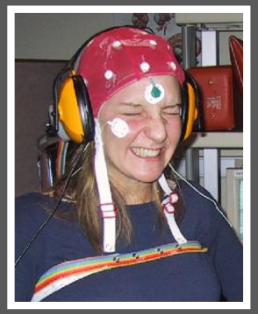
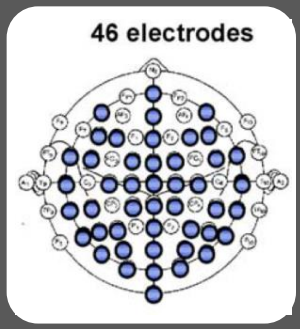
# Single-trial detection of EEG/ERP brain responses

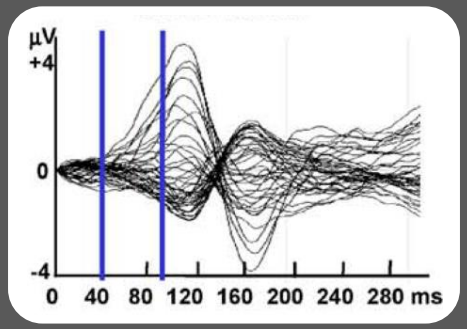
1. Basics on EEG and ERPs
2. Rationale for estimating brain responses trial-by-trial
3. Approaches for single-trial estimation
4. Possible applications

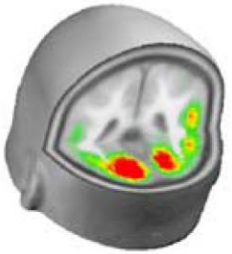
# Basics concepts of functional neuroimaging: EEG vs BOLD-fMRI

Scalp EEG

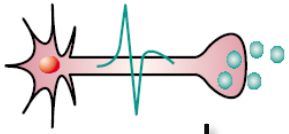




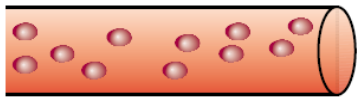



sensory stimulus



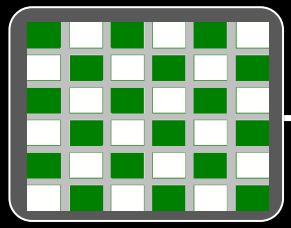
neural activity

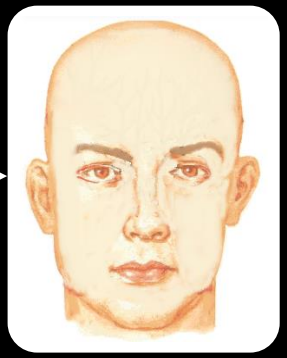
neurovascular coupling



haemodynamic response

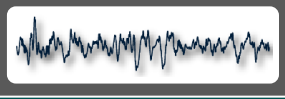
BOLD fMRI





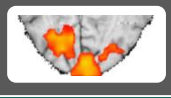
# EEG vs BOLD-fMRI: things to remember

## Scalp EEG



- Samples neural activity directly
- Excellent temporal resolution (order of ms)
- Reasonable spatial resolution (~5 mm: but depending on several factors)
- Need of a priori-hypotheses (source numbers and locations)
- Some experimental constraints (e.g. stimulus features)

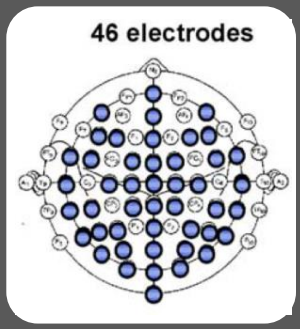
## BOLD fMRI

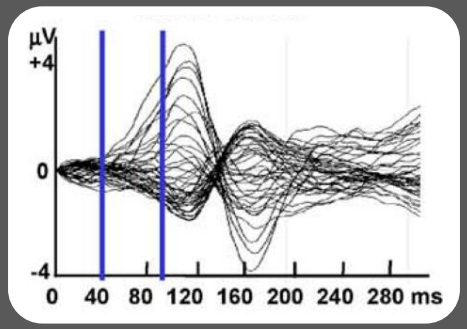


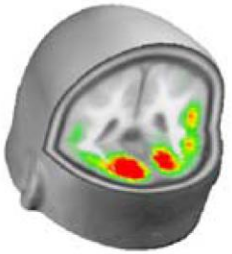
- Samples consequences of neural activity (or other phenomena with PET)
- Extremely low temporal resolution (hundreds of ms to several seconds)
- Good spatial resolution (2-10 mm; but limitations due to signal nature)
- No need of a priori-hypotheses (source numbers and locations)
- More flexible stimulation paradigms
- Some experimental constraints due to the scanner environment

# Basics concepts of functional neuroimaging: EEG vs BOLD-fMRI

Scalp EEG



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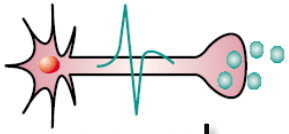
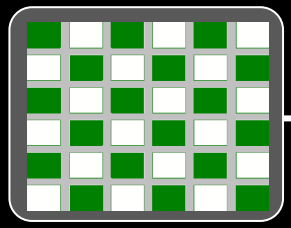


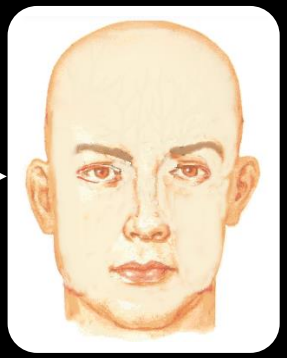
neural activity

neurovascular coupling

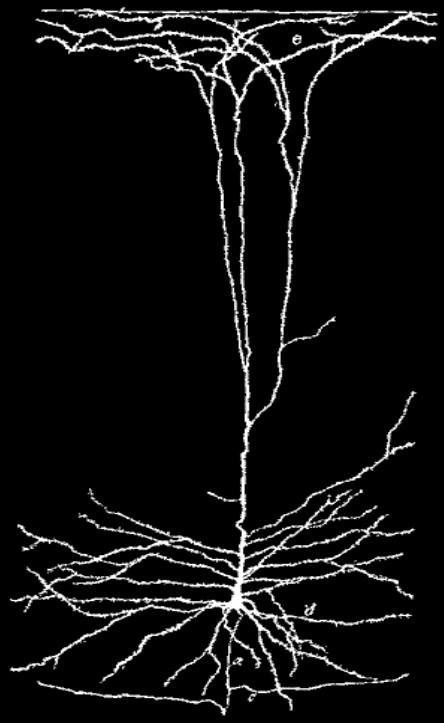
haemodynamic response

BOLD fMRI

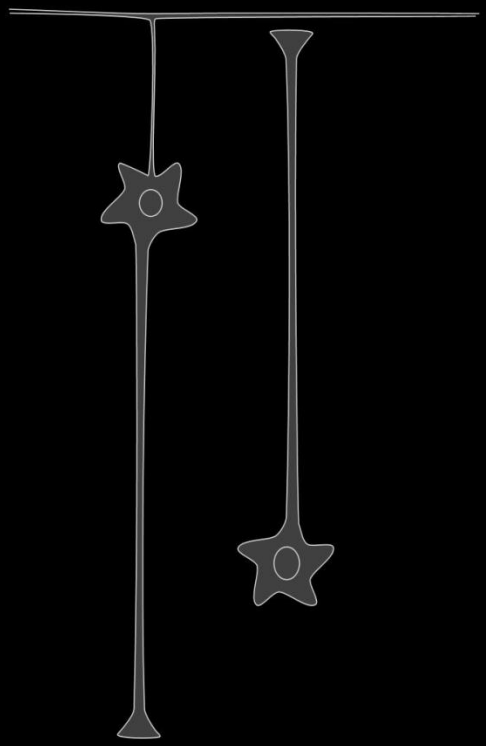




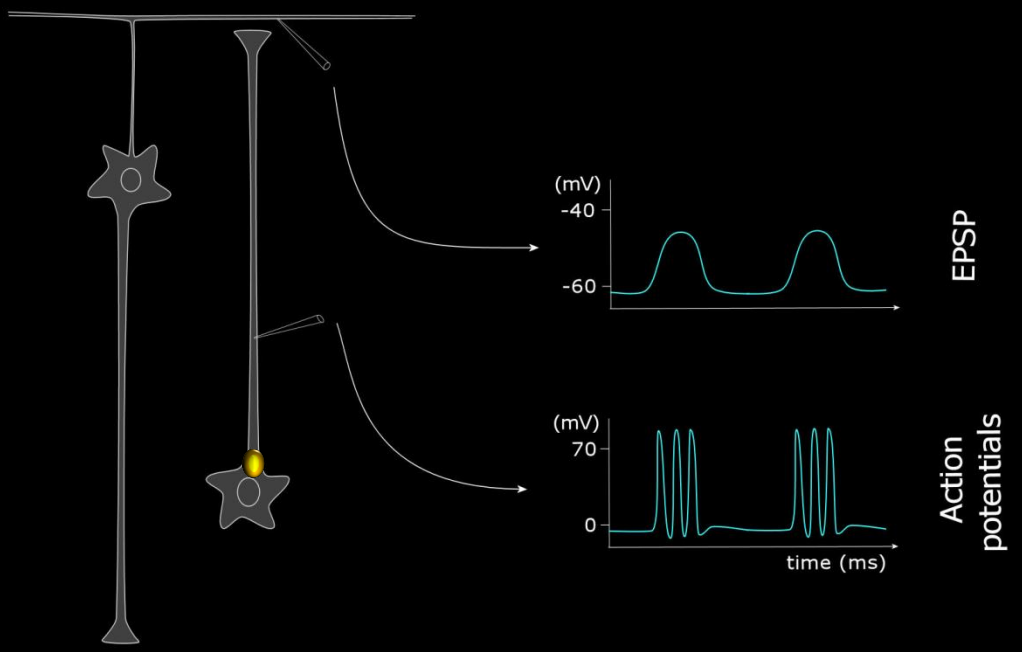
# the neocortical pyramidal neuron



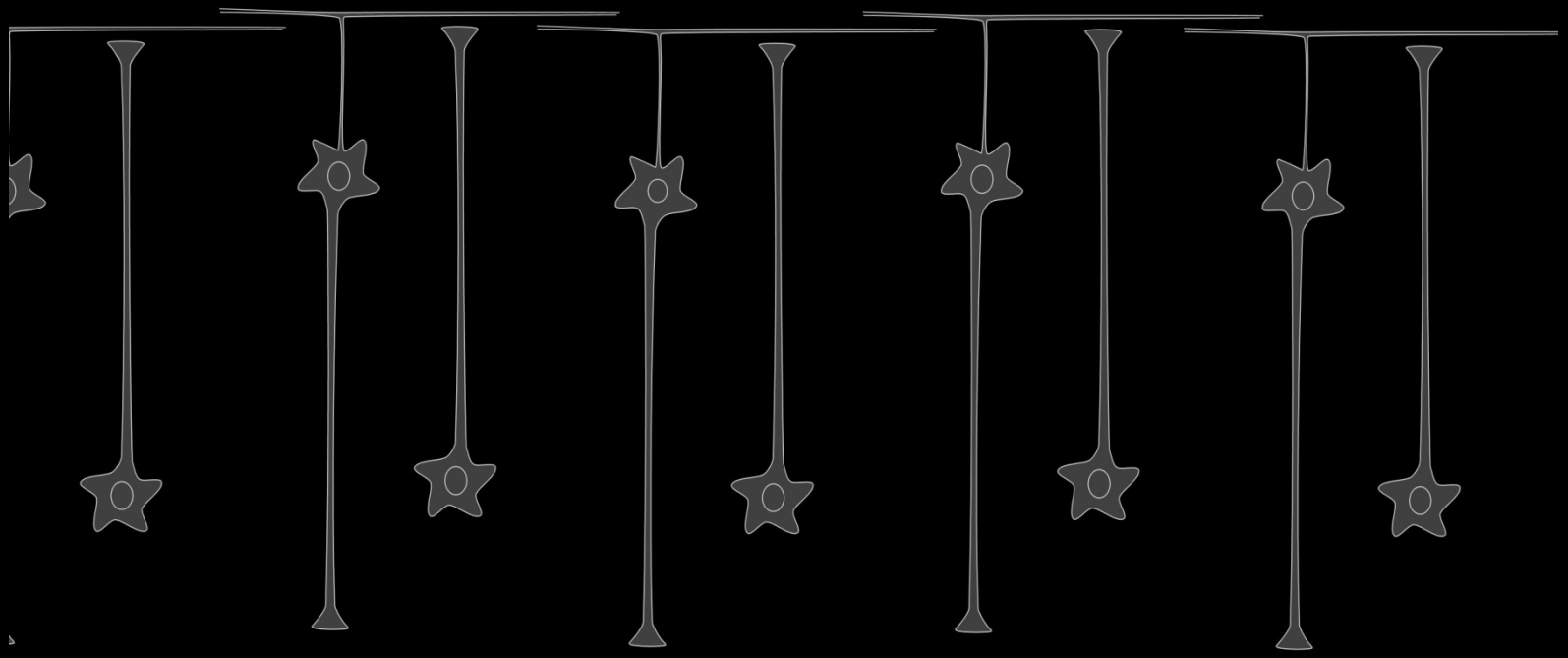
(adapted from Ramon Y Cajal, 1905)



