Analysis of Event Related Potentials (ERPs)

Robert Oostenveld

Mikkel C. Vinding

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Outline and topics to cover

What is an event-related potential (ERP) or an evoked potential (EP)

What can we use them for: timing, amplitude

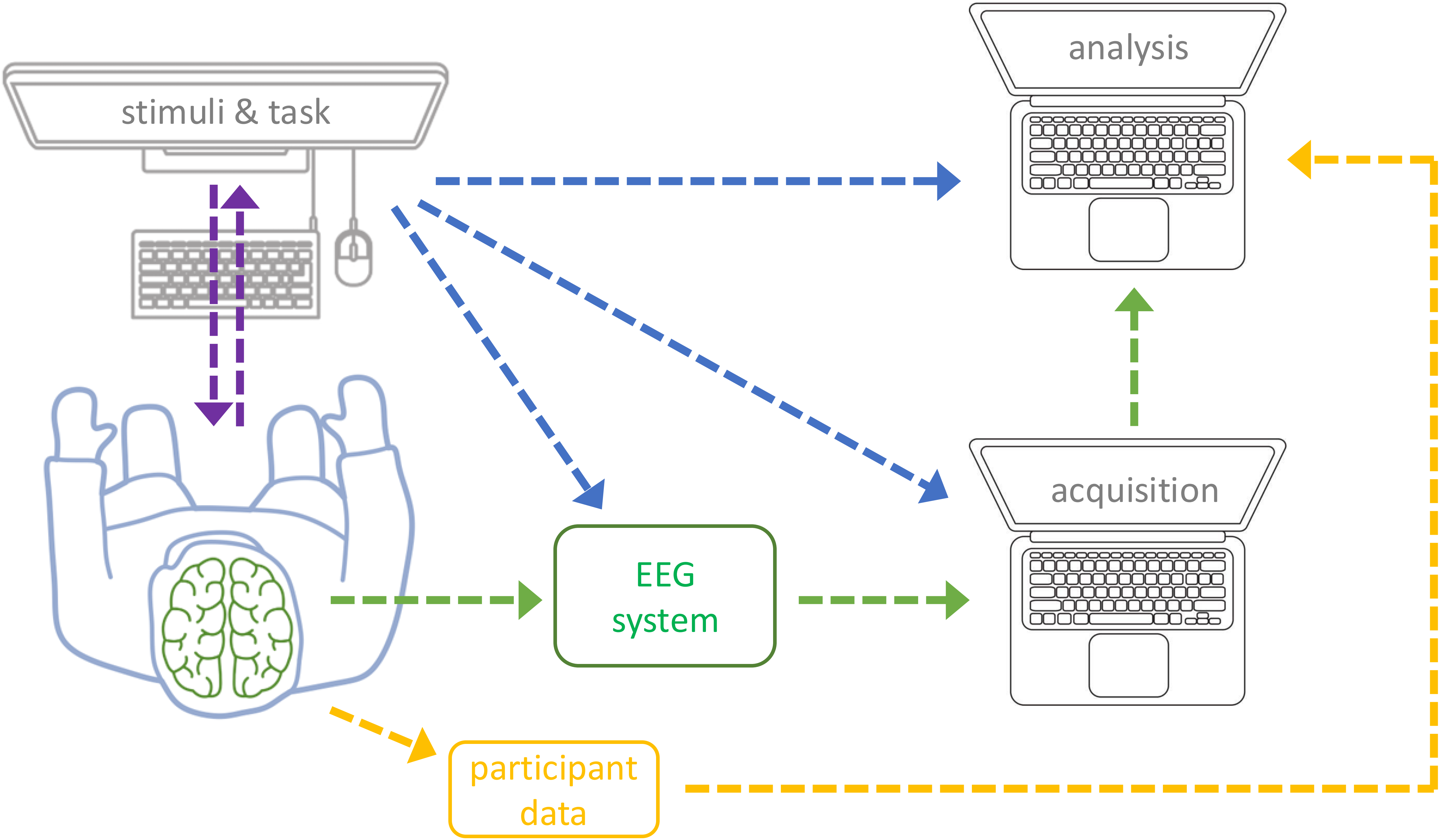
What are “components”

Nomenclature: 1, 2, 3, 50, 100, 300, P, N, LRP, CNV

How do we use the expertimental design with GLM and ANOVAs

(Linear mixed-model analysis)

Spatial and temporal distribution


stimuli & task
analysis
acquisition
EEG
system
participant
data

Brain activity following a stimulus or event

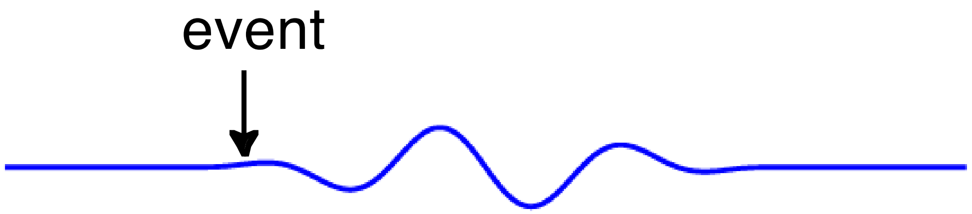
Evoked potential (EP) following a visual, tactile, or auditory stimulus

Event-related potential (ERP) around any type of event, exogenous or endogenous

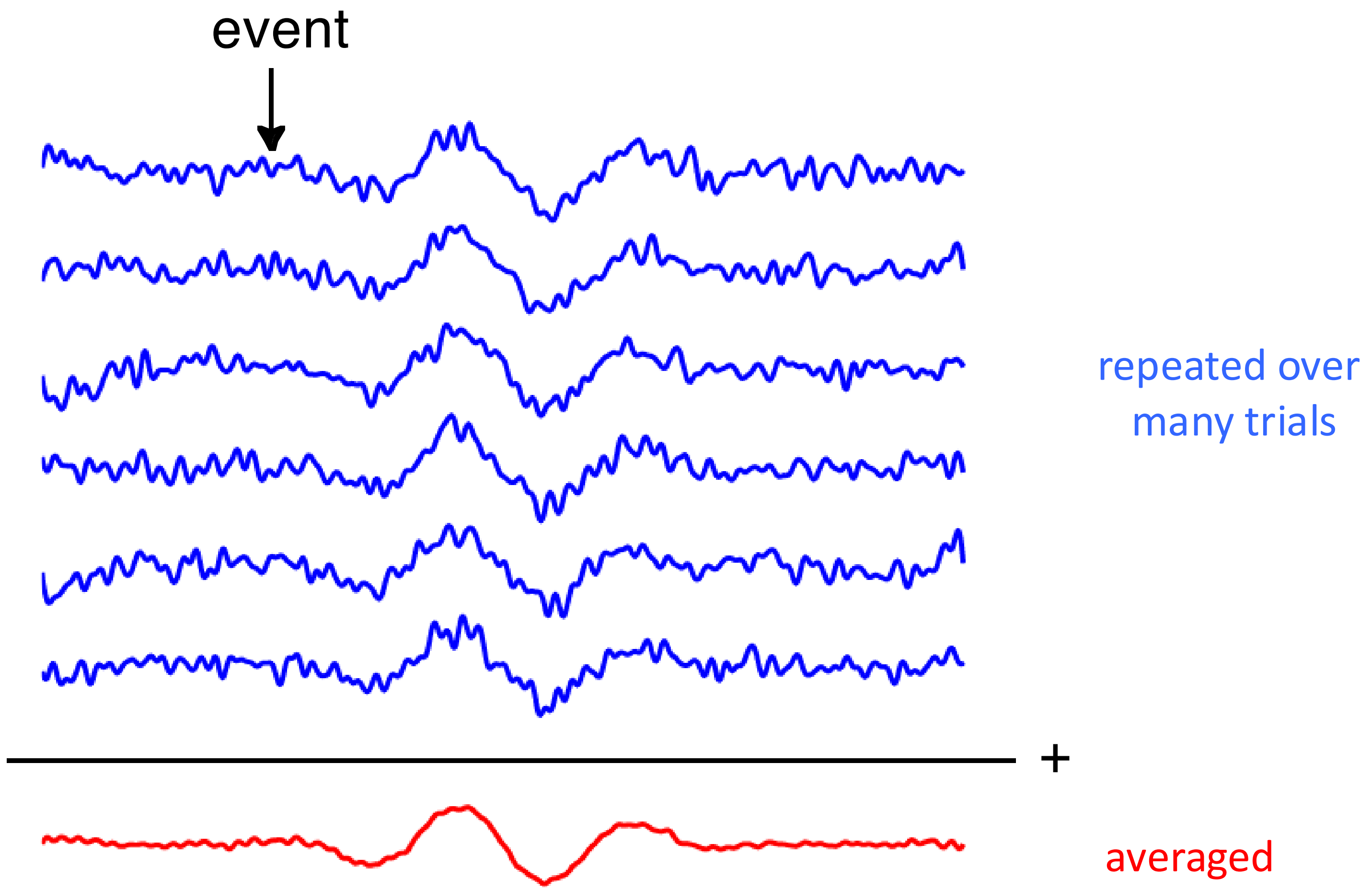
- Following an external stimulus
- Preceding the onset of a movement
- Related to external/exogenous or internal/endogenous activity

“EP” is often used in clinical reasearch, whereas in cognitive research we call it an “ERP”.

