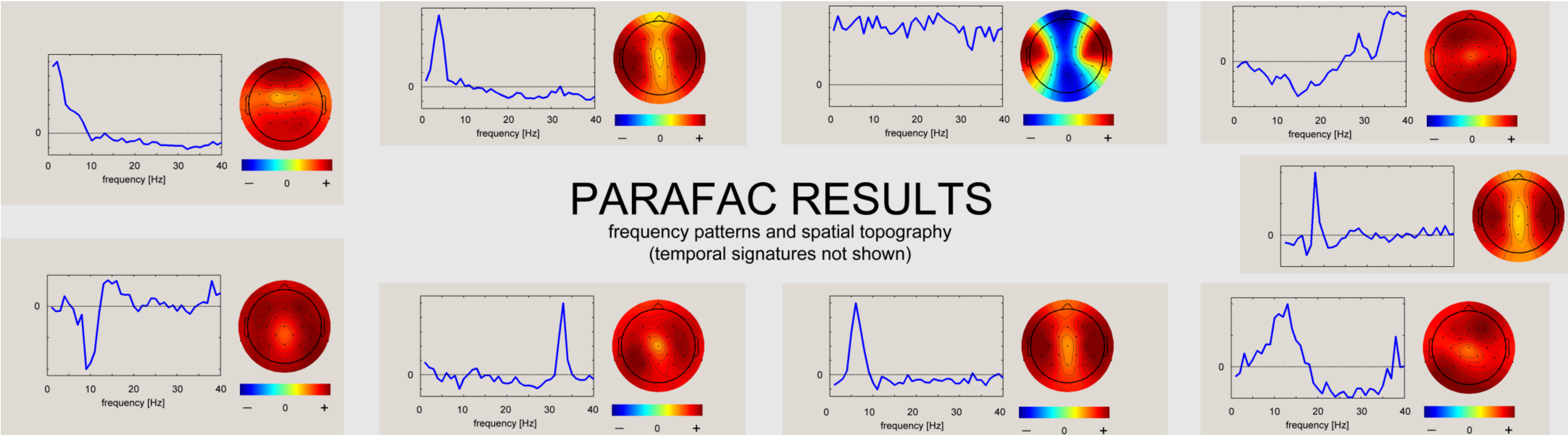
Brain rhythms

Marecek et al., 2016

- EEG-fMRI data
- semantic decision task
- identified 9 components
- time-series signatures used as a regressors for fMRI analysis



