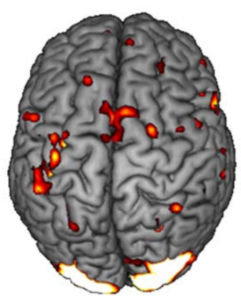
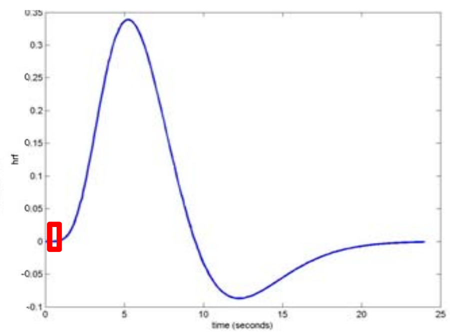
FACULTY OF PSYCHOLOGY AND EDUCATIONAL SCIENCES

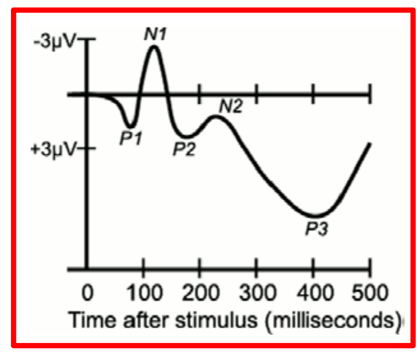
fMRI/EEG integration

Simultaneous recording of fMRI and EEG data in one session

fMRI







EEG

Outline

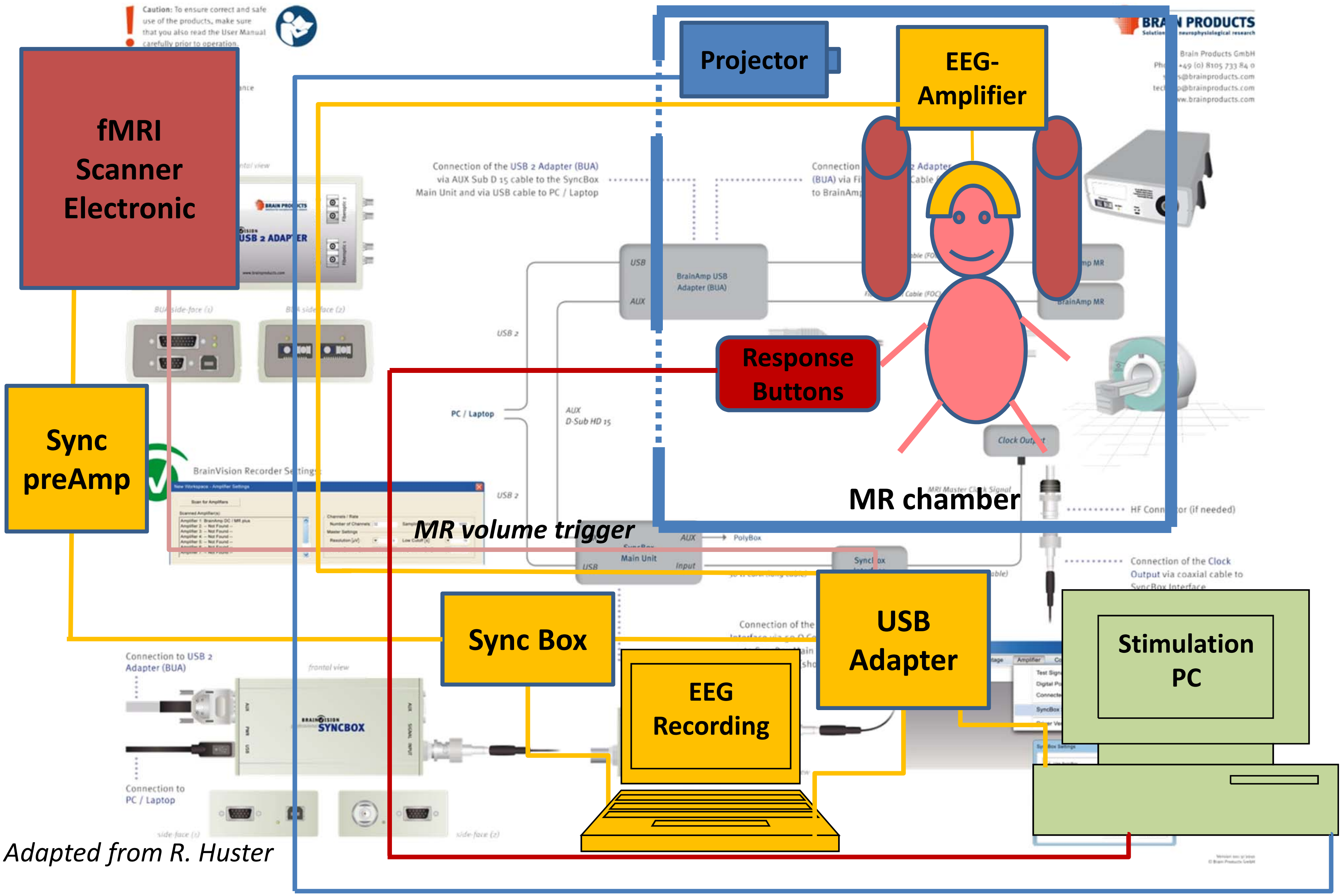
1. Data Acquisition

2. Data Preprocessing

3. Data Integration

4. Benefits and Limitations

1. Data Acquisition



Adapted from R. Huster

1. Data Acquisition

Things to consider upfront

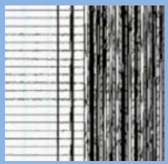
Paradigm adjustments

• Deliver task like in a regular fMRI experiment, but:
• Include event codes in EEG data for later conditional averaging
• Stimulus timing should not be locked to the TR (fMRI volume) or slice repetition frequency

EEG preparation at the scanner

• Requires extra time and space
• Requires MR-compatible EEG system
• Extra electrode on the back for cardiac signal (but real ECG is better)
• The lower the EEG impedances, the smaller the MR artifact!

EEG recording in the scanner



→ MR and pulse (cardio) artifact!