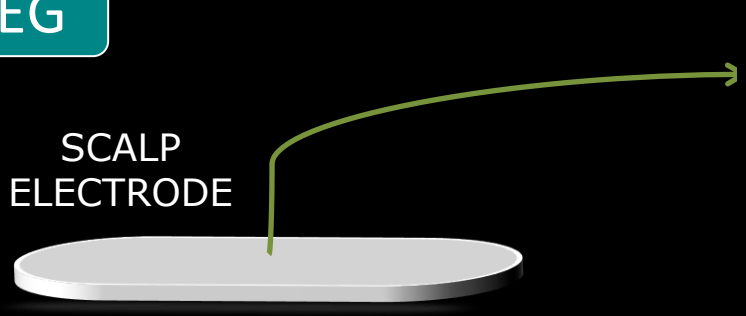
# basics of cortical electrophysiology

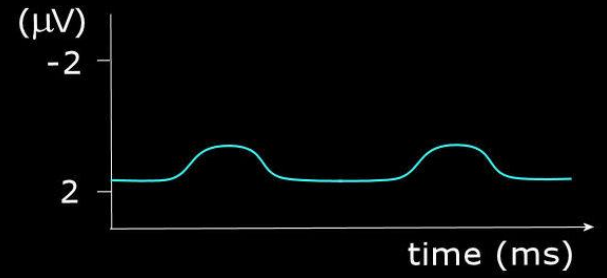


# cortical architecture

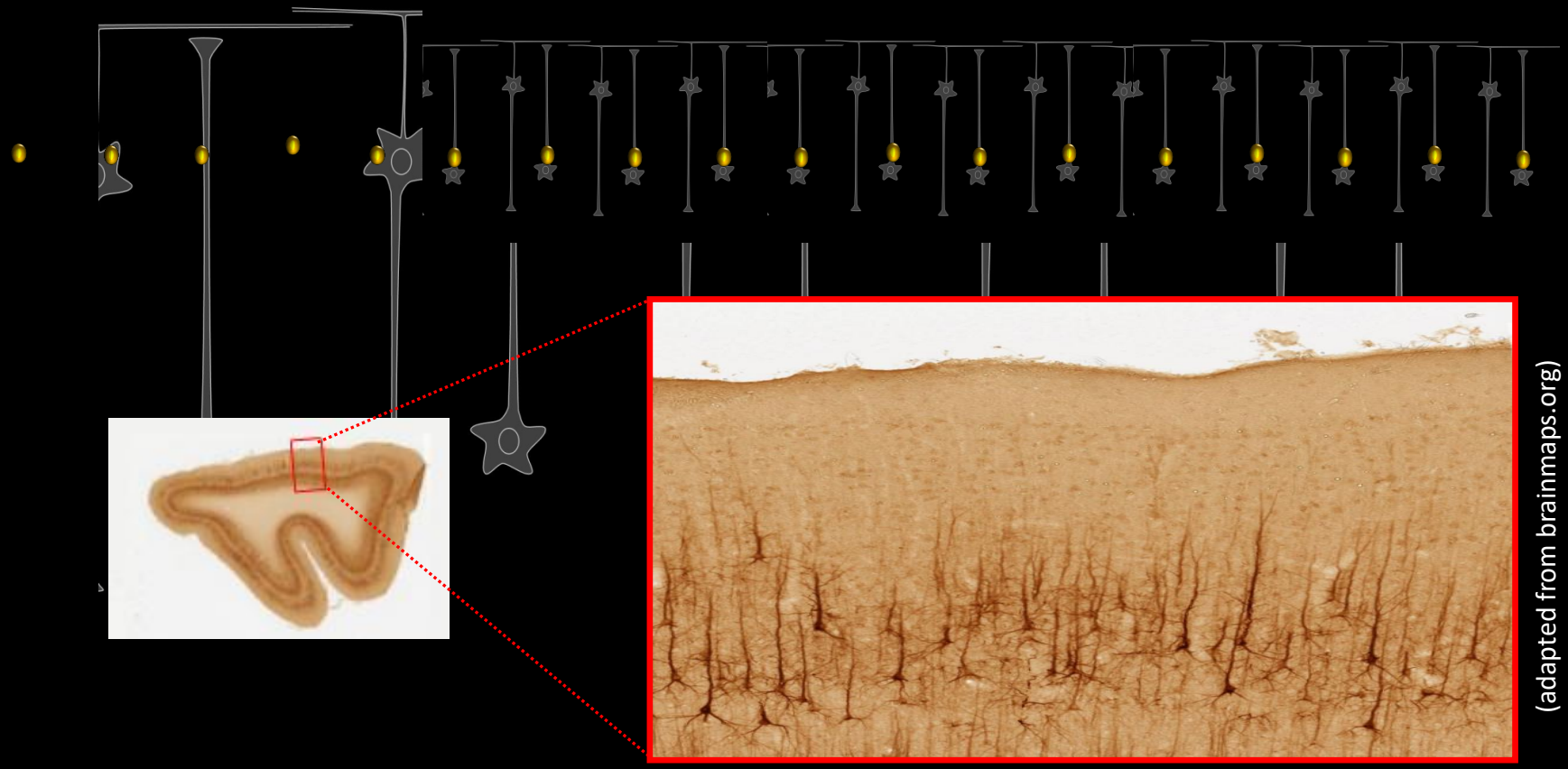


# scalp EEG



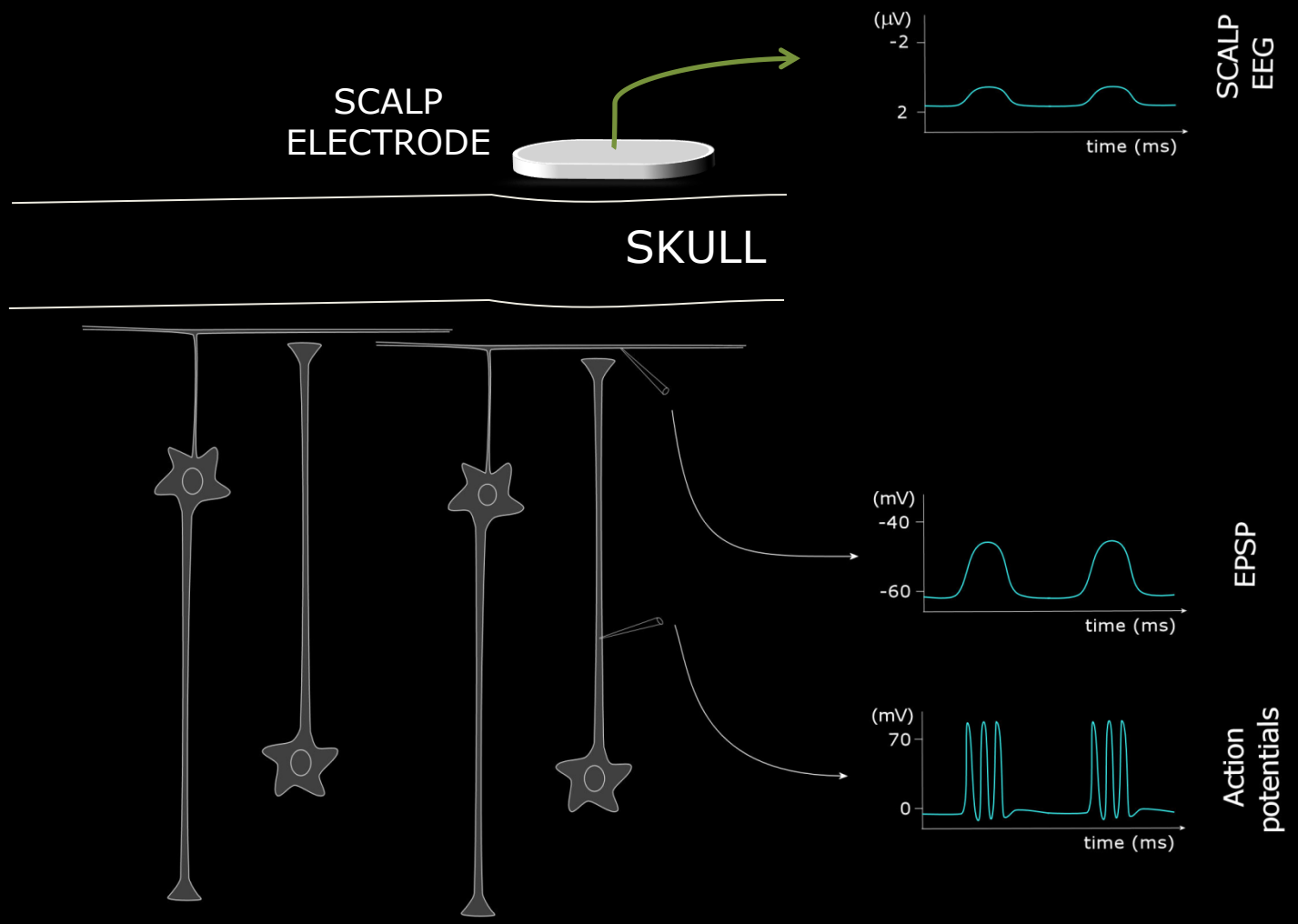




SKULL

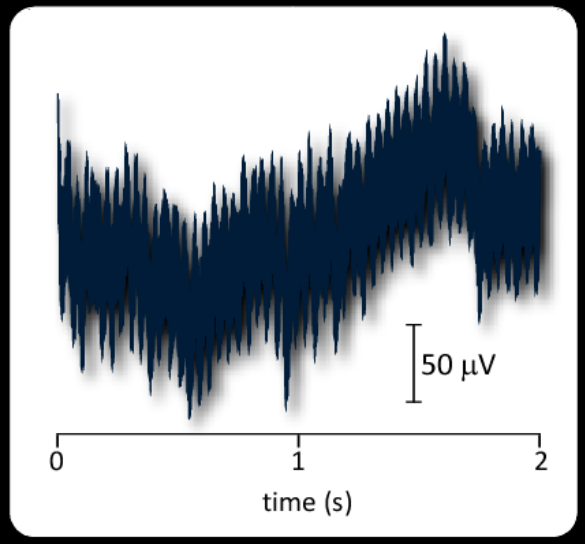


(adapted from brainmaps.org)

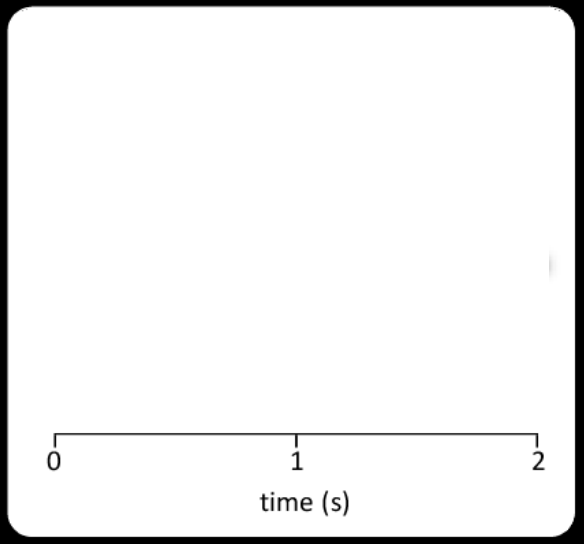
# scalp EEG vs direct cortical recording: magnitude differences



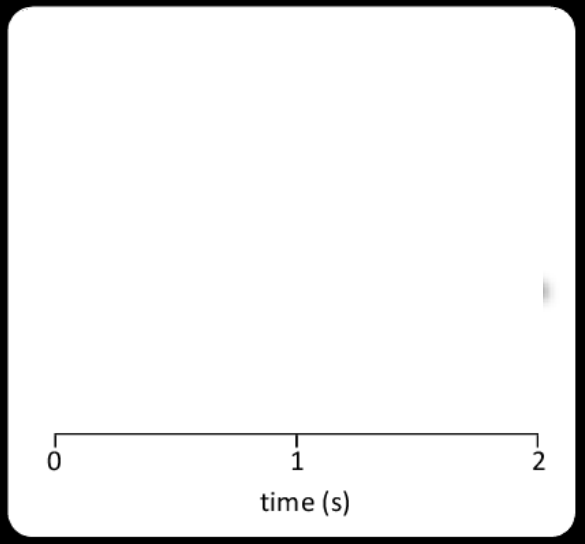
# Event-related EEG potentials (EPs) – Basics of filtering



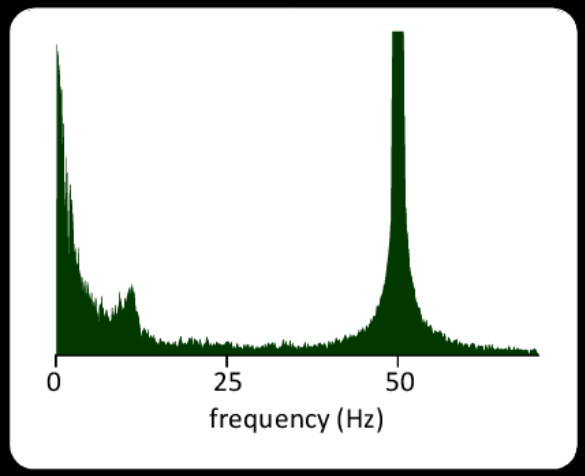

original EEG signal

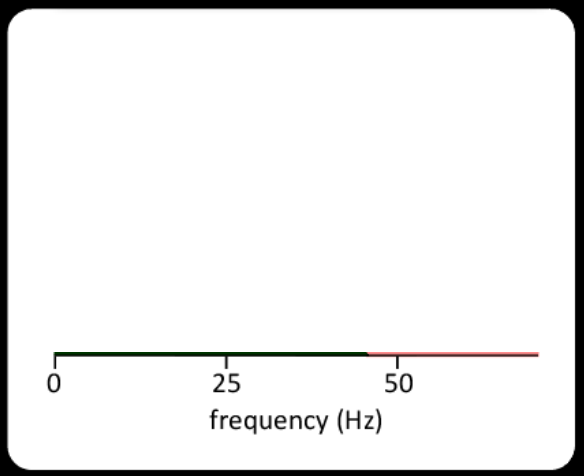


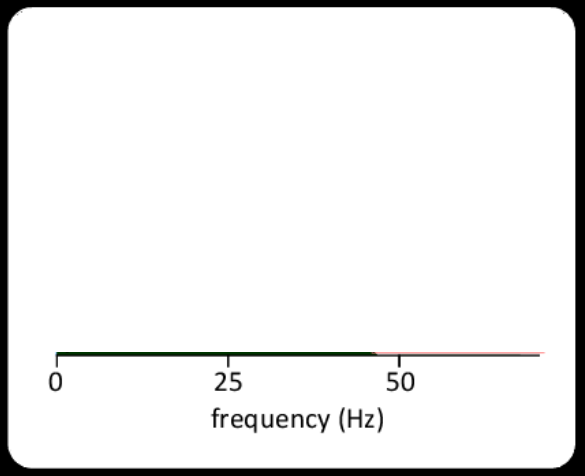

low-pass filter (cut-off = 40 Hz)



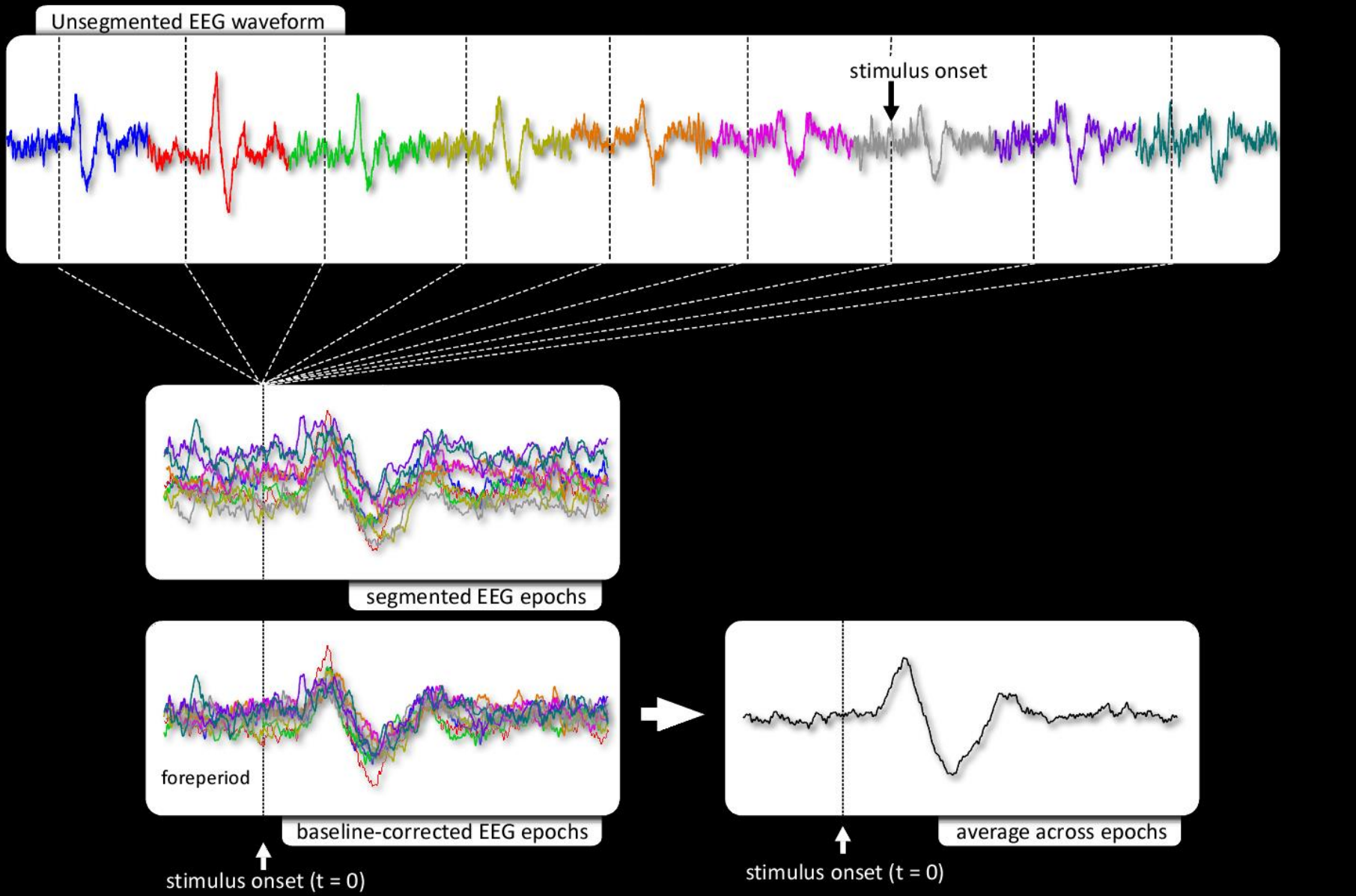

high-pass filter (cut-off = 1 Hz)



# Event-related EEG potentials (EPs) – Basics of averaging



# Take home messages – across-trial averging

1.

2.