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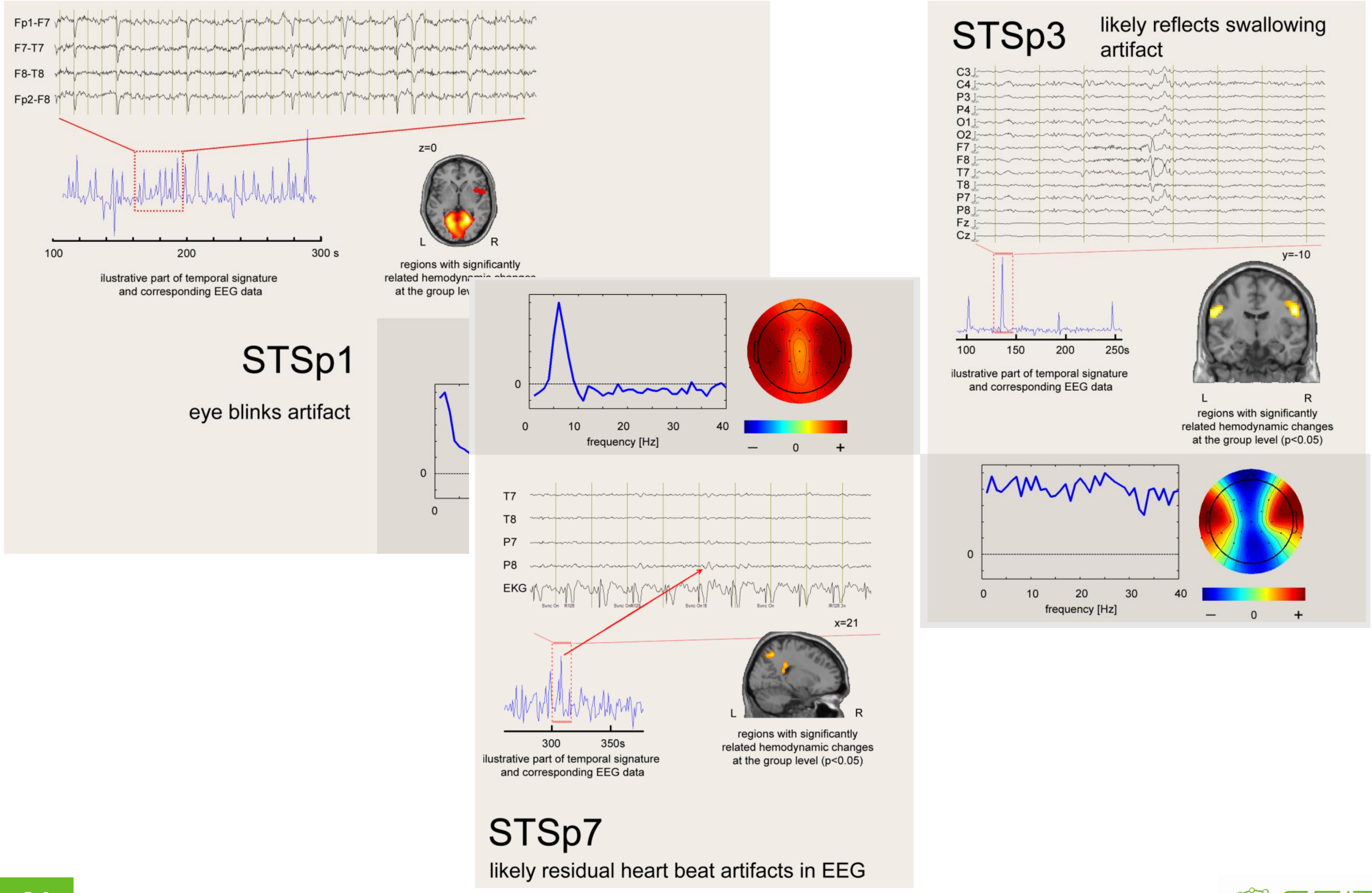
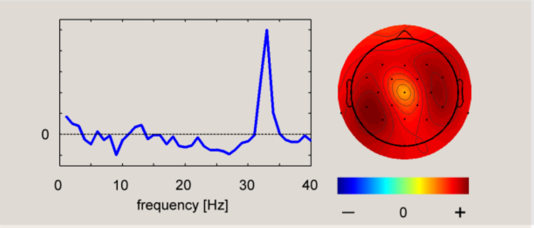
Brain rhythms