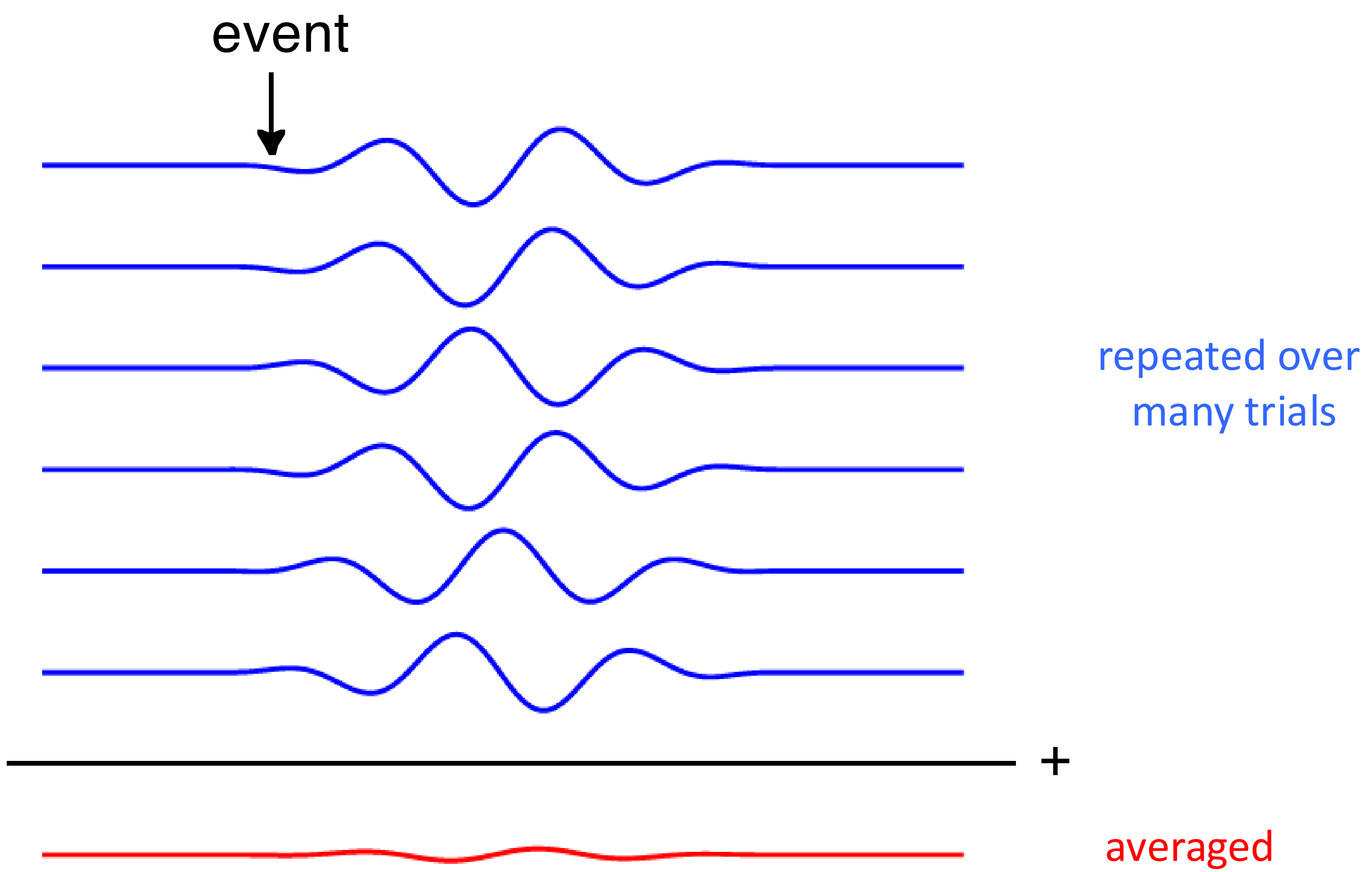
Evoked potential



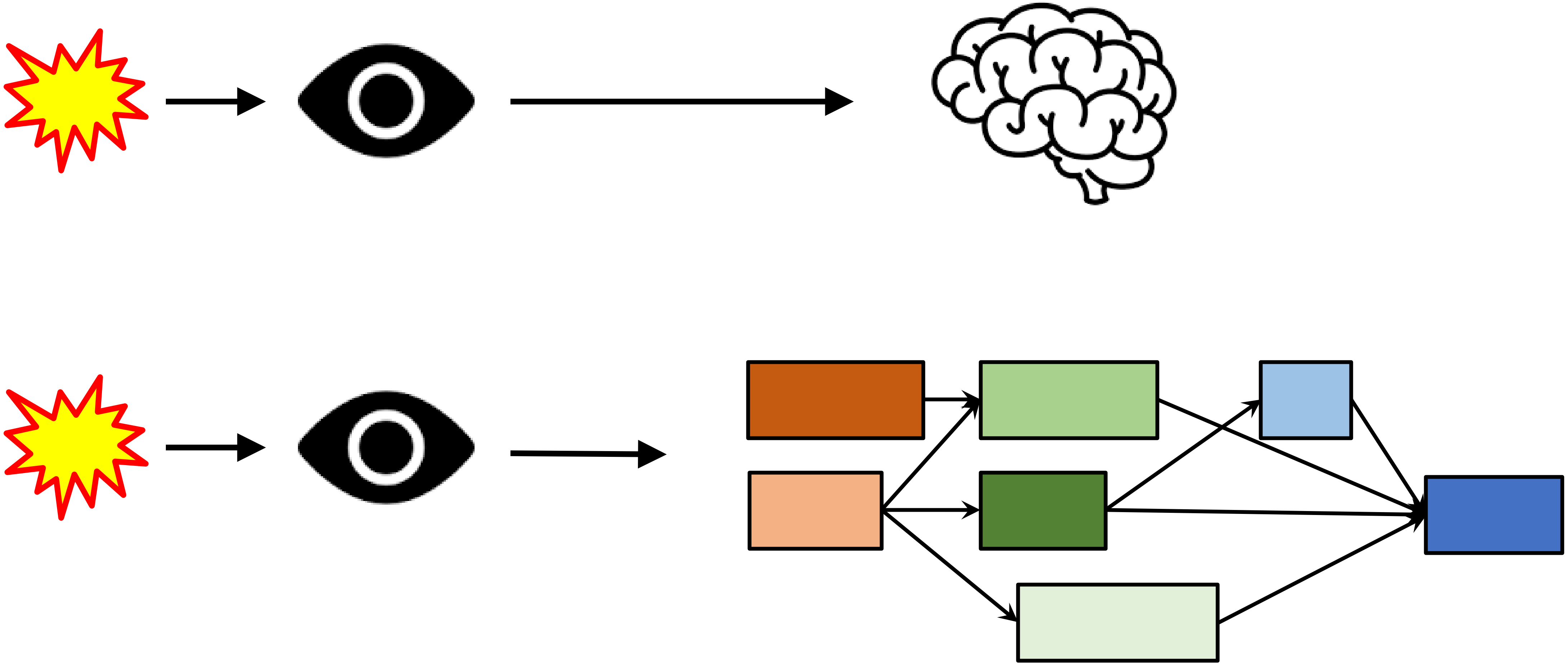
Evoked potential



Induced activity – this requires frequency or time-frequency analysis



Why study ERP components?



Analyzing a simple event-related task

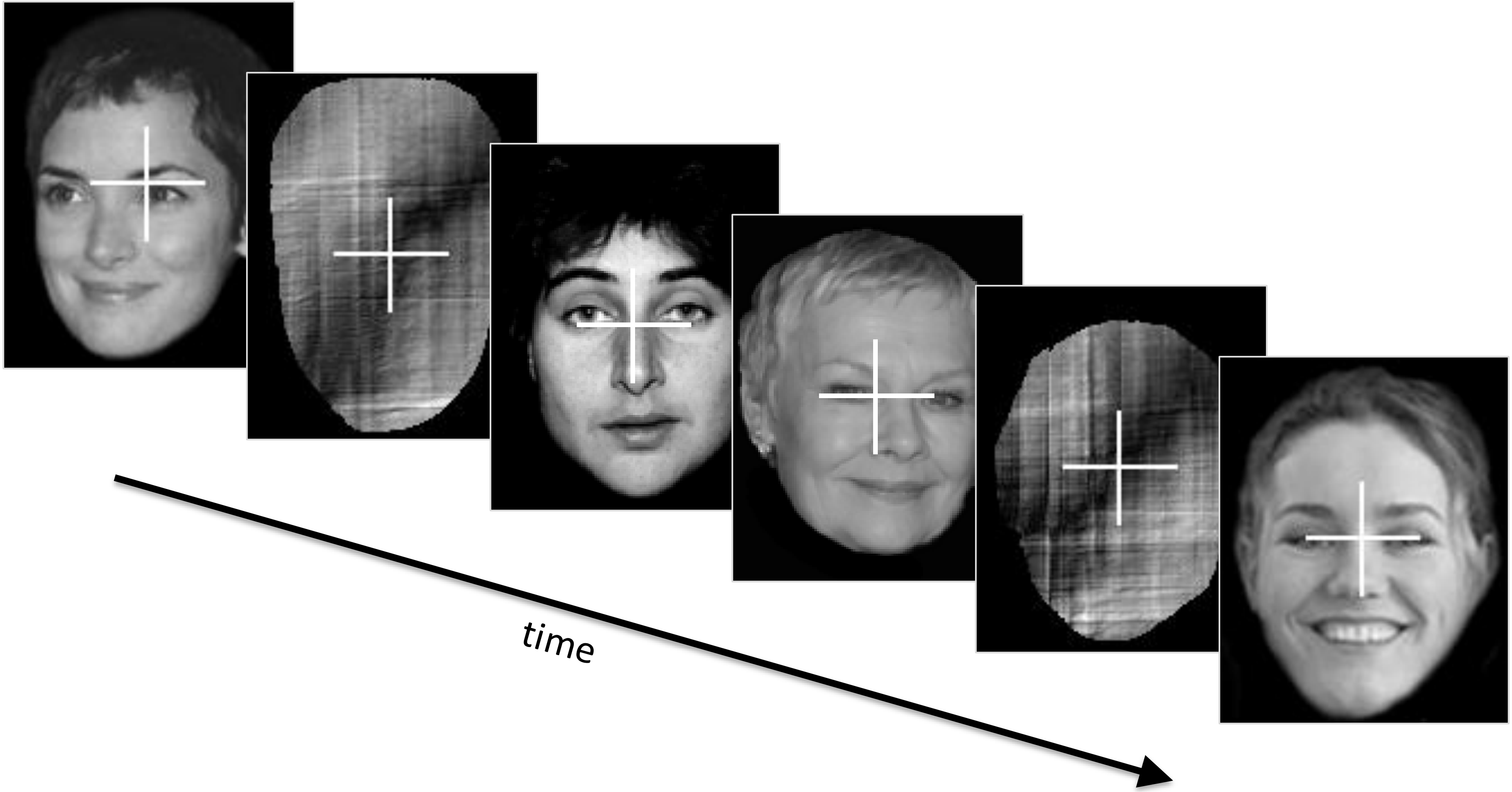
Signal-to-Noise-Ratio (SNR) is not high enough to observe brain responses in a single attempt or trial

Stimulus or task is repeated many times (i.e., trials)

- For example: one trial every 5 seconds, ~600 trials in one hour
- Experimental manipulation usually a subtle difference between trials
- EEG response of interest is only about 1 second around the stimulus
- So 1 hour (3600 seconds) results in 600 seconds of useable data

Spontaneous or “resting state” data also often for ~10 minutes

Analyzing a simple event-related task



http://doi.org/10.1038/sdata.2015.1

Analyzing a simple event-related task

300 trials

300 times a picture of a face

300 trials

100 unfamiliar faces

100 familiar faces (i.e., celebrities)

100 scrambled faces

300 trials

50 unfamilar faces 1st time, 50 unfamilar faces 2nd time

50 familar faces 1st time, 50 familar faces 2nd time

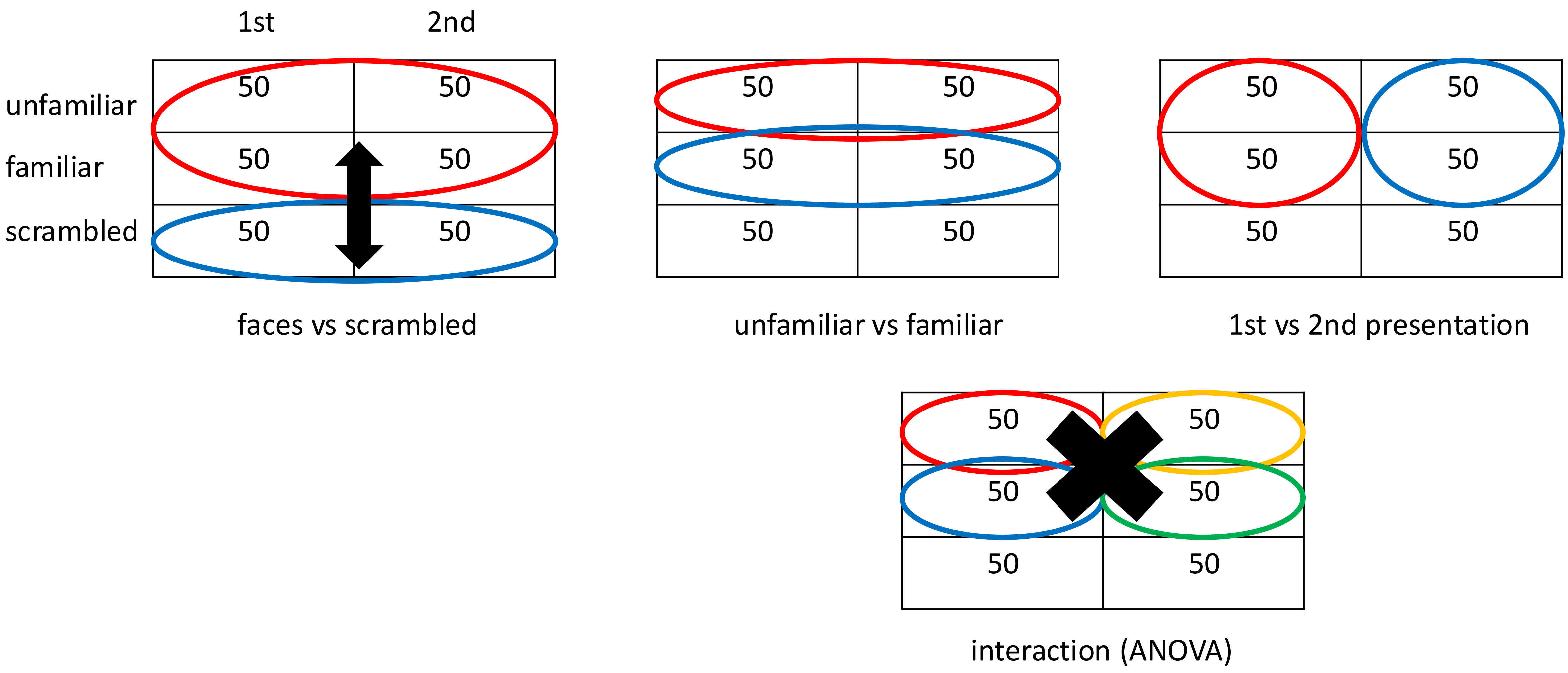
50 scrambled faces 1st, 50 scrambled 2nd time

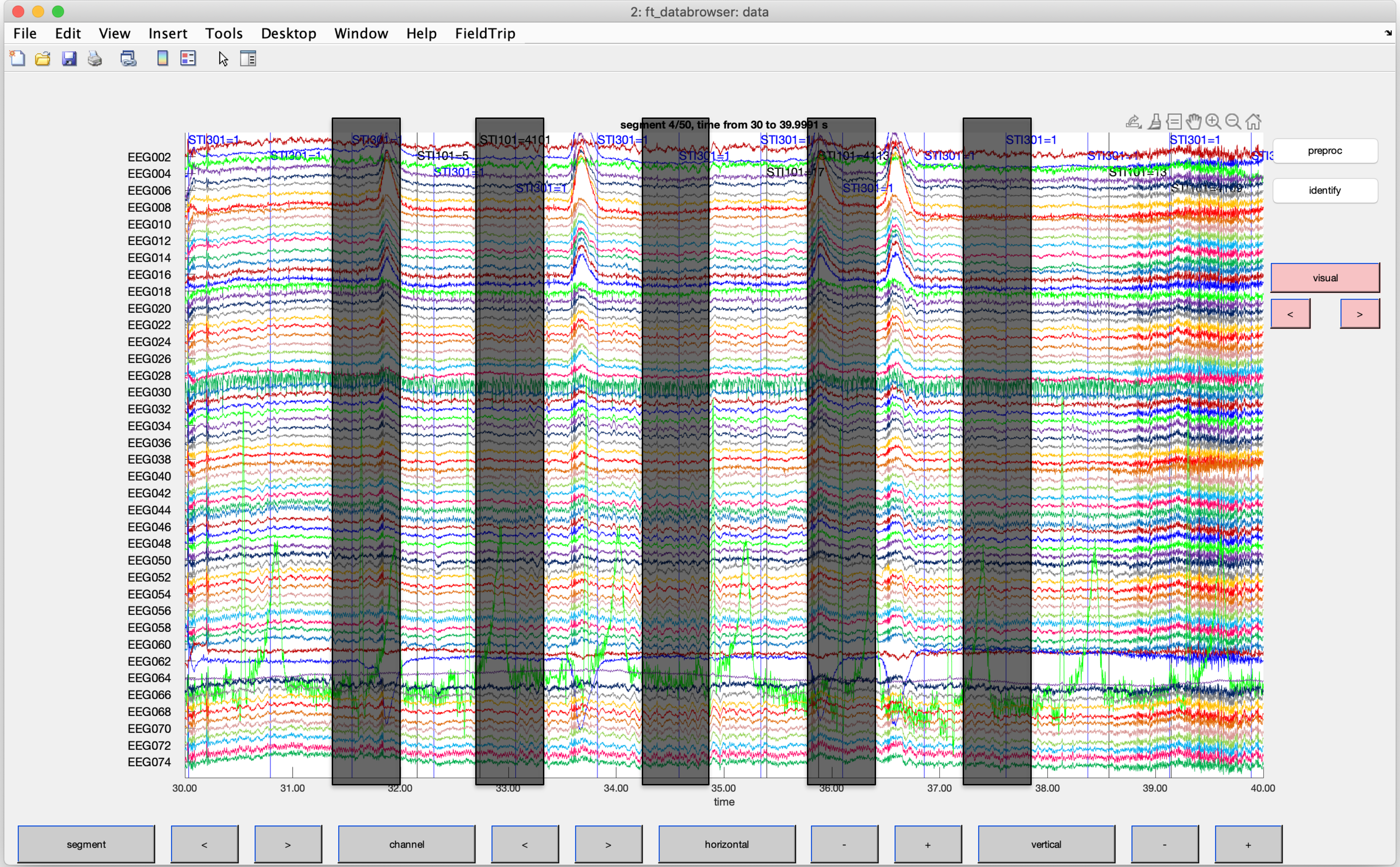
	1st presentation	*2nd presentation*
unfamiliar	**50**	**50**
familiar	**50**	**50**
scrambled	**50**	**50**

