<table>
<thead>
<tr>
<th><strong>Title</strong></th>
<th>Topographical segmentation: A new tool to optimally define temporal region-of-interests of significant difference in ERPs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author(s)</strong></td>
<td>Hu, L; Shen, JS; Zhang, Z</td>
</tr>
<tr>
<td><strong>Issued Date</strong></td>
<td>2014</td>
</tr>
<tr>
<td><strong>URL</strong></td>
<td><a href="http://hdl.handle.net/10722/204090">http://hdl.handle.net/10722/204090</a></td>
</tr>
<tr>
<td><strong>Rights</strong></td>
<td>Proceedings of the International Conference on Digital Signal Processing. Copyright © I E E E.; ©2014 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.; This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.</td>
</tr>
</tbody>
</table>
Topographical Segmentation: A New Tool to Optimally Define Temporal Region-of-interests of Significant Difference in ERPs

Li Hu, Jiasi Shen
Key Laboratory of Cognition and Personality
School of Psychology, Southwest University
Chongqing, China
huli@swu.edu.cn

Zhiguo Zhang
Department of Electrical and Electronic Engineering
The University of Hong Kong
Hong Kong, China
zgzhang@eee.hku.hk

Abstract—The statistical identification of temporal region-of-interests (ROIs) of the significant difference in event-related potentials (ERPs) was popularly achieved using the cluster-based approach, in which the clustering was achieved based on the temporal adjacency of statistical significance if data from single-electrode were tested, or based on the spatial and temporal adjacency of statistical significance if data from multi-electrodes were tested. However, this cluster-based approach would be problematic if the significant differences were strong and sustained in time, but varied greatly in space. In other words, neural generators, which contributed to the detected significant differences, changed markedly within the explored temporal-cluster. To solve this problem, we implemented a statistical approach based on topographical segmentation analysis, which did not only make use of the temporal adjacency of significance, but also utilized the scalp distribution of statistical difference. We applied this technique to assess the significant difference of SEPs between deviant and standard conditions, and we observed that temporal ROIs, captured distinct spatial distributions of statistical difference, could be correctly identified using the topographical segmentation analysis be means of quasi-stable scalp distribution.

Keywords—topographical segmentation analysis; temporal region-of-interests; event-related potentials (ERPs); somatosensory-evoked potentials (SEPs); scalp topography.

I. INTRODUCTION

Electroencephalogram (EEG) and Event-related potentials (ERPs) are normally recorded from multiple electrodes and at multiple time points, which ensures that EEG/ERP data capture a typical spatio-temporal structure. Researchers usually aim to explore the significant difference between/among the EEG/ERP data observed in different experimental conditions, which has been suggested to be better explored using the cluster-based statistical testing [1]. In this cluster-based statistical testing, the extraction of significant differences of EEG/ERP features (e.g., ERP components or event-related spectral perturbation) is achieved by defining the temporal regions of interests (ROIs) based on the temporal adjacency of statistical significance if data from single-electrode are tested, and based on the spatial and temporal adjacency of statistical significance if data from multi-electrodes are tested [1]. Indeed, this statistical method is a sensitive approach suited to solve the multiple comparison problem, and thus has been successfully applied in several EEG/ERP studies [2-4]. However, when the assessed significant differences are strong and sustained in time, this cluster-based approach would result in a long-lasting temporal ROI, within which, scalp distributions of the statistical significance varied greatly from time to time. In such case, the definition of the temporal ROI could not be successfully achieved using the cluster-based approach, since neural generators, which contributed to the detected significant differences, changed markedly within the explored temporal ROI.

In the present study, with the aim of solving the above problem and improving the reliability of temporal ROI definition, we implemented a statistical approach based on a topographical segmentation analysis that did not only utilize the information of temporal adjacency of significance, but also exploited the scalp distribution of such significant difference. This topographical segmentation analysis is conceptually identical to the method of the exploration of functional microstates [5], and the optimal number of temporal ROIs was determined using a cross-validation criterion [6]. To test the efficacy of this topographical segmentation analysis, we applied this technique to assess the significant difference of SEPs between deviant and standard conditions.

