Automatic Analysis of Event-related Potential Components

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Abstract – **The present study was aimed at investigating the automatic artifact rejection, detection and measurement of event-related potentials (ERPs) components. Auditory P1, N1, P2, N2 and P3 ERPs components at Fz, Cz and Pz signals were studied. Adequate measurements were achieved by averaging and interpolation of specific ERPs components. Overlaid graphical results are presented. The possible application in a software product is discussed.**

Keywords – **EEG, event-related potentials, automatic processing, artifact rejection, averaging, spline interpolation.**

I. Introduction

Event-related potentials (ERPs) are small in amplitude sequence of negative and positive peaks in the standard electroencephalogram (EEG), time-locked to the stimulus (event) appearance. In general ERPs components are electrophysiological correlates of the stimulus information brain processing related to: (i) the physical parameters (exogenous components P1, N1 and P2) and (ii) the late cognitive information processing, depending on the stimulus meaning in the experimental task context (endogenous components N2 and P3) [1,2]. The automatic artifact rejection, detection and measurement of the ERPs components are challenging characteristics of the contemporary software design.

II. Experimental Setting

A. Instrumentation and signal acquisition

High-resolution, multichannel signal acquisition module BioSemi Active Two Polyphysiograph system with Ag-Ag/Cl surface electrodes was used. The EEG was recorded at 4 electrodes – Fz, Cz, Pz and A1 (International 10-20 system of Electrode Placement [3]) referred to a common scalp located reference. The electrooculogram (EOG) was recorded via two electrodes located above and bellow the left eye (EOG1, EOG2). Block diagram of the signal acquisition setting is illustrated in figure 1.

The six signals (4 EEG + 2 EOG) were sampled at high-resolution 24-bit, 2048 Hz frequency. They were transferred in real time from the Polyphysiograph to PC via optically isolated interface. The signals were recorded and then offline processed to derive four signals of interest:

- EEG1 = Fz – A1;
- EEG2 = Cz – A1;
- EEG3 = Pz – A1;
- EOG = EOG1 – EOG2;

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B. Audio stimuli

In this pilot study, auditory add-ball paradigm with randomized audio stimuli of high frequency 1200 Hz (non-target) and low frequency 800 Hz (target) was applied. Both non-target and target tones were generated by a computer program in random order (with 80 % vs. 20 % probability of appearance), all tones with intensity of 60 dB, duration of 50 ms and interstimulus intervals varying between 3 and 5 seconds. The tested subject was sited on a chair, eyes closed and the stimuli were reproduced by headphones. The reaction time (RT) was measured with right index finger mouse-button click. The audio stimuli and reaction times were transmitted in real-time via the opto-isolation module and were recorded as a marker channel synchronized to the Polyphysiograph signals (see figure 1).