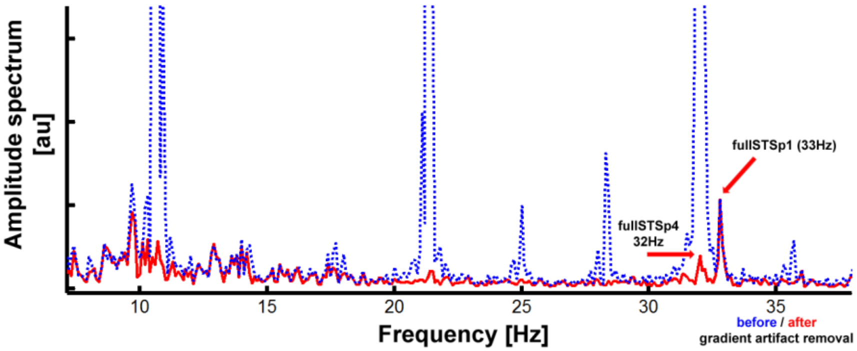


Brain rhythms



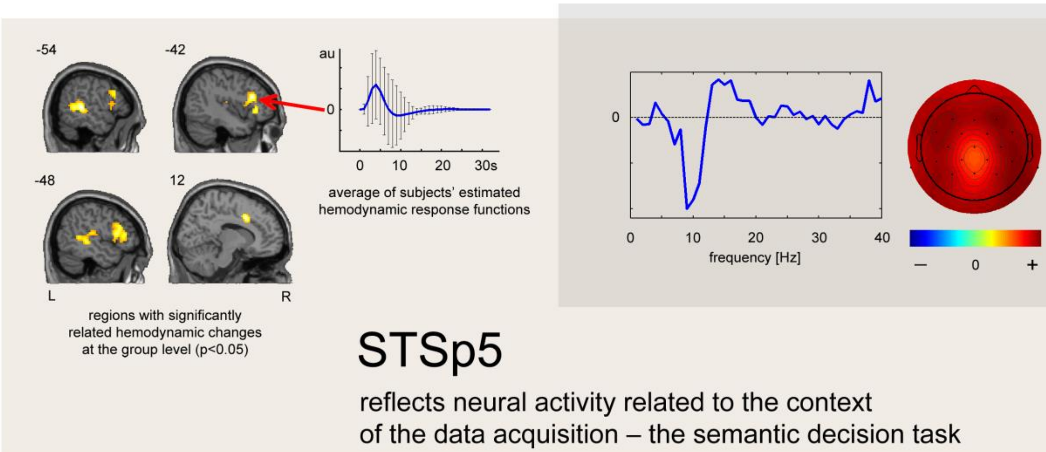
STSp6

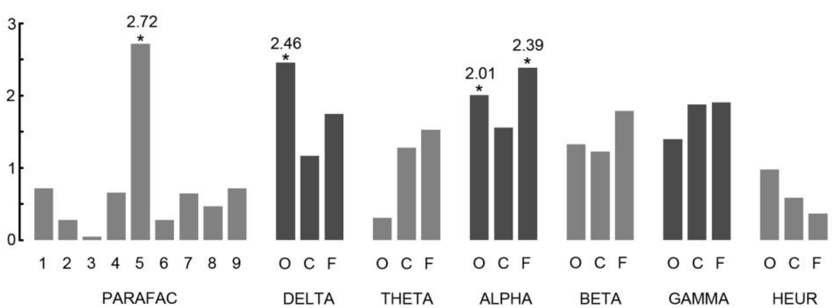
residual MR machine artifact in EEG data



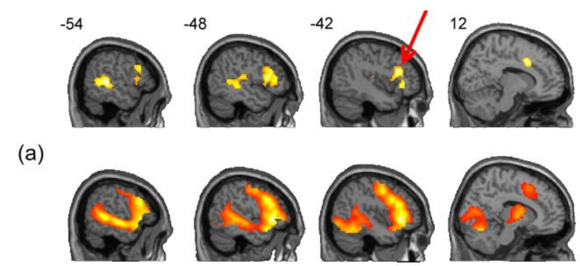
Supplementary figure 1: Amplitude spectrum of EEG before and after gradient artifact removal. The figure shows data from representative subject 28. The spectra are computed from a 10s period of EEG and averaged across channels. The blue line depicts the spectra before artifact removal – predominantly the peaks at 10.7, 21.3 and 32 Hz, i.e. harmonics of gradient artifact and other peaks at 25, 28.3, 33 and 35.7Hz. The red line shows the spectra after artifact removal. Please note, that there is left small amount of power of 3th harmonic of gradient artifact at 32Hz and full power of peak at 33Hz (depicted by red arrow). The similar situation can be seen for every subject.

