University of Glasgow | Institute of Neuroscience & Psychology
Centre for Cognitive Neuroimaging (CCNi)

Guillaume Rousselet

Robust statistics: central tendency, dispersion and inference

APS conference 3-hour workshop

ERP analyses:

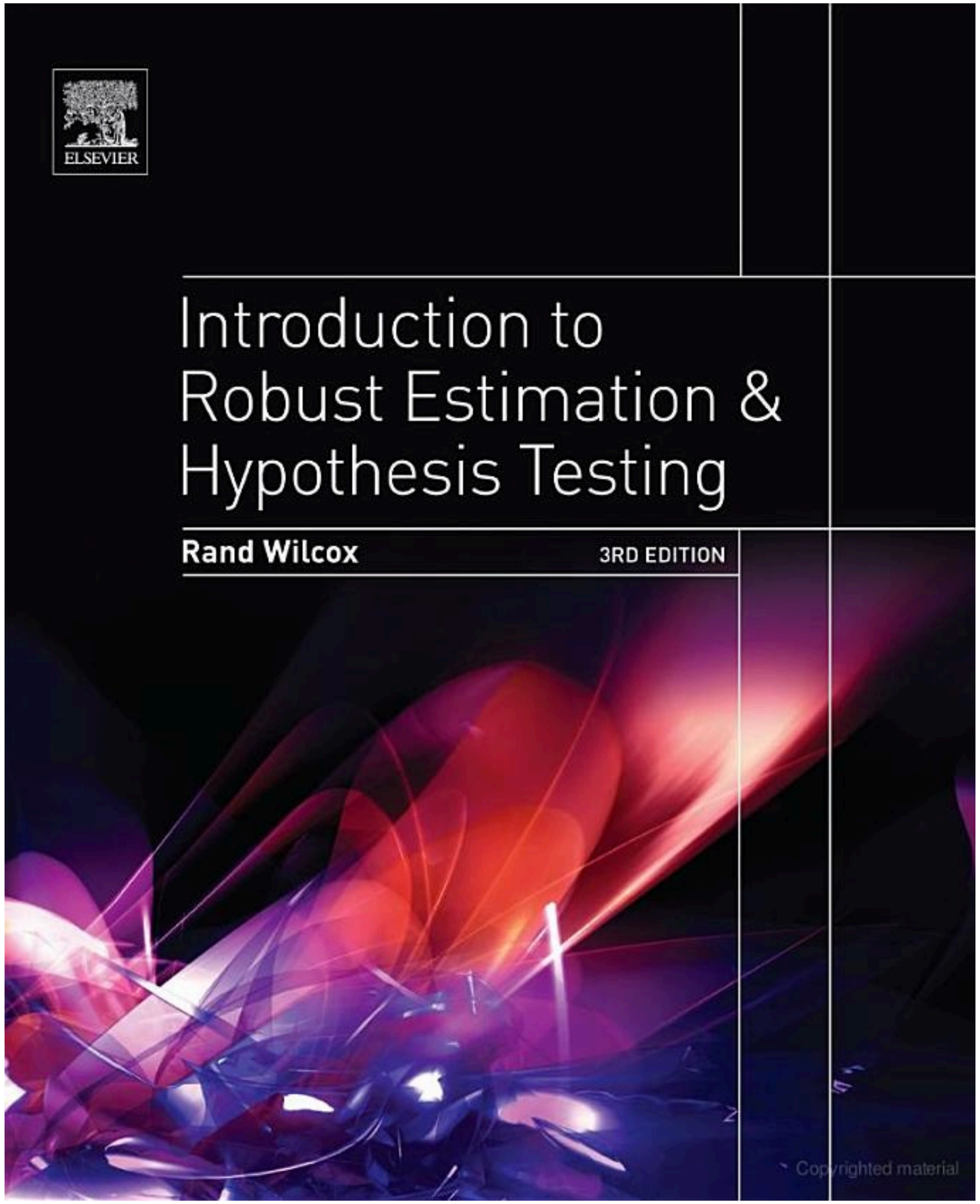
simple tips to significantly up your game

https://dl.dropboxusercontent.com/u/17233235/aps_erp_workshop.zip

Take-home messages

- ***Look at your data! Show your data!***
- ***A perfect & universal statistical recipe does not exist***
- ***Keep exploring: there are many great options, most of them available in free softwares and toolboxes***

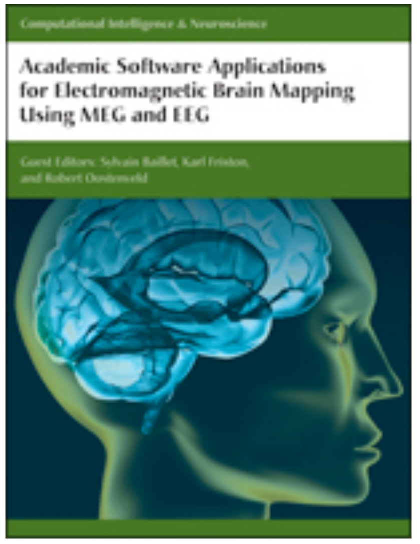
References: statistics



Computational Intelligence and Neuroscience

Academic Software Applications for Electromagnetic Brain Mapping Using MEG and EEG

Guest Editors: Sylvain Baillet, Karl Friston, and Robert Oostenveld



- EEGLAB, SIFT, NFT, BCILAB, and ERICA: New Tools for Advanced EEG Processing, Arnaud Delorme, Tim Mullen, Christian Kothe, Zeynep Akalin Acar, Nima Bigdely-Shamlo, Andrey Vankov, and Scott Makeig
  Volume 2011 (2011), Article ID 130714, 12 pages
- ELAN: A Software Package for Analysis and Visualization of MEG, EEG, and LFP Signals, Pierre-Emmanuel Aguera, Karim Jerbi, Anne Caclin, and Olivier Bertrand
  Volume 2011 (2011), Article ID 158970, 11 pages
- ElectroMagnetoEncephalography Software: Overview and Integration with Other EEG/MEG Toolboxes, Peter Peyk, Andrea De Cesarei, and Markus Junghöfer
  Volume 2011 (2011), Article ID 861705, 10 pages
- FieldTrip: Open Source Software for Advanced Analysis of MEG, EEG, and Invasive Electrophysiological Data, Robert Oostenveld, Pascal Fries, Eric Maris, and Jan-Mathijs Schoffelen
  Volume 2011 (2011), Article ID 156869, 9 pages
- EEG and MEG Data Analysis in SPM8, Vladimir Litvak, Jérémie Mattout, Stefan Kiebel, Christophe Phillips, Richard Henson, James Kilner, Gareth Barnes, Robert Oostenveld, Jean Daunizeau, Guillaume Flandin, Will Penny, and Karl Friston
  Volume 2011 (2011), Article ID 852961, 32 pages
- EEGIFT: Group Independent Component Analysis for Event-Related EEG Data, Tom Eichele, Srinivas Rachakonda, Brage Brakedal, Rune Eikeland, and Vince D. Calhoun
  Volume 2011 (2011), Article ID 129365, 9 pages
- LIMO EEG: A Toolbox for Hierarchical LInear MOdeling of ElectroEncephaloGraphic Data, Cyril R. Pernet, Nicolas Chauveau, Carl Gaspar, and Guillaume A. Rousselet
  Volume 2011 (2011), Article ID 831409, 11 pages

References

- **EEGLAB, SIFT, NFT, BCILAB, and ERICA**:
  http://www.hindawi.com/journals/cin/2011/130714/
- **FIELDTRIP**: http://www.hindawi.com/journals/cin/2011/156869/
- **SPM**: http://www.hindawi.com/journals/cin/2011/852961/
- **LIMO EEG**: http://www.hindawi.com/journals/cin/2011/831409/
- **Discriminant analysis**: Parra et al. (2005). Recipes for the linear analysis of EEG. Neuroimage, 28(2), 326-341.
  http://liinc.bme.columbia.edu/mainTemplate.htm?liinc_downloads.htm
- **PLS** (Partial Least Squares; Projection to Latent Structures)
  Krishnan et al. (2011). Partial Least Squares (PLS) methods for neuroimaging: A tutorial and review. NeuroImage, 56, 455-475.
  http://www.rotman-baycrest.on.ca/index.php?section=84

Goal	Dataset		
	Binomial or Discrete	Continuous measurement (from a normal distribution)	Continuous measurement, Rank, or Score (from non-normal distribution)
Example of data sample	List of patients recovering or not after a treatment	Readings of heart pressure from several patients	Ranking of several treatment efficiency by one expert
Describe one data sample	Proportions	Mean, SD	Median
Compare one data sample to a hypothetical distribution	χ^2 or binomial test	One-sample t test	Sign test or Wilcoxon test
Compare two paired samples	Sign test	Paired t test	Sign test or Wilcoxon test
Compare two unpaired samples	χ^2 square Fisher's exact test	Unpaired t test	Mann-Whitney test
Compare three or more unmatched samples	χ^2 test	One-way ANOVA	Kruskal-Wallis test
Compare three or more matched samples	Cochrane Q test	Repeated-measures ANOVA	Friedman test
Quantify association between two paired samples	Contingency coefficients	Pearson correlation	Spearman correlation

Matlab Statistics toolbox; Parra & Sajda plugin

EEGLAB
FIELDTRIP
LIMO EEG

Matlab Statistics toolbox

Delorme, A. (2006) Statistical methods. *Encyclopedia of Medical Device and Instrumentation*, vol 6, pp 240-264. Wiley interscience.

References

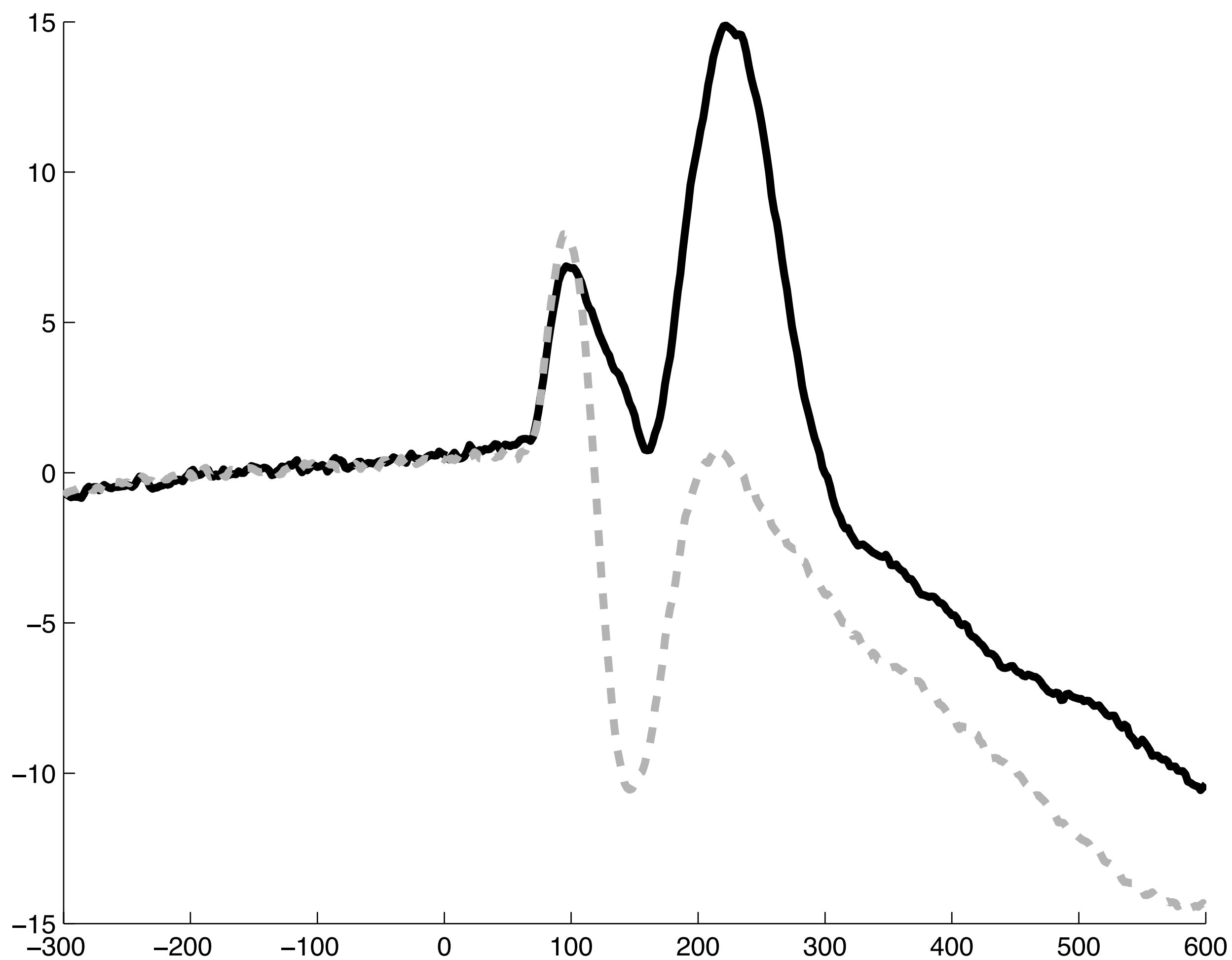
Rousselet GA and Pernet CR (2011)
Quantifying the time course of visual object processing using ERPs: it's time to up the game
Frontiers in Psychology 2:97. doi: 10.3389/fpsyg.2011.00107

Rousselet GA, Pernet CR, Caldara R and Schyns PG (2011)
Visual object categorization in the brain: what can we really learn from ERP peaks?
Frontiers in Human Neuroscience 5:156. doi: 10.3389/fnhum.2011.00156

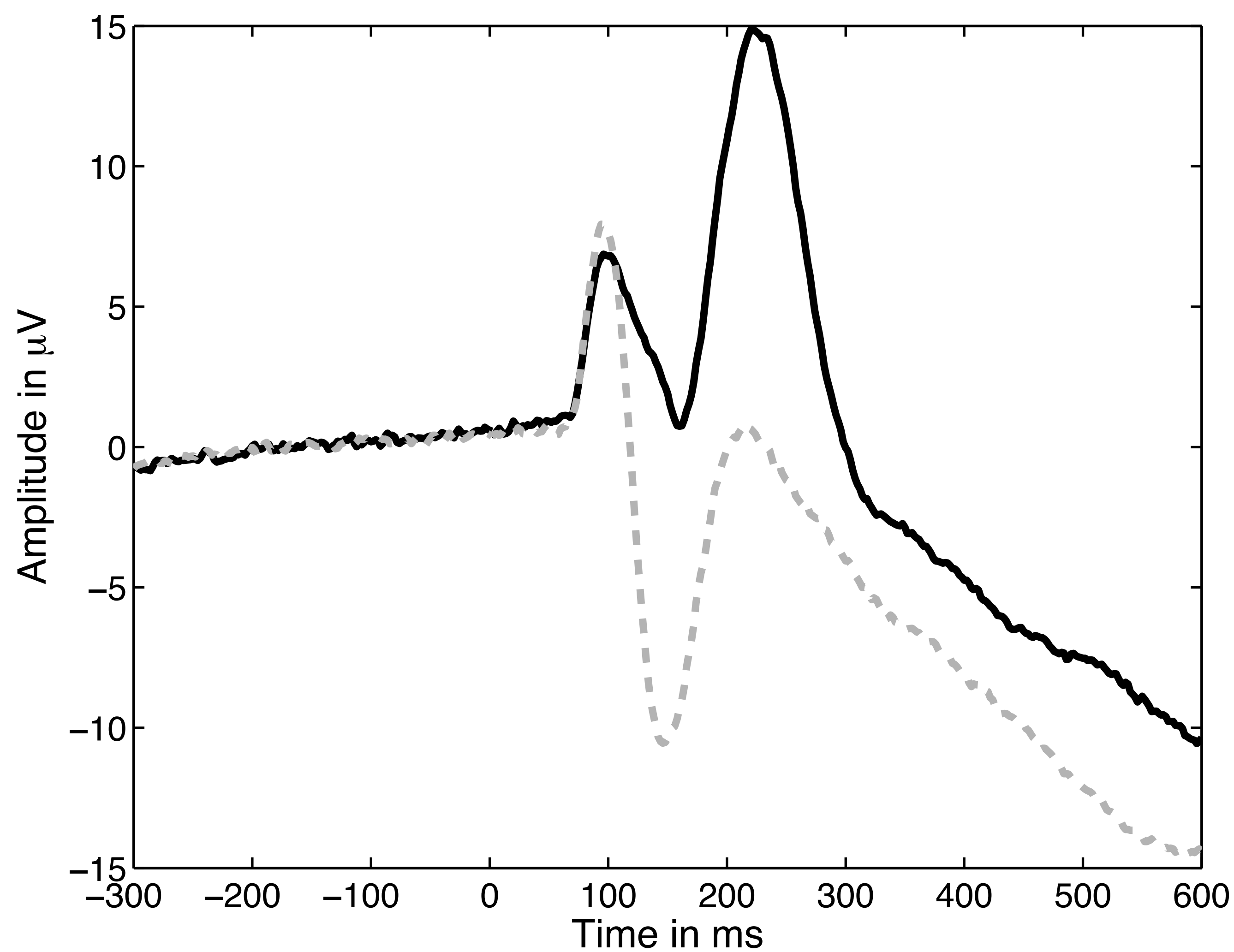
Pernet CR, Sajda P and Rousselet GA (2011)
Single-trial analyses: why bother?
Frontiers in Psychology 2:322. doi: 10.3389/fpsyg.2011.00322

Rousselet GA (2012)
Does filtering preclude us from studying ERP time-courses?
Frontiers in Psychology 3:131. doi: 10.3389/fpsyg.2012.00131

The standard ERP figure (1)



The standard ERP figure (2)



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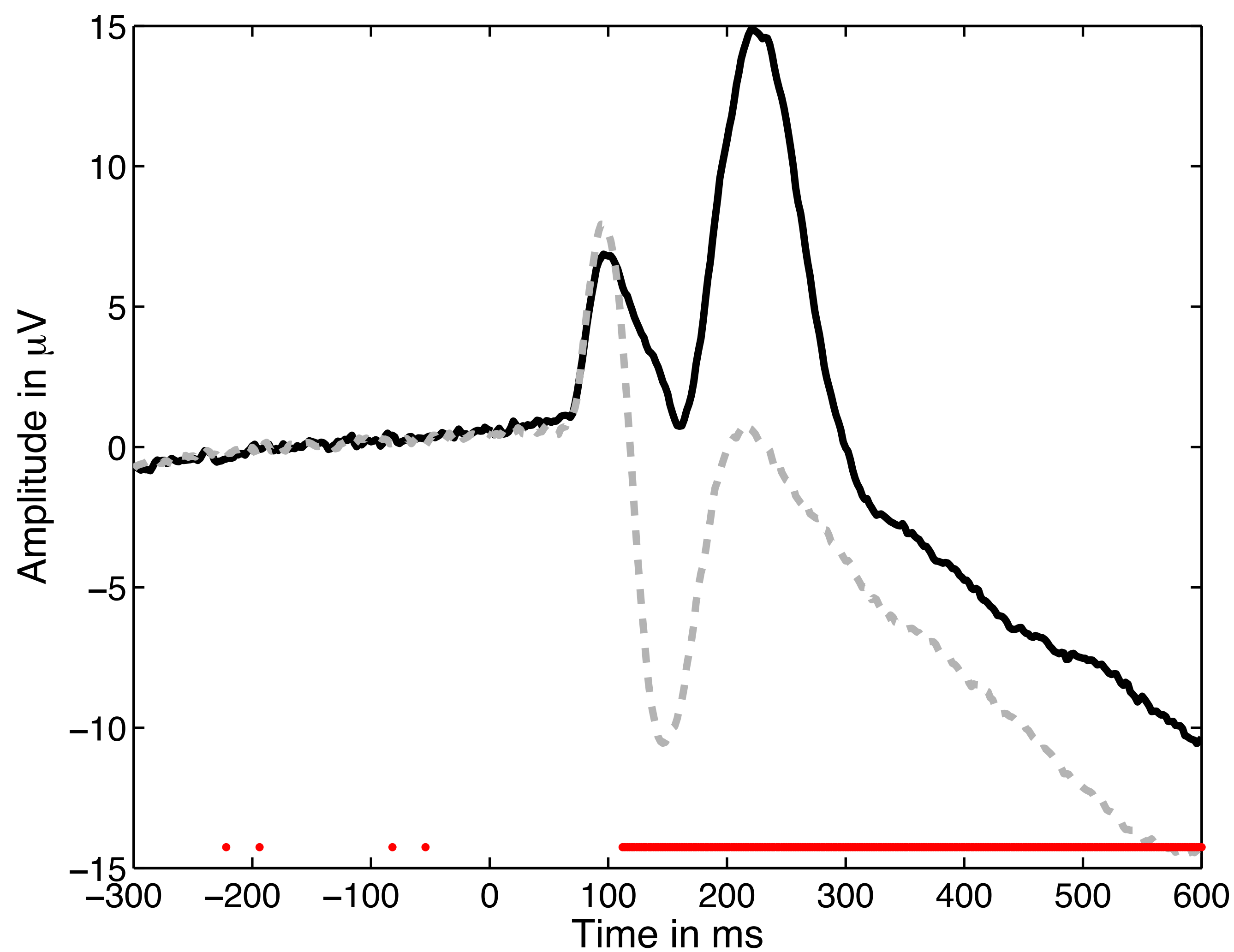
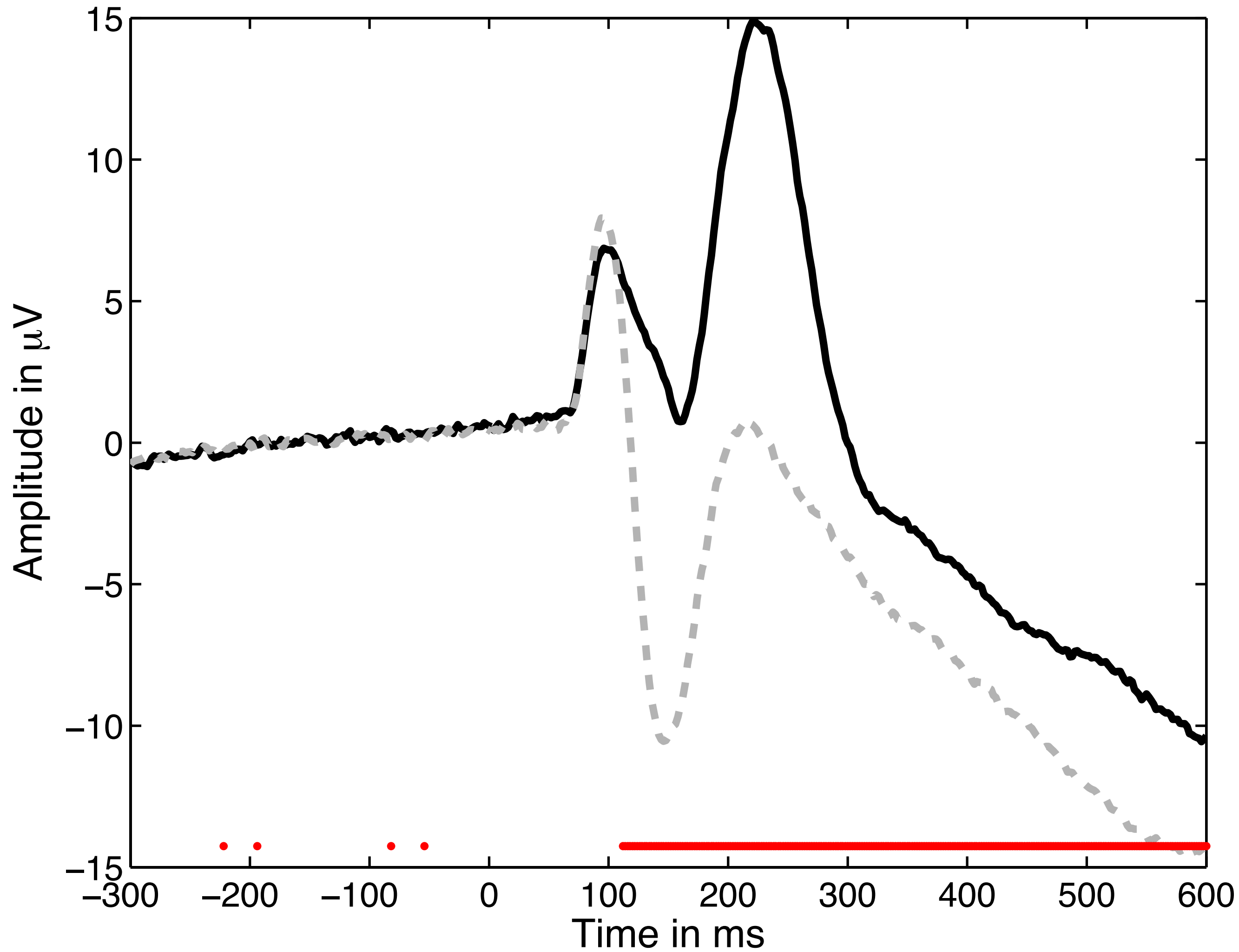


Why the standard figure is not good enough



Significant effect?

