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Extending cluster-mass tests to combined hypotheses

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Cluster-mass test on EEG signals

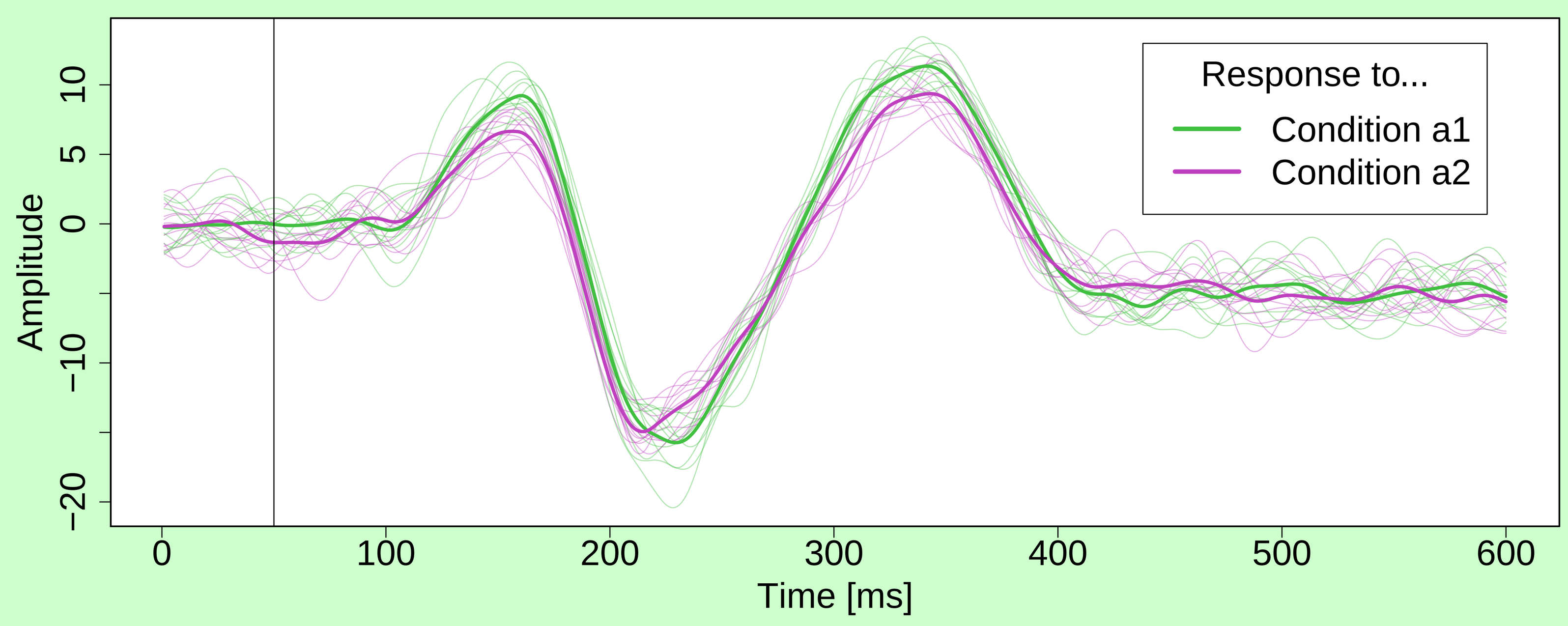
•Experiments using EEG: the analysis of ERP's.

Electroencephalography (EEG) are used in neuro-psychology to test difference in brain activity between experimental conditions. For instance, faces with emotion showing happiness or anger are shown to the participants and based on the recording of the brain electrical activity, we want to understand where and when the brain processes the informations related to emotions.

The electric signals are typically recorded at 1024Hz during 2 seconds using up to 128 electrodes, for each participant, for each trial. Those data are usually simplified into *event-related potentials (ERP)* which are the signals of one electrode, averaged over the trials in the same experimental condition for each participant.

•A massive multiple comparisons problem.

Simulated ERP of 22 participants in 2 experimental conditions emulate the data of a dummy experiment. The bold lines are averaged over participants in the same experimental condition. No a priori shapes of the signals are assumed and we test if the signal is different across the experimental conditions for each 600 time points (using t-test or ANOVA) while correcting for multiple comparisons. The state of the art solution is to perform the *cluster-mass test*.



