Linear mixed effects models for zero-training BCI

by
Siamac Fazli, Juerg Schelldorfer
and
Klaus-Robert Müller

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Introduction to LMM

Lets assume that Juerg, Klaus and me like to run 100m sprints and each one of us runs n=50 sprints a year.

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Explanatory variables (e.g. subject weight, hours of sleep, etc.) for each subject and every sprint are:

$$X_1, X_2, X_3 \in \mathbb{R}^{n \times p}$$

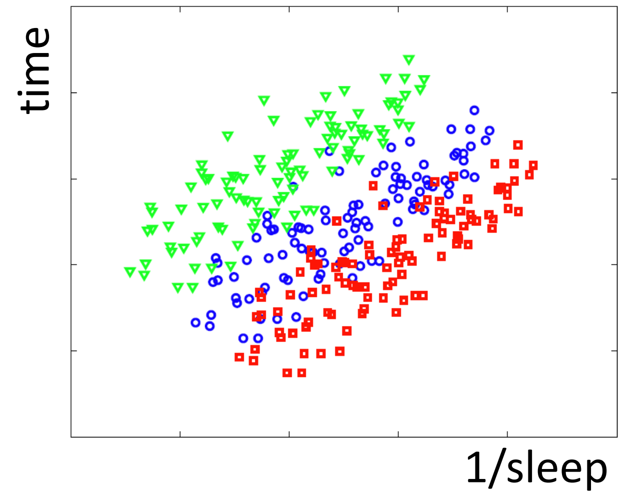
Response variable is the measured times:

$$Y_1, Y_2, Y_3 \in \mathbb{R}^n$$

$$< Y_1 >= 10 \pm 1s$$

$$< Y_2 >= 12 \pm 1s$$

$$< Y_3 >= 15 \pm 1s$$



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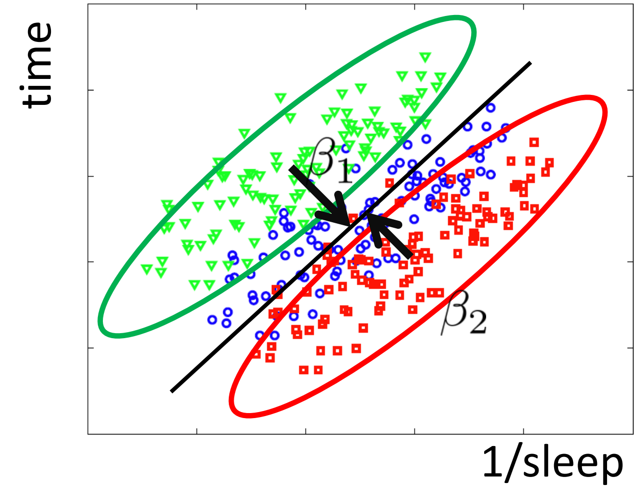

Task: find (common) linear projection b for all three subjects

$$Y = Xb + \epsilon$$

$$X = [X_1 X_2 X_3]$$
$$Y = [Y_1 Y_2 Y_3]$$

Problem: A requisite for linear regression is that the measurements are independent from each other.
In our case the input signals can have a subject-dependent bias!

Solution: model the bias term as an extra parameter for every group:

$$Y_i = X_i b + \beta_i + \epsilon_i$$

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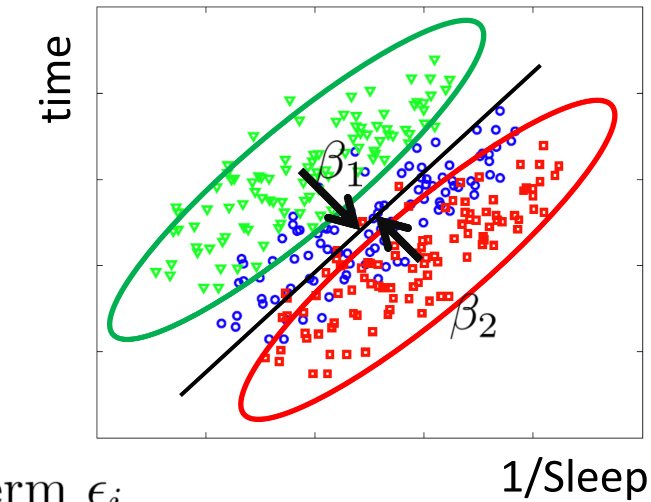