Also other dimensions: male/female, their gaze (left/right), …

http://doi.org/10.1038/sdata.2015.1

Analyzing a simple event-related task




2: ft_databrowser: data
File Edit View Insert Tools Desktop Window Help FieldTrip
segment 4/50, time from 30 to 39.9991 s
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EEG004
EEG006
EEG008
EEG010
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EEG014
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EEG022
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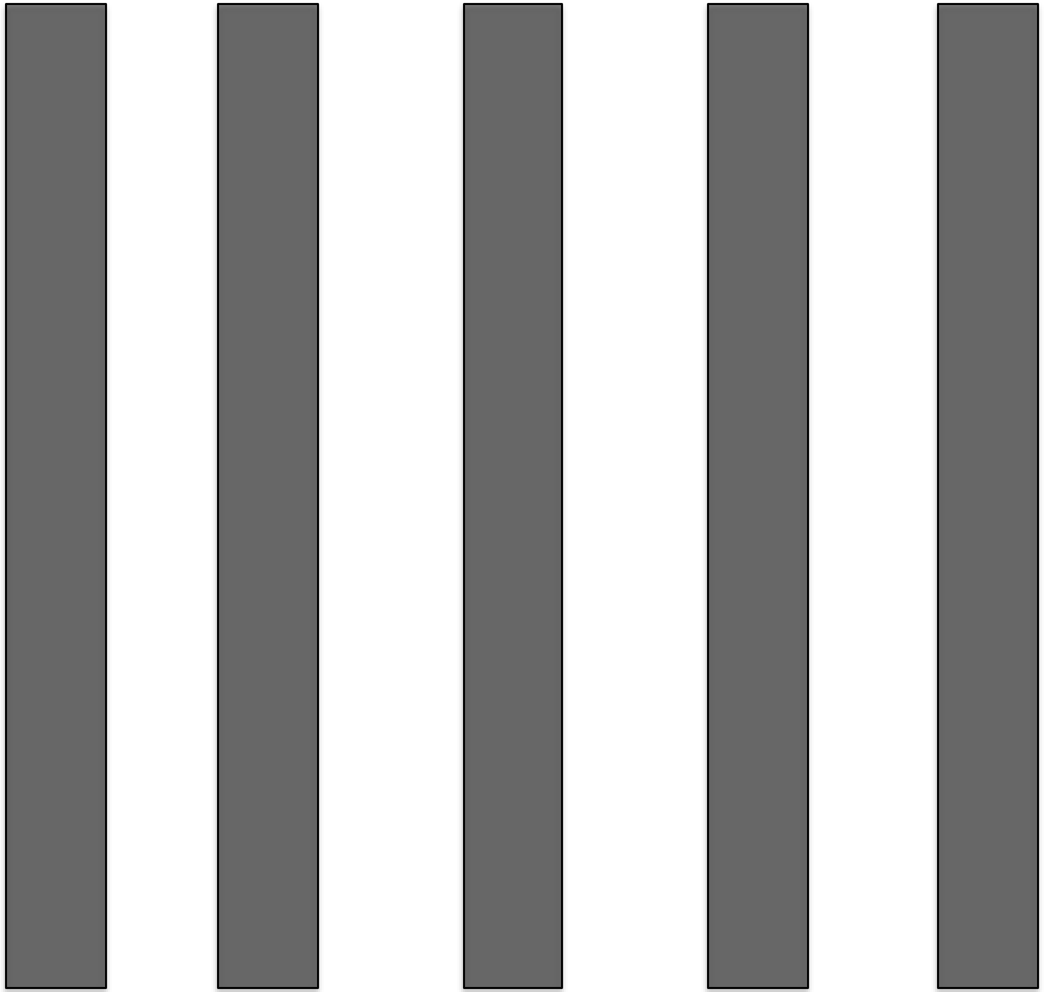
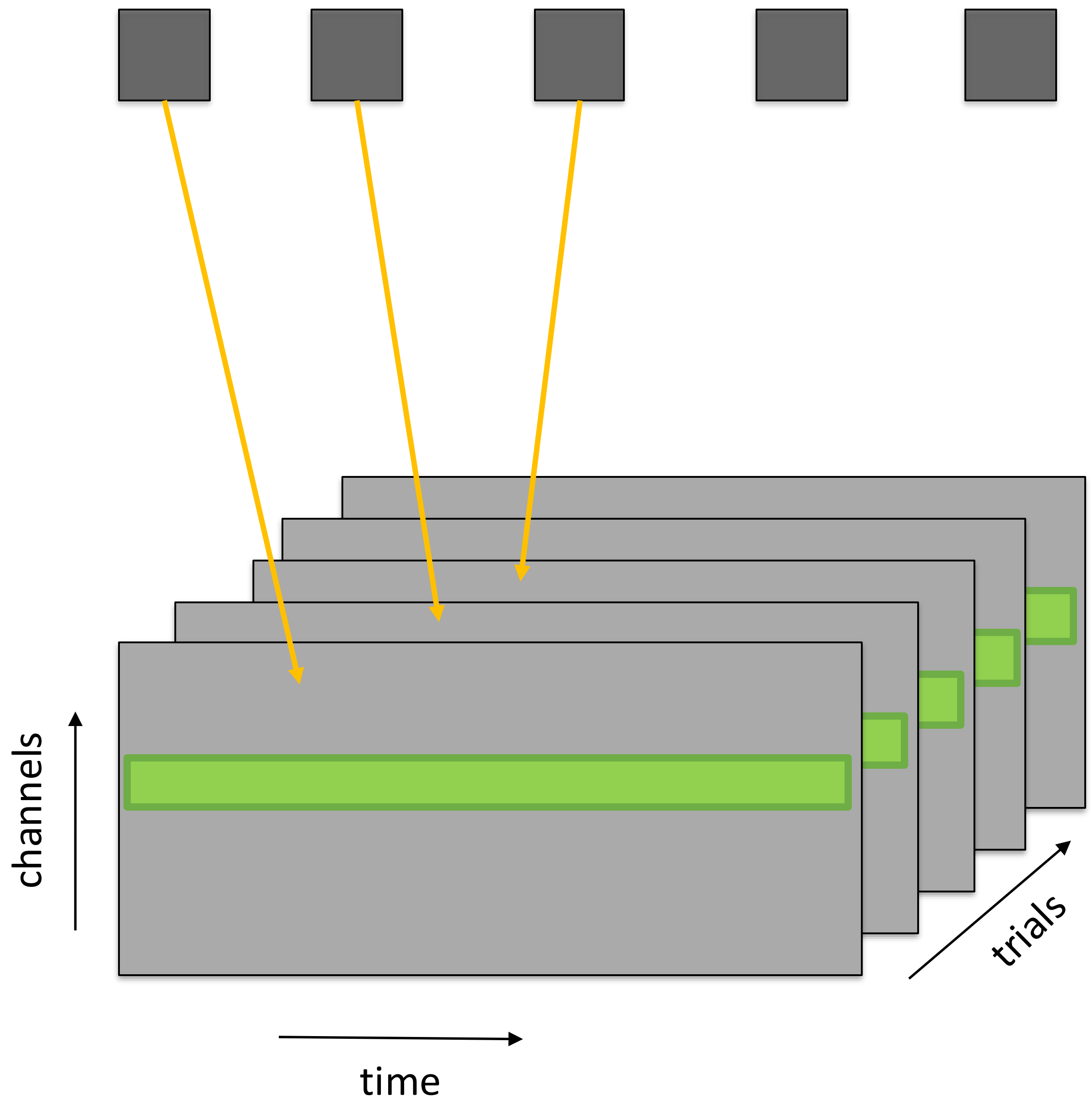
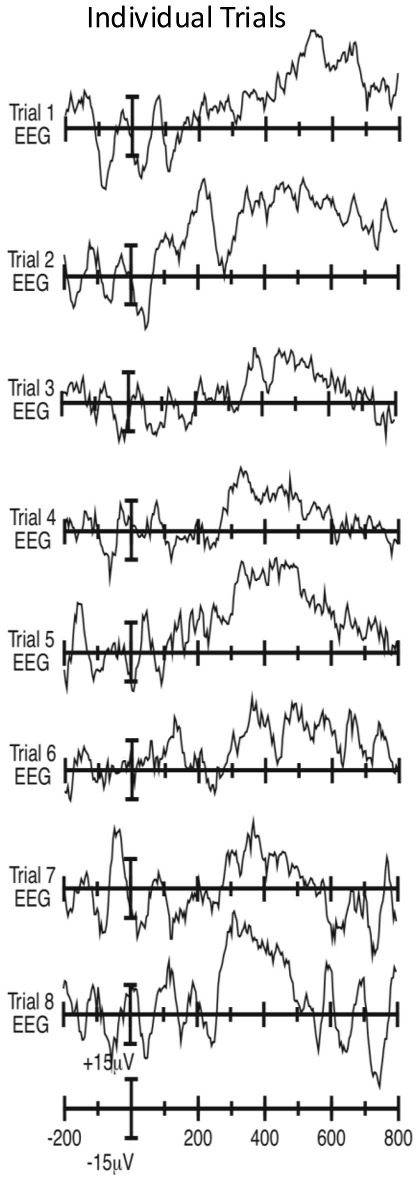


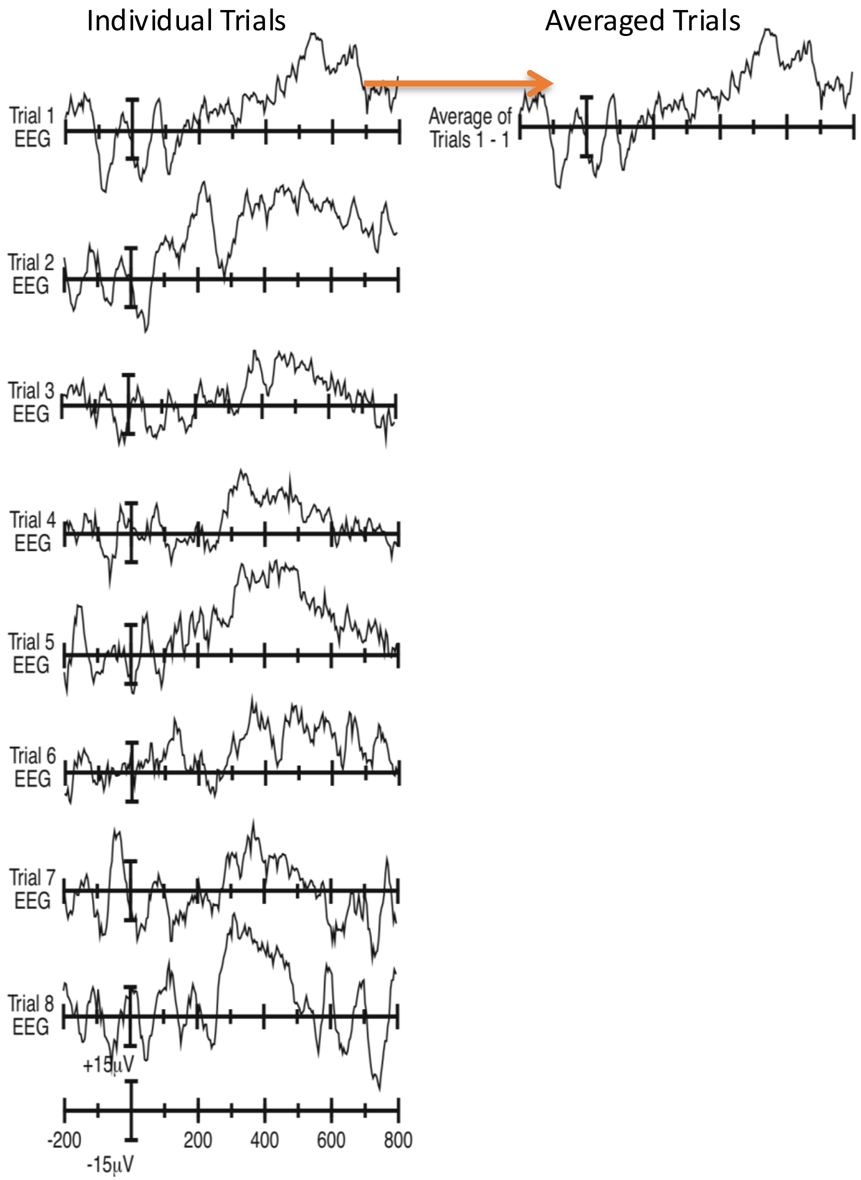
~ 100 channels
~ 1 second = 500 samples
So 100x500=50.000 numbers