•The cluster-mass is a solution for temporally correlated tests.

This multiple comparisons procedure is powerful when the true effects append by adjacent time points (cluster) and is described using the following algorithm:

1. Compute the statistic at each time point of the signals.
2. Define a threshold, usually at the 95 percentile of the statistic.
3. Define clusters as all adjacent time points which statistics are above the threshold.
4. Define the cluster-mass for each cluster as the sum (of squares) of its statistics.

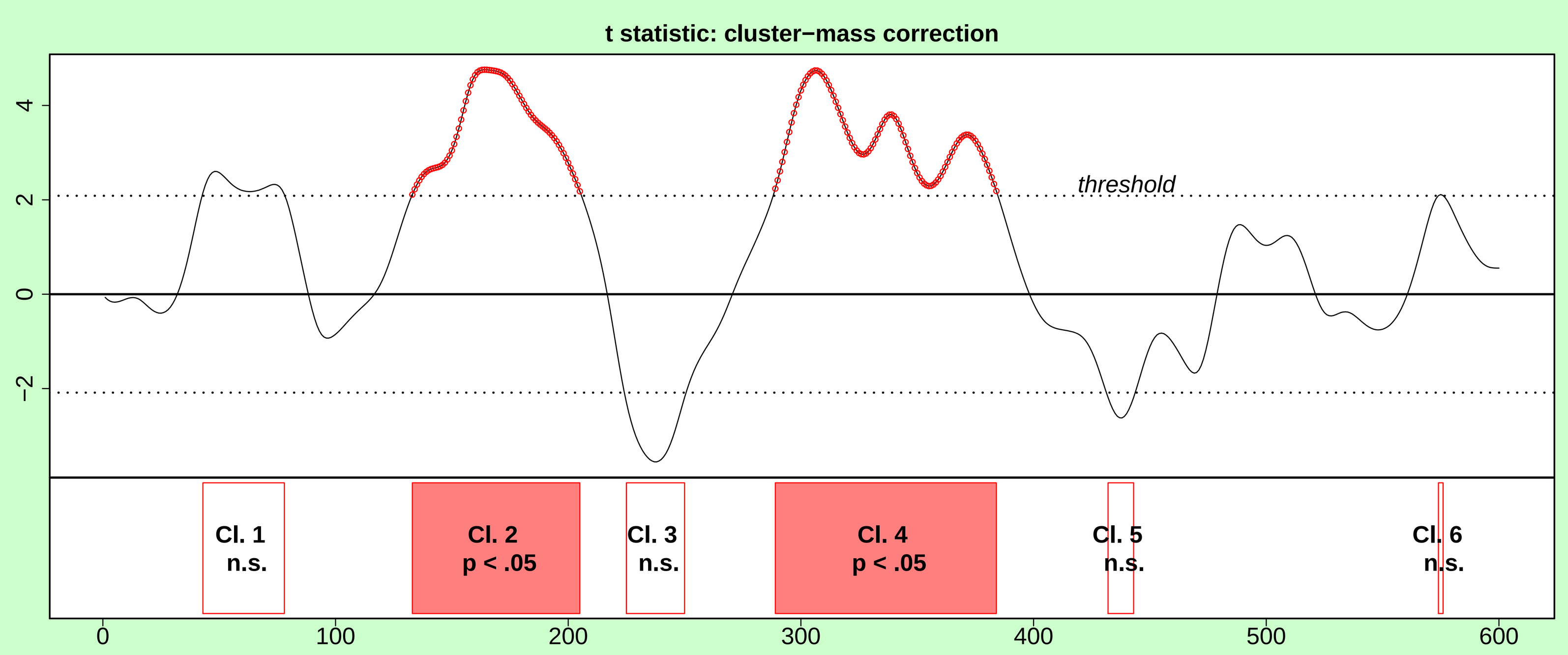
•Permuting the signals to produce the null distribution.

A permutation procedure is used to find the null distribution of the cluster-mass:

1. Permute the signals.
2. Compute the statistics on this permuted signals.
3. Compute the clusters, their cluster-masses and keep the maximal cluster-mass.

•The inference is made at the cluster level.

The p-value of a cluster is computed as the ratio of the cluster-mass null distribution above its cluster-mass. This implies that inference is made at a cluster level and each test within the same cluster is associated to the same p-value. Here 2 clusters out of 6 are significant.



