lmeEEG

Mass linear mixed-effects modeling of EEG data with crossed random effects

github.com/antovis86/lmeEEG & osf.io/kw87a/

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OUTLINE

- **Why** lmeEEG?
- lmeEEG in **3 steps**
- Validation
- When **not** lmeEEG

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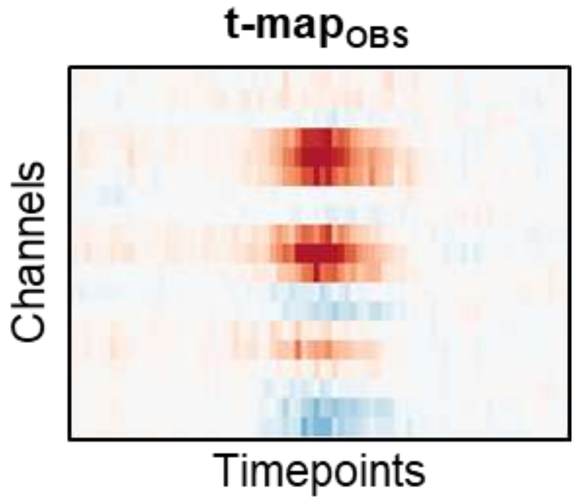
WHY lmeEEG?

- **Mass univariate EEG analysis**
  - Analysis at each electrode and timepoint (and frequency bin)
  - OLS
  - Correction for multiple comparisons (**TFCE and permutations**)



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NeuroImage
Volume 67, 15 February 2013, Pages 111-118

Advanced EEG analysis using threshold-free cluster-enhancement and non-parametric statistics

Armand Mensen, Ramin Khatami

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https://doi.org/10.1016/j.neuroimage.2012.10.027

Psychophysiology. Author manuscript; available in PMC 2014 Jun 17. Published in final edited form as: Psychophysiology. 2011 Dec; 48(12): 1711–1725. Published online 2011 Sep 6. doi: 10.1111/j.1469-8986.2011.01273.x

PMCID: PMC4060794 | NIHMSID: NIHMS449395 | PMID: 21895683

Mass univariate analysis of event-related brain potentials/fields I: A critical tutorial review

David M. Groppe, Thomas P. Urbach, and Marta Kutas

Comput Intell Neurosci. 2011;2011:831409. doi: 10.1155/2011/831409. Epub 2011 Feb 21.

LIMO EEG: a toolbox for hierarchical LInear MOdeling of ElectroEncephaloGraphic data

Cyril R Pernet [1], Nicolas Chauveau, Carl Gaspar

BRAIN, COGNITION AND MENTAL HEALTH

Unfold: an integrated toolbox for overlap correction, non-linear modeling, and regression-based EEG analysis

NeuroImage
Volume 92, 15 May 2014, Pages 381-397

Permutation inference for the general linear model

Anderson M. Winkler [a,b,c], Gerard R. Ridgway [d], Matthew A. Webster [*], Stephen M. Smith [*], Thomas E. Nichols [*,*]

https://doi.org/10.1016/j.neuroimage.2014.01.060

Jaromil Frossard

EEG Data Analysis with the Permuco Package

https://benediktehinger.de/blog/science/threshold-free-cluster-enhancement-explained/

WHY lmeEEG?

- **Mass univariate EEG analysis**
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- **Crossed random effects**

WHY lmeEEG?

Journal of Memory and Language

Volume 59, Issue 4, November 2008, Pages 390-412

ELSEVIER

Mixed-effects modeling with crossed random effects for subjects and items

R.H. Baayen[a], D.J. Davidson[b], D.M. Bates[c]

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https://doi.org/10.1016/j.jml.2007.12.005   Get rights and content

- **Mass univariate EEG analysis**
  - Analysis at each electrode and timepoint (and frequency bin)
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- **Crossed random effects**

$$32\ channels\ \times 250\ timepoints\ \times 2000\ permutations\ \times 250\ ms = 46\ days$$

$$64\ channels\ \times 500\ timepoints\ \times 2000\ permutations\ \times 250\ ms = 185\ days$$

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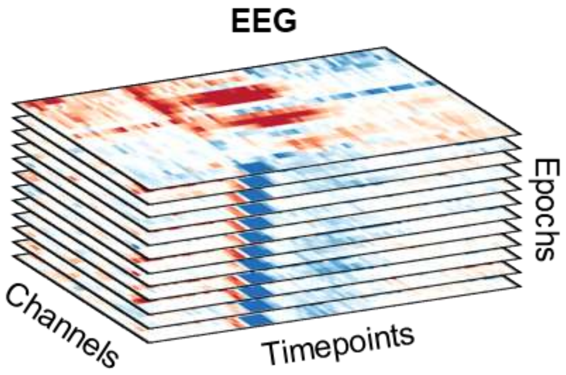
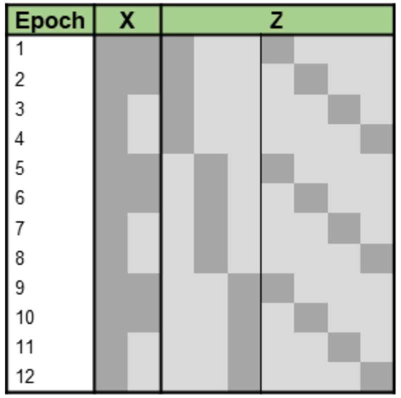
STEP 1

Conduct mixed models on each channel/timepoint combination.