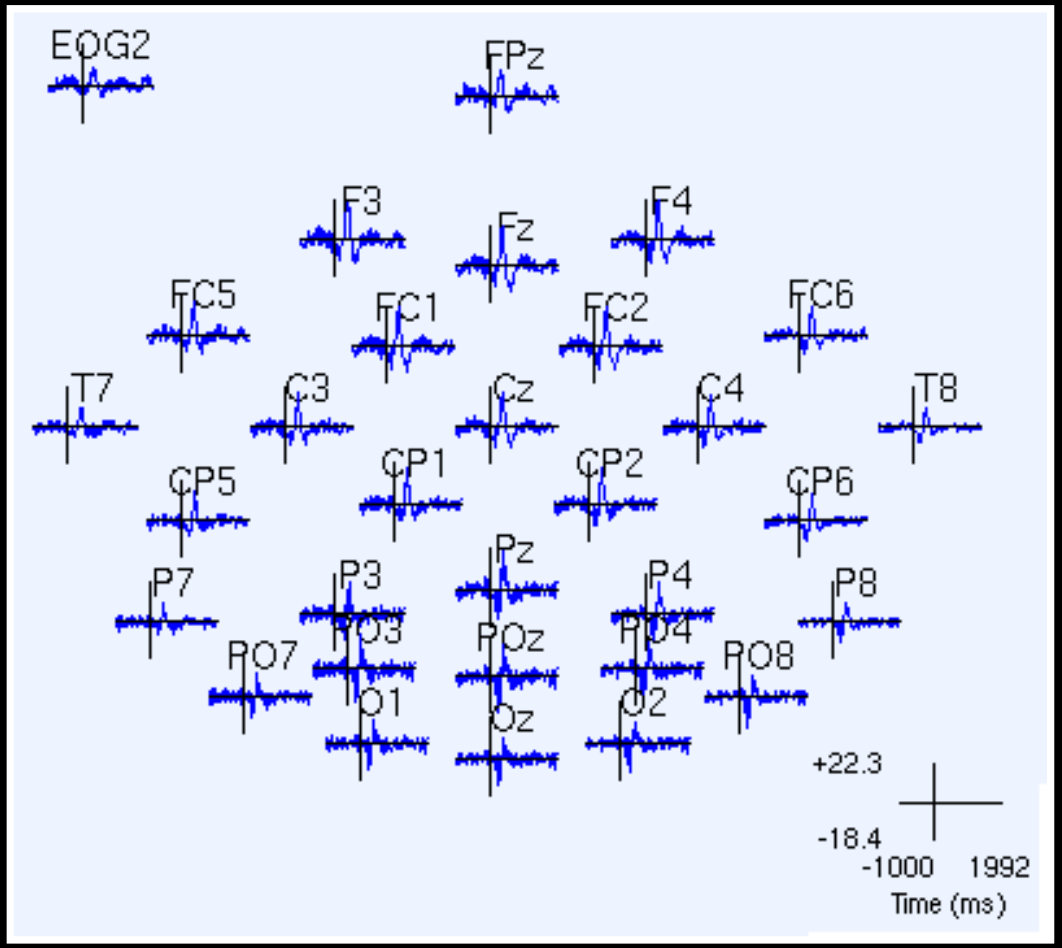
3.

4.

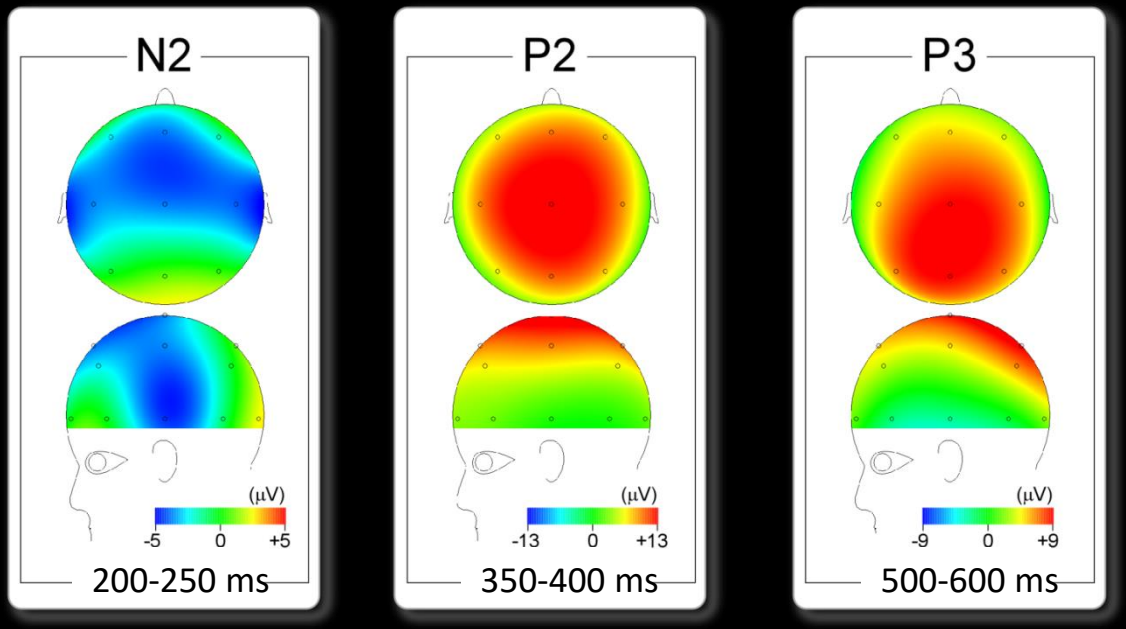
5.

# Event-related EEG potentials (EPs) – Multichannel recording

When more than one electrode is used, the average EPs can be plotted according to the relative position of each electrode on the head, thus providing some spatial information on potential distribution.



# Event-related EEG potentials (EPs) – Overview


Peaks are characterised by their latency, polarity, amplitude and scalp topography

# source analysis of event-related EEG potentials (EPs)

## The “forward problem”

The “forward problem” is well defined and has a unique solution.
For a given brain electric source distribution and a given head volume conductor, the “forward problem” determines the source-generated electric field.

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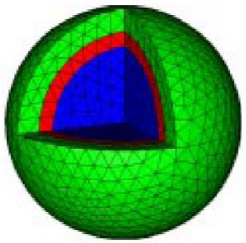
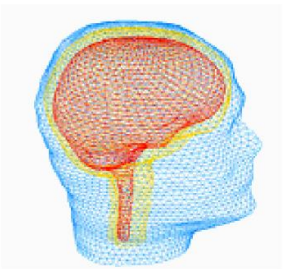


### Spherical models

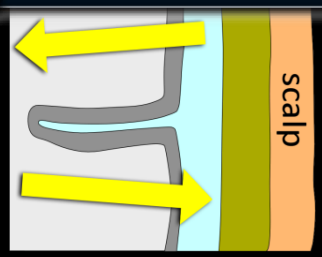
The volume conductor is modelised using a series of concentric spheres.
The conductivity of each layer is considered homogeneous

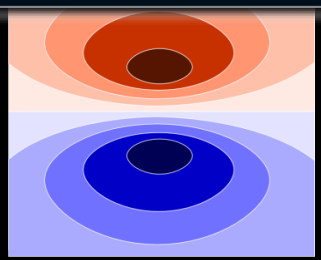
3 layer model : skin, skull, brain
4 layer model : skin, skull, CSF, brain



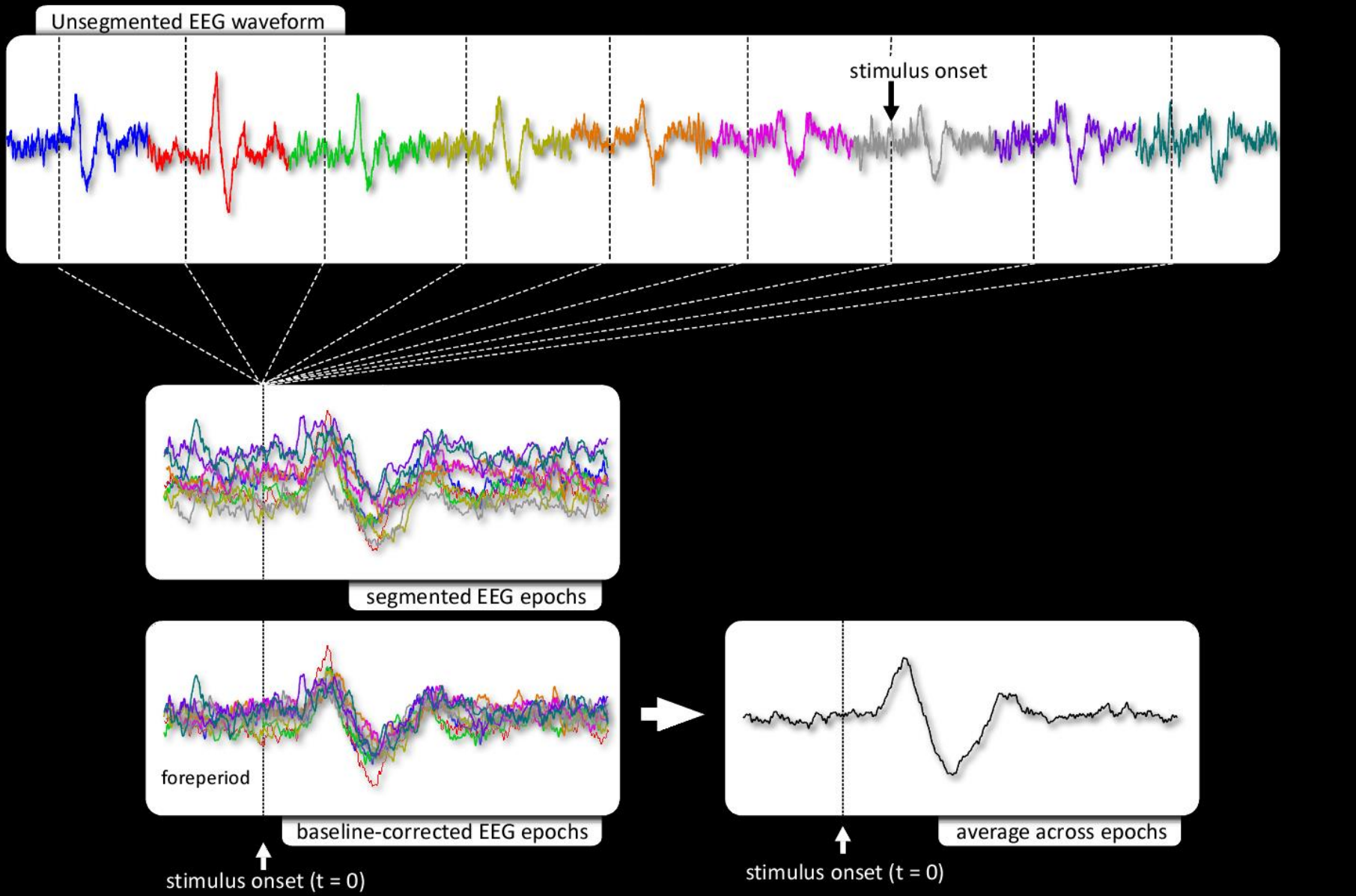
### Realistic head models

The volume conductor is built using individul MRI structural scans
Accounts for the complexity and interindividual variations of geometry

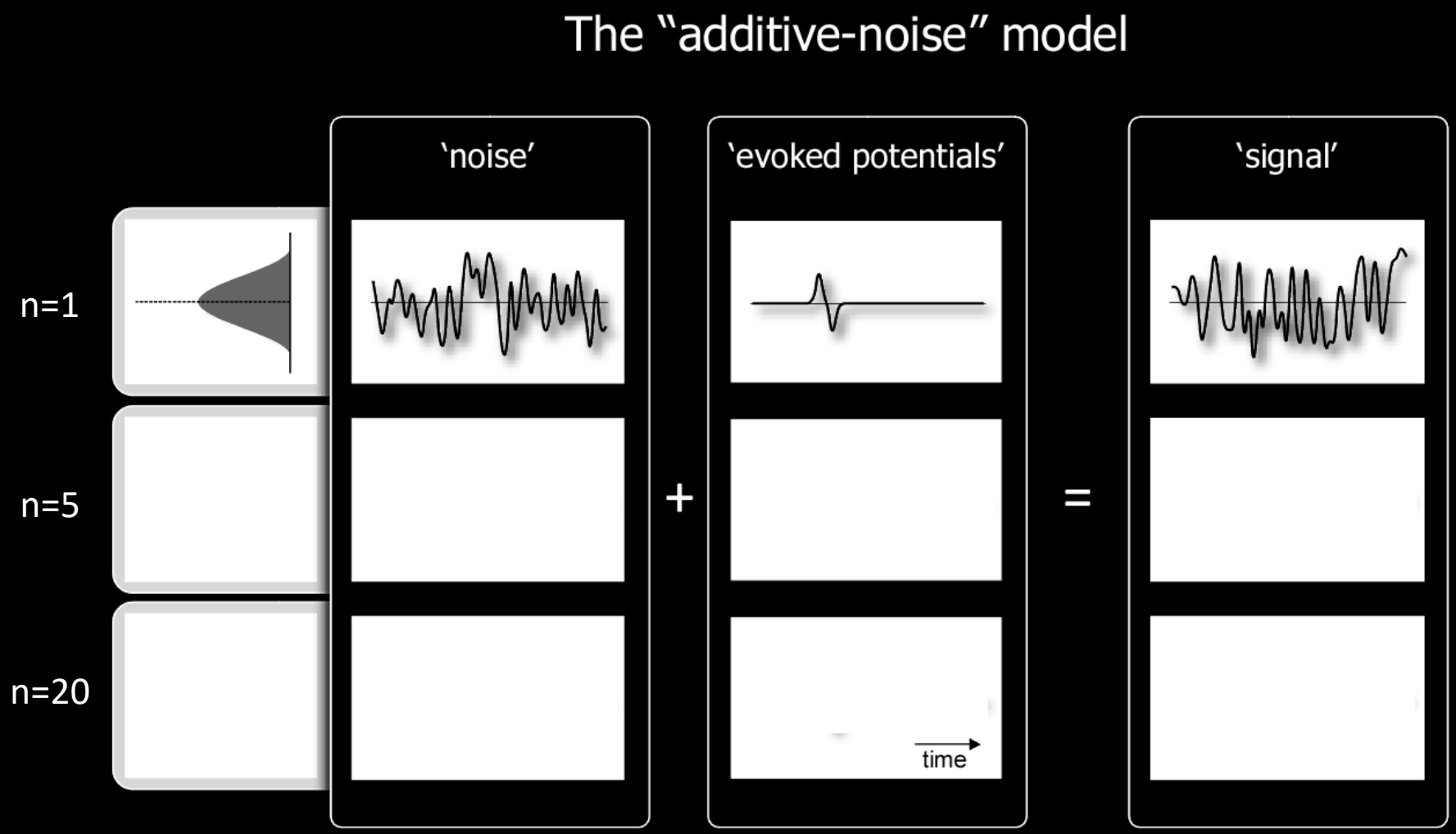


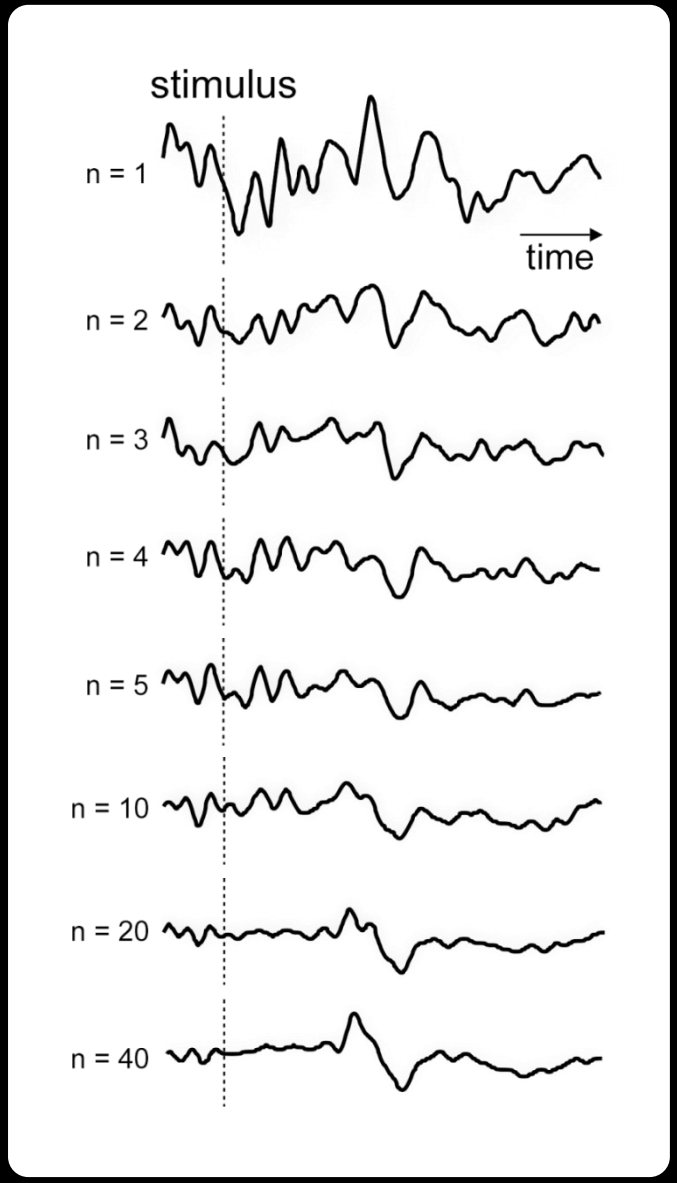
# Event-related EEG potentials (EPs) – Basics of averaging