channels
time
trials

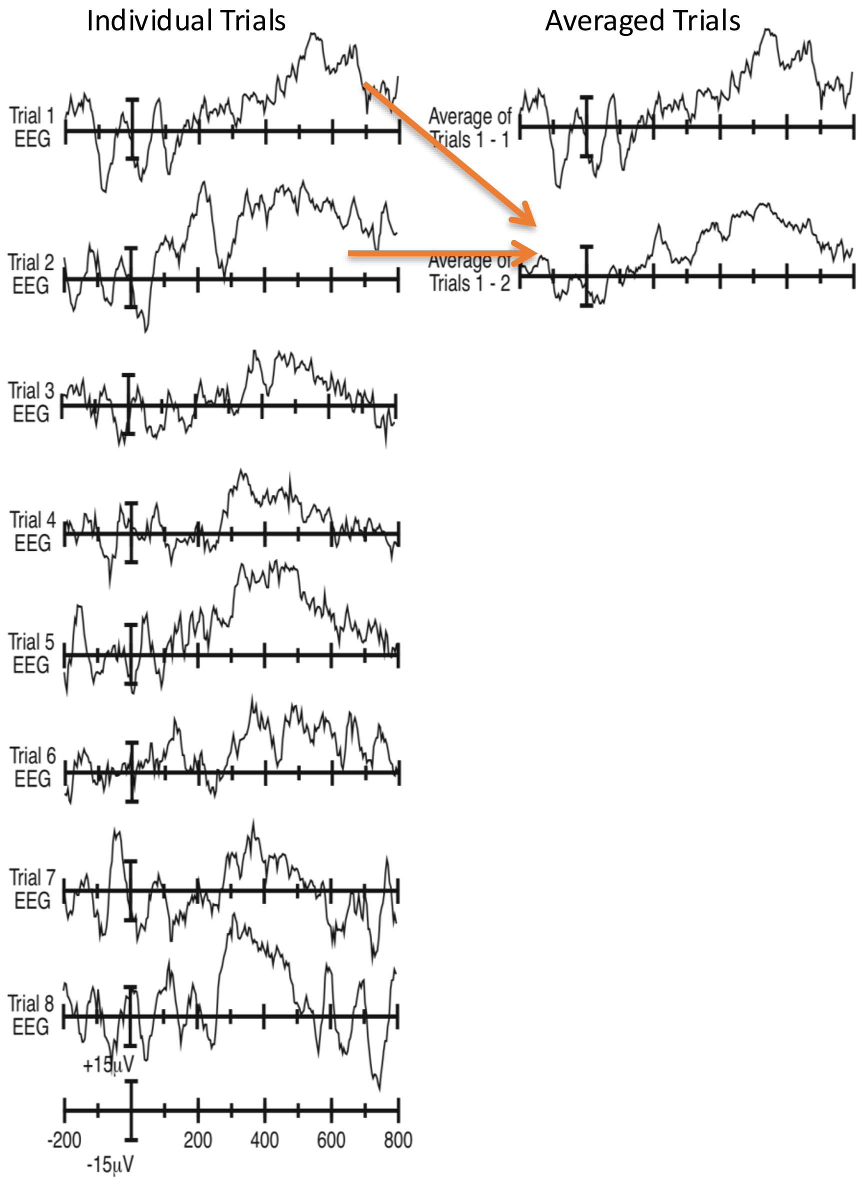
Event-Related Potential
ERP



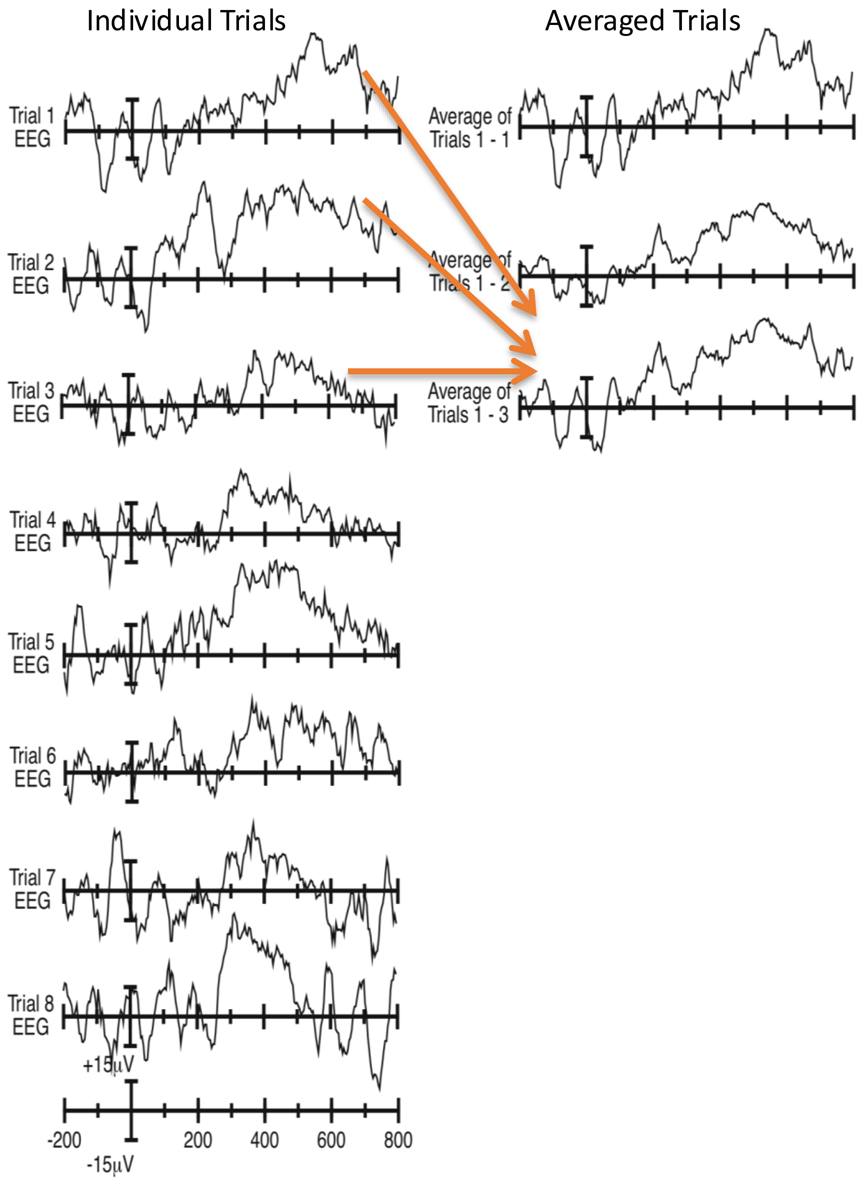
Event-Related Potential
ERP



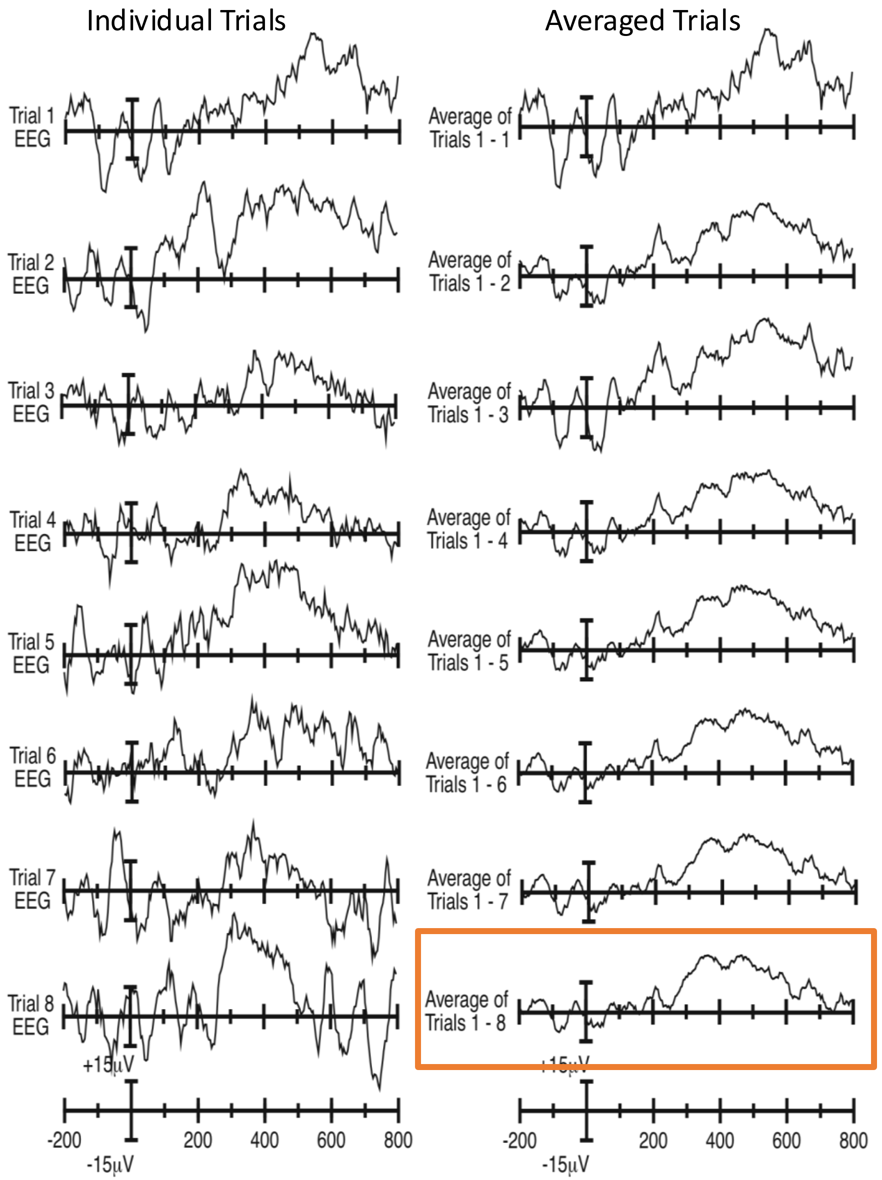
Event-Related Potential
ERP



Event-Related Potential
ERP



Event-Related Potential
ERP



Event-Related Potential
ERP

The brain *signal* of interest is assumed to be constant over all trials.

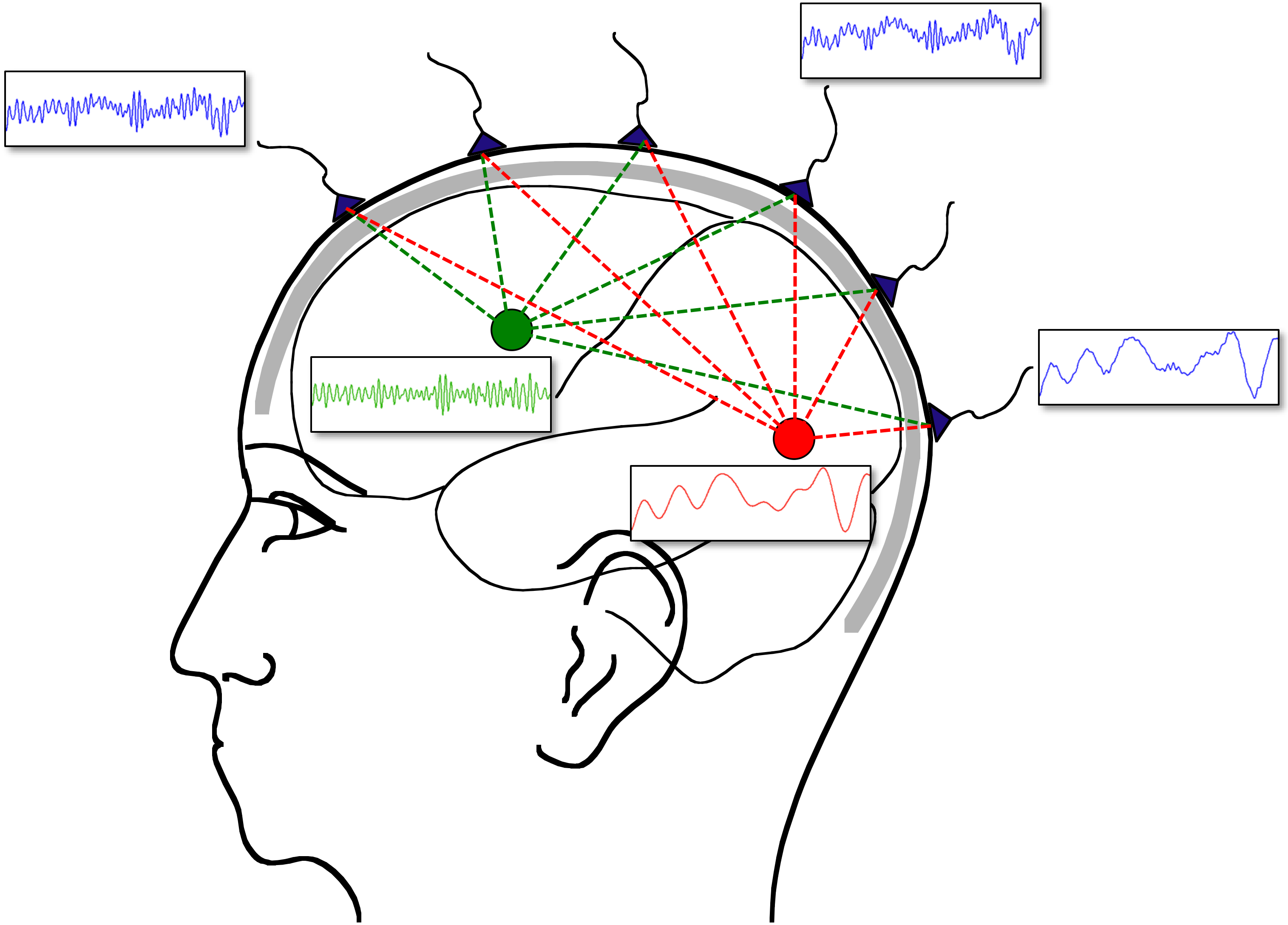
The *noise* is independent over trials.

Noise is proportional to 1/sqrt(Ntrials).

Averaging over trials improves the signal-to-noise ratio (SNR).

