Group level statistics with EEGLAB and LIMO tools

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Motivation for hierarchical models

- Most often, we compute averages per condition and do statistics on peak latencies and amplitudes

- Univariate methods extract information among trials in time and/or frequency across space
- Multivariate methods extract information across space, time, or both, in individual trials
- Averages don't account for trial variability, fixed effect can be biased – HLM allow to get around these problems

Pernet, Sajda & Rousselet – Single trial analyses, why bother? Front. Psychol., 2011, 2, 322

Fixed, Random, Mixed and Hierarchical

Fixed effect: Something the experimenter directly manipulates

y=XB+e data = beta * effects + error
y=XB+u+e data = beta * effects + constant subject effect + error

Random effect: Source of random variation e.g., individuals drawn (at random) from a population. **Mixed effect**: Includes both, the fixed effect (estimating the population level coefficients) and random effects to account for individual differences in response to an effect

Y=XB+Zu+e data = beta * effects + zeta * subject variable effect + error

Hierarchical models are a mean to look at mixed effects.

Fixed vs Random

Fixed effects:

Intra-subjects variation

suggests all these subjects

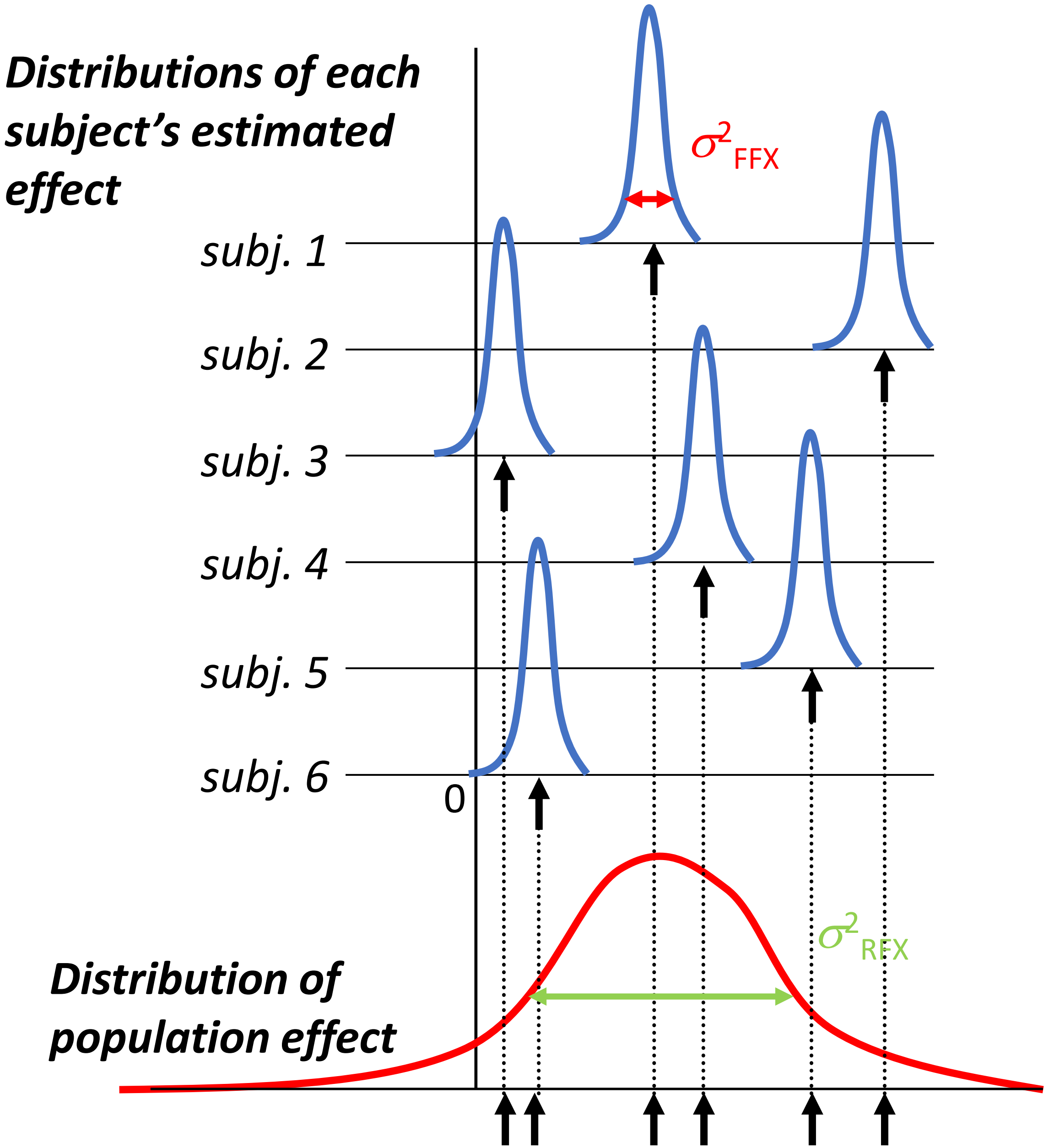
different from zero

Random effects:

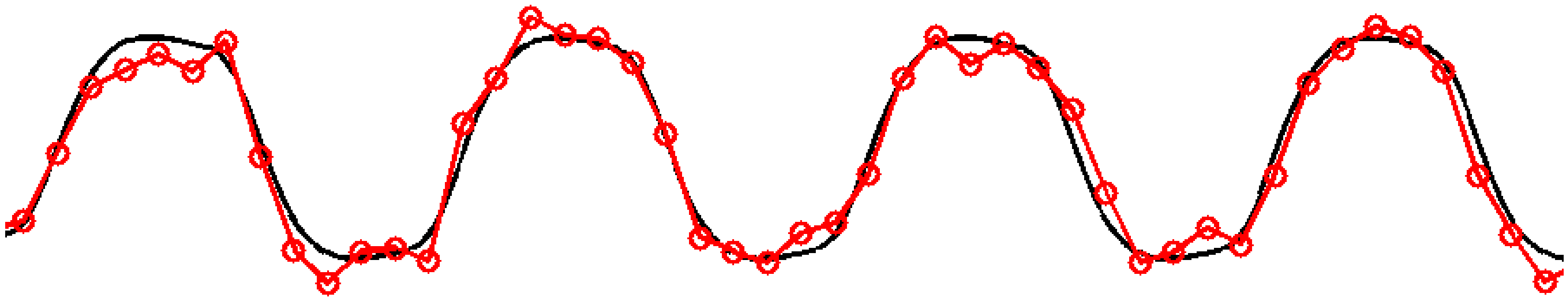
Inter-subjects variation

suggests population

not different from zero

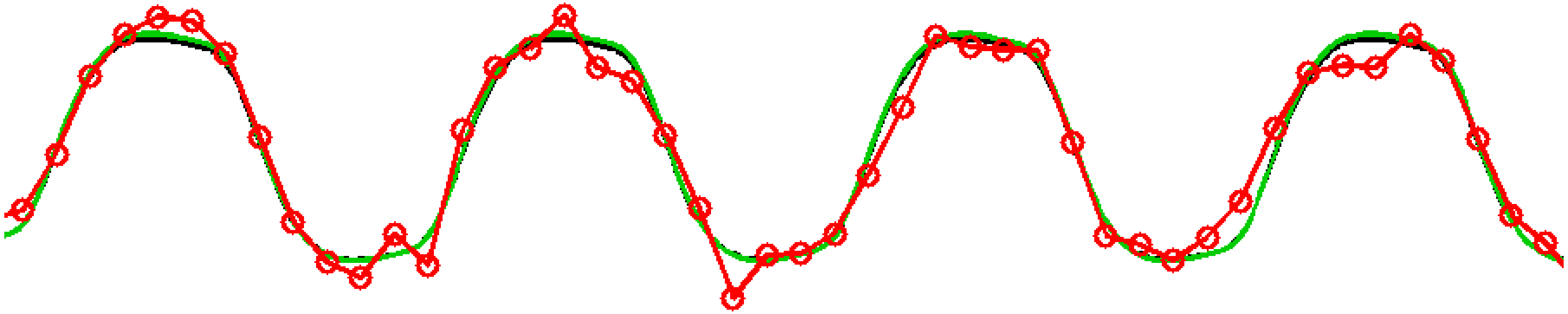


Fixed effects



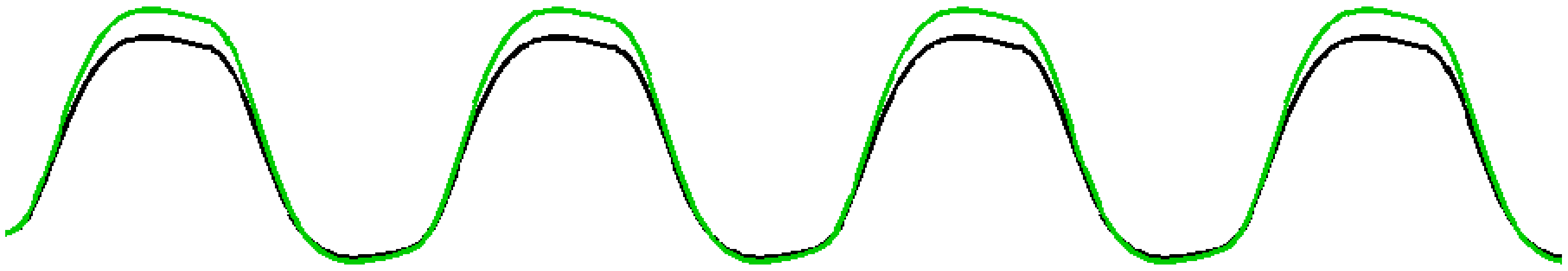
- Only source of variation (over trials) is measurement error
- True response magnitude is *fixed*