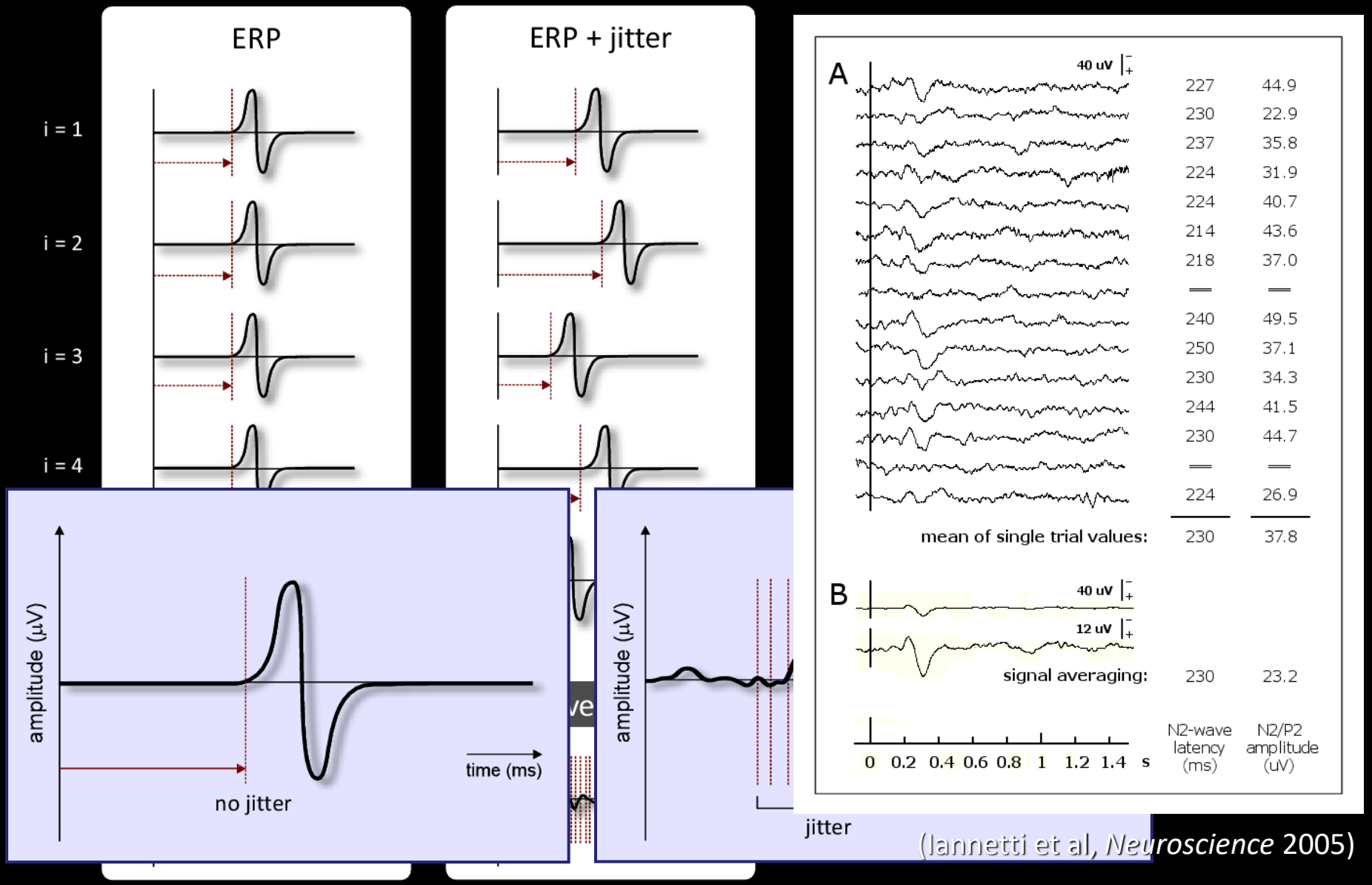
# Across-trial averaging and the additive noise model



# Across-trial averaging and the additive noise model

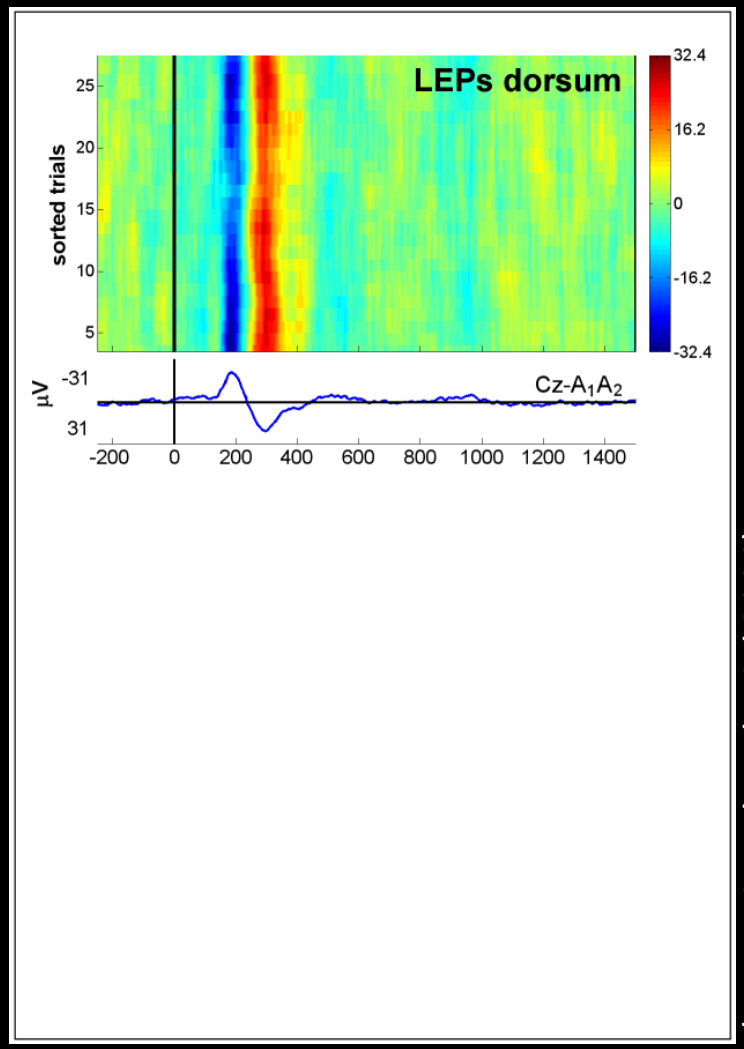


# problem #1: temporal jitter




(Iannetti et al, *Neuroscience* 2005)

# problem #1: temporal jitter




(Iannetti et al, *J Physiol* 2006)

When jitter at single-trial level is different between conditions, traditional averaging could reveal spurious differences.

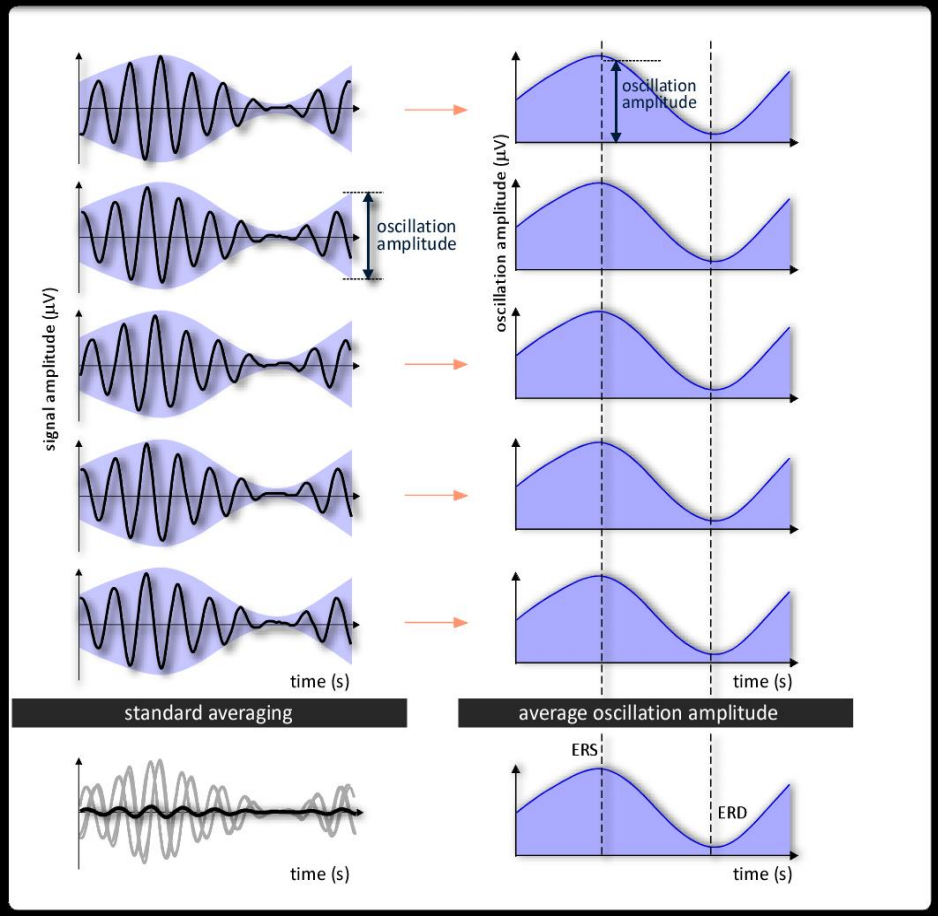
These differences are a potentially important confounding factor that must be taken into account to allow safe inference of physiological results.

In order to rule out any contribution of jitter-dependent amplitude reduction of standard averages, all responses should be analysed at single-trial level

# problem #3: ‘phase resetting’

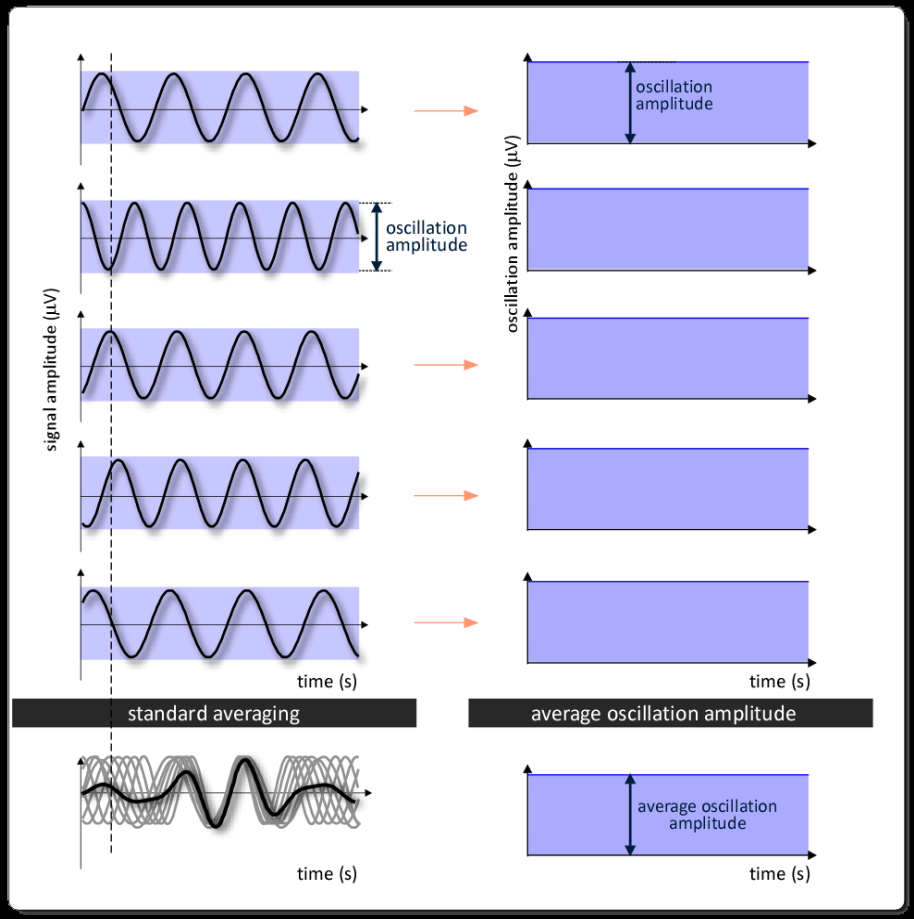
Solution: compare stimulus-evoked amplitude changes in the average vs single trials.

ERD/ERS:




Transient change in amplitude!

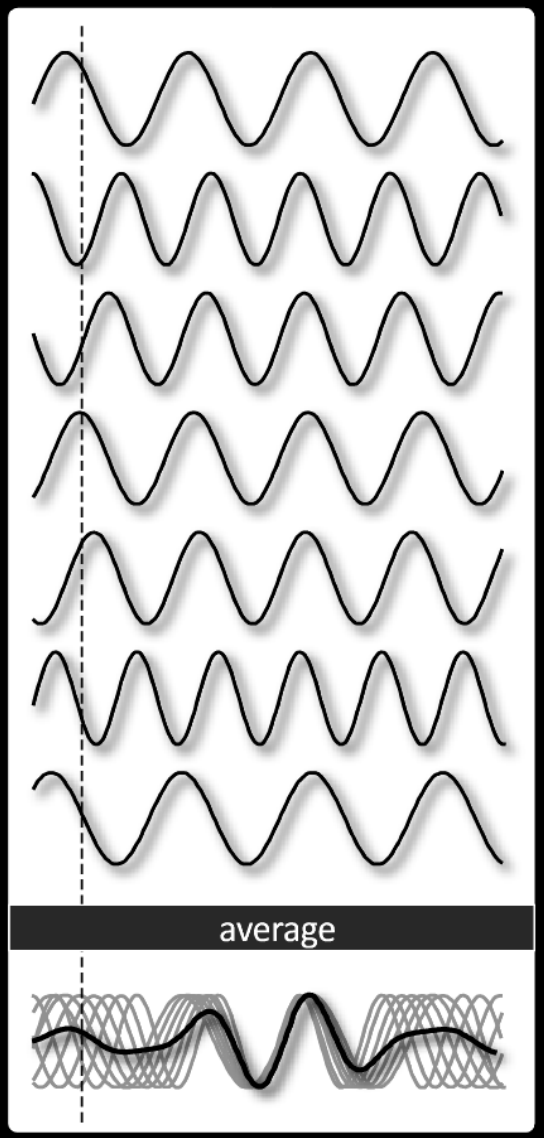
Pure phase-resetting:



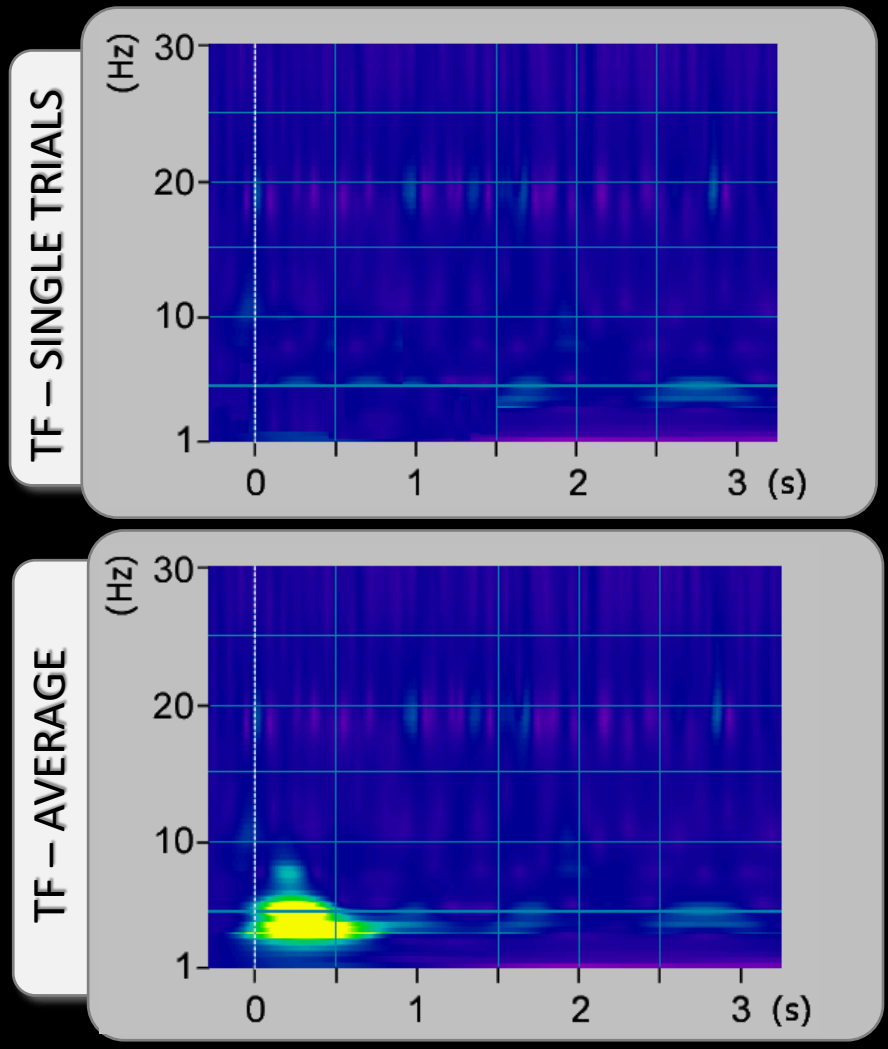

Transient change in phase!

# problem #3: ‘phase resetting’ vs..

Solution: compare stimulus-evoked amplitude changes in the average vs single trials.