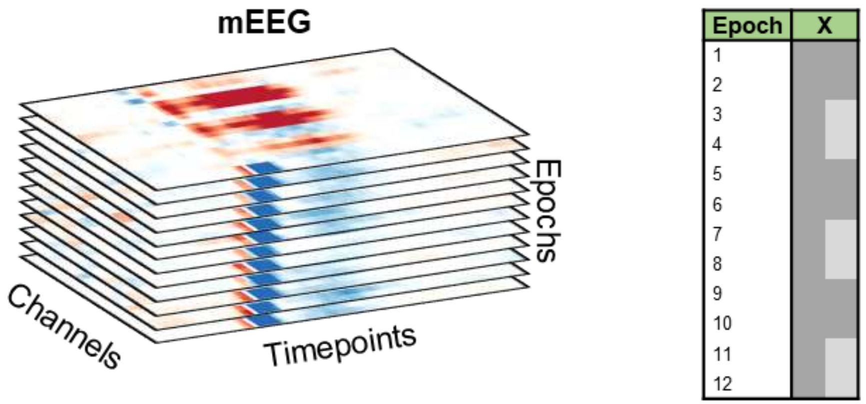


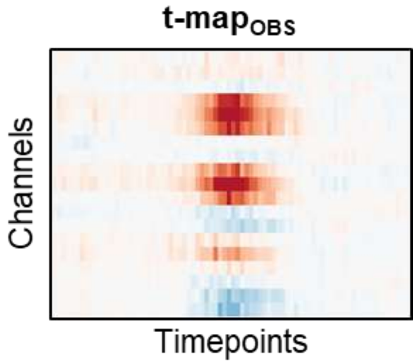


$$EEG_{ch,t} = X\beta + Zu + \varepsilon$$

STEP 2

Extract "marginal" EEG data and perform mass univariate linear regressions.



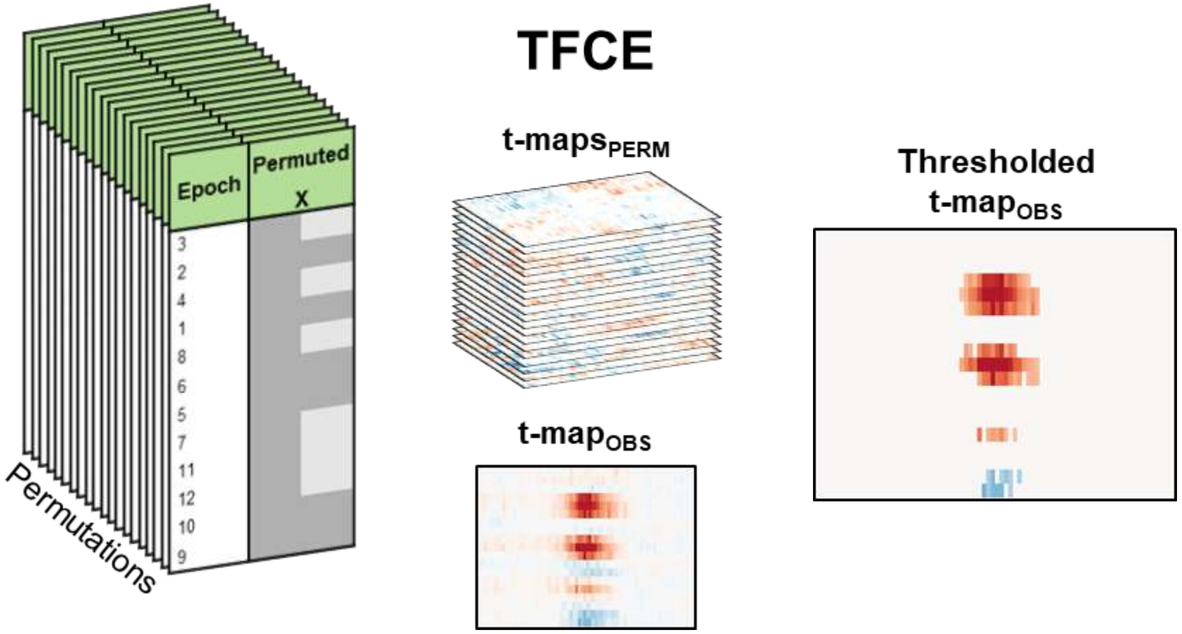


$$EEG_{ch,t} = X\beta + Zu + \varepsilon$$

$$mEEG_{ch,t} = EEG - Zu = X\beta + \varepsilon$$

STEP 3

Perform permutation testing and apply threshold-free cluster enhancement (TFCE).