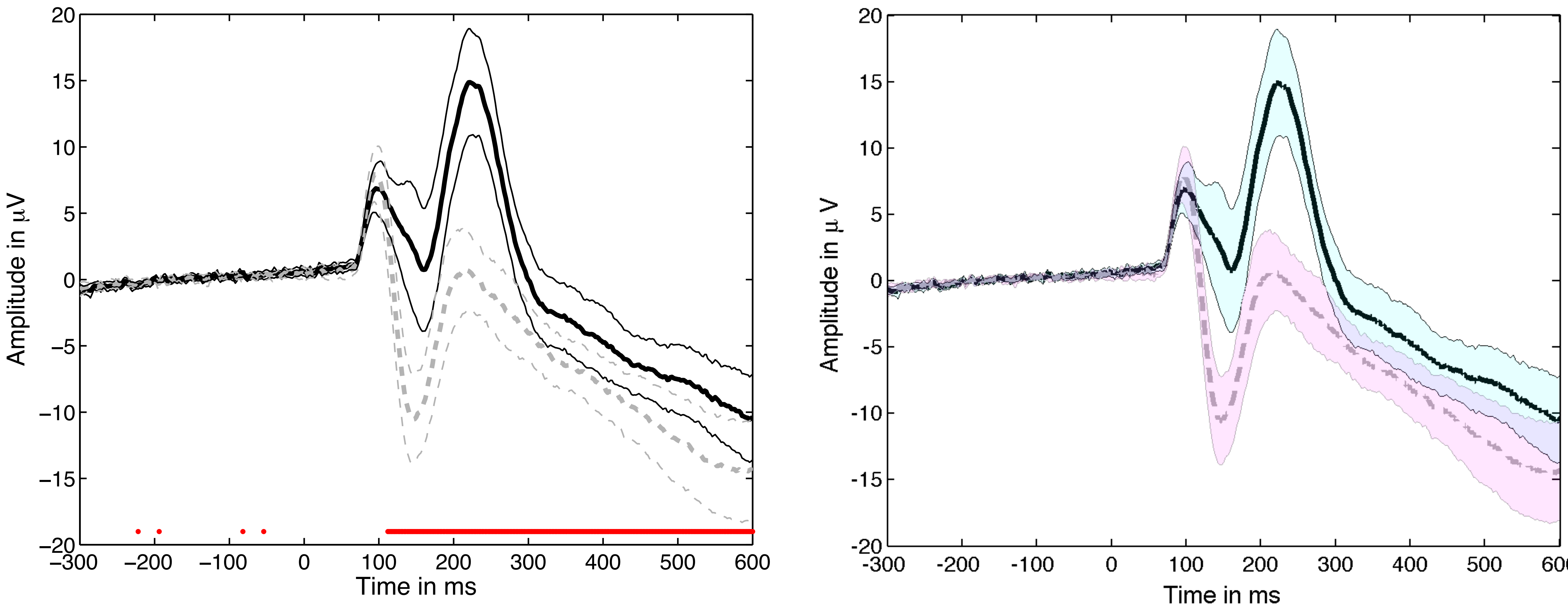
- interesting?
- how many subjects?
- effect size?

Non-significant effect?

- not there?
- lack of power?
- how many subjects?
- effect size?

Interpretations should be limited to what was measured: group differences in means

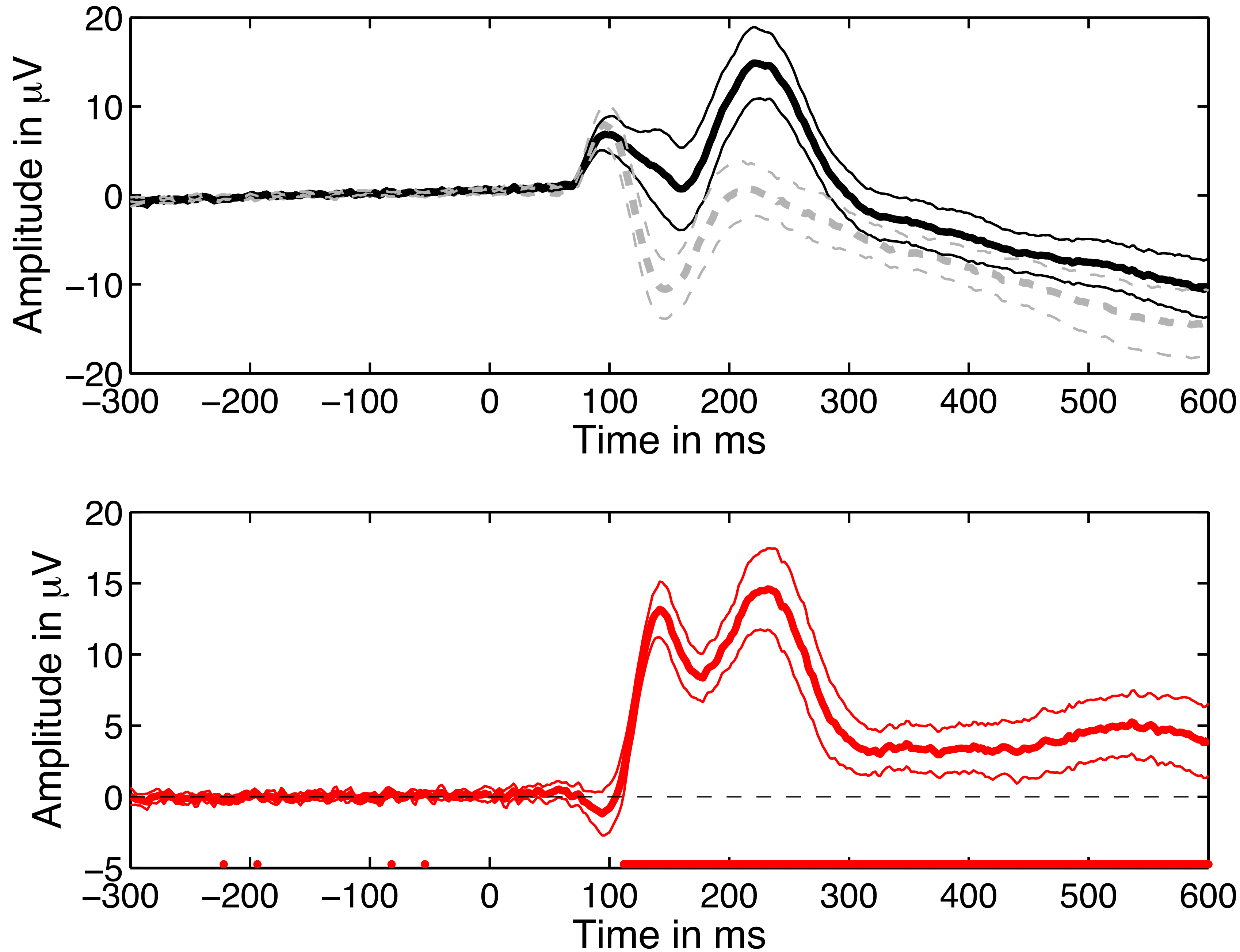
Add confidence intervals



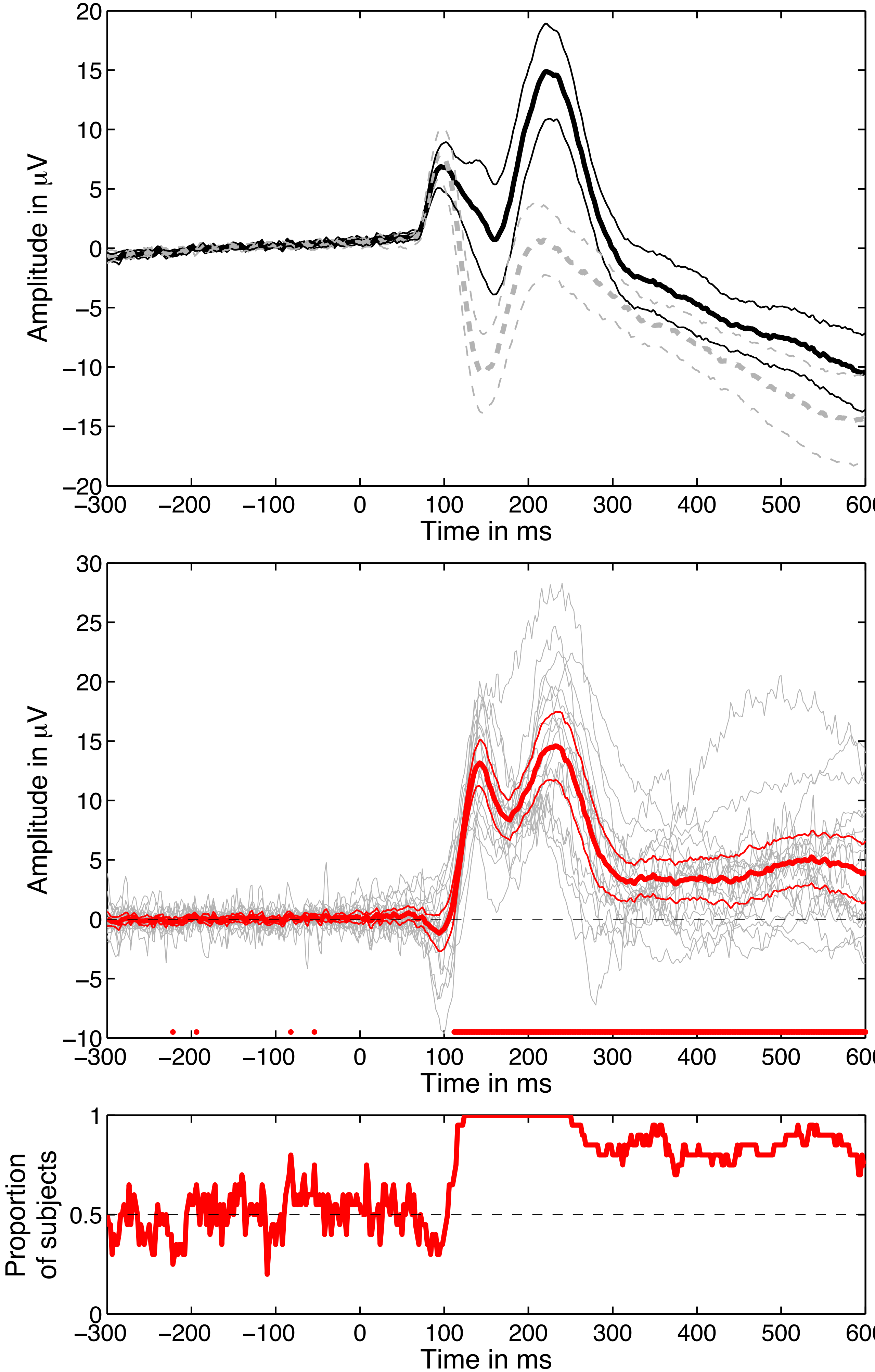
Confidence intervals

- ***limo_ttest***
- ***limo_trimci / limo_yuend_ttest / limo_yuen_ttest***
- ***limo_pbci***
- ***limo_bootttest1***
- ***limo_boot_yuen_ttest***
- *limo_central_tendency_and_ci*
- *limo_robust_ci*

Add plot of the difference

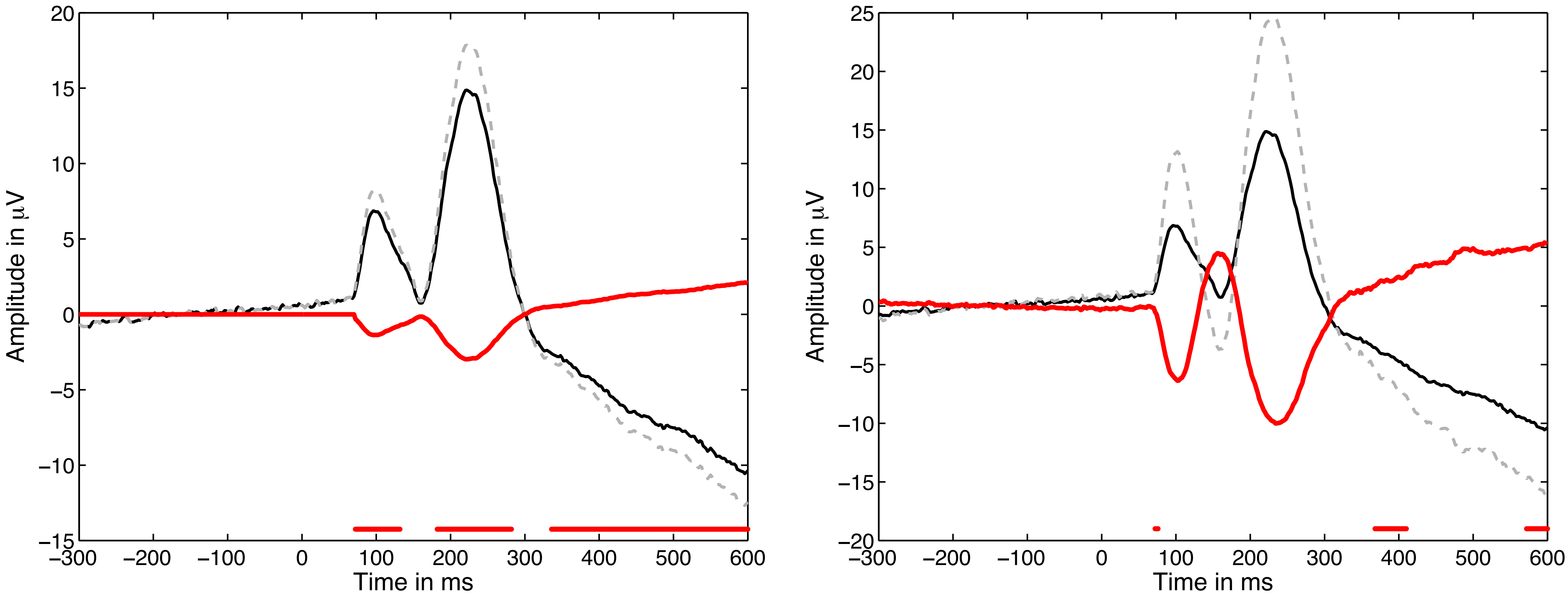


How many subjects show an effect?

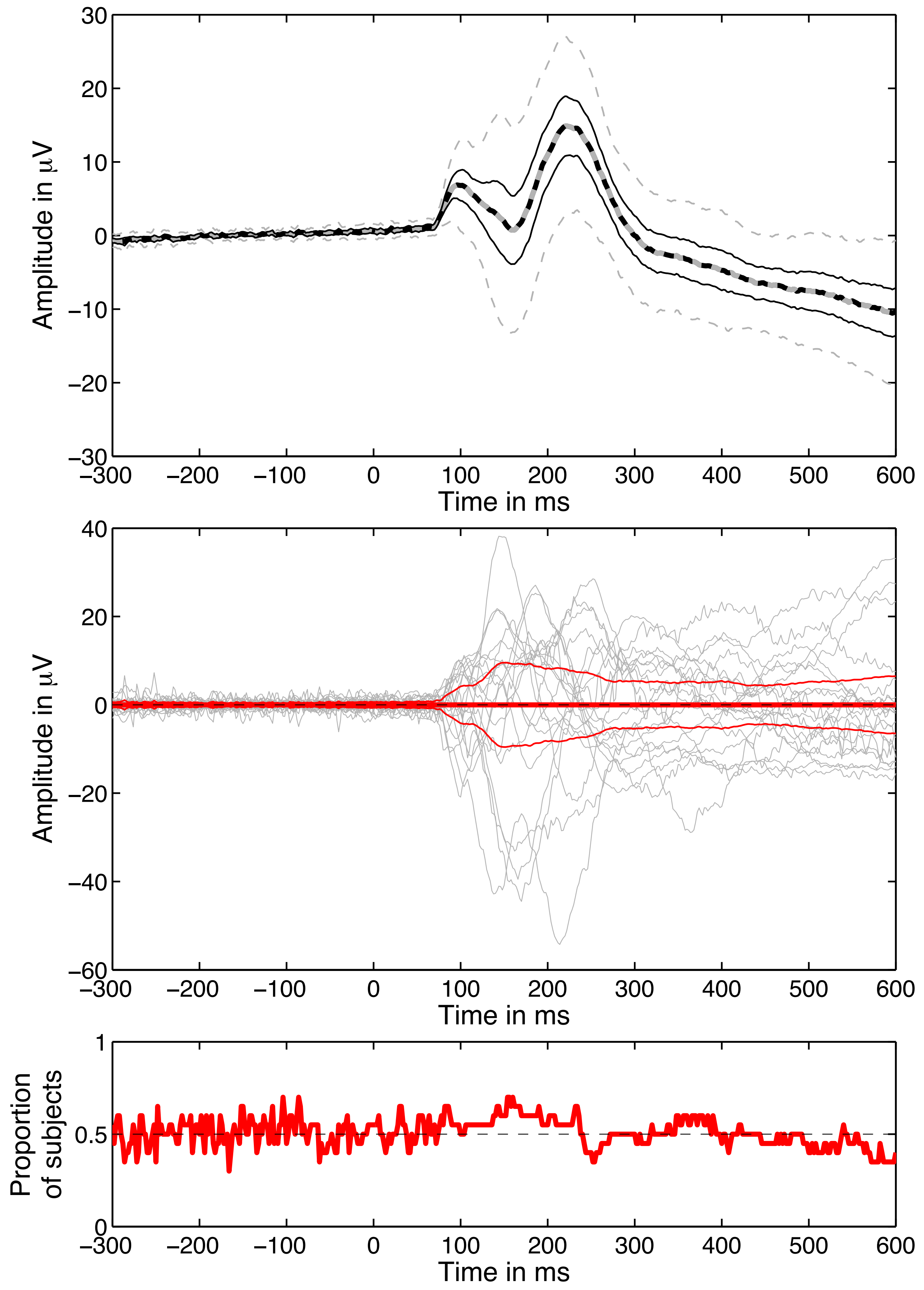


No effect? Case study 1

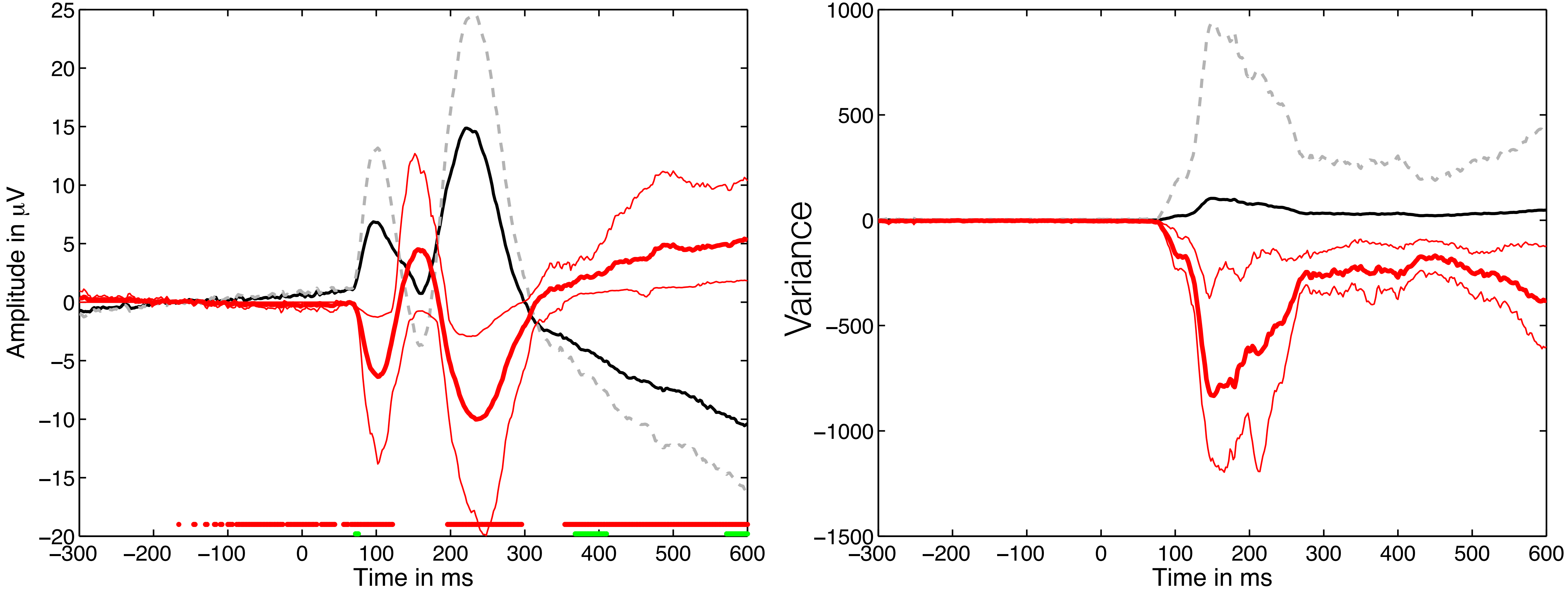
$$t = \frac{\bar{X}_n - \mu}{s/\sqrt{n}}$$



No effect? Case study 2



Solving case studies: percentile bootstrap

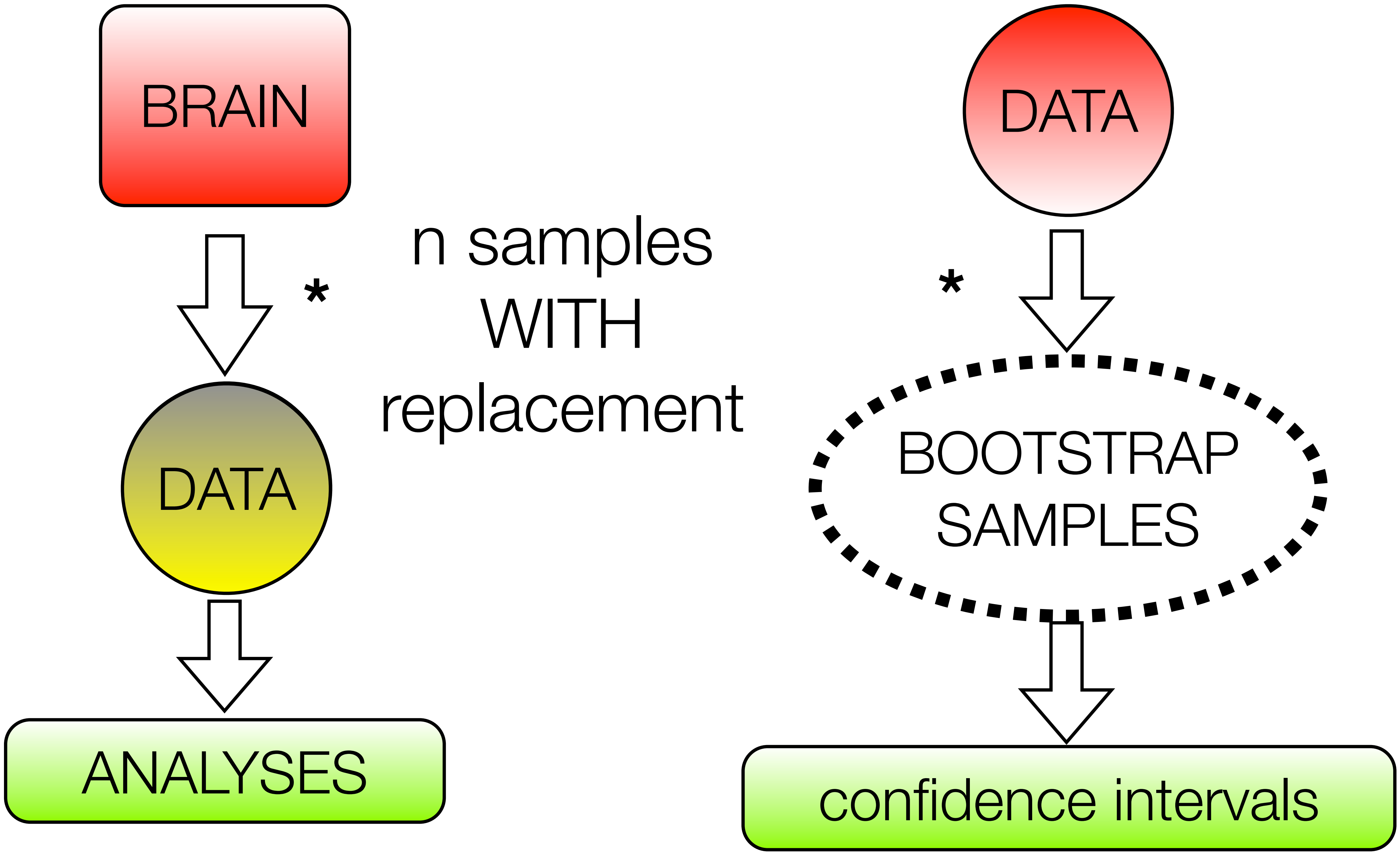


Bootstrap: central idea

- “The bootstrap is a computer-based method for assigning measures of accuracy to statistical estimates.” Efron & Tibshirani, 1993

- “The central idea is that it may sometimes be better to draw conclusions about the characteristics of a population strictly from the sample at hand, rather than by making perhaps unrealistic assumptions about the population.” Mooney & Duval, 1993

bootstrap philosophy



Percentile bootstrap: general recipe

- sample = X1, ..., Xn
- resample n observations with replacement
- compute estimate
- repeat B times

