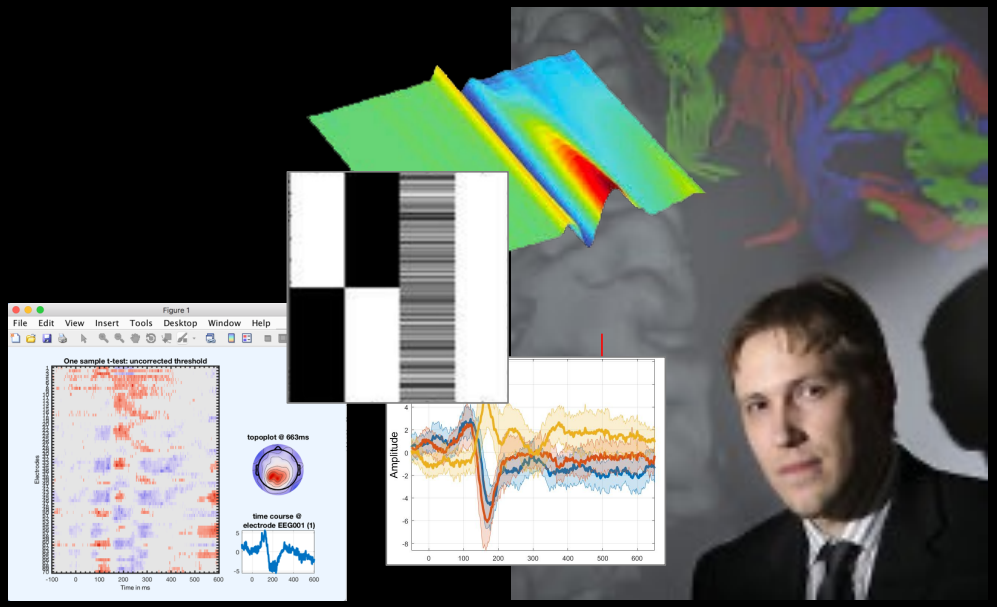
General Linear Modeling in EEGLAB/LIMO

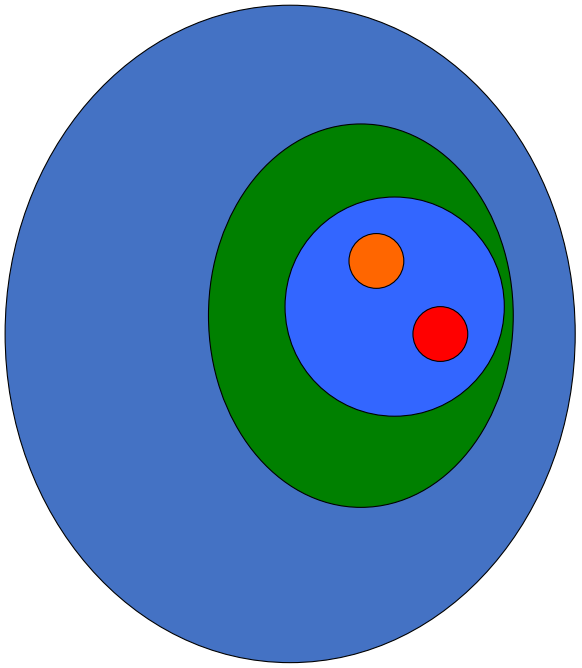
Basic Theory

Arnaud Delorme



Cyril Pernet

The GLM family



T-tests

Simple regression

ANOVA

Multiple regression

General linear model

- Mixed effects/hierarchical
- Timeseries models (e.g., autoregressive)
- Robust regression
- Penalized regression (LASSO, Ridge)

Generalized linear models

- Non-normal errors
- Binary/categorical outcomes (logistic regression)