$$Y_i = X_i b + \beta_i + \epsilon_i$$

common b for all observations

group-specific deviations β_i

noise term ϵ_i

$$\beta_i \sim \mathcal{N}(0, \tau^2)$$

between-group variance τ

$$\epsilon_i \sim \mathcal{N}(0, \sigma^2)$$

within-group variance σ

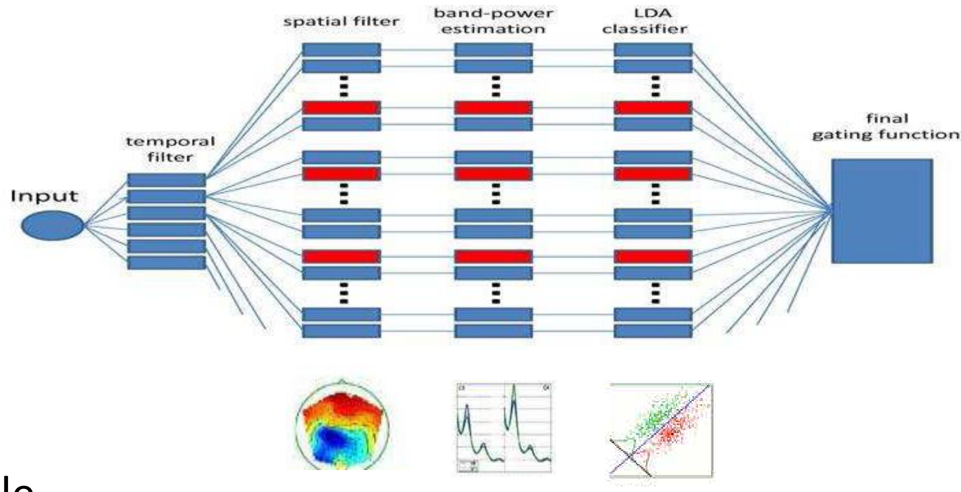
assumption: ϵ_i is independent of β_i

Generation of the data

ensemble generation

- 18 parallel temporal filters (predefined)
- 80 spatial filters per parallel filter (estimated)
- 80 classifiers per parallel filter (estimated)