10 trials	-> SNR is sqrt(10)	≅ 3x better
100 trials	-> SNR is sqrt(100)	≅ 10x better

Superposition (summation) of source activity



Linear model for ERP activity

Related to the task, constant over trials

Not related to the task

Data = signal + noise

Data in condition 1 = signal_1 + **noise**

Data in condition 2 = signal_2 + **noise**

ERP_1 = average(Data in condition 1) = signal_1 + noise

ERP_2 = average(Data in condition 2) = signal_2 + noise

$\text{ERP}_1 – \text{ERP}_2 = \text{signal}_1 – \text{signal}_2$ + noise

ERP components and difference waves

An ERP can consist of multiple components that respond differently to different aspects of the experimental stimulus. For example in an auditory oddball task

beep-beep-beep-beep-beep-beep-boop-beep-…

boop-boop-boop-boop-boop-boop-beep-boop-…

Some sounds are expected, whereas others are unexpected.

The "beep" is *expected* in the 1st condition, whereas the same "beep" is *unexpected* in the 2nd condition.

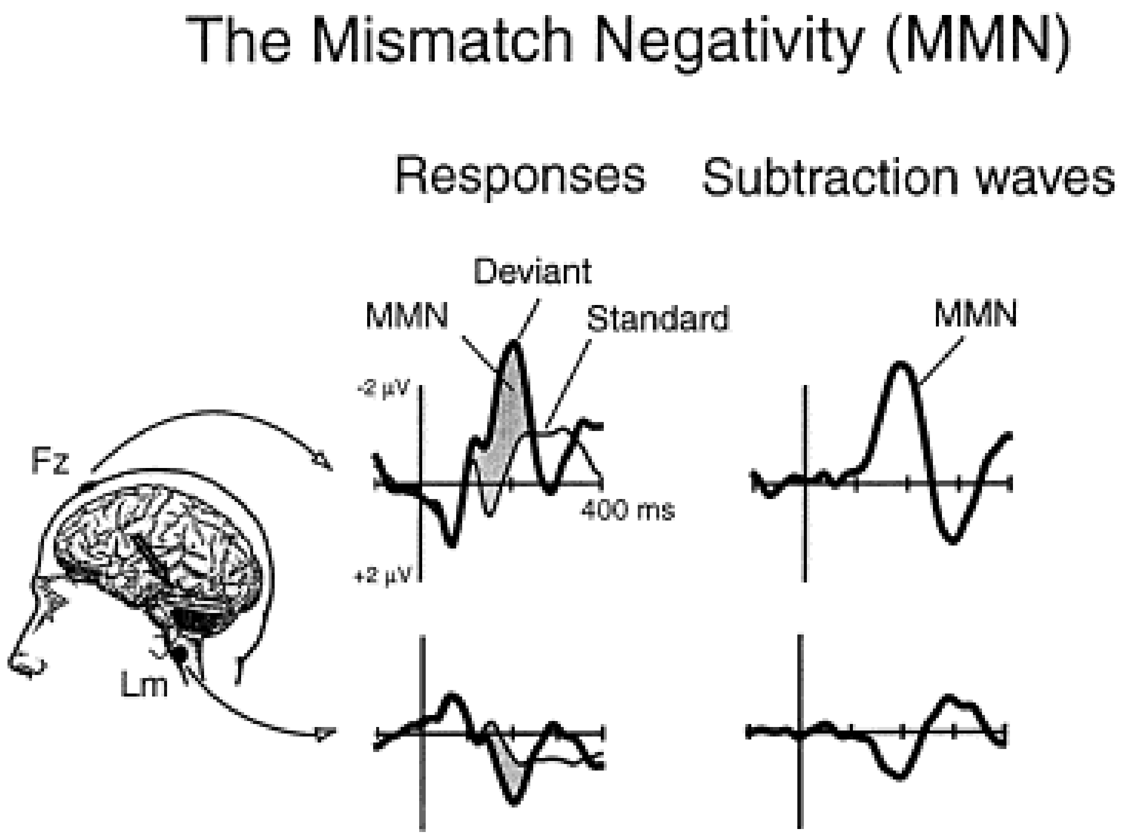
The sensory input of the "beep" is always processed by the auditory cortex, but the conditions have a different surprise response.

Auditory oddball experiment – Mismatch Negativity

The MMN is not the sensory response to the beep or the boop, but the difference in the standard/expected versus deviant/unexpected beep.

Similarly, the MMN is also the difference between the standard/expected versus deviant/unexpected boop.

Experimentally separate between the detection of the sound (beep/boop) and the expectancy.

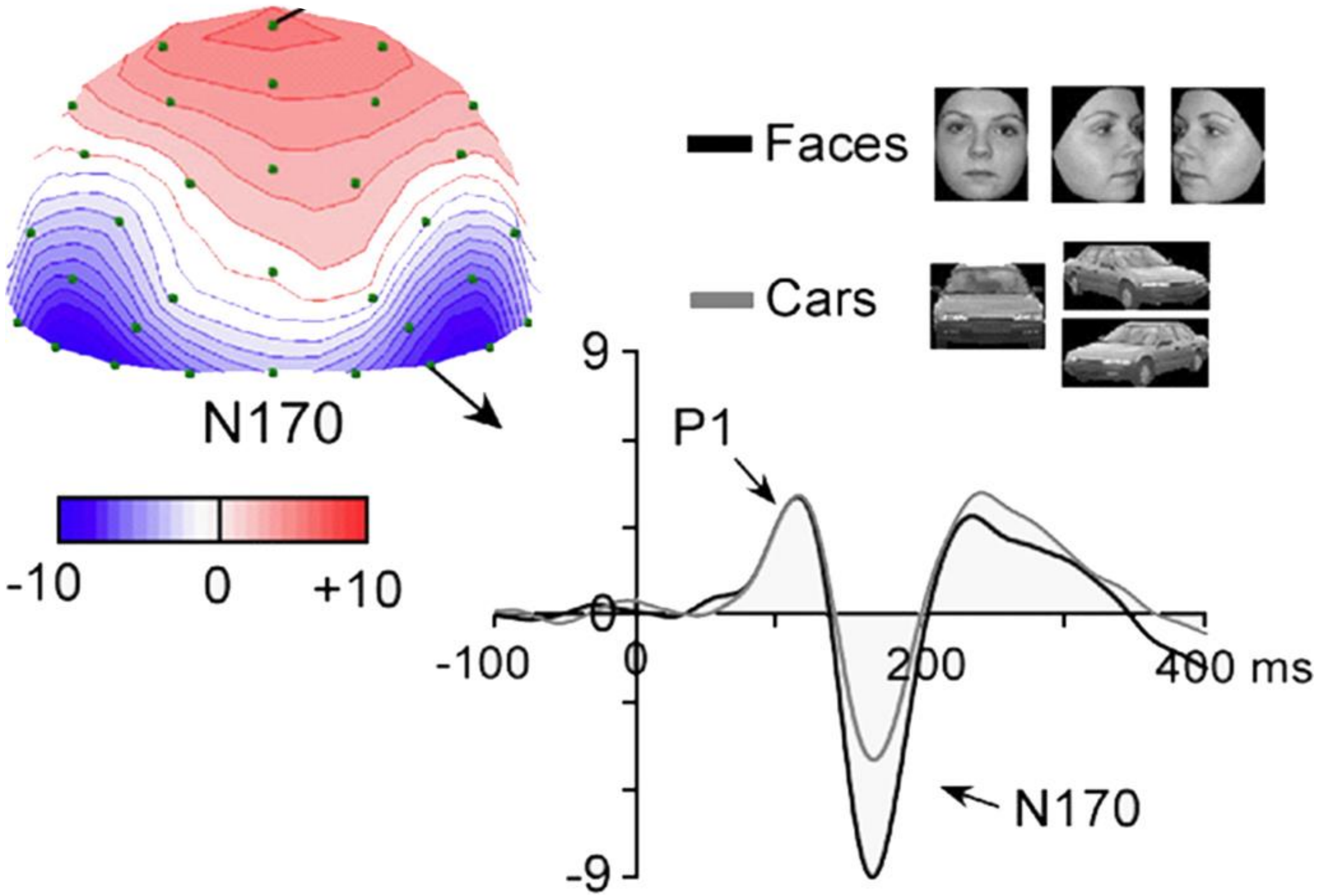


Kujala and Näätänen (2001), https://doi.org/10.1016/S0149-7634(01)00032-X

Faces versus houses, or cars, or flowers, or scrambled faces, …

The N170 is an ERP response specific for faces, when contrasted to other visual stimuli.

The N170 originates from the fusiform face area (FFA) which is located on the ventral surface of the brain.



Kuefner et al. (2010), https://doi.org/10.3389/neuro.09.067.2009

ERP components and nomenclature

Steve Luck (2014). An Introduction to the Event-Related Potential Technique. MIT Press

Px or Nx, for example P1 or P3

N or P = negative or positive deflection

x = which component is it (1st, 2nd, etc)

Pxxx or Nxxx, for example P50 or N170

N or P = negative or positive deflection

xxx = latency (approximately) in miliseconds

Sometimes more unique names

RP/BP = readiness potential or Bereitschaftspotential (German)

LRP = lateralized readiness potential

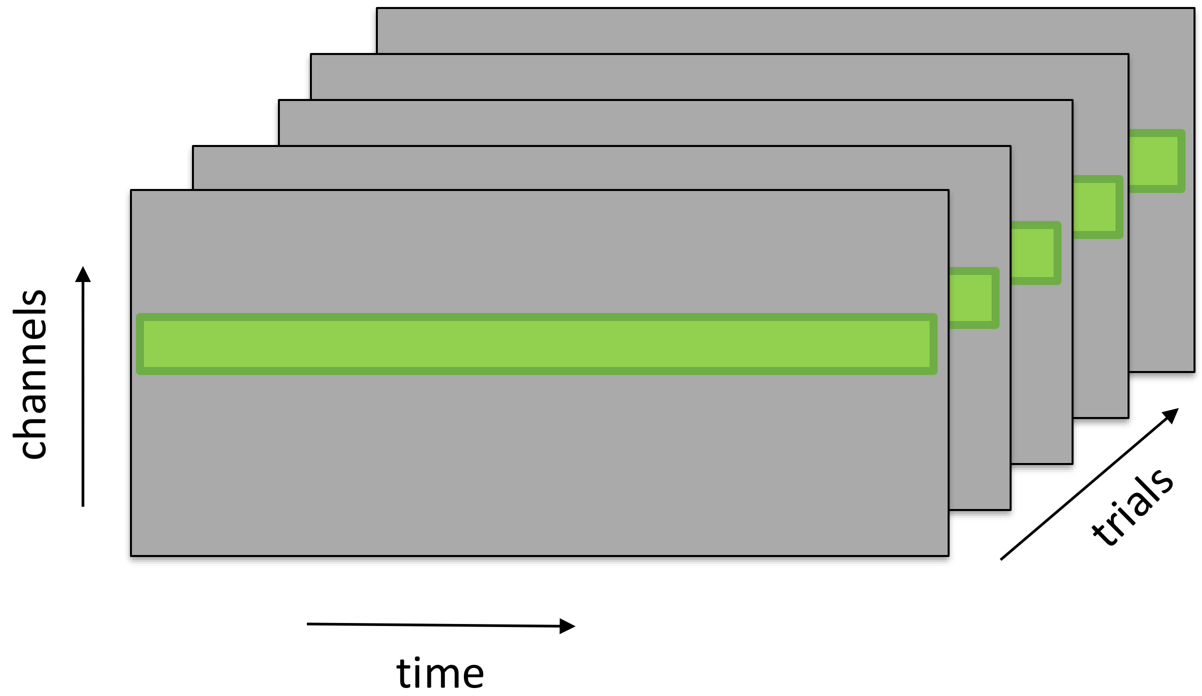
CNV = contingent negative variation

N2pc = second negative component, posterior and contralateral to the stimulus

One channel, all time points

When does specific brain activity start (in one condition)?

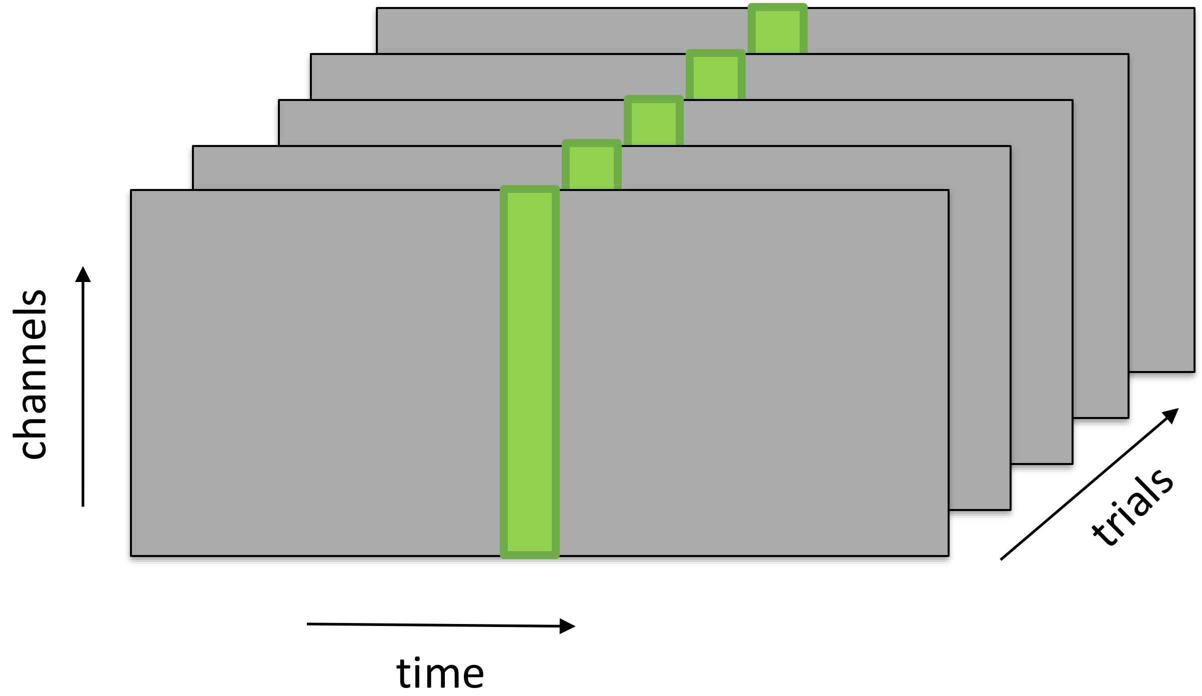
When is the activity different between conditions?