• Synchronization of fMRI and EEG is essential for MR artifact correction!
(TR = multiple of EEG clock period of 200 µsec)

• Attenuate noise sources to reduce artifacts:
- fMRI sequences may have to be optimized
- Some head coils are better than others
- Straight cable routing, isolate from MR table, use tape and sandbags to reduce vibrations
- Turn off cryo pumps during scanning
- Help participant to keep head still because motion amplifies artifacts!

1. Data Acquisition

Things to consider upfront

! SAFETY FIRST !

(in addition to the rules for regular fMRI experiments)

- Only use MR-certified non-magnetic equipment (caps, amplifiers, cables) !
- Only use “safe” MR sequences, check with local MR physicist (risk of heating) !
- Be extra careful when multiple helpers are involved (assign responsibilities) !

1. Data Acquisition

The procedure in brief

- **Prepare:** MR scanner, stimulus computer, **EEG system for capping**
- **Participant arrival:** informed consent, MR checklist, instruction and practice, metal check
- **Placing EEG and ECG: correct cap size, electrode-scalp connection, impedance and signal check**
- **Positioning:** noise protection, **ensure "comfortable position"**, padding, place head coil, scanner table positioning, **connect amplifiers, fixate cables**

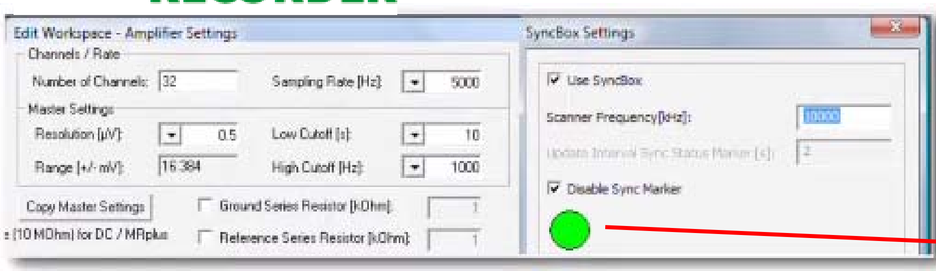
Mullinger et al. 2013, University of Nottingham

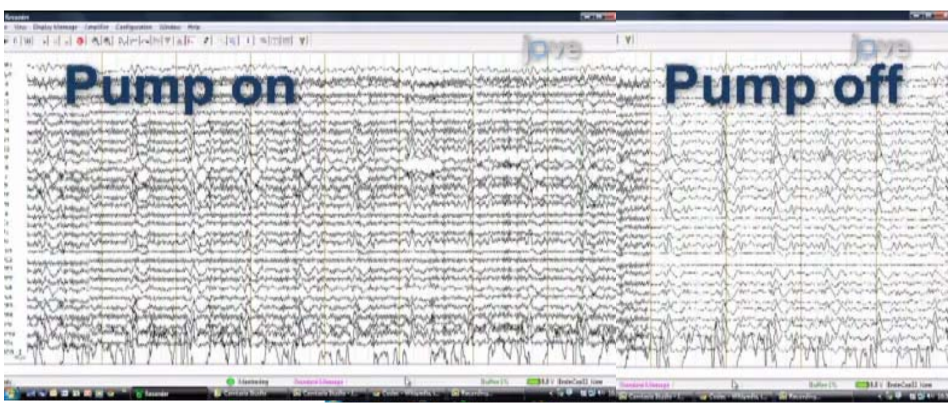
1. Data Acquisition

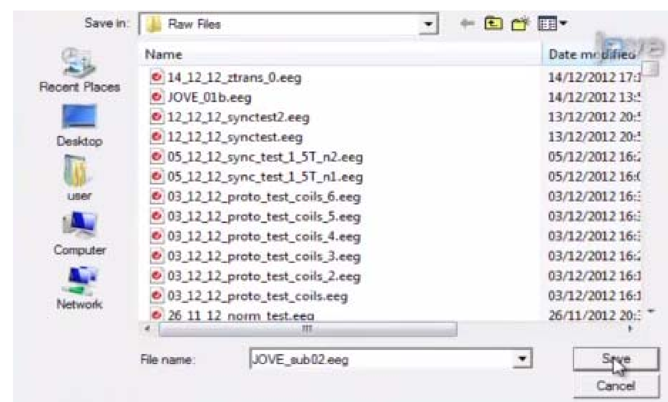
The procedure in brief

- **Connect hardware**: **amplifiers (via fiber optic cables), EEG acquisition laptop, MR scanner, and stimulus computer (via sync box)**
- **Run experiment**: anatomical MR, **check EEG signal, check synchronization, turn off cryo pumps, start EEG recording**, start paradigm and fMRI acquisition, **check MR and event markers in EEG**

