Simultaneous EEG-fMRI technique - benefits and drawbacks

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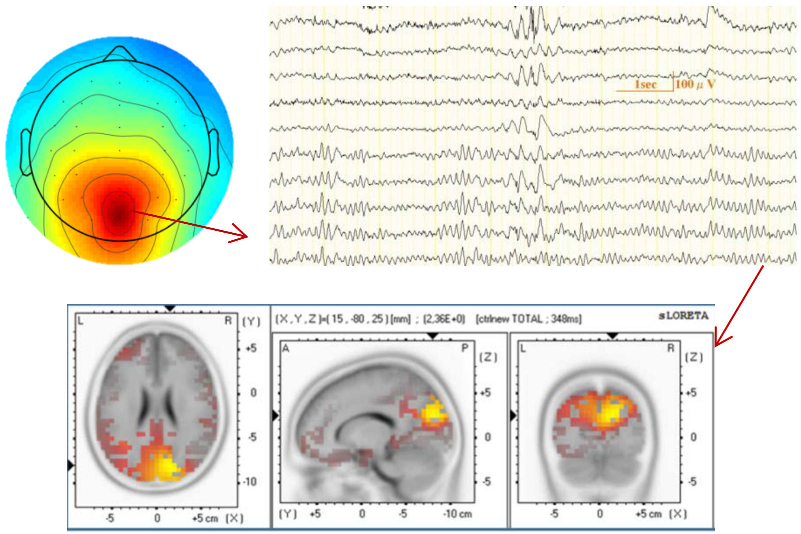
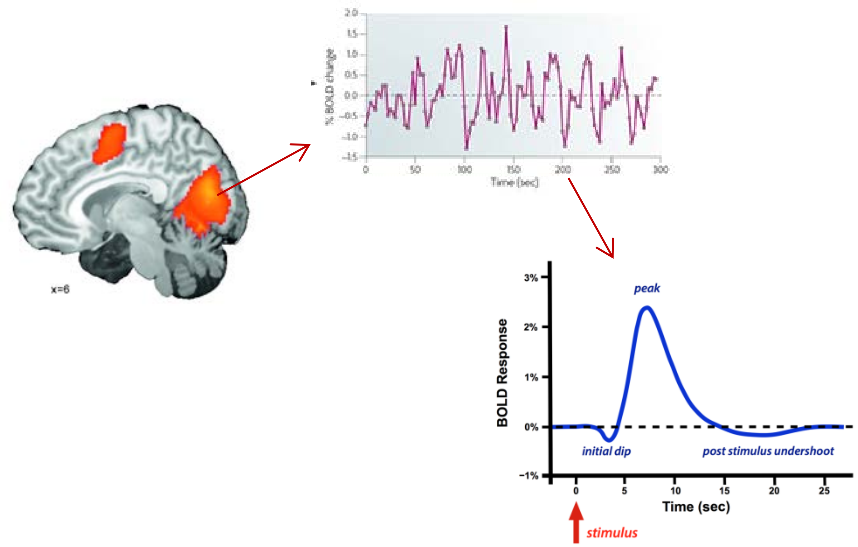
EEG



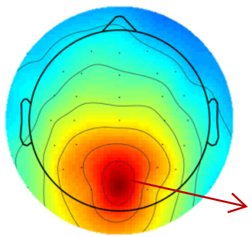
- records electrical activity of the brain
- excellent temporal resolution
- sources can only be estimated

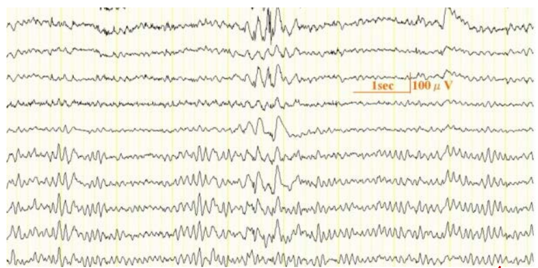
fMRI

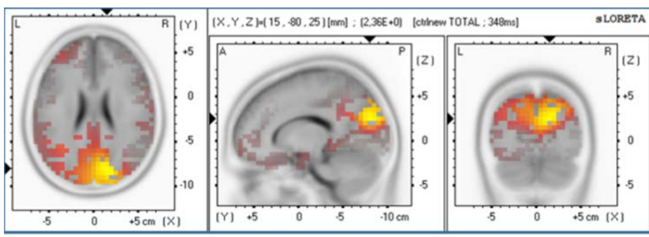


- measures change in blood flow (hemodynamic response) related to energy use by brain cells
- poor temporal resolution
- excellent spatial resolution
- whole-brain (i.a. subcortical structures)

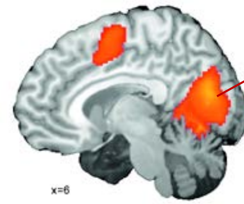
EEG

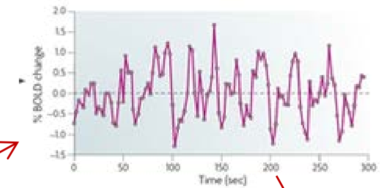


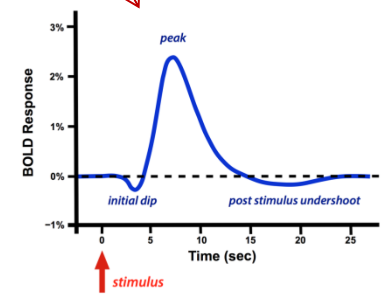




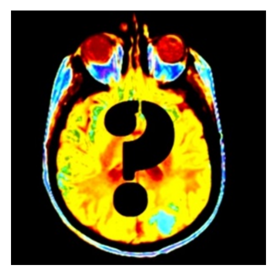
fMRI





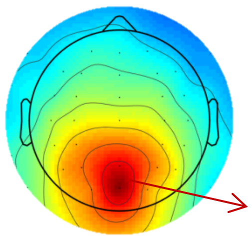


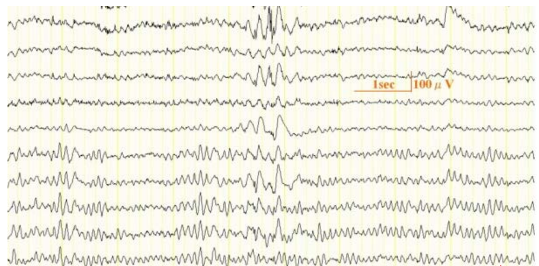
- susceptible to type I error

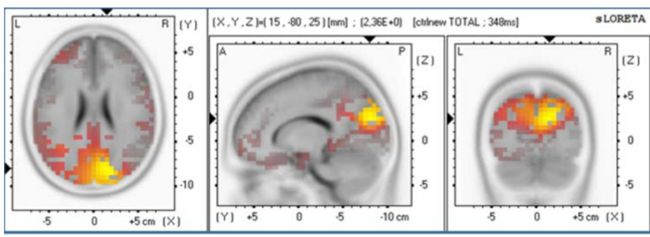


Eklund et al. (**2016**). Cluster failure: why fMRI inferences for spatial extent have inflated false-positive rates. ***PNAS***
(cited by 740)

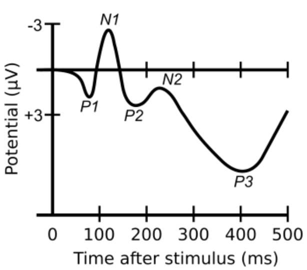
EEG

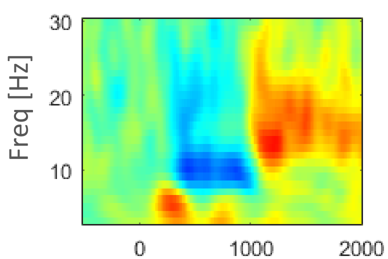




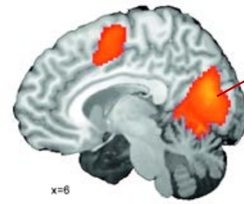


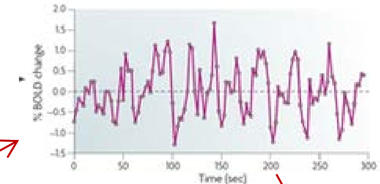
- informative

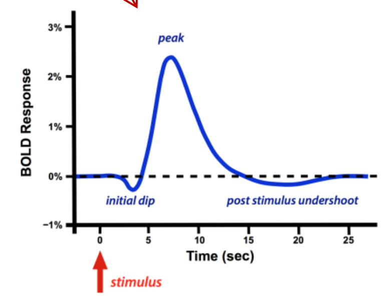




fMRI

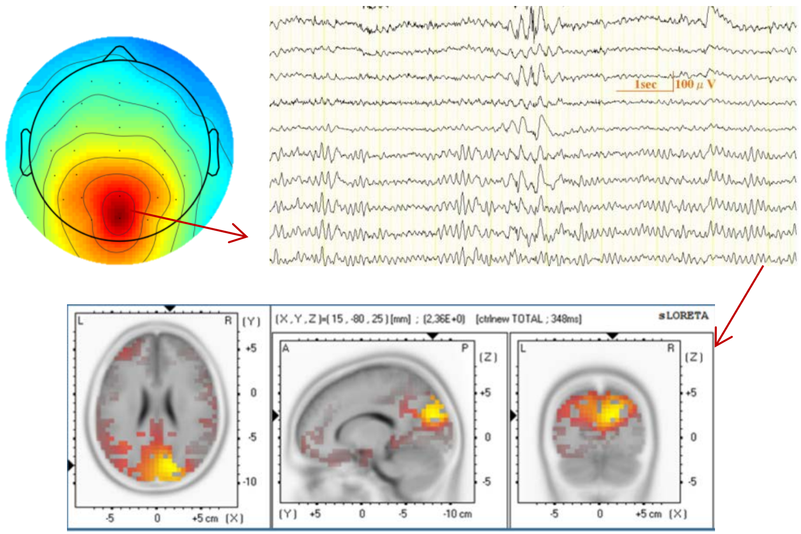


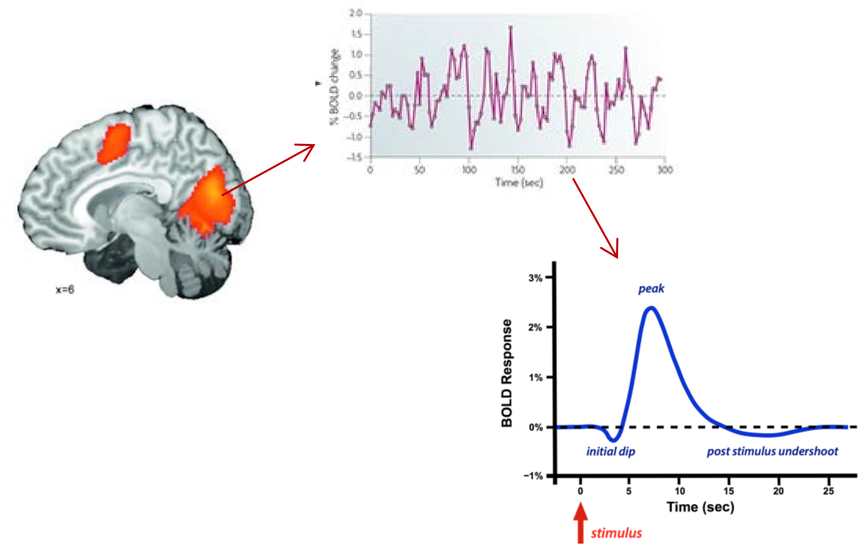




EEG

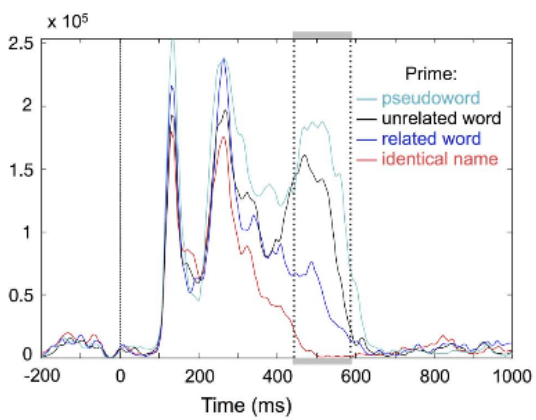
fMRI

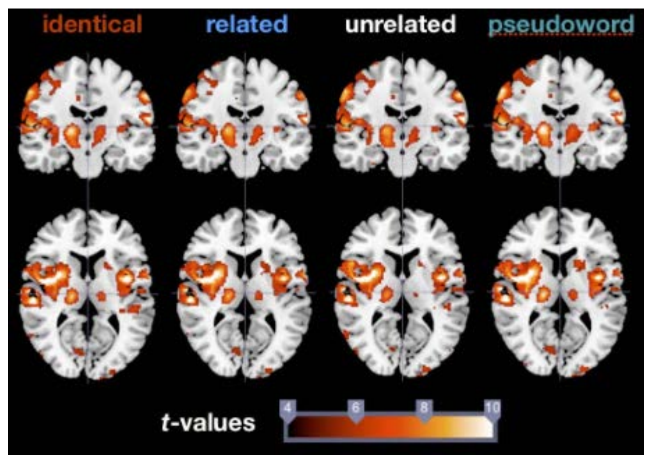




- informative
- sensitive

Geukes, et al. (**2013**) "A large N400 but no BOLD effect– comparing source activations of semantic priming in simultaneous EEG-fMRI." ***PloS one*** (cited by 22)





A little bit of history...