Brain rhythms



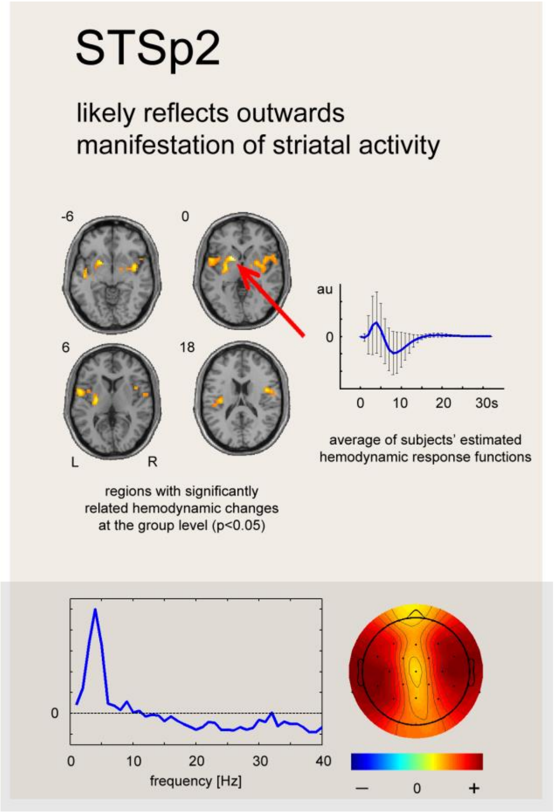


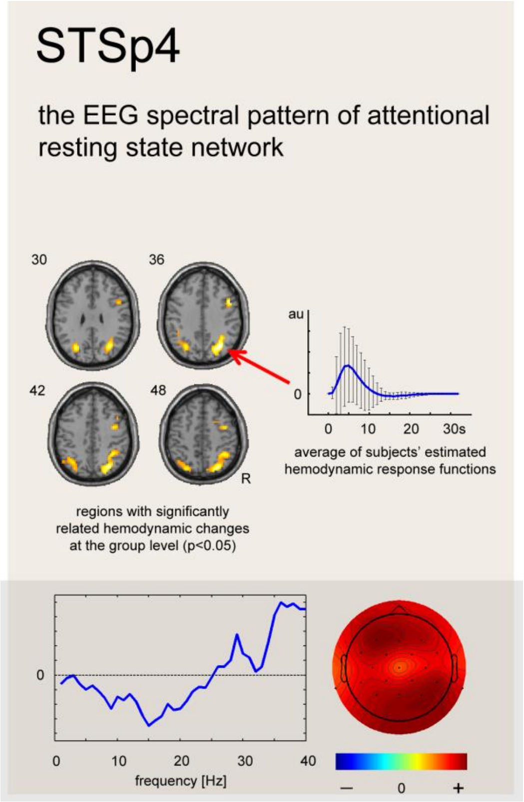
STSp5



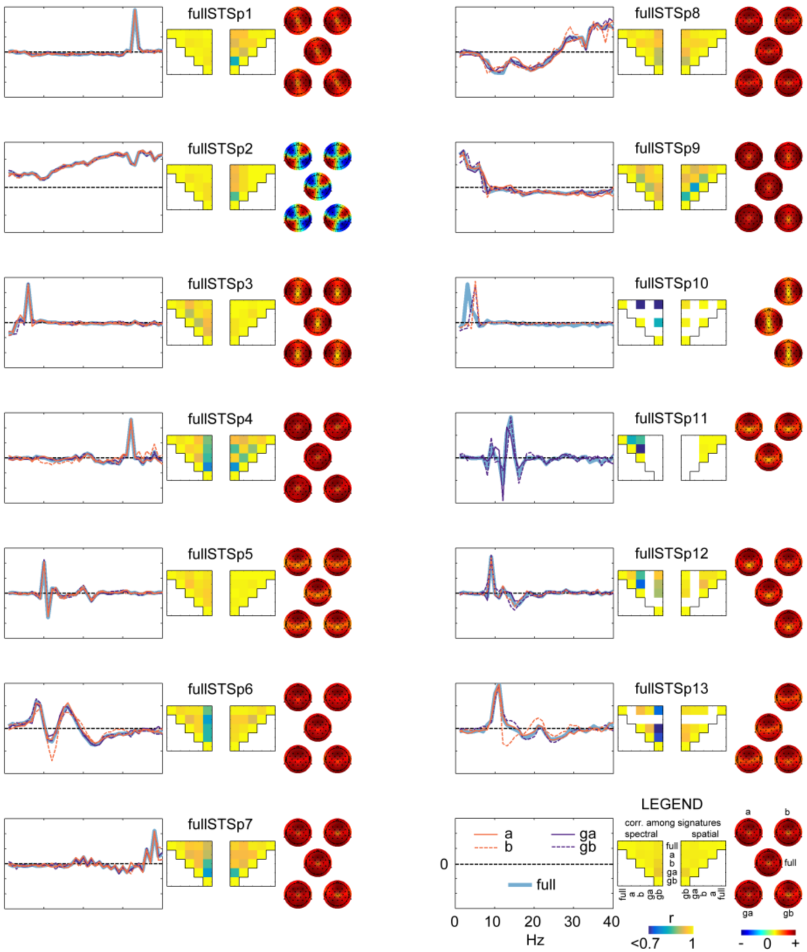
task activation based on “standard” GLM

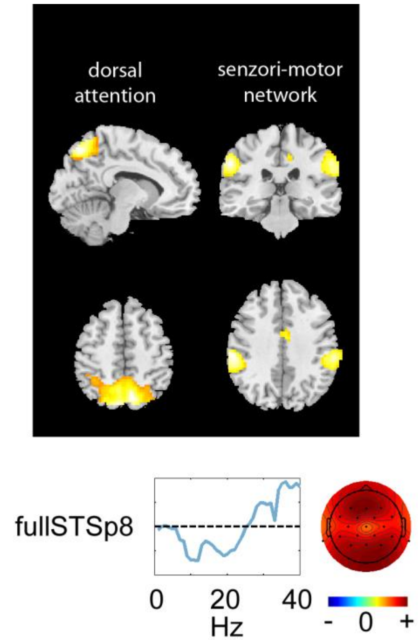
Brain rhythms

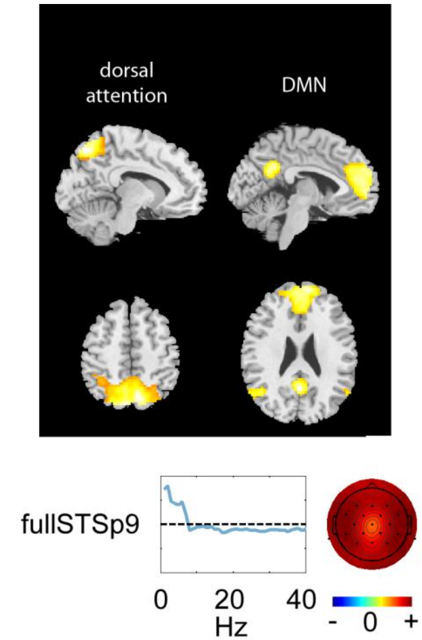




Brain rhythms







Marecek et al., 2016

- EEG-fMRI data divided to subsets
- PARAFAC estimation of each subset of data
- high stability of decomposition
- stable correspondence of some patterns to large scale brain networks

Brain rhythms

- there is a relationship between brain rhythms in EEG and hemodynamic fluctuations in large scale brain networks

- it seems that it is reasonable to use data driven methods

- some spatial-temporal-spectral patterns of EEG activity have stable correspondence to the large scale brain networks

Tensors in EEG

Perhaps new trends in EEG-fMRI data processing

- tensor representation – multiway-array data representation
- blind decomposition

INVITED PAPER

Tensor Analysis and Fusion of Multimodal Brain Images

This paper presents a general framework for tensor analysis of single-modality model inversion and multimodal data fusion using neuroimaging data as an example.