BRAINVISION professional RECORDER







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2. Data Preprocessing

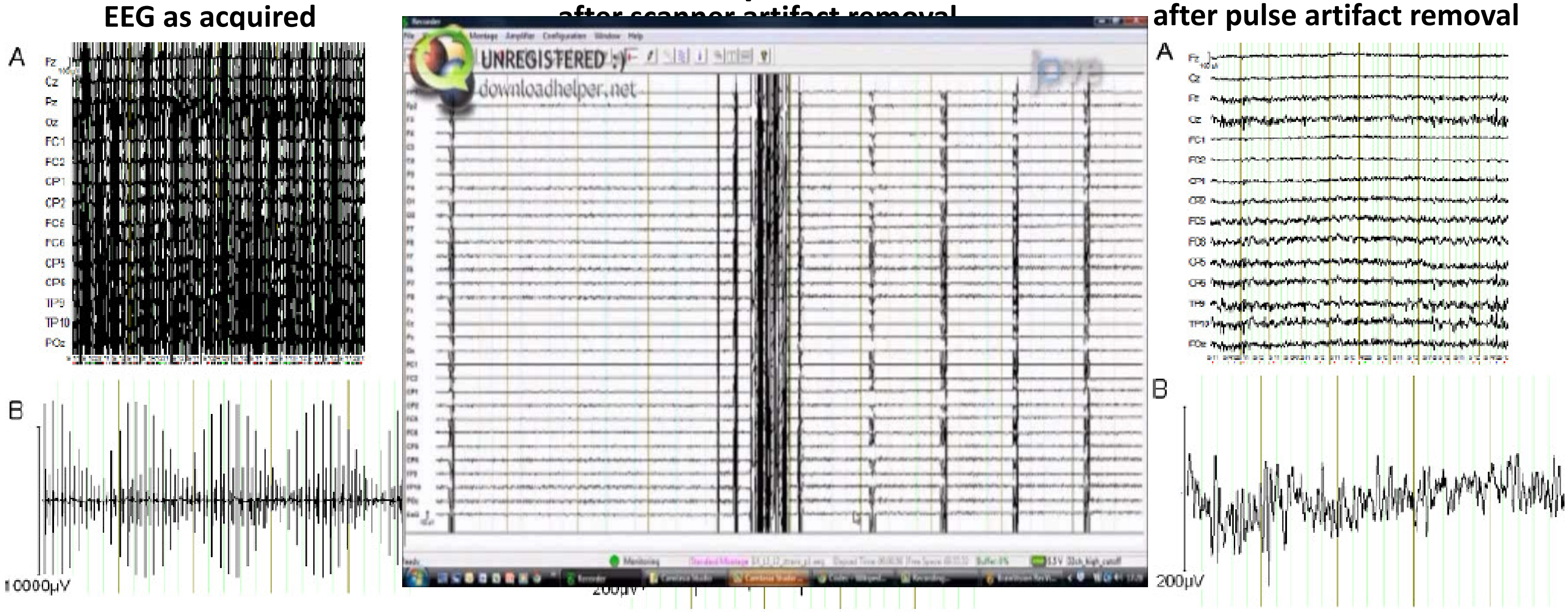
Regular for fMRI, special for EEG

The problem

EEG as acquired

after scanner artifact removal

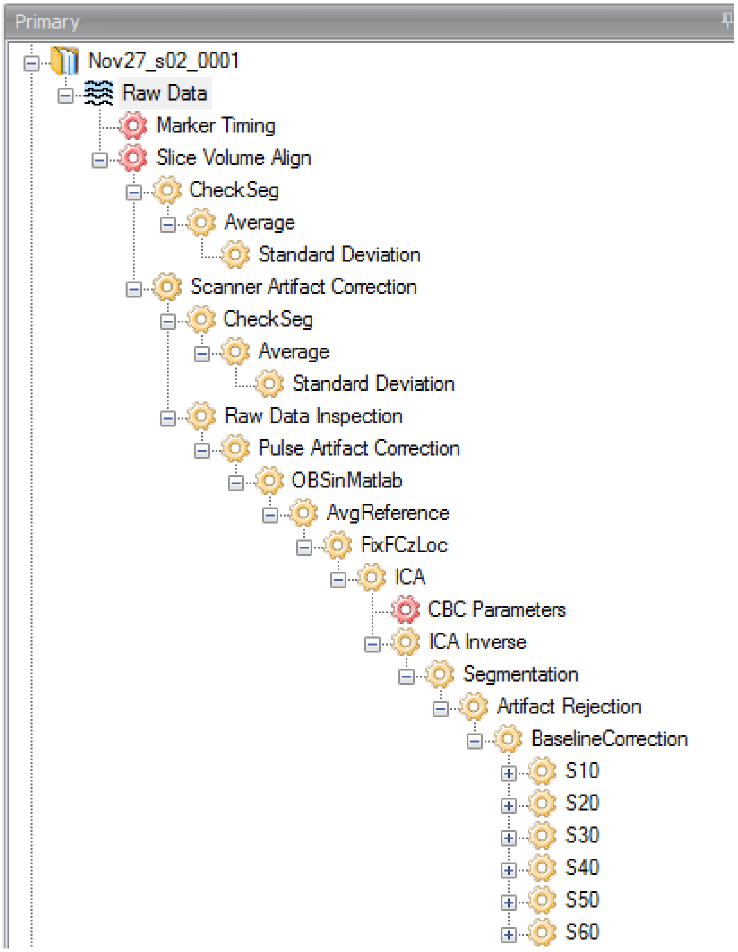
after pulse artifact removal



Mullinger et al. 2013

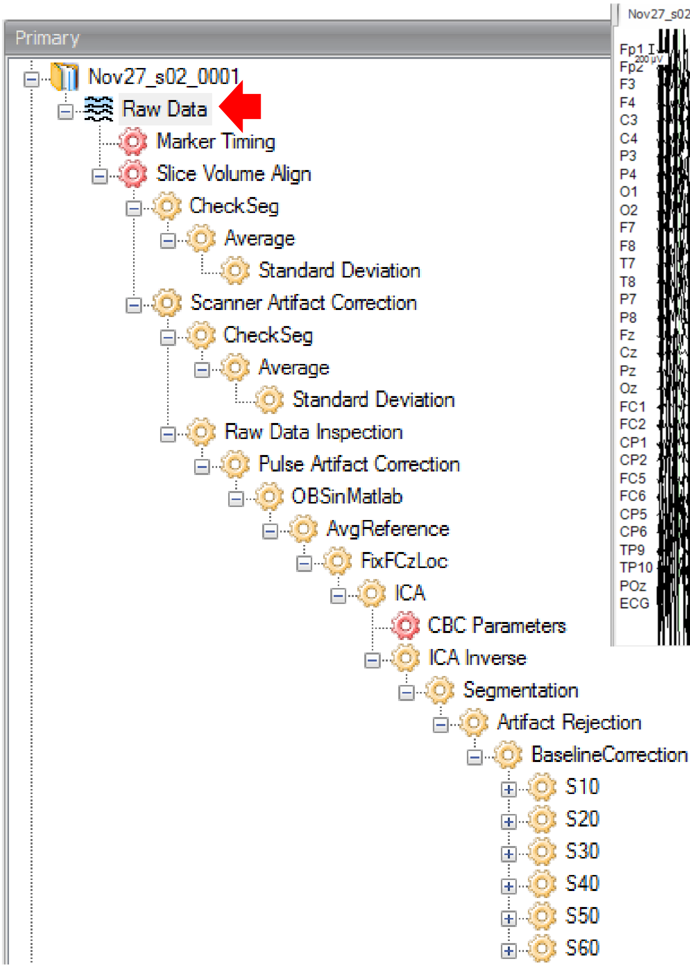
2. Data Preprocessing