One-step solution

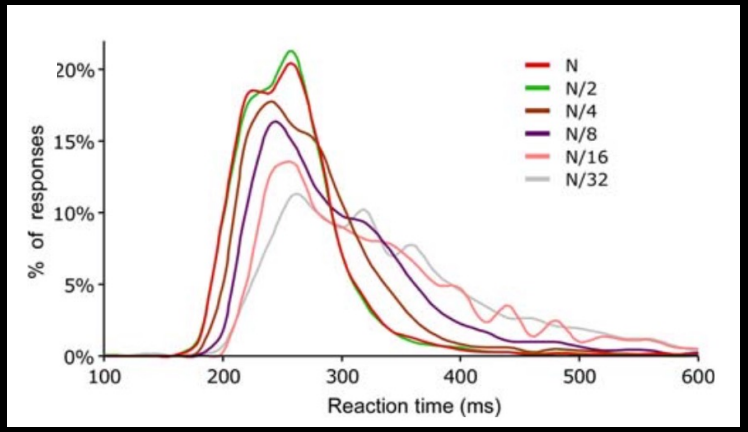
Iterative solutions (e.g., IWLS)

Slide from Tor Wager

A regression is a linear model

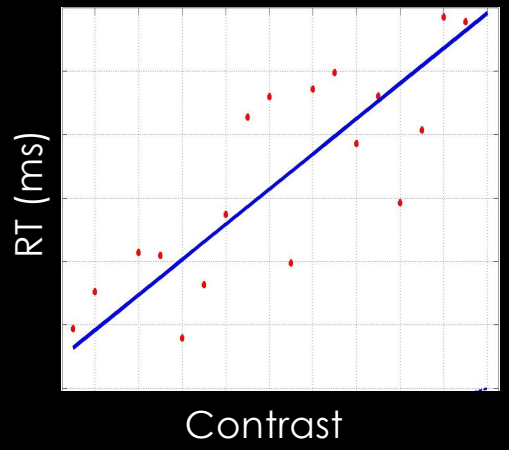
Varying factor: Contrast of image

Outcome: Reaction time



Mace, M., Delorme, A., Richard, G., Fabre-Thorpe, M. (2010) Spotting animals in natural scenes: efficiency of humans and monkeys at very low contrasts. *Animal Cognition*, 13(3):405-18.

A regression is a linear model



- Given an experimental measure x (e.g. contrast)
- We then do the experiment and collect data RT (e.g. reaction time)
- Model: $RT = \beta_0 + x\beta_1 + \varepsilon$
- Do some maths / run a software to find β_1 and β_0
- $\hat{RT} = 23.6 + 2.7x$

A regression is a linear model

For each trial

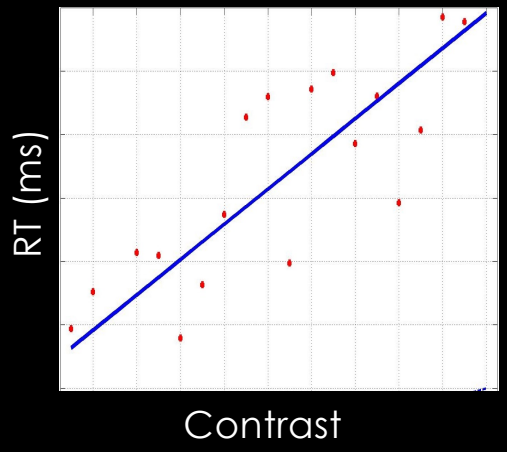
Contrast level

$RT_1 = \beta_0 + 10*\beta_1 + \varepsilon_1$

$RT_2 = \beta_0 + 5*\beta_1 + \varepsilon_2$

$RT_3 = \beta_0 + 7*\beta_1 + \varepsilon_3$

…



To test for significance compare the original regression model $RT_i = \beta_0 + c_i*\beta_1 + \varepsilon_i$ with the simplified model $RT_i = \beta_0 + \varepsilon_i$