II. MATERIALS AND METHODS

A. Subjects

EEG data were collected from 30 healthy right-handed volunteers (15 males and 15 females), aged 22 ± 1.7 (mean ± SD, range = 18–26 years). All participants gave their written informed consent and were paid for their participation. The local ethics committee of Southwest University (Chongqing, China) approved the procedures, which were in accordance with the standards of the Declaration of Helsinki.
B. Experimental design and data collection

Somatosensory electrical stimuli (i.e., trans-cutaneous electrical stimuli), which consisted of three rapidly succeeding constant-current square-wave pulses (0.5 ms duration each pulse) delivered through a pair of ring electrodes (2 cm distance between electrodes) applied to the index finger, between the metacarpophalangeal and the interphalangeal joint. The inter-pulse interval was 12 ms. The stimulus intensity was set as twice the individual perceptual threshold, an intensity classically used to activate the Aβ fibers in humans [7-8]. The somatosensory stimuli were presented according to a classical roving paradigm [9]. The first somatosensory stimulus in each train was a deviant that became a standard through repetition. During stimulation, participants were instructed to watch a silent video with subtitles, and to answer several questions about the video content in a structured interview taking place at the end of each block.

The EEG data were recorded using a Brain Products system (band-pass: 0.01–100 Hz, sampling rate: 1000 Hz), connected to a standard EEG cap with 64 scalp Ag-AgCl electrodes placed according to the International 10-20 system. The nose was used as reference channel, and all channel impedances were kept below 10 kΩ. To monitor ocular movements and eye blinks, electrooculographic signals were simultaneously recorded from two surface electrodes placed over the lower eyelid and 1 cm lateral to the outer corner of the orbit, respectively.

C. EEG data preprocessing

EEG data were processed using EEGLAB [10], an open source toolbox running in the MATLAB environment. Continuous EEG data were low-pass filtered at 30 Hz. EEG epochs were extracted using a time window of 1000 ms (200 ms pre-stimulus and 800 ms post-stimulus) and baseline corrected using the pre-stimulus interval. After all preprocessing, epochs were re-referenced to a common average reference. The stimulus in the first position of each train was defined as deviant, and the stimuli in the fourth to the last positions of each train were defined as standard. The significant difference between deviant and standard was induced by the repetition of the same somatosensory stimuli (i.e., 'repetition' effect).

D. Topographical segmentation analysis

A point-to-point, paired-sample t-test was used to assess the difference between deviant and standard on somatosensory-evoked potentials (SEPs). This procedure yielded a time course of t values for each channel, which represented the effect of 'repetition' on SEPs (i.e., the difference between deviant and standard).

To optimally define the temporal ROIs, a topographical segmentation analysis was implemented on the 'repetition' modulated t time courses. This analysis is conceptually identical to the method of the exploration of functional microstates [11], which were defined as a temporal parceling of successive scalp topographies with quasi-stable landscape [12-13]. The topographical segmentations analysis to statistically parcel t time courses can be expressed as

\[ T_i = \sum_{k=1}^{N} a_{ki} \Gamma_k + E_i \]  

where \( N \) is the number of different segmentations, \( T_i \) is a \( N \times I \) vector, representing the scalp topography of statistical t values at time instant i (\( i = 1 \ldots N_i \)), \( \Gamma_k \) is the normalized \( N \times I \) vector, representing the k-th segmentation intensity at time instant i, and \( E_i \) is the zero mean random noise at time instant i. Since different segmentations cannot be overlapped in the time domain, \( a_{ki} \) should be zero except for one time instant.

The estimation of segmentations would ensure (1) the goodness of fit between the measurement and the estimated segmentations (i.e., the residual variance between the measurement and the estimation should be small), and (2) the smoothness of neighboring measurements (i.e., the measurements that are close in time tend to be classified to the same segmentation). This compromise was established using some smoothing techniques [6]. Finally, the optimal number of segmentations (temporal ROIs) was determined using a cross-validation criterion [6].

As far as possible physiologically-relevant difference of brain responses were concerned, temporal ROIs, which met the following criteria, were considered in this analysis: (1) resulted in clusters included in the time-interval from 0 to 400 ms; (2) showed an increased standard deviations as compared to that within the pre-stimulus time-interval (-200 to 0 ms); and (3) lasted no less than 30 ms.

III. Results

Figure 1 shows the grand average SEP time courses in deviant and standard conditions (top left: deviant; top right: standard; bottom left: deviant-standard; bottom right: statistical t value), with the scalp topographies at the latencies from 50 ms to 300 ms (in step of 50 ms). Even SEPs were markedly stronger in deviant condition than in standard condition, SEPs at both conditions showed several similarities in scalp distribution. First, at 50 ms, a positive maximum was observed at the hemisphere contralateral to the stimulated site (around C4). Second, from 100 ms to 200 ms, a negative maximum was observed at bilateral temporal regions (around T7 and T8). Third, from 150 ms to 300 ms, a positive activity was observed at central electrodes (around Cz). Note that the significant difference of SEPs between deviant condition and standard condition was sustained in the temporal domain, but varied markedly in the spatial domain (bottom right).
Figure 1. Time courses and scalp topographies of SEPs. Top left: SEPs in deviant condition. Top right: SEPs in standard condition. Bottom left: Difference of SEPs between deviant and standard conditions. Bottom right: Statistical t values showing the difference of SEPs between deviant and standard conditions.