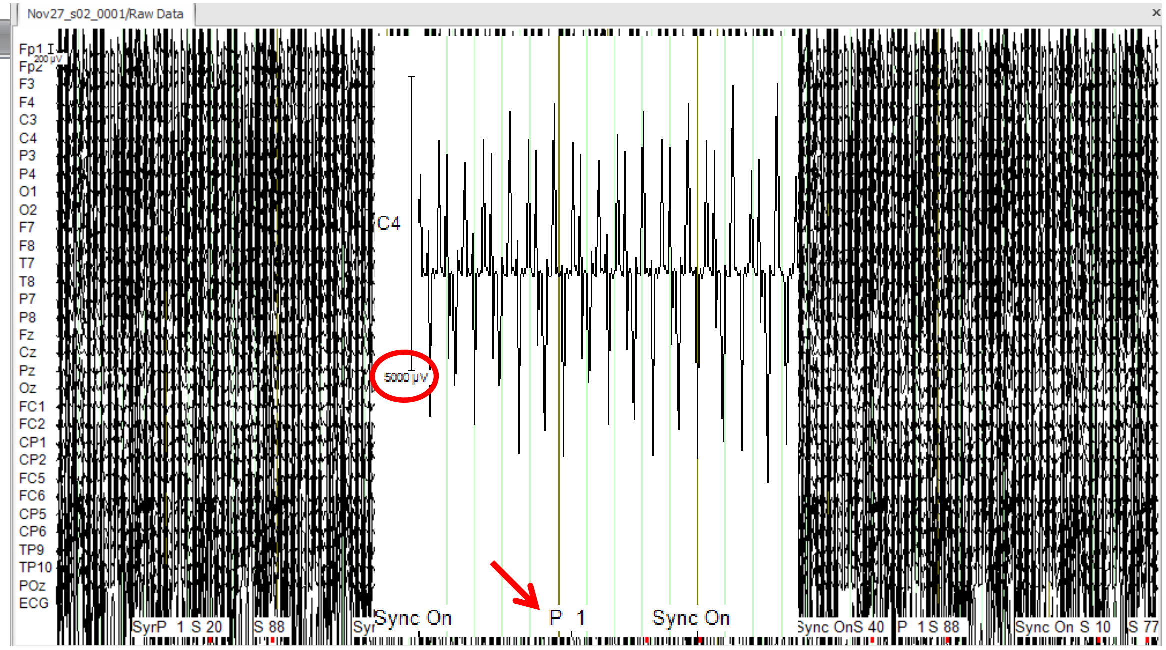
EEG preprocessing single subject



2. Data Preprocessing

Scanner artifact correction





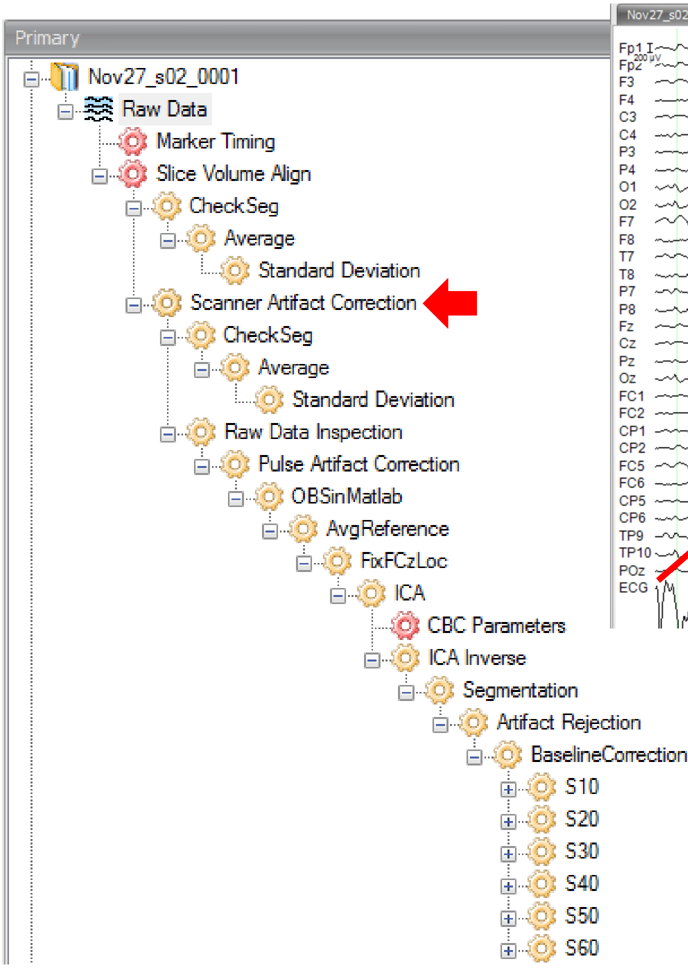
Looks bad, but hurray, it's a technical artifact! (stable)

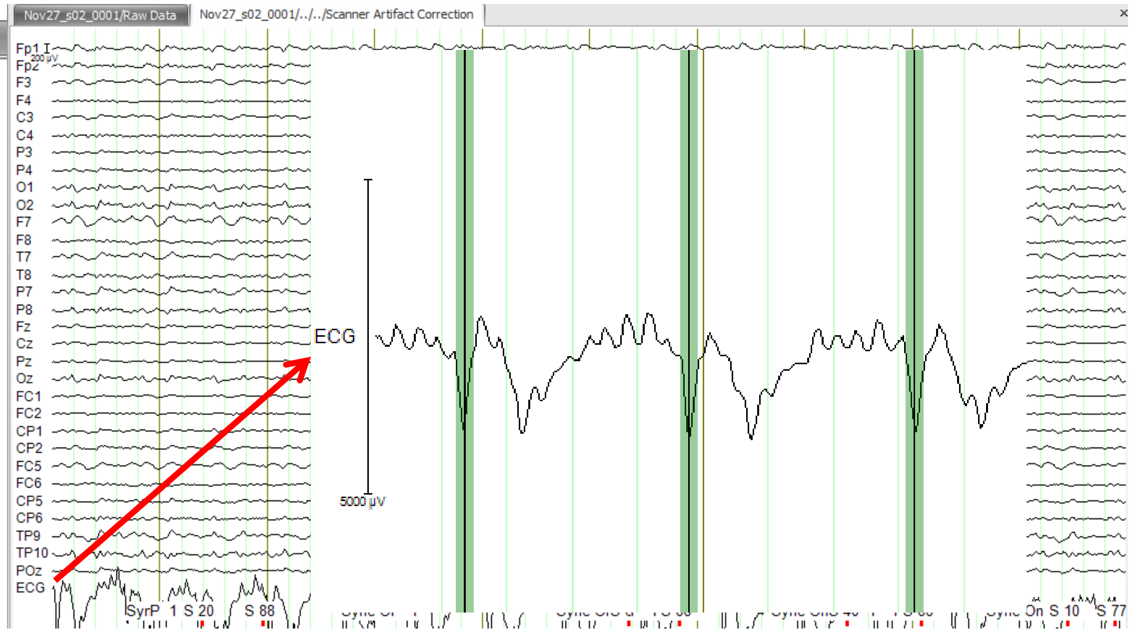
MR markers: volume-based vs. slice-based correction (depends on scanner, here volume-based), check timing! (should be stable)