Random effects



- Two sources of variation
  - measurement errors
  - response magnitude (over subjects)
- Response magnitude is *random*
  - each subject has random magnitude

Random effects



- Two sources of variation
  - measurement errors
  - response magnitude (over subjects)
- Response magnitude is *random*
  - each subject has random magnitude
  - but note, population mean magnitude is *fixed*

Hierarchical model = 2-stage Linear Model

Single subject

Each subject's EEG trials are modelled
Single subject parameter estimates

1st level

Single subject parameter estimates or combinations taken to 2nd level

Group/s of subjects

For a given effect, the whole group is modelled
Parameter estimates apply to group effect/s

2nd level

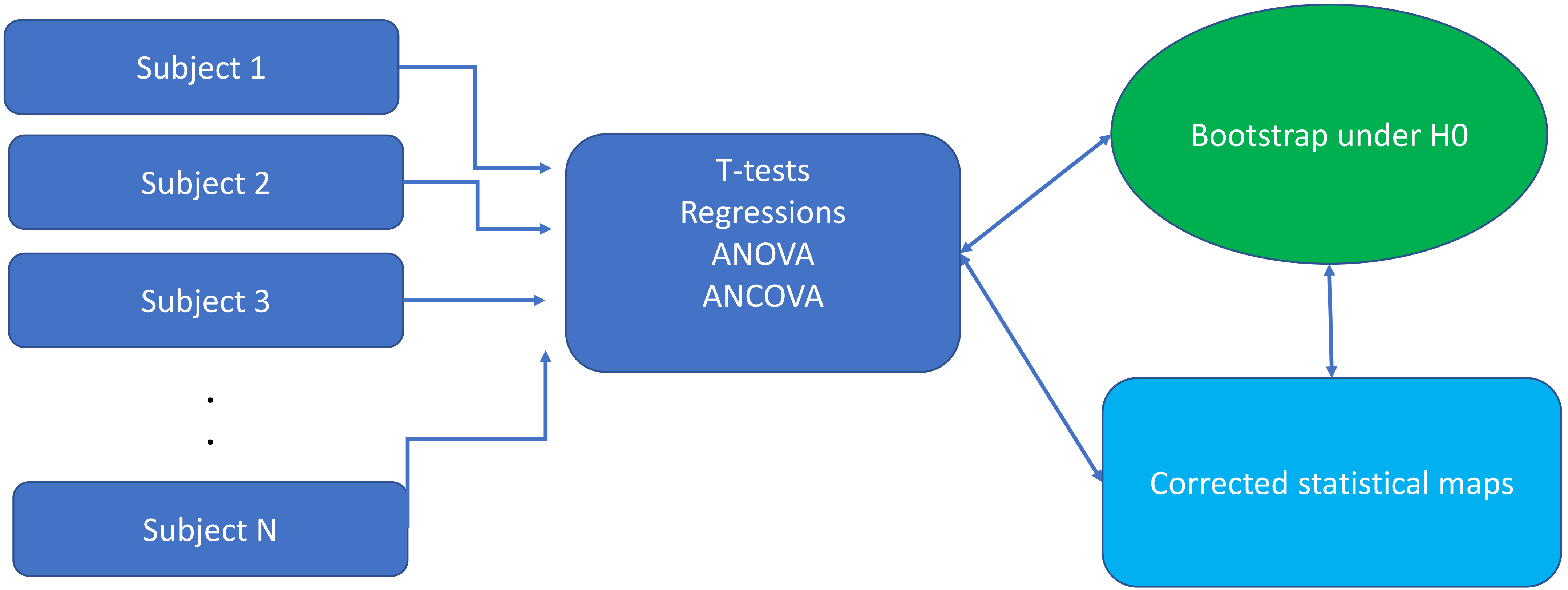
Group level of 2nd level parameter estimates are used to form statistics

Hierarchical Linear Model Framework

<u>1st level</u>
Robust GLM: Y = WXβ
Like getting weighted averages

<u>2st level</u>
Robust statistics on trimmed mean
~usual tests but account for outliers

<u>Multiple Comparisons correction</u>
Max stats, max clusters and TFCE



What are linear models?