The idea of EEG–fMRI integration was clinically motivated.
Its development was driven by the desire of epileptologists to localize sources of epileptic discharges.

First EEG recording inside MR bore was in...

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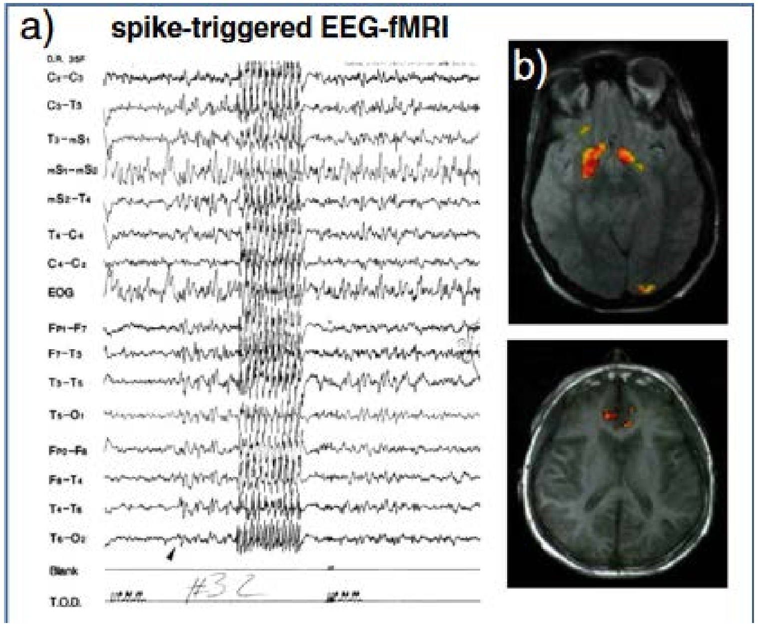
First EEG recording inside MR bore was in...
... 1992!

Ives et al. (**1993**) "Monitoring the patient's EEG during echo planar MRI." *Clin. Neurophy.* (cited by 394)

In 1996, Warach and colleagues demonstrated the first epileptic discharges correlating with BOLD signal changes



Part I

Methodology

Part I

The drawbacks

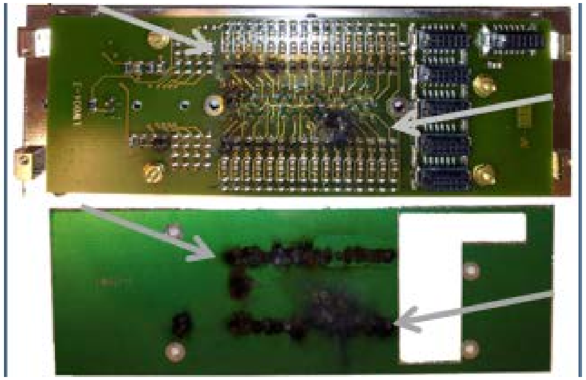
Data acquisition – patient safety issues

Improper application can lead to heating of the equipment, which may cause:

- subject injuries
- damaged equipment

Specifically designed caps (MR compatible) prevent from direct contact of electrodes with the skin

Only MR sequences with a low specific absorption rate (SAR) can be used



Data acquisition

- impedance must be below 20 kΩ
- amplifiers must be carried inside the MR room (and put inside MR bore) for every subject
- wires are plugged-in to the amplifiers after the subject is inserted
- wires must be fasten

- thus, two people are required to conduct the experiment

MR artifacts

Until decent artifact reduction methods were available, EEG – fMRI had to be performed in an ‘interleaved’ fashion making use of the fact that the BOLD response lags neural activity by several seconds

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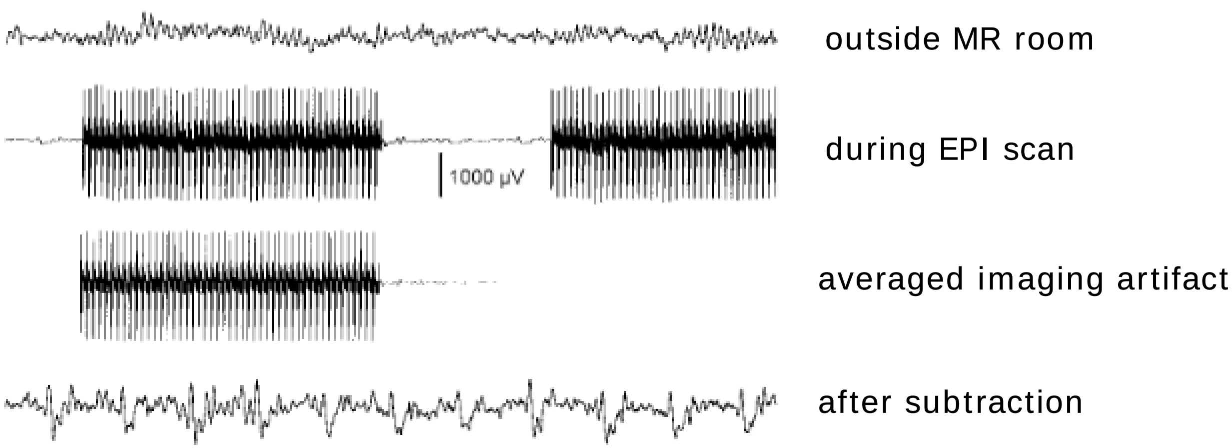
In 2000, averaged artifact subtraction (AAS) was introduced.

Allen et al. (**2000**). A method for removing imaging artifact from continuous EEG recorded during functional MRI. ***Neuroimage***
(cited by 979)



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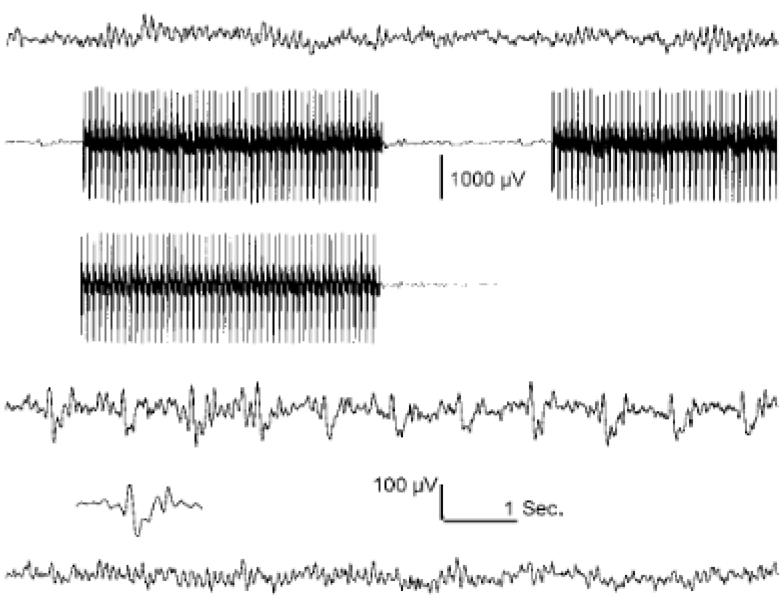


outside MR room

during EPI scan

averaged imaging artifact

after subtraction

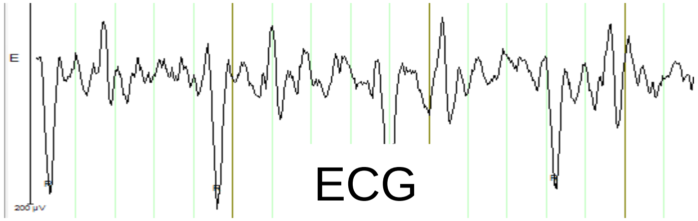
averaged pulse artifact

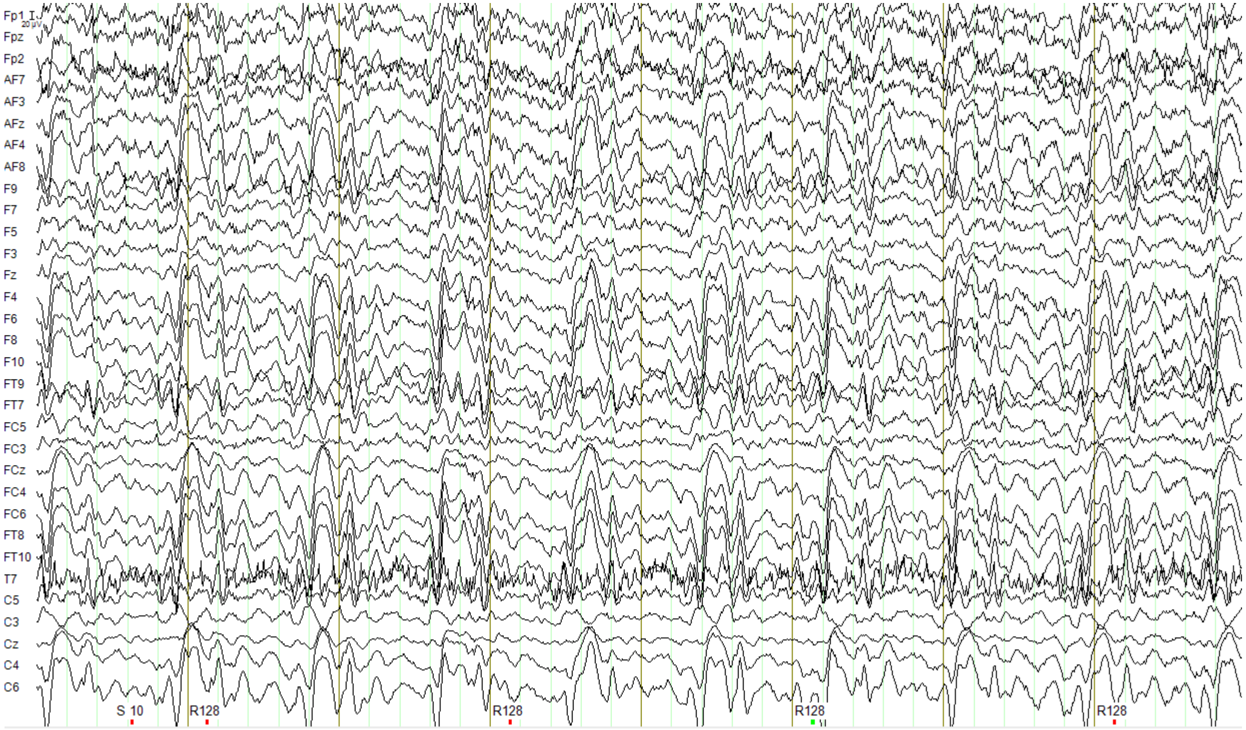
after subtraction

MR artifacts

Pulse artifact results form the interaction between the active cardiovascular system and the main static field B_0.