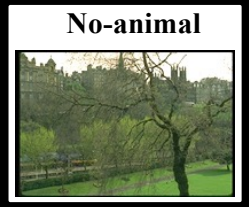
Compare the fit

Test if 0 included in confidence interval

An ANOVA is a linear model

Varying factor: Type of image

Outcome: Reaction time (go/no-go)



$$RT_{i,j} = \beta_0 + \beta_i + \varepsilon_{i,j}$$

that is to say the data (e.g. RT) = a constant term (grand mean β_0) + the effect of a treatment (β_1 for fishes 1 and β_2, β_3 for birds and reptiles) and the error term ($\varepsilon_{i,j}$)

For trial 4 (for example first trial of birds) we have

$$RT_{2,1} = \beta_0 + 0*\beta_1 + 1*\beta_2 + 0*\beta_3 + \varepsilon_{2,1}$$

This is a GLM that is equivalent to an ANOVA

For trial 13 (for example second trial of birds) we have

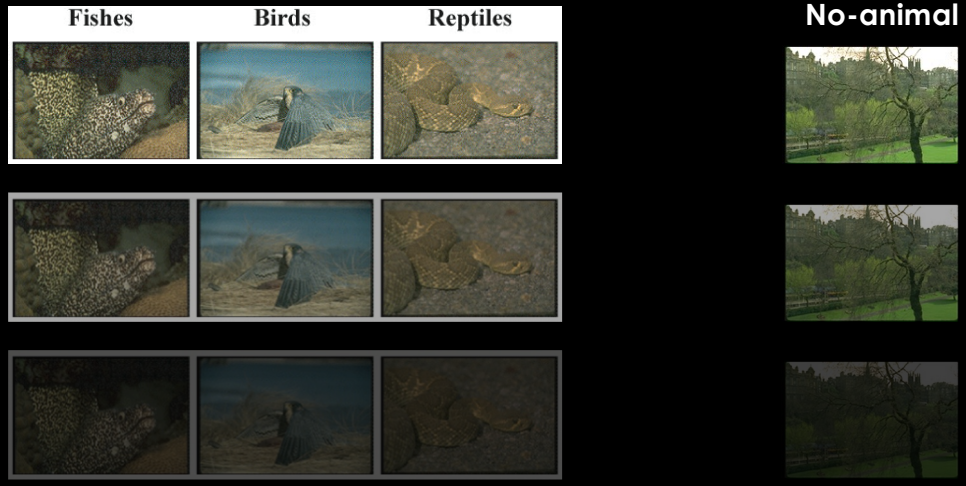
$$RT_{2,2} = \beta_0 + 0*\beta_1 + 1*\beta_2 + 0*\beta_3 + \varepsilon_{2,2}$$

Statistics: if there is an effect of treatment then error of the simplified model $RT_{i,j} = \beta_0 + \varepsilon_{i,j}$ should be lower than the original model $RT_{i,j} = \beta_0 + \beta_i + \varepsilon_{i,j}$

Compare the fit

A GLM can do both a Regression and an ANOVA (ANCOVA)

Varying factor: Type of image **AND** contrast
Outcome: Reaction time (go/no-go)



For example, for trial (first bird with contrast $c_{2,1}$) we have

$$RT_{2,1} = \beta_0 + \underbrace{0*\beta_1 + 1*\beta_2 + 0*\beta_3 + 0*\beta_3}_{\text{Categorical var. ANOVA}} + \underbrace{c_{2,1}*\beta_4}_{\text{Continous var. REGRESSION}} + \varepsilon_{2,1}$$