By Esin Karahan, Pedro A. Rojas-López, Maria L. Bringas-Vega, Pedro A. Valdés-Hernández, and Pedro A. Valdes-Sosa

Vol. 103, No. 9, September 2015 | Proceedings of the IEEE

Tensor Decompositions for Signal Processing Applications

From Two-way to Multiway Component Analysis

A. Cichocki, D. Mandic, A-H. Phan, C. Caiafa, G. Zhou, Q. Zhao, and L. De Lathauwer

2015

Journal of Neuroscience Methods 248 (2015) 59–69

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Computational neuroscience

Tensor decomposition of EEG signals: A brief review

CrossMark

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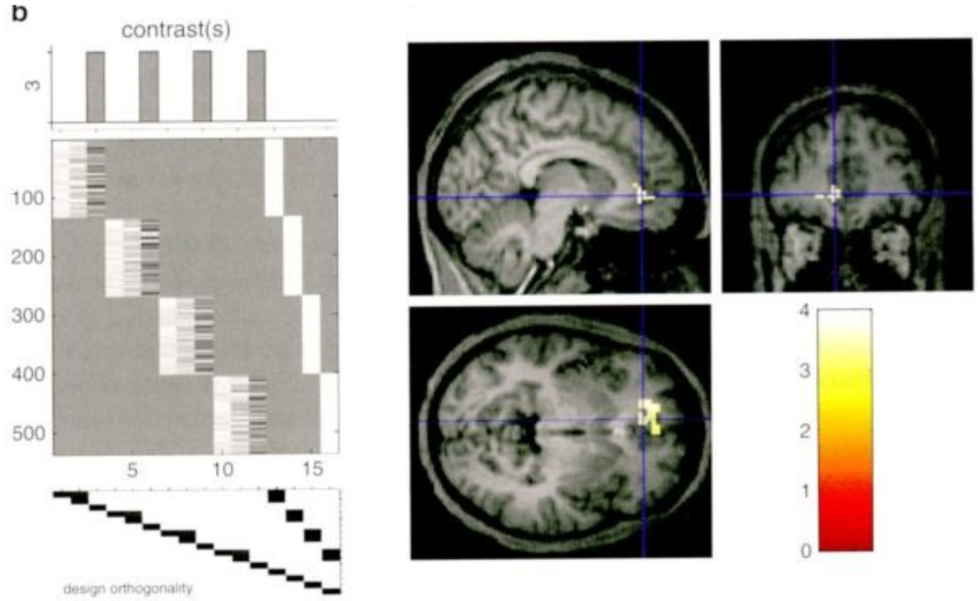
HIGHLIGHTS

- EEG signals are naturally born with multi modes.
- EEG signals can be represented by the high-order multi-way array, tensor.
- Tensor of EEG can be exploited by tensor decomposition for multi-way analysis.

ERP and hemodynamics

Relationships between ERP features and BOLD

- Benar et al. 2007
- activity of anterior cingulum is significantly related to the amplitude of P300 wave in oddball task



Benar et al. 2007

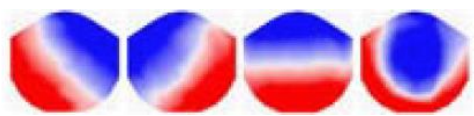
Microstates and BOLD

Relationships between topography of scalp EEG and BOLD

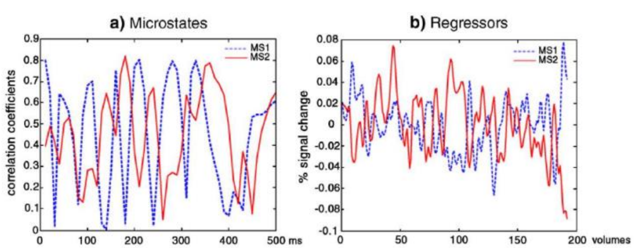
- Britz et al. 2010
- relationship between occurrence of microstates and resting state networks