•One downside: failure to detect sign switching effects.

The cluster 3 is not significant. A more powerful approach would have detected clusters 2, 3 and 4 as coming from the same underlying effect.

Extending the cluster-mass test using slopes

•Typical behaviour of EEG signal.

1. The true effects are usually composed by a positive difference followed by a negative difference between experimental conditions;
2. When the mean-difference between experimental conditions of signals are null in an interval then their differences of slope are also null:

$$\text{For any interval } I,\ \beta_t = 0\ \forall t \in I \implies \frac{\partial \beta^t}{\partial t} = 0\ \forall t \in I$$

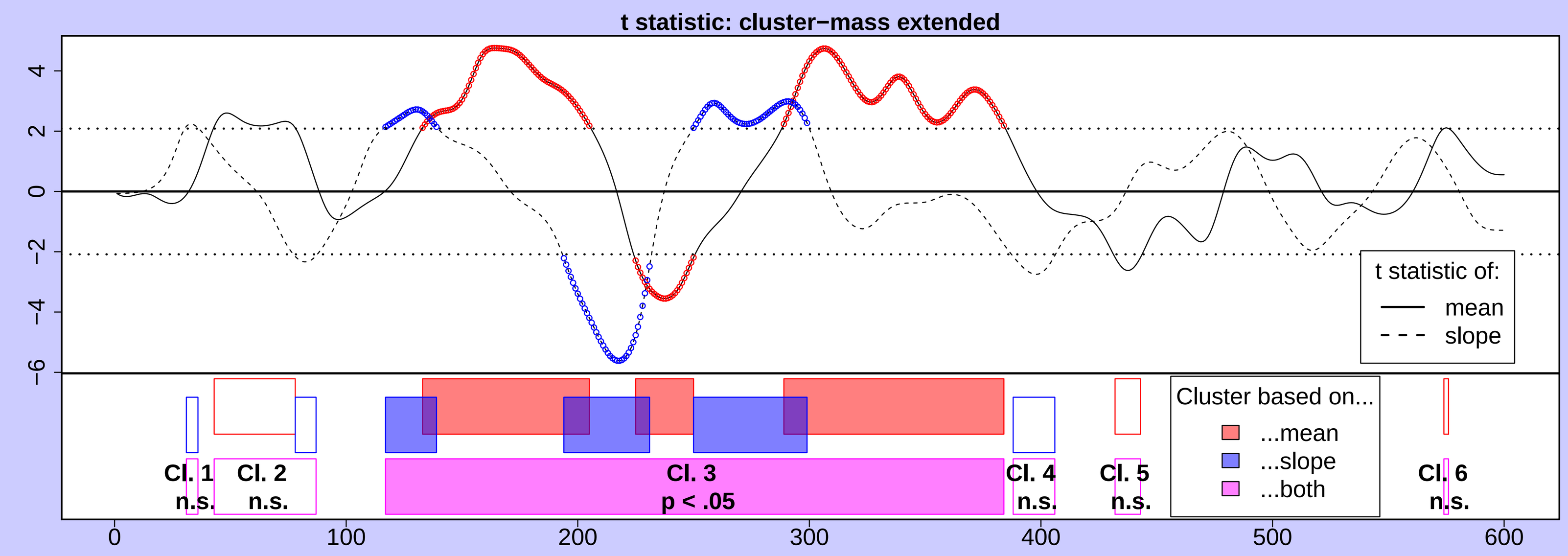
•Testing simultaneously mean and slope in cluster-mass.

The null hypotheses are written $H_0^t : \beta^t = 0$ AND $\frac{\partial \beta^t}{\partial t} = 0$, for $t \in 1, \dots, T$ where T is the length of the signals and are tested using the following procedure:

1. Compute the statistics on the signal and its slope.
2. Two sets of clusters are found based on a threshold.
3. Extend clusters based the test of the means with clusters based on the slopes.
4. Compute a cluster-mass for each new cluster.
5. The null distribution is computed using permutations of the signals and their slopes.

•Creating larger clusters for higher cluster-masses.

Using the slope on the same data, 3 clusters are bounded together. This test detects a larger cluster from 117ms to 384ms.