The design matrix

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

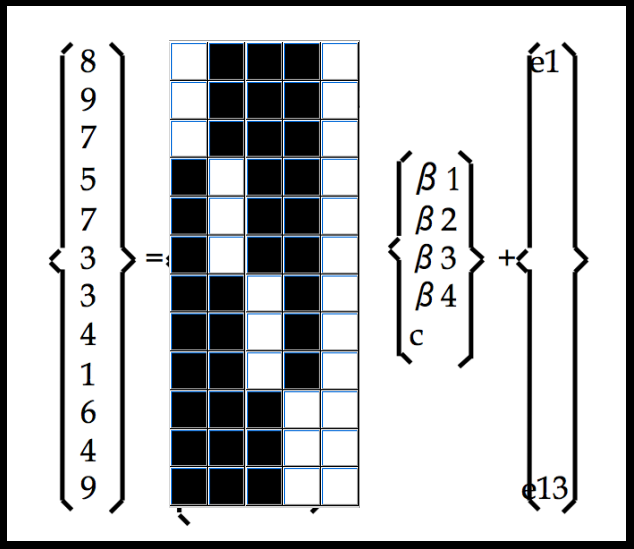
$y(1..3) = 1x\beta1+0x\beta2+0x\beta3+0x\beta4+c+error$

$y(4..6) = 0x\beta1+1x\beta2+0x\beta3+0x\beta4+c+error$

$y(7..9) = 0x\beta1+0x\beta2+1x\beta3+0x\beta4+c+error$

$y(10..12) = 0x\beta1+0x\beta2+0x\beta3+1x\beta4+c+error$

Design matrix
$G_1\ G_2\ G_3\ G_4\ C$

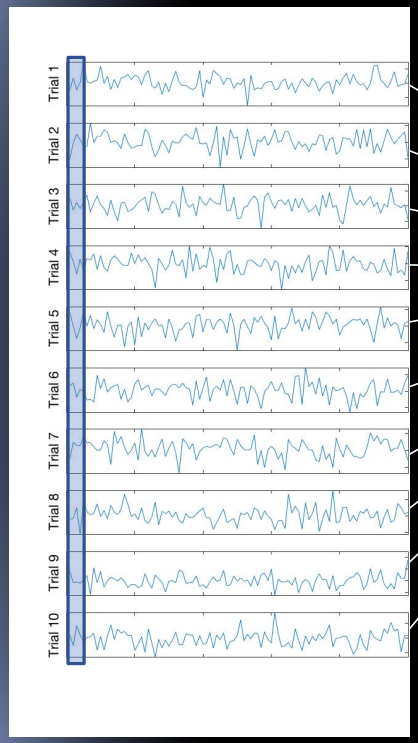


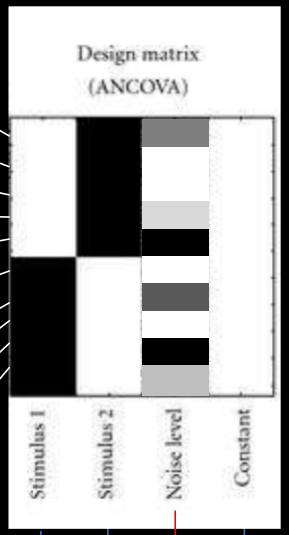
Y = D * β + ε

Measures — Model/ Design matrix — Unknown — Errors

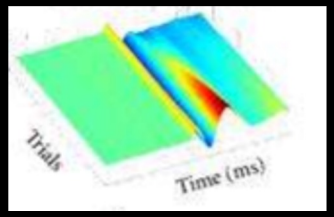
Linear Modeling of EEG data: level 1

Electrode 1

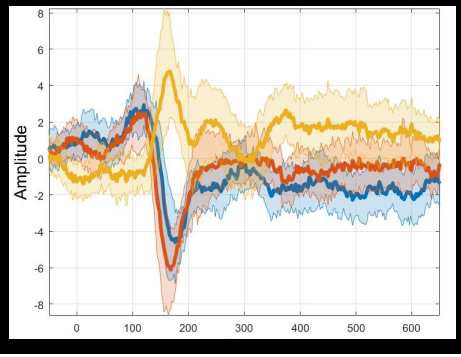




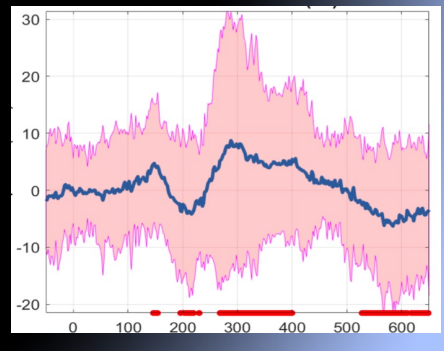
Continuous var.



