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Cluster-based computational methods for mass univariate analyses of event-related brain potentials/fields: A simulation study

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ABSTRACT

Background: In recent years, analyses of event related potentials/fields have moved from the selection of a few components and peaks to a mass-univariate approach in which the whole data space is analyzed. Such extensive testing increases the number of false positives and correction for multiple comparisons is needed.
Method: Here we review all cluster-based correction for multiple comparison methods (cluster-height, cluster-size, cluster-mass, and threshold free cluster enhancement – TFCE), in conjunction with two computational approaches (permutation and bootstrap).
Results: Data driven Monte-Carlo simulations comparing two conditions within subjects (two sample Student's t-test) showed that, on average, all cluster-based methods using permutation or bootstrap alike control well the family-wise error rate (FWER), with a few caveats.
Conclusions: (i) A minimum of 800 iterations are necessary to obtain stable results; (ii) below 50 trials, bootstrap methods are too conservative; (iii) for low critical family-wise error rates (e.g. $p = 1\%$), permutations can be too liberal; (iv) TFCE controls best the type 1 error rate with an attenuated extent parameter (i.e. power < 1).

1. Introduction

Event-related potentials (ERP) and magnetic fields (ERF) are measurable cortical responses to events used to track cognitive processes. In a given experiment, they are observable at multiple locations in space (electrodes or magnetic field sensors) and time. ERP and ERF are characterized by various components which are stereotypic features such as a peak or trough at particular latencies.[1] While for decades researchers have focused on analyzing such specific components, recent tools have been developed to analyze simultaneously the whole data space using a mass-univariate approach, whereby statistical tests are performed at every location and time point (e.g. Kiebel and Friston, 2004; Oostenveld et al., 2011; Pernet et al., 2011). This approach has the merit of not choosing locations or components a priori and therefore allows to potentially observing non-expected effects. Because so many statistical tests are performed, such approach can dramatically increase the odds of obtaining significant effects, i.e. there is a high probability of false positive results (type 1 error rate). Fortunately, different methods exist to control the family-wise error rate (FWER), i.e. the type 1 error rate over an ensemble, or family, of tests. The type 1 FWER is defined as the probability to make at least one type 1 error over the family of tests. Probably the best known method to control the FWER is the Bonferroni correction (Dunn, 1961) for which the alpha level is simply adjusted for the number of tests. This method is however overly conservative in the context of ERP/ERF analyses because it assumes statistical independence of the tests. For ERP and ERF, there are a large number of dependencies in space and in time, such that statistical tests are not independent. Methods used to control the type 1 FWER in such context must therefore account for these spatiotemporal dependencies.

ERP and ERF are distributed signals. Because there are a priori effects everywhere, it is common practice to discretize the data space and define treatment effects. Such discretization leads to the examination of treatment effects in terms of topological features

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[1] http://www.sinauer.com/fmri2e/html/glossary.html.

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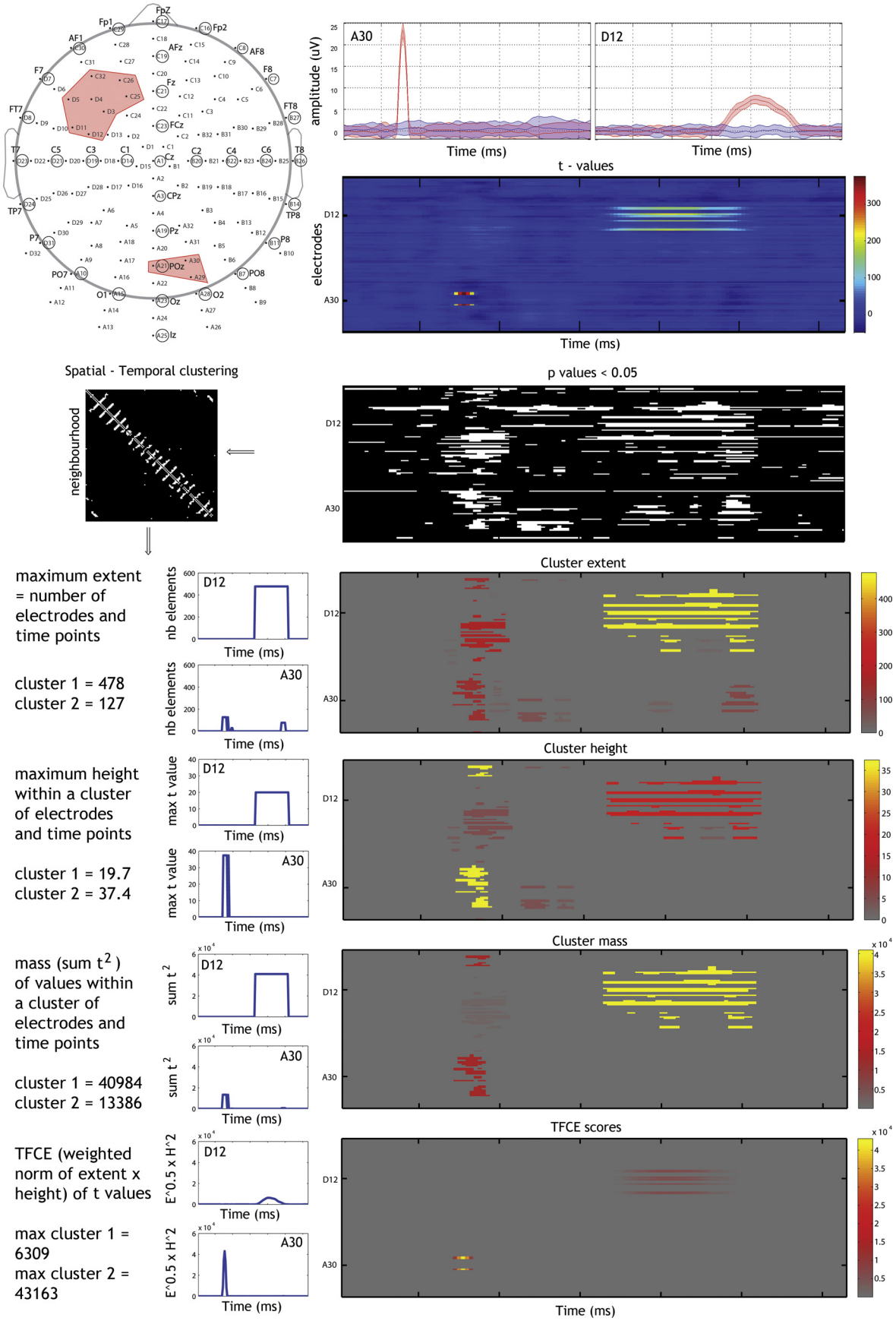

Fig. 1. Illustration of cluster-based methods applied to caricatured ERP data. Two effects were created, one transient effect (+25 μV) over 3 right posterior electrodes and one more sustained effect (+7 μV) over 8 electrodes. These effects are not meant to represent true EEG signal, but illustrate the different cluster attributes that are obtained on the basis of thresholded *t* values. From the observed *t* values, a binary 'map' is obtained (i.e. $p < 0.05$), and cluster attributes and TFCE data are computed via spatiotemporal clustering (3 first rows of the figure). The transformed data, to be thresholded, are presented for 2 electrodes (D12 and A30) and over the full space. Because the statistics