Figure 2 shows the grand average SEP time courses at deviant and standard conditions, along with the statistical t values, in three representative electrodes (top: T7; middle: Cz; bottom: T8). Notably, the difference of SEPs between deviant and standard conditions was sustainedly significant in all three electrodes (T7: from 145 ms to 790 ms; Cz: from 125 ms to 635 ms; T8: from 117 ms to 800 ms; Pfdr < 0.05 for all comparisons). The observations that (1) the significant difference of SEPs between deviant and standard conditions was varied greatly in the spatial domain, and (2) such difference was sustainedly significant in the temporal domain. In this case, the traditional way to define the temporal ROIs, which was achieved only based on the temporal adjacency of significance, cannot provide an accurate definition of temporal ROIs, since only a single spatially-varied temporal ROI would be defined due to the temporal adjacency of significance.

To optimally define the temporal ROIs, the incorporation of the spatial information of t values, which could be achieved using the topographical segmentation analysis, would be necessary. Figure 3 shows the time courses (bottom), standard deviations (middle) of ‘repetition’ modulated t values of SEPs, and the estimated topographical segmentations (top). The optimal number of temporal ROIs, estimated using the cross-validation criterion [6], was 7. The first temporal ROI, with a clear positive maximum at contralateral central region, was detected from 40 ms to 118 ms. The second temporal ROI, showed a negativity at contralateral temporal region, was detected from 119 ms to 149 ms. The third temporal ROI, displayed a negativity at bilateral temporal regions, was detected from 150 ms to 260 ms. The fourth temporal ROI, showed a strong positivity at central region, was detected from 261 ms to 414 ms. These topographical segmentations were estimated from the statistical t value time courses, which, from another perspective, indicated that the significant difference of SEPs between deviant and standard conditions was spatially-varied from time to time. In other words, neural generators, who were responsible for the explored significant difference, changed marked at different time.

Figure 2. Time courses of SEPs measured at T7 (top), Cz (middle), and T8 (bottom). SEP waveforms are marked in red and blue for deviant and standard conditions respectively. The statistical t values, which showed the significant difference of SEPs between deviant and standard conditions are displayed in green. The significant time intervals are marked in grey, which indicated that the significant difference between deviant and standard conditions is temporally sustained.
Scalp topographies of the explored temporal ROIs are displayed in the 'repetition' modulated temporal ROIs. Time courses and standard deviations of Figure 3. activity without any user-bias. This topographical segmentation according to the emergent topographical organization of scalp amplitude ranges) [6]. Thus, ERP components could be defined minimize the use of any empirical assumptions (e.g., latency or statistical approaches (e.g., k-means clustering), which present at single-subject or group level [13]. Second, the topographies [11] even when no clear peak ERP difference is summarized of the statistical time series (e.g., topographical segmentation analysis, which resulted in the top part. temporal ROIs, which captured distinct spatial distributions, could be correctly identified using the topographical segmentation analysis be means of quasi-stable scalp distribution.

In addition, several advantages of topographical segmentation analysis with respect to the traditional cluster-based statistical testing should be noted. First, the topographical segmentation analysis, which resulted in the summarization of the statistical time series (e.g., t values) by several distinct patterns, can capture different scalp topographies [11] even when no clear peak ERP difference is present at single-subject or group level [13]. Second, the extraction of temporal ROI is based on well-established statistical approaches (e.g., k-means clustering), which minimize the use of any empirical assumptions (e.g., latency or amplitude ranges) [6]. Thus, ERP components could be defined according to the emergent topographical organization of scalp activity without any user-bias. This topographical segmentation analysis could also be potentially applied on the time-frequency domain to identify the time-frequency ROIs.

IV. DISCUSSION

In the present study, we applied the topographical segmentation analysis to define the temporal ROI of the significant difference of SEPs between deviant and standard conditions. We observed that the significant difference of SEPs between deviant and standard conditions were temporally sustained, but spatially varied. In opposite to the traditional approach to define temporal ROIs, which was achieved only based on the temporal adjacency of significance, reliable temporal ROIs, which captured distinct spatial distributions, could be correctly identified using the topographical segmentation analysis be means of quasi-stable scalp distribution.

ACKNOWLEDGMENT

LH is supported by the National Natural Science Foundation of China (31200856), Natural Science Foundation Project of CQ CSTC.

REFERENCES