Categorical var.



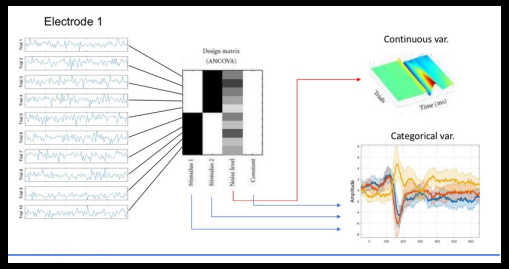
Electrode difference
Between conditions



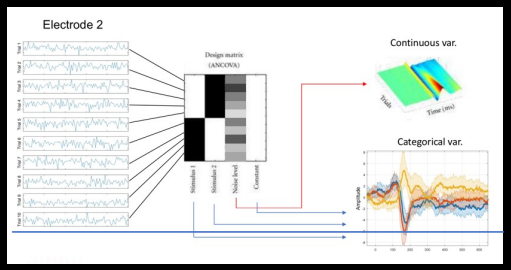
Significance: bootstrap trials to get confidence interval of βs

Linear Modeling of EEG data: level 1

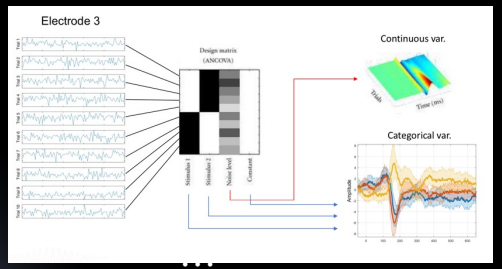
Electrode 1



Electrode 2



Electrode 3



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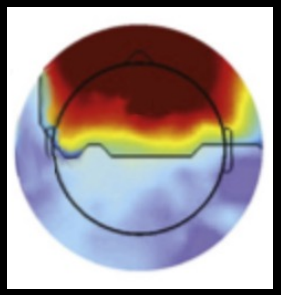
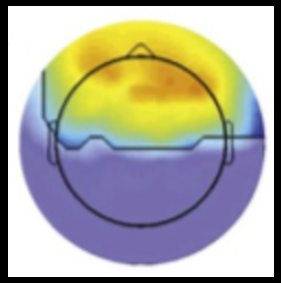
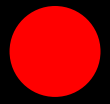
Scalp topography of
beta difference
at a given latency



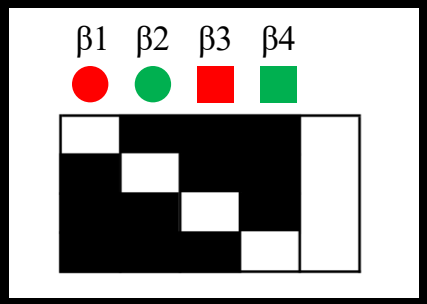
Scalp topography of
potential difference
(masked using beta signif.)



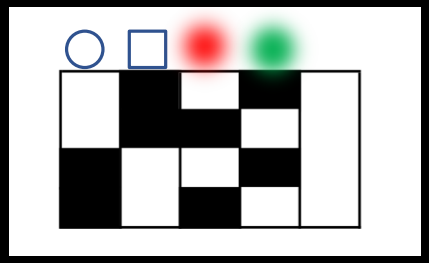
Limit of the regions masked for significance