Often referred to as ballistocardiogram (BCG) artifacts





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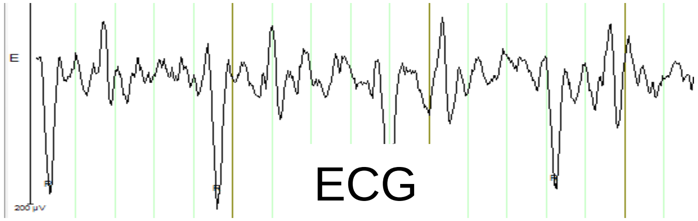
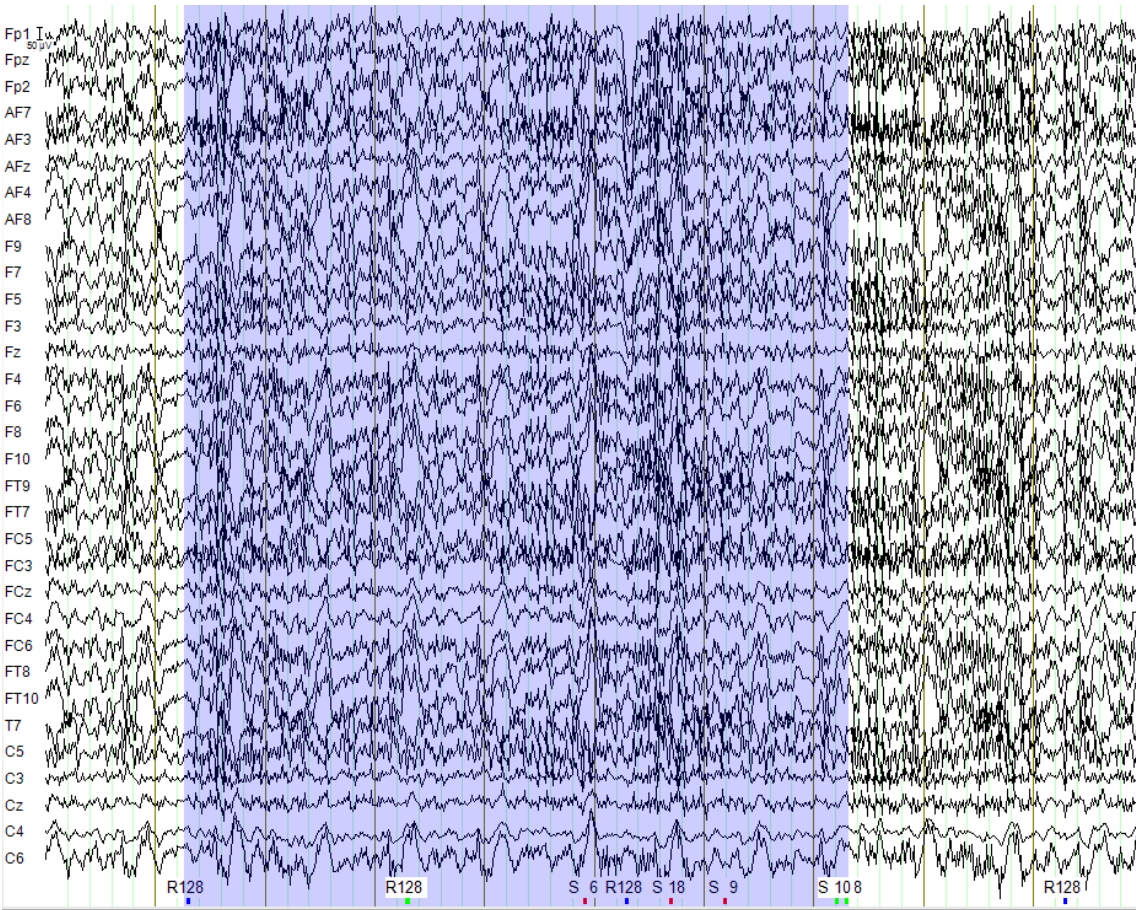
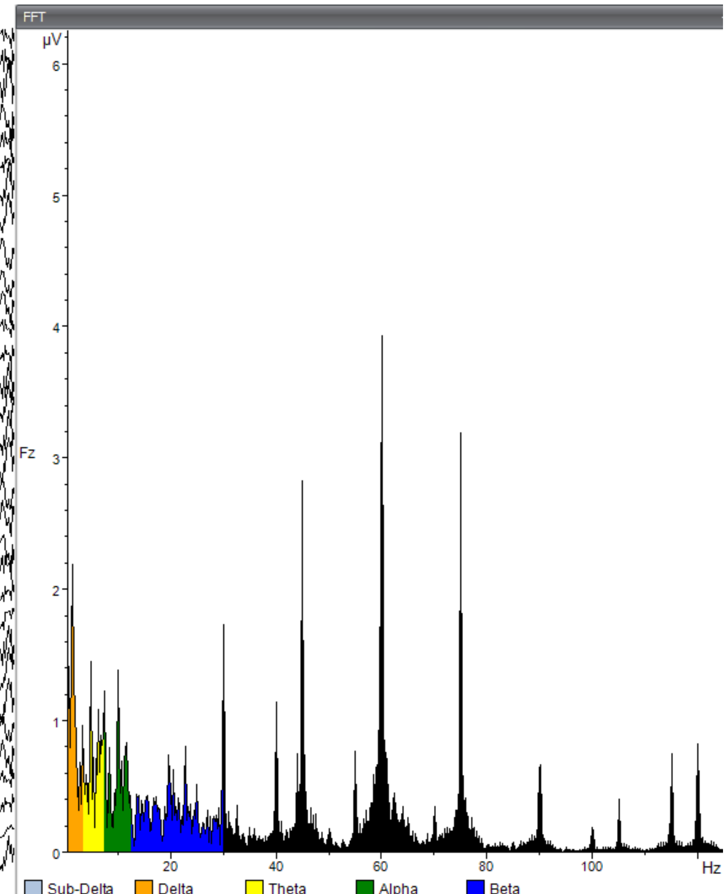


Often referred to as ballistocardiogram (BCG) artifacts

MR artifacts

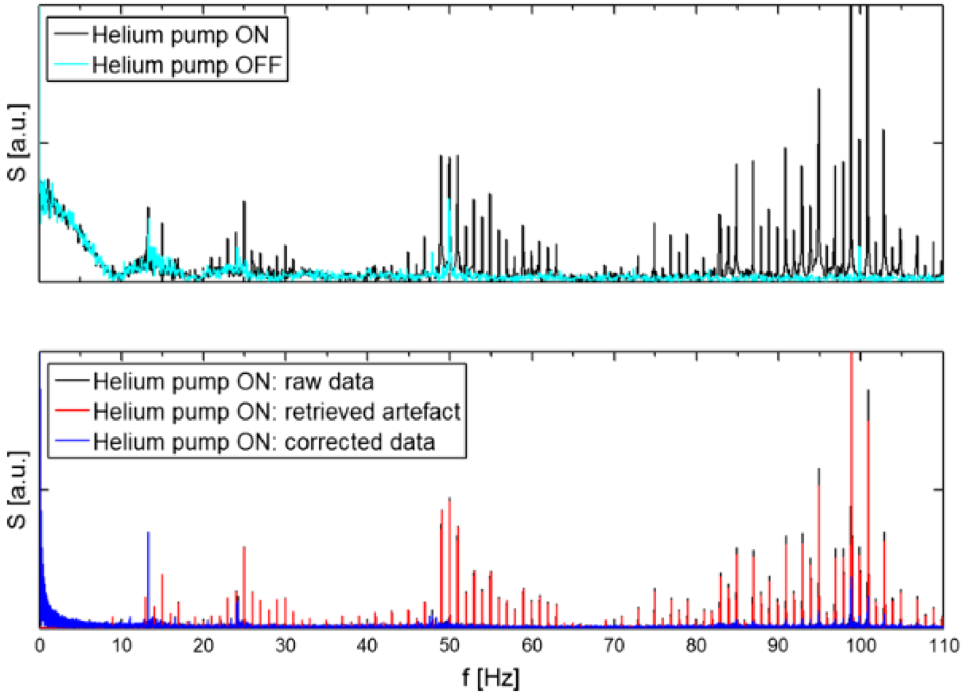
Even after MR artifacts correction, a lot of noises in high frequencies are still present…
.. for instance, the residuals from EPI scanning





MR artifacts

Even after MR artifacts correction, a lot of noises in high frequencies are still present...
... for instance, the helium pump artefact



Rothlübbers et al. (**2015**). Characterisation and reduction of the EEG artefact caused by the helium cooling pump in the MR environment: validation in epilepsy patient data. **Brain topography** (cited by 7)

Preprocessing of EEG data

1) MR-artifact correction

   21 intervals for sliding average

2) pulse artefact correction

   semiautomatic mode of R-detection based on ECG channel,
   21 pulses for correction

3) low-pass filter or vibration artefact correction

4) down-sampling

5) high pass filter 0.5Hz

6) average reference

7) removing bad channels and epochs

8) running ICA and removing artificial IC

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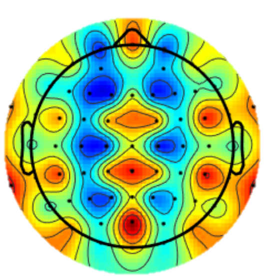
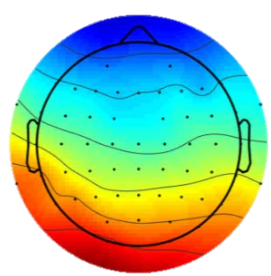
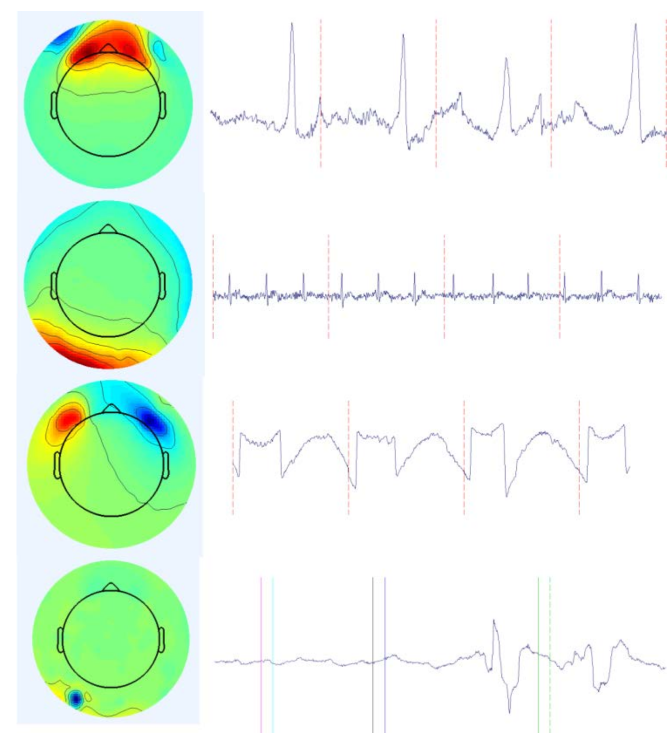


MR
artifact



CB
artifact

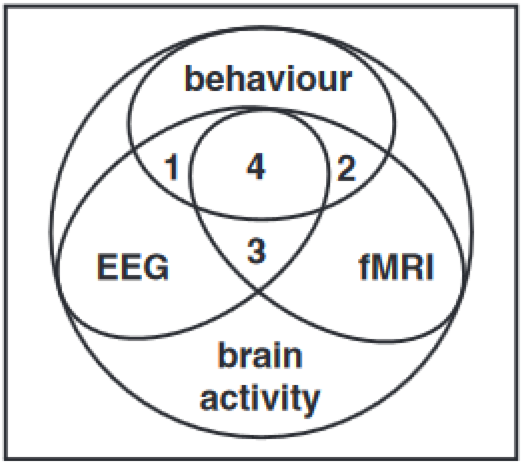


Challenges of coupling

Laufs, H. (2012). A personalized history of EEG–fMRI integration. *Neuroimage* (cited by 70)

„...it took my colleagues and myself looking at **hundreds of empty or speckled EEG-correlated statistical result maps** – in addition to a few meaningful ones – to develop a vague appreciation of what EEG-correlated fMRI maps might or might not mean.