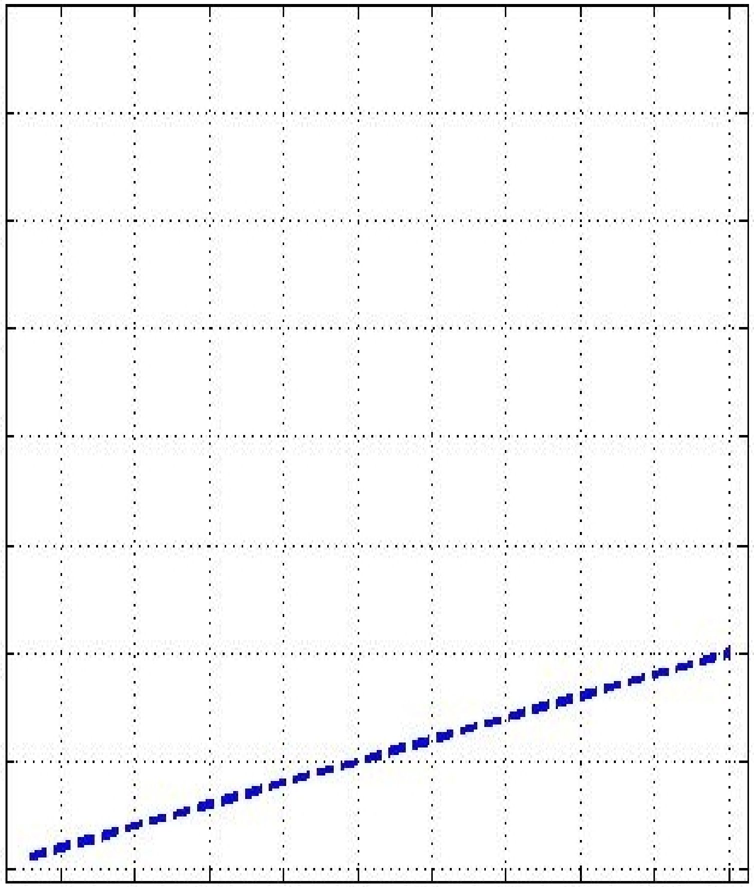
What is a linear model?

- An equation or a set of equations that models data and which corresponds geometrically to straight lines, planes, hyper-planes and satisfy the properties of additivity and scaling.

- Simple regression: $y = \beta1x+\beta2+\varepsilon$
- Multiple regression: $y = \beta1x1+\beta2x2+\beta3+\varepsilon$
- One way ANOVA: $y = u+\alpha i+\varepsilon$
- Repeated measure ANOVA: $y=u+\alpha i+\varepsilon$
- …

A regression is a linear model

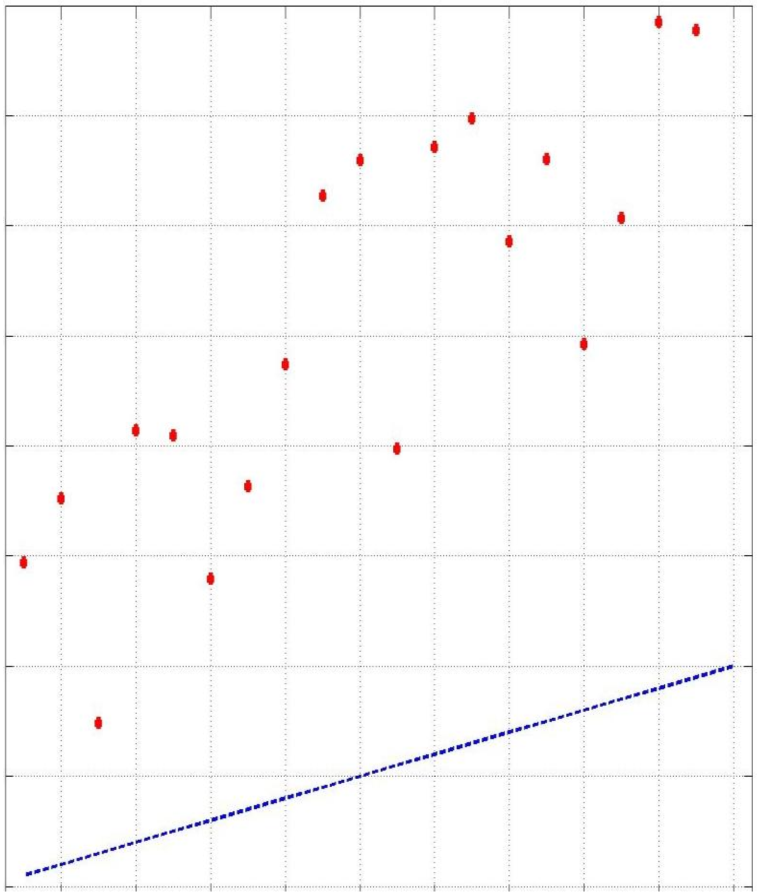
- We have an experimental measure x (e.g. stimulus intensity from 0 to 20)