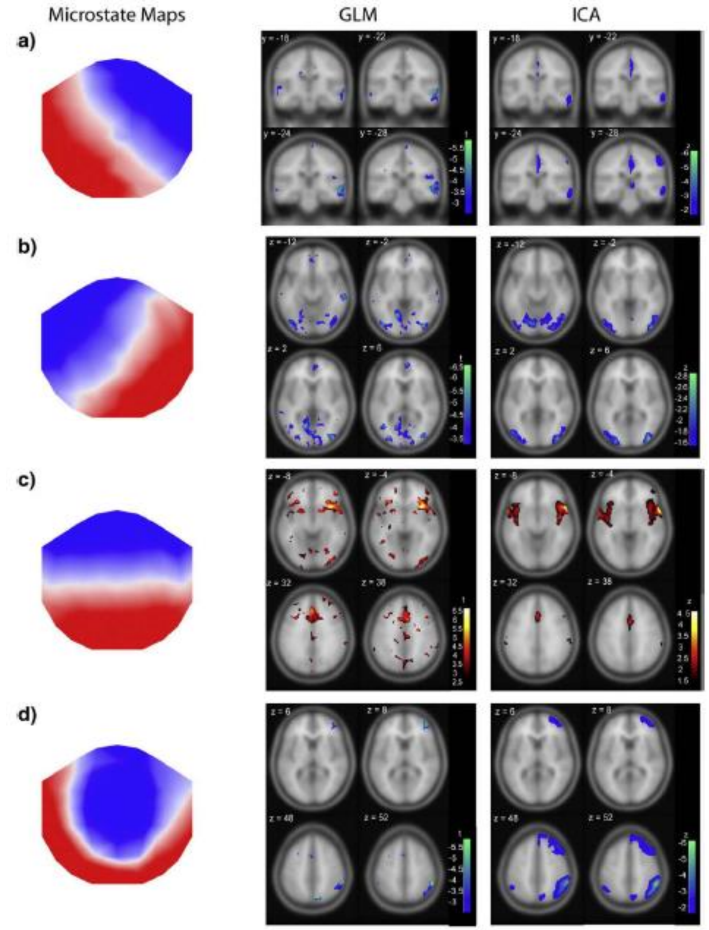
Microstates

- the concept of short-term stable topographies



- the time-series of microstate occurrences used to process fMRI data

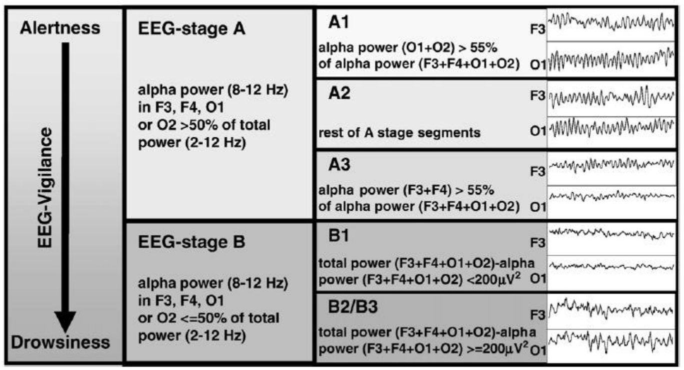


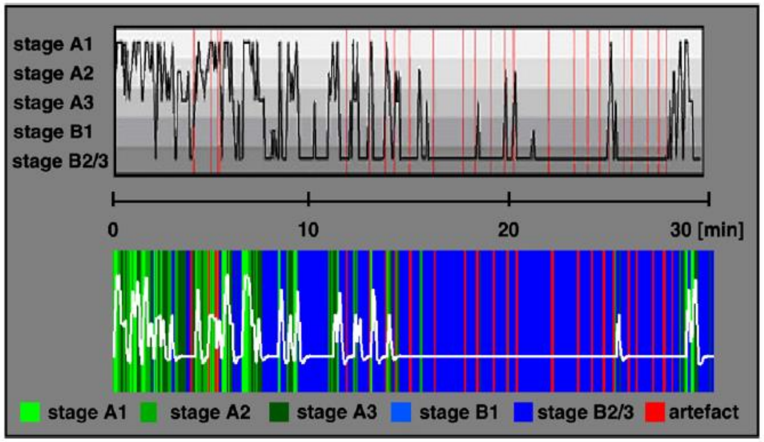


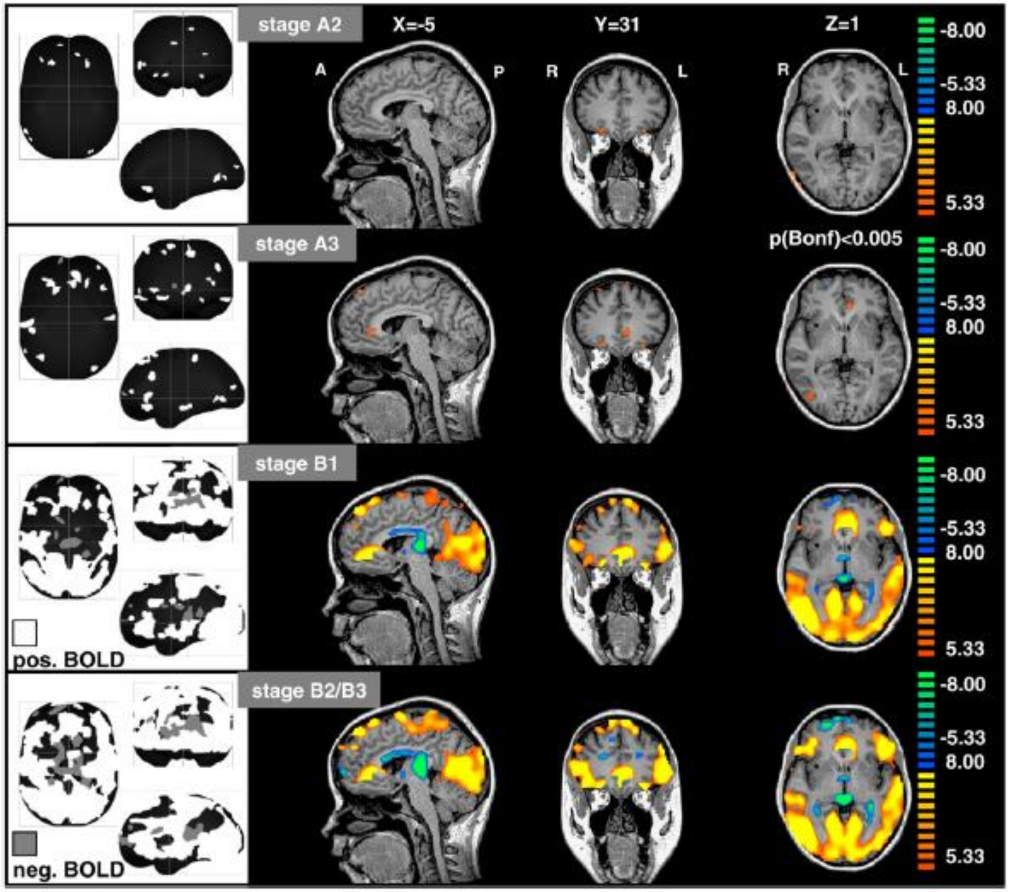
Britz et al. 2010

Sleep research

- **the sleep research** (Olbrich et al. 2009)