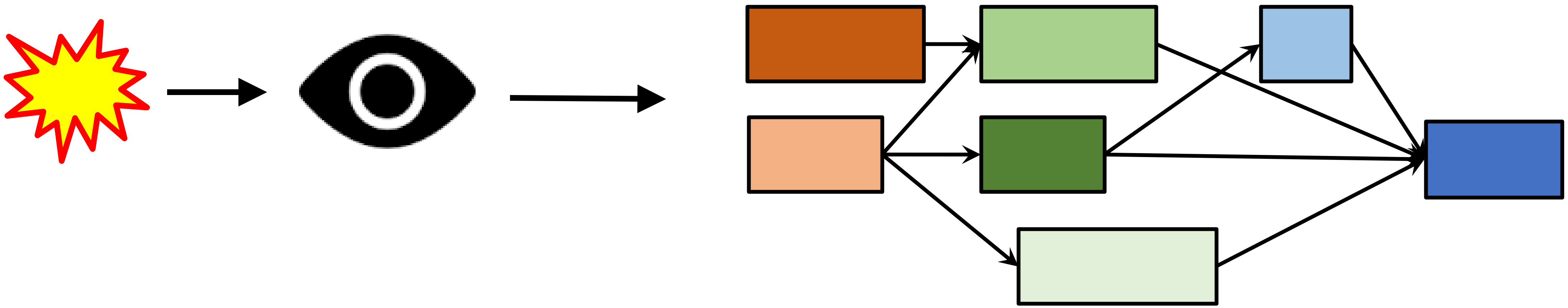
All channels, one time point

What is the *topographic distribution* (in one condition) at latency t ?

What is the *topographic distribution* of the difference at latency t ?



ERP components reveal the *when* and *where*



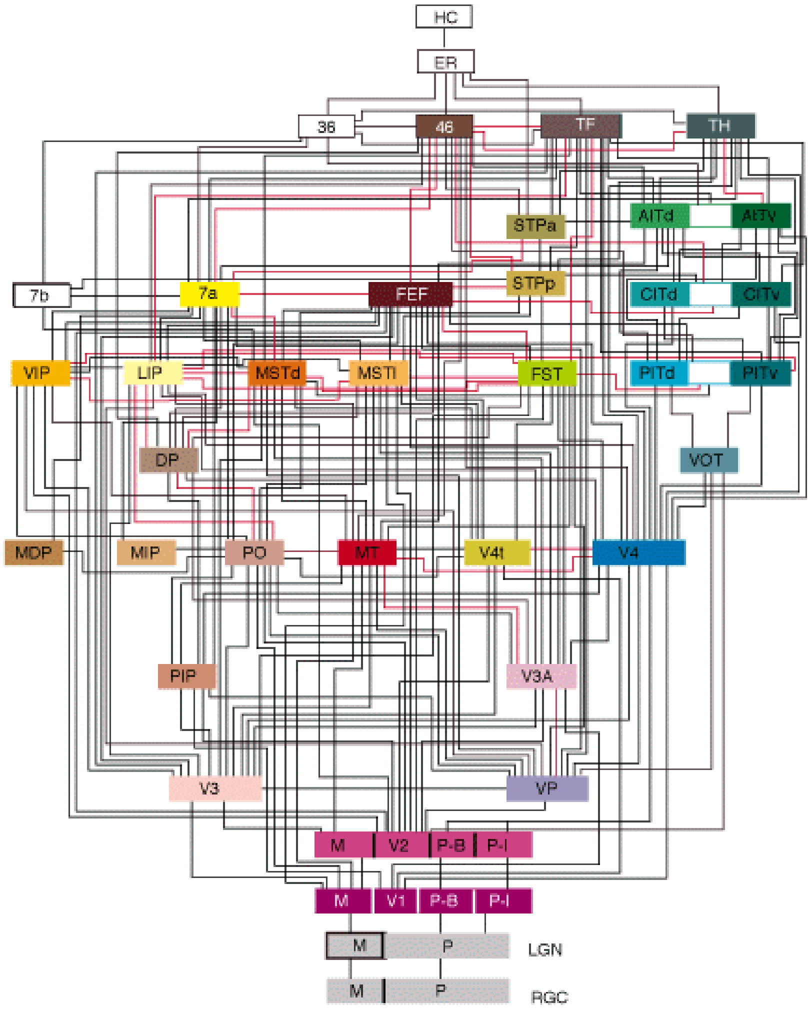
Different functions in different brain areas.

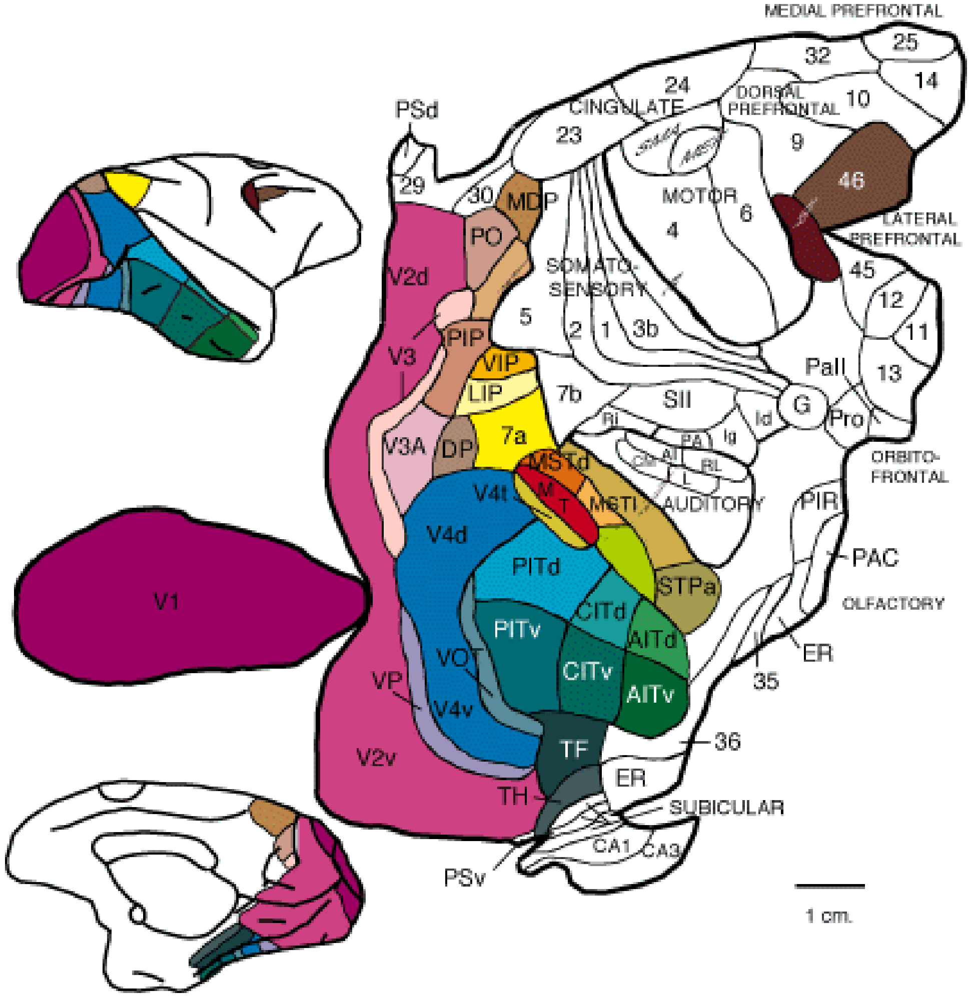
The brain is a hierarchical functional network.

Serial/sequential and parallel processing at different times/latencies in different areas.

Identifying the latency and topography of ERP components helps to disentangle functional networks.

Example: distributed hierarchical processing in the primate cerebral cortex





Felleman and Van Essen (1991) Cerebral Cortex. https://doi.org/10.1093/cercor/1.1.1-a

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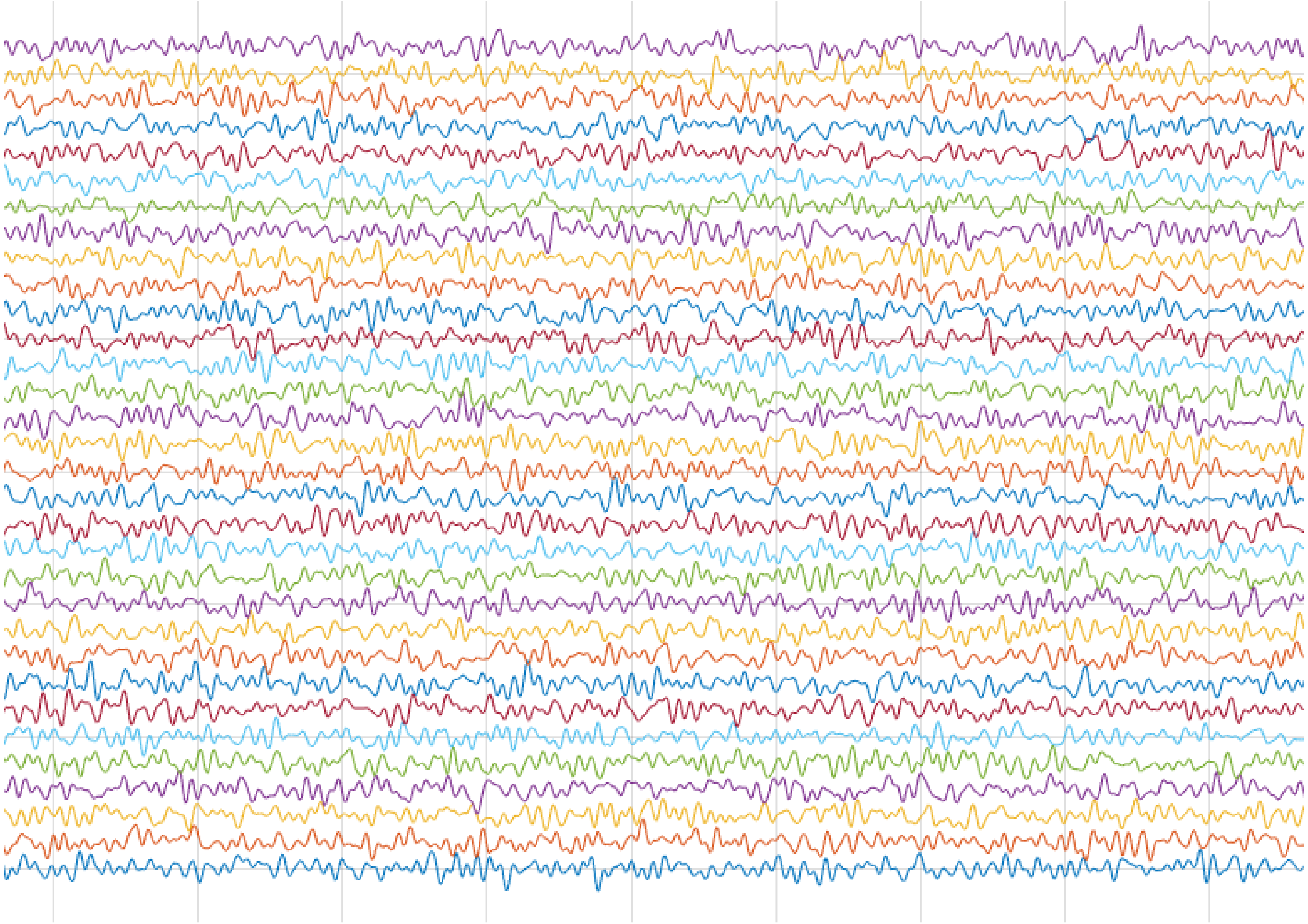
African
Brain
Data
Network