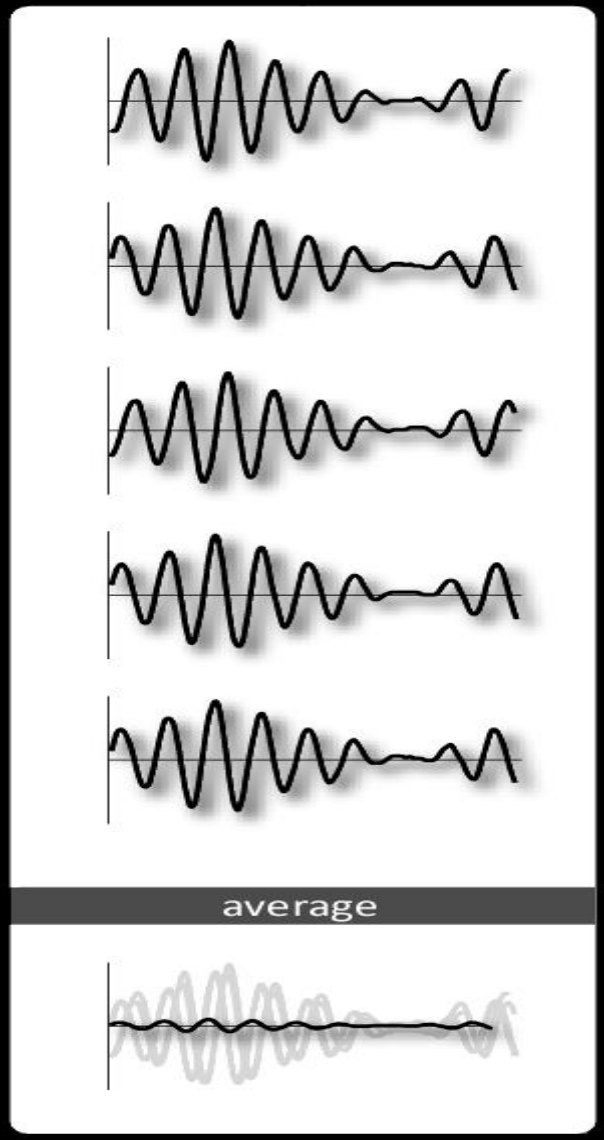

Pure phase resetting:



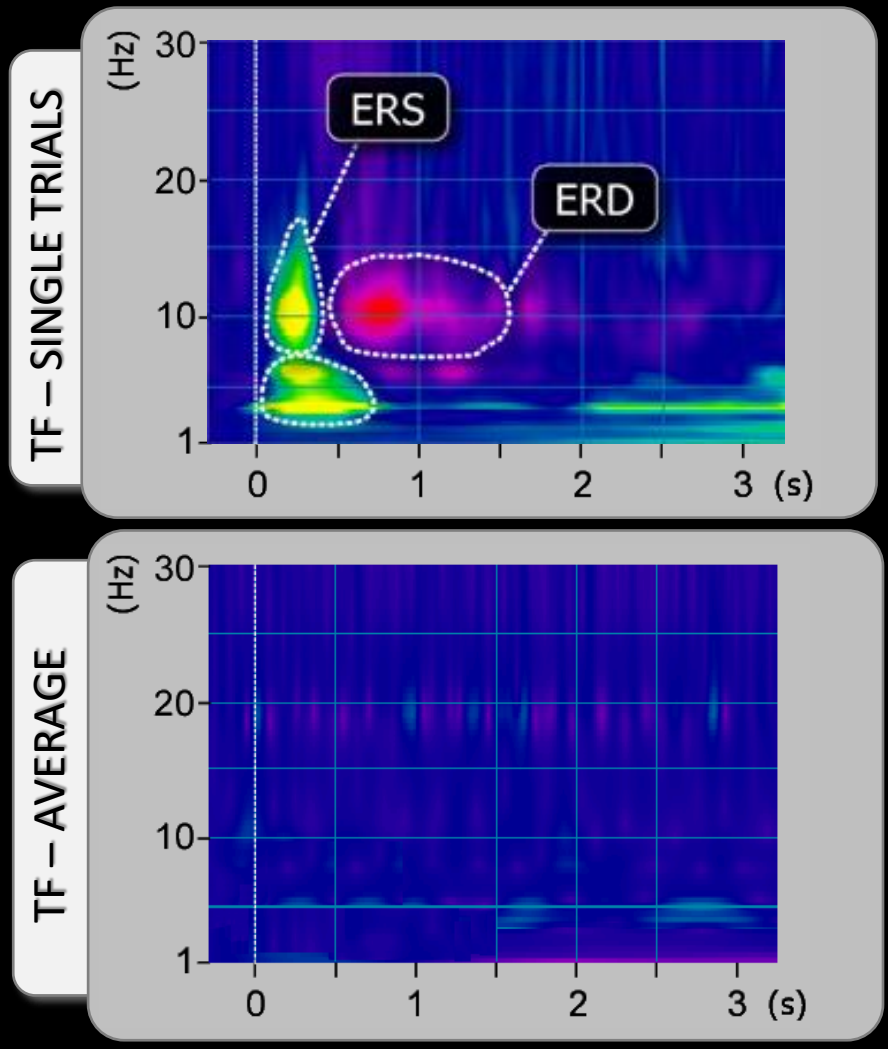

Transient change in phase!

# … vs problem #2: ERD/ERS

Solution: compare stimulus-evoked amplitude changes in the average vs single trials.

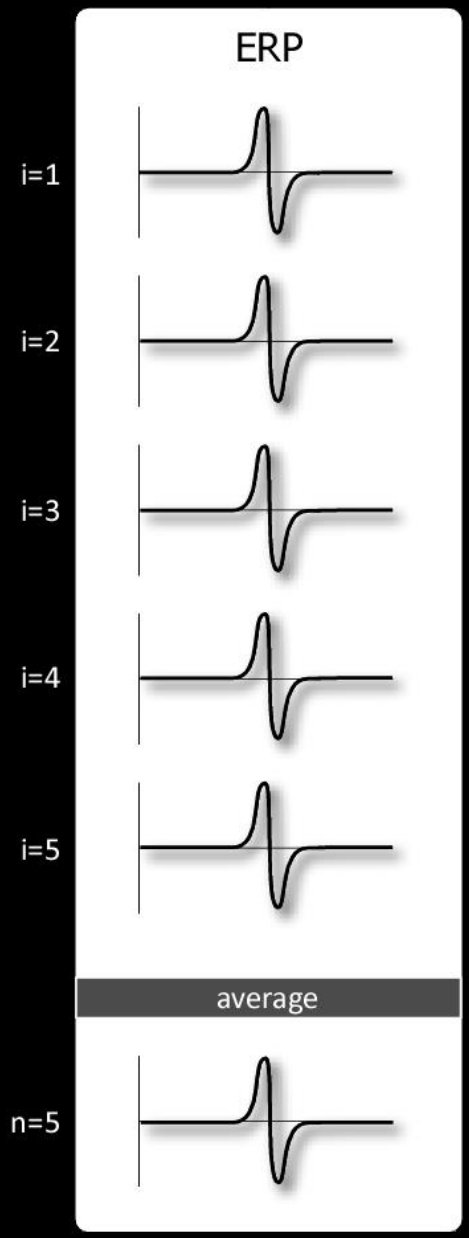



Pure ERD/ERS:




Transient change in amplitude!

# standard averaging: summary of limitations…



# Take home messages – across-trial averging

1. The magnitude of ERPs is often several factors smaller than the magnitude of the background electroencephalogram.

2. Across-trial averaging is a widely-used approach to enhance the signal-to-noise ratio (SNR) of both evoked induced EEG responses.

3.

4.

5.

# Wavelet filtering to enhance ERP signal-to-noise ratio

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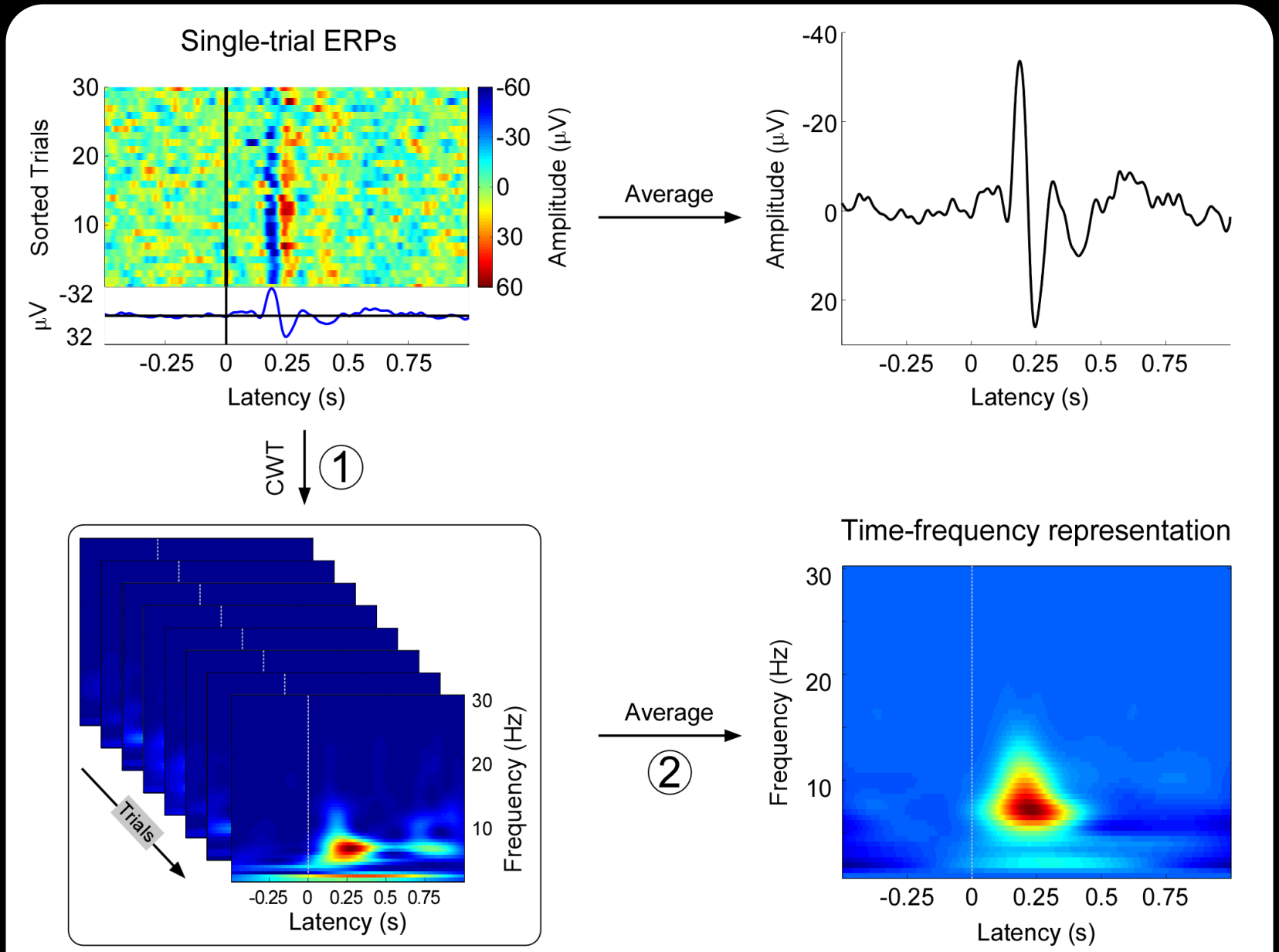
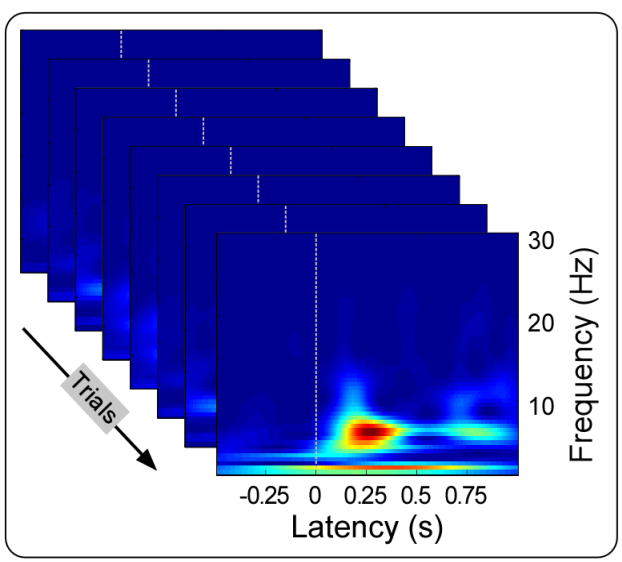


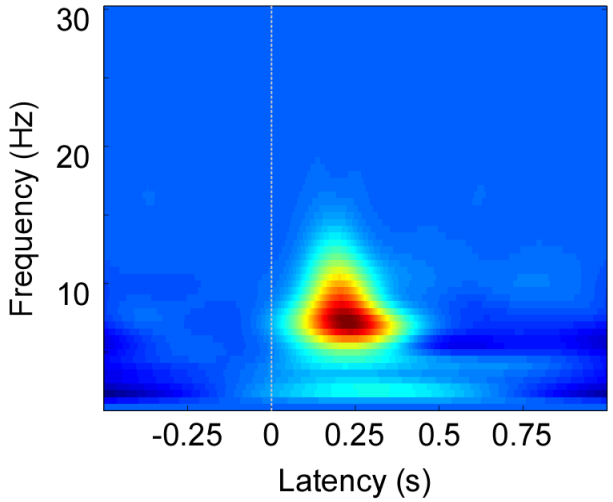
# Wavelet filtering to enhance ERP signal-to-noise ratio