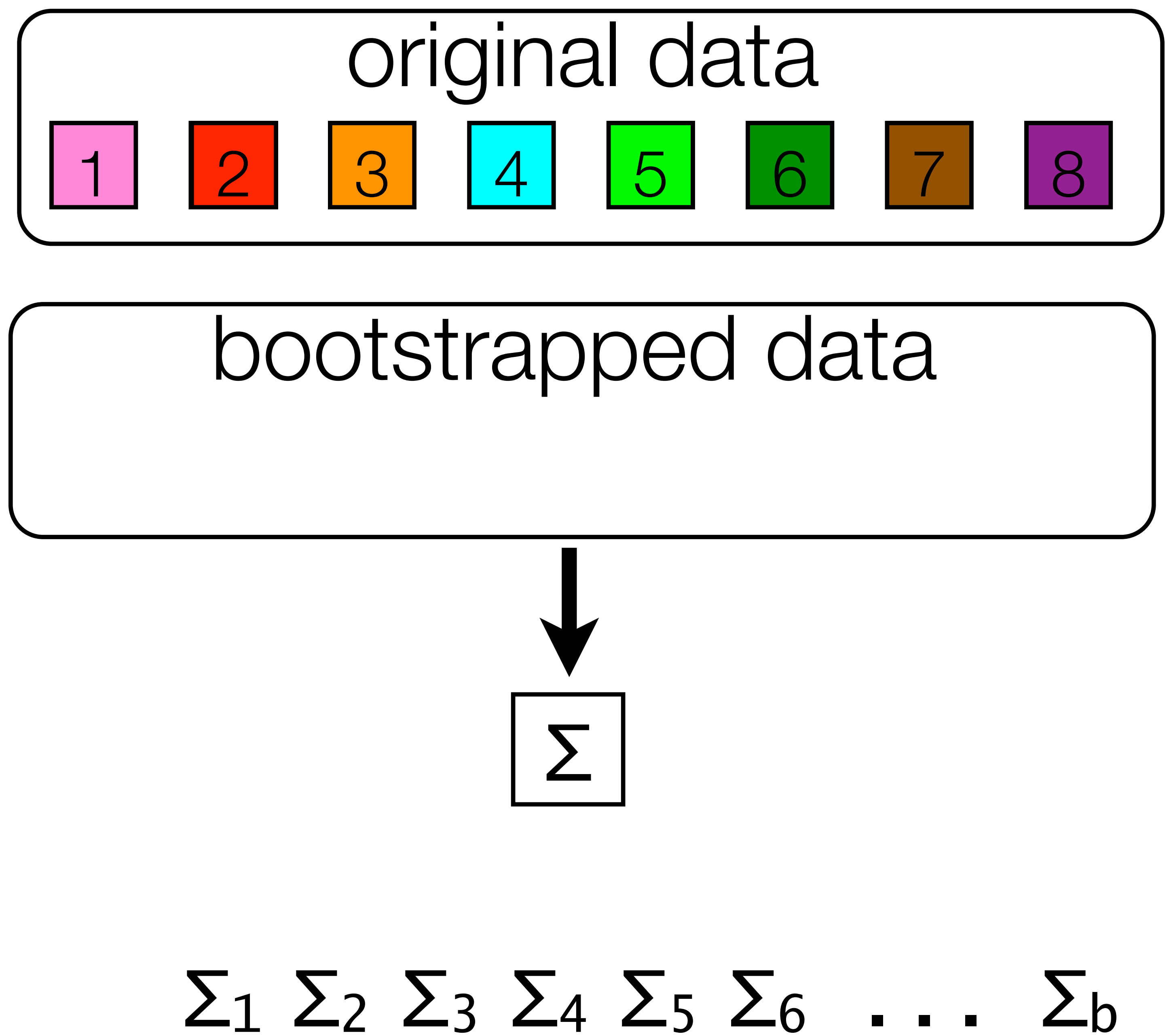
- with B large enough the B estimates provide a good approximation of the distribution of the estimate of the sample

Percentile bootstrap: general recipe

(1) sample WITH replacement n observations

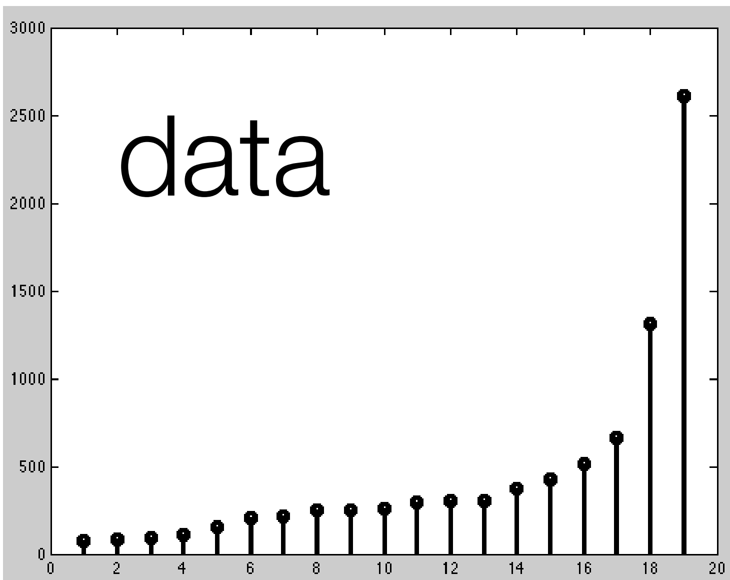
(2) compute estimate
e.g. sum, trimmed mean

(3) repeat (1) & (2) b times
(4) sort the b estimates*
(5) get 1-alpha confidence interval



Percentile bootstrap estimate of mean

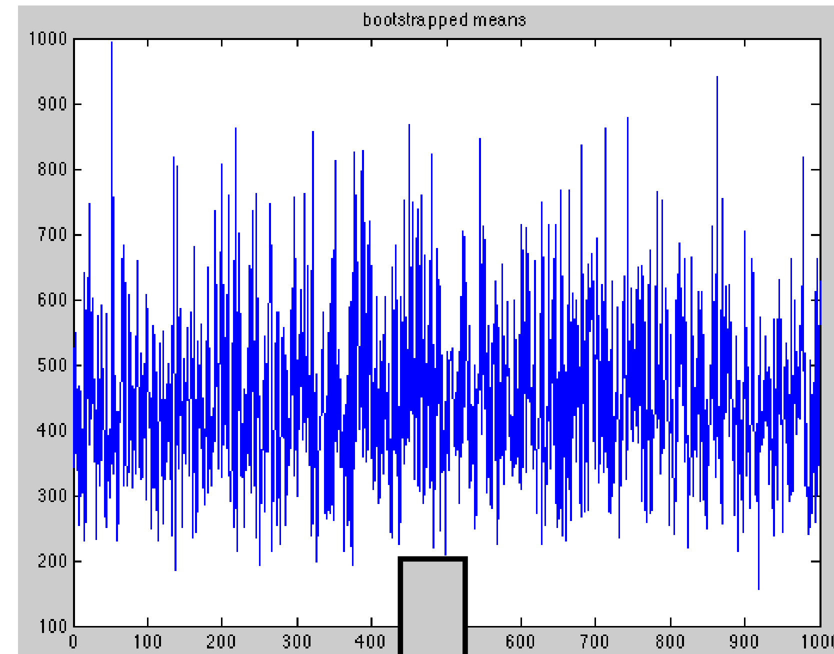
% self-awarness data, Wilcox, 2005, p58



Sample with replacement b times

compute estimate

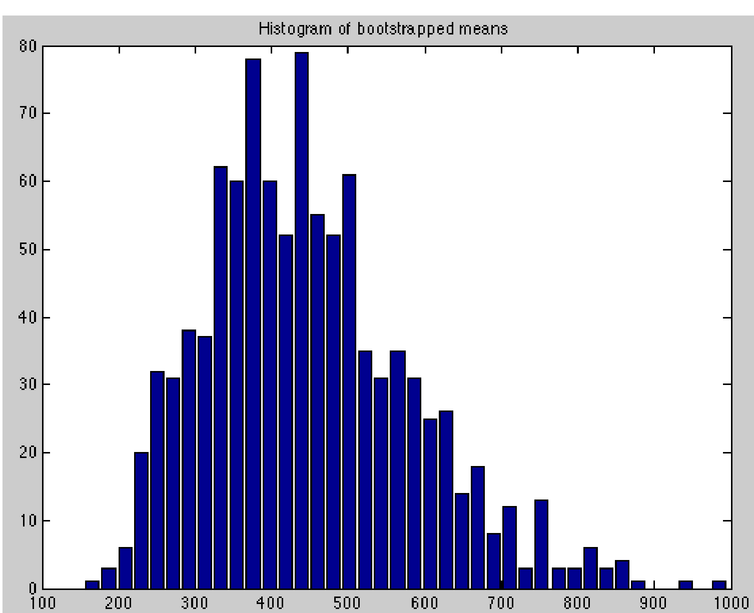
Bootstrapped estimates

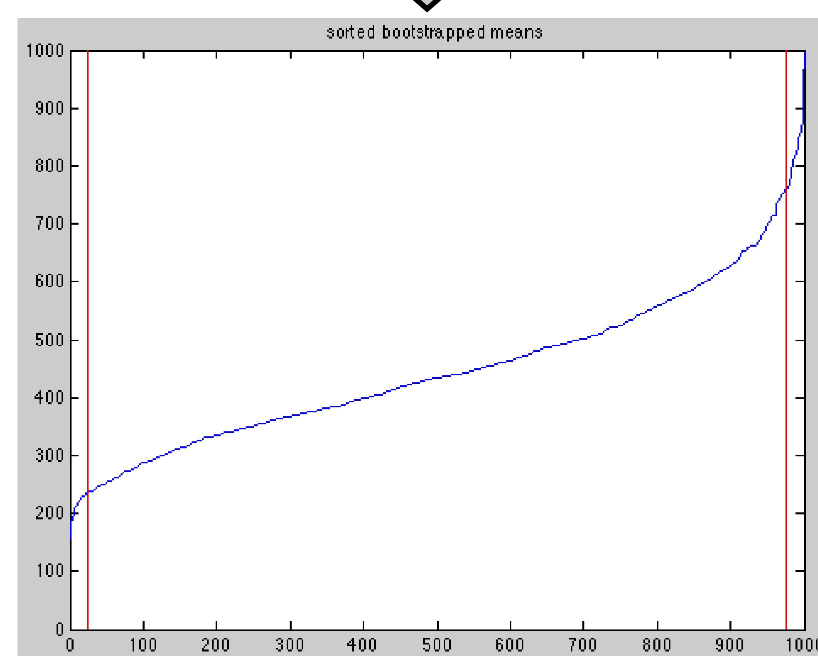


get PDF

Sort & get CI

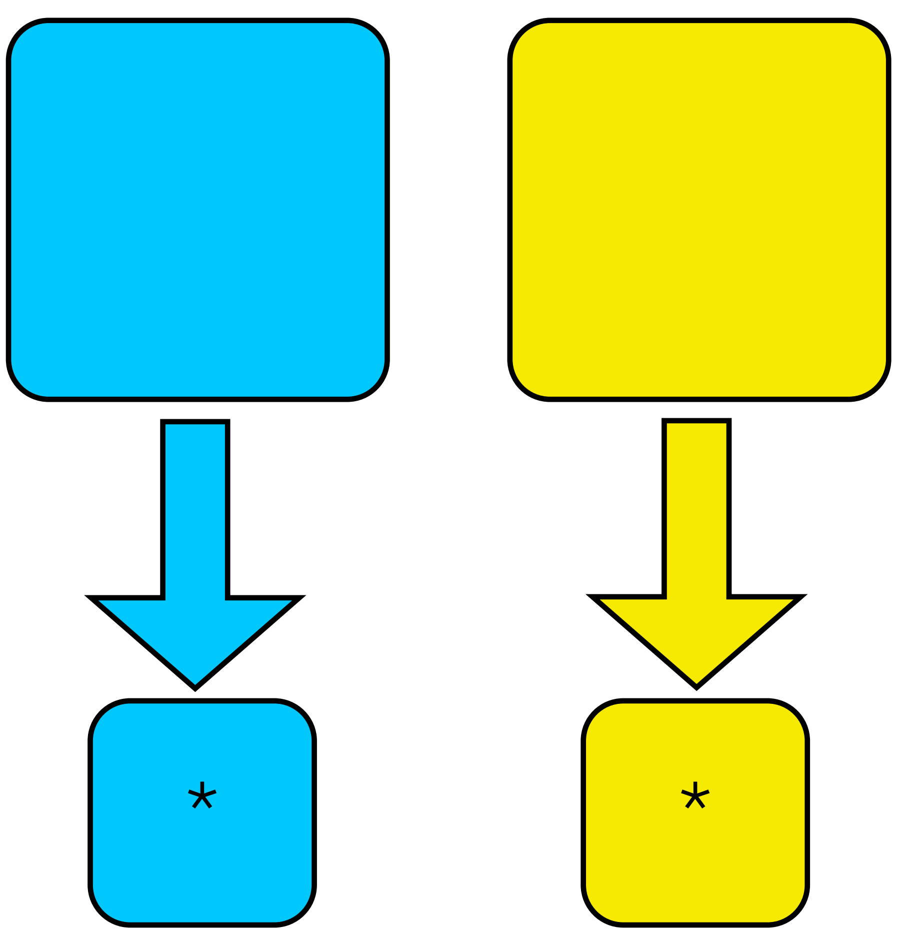
Distribution of bootstrapped estimates of the mean



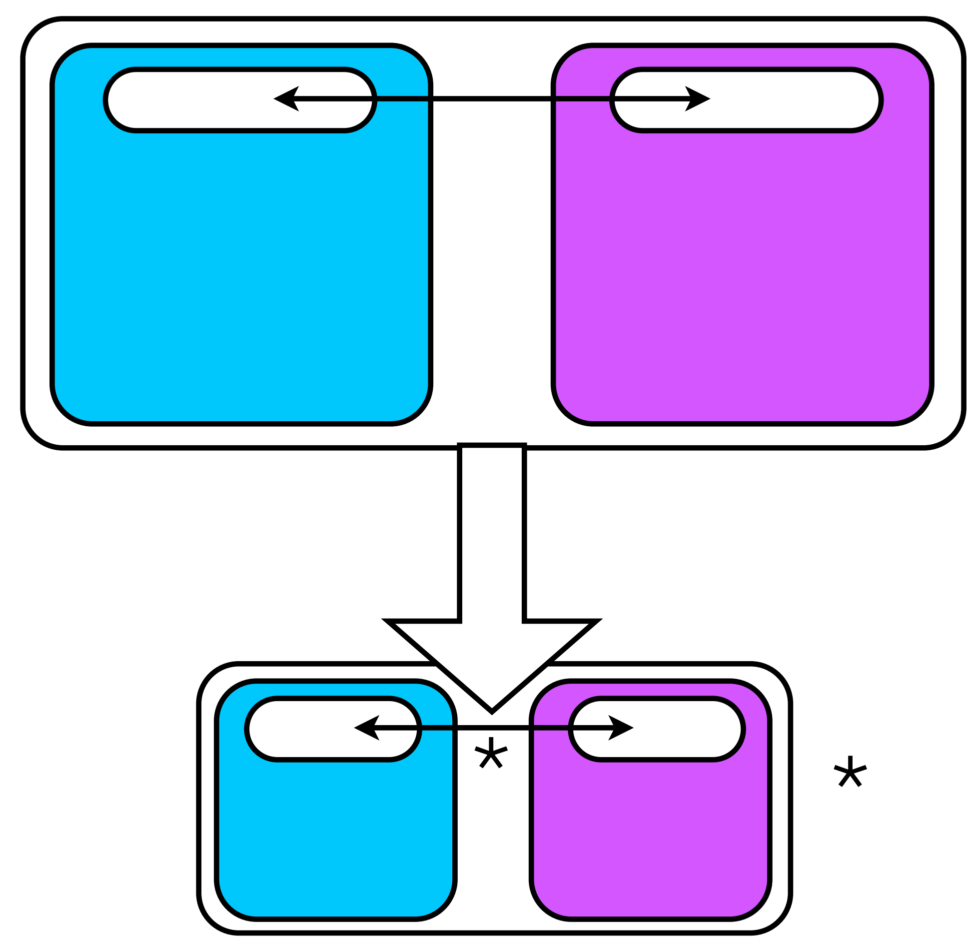


resampling strategies:
follow the data acquisition process

independent sets:
- 2 conditions in single-subject analyses
- 2 groups of subjects, e.g. patients vs. controls

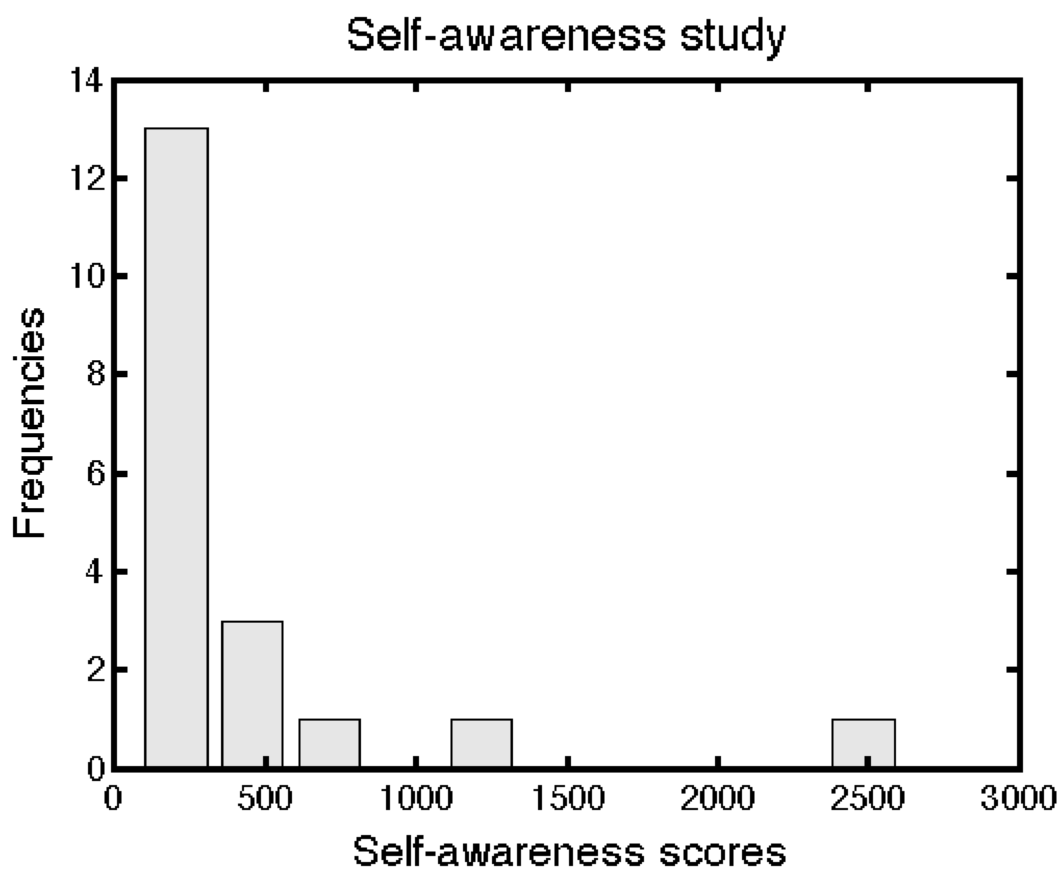


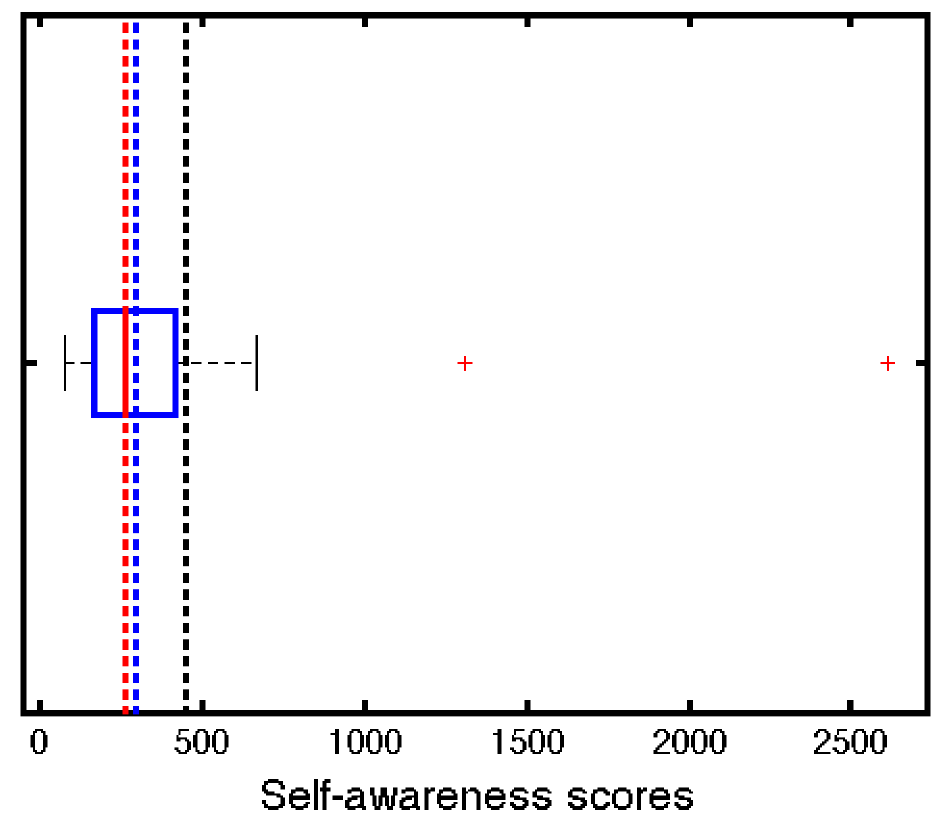
dependent sets:
- 2 conditions in group analyses
- correlations
- linear regression



Why we need robust estimators

$$t = \frac{\bar{X}_n - \mu}{s/\sqrt{n}}$$





The mean and the variance are very sensitive to small departures from normality, so that tests relying on them (t-tests & ANOVAs) can perform poorly.

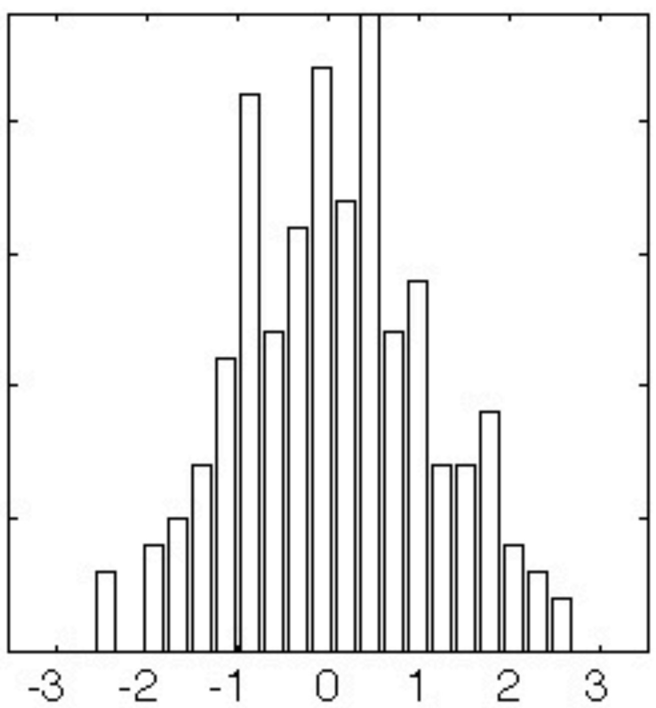
Wilcox, R. R., & Keselman, H. J. (2003). Modern robust data analysis methods: measures of central tendency. Psychol Methods, 8(3), 254-274.

robust measures of central tendency (location)

- mean $\sum(X_i-c)^2$ $\sum(X_i-c)=0$ $c=\overline{X}$
- median $\sum|X_i-c|$
- trimmed mean
- Winsorized mean
- M estimators
- ...