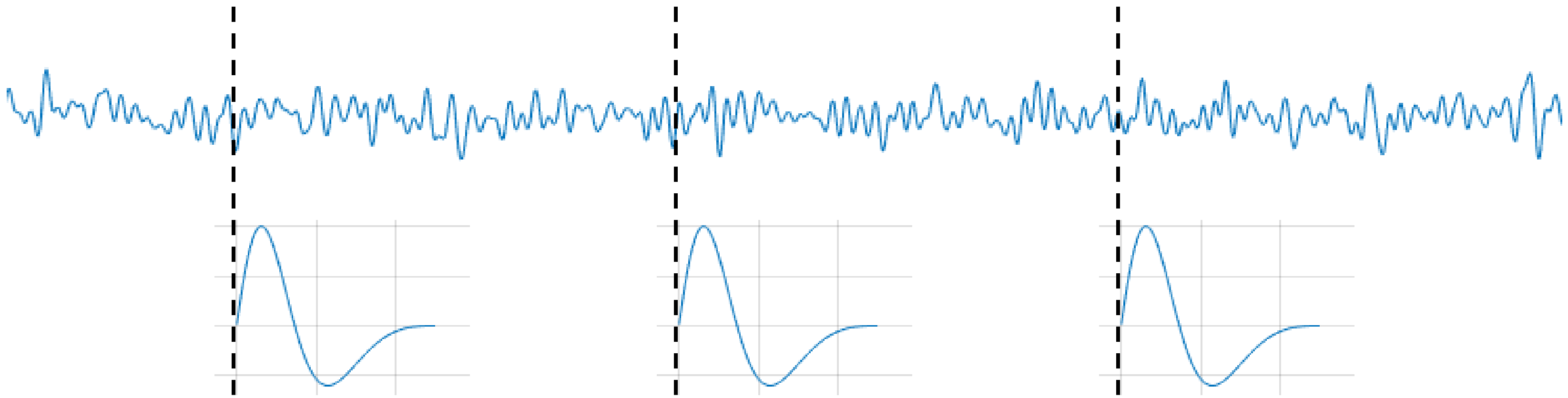
More advanced ERP-like methods

EEG data is very noisy



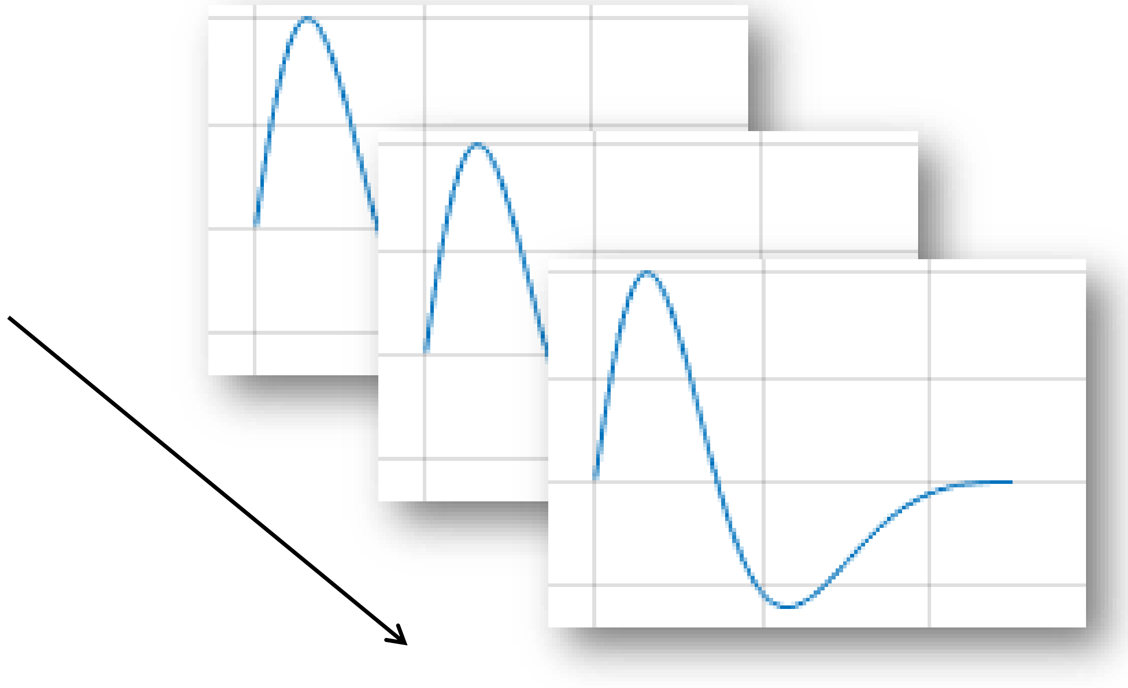
```
nchan    = 32;
fsample  = 1000; % Hz
duration = 5;    % seconds
Nsample  = fsample*duration;

time = ((1:nsample)-1)/fsample - 0.5;

noise = 0.1 * randn(nchan,nsample);

noise = ft_preproc_lowpassfilter(...
        noise, fsample, 30);

for i=1:nchan
noise(i,:) = noise(i,:) + (i-1)*0.1;
end


plot(time, noise);
grid on
```

Responses to sensory, cognitive or behavioral events are measured against a noisy background



Linear superposition: signal + noise

Reduce the noise: Event-related average

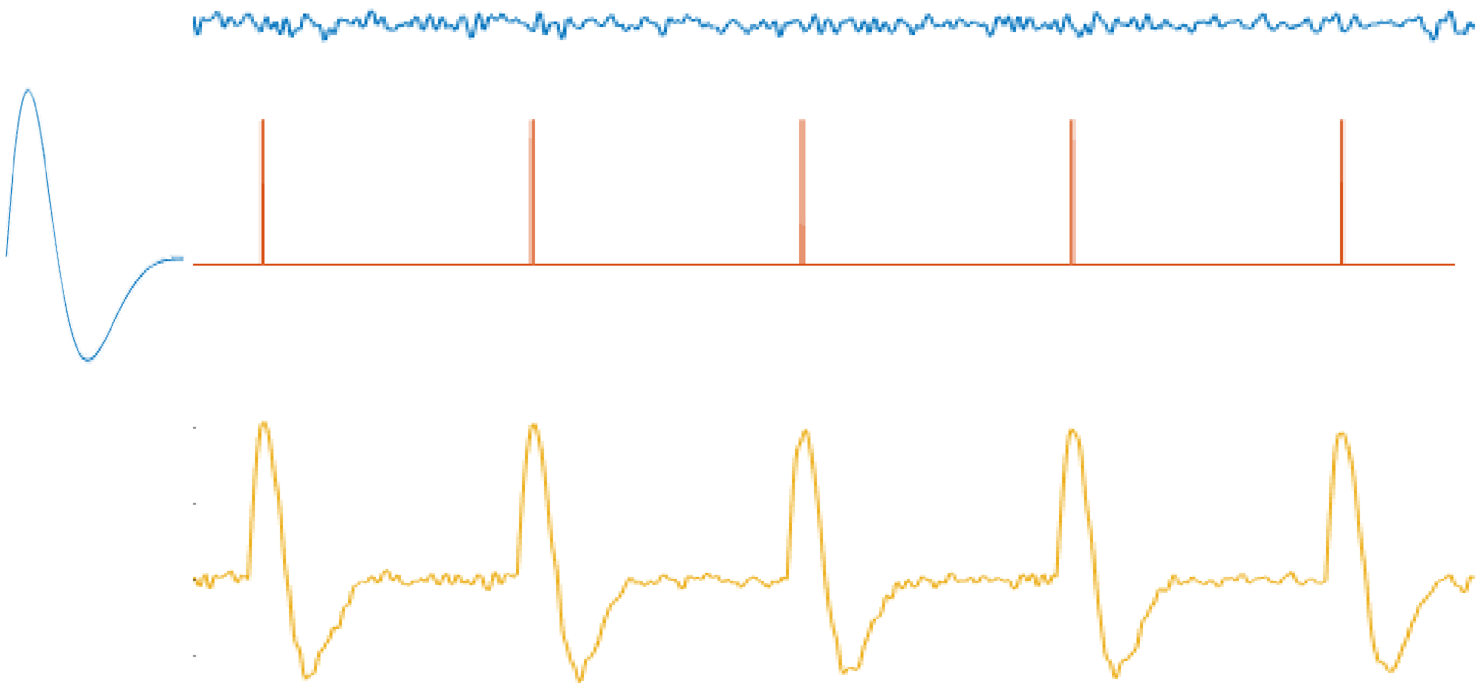


Linear model for EEG activity

data = noise + signal

signal = conv(event, ERP-component)

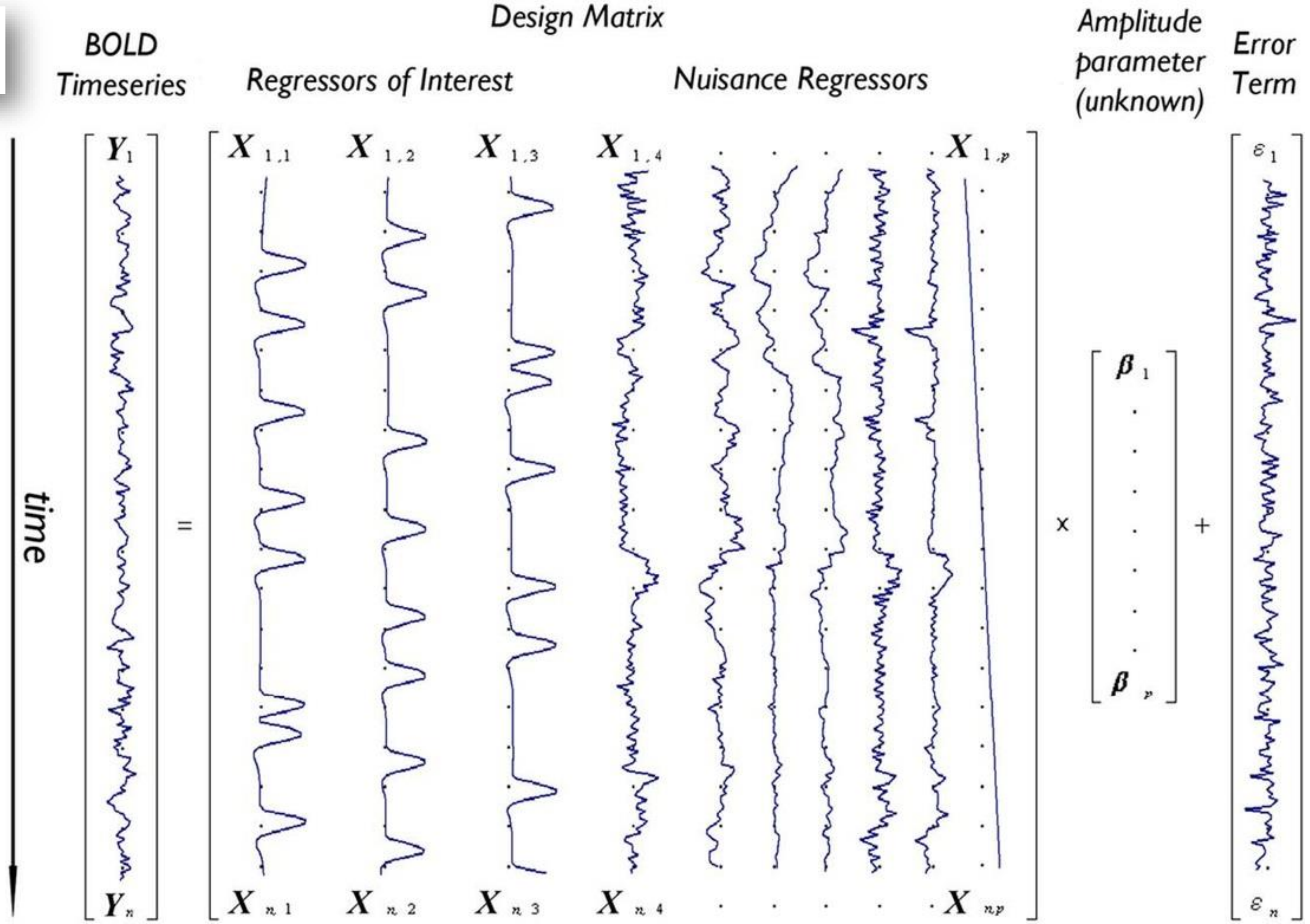
signal = conv(impulse-train, impulse response)



General Linear Model (GLM)

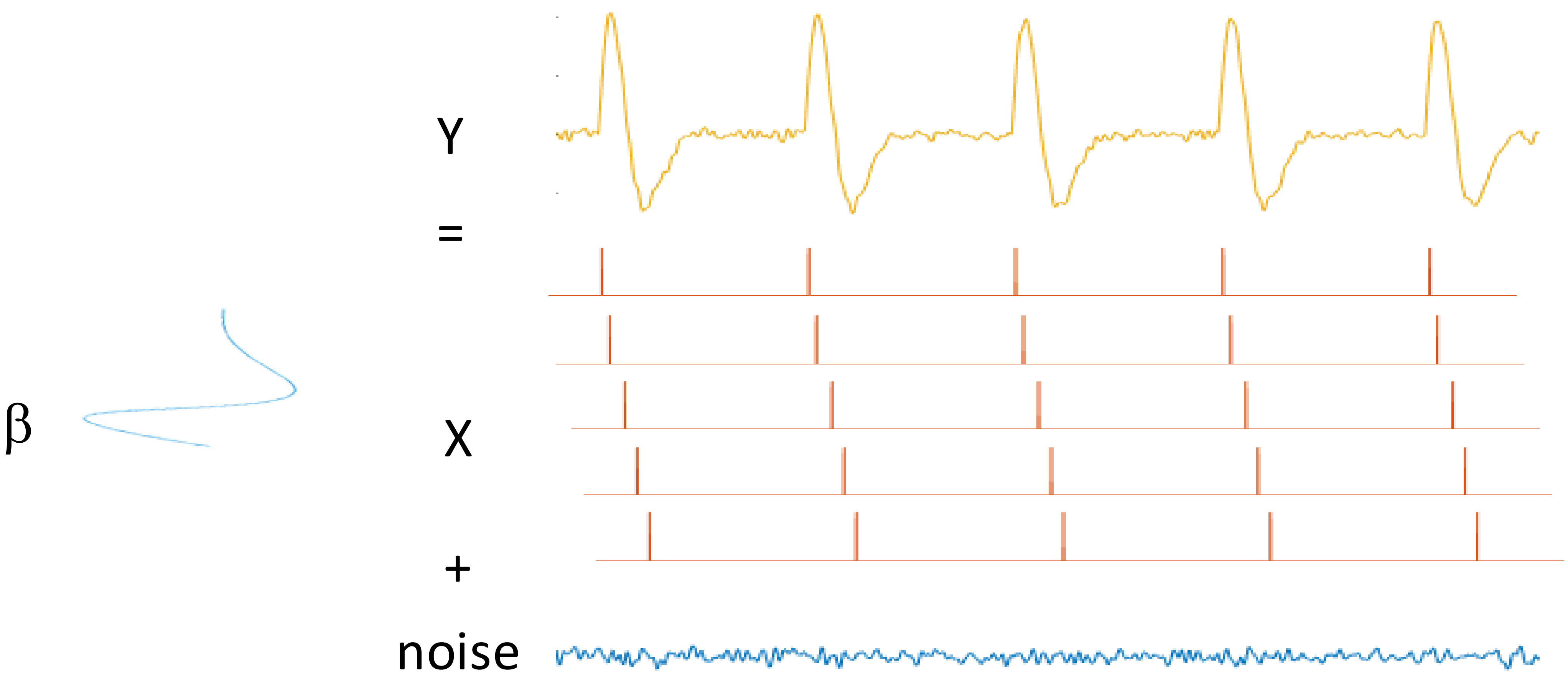
$$
\begin{aligned}
y_1 &= x_1\beta + \varepsilon_1 \\
y_2 &= x_2\beta + \varepsilon_2 \\
y_3 &= x_3\beta + \varepsilon_3 \\
&\vdots \\
y_n &= x_n\beta + \varepsilon_n
\end{aligned}
\quad \longrightarrow \quad
\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_n \end{bmatrix} [\beta] + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \vdots \\ \varepsilon_n \end{bmatrix}
\quad \longrightarrow \quad
\mathbf{Y} = \mathbf{X}\beta + \boldsymbol{\varepsilon}
$$