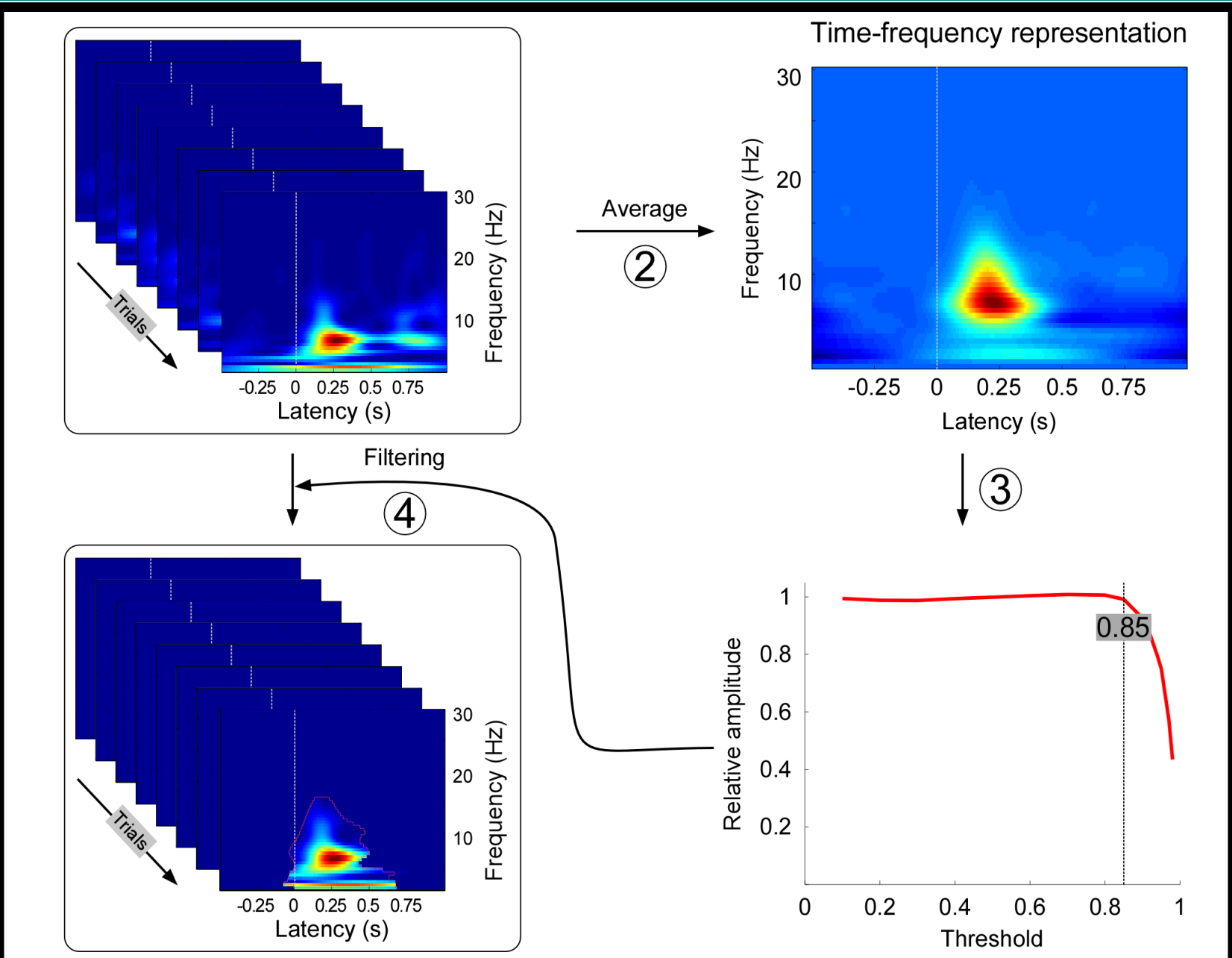

Average

②

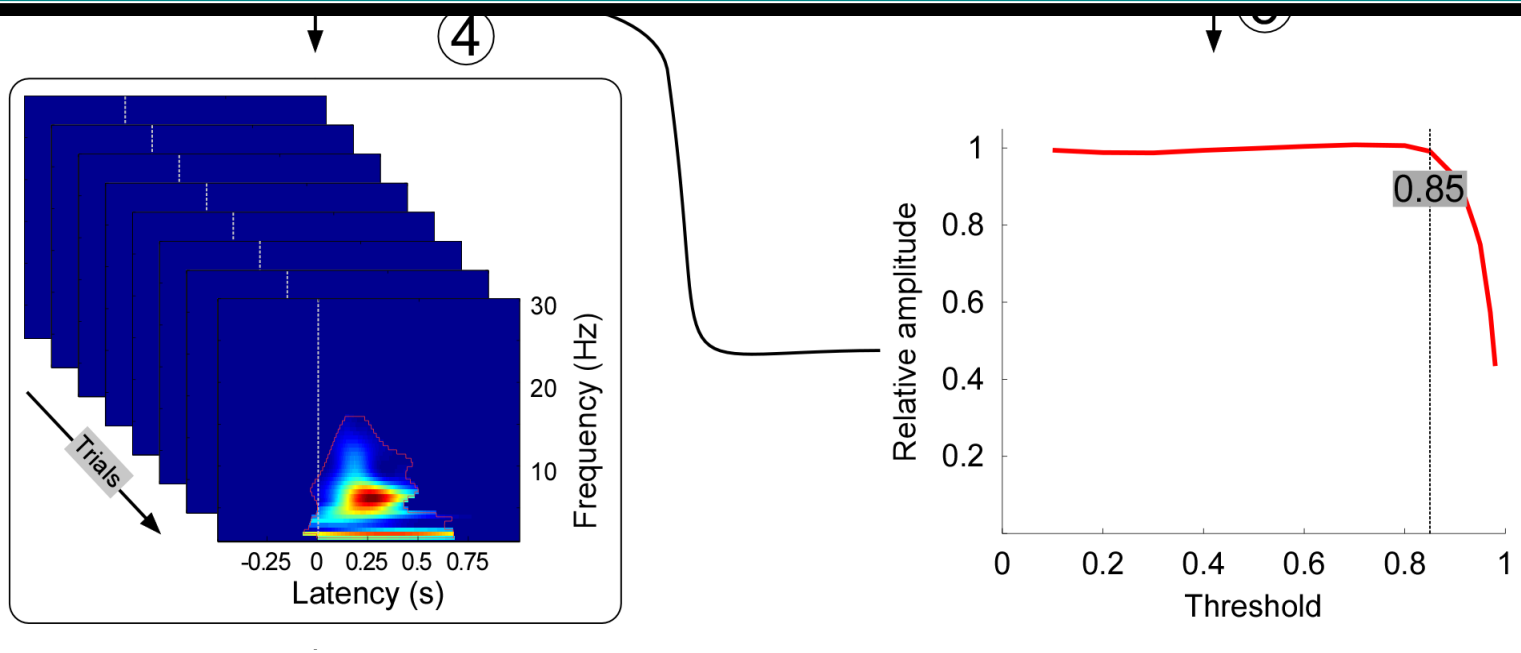
Time-frequency representation



# Wavelet filtering to enhance ERP signal-to-noise ratio

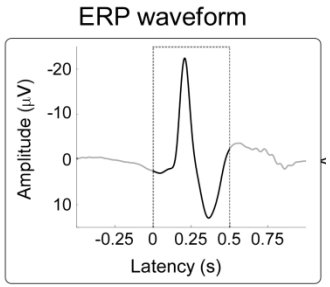


# Wavelet filtering to enhance ERP signal-to-noise ratio



# Multiple linear regression…

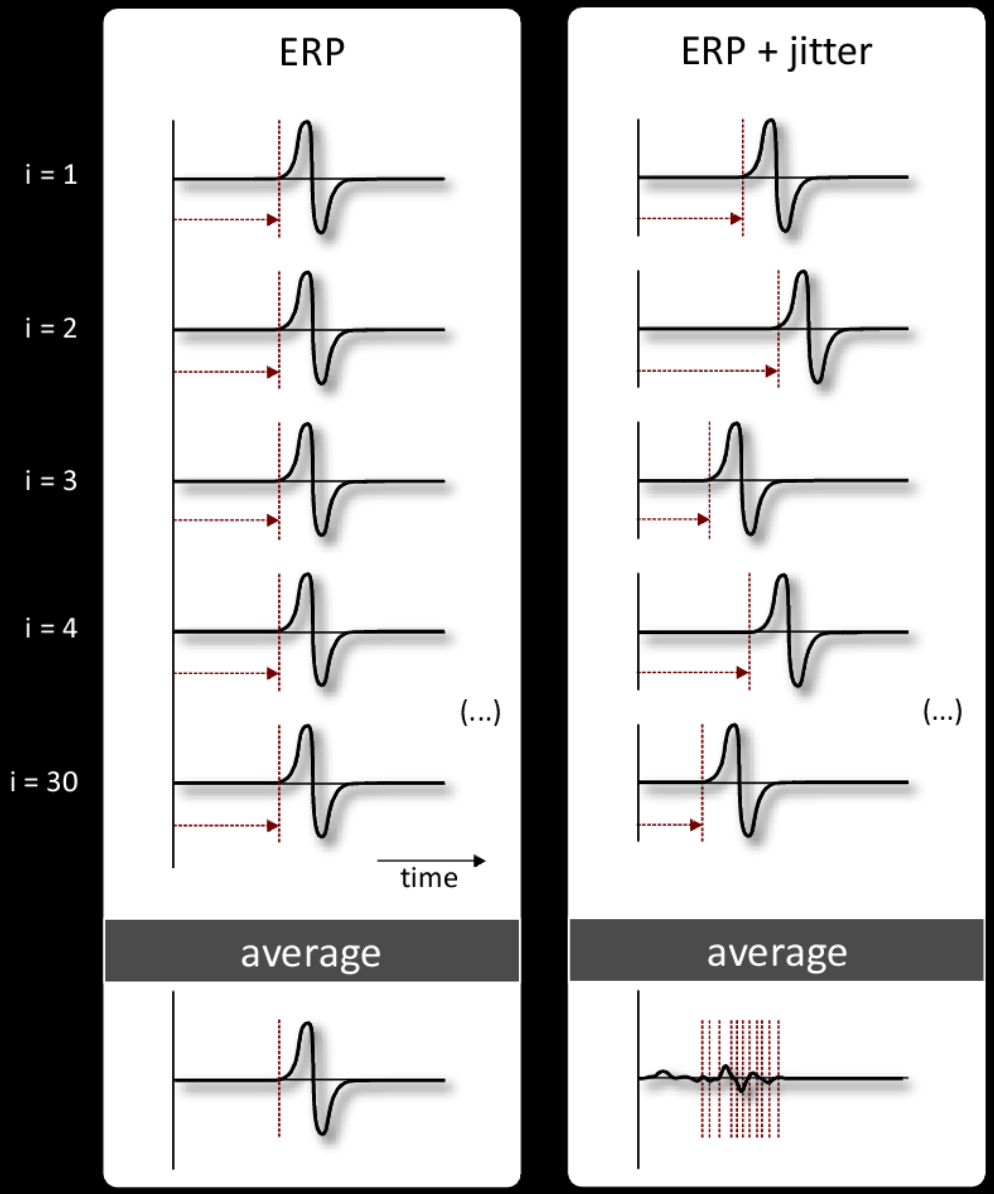
Multiple linear regression (MLR)

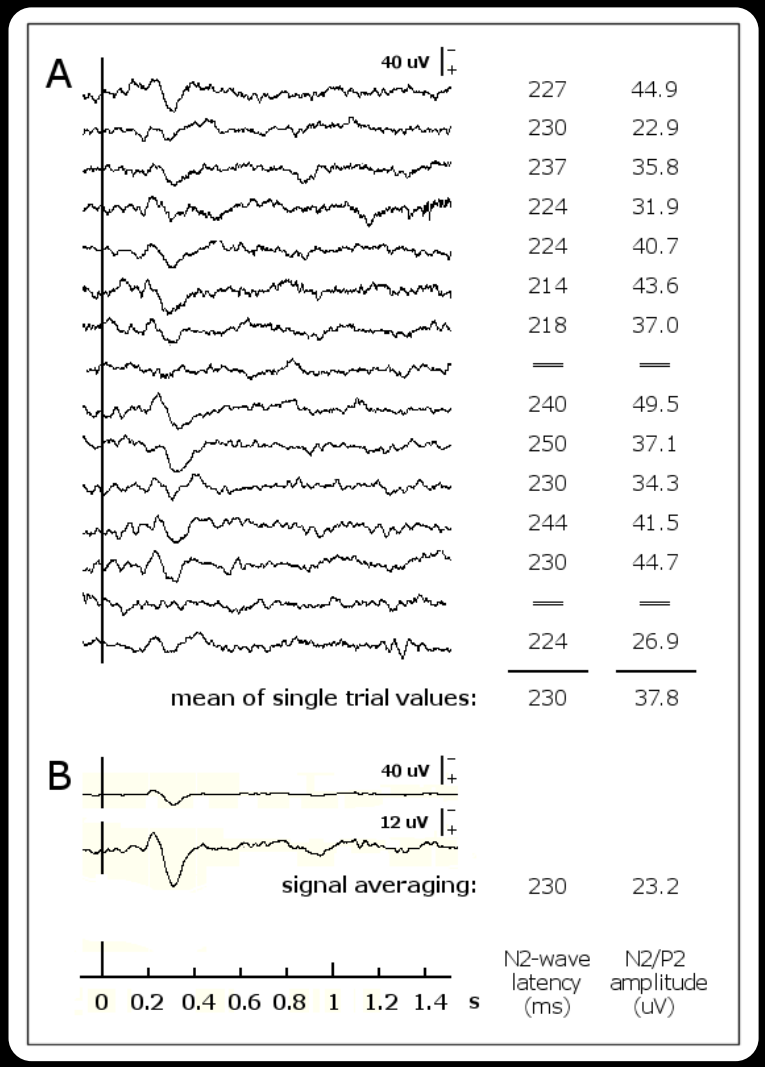



(Mahyew et al, *CLINPH* 2006)

Multiple linear regression with dispersion term ($MLR_d$)

# Variability of single-trial latency… and morphology

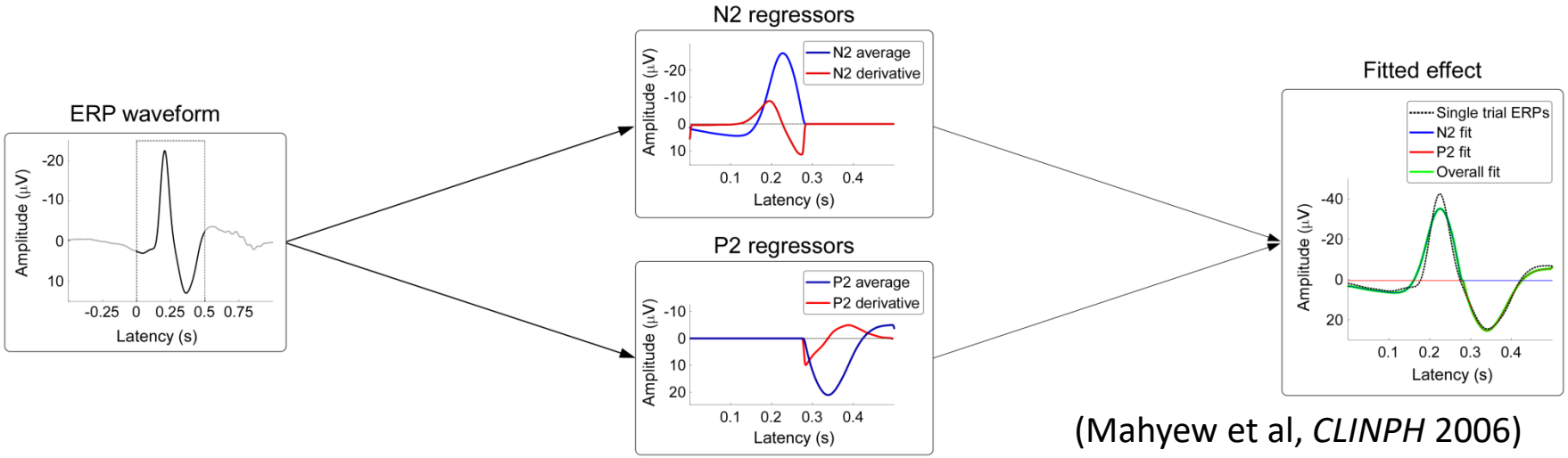



(Iannetti et al, *Neuroscience* 2005)

# Multiple linear regression… with dispersion term

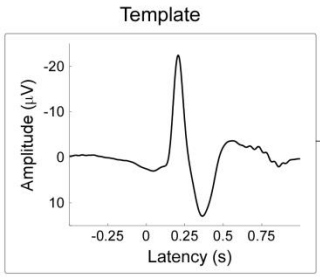
Multiple linear regression (MLR)



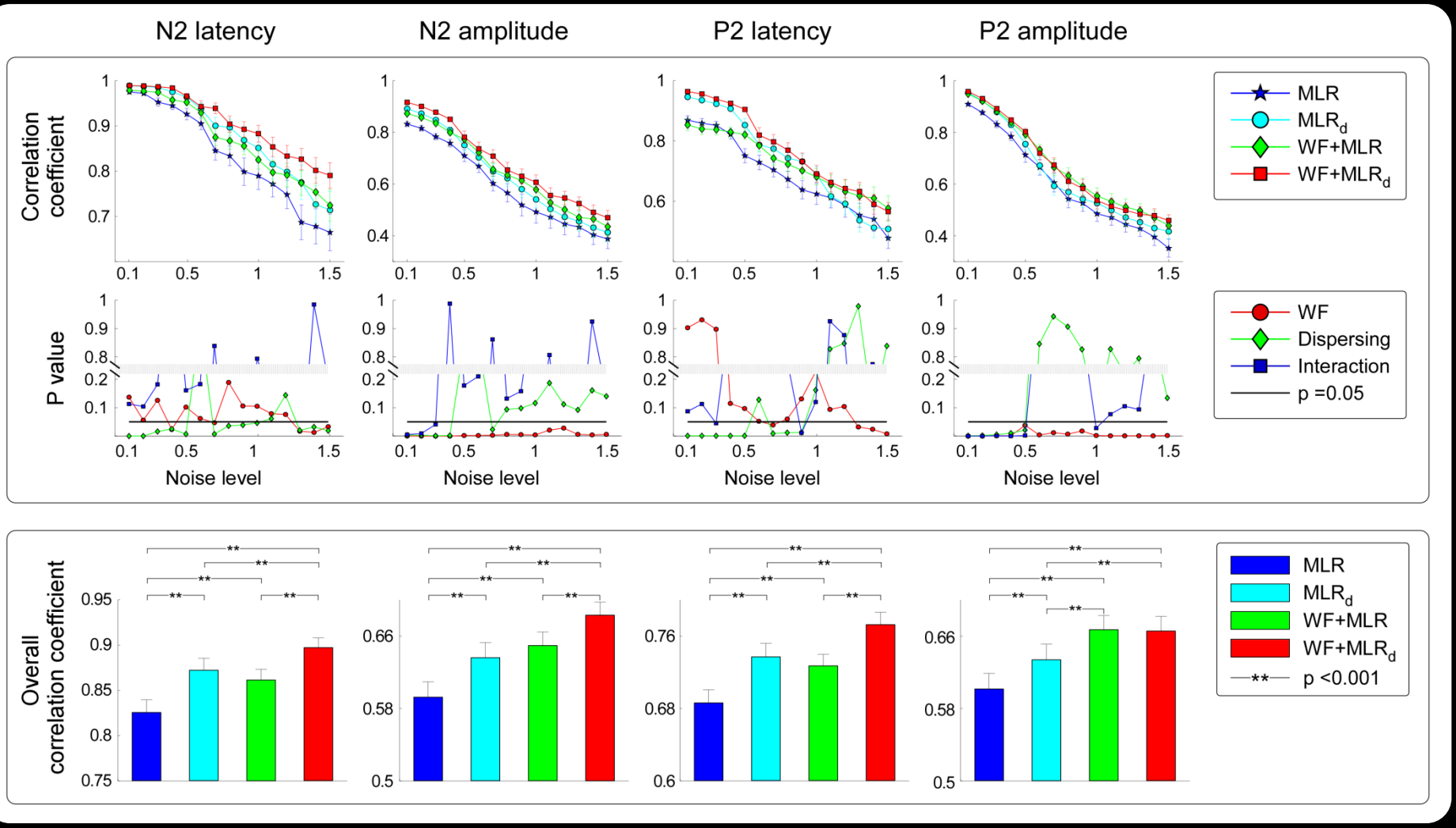

(Mahyew et al, *CLINPH* 2006)