A regression is a linear model

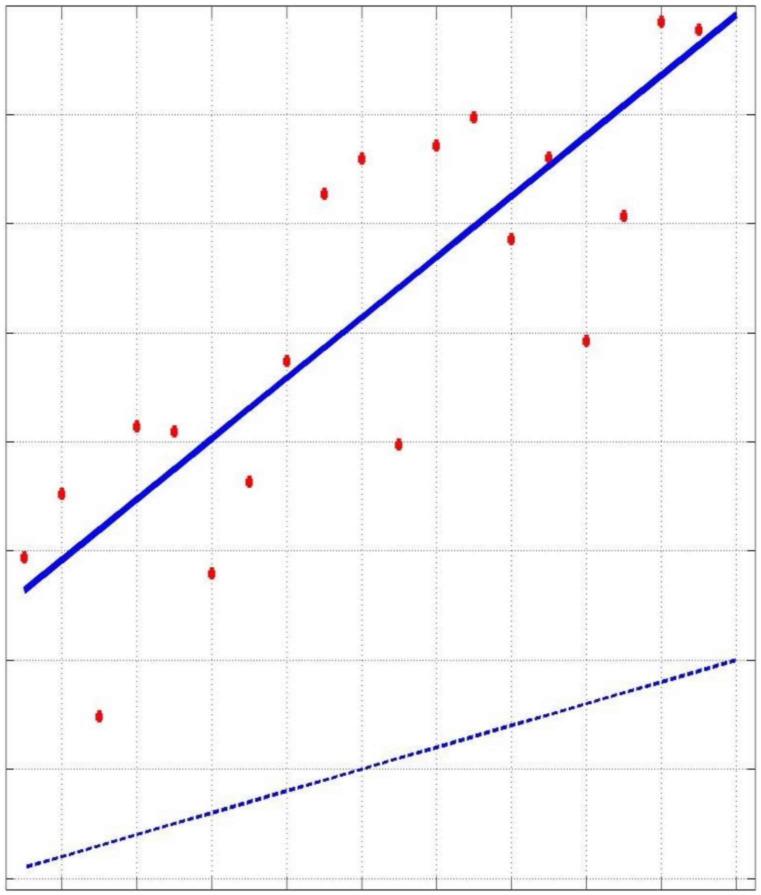
- We have an experimental measure x (e.g. stimulus intensity from 0 to 20)

- We then do the expe and collect data y (e.g. RTs)



A regression is a linear model

- We have an experimental measure x (e.g. stimulus intensity from 0 to 20)
- We then do the expe and collect data y (e.g. RTs)
- Model: $y = \beta 1x+\beta 2$
- Do some maths / run a software to find $\beta 1$ and $\beta 2$
- $\hat{y} = 2.7x+23.6$



Linear algebra for ANOVA

- In text books we have $y = u + xi + \varepsilon$, that is to say the data (e.g. RT) = a constant term (grand mean u) + the effect of a treatment (xi) and the error term (ε)
- In a regression xi takes several values like e.g. [1:20]
- In an ANOVA xi is designed to represent groups using 1 and 0

Linear algebra for ANOVA

Y	Gp
8	1
9	1
7	1
5	2
7	2
3	2
3	3
4	3
1	3
6	4
4	4
9	4

y(1..3)1= 1x1+0x2+0x3+0x4+c+e11
y(1..3)2= 0x1+1x2+0x3+0x4+c+e12
y(1..3)3= 0x1+0x2+1x3+0x4+c+e13
y(1..3)4= 0x1+0x2+0x3+1x4+c+e13

$$\begin{Bmatrix} 8 \\ 9 \\ 7 \\ 5 \\ 7 \\ 3 \\ 3 \\ 4 \\ 1 \\ 6 \\ 4 \\ 9 \end{Bmatrix} = \begin{Bmatrix} 1\,0\,0\,0\,1 \\ 1\,0\,0\,0\,1 \\ 1\,0\,0\,0\,1 \\ 0\,1\,0\,0\,1 \\ 0\,1\,0\,0\,1 \\ 0\,1\,0\,0\,1 \\ 0\,0\,1\,0\,1 \\ 0\,0\,1\,0\,1 \\ 0\,0\,1\,0\,1 \\ 0\,0\,0\,1\,1 \\ 0\,0\,0\,1\,1 \\ 0\,0\,0\,1\,1 \end{Bmatrix} * \begin{Bmatrix} \beta 1 \\ \beta 2 \\ \beta 3 \\ \beta 4 \\ c \end{Bmatrix} + \begin{Bmatrix} e1 \\ \vdots \\ e13 \end{Bmatrix}$$