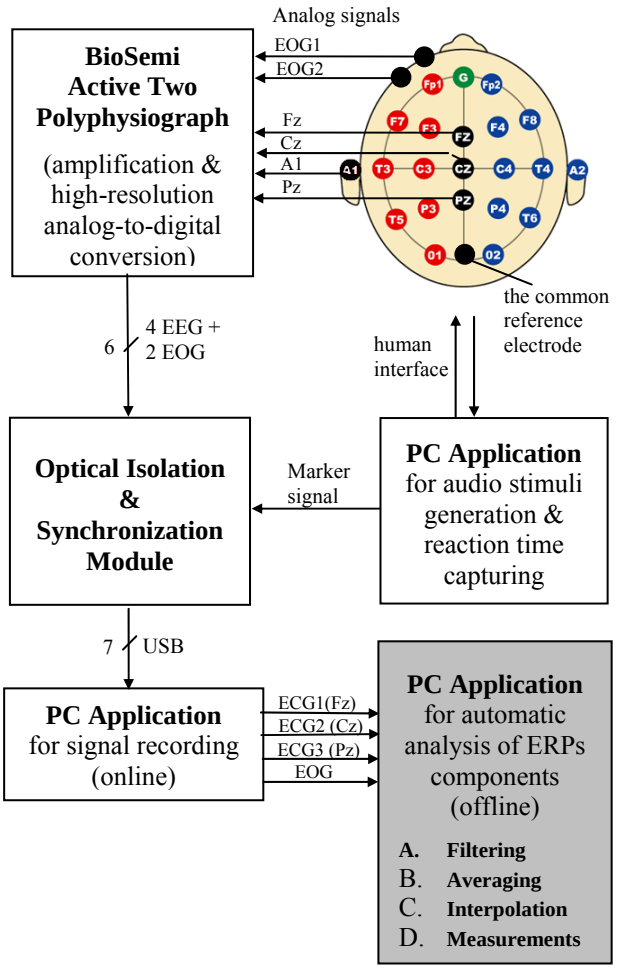

FIGURE 1. EXPERIMENTAL SETTING: ELECTRODES PLACEMENT, SIGNAL ACQUISITION MODULES, SUPPORTING PC APPLICATIONS. THE PC APPLICATION FOR OFFLINE ANALYSIS OF THE ERPS COMPONENTS (HIGHLIGHTED IN GRAY) IS DESCRIBED BELOW.

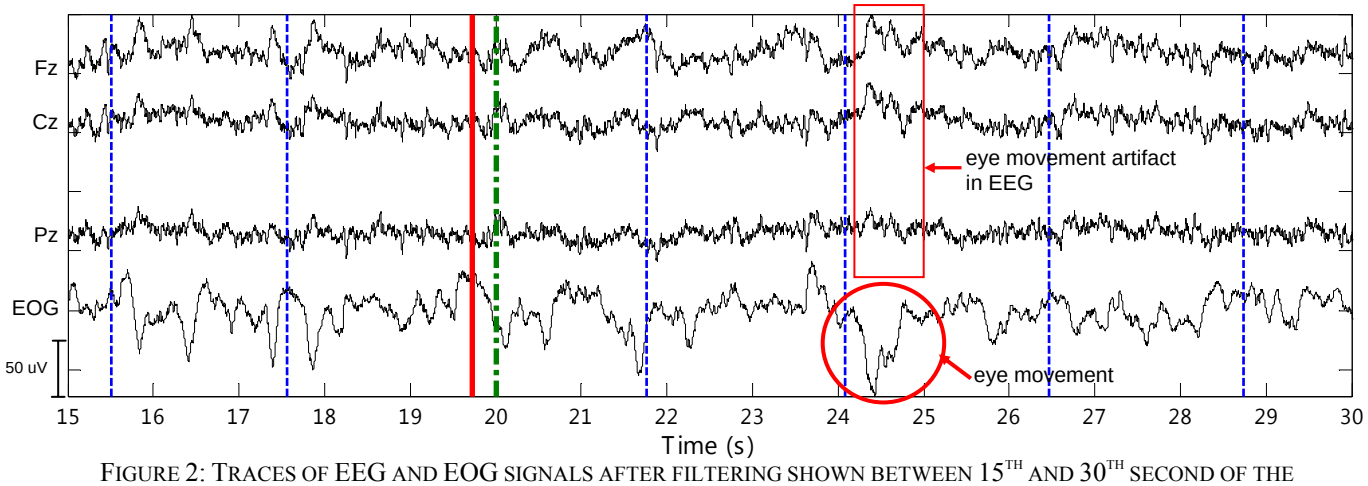

FIGURE 2: TRACES OF EEG AND EOG SIGNALS AFTER FILTERING SHOWN BETWEEN 15TH AND 30TH SECOND OF THE RECORDING.THE VERTICAL DASHED LINES CORRESPOND TO THE NON-TARGET STIMULI, THE VERTICAL THICK LINE CORRESPOND TO A TARGET STIMULUS, THE NEXT VERTICAL DASH-DOTTED LINE SHOW THE REACTION TIME.

III. OFFLINE SIGNAL PROCESSING

The offline signal processing techniques described below were implemented in a software running in Matlab 7.0.