Trimmed means

original distribution



- 20% trimmed means provide high power under normality and high power in the presence of outliers

Rand Wilcox, 2012, Introduction to Robust Estimation and Hypothesis Testing, Elsevier

ERP application: Rousselet, Husk, Bennett & Sekuler, 2008, *J. Vis.* + Desjardins 2013

Robust estimators of central tendency

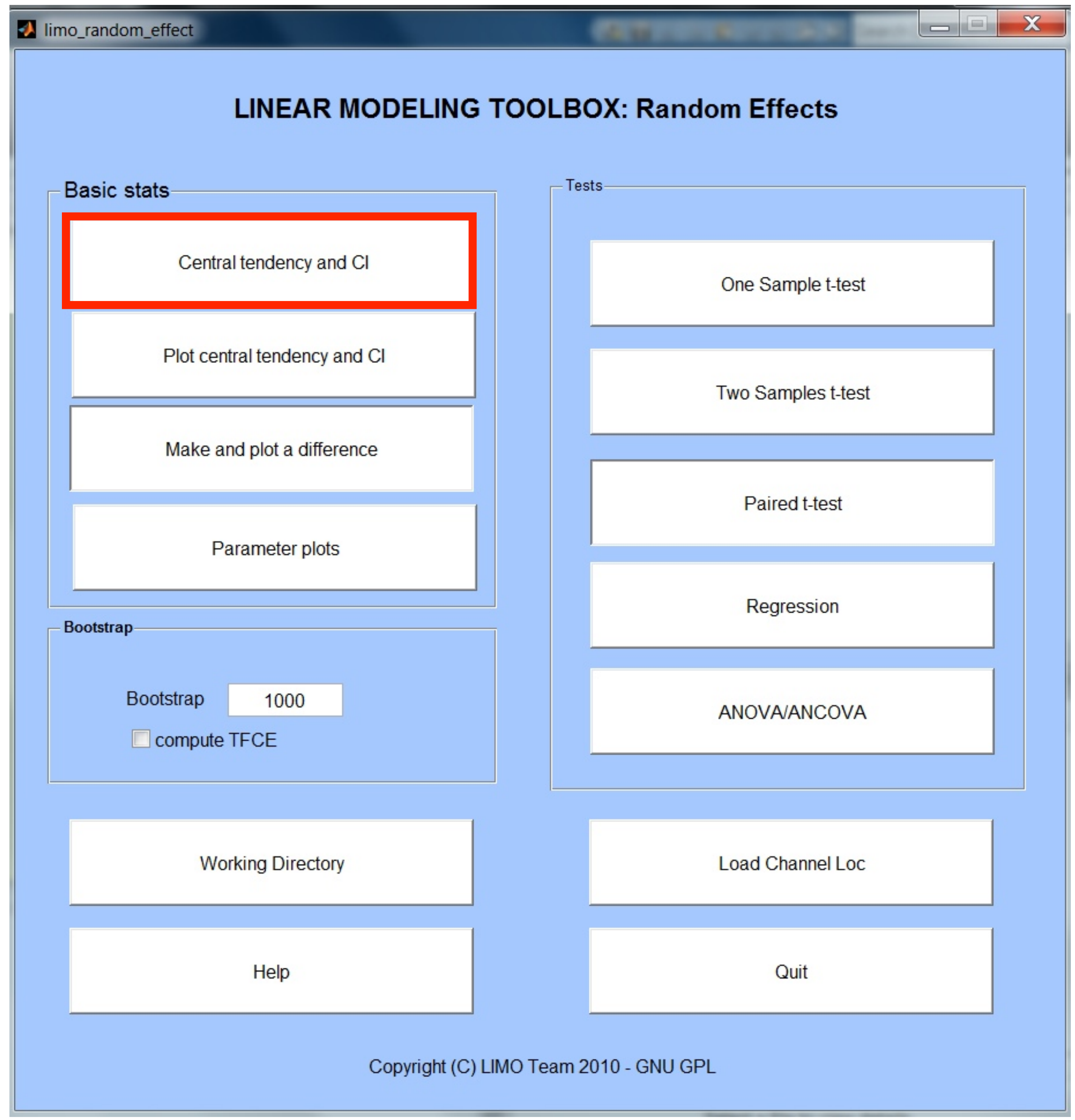
- tmERP = trimmean(EEG.data,...)
- mdERP = median(EEG.data,...)
- in LIMO EEG:
    - mdERP = limo_median(EEG.data,...)
    - tmERP = limo_trimmed_mean(EEG.data,...)
    - hdERP = limo_harrell_davis(EEG.data,...)

Robust estimators of dispersion

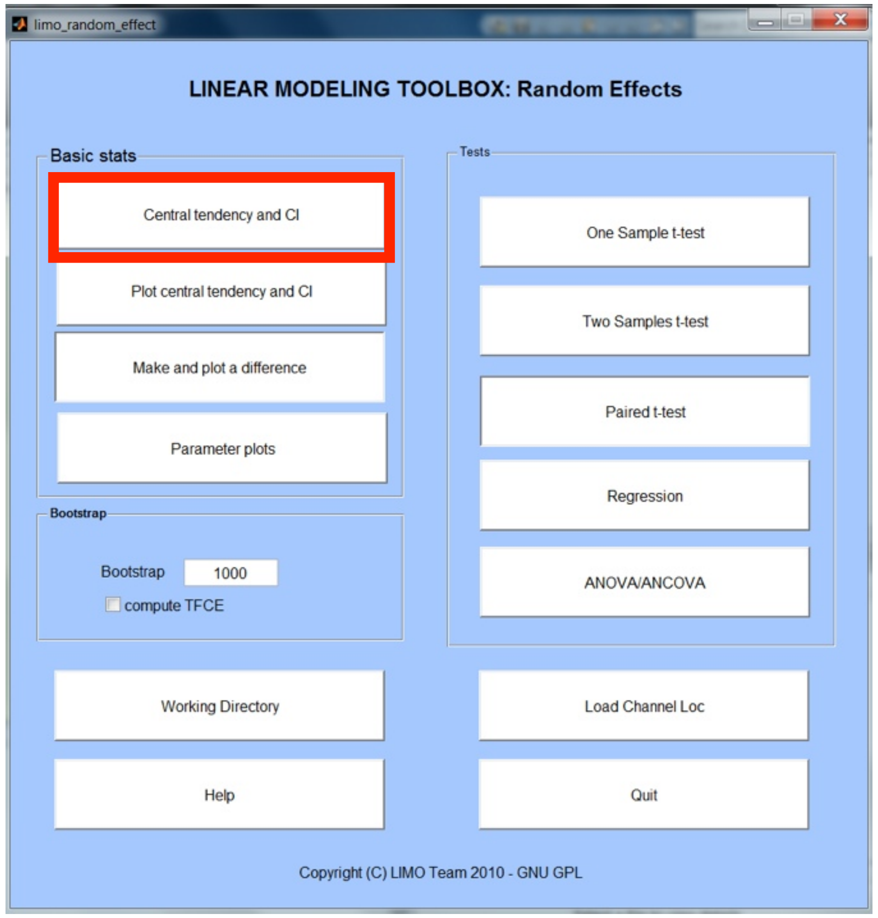
- madERP = mad(EEG.data,...)
- in LIMO EEG:
  - wERP = limo_winvar(EEG.data,...)
  - sehdERP = limo_bootse(EEG.data,...)

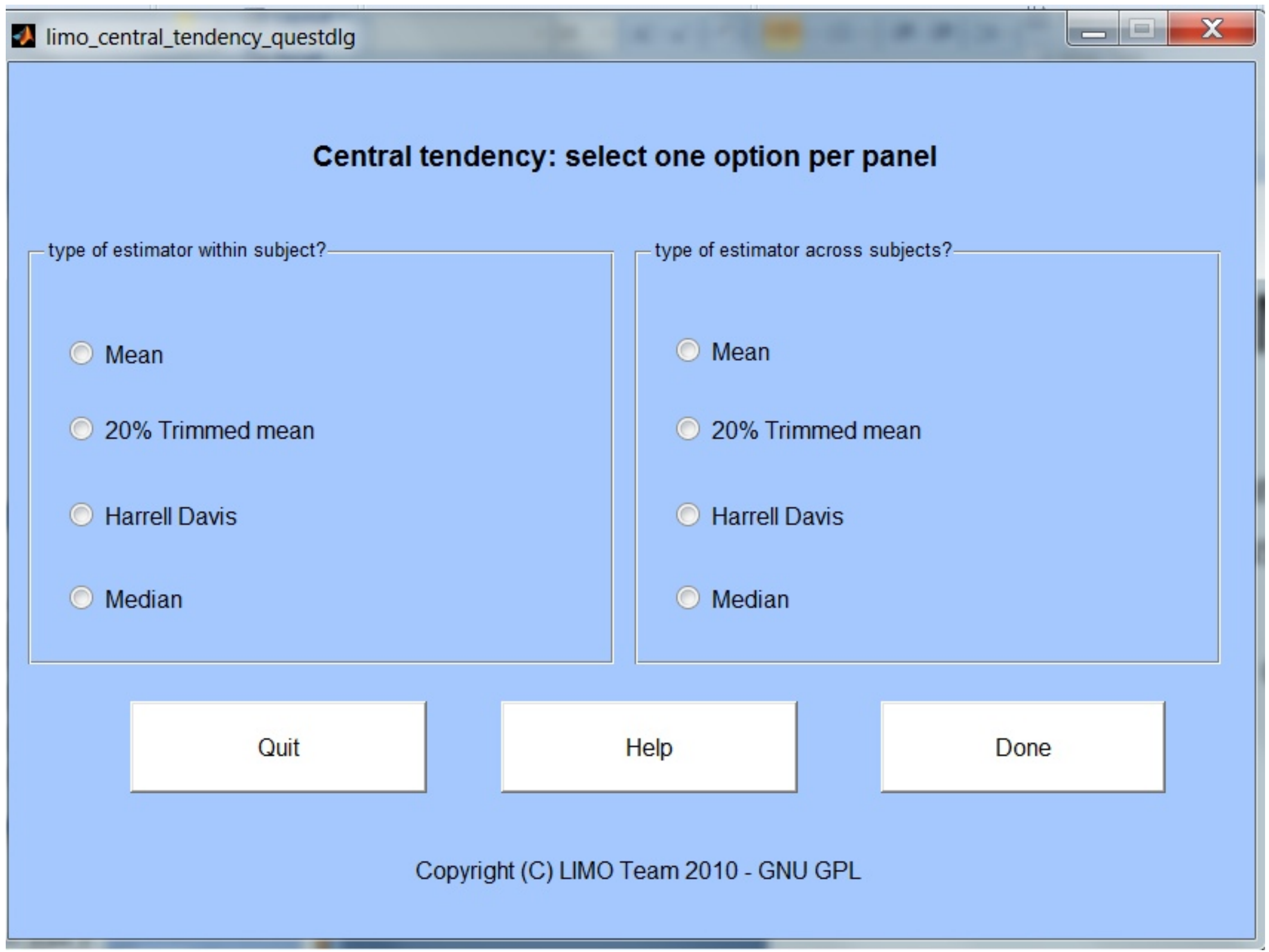
LIMO BASIC STATS

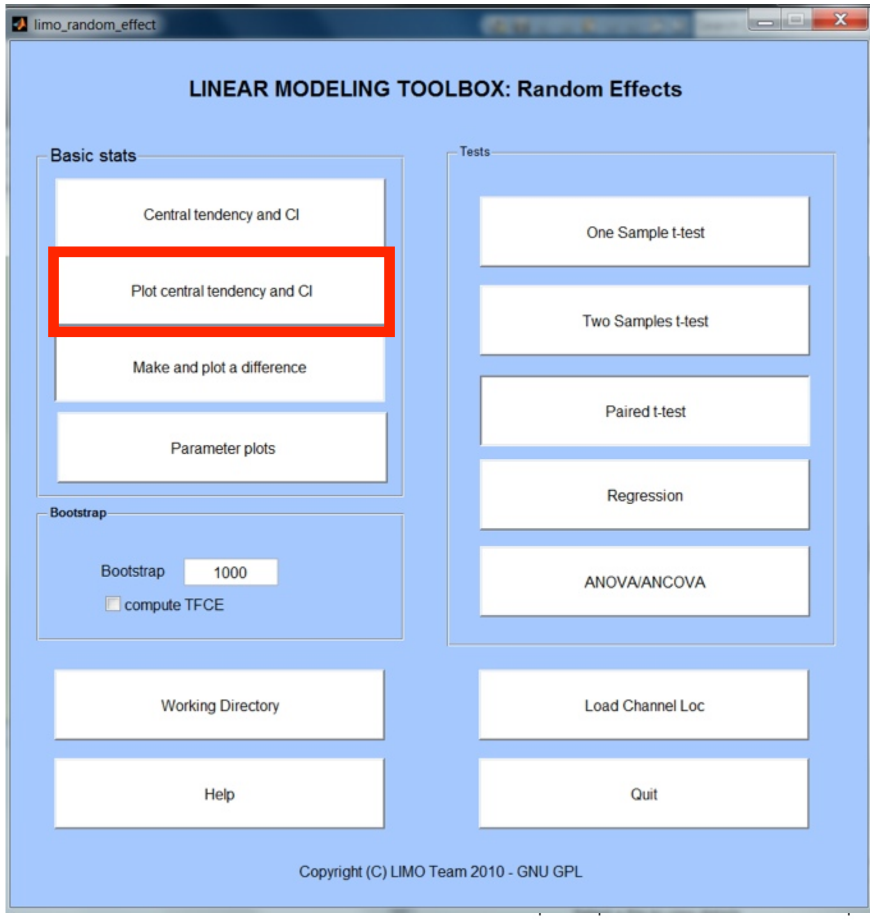
- **average** single trials for a subject or parameters across subjects: trimmed means, median & Harrell Davis estimator + confidence intervals