Different methods for marker-based template generation:
- Average across all volumes (OK if there's no movement)
- Sliding average (better in case the participant moved)
- Average across selected volumes (if there are known bad volumes)

2. Data Preprocessing

Pulse (cardio) artifact correction





Problem: this is a non-technical artifact (not stable)!

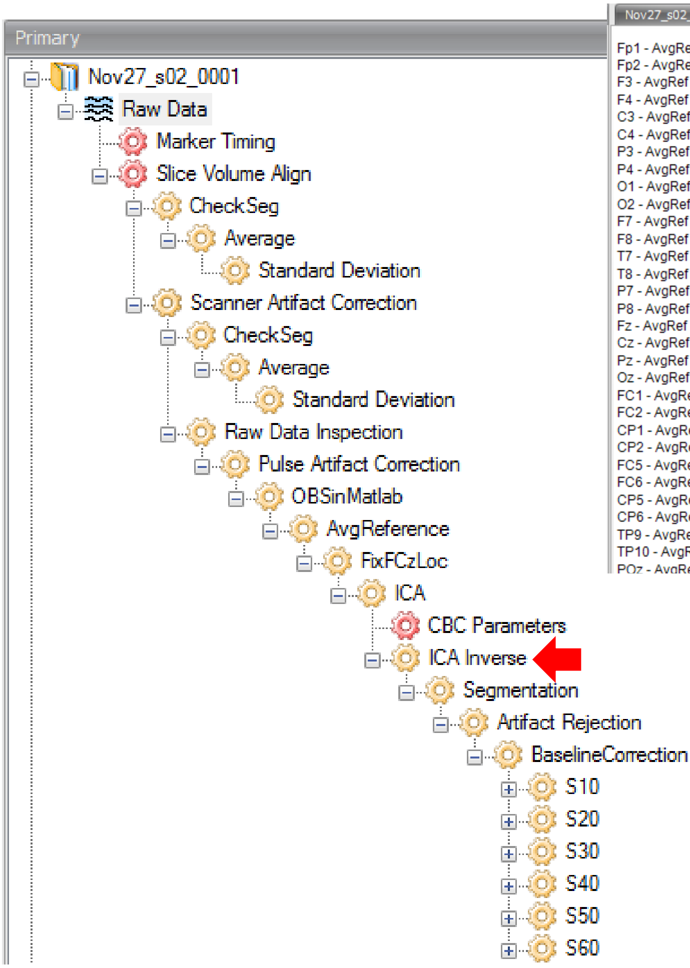
Place ECG markers for template generation (semi-automatic mode!)

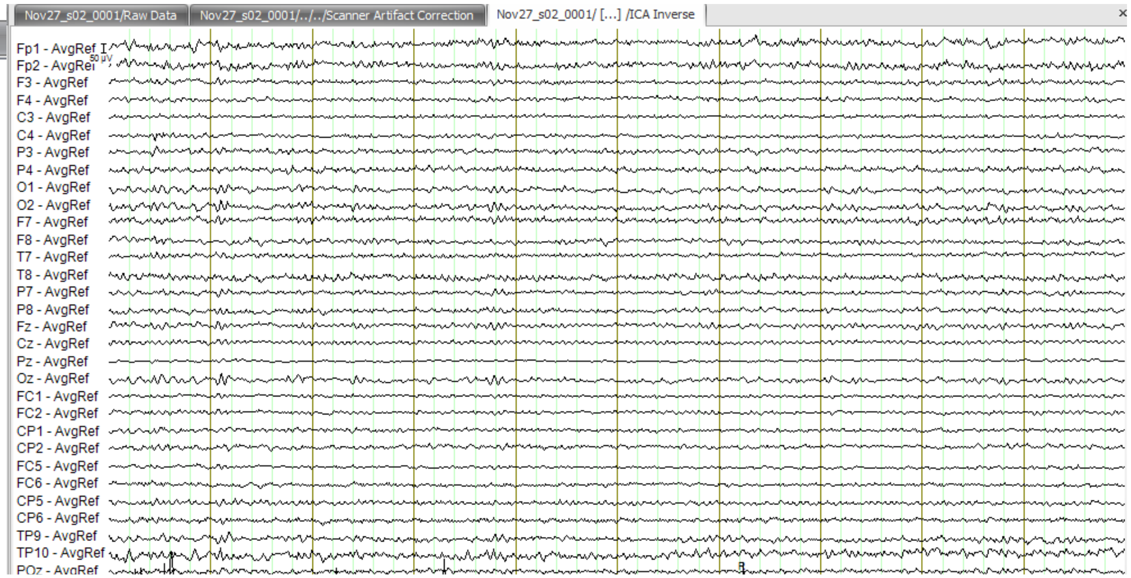
Different approaches - can be used in combination:

- Marker-based template generation and subtraction
- Optimal Basis Set (*EEGlab*): finds and removes principle components in the EEG signal that carry the signature of the ECG
- ICA and inverse ICA (*Analyzer*): decomposition into ICs, suggesting ECG-related ICs, removal of those ICs (after visual inspection!)