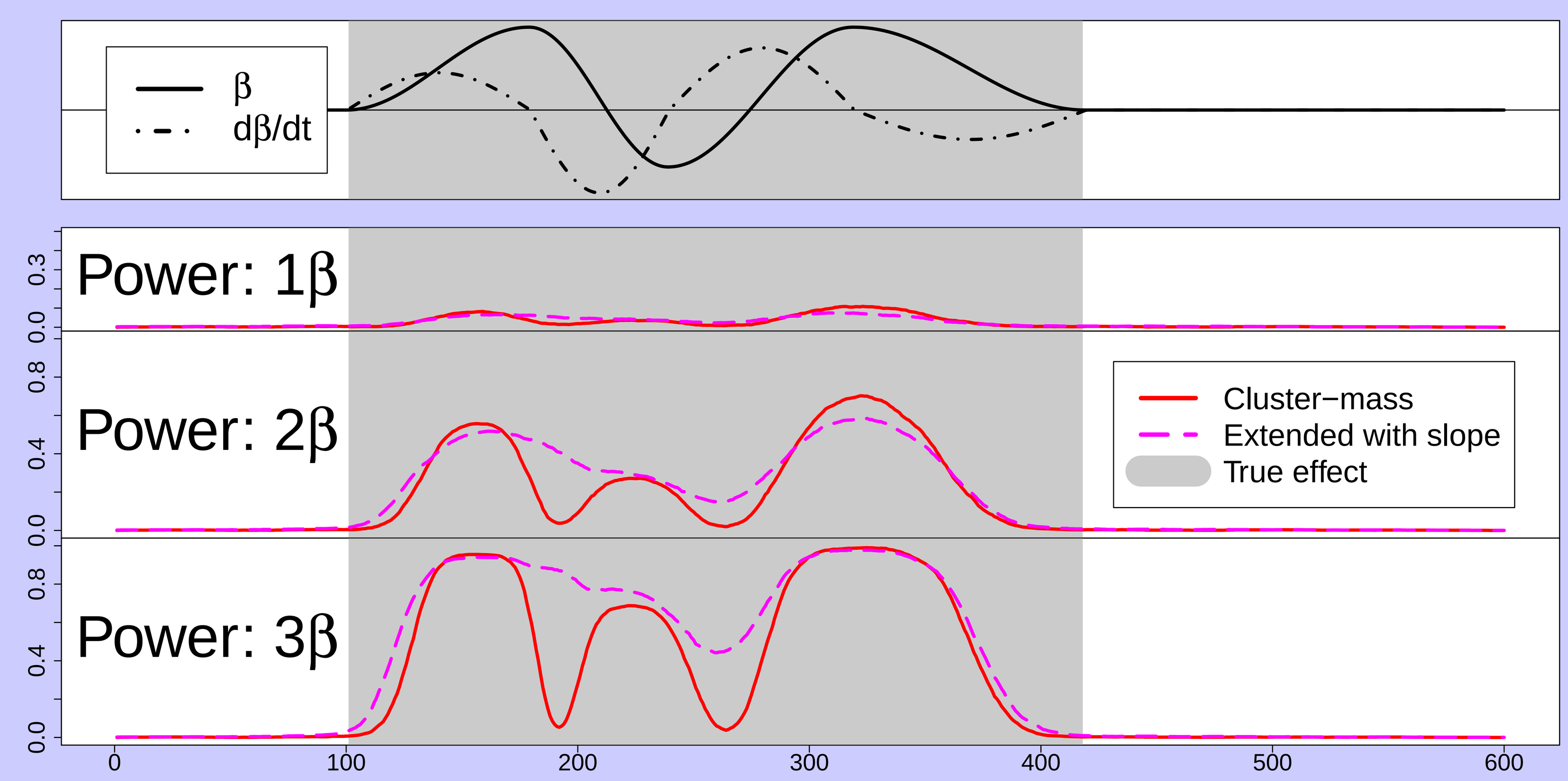
•We need your help!

The slope of a signal is computed using local polynomial or splines. Do you have better suggestions?

•Simulation study: FWER at the nominal level...

