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

- susceptible to type I error

fMRI

Eklund et al. (2016). Cluster failure: why fMRI inferences for spatial extent have inflated false-positive rates. PNAS (cited by 740)
• informative
• 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...
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... ... 1992!


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

Methodology
Part I

The drawbacks
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)

- outside MR room
- during EPI scan
- averaged imaging artifact
- after subtraction
MR artifacts

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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 from 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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MR artifacts

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


\[\ldots\text{it took my colleagues and myself looking at hundreds of empty or speckled EEG-correlated statistical result maps -- in addition to a few meaningful ones -- to develop a vague appreciation of what EEG-correlated fMRI maps might or might not mean.}\]

\[\ldots\text{the creativity of the growing community of researchers applying EEG–fMRI in their fields of interest and their augmented experience over time will bring about further advances in the field of EEG–fMRI integration}\]
Part II

Further analysis and results
Part II

Benefits
Coupling of EEG and fMRI - scheme
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EEG-informed fMRI

fMRI-informed EEG
Coupling of EEG and fMRI - scheme

EEG-informed fMRI

combined EEG-fMRI

fMRI-informed EEG
Coupling ERPs with BOLD

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:

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 investigate 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

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

Coupling oscillations with BOLD

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

Coupling oscillations with BOLD


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

Coupling oscillations with BOLD


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

GoFast - max at Cz at 4Hz at 502ms

GoMed - max at Fz at 4Hz at 794ms

GoSlow - max at FC1 at 4Hz at 1400ms

NoFast - max at FC1 at 5Hz at 456ms

NoMed - max at FC1 at 4Hz at 850ms

NoSlow - max at FT9 at 4Hz at 1500ms

GoON - max at Fz at 4Hz at 748ms

NoON - max at FC2 at 4Hz at 842ms

novel - max at F1 at 4Hz at 474ms
My experiment – max alpha decrease

GoFast - max at CP3 at 10Hz at 766ms

GoMed - max at CP3 at 10Hz at 842ms

GoSlow - max at P5 at 9Hz at 766ms

NoFast - max at PO8 at 10Hz at 530ms

NoMed - max at CP3 at 11Hz at 644ms

NoSlow - max at PO8 at 10Hz at 588ms

GoON - max at PO4 at 10Hz at 522ms

NoON - max at PO4 at 10Hz at 540ms

novel - max at PO4 at 11Hz at 616ms
My experiment – max beta decrease
My experiment - ERSP results – gamma

Stim-locked

Go

100ms

500ms

1200ms

NoGo

novel

Resp-locked

Go
My experiment – fMRI results
Coupling EEG and fMRI results in future...

Thank you for your attention!