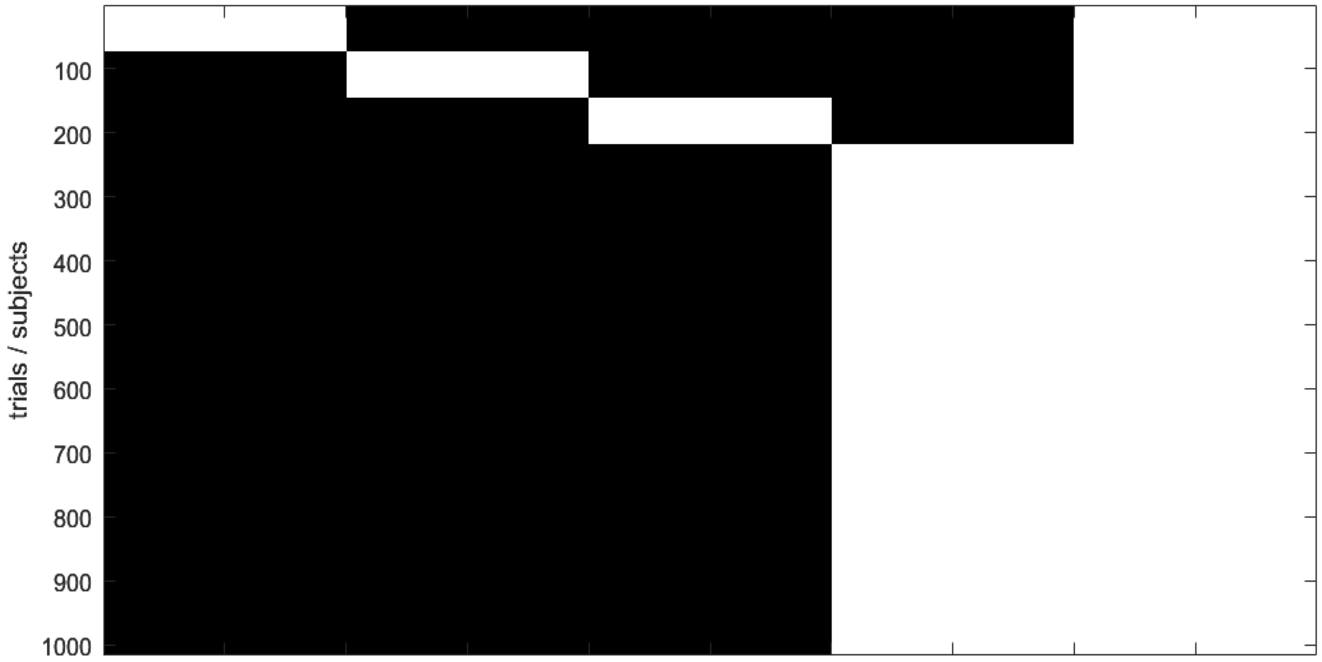
→ This is like the multiple regression except that we have ones and zeros instead of 'real' values so we can solve the same way

Group analyses examples for ERPs

MMN

Mismatch Negativity: is an auditory event-related potential that occurs when a sequence of repetitive sounds is interrupted by one or more occasional "oddball" sounds that differs in e.g. frequency or duration.

1st level



2nd level

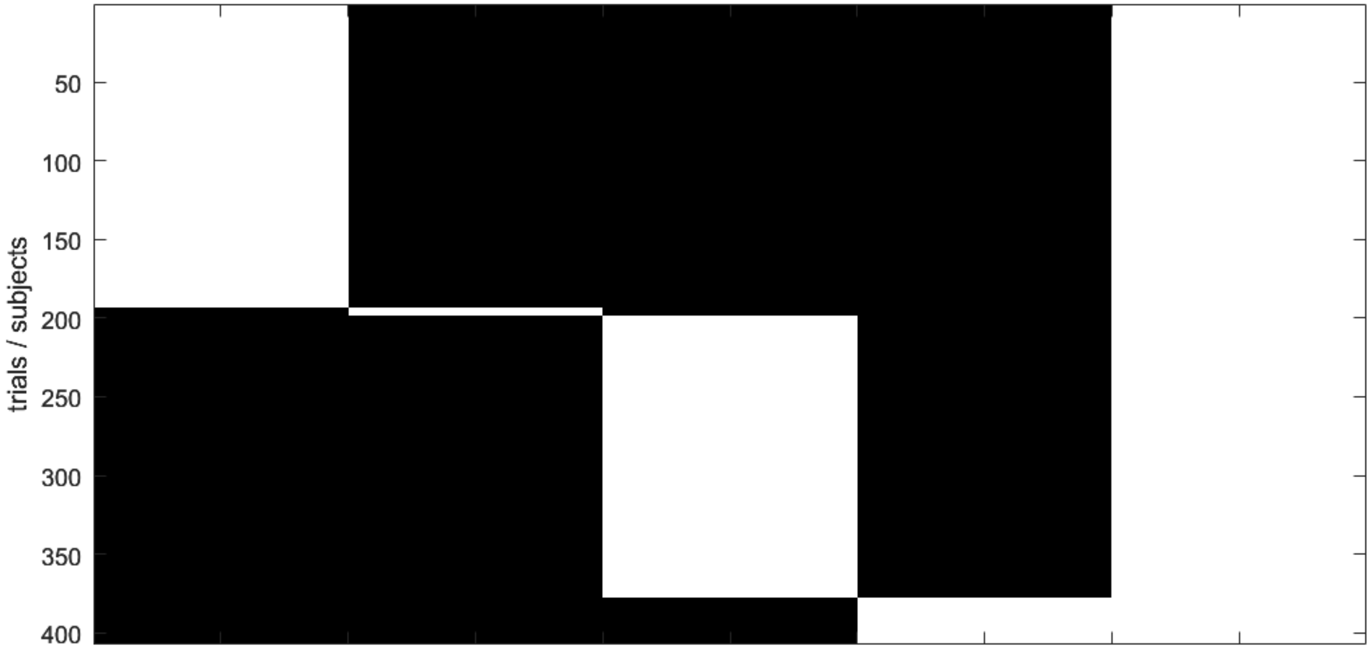
Average MMN
→ One sample t-test on a contrast between all oddball trials vs standard
[-1 -1 -1 3 0]