Stimuli  Or  Or  Or 

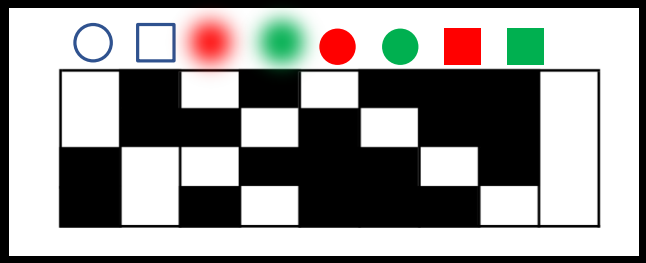
1. Interaction design
(EEGLAB default)



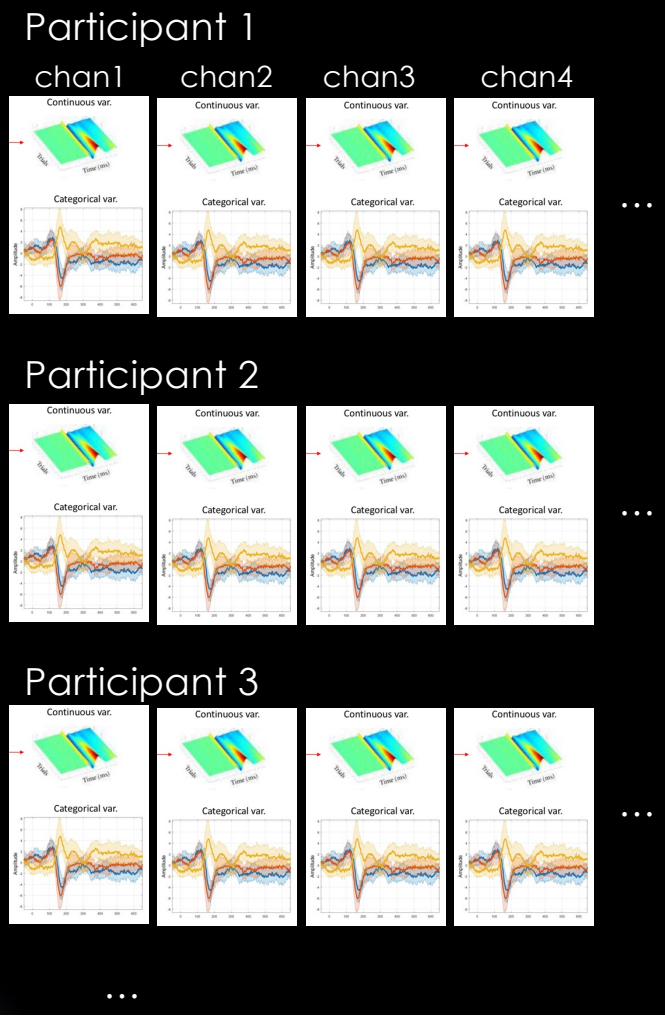
2. Factorial design



3. Full factorial design



Linear Modeling of EEG data: level 2

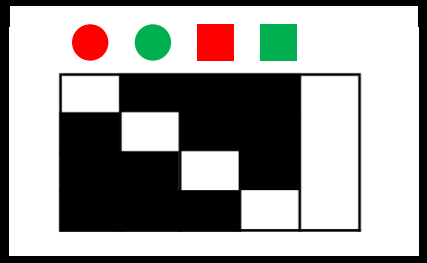


GLM: ordinary least square (OLS) vs. weighted least square (WLS)