(…) the creativity of the growing community of researchers applying EEG–fMRI in their fields of interest and their augmented experience over time will bring about further advances in the field of EEG–fMRI integration"



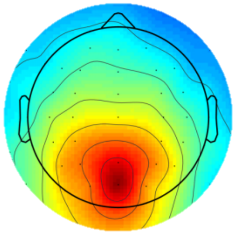
Part II

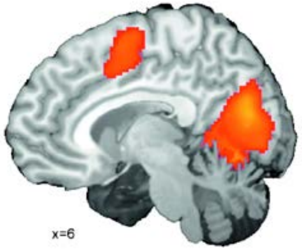
Further analysis and results

Part II

Benefits

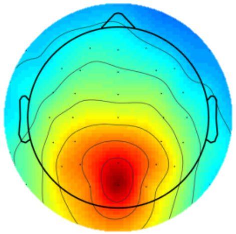
Coupling of EEG and fMRI - scheme

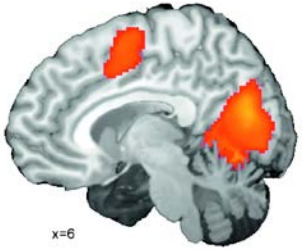




Coupling of EEG and fMRI - scheme

EEG-informed fMRI





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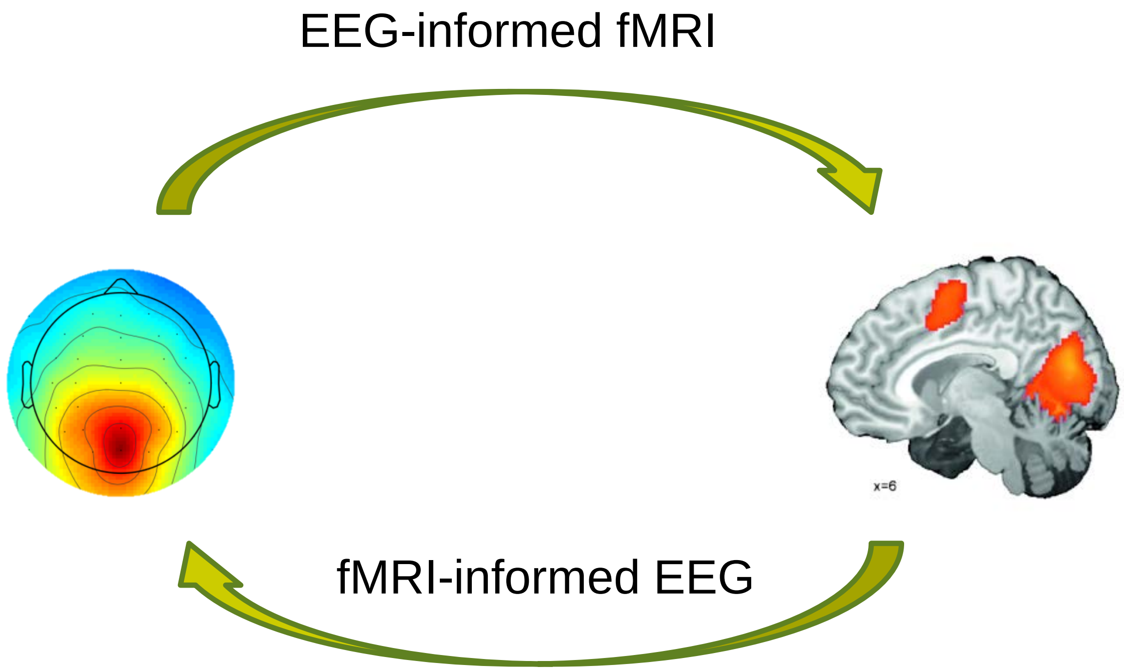

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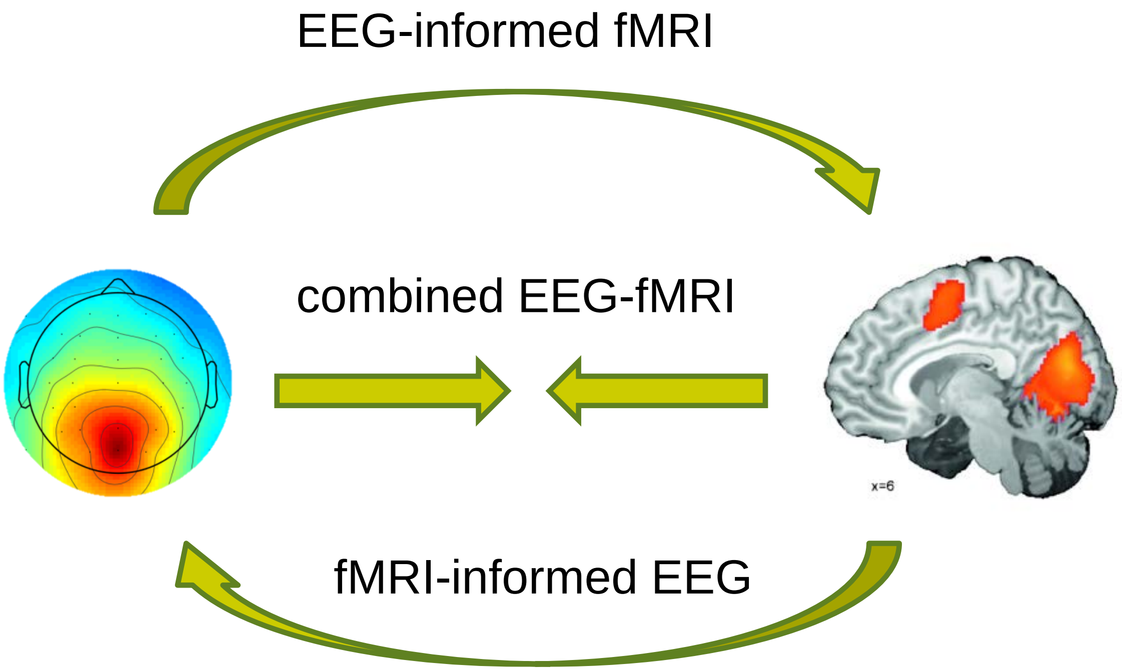
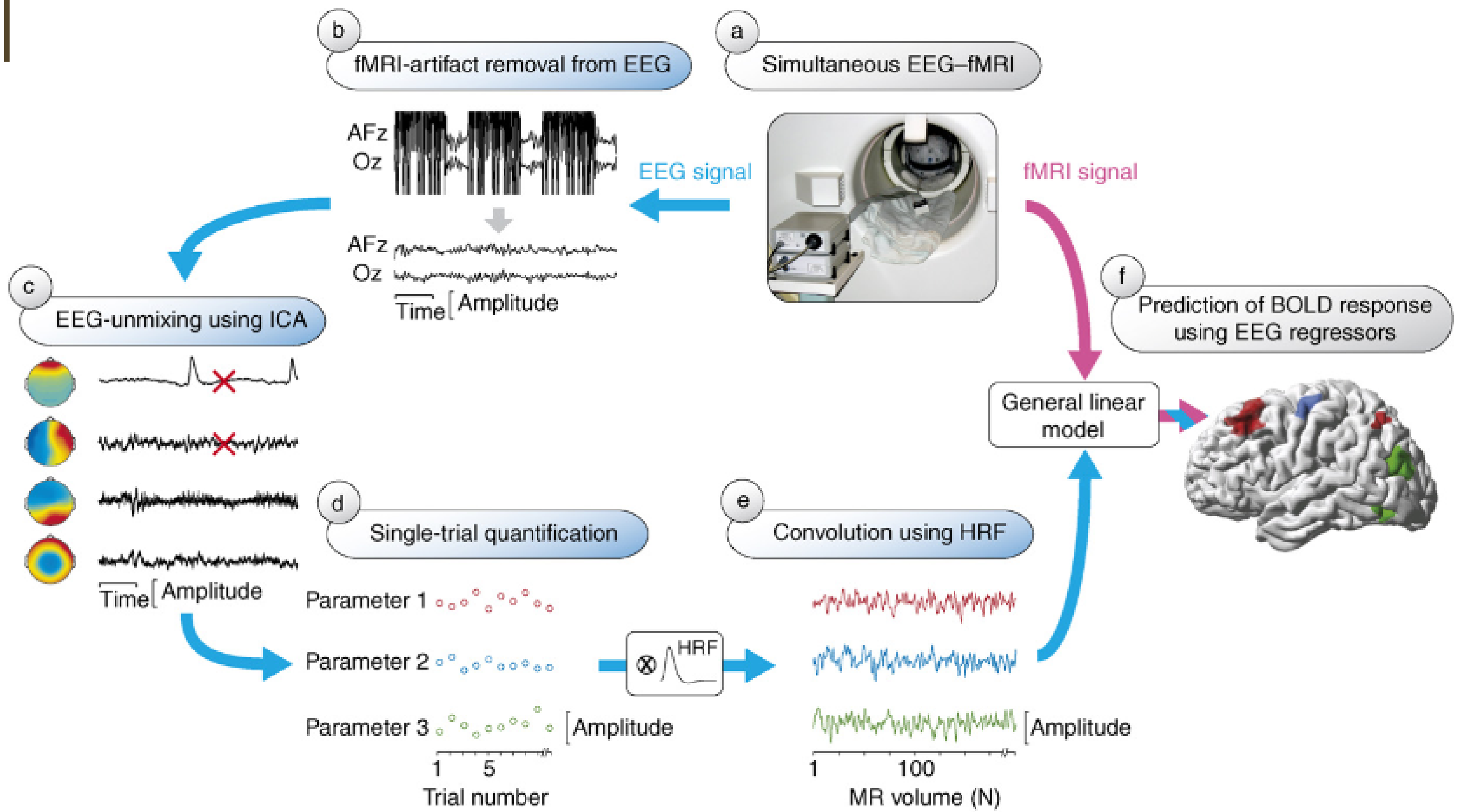


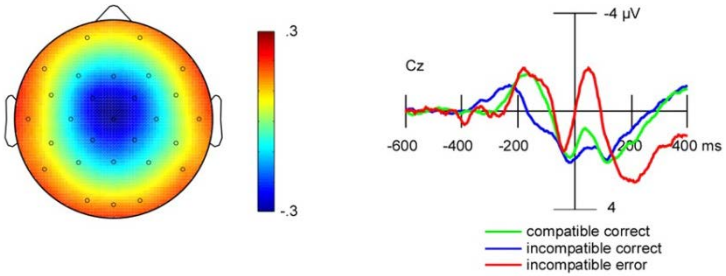
Coupling ERPs with BOLD



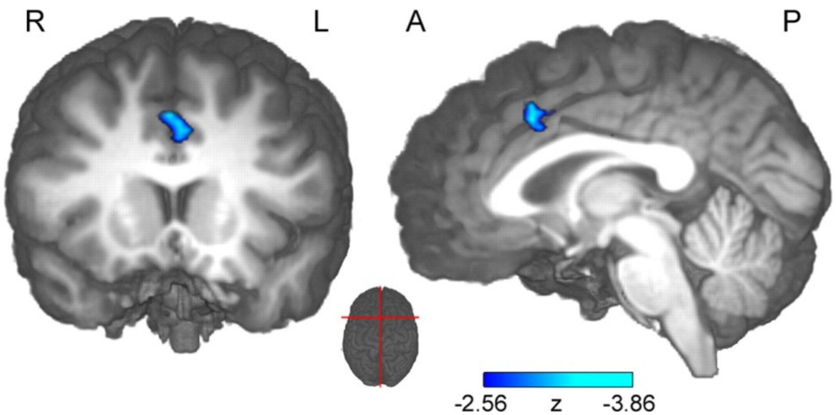
Debener et al. (**2006**). Single-trial EEG–fMRI reveals the dynamics of cognitive function. ***Trends in cognitive sciences*** (cited by 341)

Coupling ERPs with BOLD

EEG results

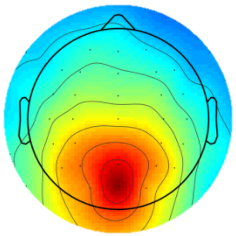


EEG-informed fMRI results

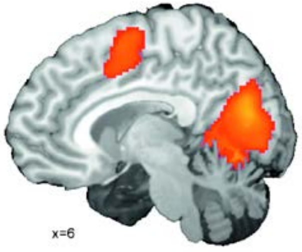


Debener et al. (**2005**). Trial-by-trial coupling of concurrent electroencephalogram and functional magnetic resonance imaging identifies the dynamics of performance monitoring. ***Journal of Neuroscience*** (cited by 835)