MMN differences
→ Repeated measure ANOVA on item specific oddball trials
[-1 0 0 1 0] vs [0 -1 0 1 0] vs [0 0 -1 1 0]

ERN

Error-Related Negativity using a flanker task: ask to pay attention to a stimulus at a known location on the right or left side of the fixation point and give a congruent or incongruent primer.

1st level



2nd level

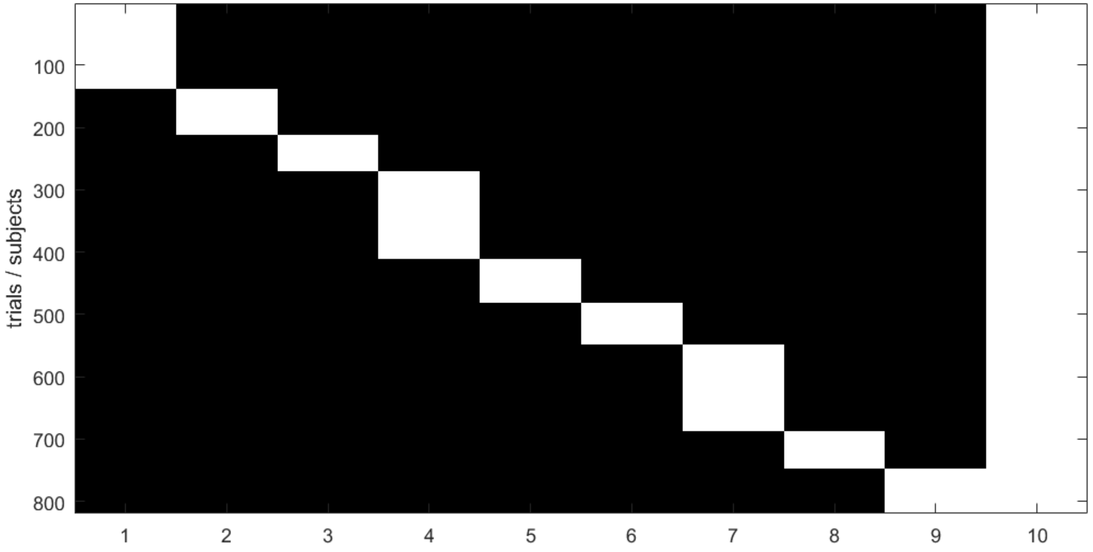
ERN
→ One sample t-test on a contrast error - correct [1 -1 1 -1 0]