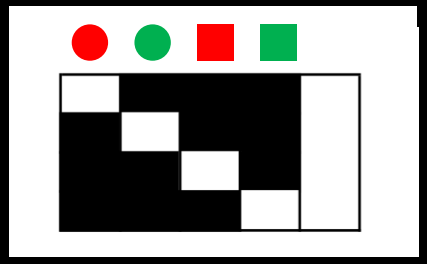
Linear Modeling of EEG data: level 2

Level 1

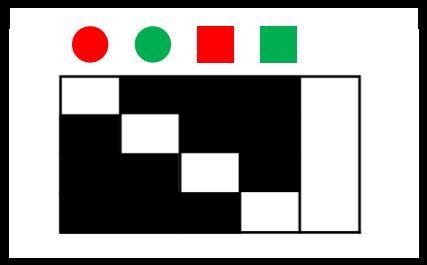
Participant 1



Participant 2



Participant 3



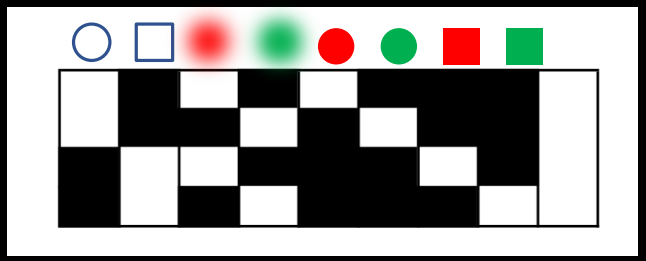
Level 2

2-way ANOVA:

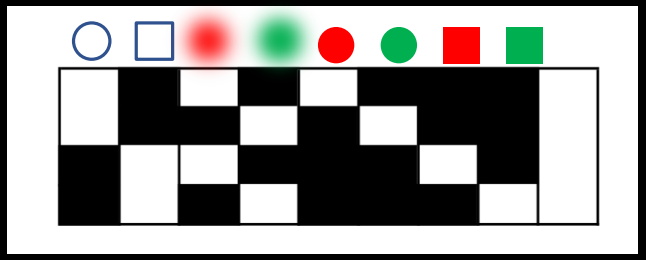
- Main effect 1 (shape)
- Main effect 2 (color)
- Interaction

Linear Modeling of EEG data: level 2

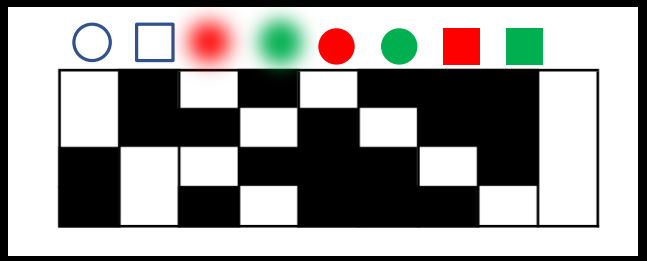
Participant 1



Participant 2



Participant 3



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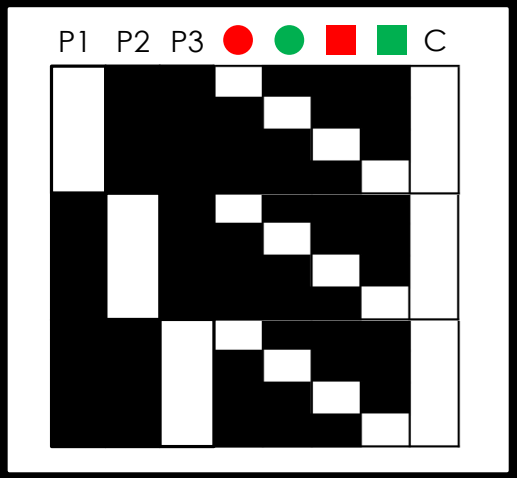
Shape:
Group t-test on β○– β□

Color
Group t-test on β✸ – β✸

Interaction
- One sample t-test on
β●, β●, β■, β■

Linear Modeling of EEG data: level 2

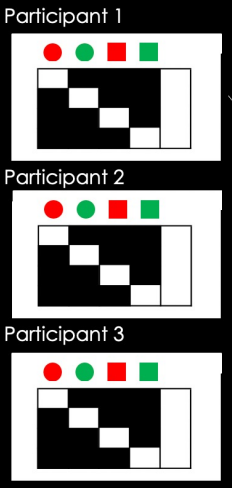
Mixed effect model
(still a GLM)



VS

Hierarchical GLM

Level 1



Level 2

2-way ANOVA:
- Main effect 1 (shape)
- Main effect 2 (color)
- Interaction