2. Data Preprocessing

After artifact correction: From continuous EEG to ERPs

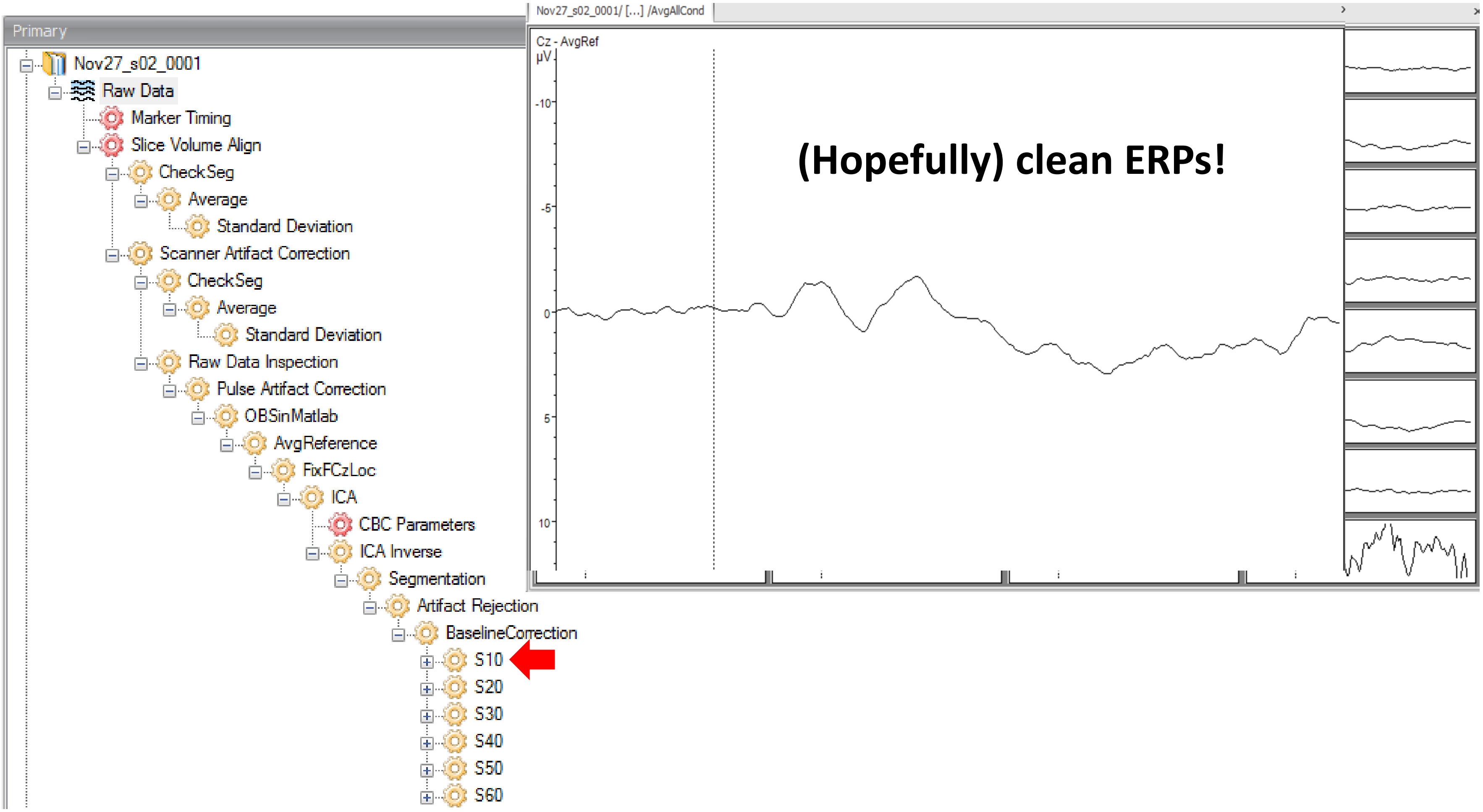




- **Re-referencing**
- **Segmentation (based on trial event markers)**
- **Regular artifact rejection (blinks etc.)**
- **Baseline correction**
- **Condition-based averaging (ERPs)**

2. Data Preprocessing

After artifact correction: From continuous EEG to ERPs



Outline

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3. Data Integration

Two data sets per participant

	fMRI	**EEG**
Pre-processing	Coregistration Slice-time correction Realignment Normalization Smoothing	MR and pulse artifact correction Re-referencing Segmentation Regular artefact rejection (blinks etc.) Baseline correction
1st level (subject)	Condition-based BOLD averaging (General Linear Model, GLM) ICA Functional connectivity	Condition-based averaging (amplitude or oscillatory power) ICA Source reconstruction
2nd level (group)	Across-subject averaging and stats (voxel-wise analysis, ROI, ICA, functional connectivity)	Across-subject averaging and stats (ERPs, amplitude and latency, topography, ICA, frequencies)

3. Data Integration

3.1 Treat as separate data sets. Get two experiments for the price of one.

	fMRI	**EEG**
Pre-processing	Coregistration Slice-time correction Realignment Normalization Smoothing	MR and pulse artifact correction Re-referencing Segmentation Regular artefact rejection (blinks etc.) Baseline correction
1st level (subject)	Condition-based BOLD averaging (General Linear Model, GLM) ICA Functional connectivity	Condition-based averaging (amplitude or oscillatory power) ICA Source reconstruction
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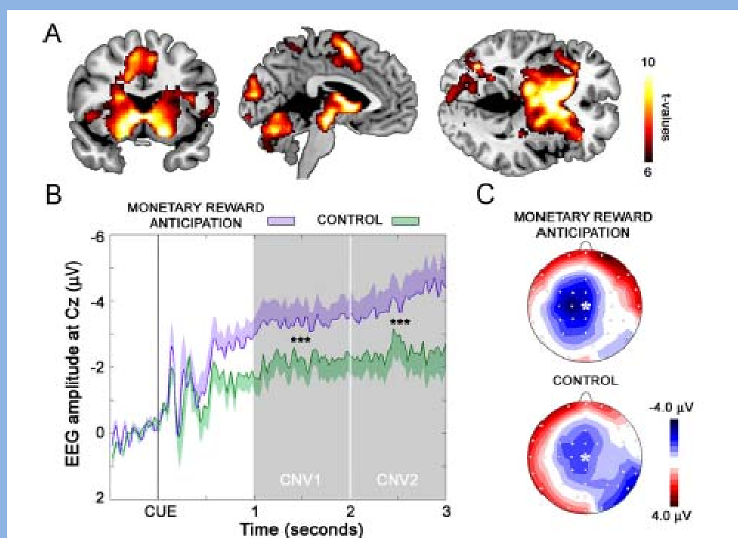
3. Data Integration