18*80= **1400 classifiers in total**



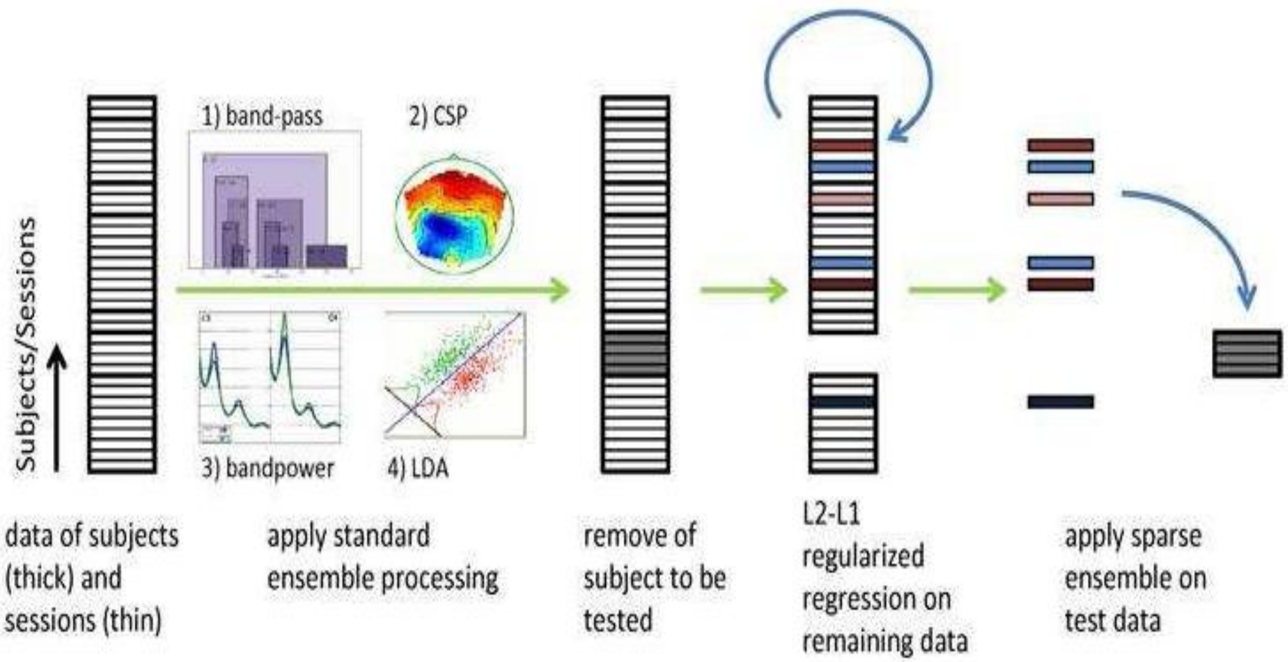
dataset generation

- each dataset has 150 trials
- all trials (80 * 150) are fed into the ensemble (this is the group stucture)

Thus our data set has **1400 features x 12450 trials**

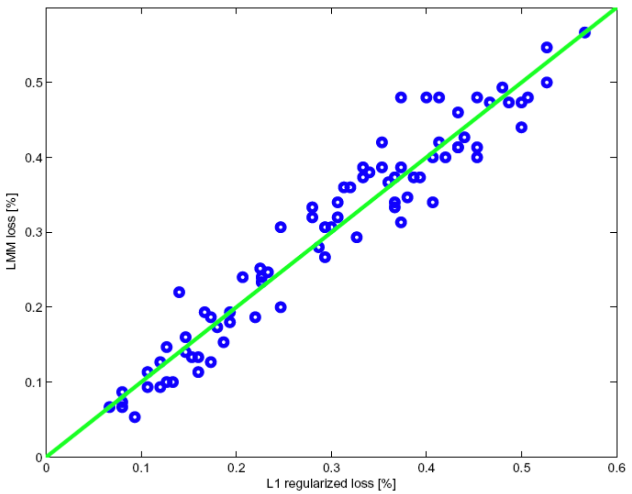
Leave-one-subject-out-cross-validation

..of course we are not allowed to use all features, but must exclude those, which stem from the subject itself…



Results -prediction

	model	
training data	LMM	L1-LSR
10%	29.8	29.52
20%	29.24	29.3
30%	29.21	29.44
40%	28.91	28.81



LMM does not outperform our original approach, percentage-wise…

Results – model interpretation

- surprisingly the estimated between-group variance low $\hat{\tau} \approx 0.1$, as compared to the within-group variance is large $\hat{\sigma} \approx 0.9$