Coupling of EEG and fMRI - scheme

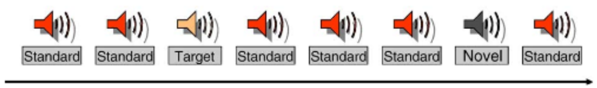


combined EEG-fMRI

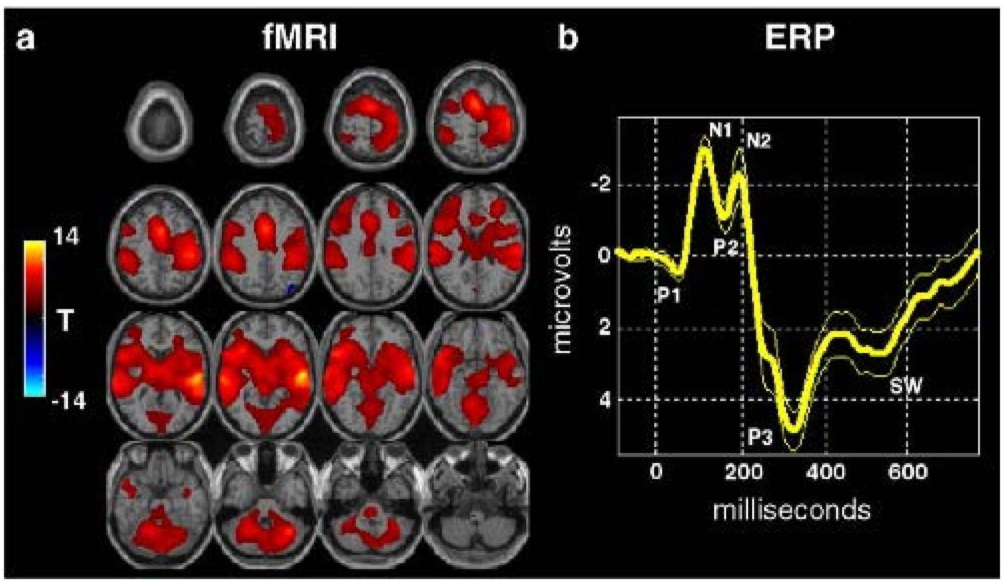


Joint ICA

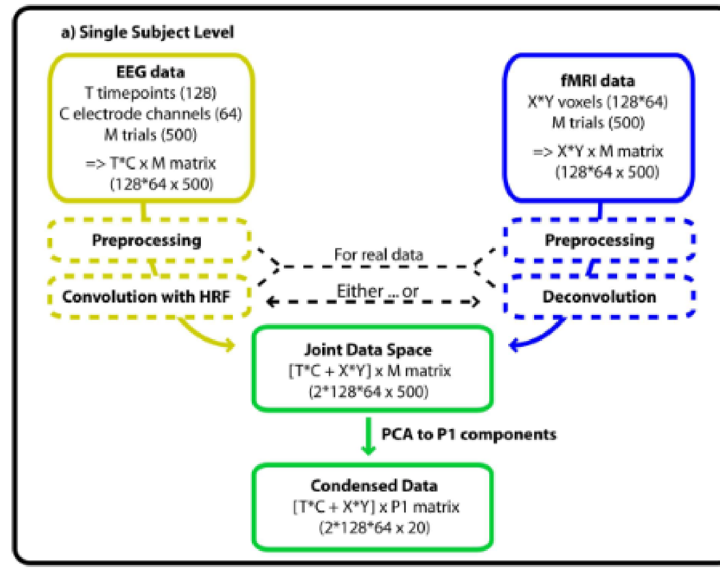
Auditory oddball paradigm



Brain activity in response to target:

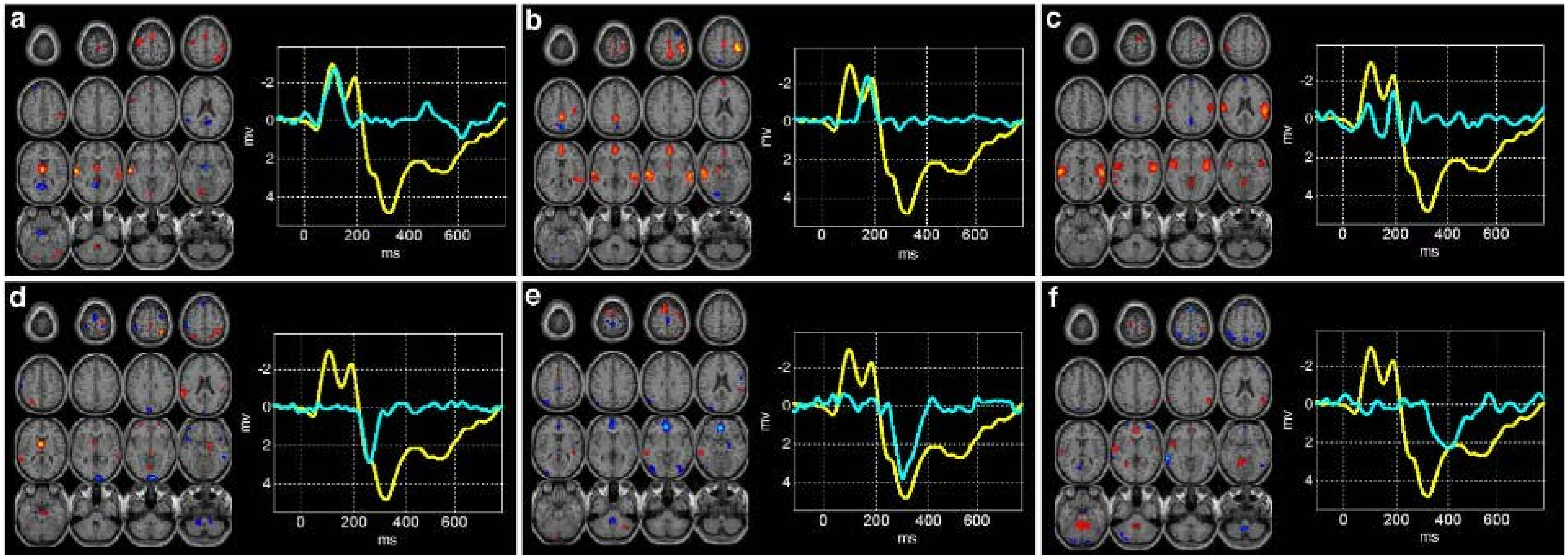


Scheme of the joint ICA approach



Calhoun et al. (**2006**). Neuronal chronometry of target detection: fusion of hemodynamic and event-related potential data. ***Neuroimage*** (cited by 143)

Joint ICA



Neuronal chronometry of target detection:

1. auditory and motor planning regions
2. auditory association cortex and motor execution regions
3. the P3 response is associated with brainstem, temporal lobe, and medial frontal activity
4. late temporal lobe "evaluative" response

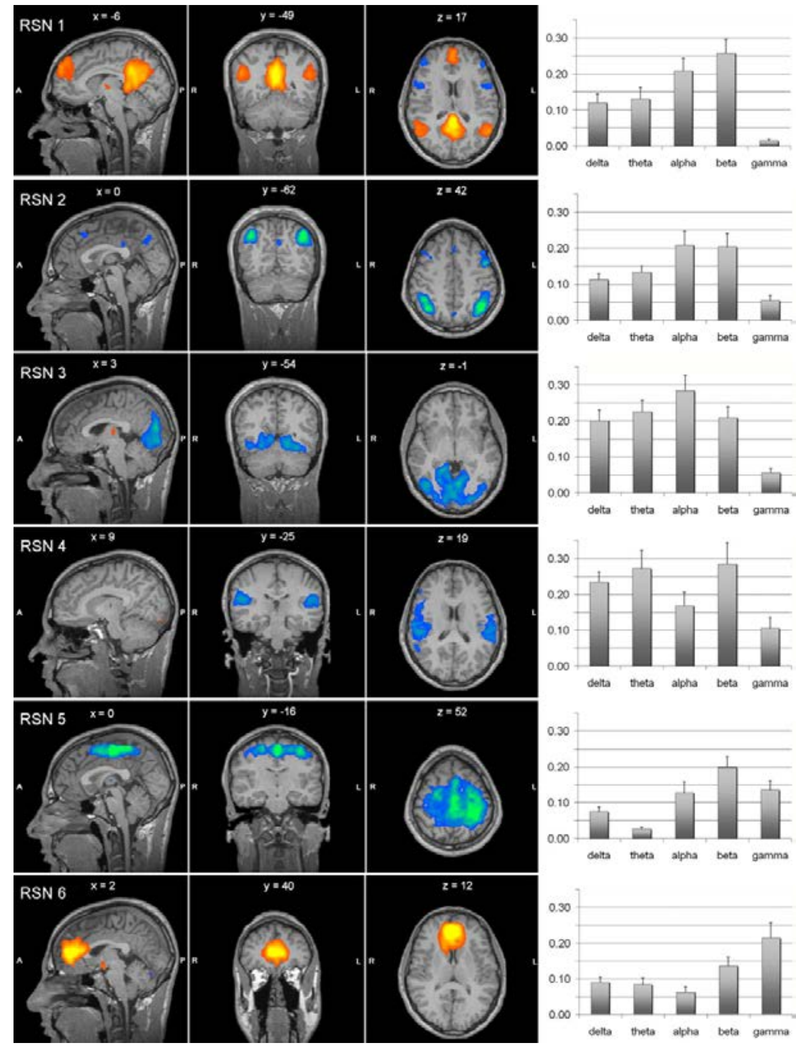
Calhoun et al. (**2006**). Neuronal chronometry of target detection: fusion of hemodynamic and event-related potential data. ***Neuroimage*** (cited by 143)

Coupling of EEG and fMRI - scheme

Coupling oscillations with BOLD

The goal was to investigaet the relationship between hemodynamic and electrical oscillations:

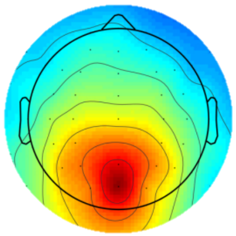
- six widely distributed resting state networks were investigated using group ICA
- BOLD signal fluctuations were correlated with the EEG power variations of delta, theta, alpha, beta, and gamma rhythms
- each network was characterized by a specific electrophysiological signature

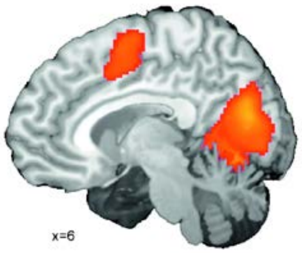


Mantini et al. (**2007**). Electrophysiological signatures of resting state networks in the human brain. ***PNAS*** (cited by 1228)