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VALIDATION 1 *(univariate case)*

- 2000 datasets simulated according to the following model: **$y \sim 1 + A \times B + (1 | Subject) + (1 | Item)$**
  - A : two-level factor (effects coding). Main effect Cohen's d = 0
  - B : two-level factor (effects coding). Main effect Cohen's d = 0.07
  - A:B interaction Cohen's d = 0.054
  - Random intercepts for Subjects (N = 50) and for Items (N = 50): SD of 0.2
  - Residual errors: SD of 0.2

Effect	Westfall's power	LMM power	lmeEEG power
A	.05	.045	.045
B	.95	~1.00	~1.00
AB interaction	.80	.828	.829

VALIDATION 1 *(univariate case)*

SD of residual errors	Effect	LMM PR	lmeEEG PR
0.6	A	.053	.053
	B	1	1
	AB	.678	.679
1.2	A	.053	.053
	B	.989	.989
	AB	.371	.371
2.4	A	.057	.057
	B	.665	.666
	AB	.161	.161

VALIDATION 2 *(Simulated EEG)*

- 30 Subject and 10 items and 2 experimental conditions (50 epochs)
- Simulated 19 channels × 110 timepoints EEG data
  - 18 noise components: 2 μV brown noise + 2 μV white noise
  - One P3a: 10 μV (SD = 0.2) + 0.2 μV for Condition B:
    - P3 ~ 1 + Condition + (1 | Subject) + (1 | Item)

VALIDATION 2 *(Simulated EEG)*

Comparison between LMM and lmeEEG (500 permutations):

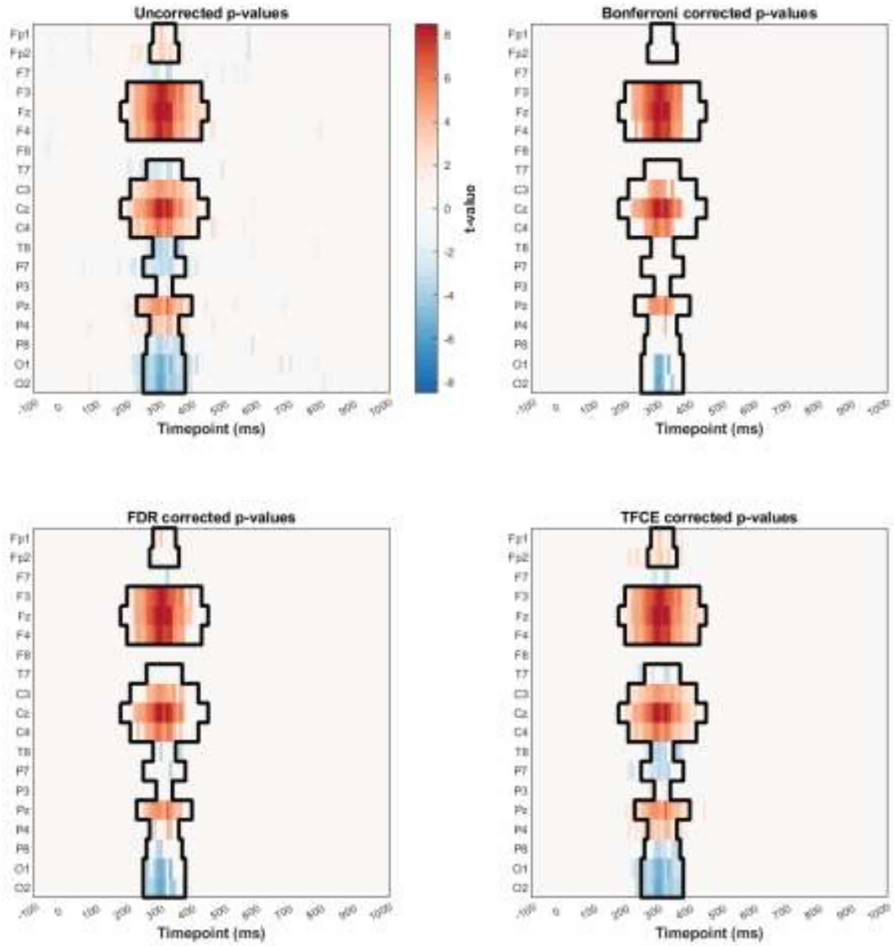
- Identical β coefficients: no differences in Type S Type M errors
- Standard Errors correlated to ~1
- Same dichotomous decisions: No difference in Type 1 and Type 2 errors
- lmeEEG **300 times** faster!!!