Factorial ERP

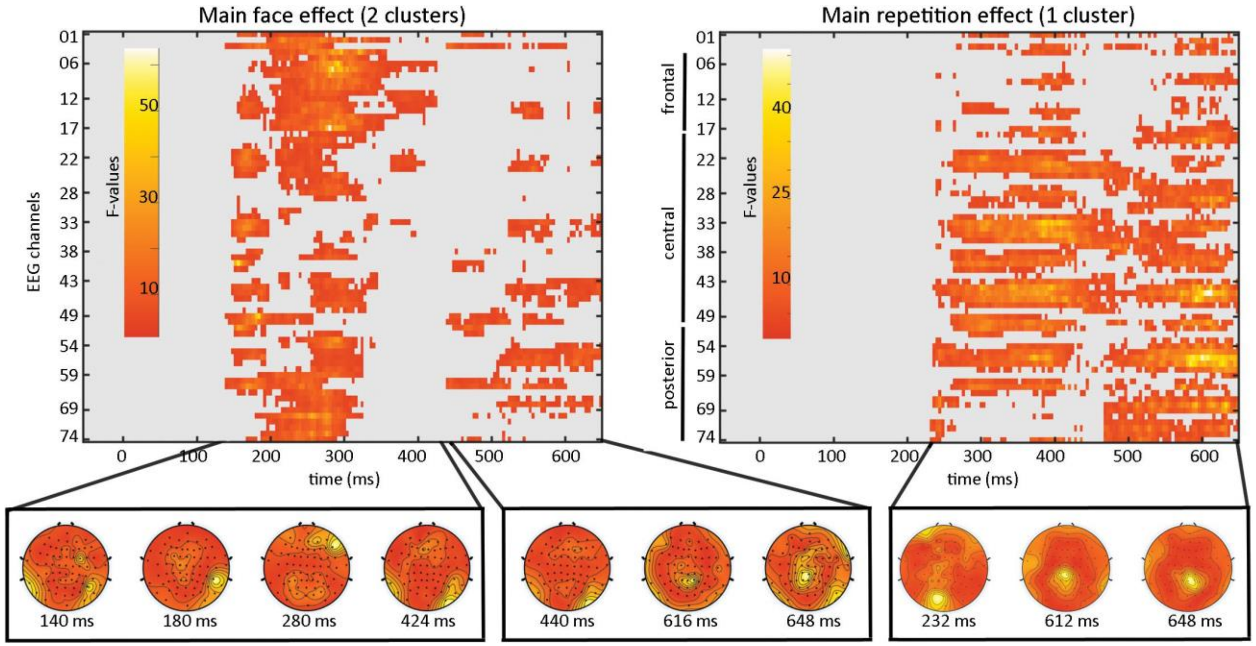
ERP from 9 conditions: 3 types of faces (famous, scrambled, unfamiliar) by 3 levels of repetition (immediately, soon after, much later)

2nd level

1st level



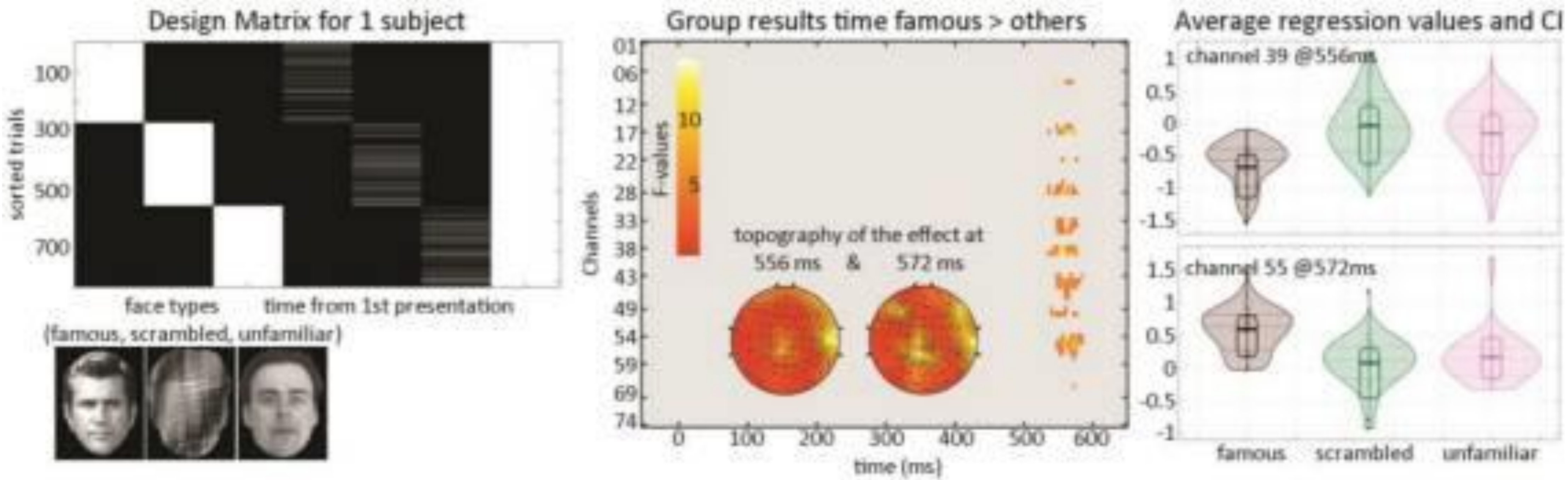
Repeated measures ANOVA of Beta parameters (i.e. one beta per condition)



Modulation of ERP

ERP from 3 modulated conditions: 3 types of faces (famous, scrambled, unfamiliar) repeated at different distances from each other

<u>1st level</u> **<u>2nd level</u>** Repeated measures ANOVA of Beta parameters 4,5,6.



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- **Pernet, C., et al. (2015)** Cluster-based computational methods for mass univariate analyses of event-related brain potentials/fields: A simulation study. Journal of *Neuroscience Methods, 250*, 85-93
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- **Pernet et al. (2022)** Electroencephalography robust statistical linear modelling using a single weight per trial. *Aperture Neuro* 51