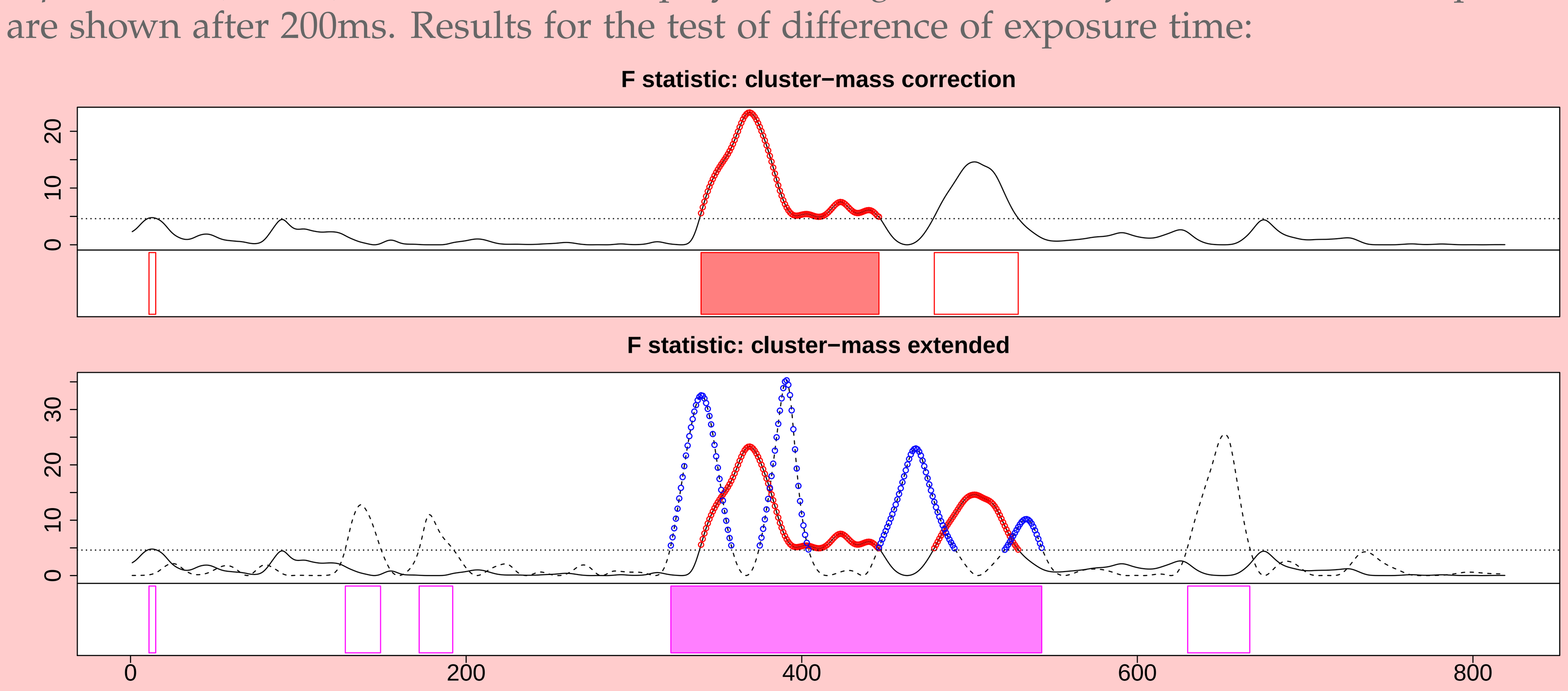
	Cluster-mass	Cluster-mass extended
FWER	0.051	0.048

•... and higher power between spikes.



Data analysis: an experiment in attention shifting

The FC5 electrode of participants who were shown images of *angry* and *neutral* faces is recorded at 1024Hz. The exposure of the images varies from a *subliminal* (16ms) level to *supraliminal* (166ms) level and were display to the *right* or to the *left* of the screen. The pictures are shown after 200ms. Results for the test of difference of exposure time:



Using the slope of the signals increases the number of significant time points and we detect 221 significant time points instead of 106.

R package

•Cluster-mass test is available in the *permuco* package.

The *permuco* package has functions for permutation tests in complex design and multiple comparisons procedures like cluster-mass test, and more.
https://cran.r-project.org/package=permuco

•The extension with slope is available on github.

The *permucoSlope* package works with *permuco* to produce cluster-mass extended with slope.
https://github.com/jaromilfrossard/permucoSlope

References

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