VALIDATION 2 *(Simulated EEG)*

Corrections	Power [TP/(TP+FN)]	Precision [TP/(TP+FP)]	FPR [FP/(FP+TN)]	MCC*
Uncorrected	.8755	.7352	.0441	.7722
Bonferroni	.3670	1	0	.5827
FDR	.4864	.9843	.0011	.6671
TFCE	.8483	.8583	.0196	.8328
lmeEEG TFCE	.8483	.8583	.0196	.8328

*Matthews correlation coefficient:

$$MCC = \frac{TP \times TN - FP \times FN}{\sqrt{(TP+FP)(TP+FN)(TN+FP)(TN+FN)}}$$



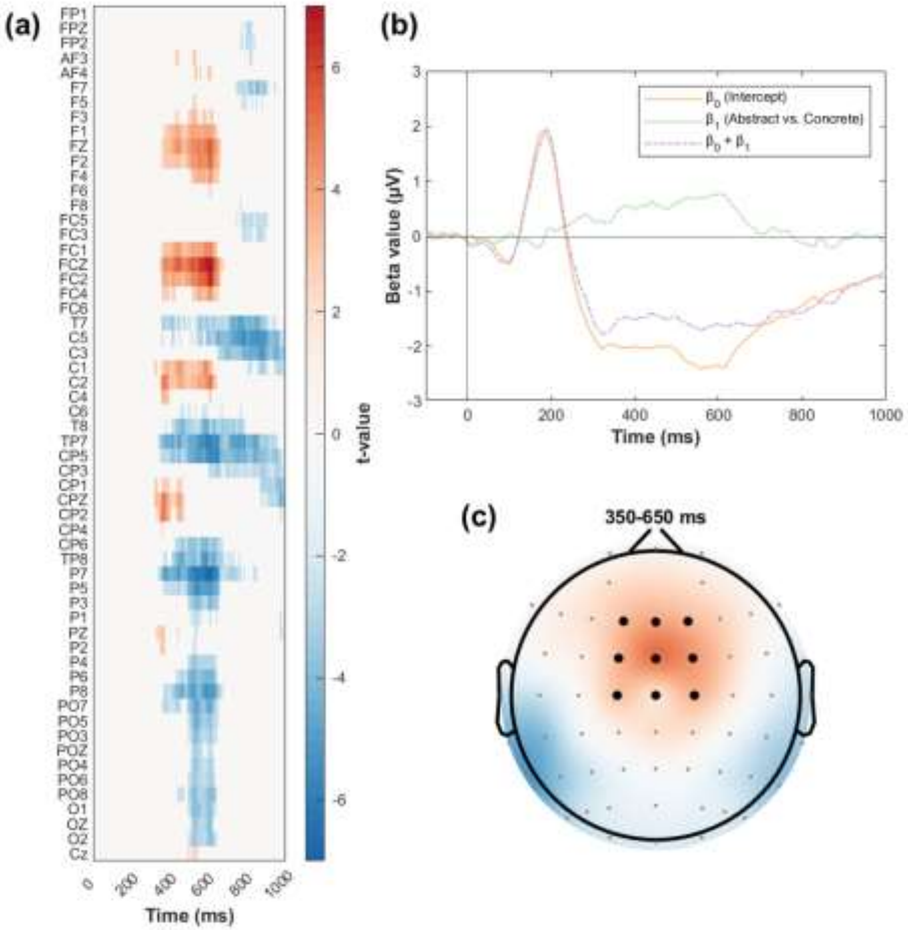
REAL EEG DATA

Psycholinguistic experiment

Semantic decision task

Participants = 58

Words = 176



Montefinese et al. (2024) “How Continuous Concreteness Shapes Brain Processing and Concept Representation Across Diverse Tasks: Insights from an ERP Study”. doi:10.22541/au.171249584.45053538/v1

FURTHER APPLICATIONS

Time-frequency data

Source-reconstructed ERP

MEG data

Pupillometry and eye movement data.

It can also account for designs with “nested” random effects, such as in **multi-site** neuroimaging studies.

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When **NOT** lmeEEG

Don’t use it when you don’t have crossed or nested random-effects designs:

- Hard to assess and manage convergence and singularity issues with massive testing
- No available methods to validate lmeEEG with random **SLOPES**

#FUEL4PSICOSTAT

CONCLUSIONS

- lmeEEG is a valid method to use LMM with EEG mass univariate analyses.
- lmeEEG showed excellent performance properties in terms of power and false positive rate
- lmeEEG overcomes the computational costs of standard available approaches (our method was indeed more than 300 times faster than LMM).
- lmeEEG codes and a tutorial are available at github.com/antovis86/lmeEEG

THANK YOU

Progetto “Giovani Ricercatori”

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