Coupling of EEG and fMRI - scheme

EEG-informed fMRI

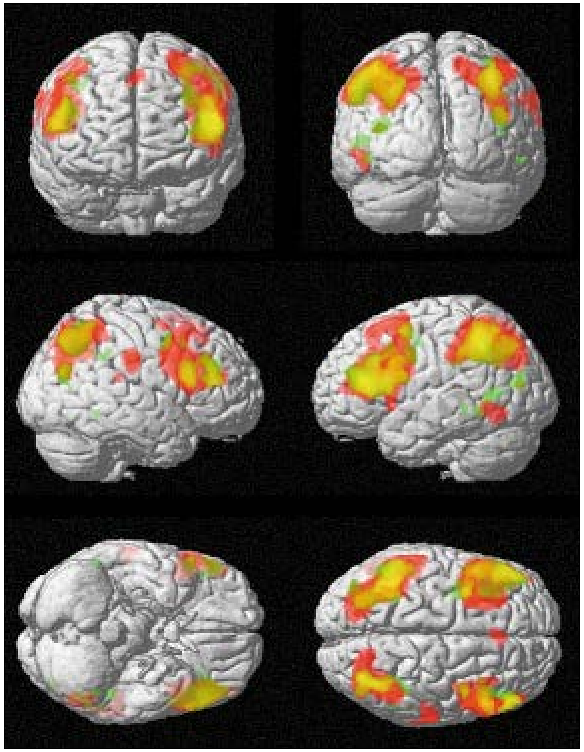




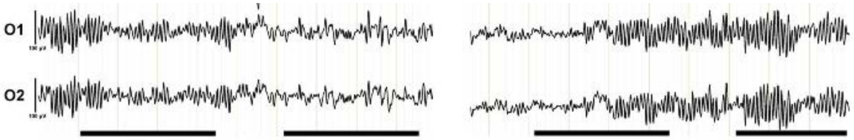
Coupling oscillations with BOLD

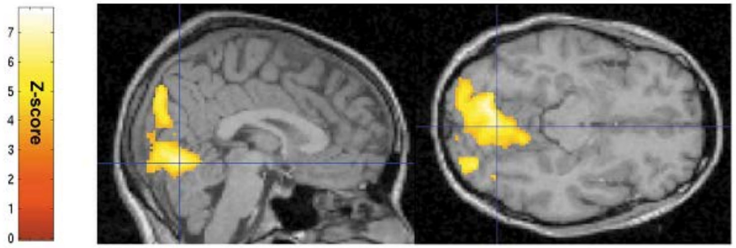
EEG-correlated fMRI of human alpha activity

- whole-brain EPI TR=4s
- average alpha power over 1-s epochs at several electrode
- power time course convolved with a canonical hemodynamic response function
- down-sampled
- statistical parametric mapping with BOLD



The Berger effect in EEG-correlated fMRI

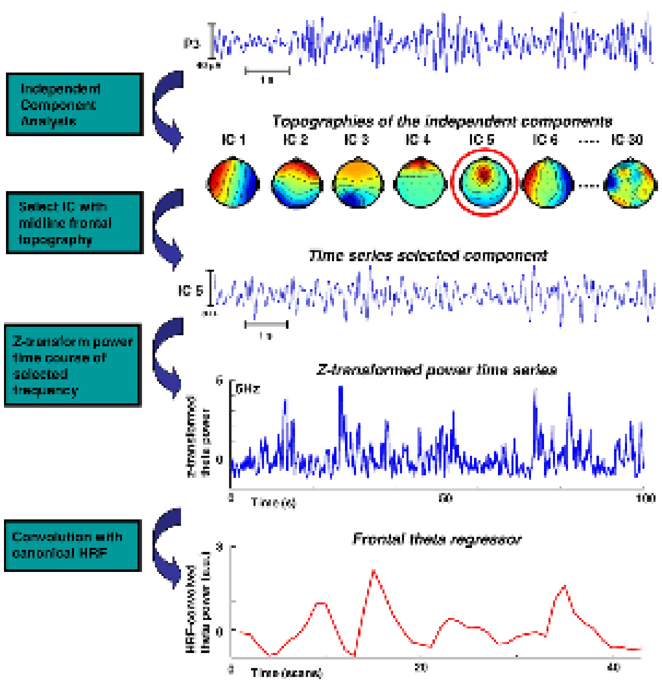


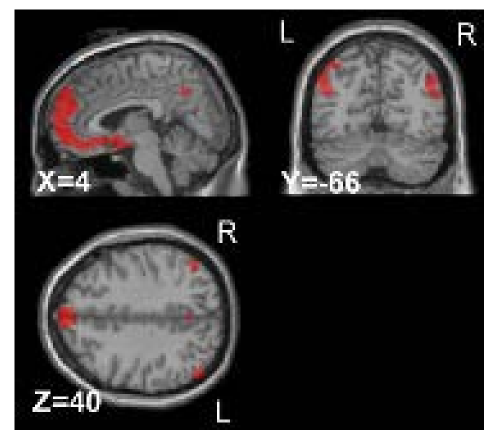


Laufs et al. (2003). EEG-correlated fMRI of human alpha activity. *Neuroimage* (cited by 795)

Coupling oscillations with BOLD

investigating the BOLD correlates of frontal theta power changes in resting-state (eyes open)





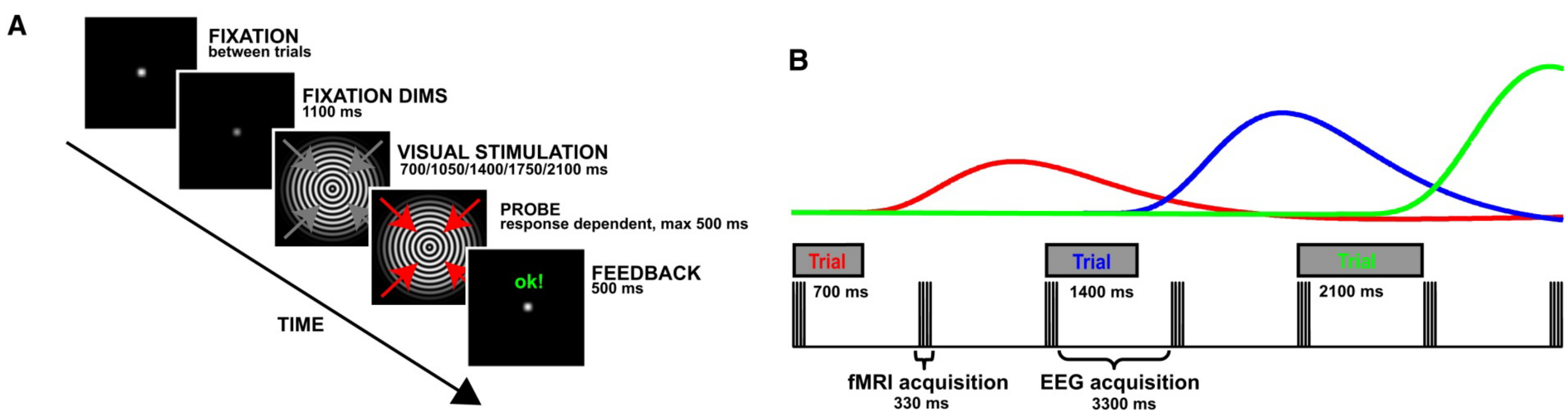
Scheeringa (**2008**). Frontal theta EEG activity correlates negatively with the default mode network in resting state. ***Int. J. Psychophy***. (cited by 233)

Coupling oscillations with BOLD

Niessing et al. (**2005**). Hemodynamic signals correlate tightly with synchronized gamma oscillations. ***Science*** (cited by 662)

Engell et al. (**2012**). The fMRI BOLD signal tracks electrophysiological spectral perturbations, not event-related potentials. ***Neuroimage*** (cited by 36)

Scheeringa et al. (**2011**). Neuronal dynamics underlying high-and low-frequency EEG oscillations contribute independently to the human BOLD signal. ***Neuron*** (cited by 251)



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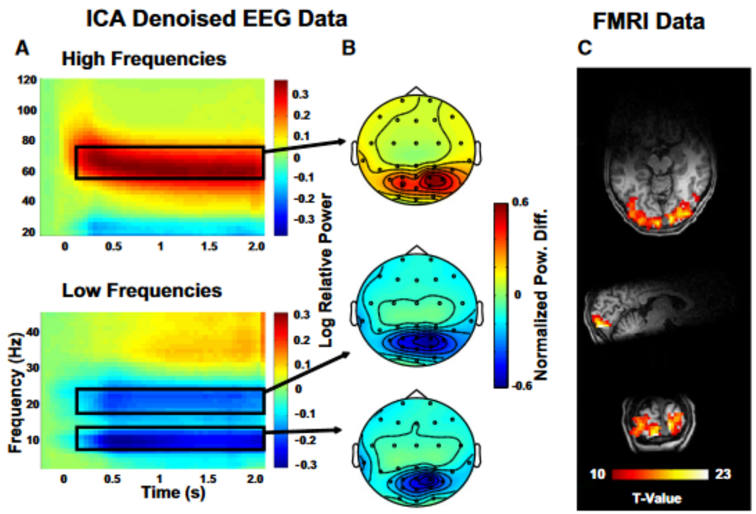
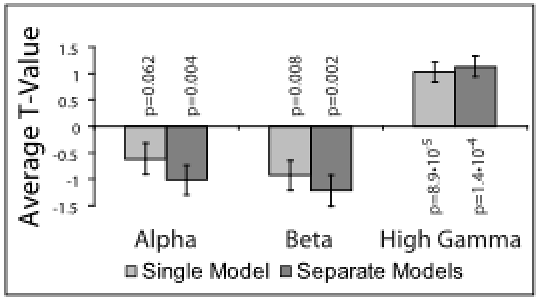
Scheeringa et al. (**2011**). Neuronal dynamics underlying high-and low-frequency EEG oscillations contribute independently to the human BOLD signal. ***Neuron*** (cited by 251)

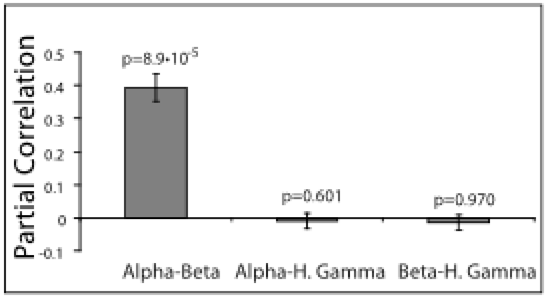


BOLD fluctuations correlated

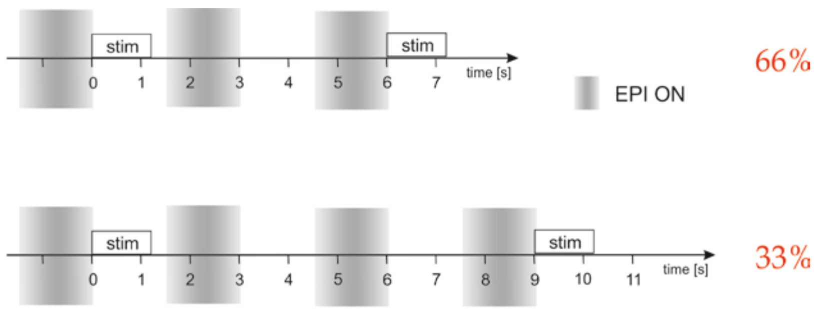
- positively with high-EEG gamma power (60–80 Hz)
- negatively with alpha and beta power.

Gamma power on the one hand, and alpha and beta power on the other hand, independently contributed to explaining BOLD variance.