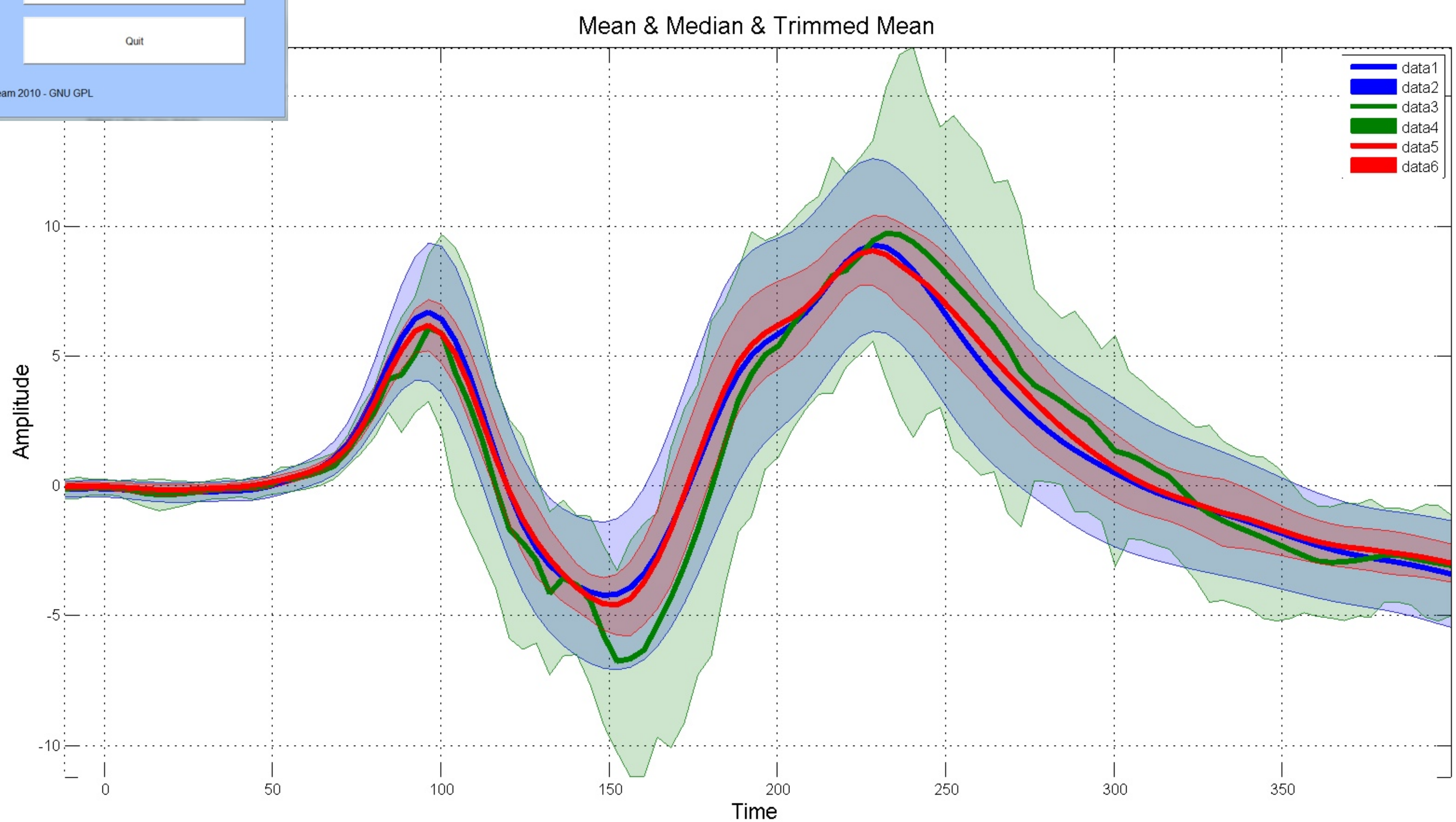
central tendency and CI

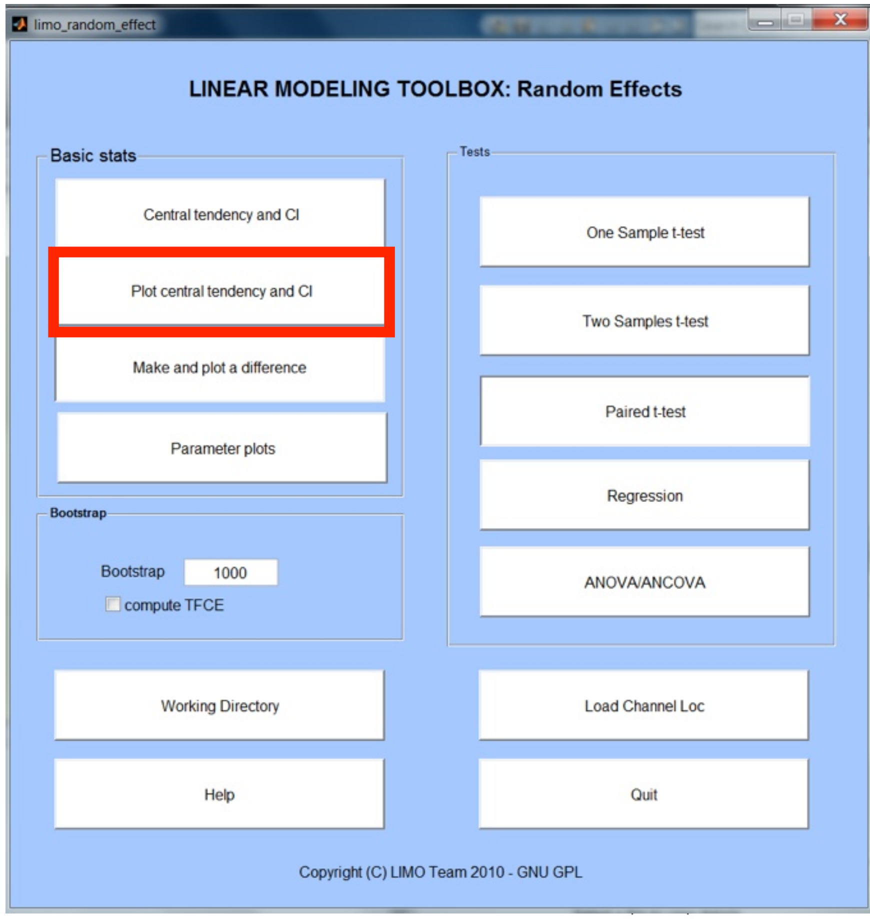




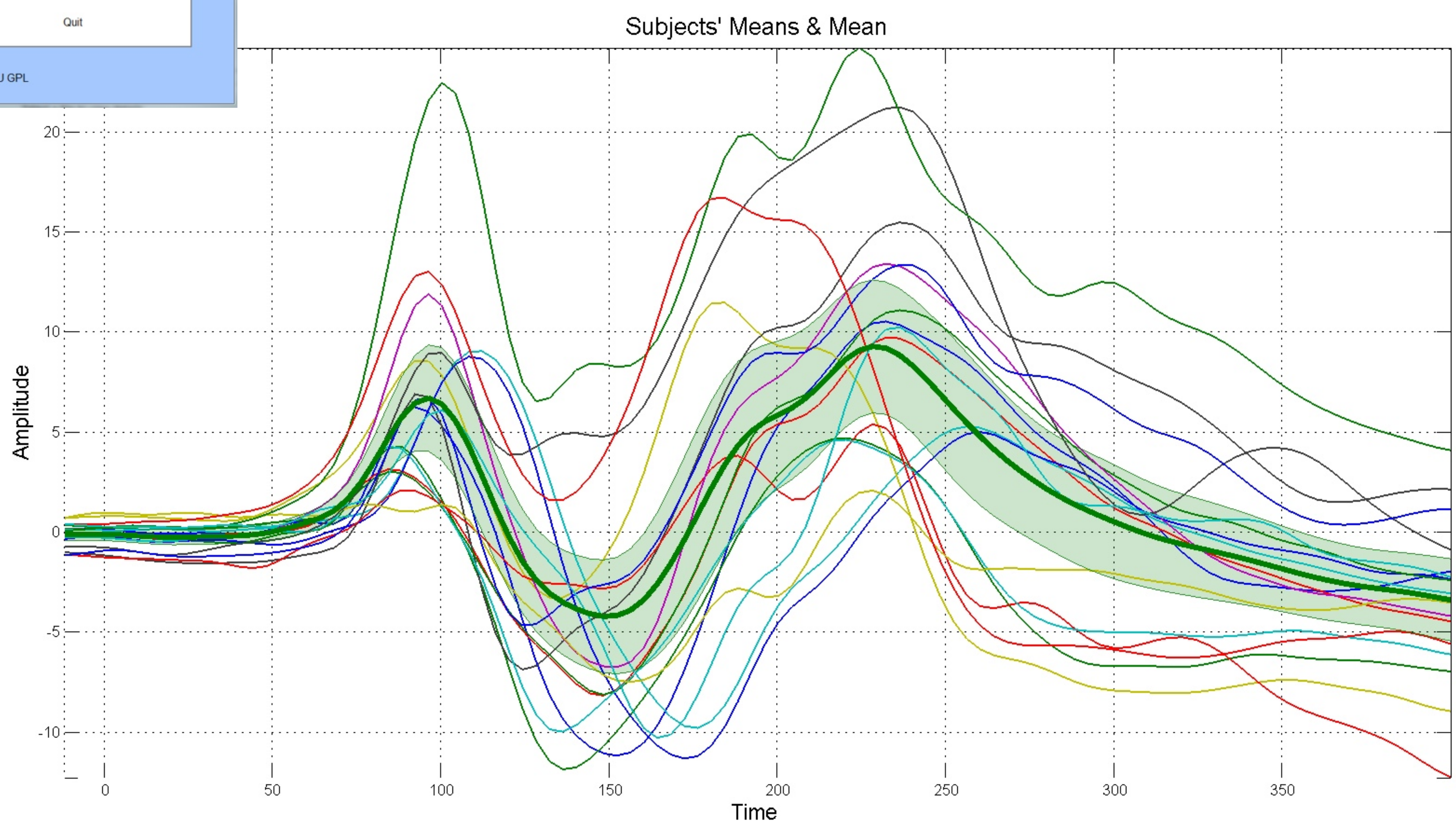


Plot central tendency and CI





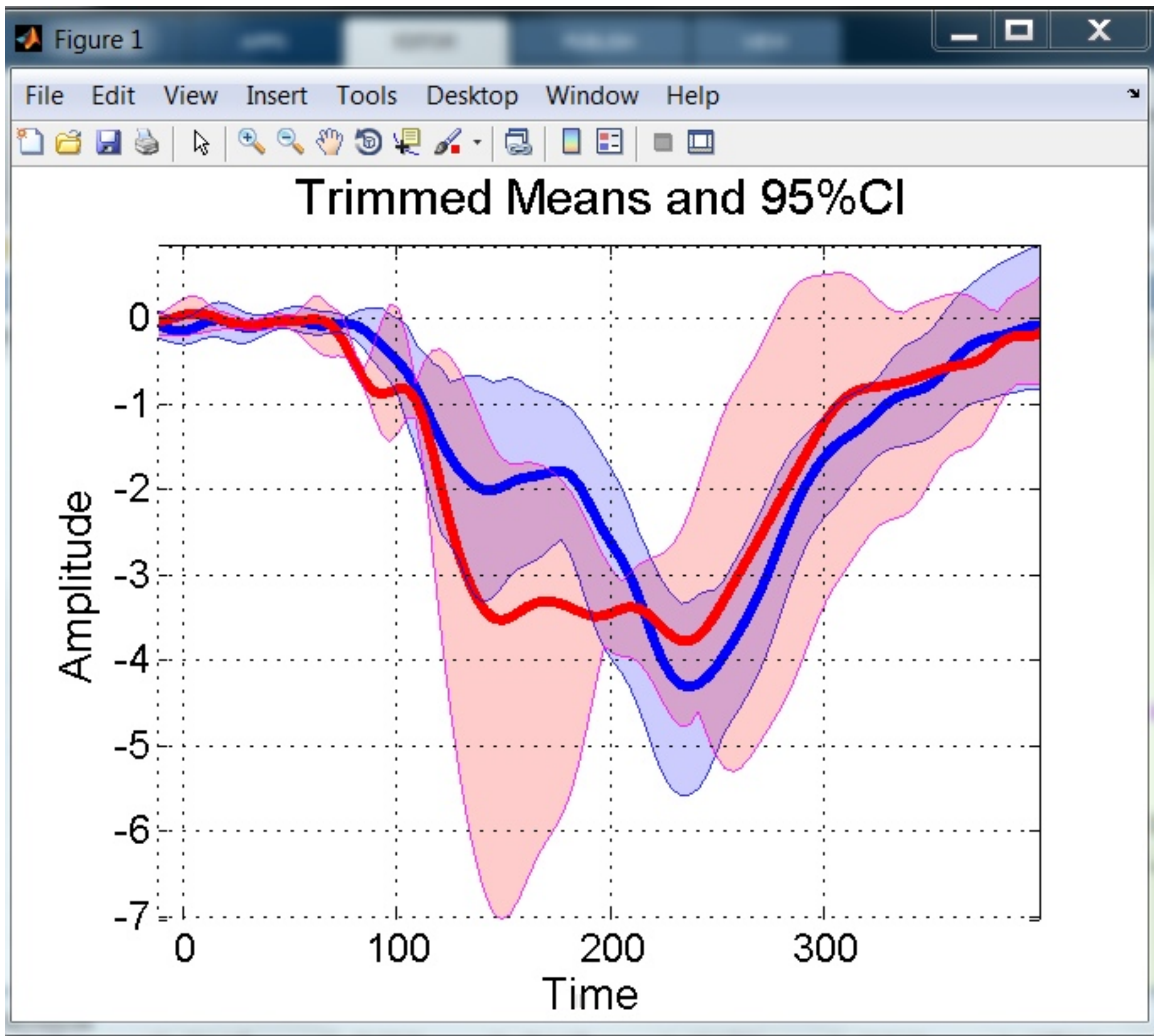
Plot central tendency and CI

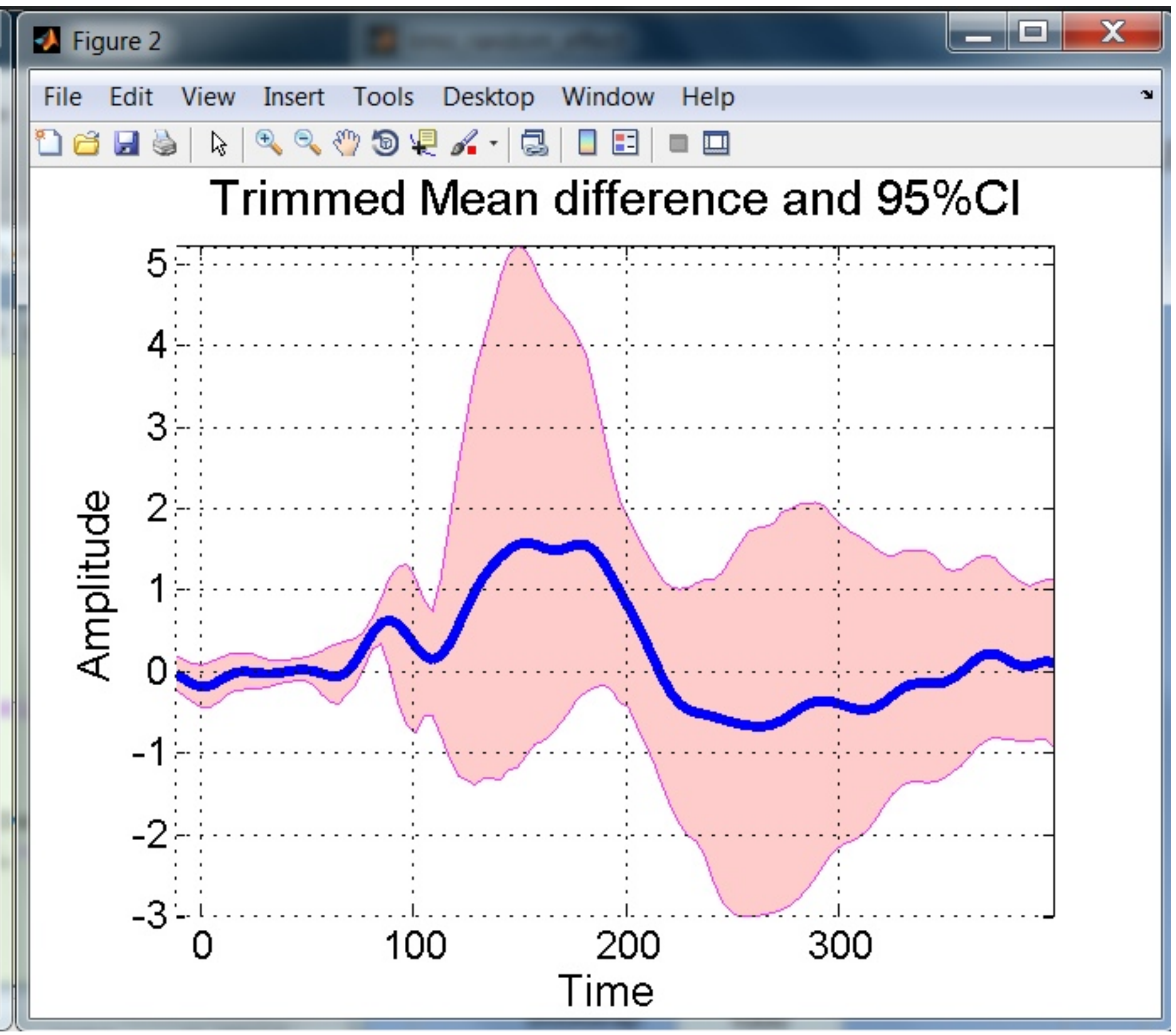


Make and plot a difference

- 20% trimmed means

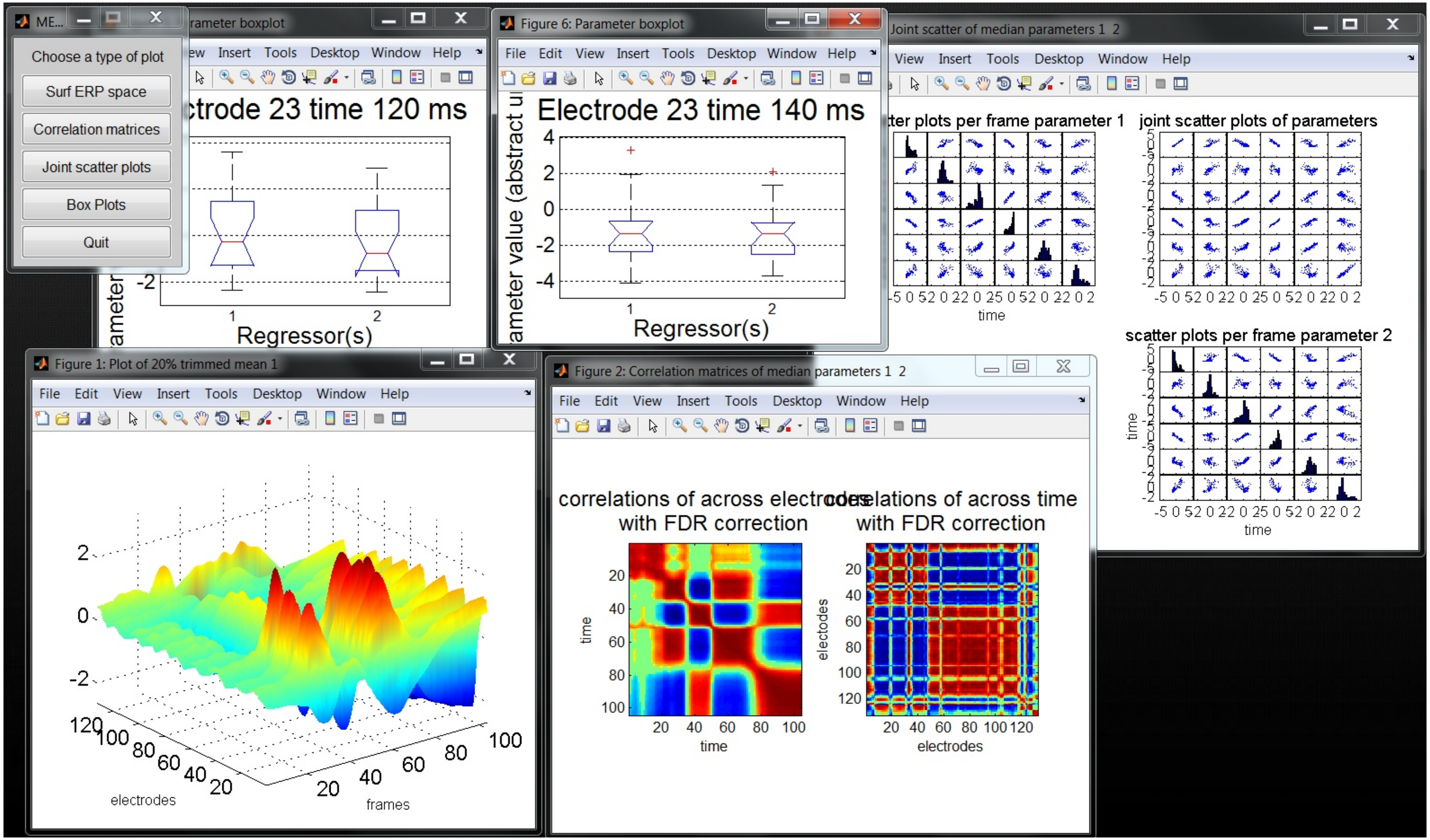
- 20% trimmed mean difference





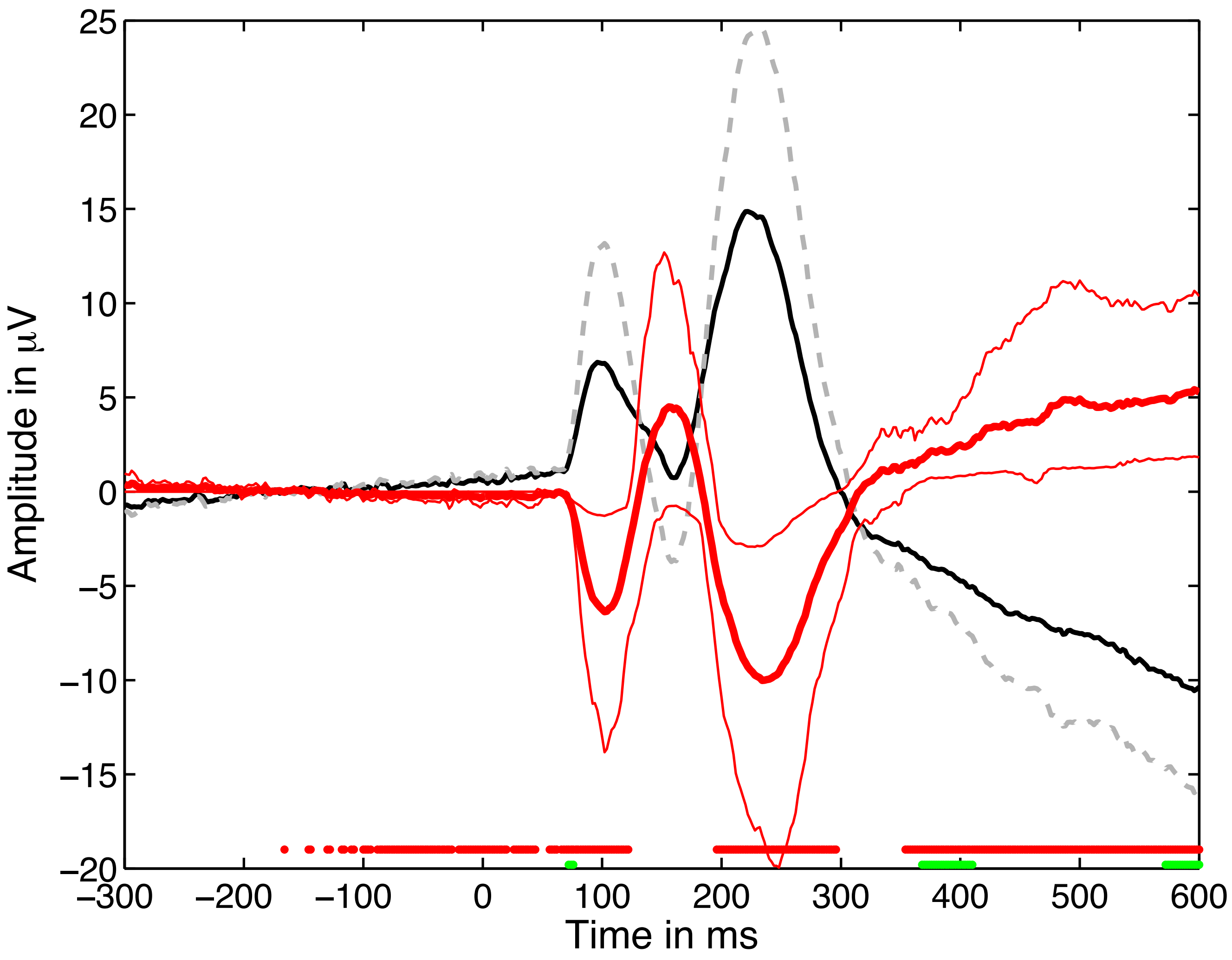
Parameter plots

- Extra visualization tools to explore beta parameters

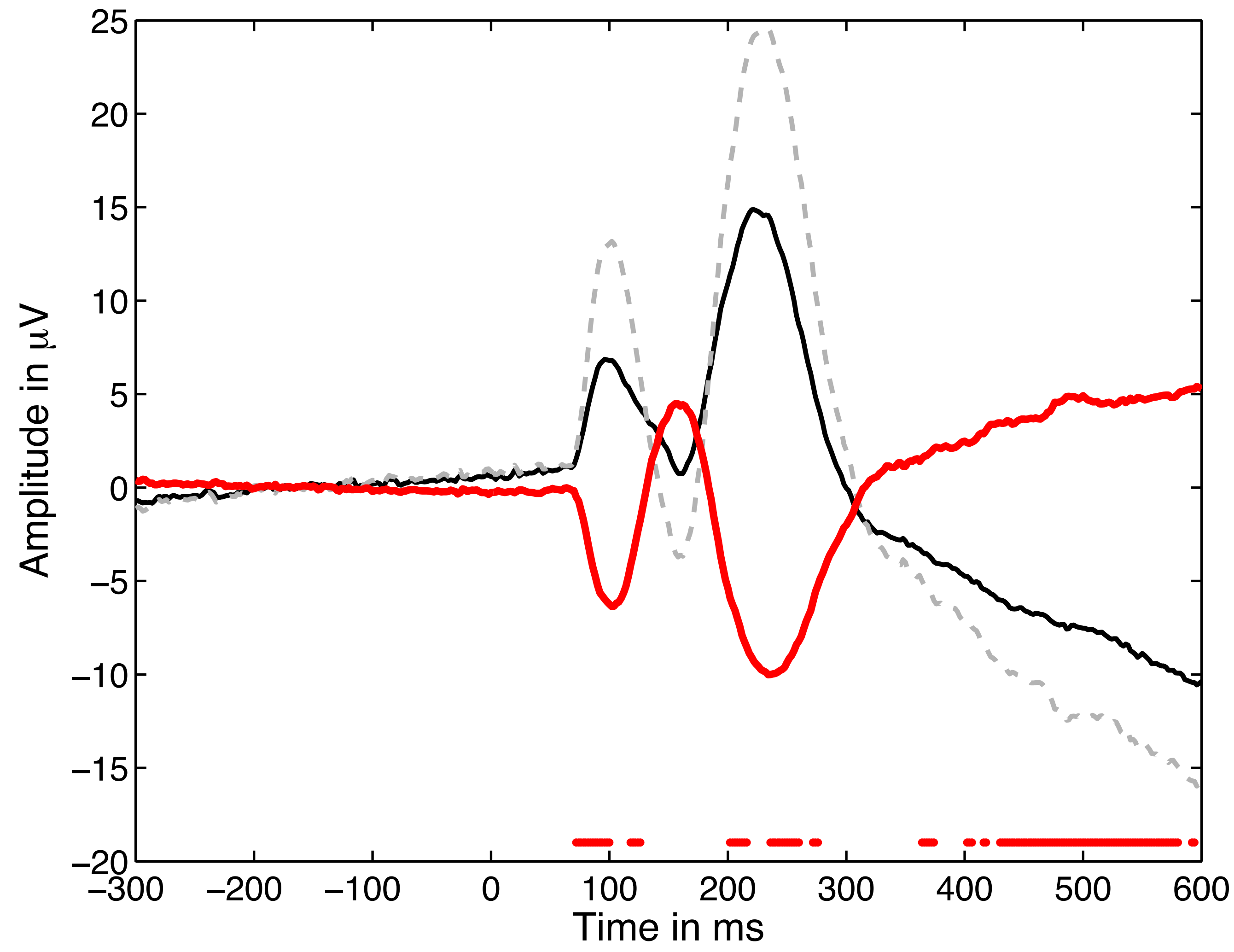


Solving case study 1: robust estimators

t-test and percentile bootstrap



t-test on 20% trimmed means

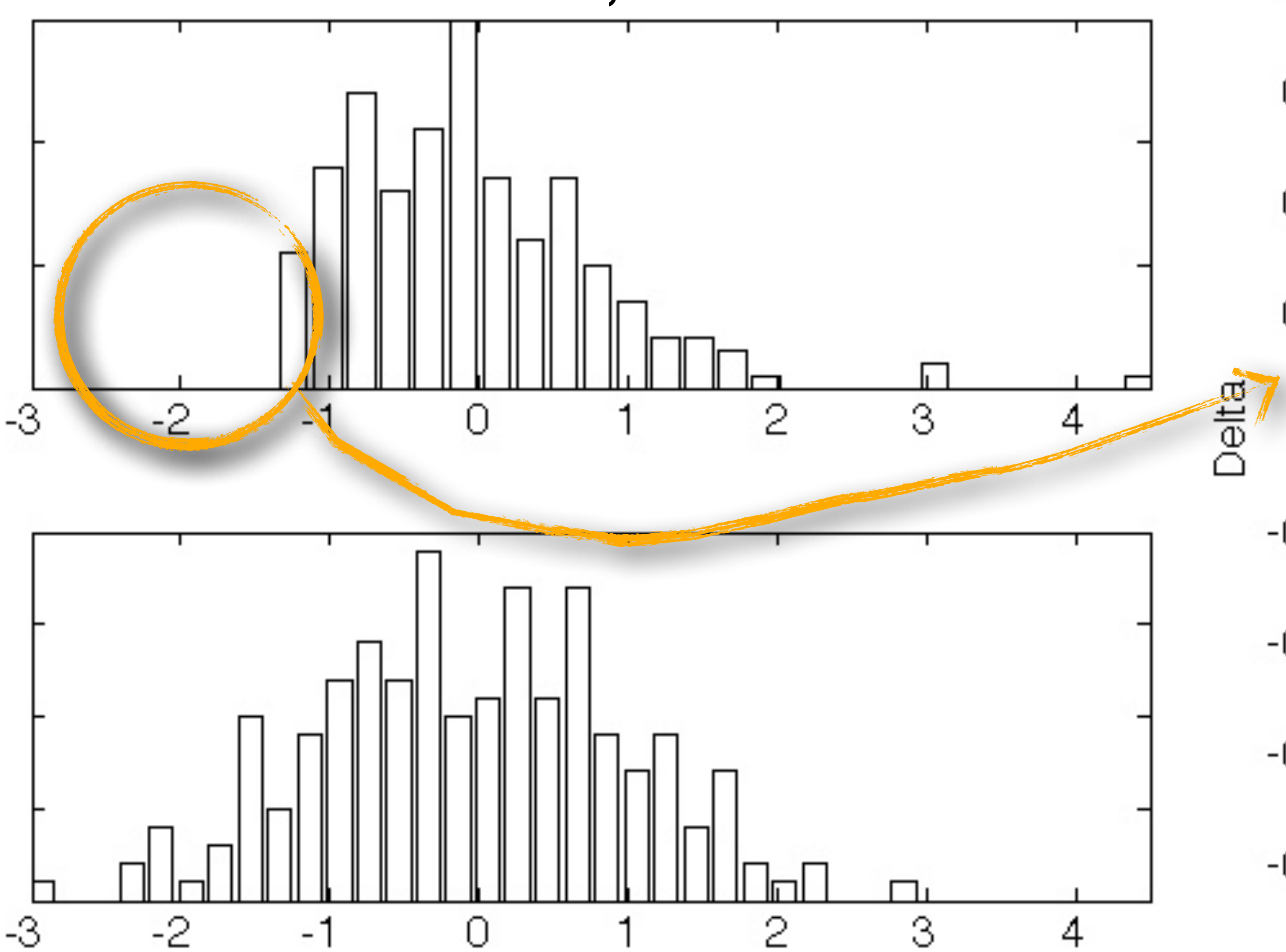


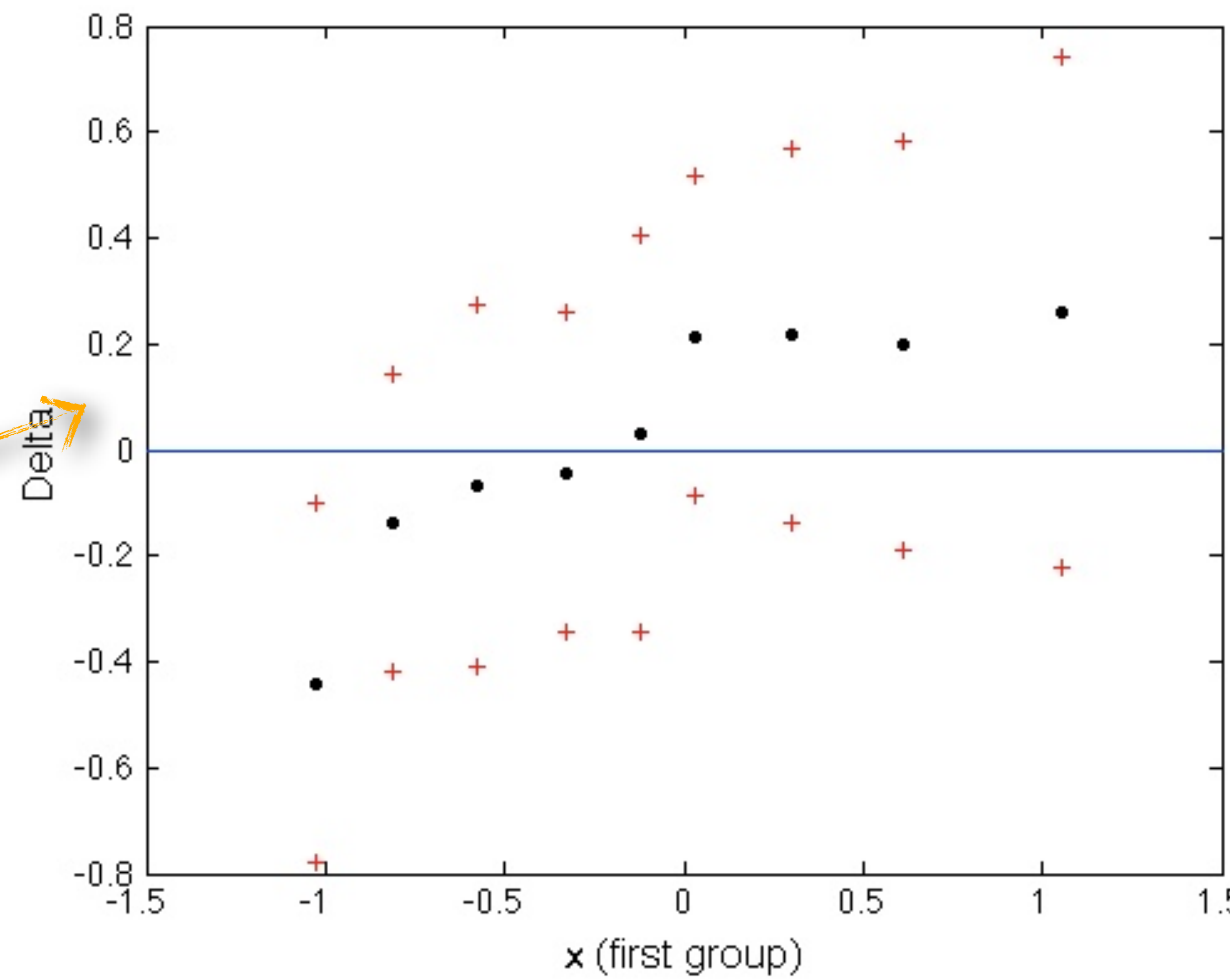

I AM THE LAW
JUDGE DREDD

Compare entire distributions using the **shift function**

If there is no significant difference between the means or the medians of 2 conditions, we CANNOT conclude that 2 conditions do not differ in general: check all the DECILES