$$\frac{\tau^2}{\tau^2 + \sigma^2} = 0.012$$

- i.e. **98.8%** of total variability is explained by **within-group variance**

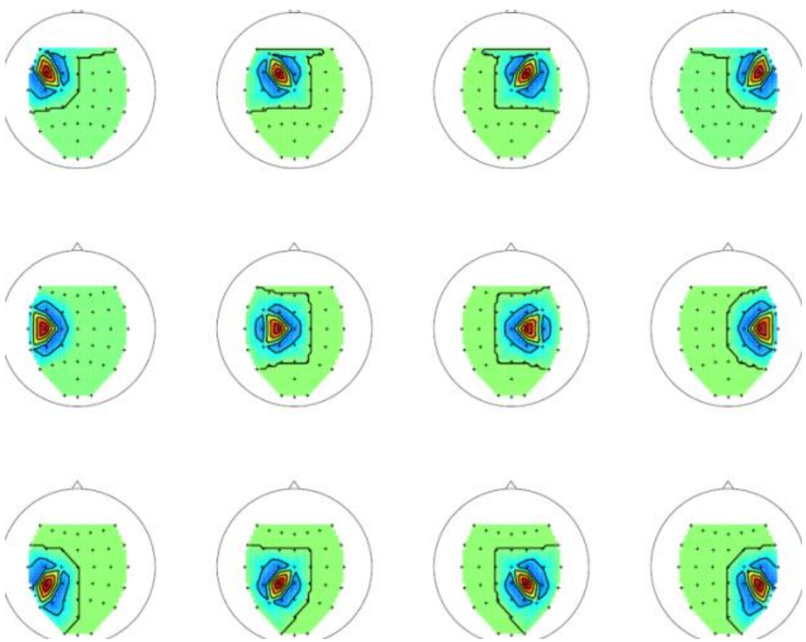
-> β_i has a very small effect => set $\beta_i = 0$ brings us back to LSR

-> it seeems our original approach was viable

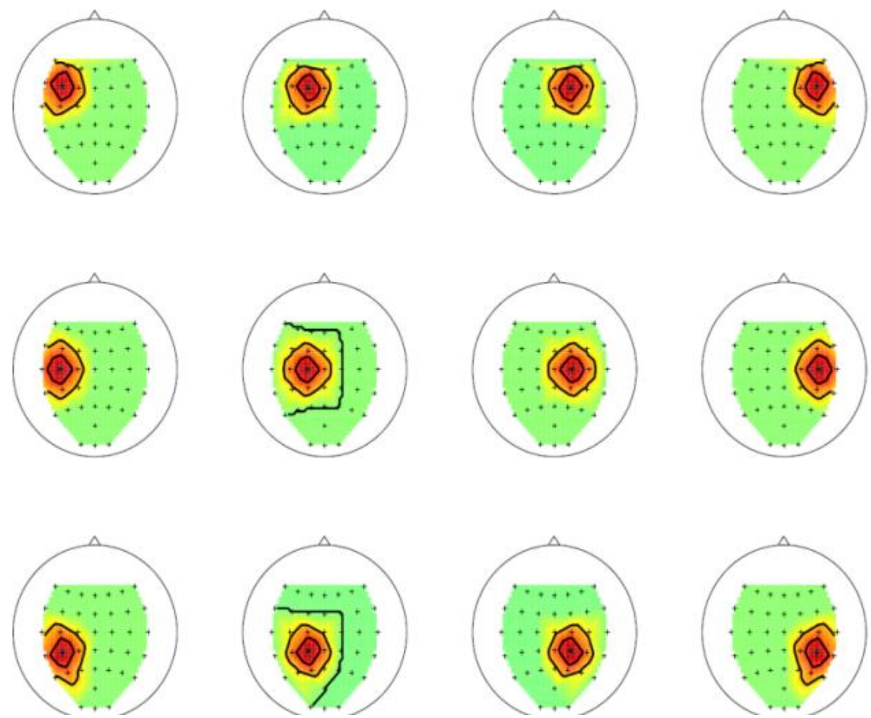
Thank you for your time

adding artificial spatial features

‘mexican hat’



simple laplacians



Introduction to LMM

Linear regression

$$Y = Xb + \epsilon$$

In case inputs are grouped and not independent within groups..

$$X_i = X_1, X_2, ...X_N \qquad i = 1, ..., N$$

..one can consider a Linear mixed-effects model

$$Y_i = X_i b + \beta_i + \epsilon_i$$