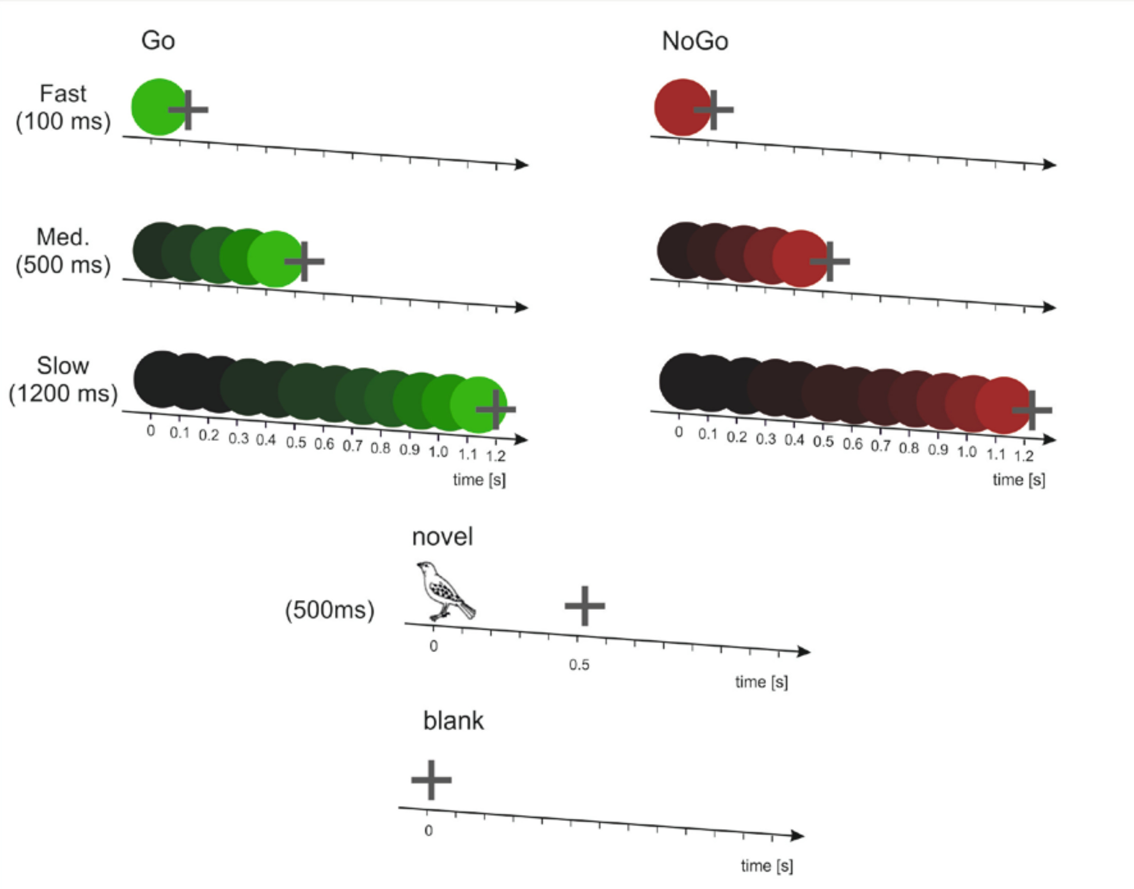




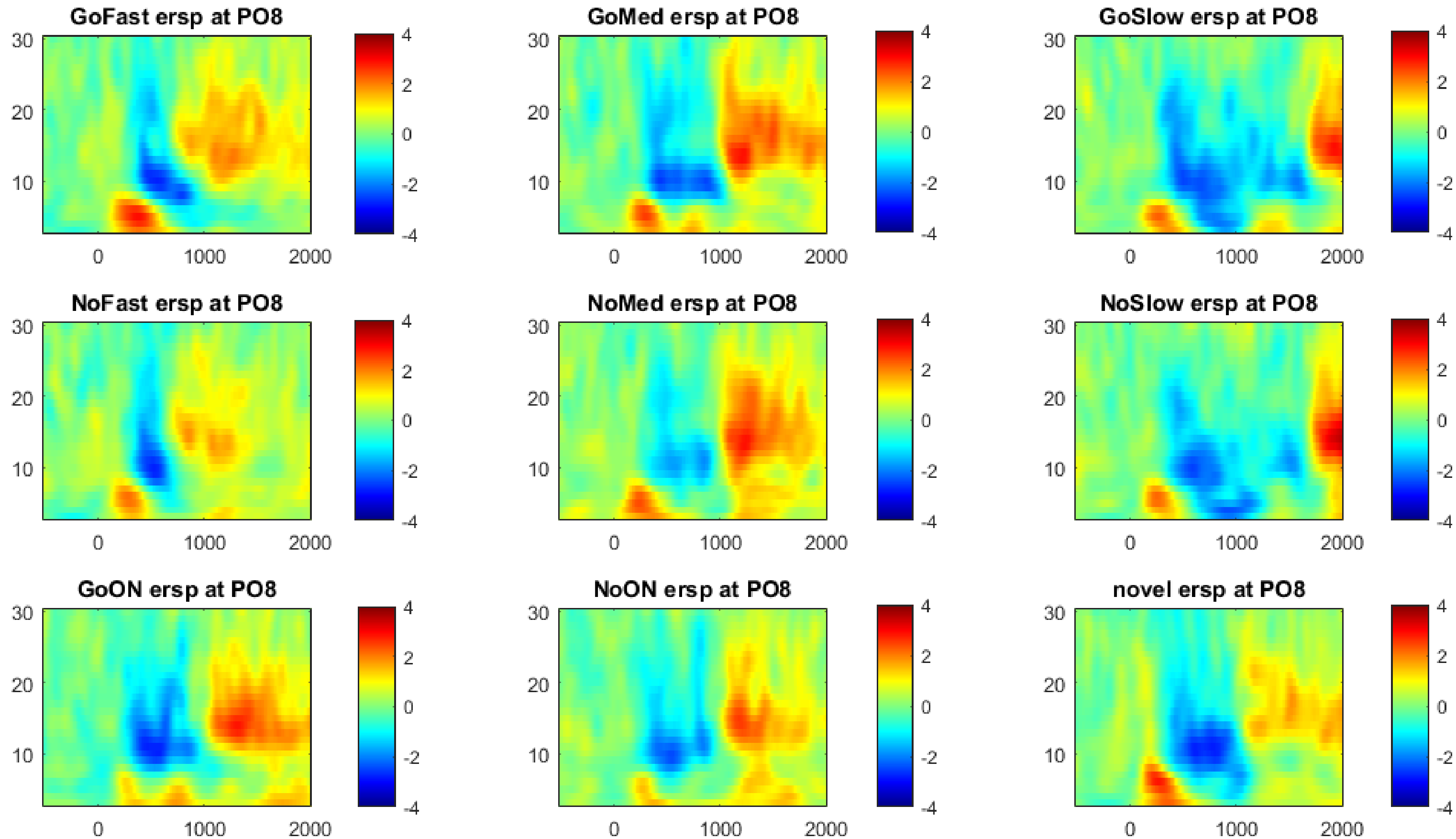
My experiment



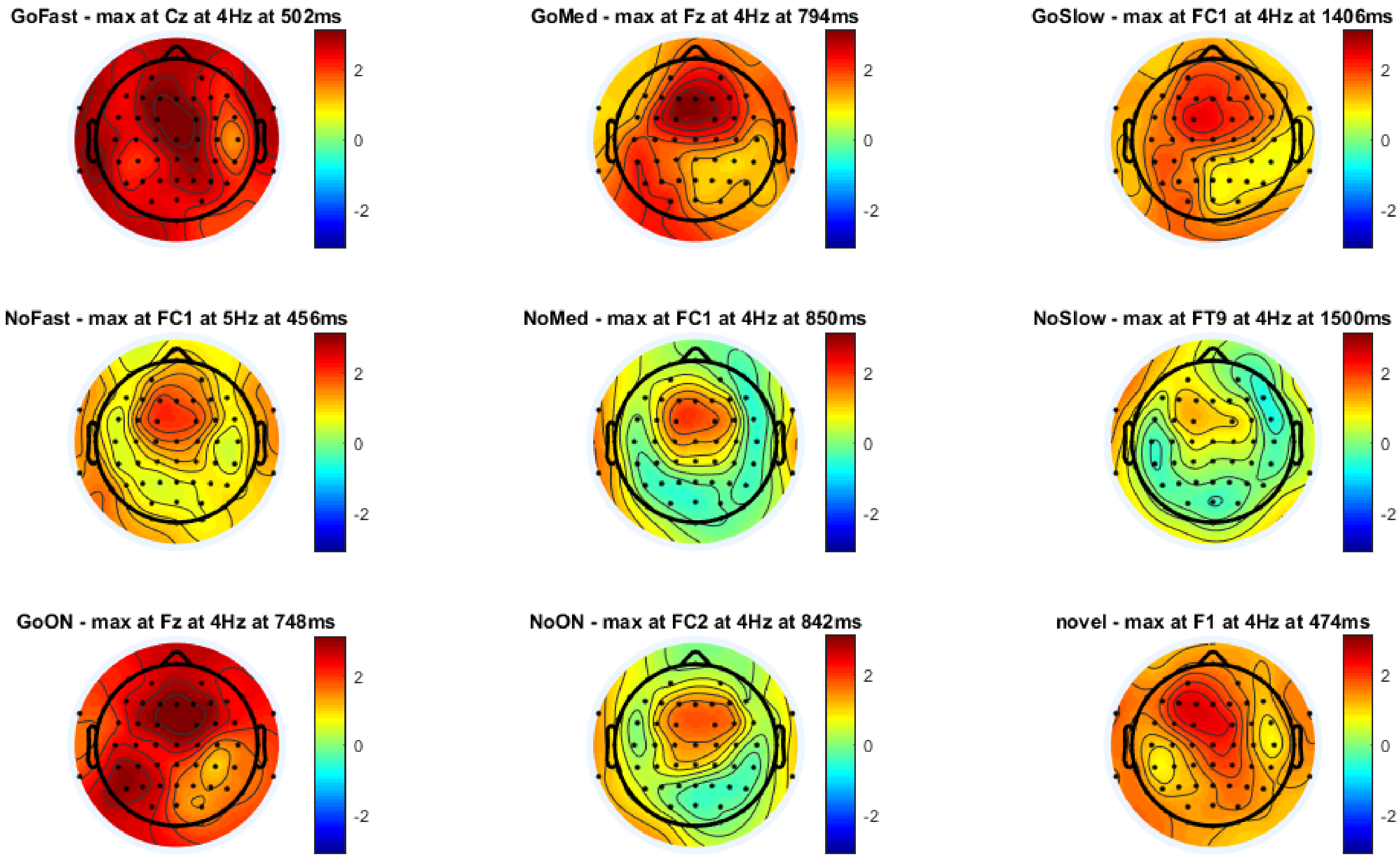
ITI ~ 7s   300 trials x 7 s = 35 min   2 x 30s break