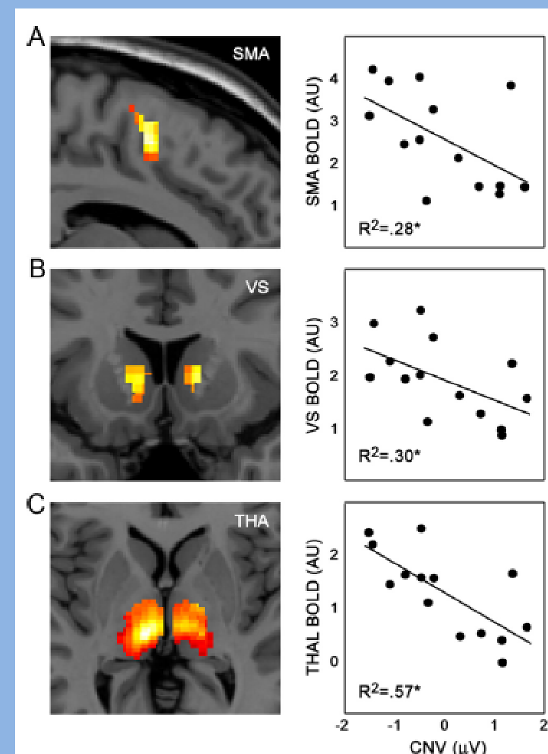
3.2 <u>Covariation of EEG and fMRI activity</u>. Use averaged EEG measure (amplitude or oscillatory power) as covariate in 2nd level fMRI analysis or correlate directly with BOLD signal.

<u>Example:</u>

Plichta et al. 2013 (*JNeurosci*)
average CNV during reward anticipation is correlated with averaged BOLD activity in the supplementary motor area, striatum, and thalamus (across trials)



One across-subject covariate (CNV):

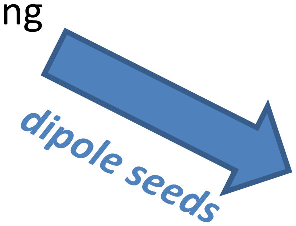


(Examples: Liebenthal et al. 2003; Plichta et al. 2013)

3. Data Integration

3.3 <u>fMRI-informed EEG source localization</u>. Especially useful in clinical contexts. In fact, the origin of simultaneous fMRI/EEG lies in epilepsy treatment.

	fMRI	**EEG**
Pre-processing	Coregistration Slice-time correction Realignment Normalization Smoothing	MR and pulse artifact correction Re-referencing Segmentation Regular artefact rejection (blinks etc.) Baseline correction
1st level (subject)	Condition-based BOLD averaging (General Linear Model, GLM) ICA Functional connectivity	Condition-based averaging (amplitude or oscillatory power) ICA Source reconstruction
2nd level (group)	Across-subject averaging and stats (voxel-wise analysis, ROI, ICA, functional connectivity)	Across-subject averaging and stats (ERPs, amplitude and latency, topography, ICA, frequencies)



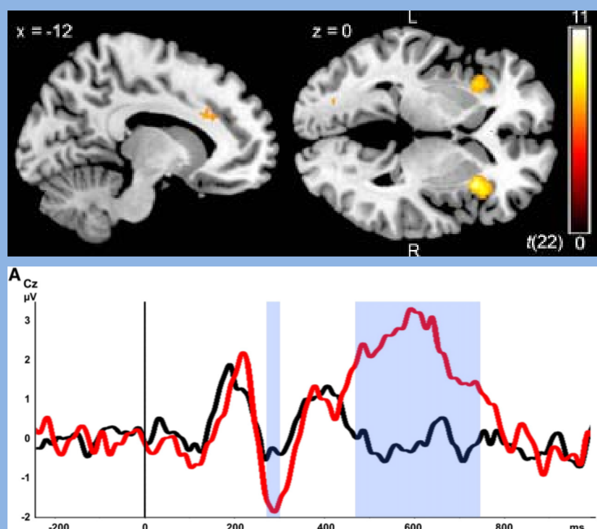
(Examples: Lemieux et al. 2004; Vanni et al. 2004; Grouiller et al. 2011)

3. Data Integration

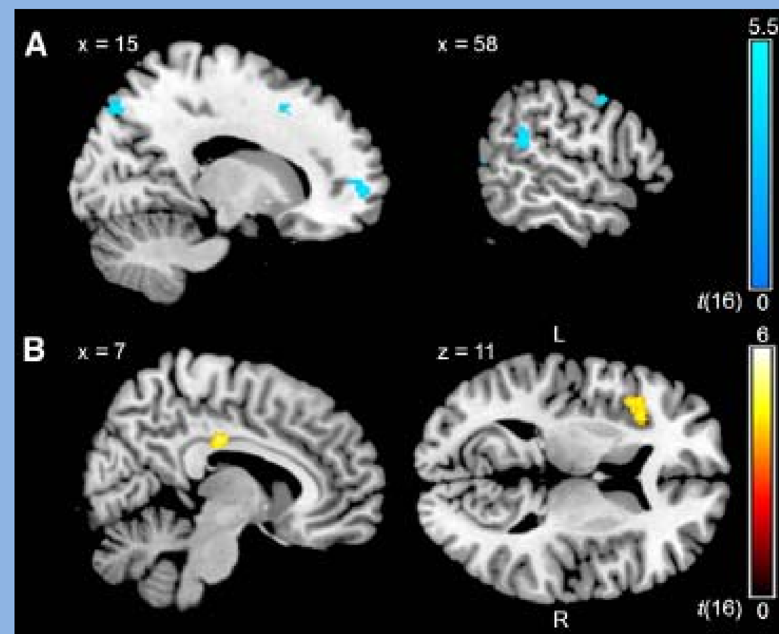
3.4 <u>EEG-informed fMRI analysis</u>. Use single-trial EEG measure (amplitude or oscillatory power) as parametric modulator in 1st-level fMRI model and test at 2nd level (additional variance?).