Multiple linear regression with dispersion term ($MLR_d$)

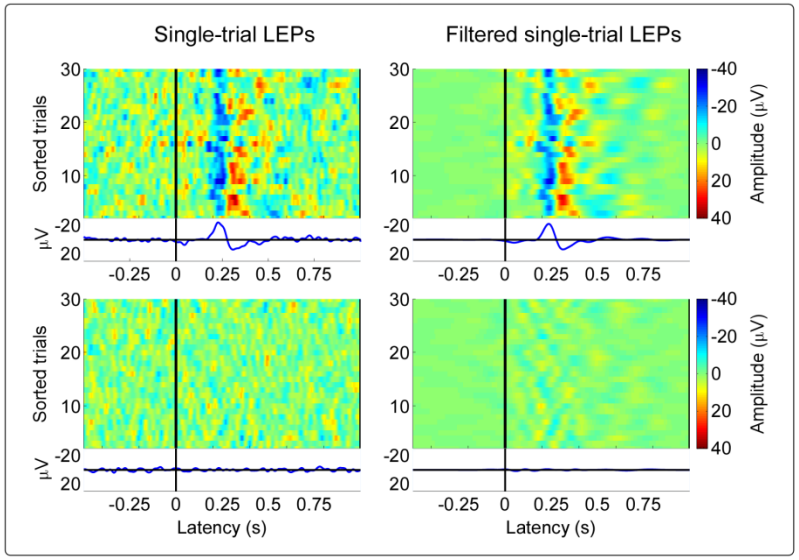
# Generation of a realistic ERP dataset



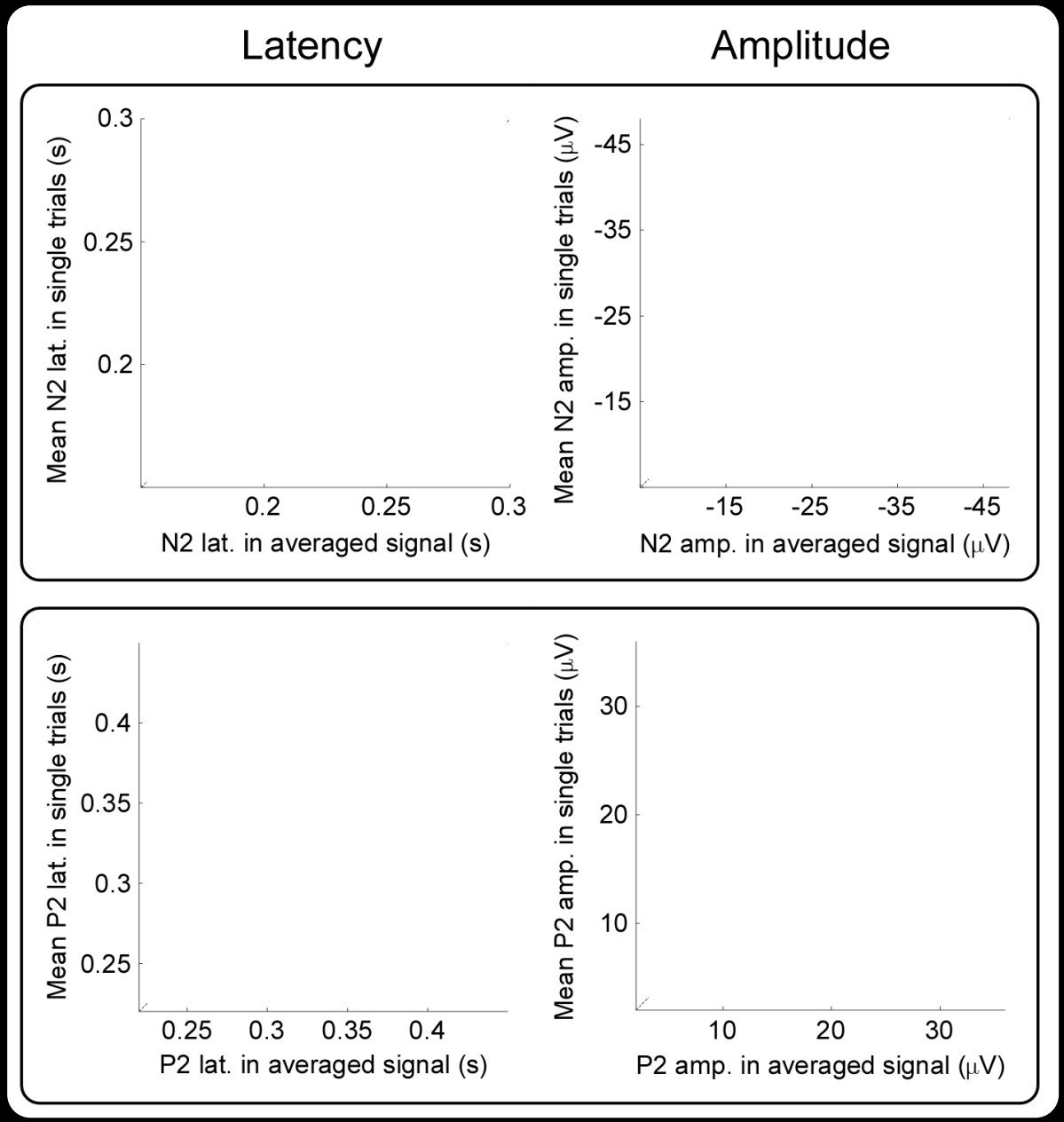
# Wavelet filtering to enhance ERP signal-to-noise ratio



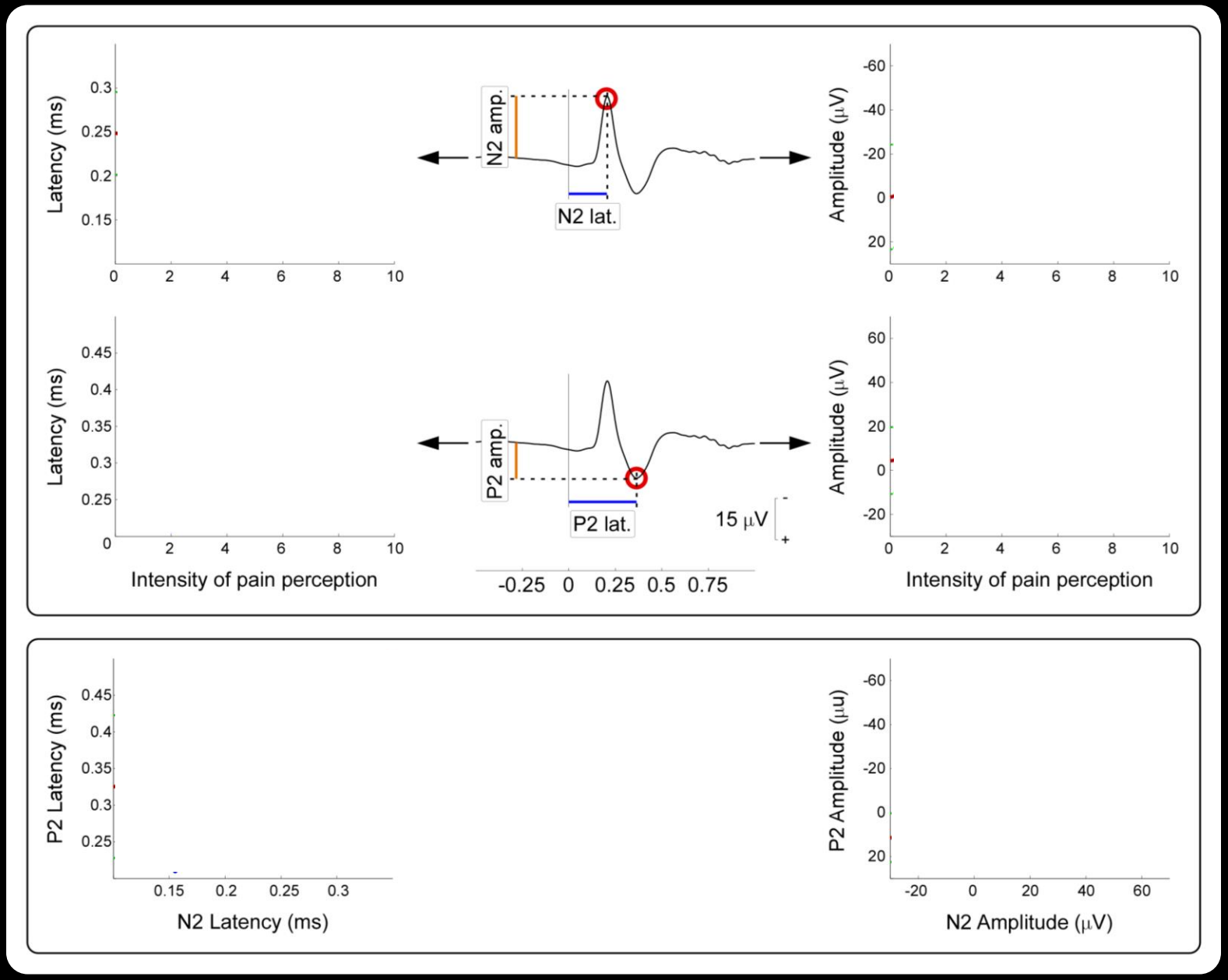
# Detection bias (on a real ERP dataset)



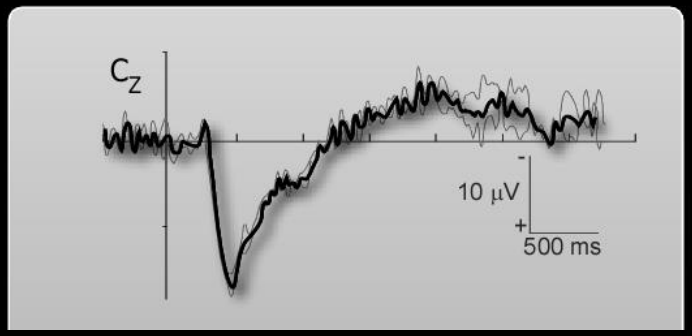
# Single-trial estimation - a real ERP dataset



# Correlation with behavioural measures



# ‘phase-locked’ and ‘non-phase-locked’ EEG responses



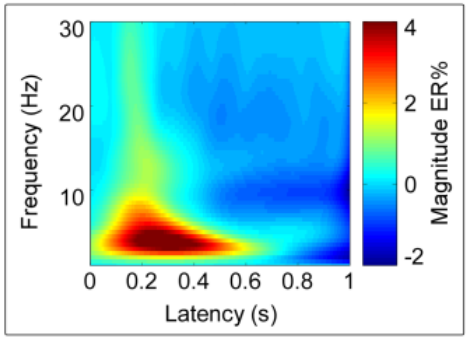

TF-AVERAGE

TF-SINGLE

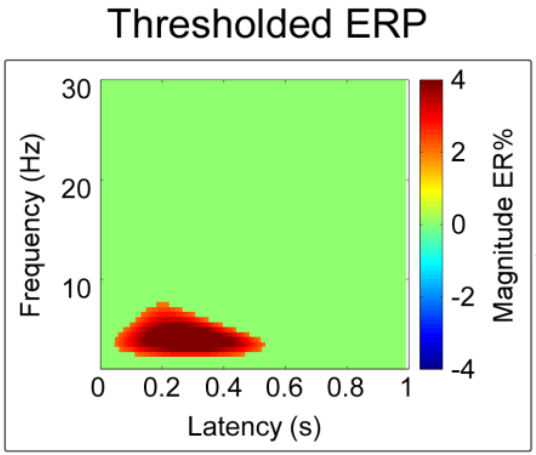

(Mouraux et al, *CLINPH* 2005)

# Time-frequency ROIs definition

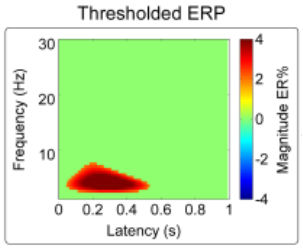
Time-frequency representation



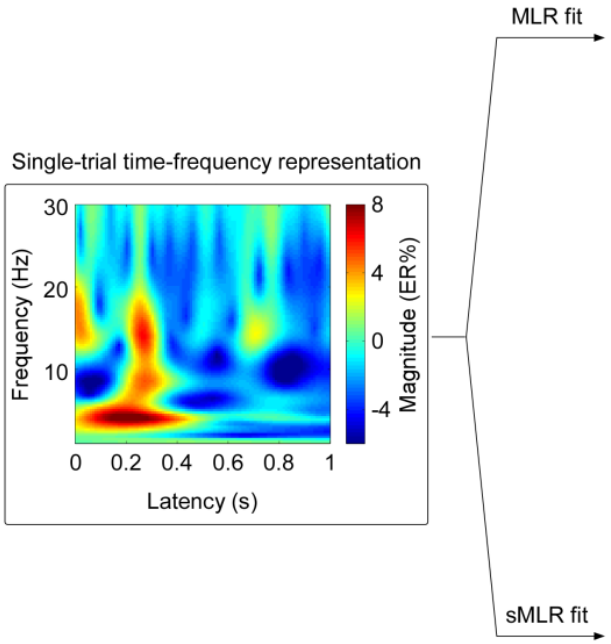
# Multiple linear regression in the time-frequency domain…



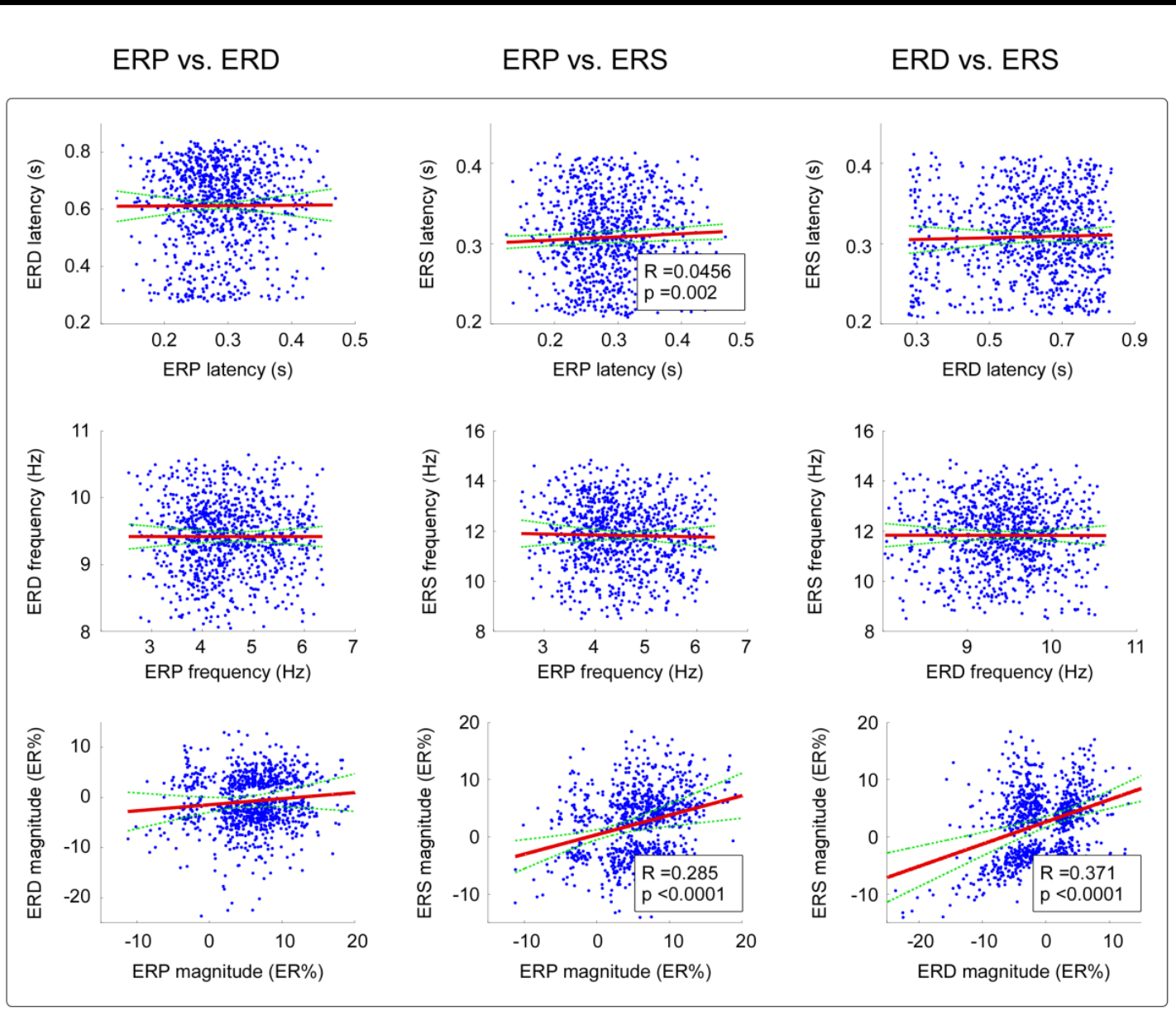
# …taking ROI morphology into account.