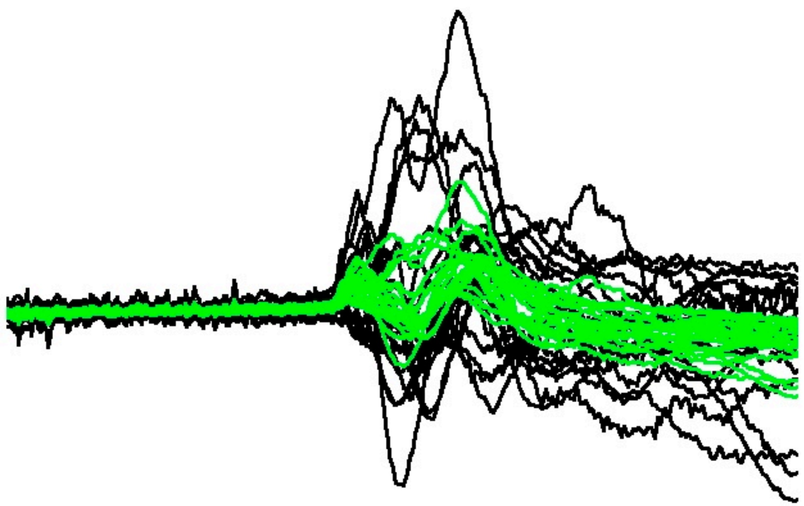
mean=0, std=1

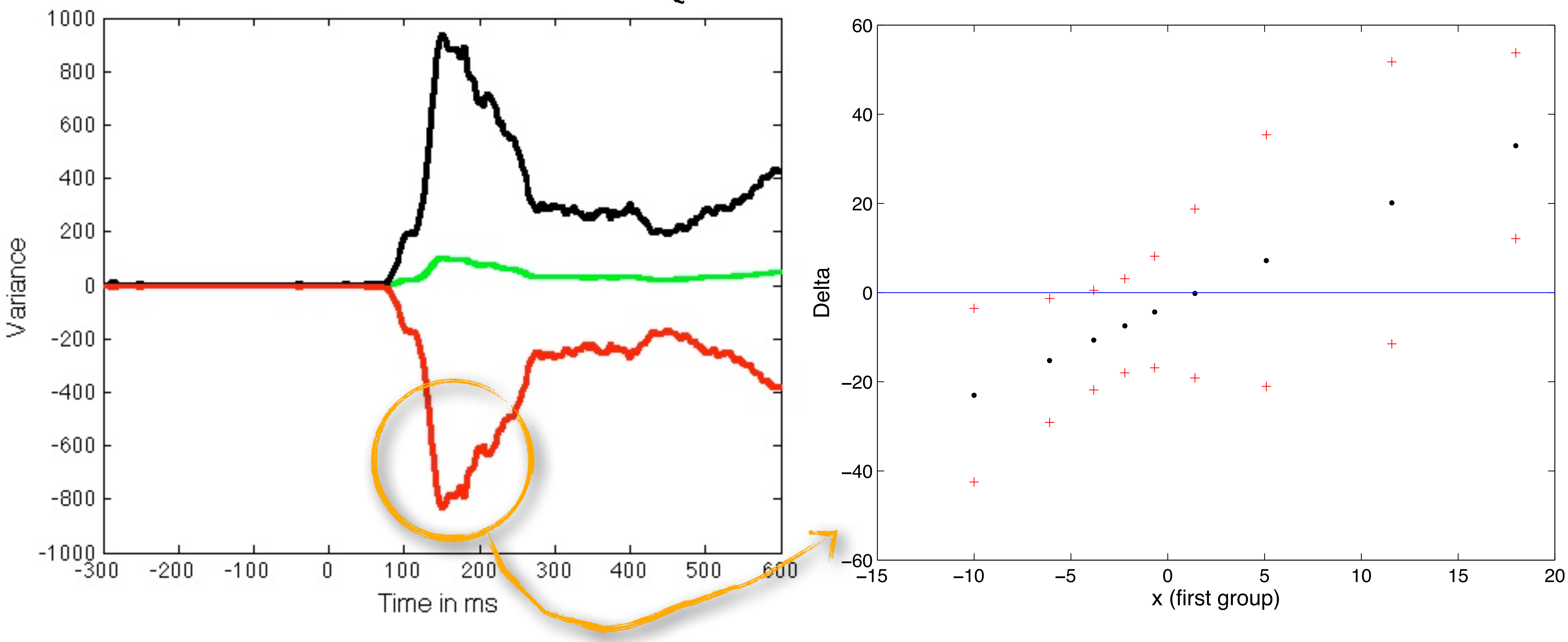




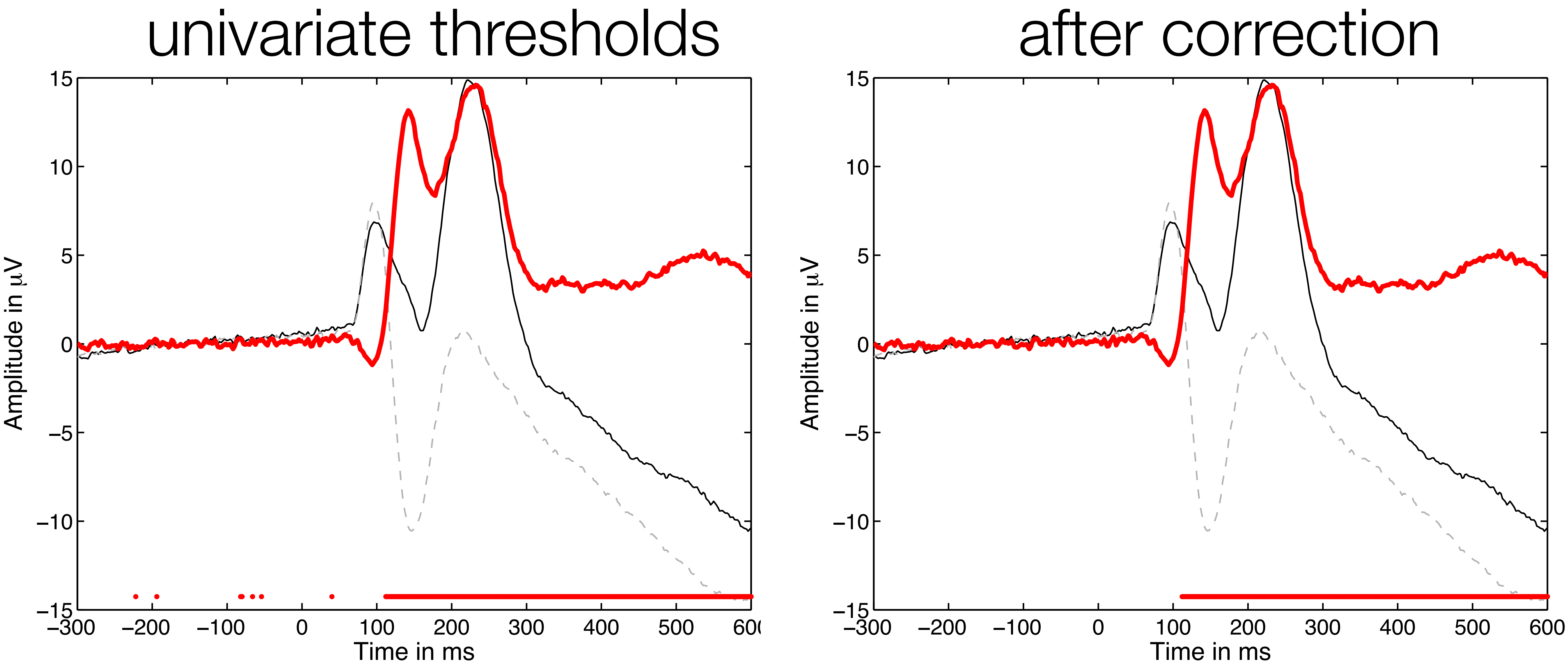
Doksum, K. (1974). Empirical Probability Plots and Statistical Inference for Nonlinear Models in the two-Sample Case. *Annals of Statistics*, *2*(2), 267–277.

Solving case study 2: shift function



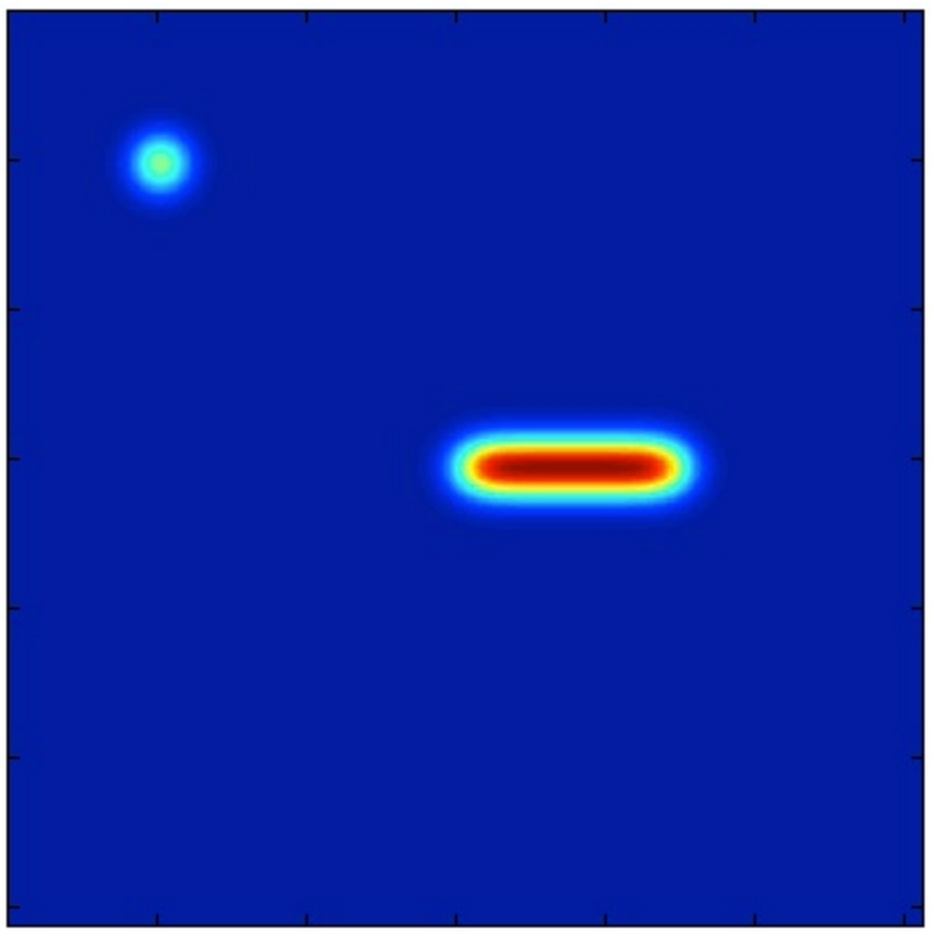


Control for multiple comparisons: bootstrap-t technique & spatial-temporal clustering



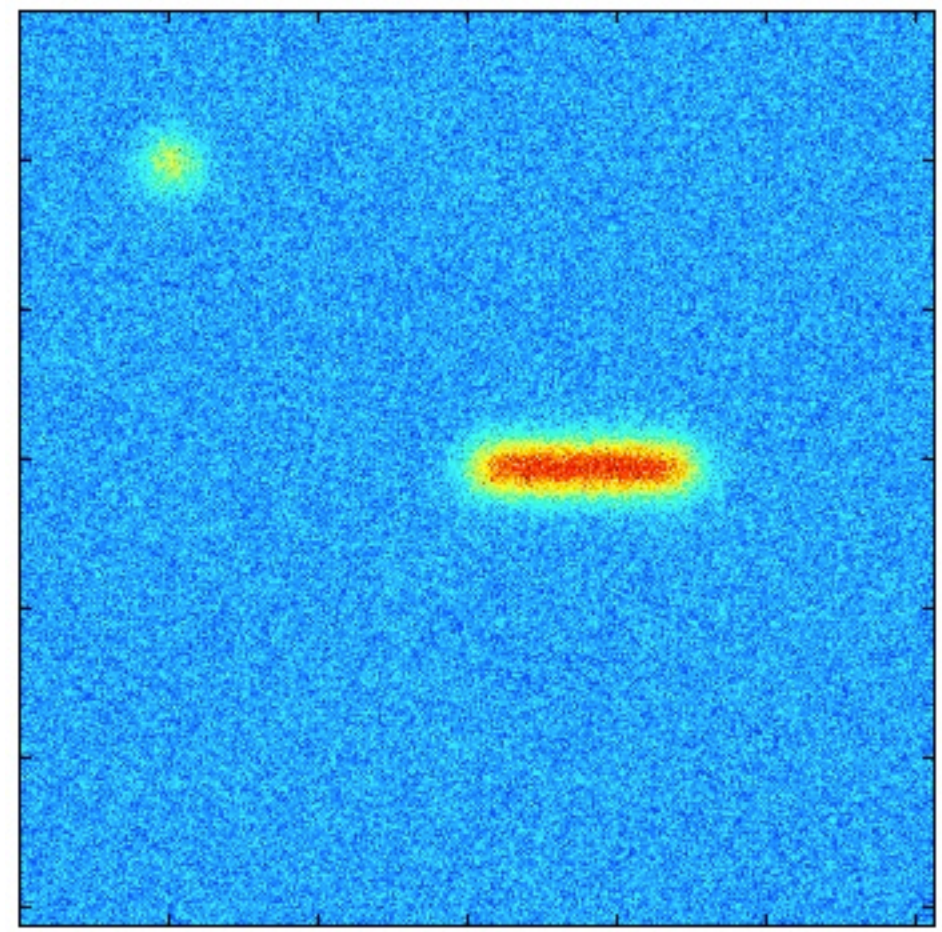
Control for multiple comparisons

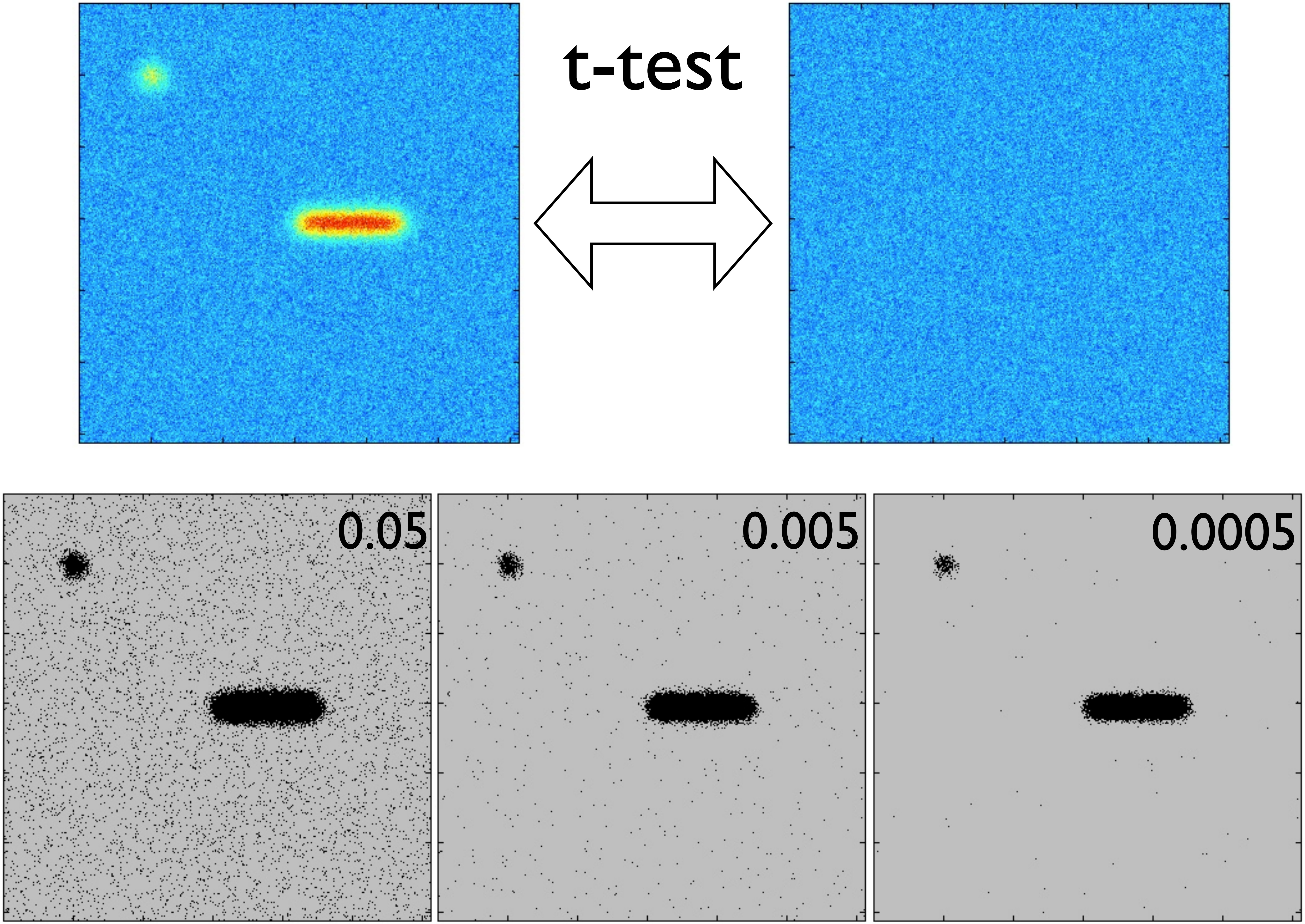
signal



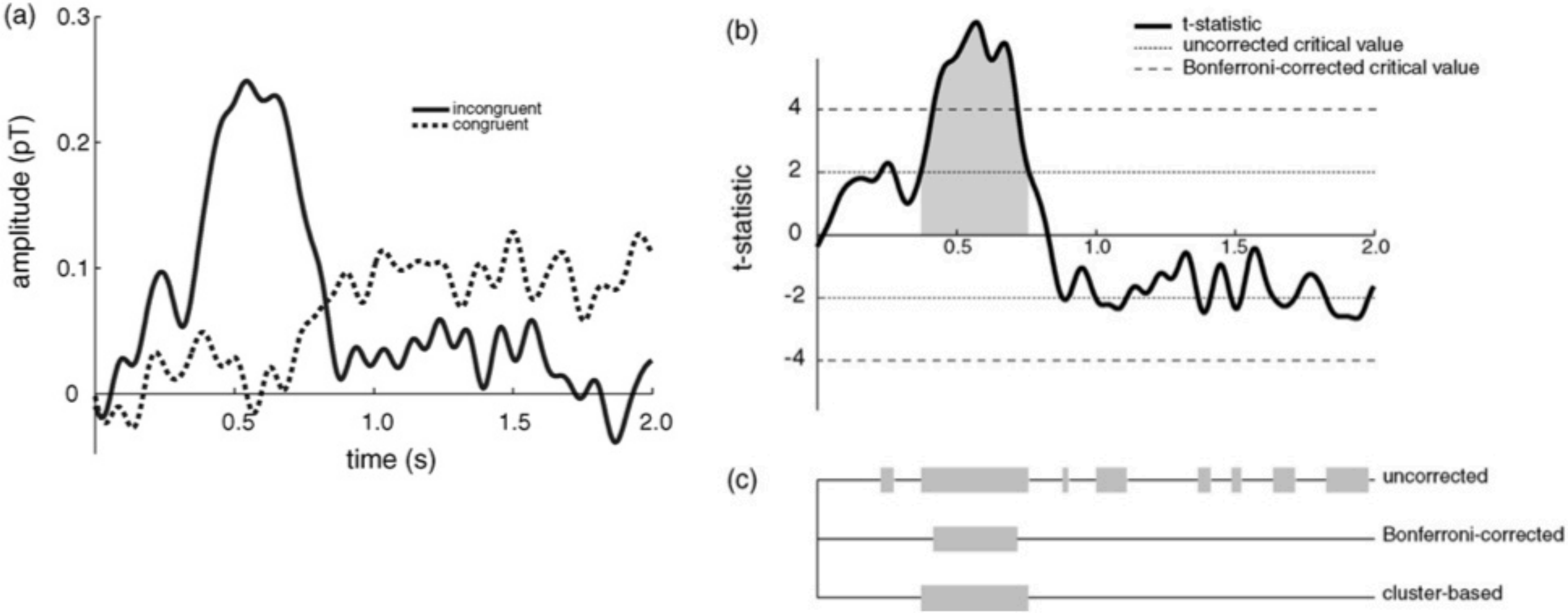
100 trials =
signal +
white noise

mean




t-test
0.05
0.005
0.0005

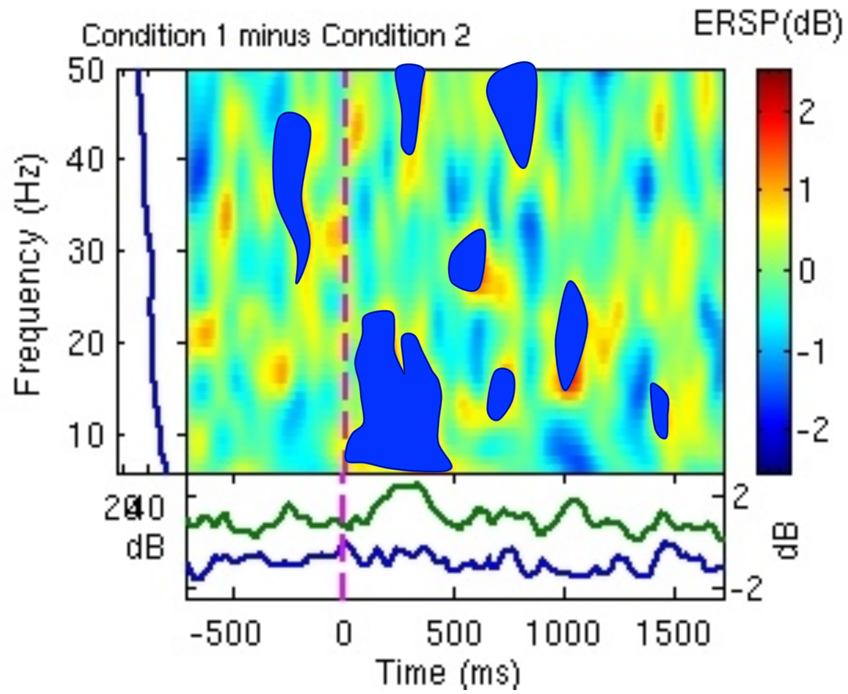
Control for multiple comparisons



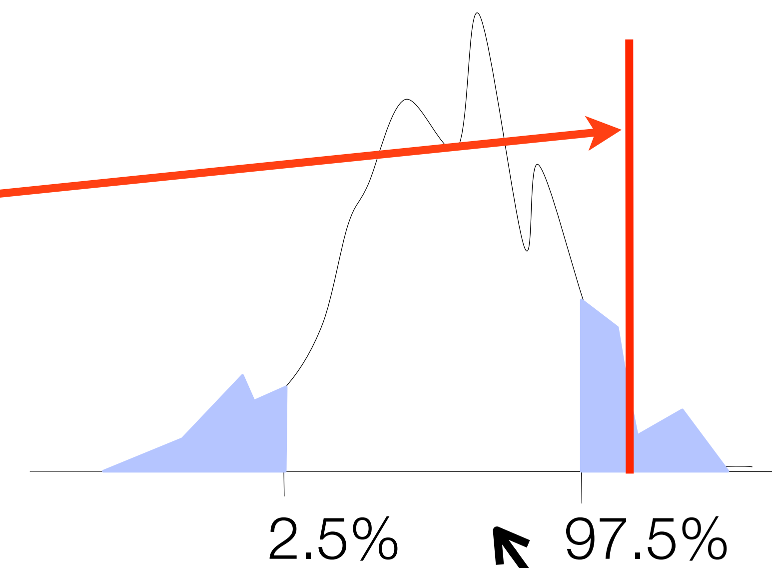
Maris & Oostenveld, J. Neurosci. Methods 2007
Matlab toolboxes: Fieldtrip + LIMO_EEG

Cluster correction for multiple comparisons

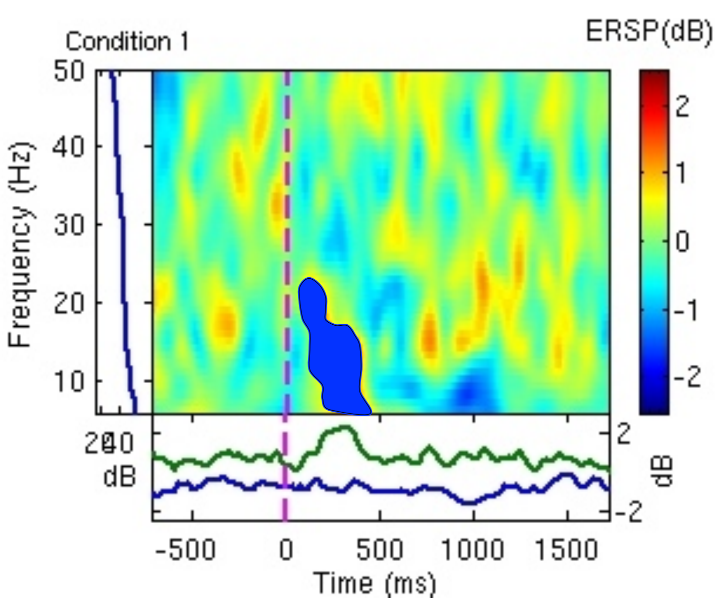
Original difference



44 pixels

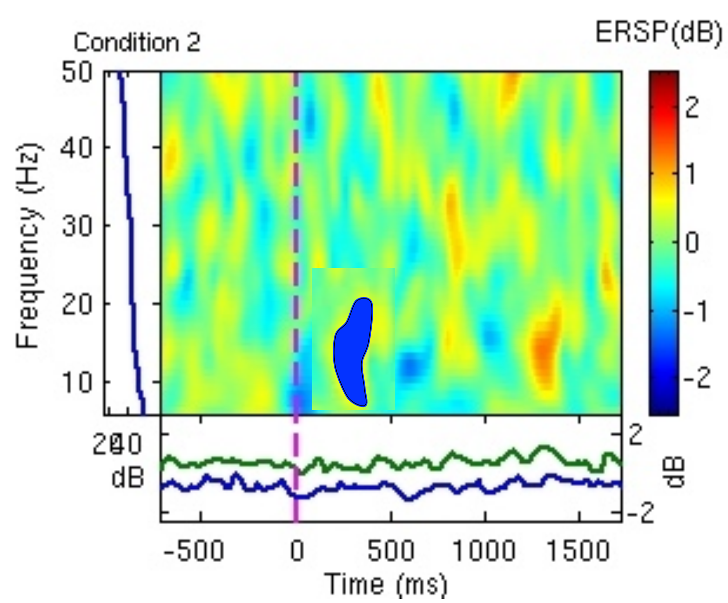


bootstrap difference 1



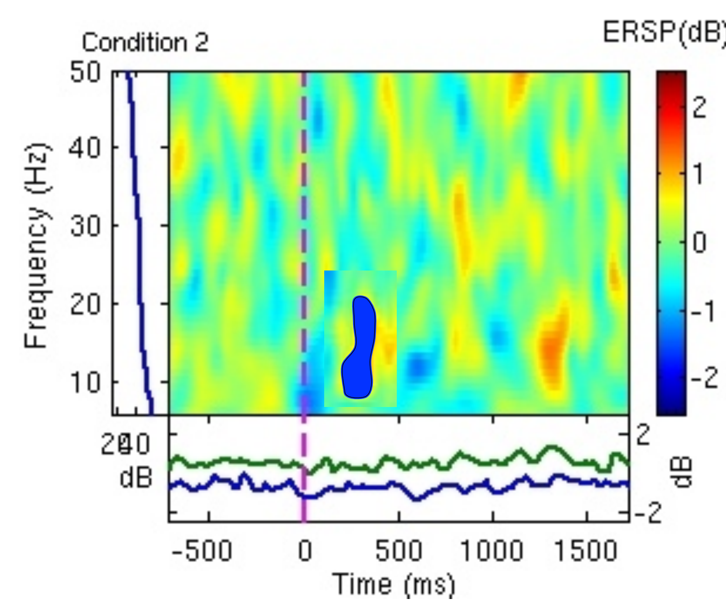
35 pixels

bootstrap difference 2



27 pixels

bootstrap difference 3



26 pixels

....