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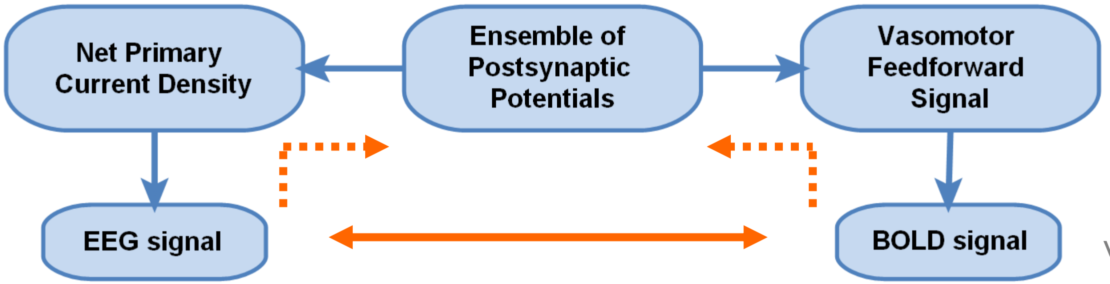
Data fusion – current research



Valdes-Sosa et al., 2009

- the most of methods use direct comparison between acquired EEG and fMRI signals (or parameters derived from the signals)

- the current directions of research is aimed on forward models and their incorporation to the data processing pipelines

Thank you for your attention

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