$$\mathbf{Y} = \mathbf{X}\,\beta + \boldsymbol{\varepsilon}$$



ERP ~ GLM

$$\mathbf{Y} = \mathbf{X}\beta + \boldsymbol{\varepsilon}$$



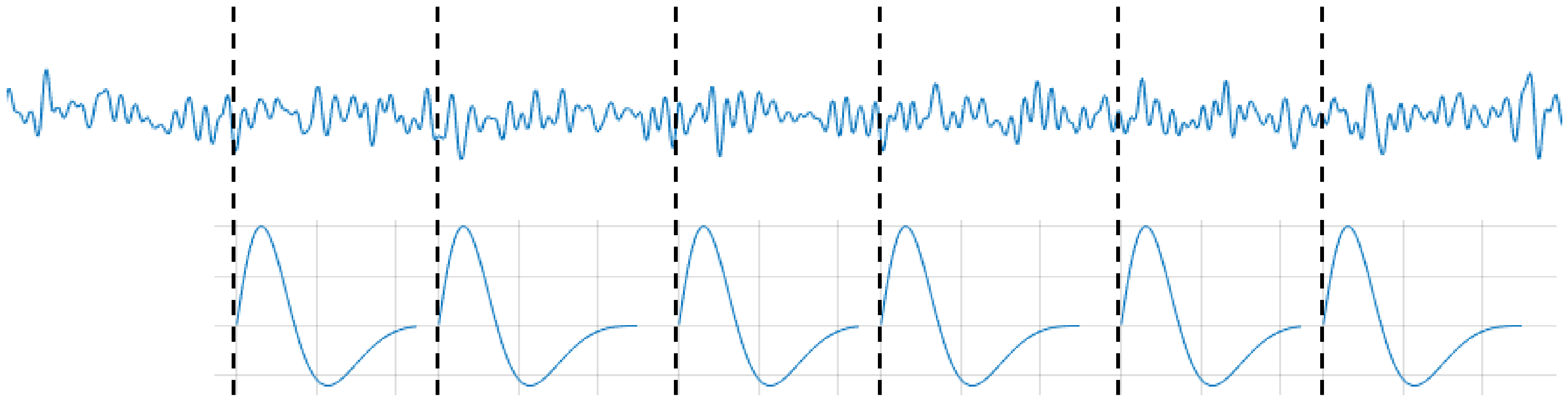
Averaging ERPs over trials is perfectly valid if …

The inter-trial interval (ITI) is large enough so that trials can be assumed to be independent.

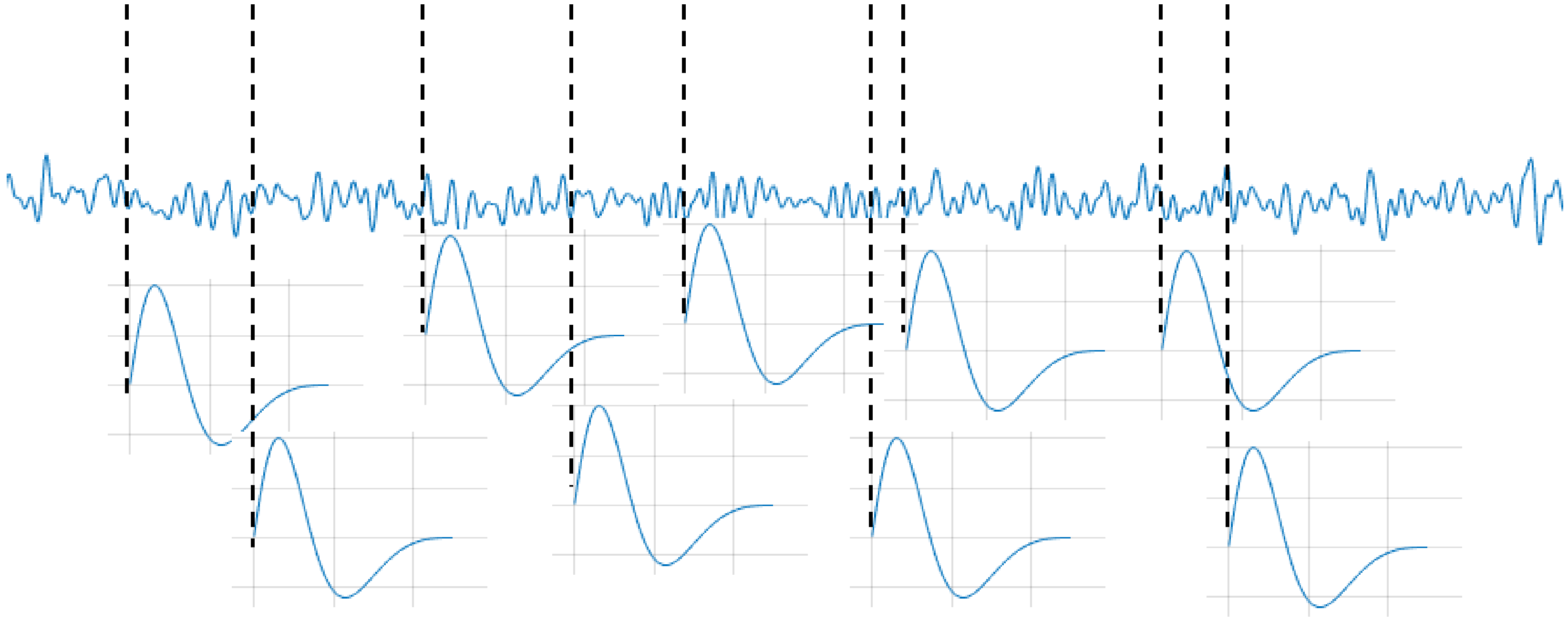
Noise is independent over trials.

Subsequent ERPs are not overlapping.

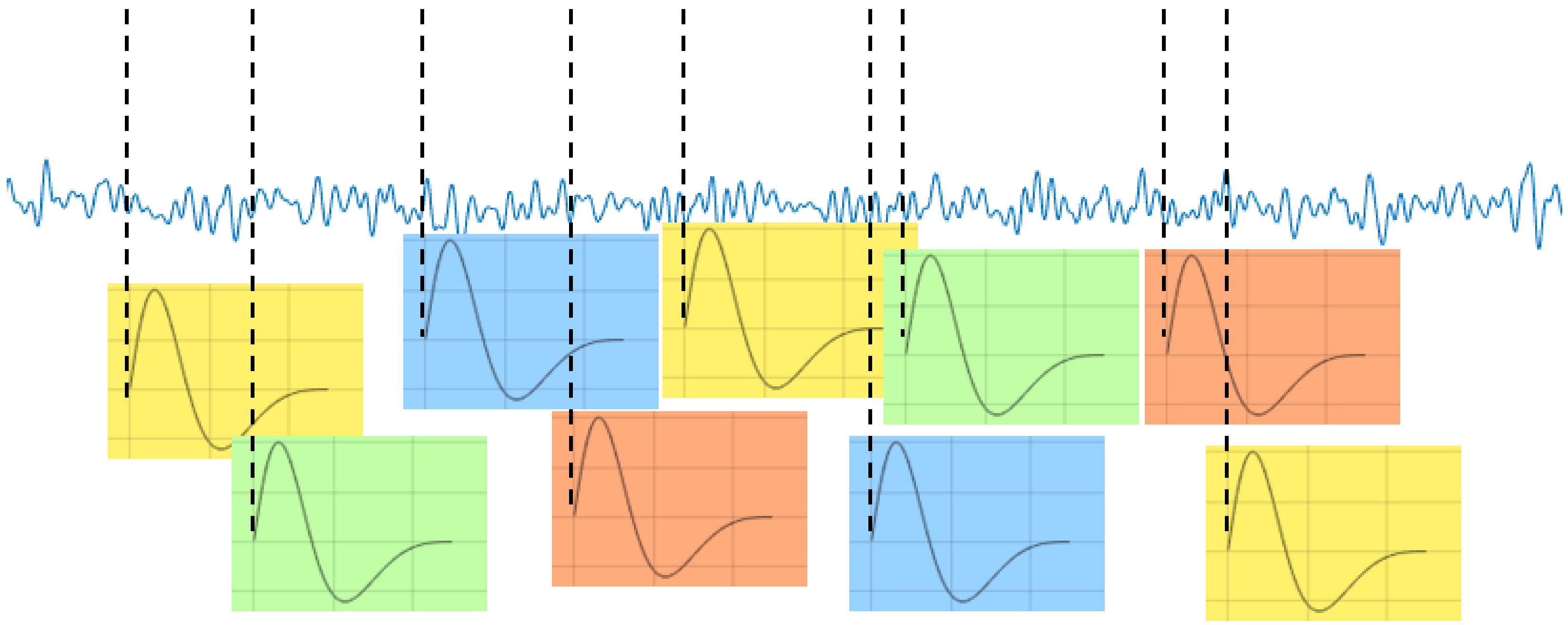
What if ITI is not sufficiently large?



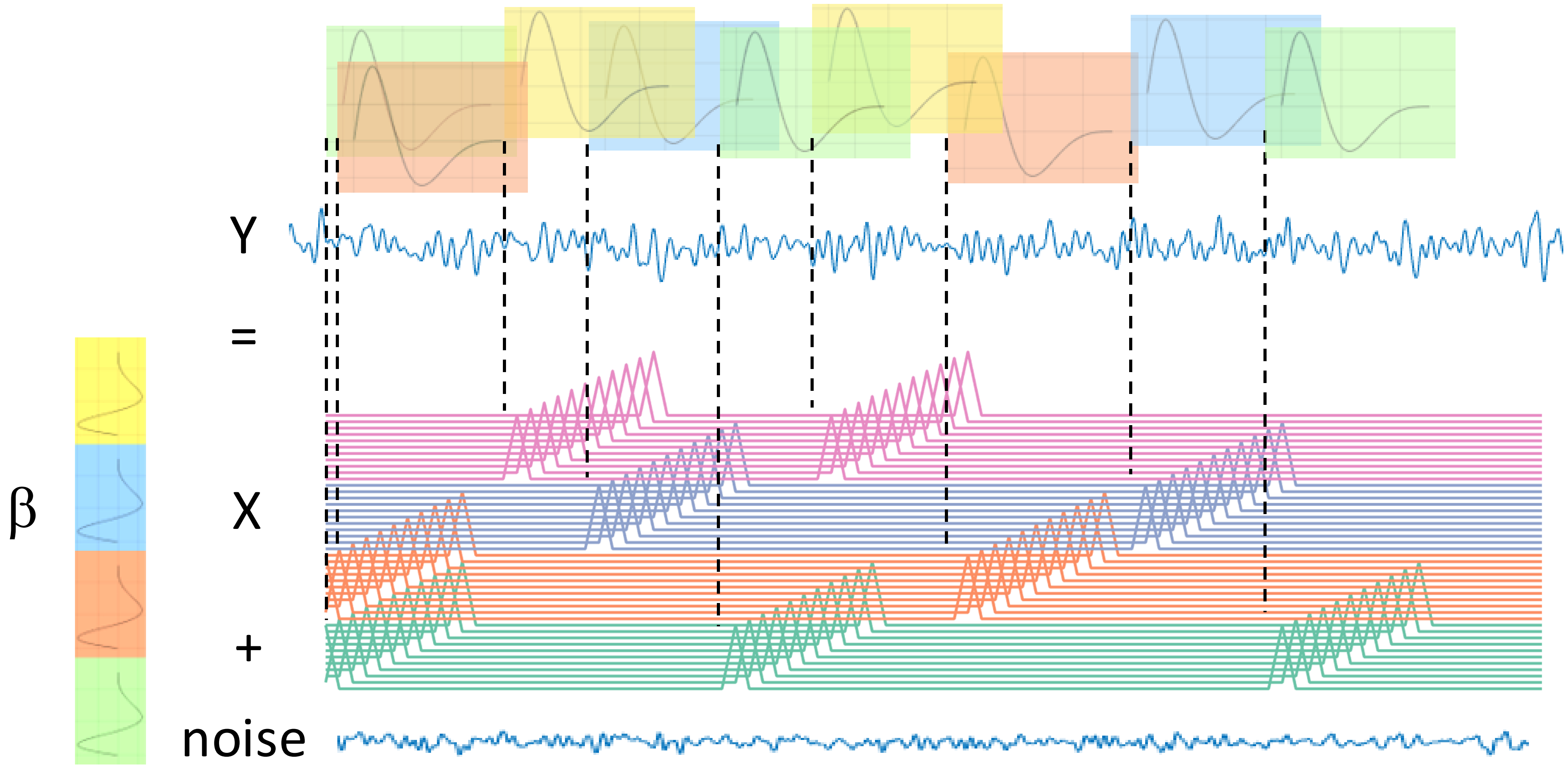
What if the responses to events are overlapping?



What if different types of events are overlapping?



Temporal-response functions (TRFs)
Time-shifted GLM with multiple regressors



Temporal-response functions (TRFs)
Time-shifted GLM with multiple regressors

Litvak et al (2013) Neuroimage
www.fil.ion.ucl.ac.uk/spm/
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Ehinger & Dimigen (2018) PeerJ
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github.com/mickcrosse/mTRF-Toolbox
J.M.Schoffelen et al.
https://github.com/fieldtrip/fieldtrip/blob/master/ft_denoise_tsr.m