bootstrap-t method (percentile-t technique)

create <u>standardized bootstrap distribution of the estimator</u> in a way completely analogous to the use of Student's t distributions. When working with means, strategy = use the observed data to approximate the *t* distribution.

$$T = \frac{\sqrt{n}(\bar{X} - \mu)}{s}$$

- compute T using original data
- center each group -> H0 is true
- sample = X1, ..., Xn
- resample n observations with replacement
- compute T*
- repeat B times
- compare T* distribution to T

$$T^* = \frac{\sqrt{n}(\bar{X}^* - \bar{X})}{s^*}$$

bootstrap-t method for a trimmed mean

1. compute sample trimmed mean

2. generate bootstrap sample by randomly sampling with replacement n observations

3. compute tmean* →

$$T_t^* = \frac{(1-2\gamma)\sqrt{n}(\bar{X}_t^* - \bar{X}_t)}{s_\omega^*}$$

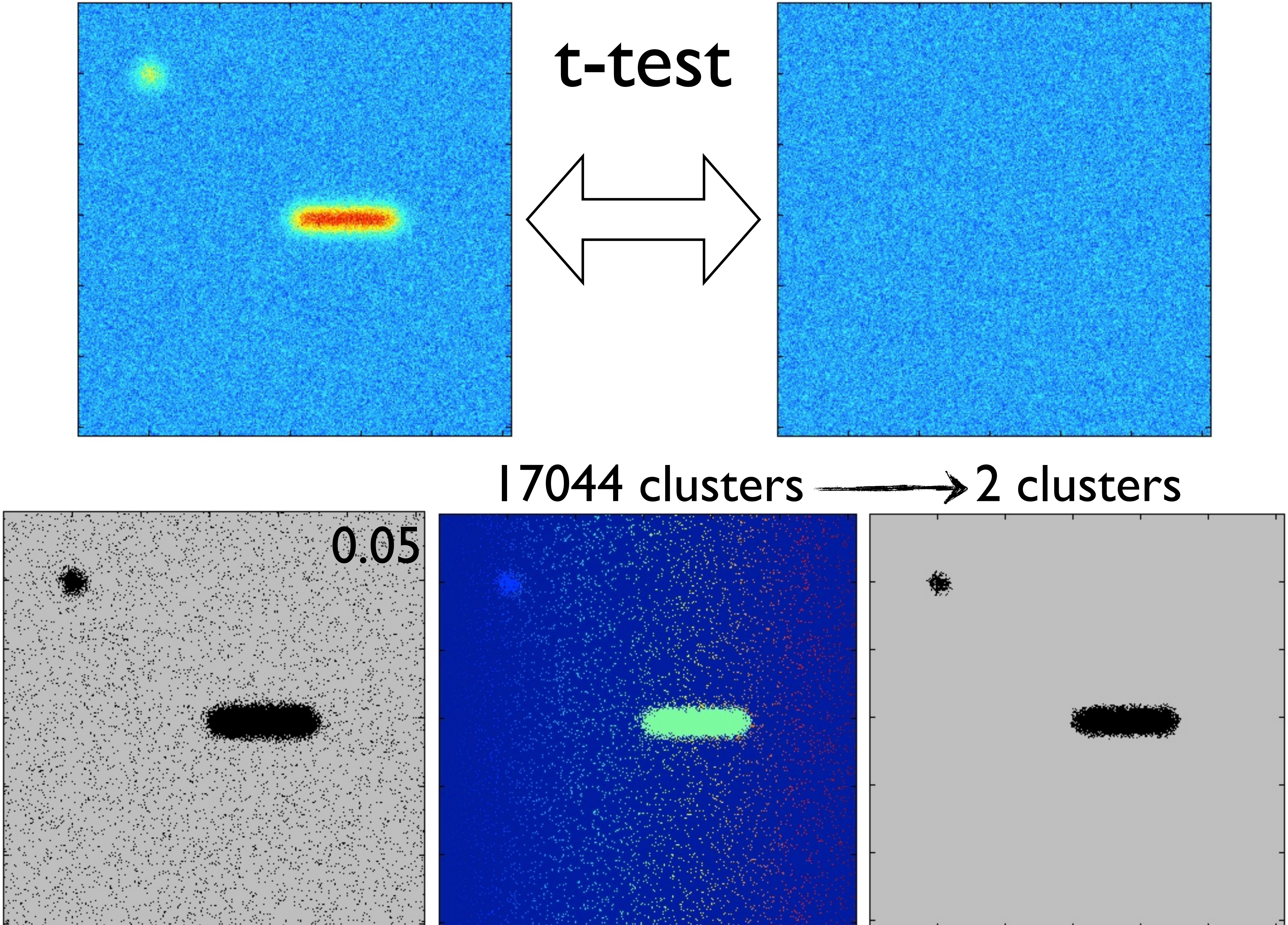
4. repeat steps 2 & 3

5. sort tmean* values

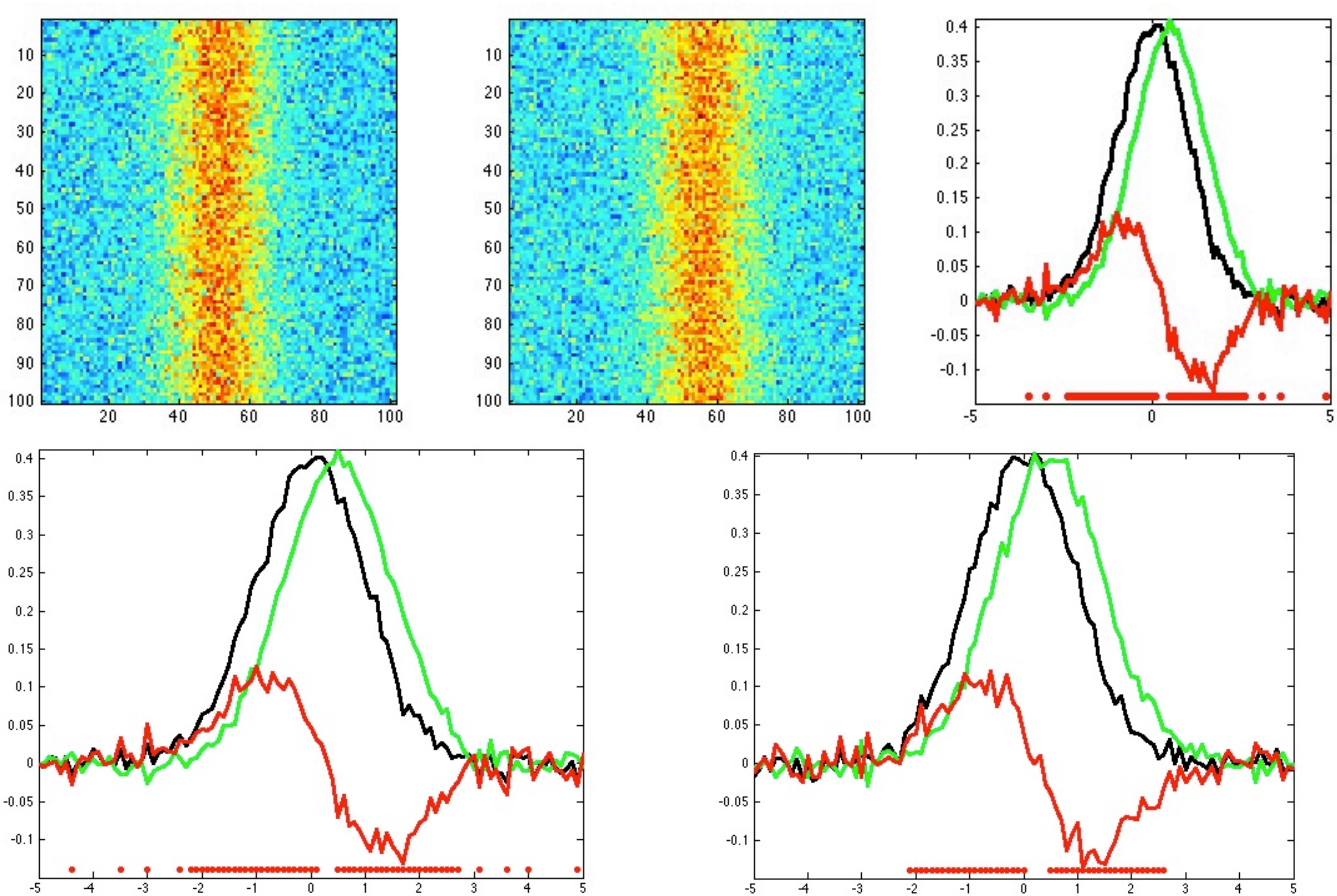
1-α CI: $$\left(\bar{X}_t - T_{t(u)}^* \frac{s_\omega}{\sqrt{n}}, \bar{X}_t - T_{t(l)}^* \frac{s_\omega}{\sqrt{n}}\right)$$

Which bootstrap method to use?

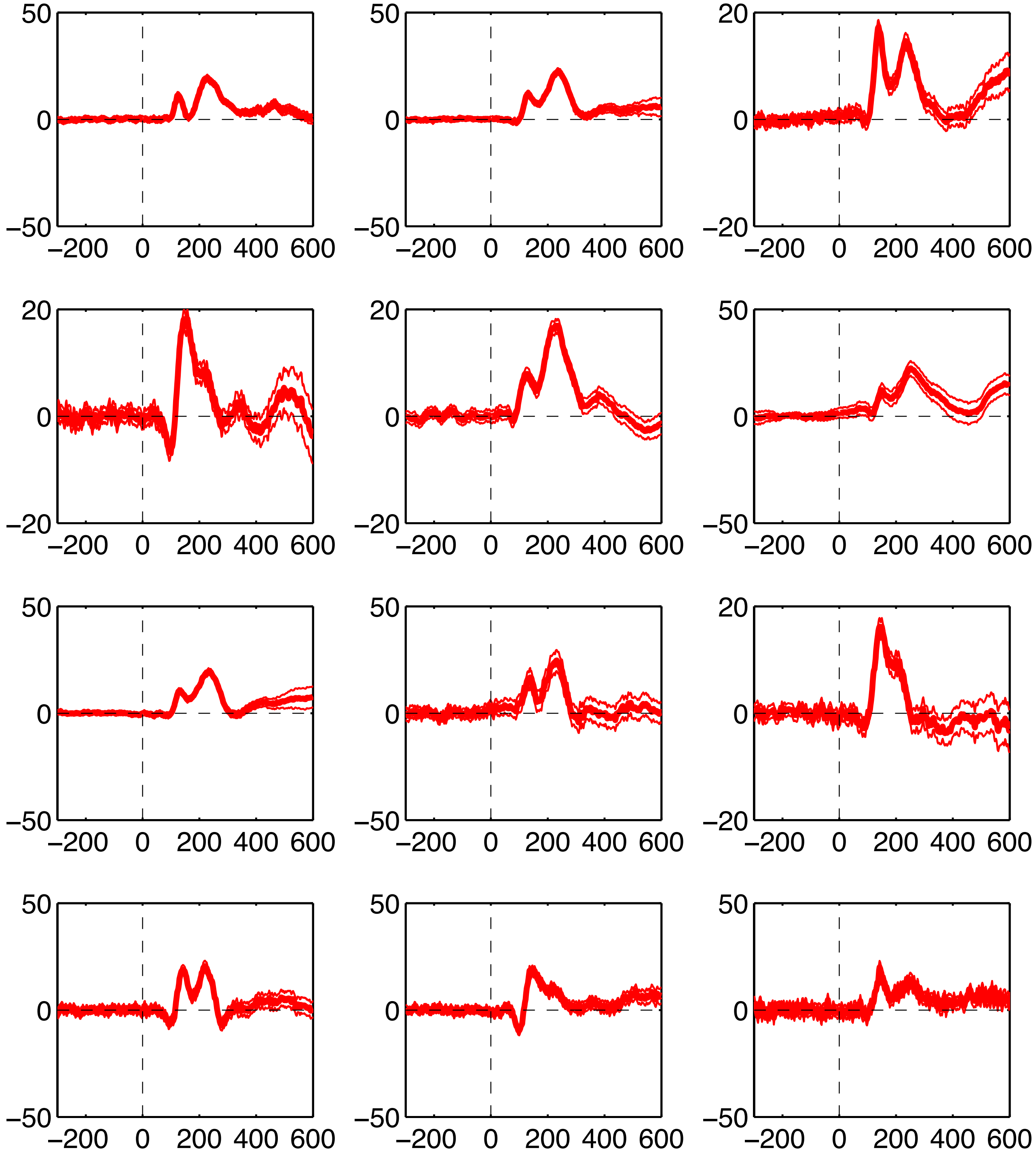
- How do we build good confidence intervals?
    - choose estimator
    - choose technique
- Rand Wilcox recommends:
    - trimming ≥ 20%: percentile technique
    - trimming < 20%: percentile-t technique
    - M-estimators: percentile technique