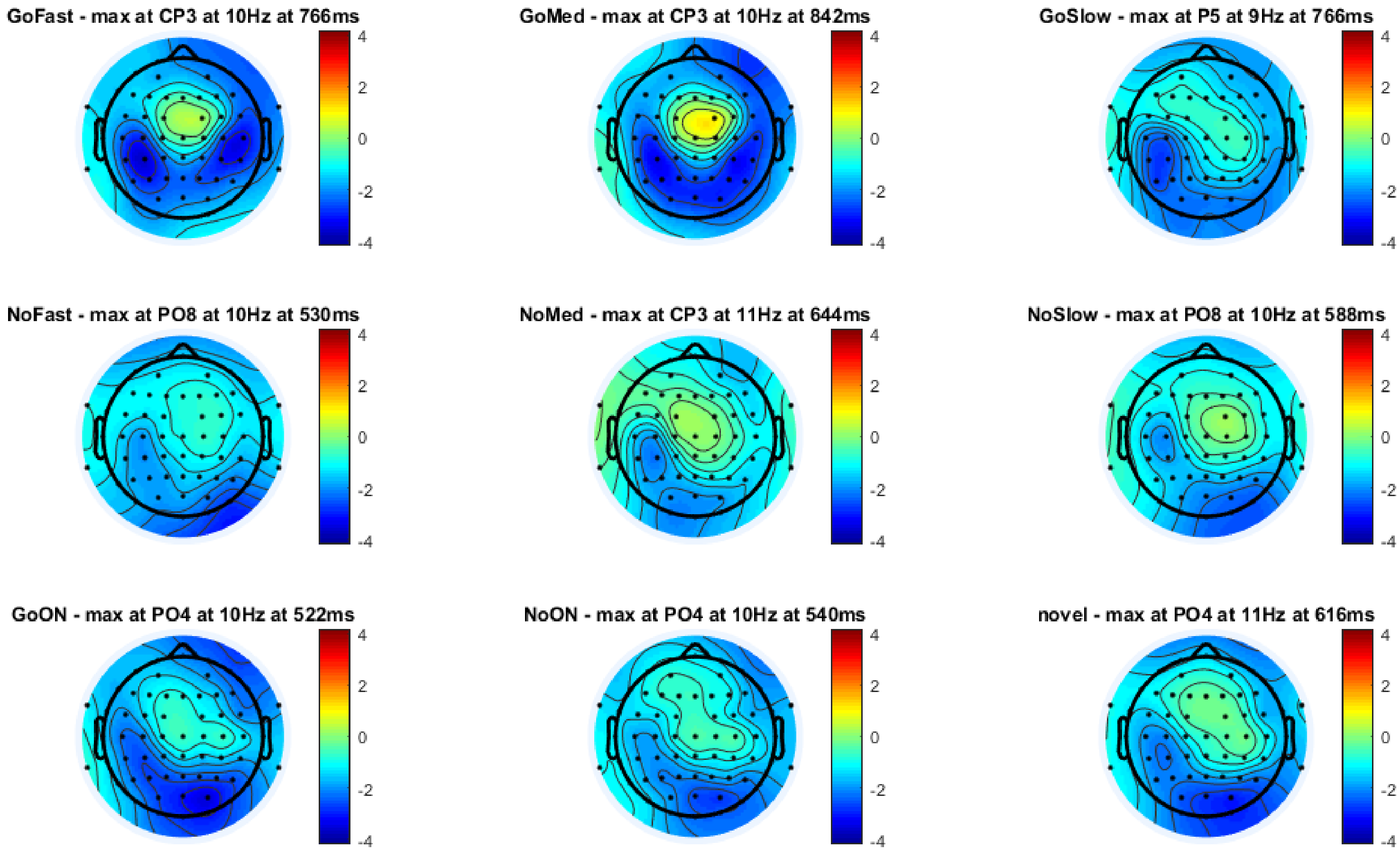
My experiment – ERSP at PO8



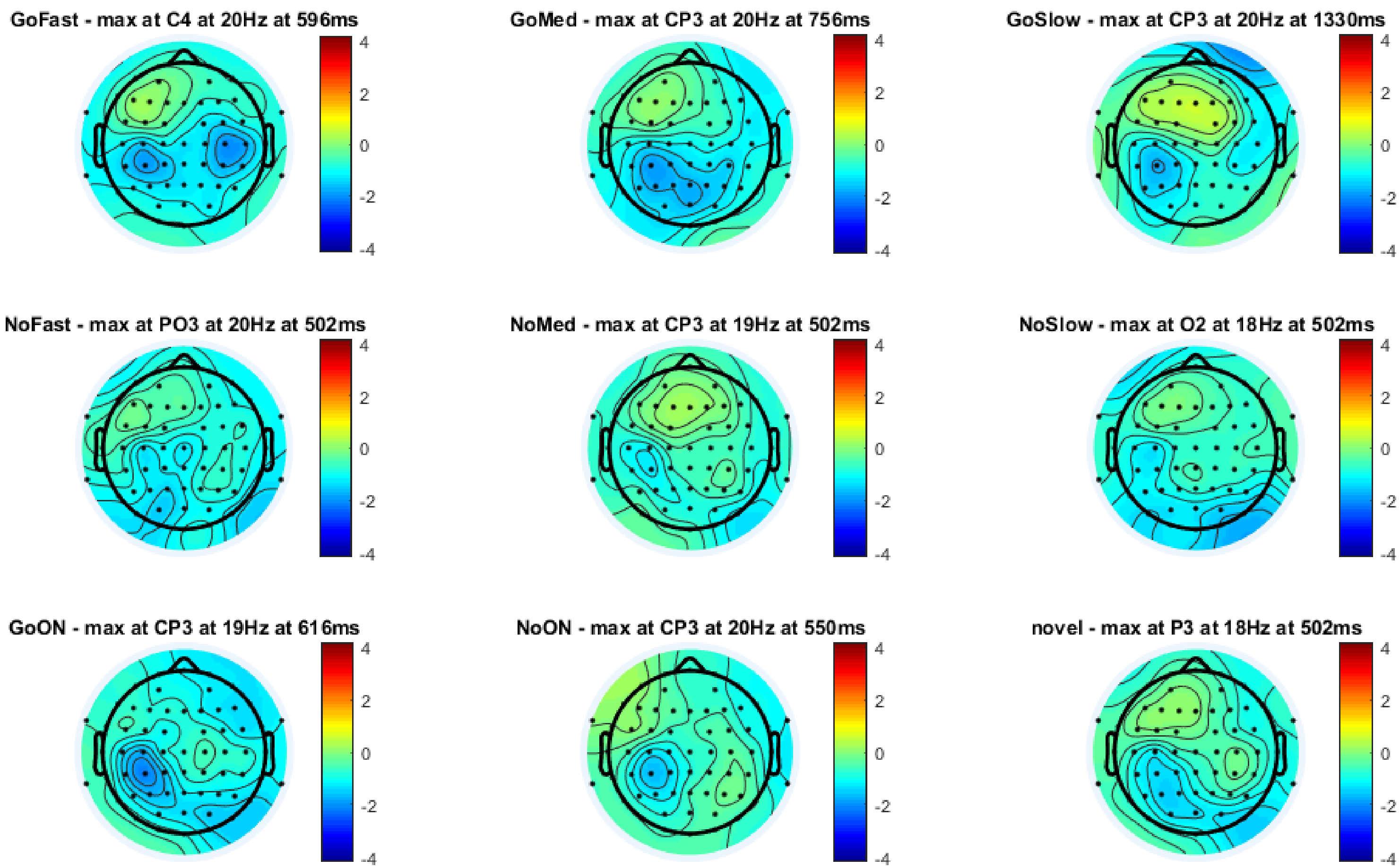
My experiment – max theta



My experiment – max alpha decrease



My experiment – max beta decrease

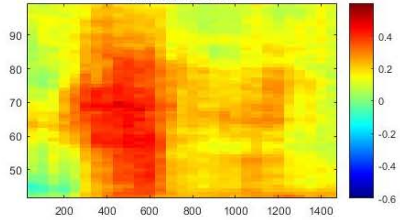


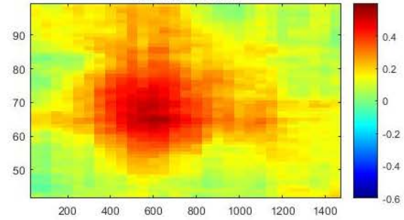
My experiment - ERSP results – gamma

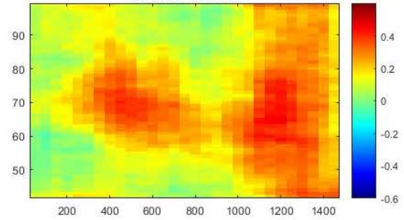
Stim-locked

100ms 500ms 1200ms

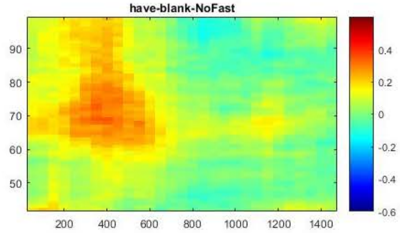
Go

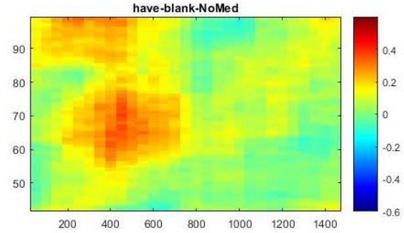


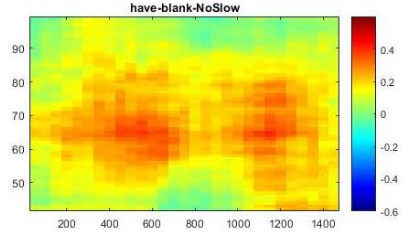




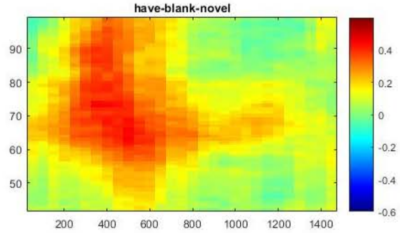
NoGo





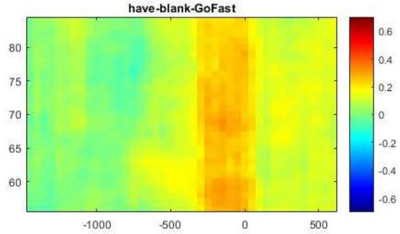


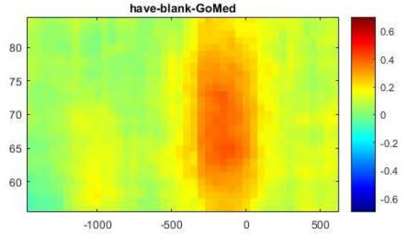
novel

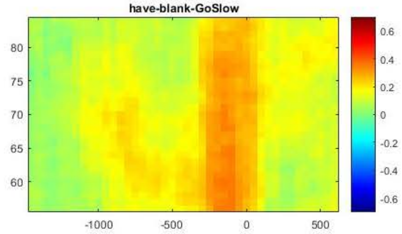


Resp-locked

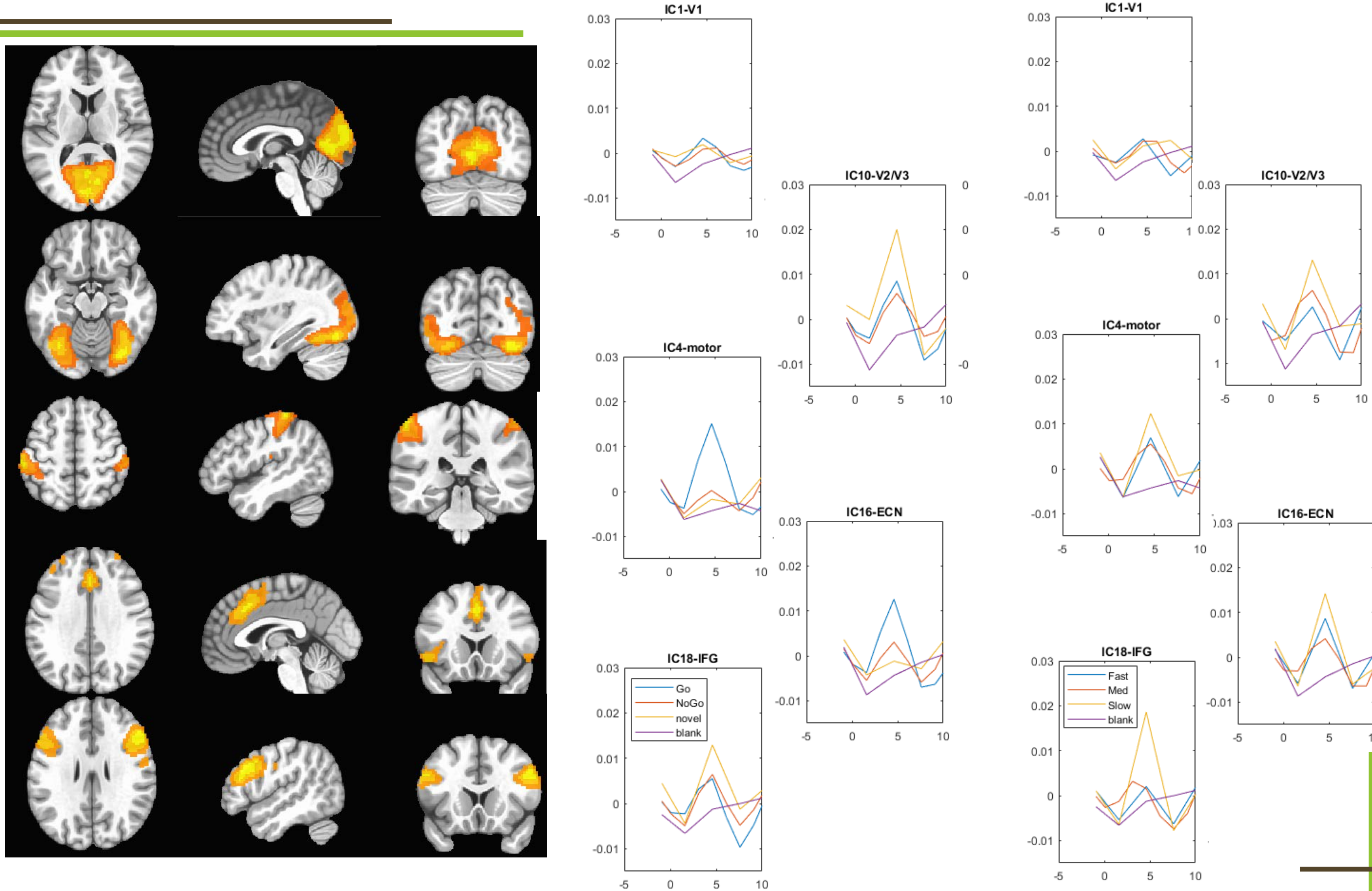
Go







My experiment – fMRI results



Coupling EEG and fMRI results in future…

Thank you for your attention!