# MLR vs dMLR


Single-trial time-frequency representation
Frequency (Hz)
30
20
10
0
0.2
0.4
0.6
0.8
1
Latency (s)
8
4
0
-4
Magnitude (ER%)
MLR fit
sMLR fit

# Single-trial correlations



# Summary and possible applications

1. Wavelet filtering significantly enhances the SNR of ERPs/ERS/ERD in single trials.

2. Multiple linear regression effectively captures the variability in the morphology of single-trial ERPs.

3. Combined, WF and MLR provides accurate and unbiased estimate of their peak latency and amplitude.

1. Within subject comparison!

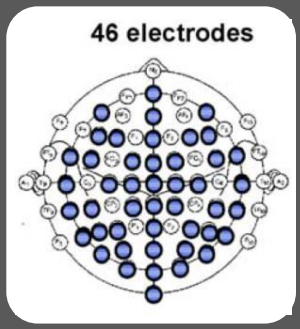
2. Correlation with behavioural responses (perception, performance, reaction times - SDT), stimulus features, prestimulus features, experimental factors (e.g. drug concentration).

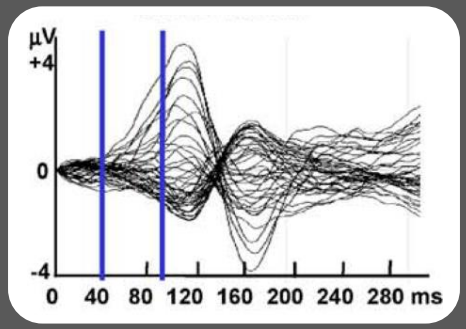
3. Correlation with other laboratory measures (withdrawal reflexes, EMG, BOLD-fMRI, MEG).

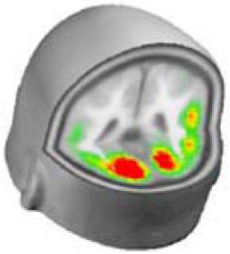
4. Robust estimation even in average waveforms (e.g. patient and drug studies)

# Simultaneous EEG-fMRI

Scalp EEG



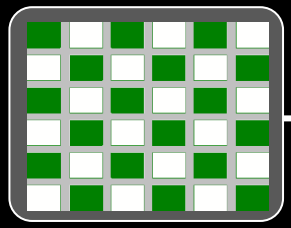
sensory stimulus

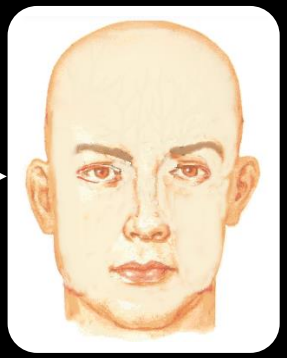
neural activity

neurovascular coupling

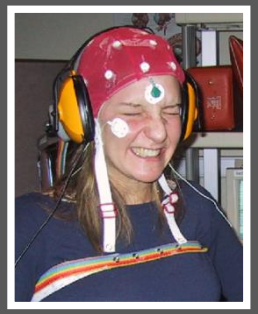
haemodynamic response

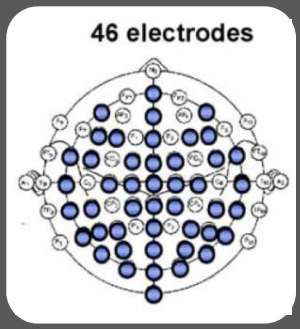
BOLD fMRI

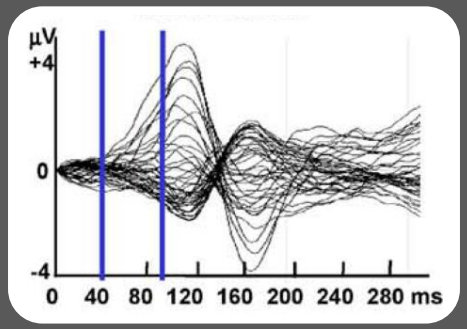




# Simultaneous EEG-fMRI



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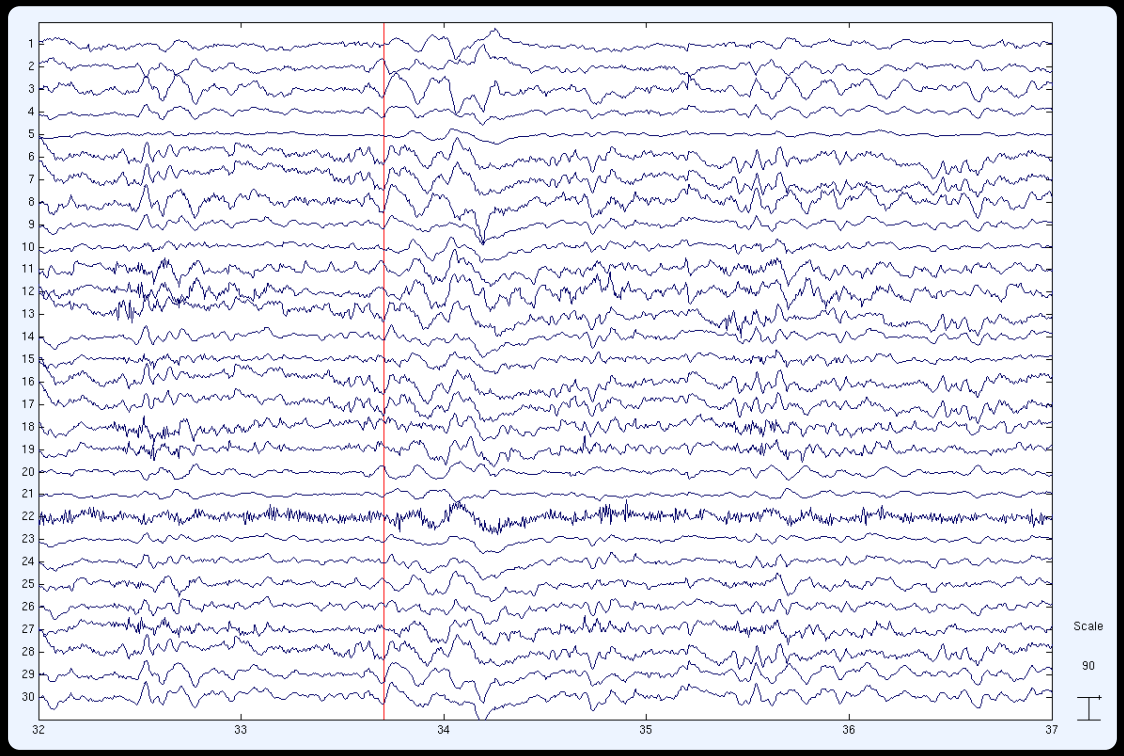
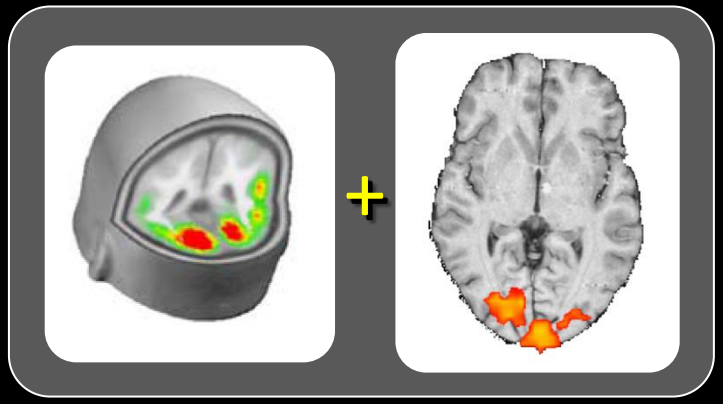
# Basics concepts of functional neuroimaging: EEG vs BOLD-fMRI

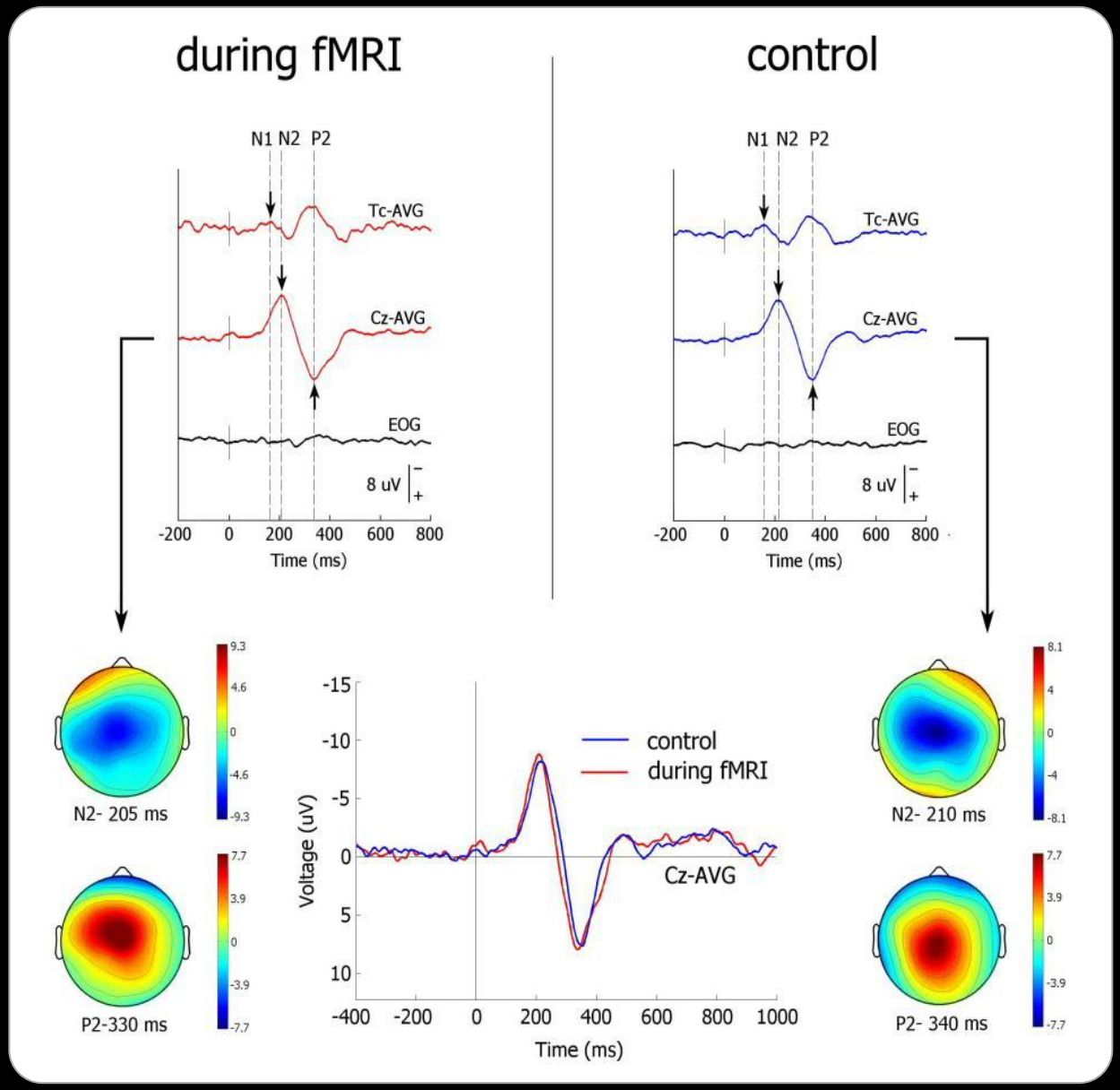



MR-induced artifacts on EEG
(www.fmrib.ox.ac.uk/~rami)



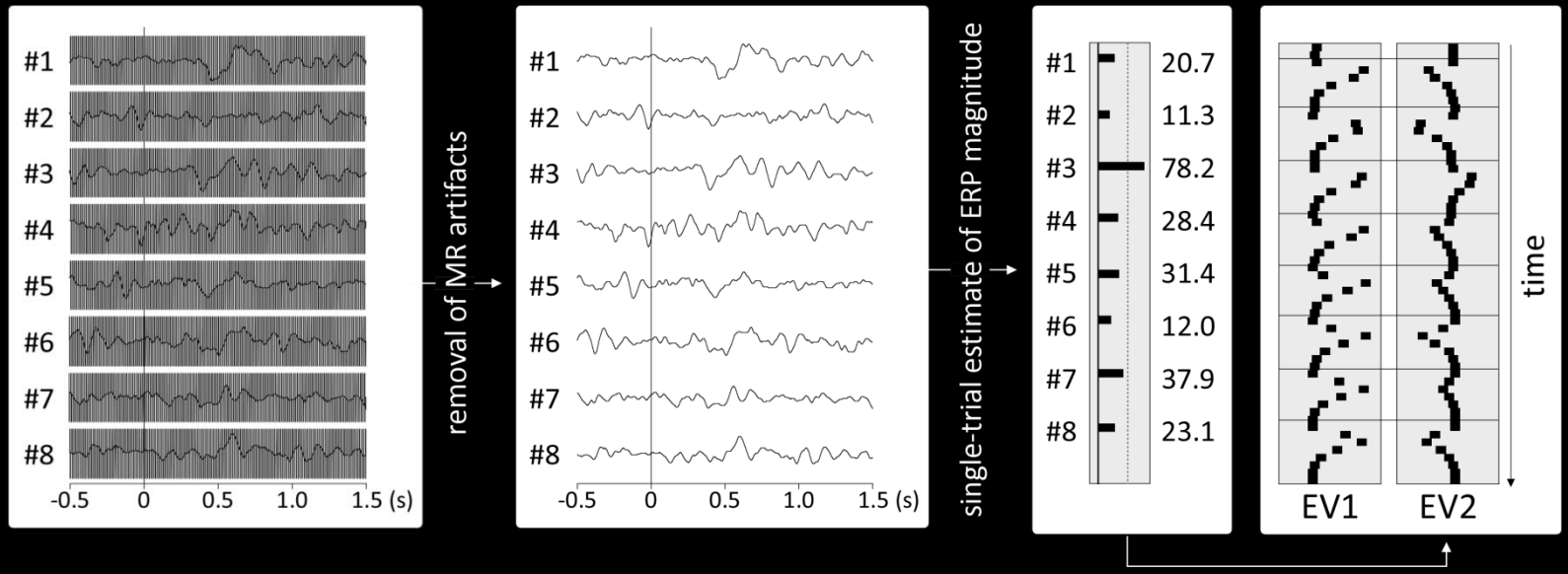
EEG fMRI

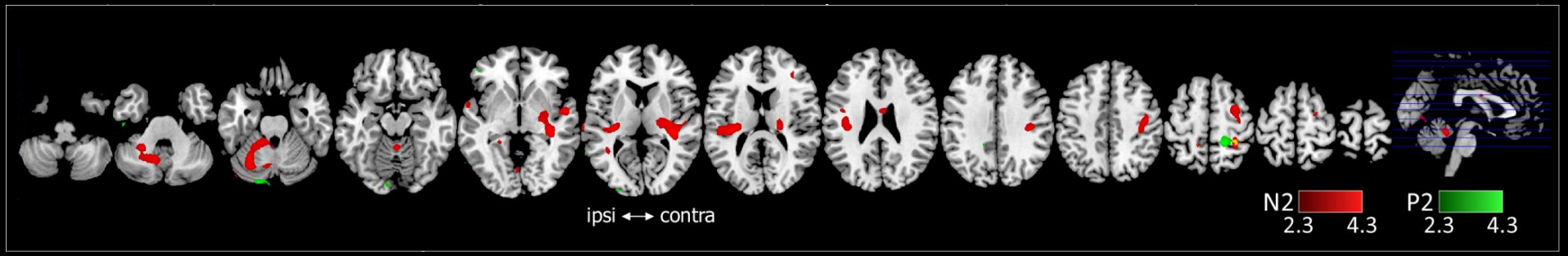
# Simultaneous EEG-fMRI of somatosensory-evoked ERPs




(Iannetti et al *NeuroImage* 2005)

# EEG-driven analysis of the fMRI responses to sensory stimulation



# EEG-driven analysis of the fMRI responses to sensory stimulation