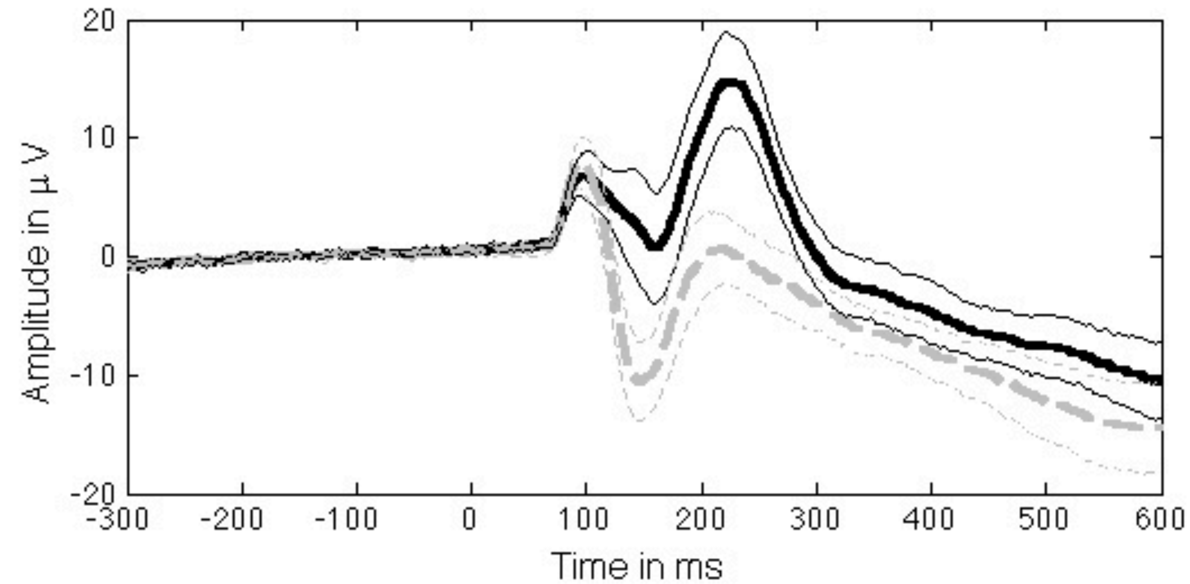

t-test
0.05
17044 clusters
2 clusters

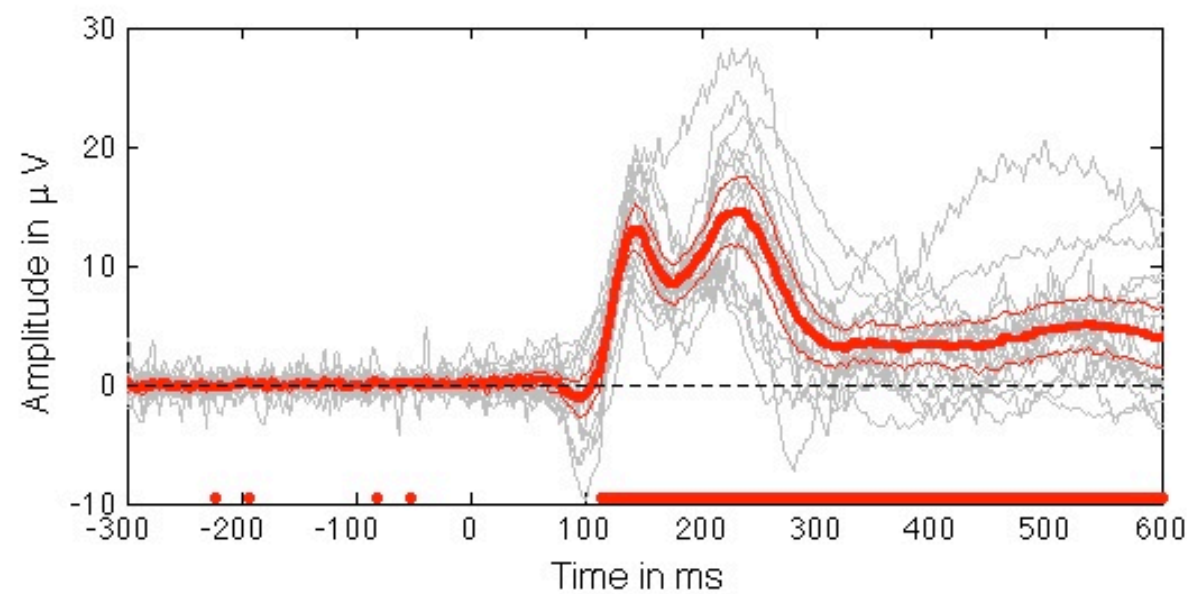
1D cluster test cmc_example.m

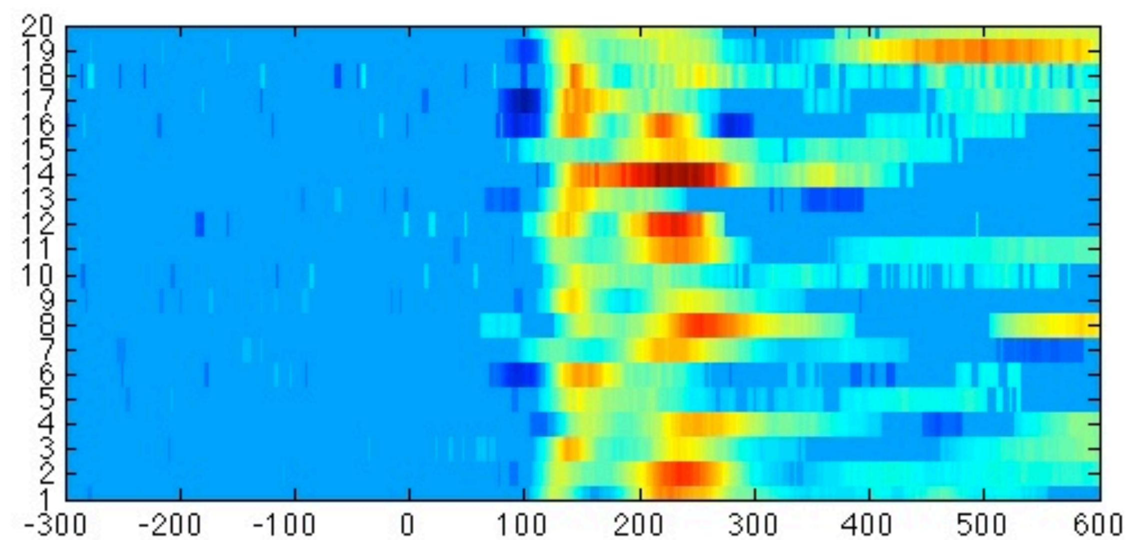


Single-subject analyses

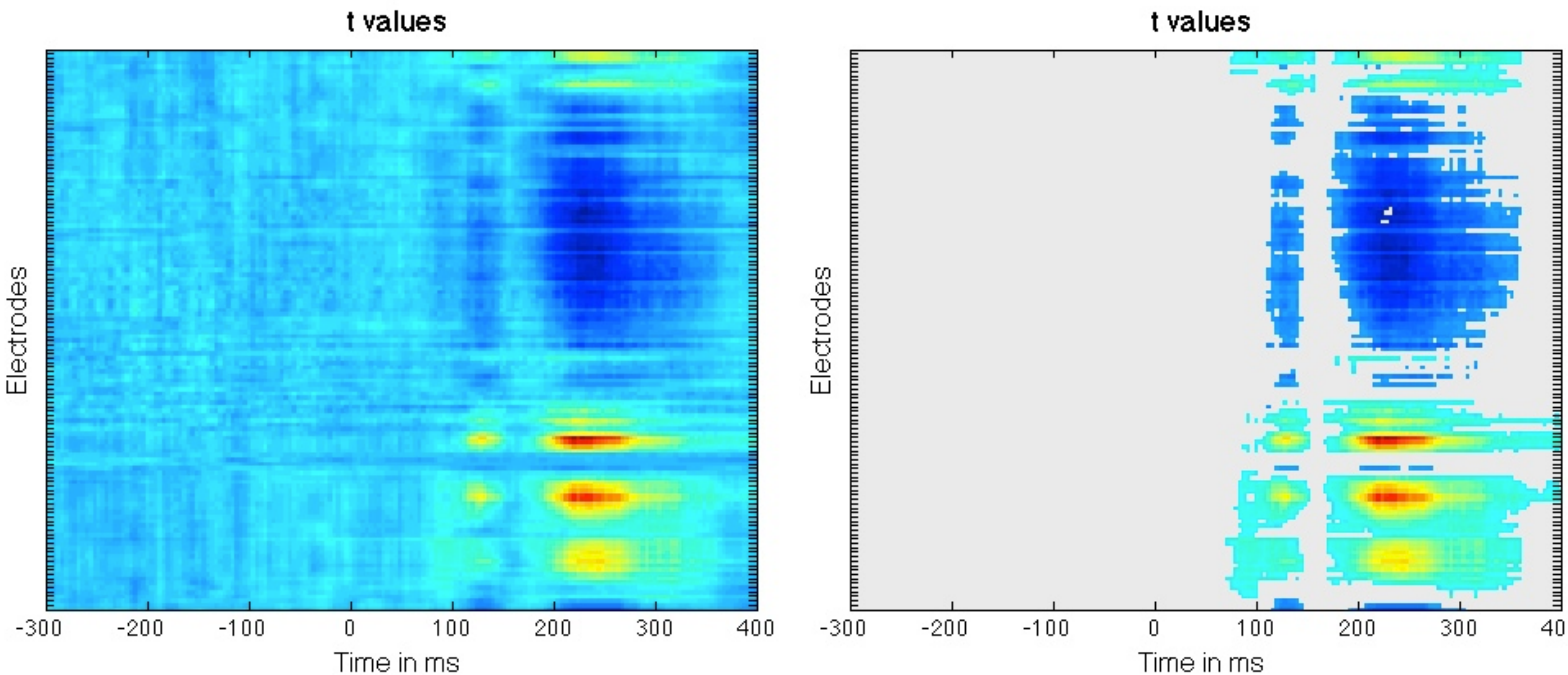




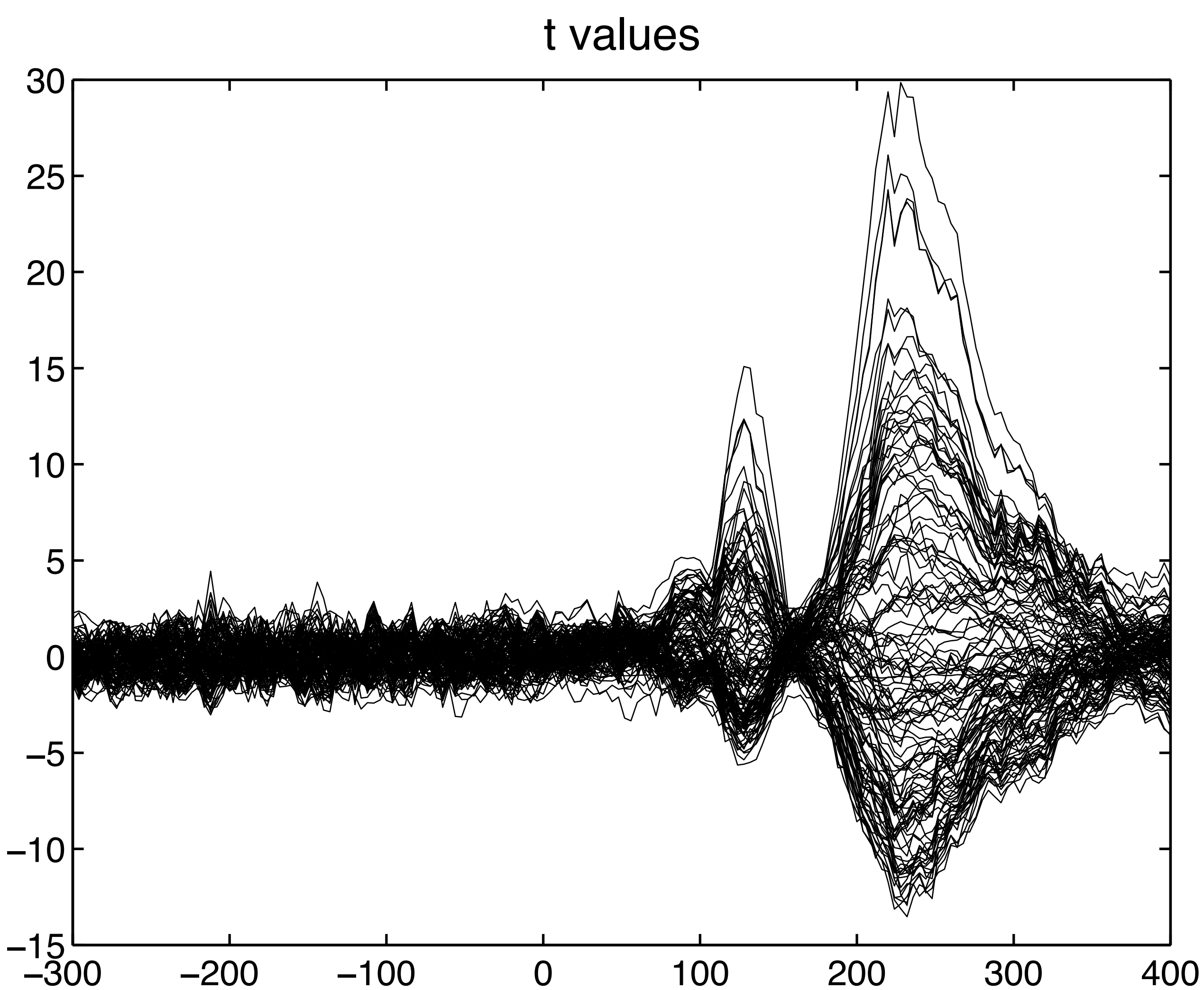


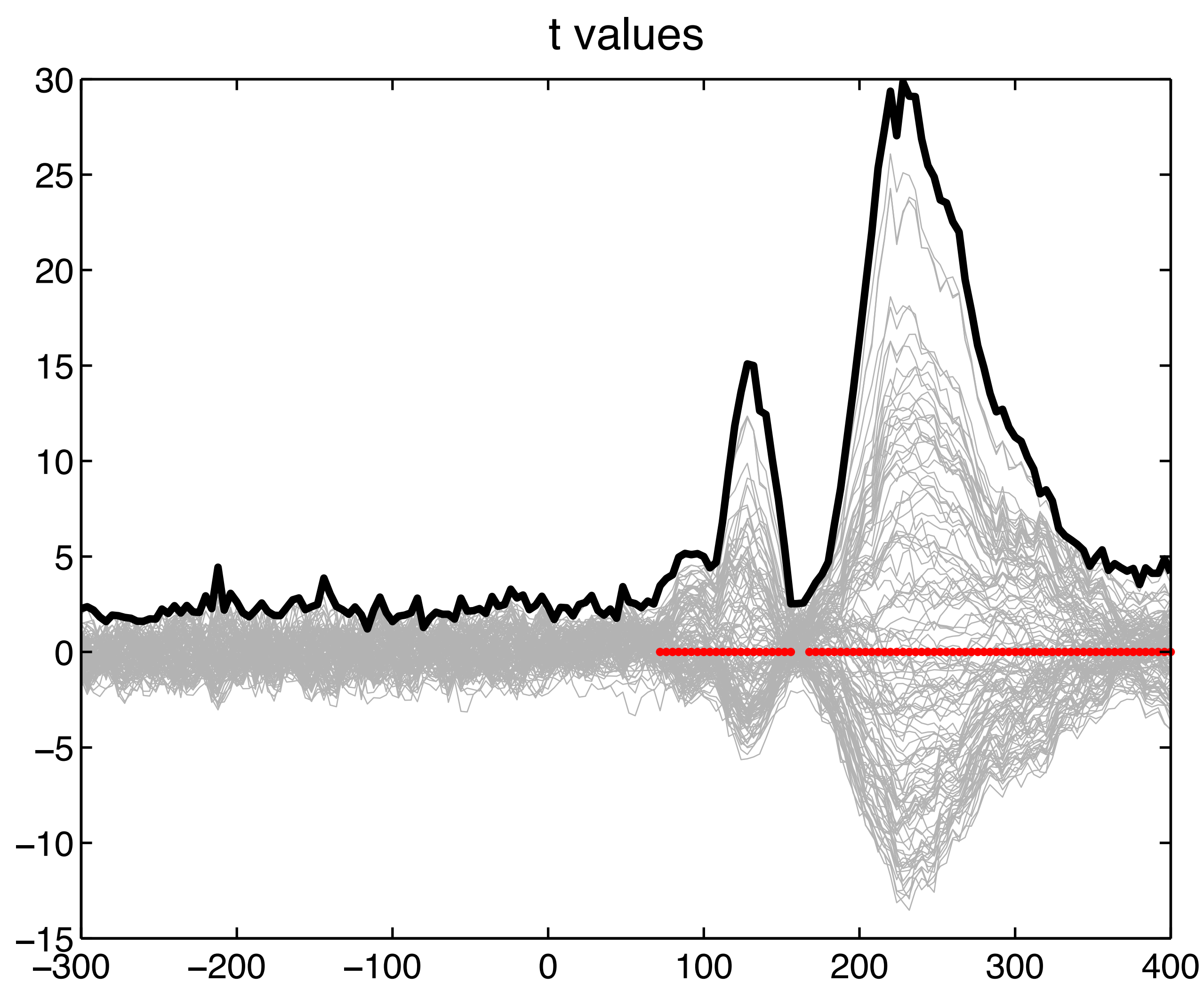


Single-subject analyses: all electrodes

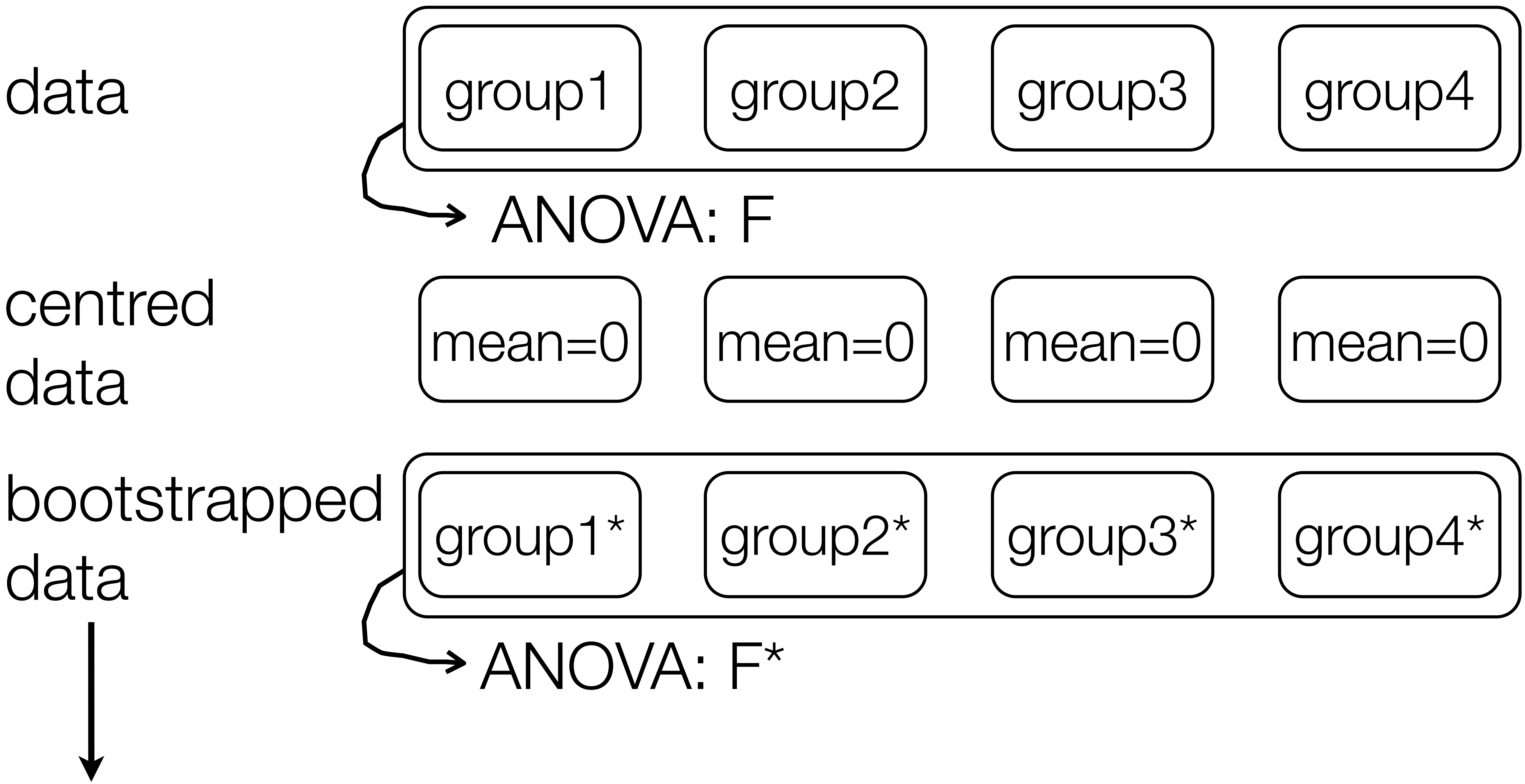


Single-subject analyses: all electrodes



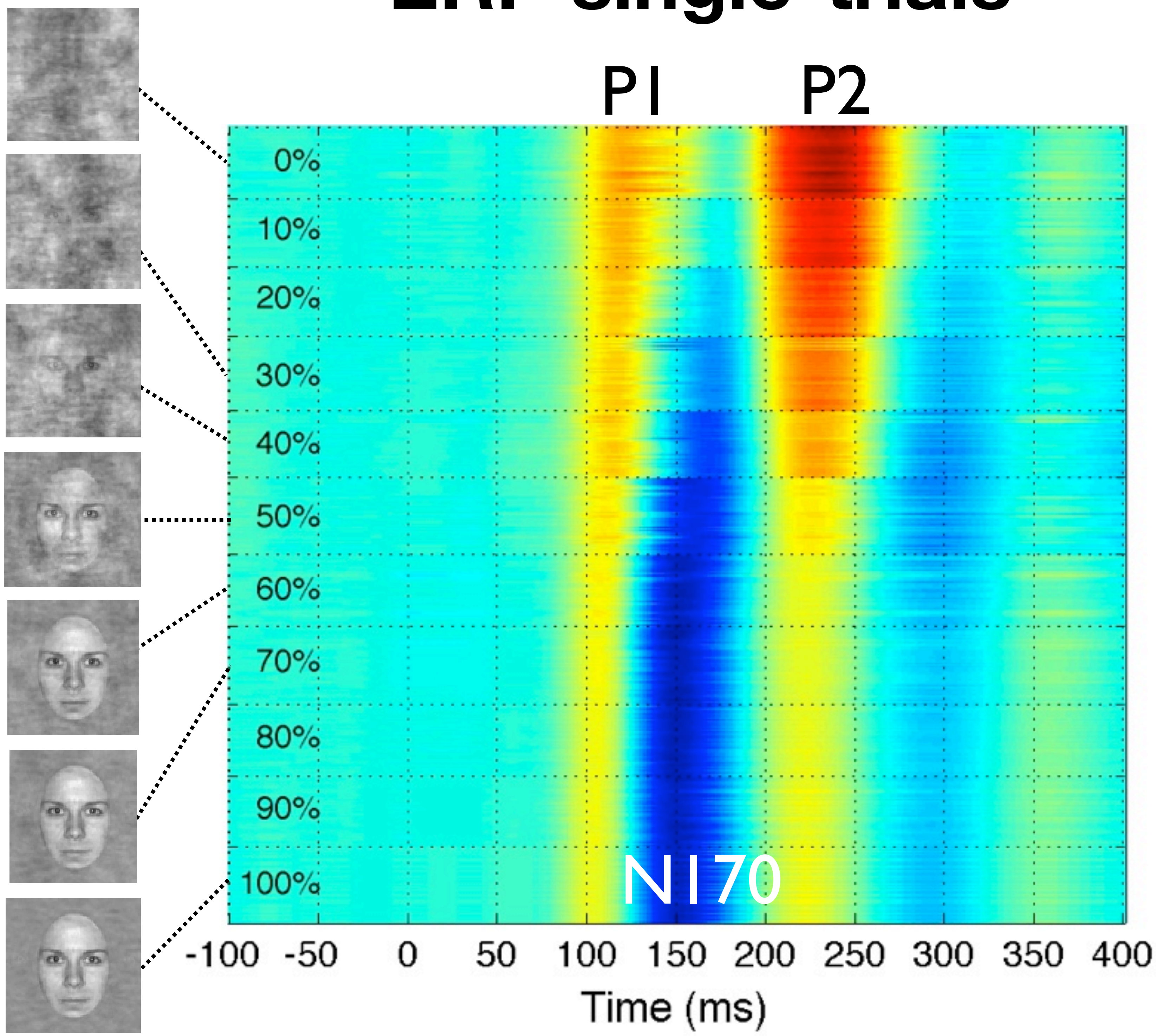


bootstrap-F technique



repeat b times => data driven bootstrapped F table

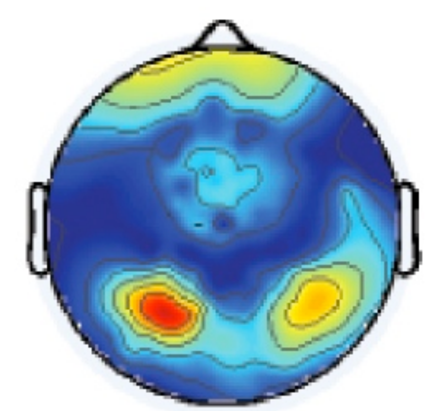
ERP single-trials



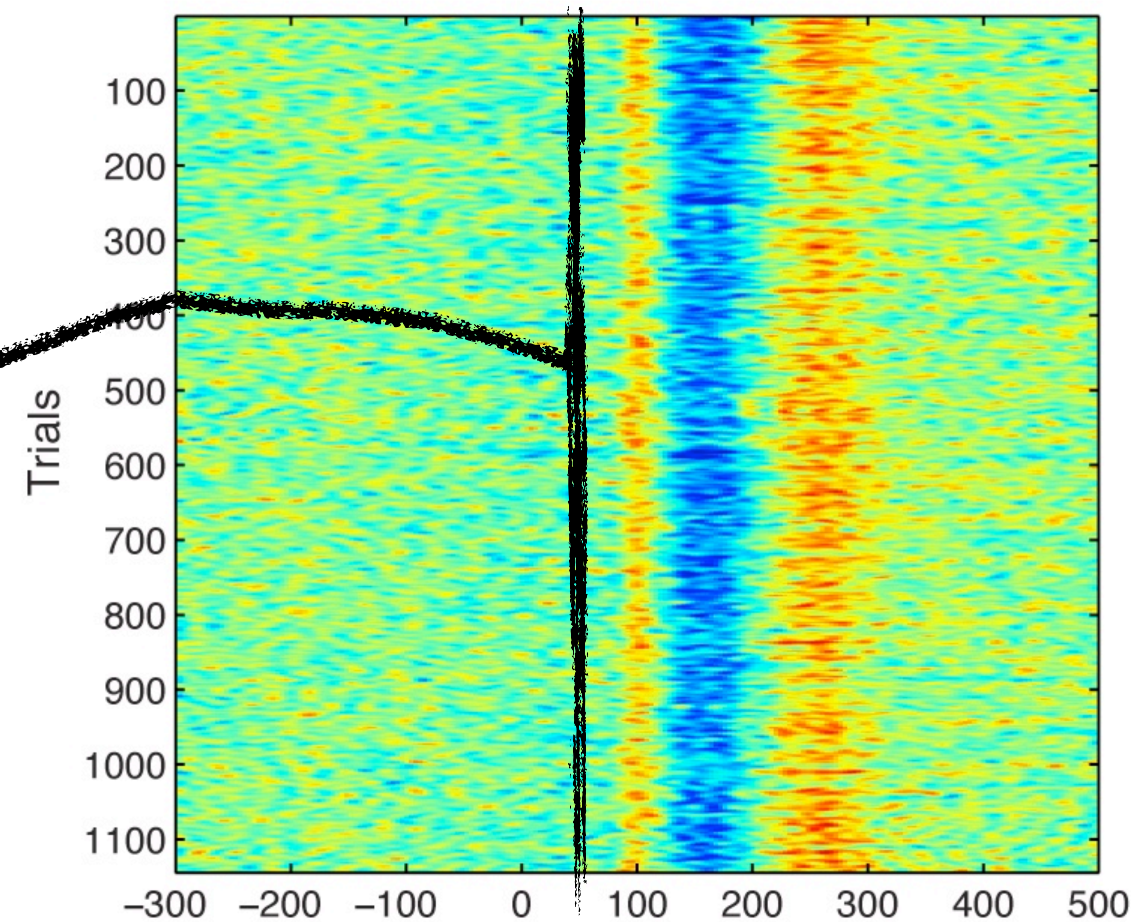
Phase noise sensitivity:

single subject

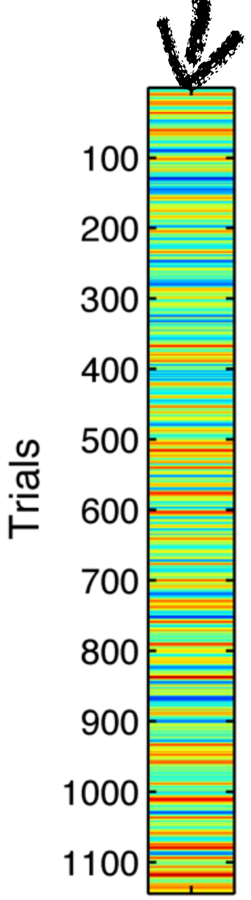
posterior electrode



Rousselet, Pernet, Bennett & Sekuler, *BMC Neuroscience*, 2008

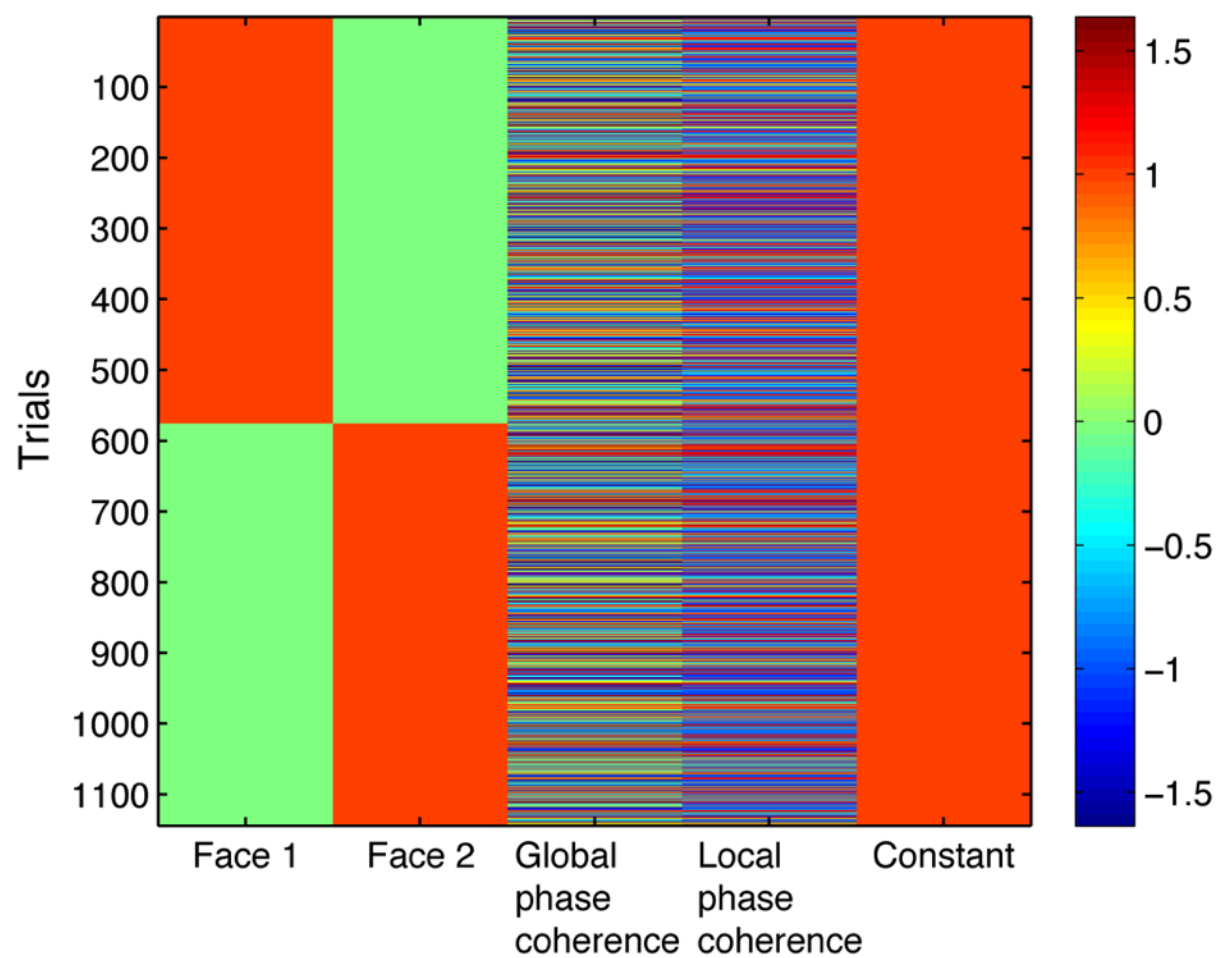


Design matrix

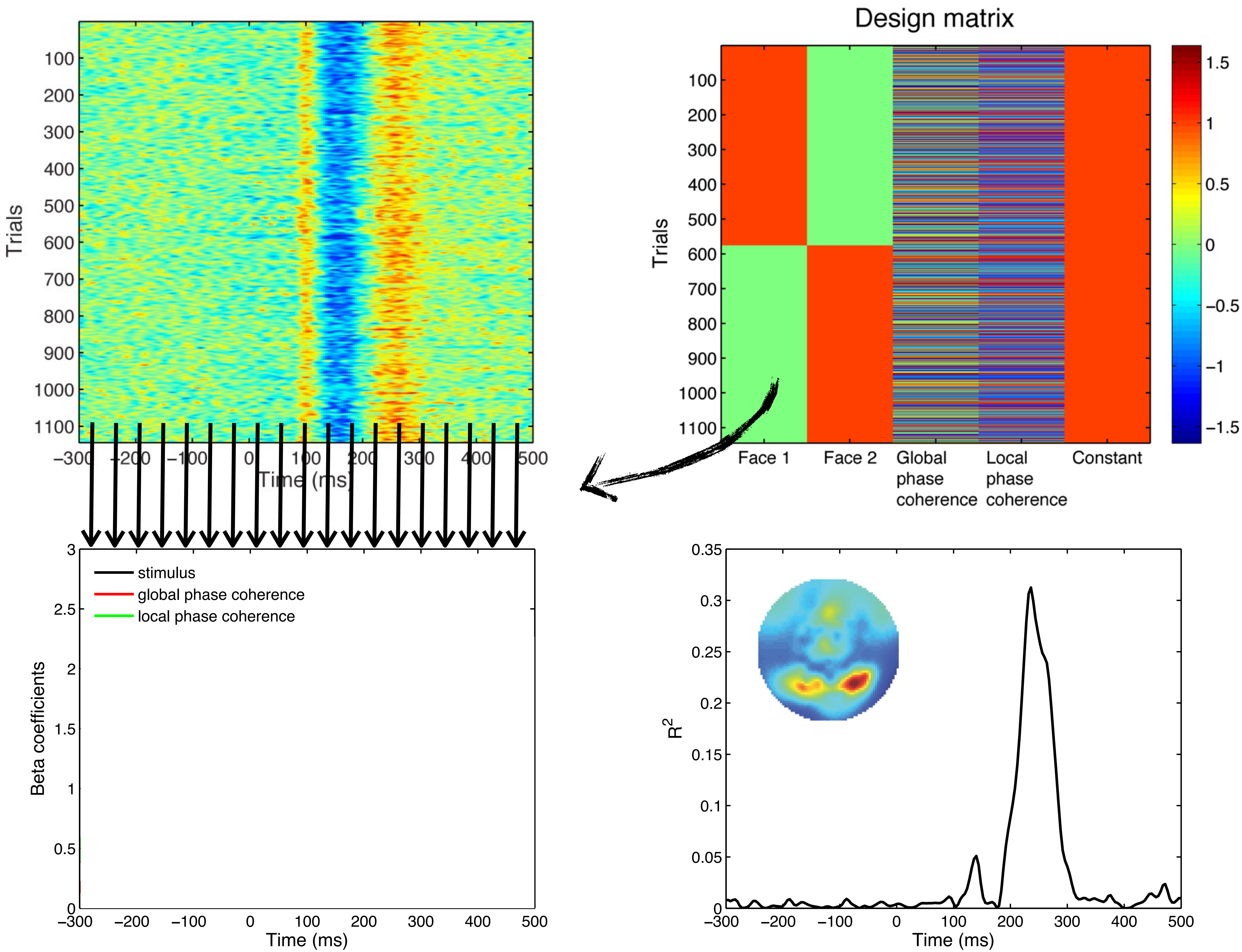


Beta coefficients

$$= [\, B_1 + B_2 + B_3 + B_4 + B_0 \,] \times$$



+ error


Design matrix
Trials
Time (ms)
Face 1
Face 2
Global phase coherence
Local phase coherence
Constant
stimulus
global phase coherence
local phase coherence
Beta coefficients
Time (ms)
R^2
Time (ms)

Questions?

Don’t hesitate to get in touch about the workshop or LIMO_EEG:

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& GLM mastermind:

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