<u>Example:</u>

Baumeister et al. 2014 (*NeuroImage*)
N2 and P3 amplitudes during response inhibition are anti-correlated and correlated with the BOLD signal in distinct regions on a trial-to-trial basis



Two single-trial parametric modulators (N2, P3):



(Examples: Debener et al. 2005; Benar et al. 2007; Scheeringa et al. 2009; Nguyen et al. 2014; Baumeister et al. 2014)

3. Data Integration

3.5 <u>Symmetrical integration of fMRI/EEG data</u>. e.g. joint ICA (data-driven, integrated spatiotemporal ICs) and complex neural models (model-based, integration of multiple levels).

	fMRI	**EEG**
Pre-processing	Coregistration Slice-time correction Realignment Normalization Smoothing	MR and pulse artifact correction Re-referencing Segmentation Regular artefact rejection (blinks etc.) Baseline correction
	neural model	
1st level (subject)	Condition-based BOLD averaging (General Linear Model, GLM) ICA Functional connectivity	Condition-based averaging (amplitude or oscillatory power) ICA Source reconstruction
	joint ICA	
2nd level (group)	Across-subject averaging and stats (voxel-wise analysis, ROI, ICA, functional connectivity)	Across-subject averaging and stats (ERPs, amplitude and latency, topography, ICA, frequencies)

(Examples: Valdes-Sosa et al. 2009; Mijovic et al. 2014)

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4. Benefits and Limitations

Benefits (presuming good data quality and sufficient power!)

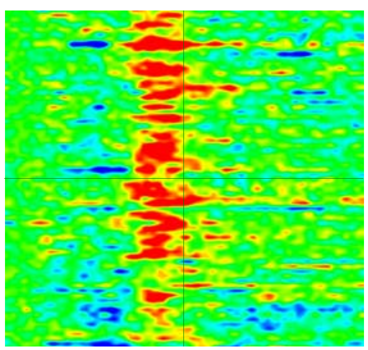
➢ Simultaneous fMRI/EEG is favorable compared to separate data sets, even if those were acquired in the same participant:
- no between-subject variance (obvious)
- no order and practice effects
- identical situation with respect to task performance, stimulus perception, body position, noise level, instruction /experimenter effects

→ these aspects increase statistical power and ensure that differences between conditions in one measure are not due to differences between fMRI and EEG session

➢ Simultaneous fMRI/EEG allows trial-by-trial covariation of spatial and temporal signatures of condition-specific brain states, exceeding across-participant approaches

→ the same logic applies to covariation analyses between neural activity and task performance

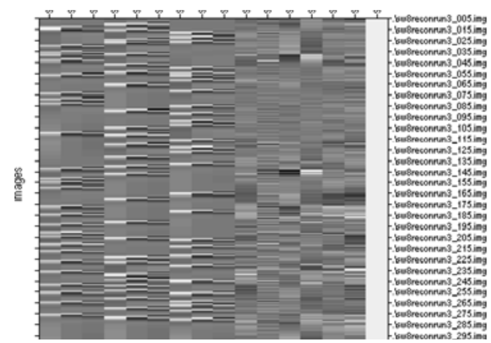
EEG Amplitude



time

trials ↓

fMRI GLM



regressors

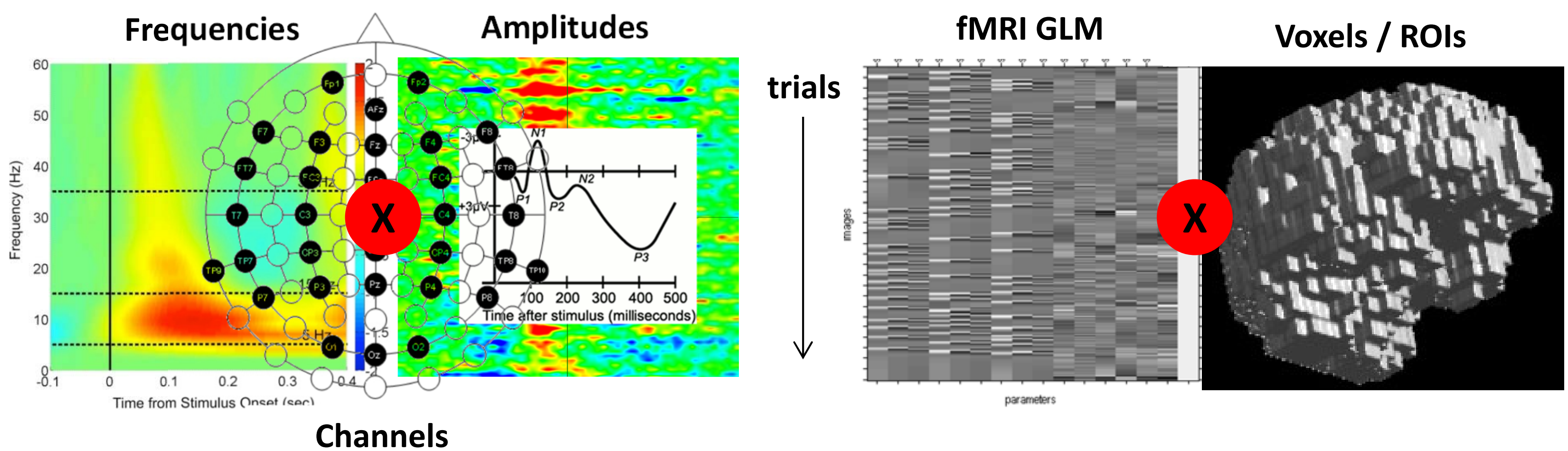
4. Benefits and Limitations

Limitations (beyond practical and technical issues)

➢ Experimental limitations in both acquisition modalities due to compatibility issues (e.g., sub-optimal stimulus timing; special sequences may not be allowed)

➢ The high number of degrees of freedom require good a priori hypotheses and adequate corrections for multiple comparisons

→ well, let’s consider this a luxury problem!



Take home:

Simultaneous fMRI/EEG is more complicated to set up, but you can get the best out of two worlds with just a little more effort.

In best case, the data can be related to one another (and to performance) to gain insights into both the WHERE and the WHEN of a specific cognitive process.

But: good hypotheses are all the more important here as degrees of freedom are very high! (if you correlate stuff wildly, you may find something by accident)

That’s all!

<u>Useful references:</u>

- Huster et al. 2012, *JNeuroscience* (review article data integration)
- Mullinger et al. 2013, *JOVE* (best practice data acquisition, incl. movie)
- Jorge et al. 2014, *NeuroImage* (review article data integration)
- Debener et al. 2006, *TICS* (opinion article single-trial analysis)