A. Filtering

Digital filtering on the EEG signal was applied. The narrowest standard bandwidth (0.5÷15 Hz) was adopted to minimize the effect of neck and scalp muscle artifacts but to keep intact the ERPs component frequencies [4], which in the case of auditory ERPs are not exceeding the defined pass-band range.

The EOG register the voluntary eye movements, the saccadic ones and the movements of the eyelid during blinking. These relatively slow movements were analyzed after band-pass digital filtering in the range 1÷10 Hz.

The defined two band-pass filters were simulated as Butterworth, 1st order.

The filtered EEG and EOG signals are shown in figure 2.

B. Averaging

The ERPs epoch of interest was set between 200 ms before and 500 ms after the auditory trigger. Within the total experiment lasting about 450 s, there were 31 target realizations recorded and all of them were adopted for analysis. In order to be correctly comparable the same number of non-target ERPs were selected as those 31 from all 159 epochs in the whole series with the lowest EOG artifacts measured as its peak-to-peak amplitude below 32μV (figure 3).

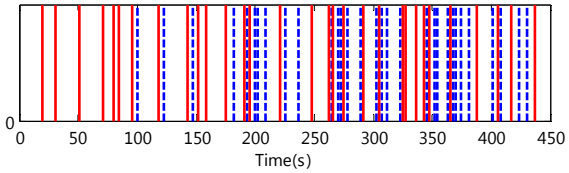

FIGURE 3. TIMES OF ERPS CONSIDERED FOR ANALYSIS DISTRIBUTED WITHIN THE TOTAL RECORDING OF ABOUT 450 S. THICK LINES SHOW THE TARGET EPOCHS, DASHED LINES SHOW THE NON-TARGET EPOCHS WITH THE MINIMAL EOG ARTIFACTS.

In fact, the presence of high-amplitudes in EOG is a sign for voluntary eye movements, which are volume conducted and overlap the recorded EEG brain activity as an eye artifact with fronto-occipital distribution (highlighted in figure 2). This approach of excluding such non-target ERPs epochs aimed to minimize the influence of the EOG artifact on the auditory ERPs components along the whole experimental session.

Averaging the groups of all target and non-target ERPs was performed to reduce the non-trigger related random effects in EEG and EOG (figure 4). The baseline of the averaged ERPs is calculated from the averaged pre-stimulus activity.

C. Interpolation

The averaged ERP waveforms were not enough smoothed to measure accurately the amplitude and latency of the components P1,N1,P2,N2,P3 (figure 5). Therefore, interpolation was needed to reconstruct the corrupted ERPs waves by fitting the data in a least squares sense.

Method 1 was derived as a standard interpolation based on a common polynomial fitted to all ERPs samples. Our tests showed optimal results with large 15 coefficients polynomial, which however failed to reconstruct fast waves such as in the P2-N2 zone (figure 5).

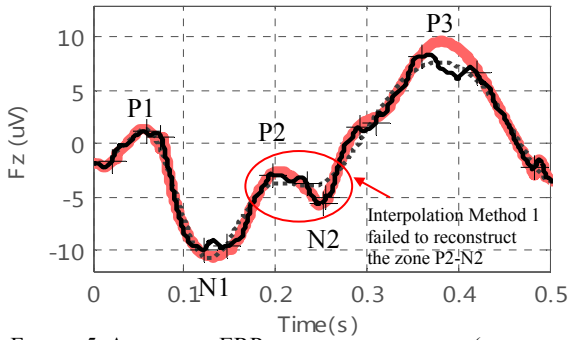

FIGURE 5. AVERAGED ERP OF TARGET STIMULUS (BLACK CURVE); ERP INTERPOLATED BY METHOD1 (DOTTED CURVE); ERP INTERPOLATED BY METHOD2 (BOLDED LIGHT CURVE). THE CROSS MARKS '+' INDICATE THE MOMENTS OF THE ERP SLOPE CHANGE ACCORDING TO THE DEFINITIONS IN METHOD2.

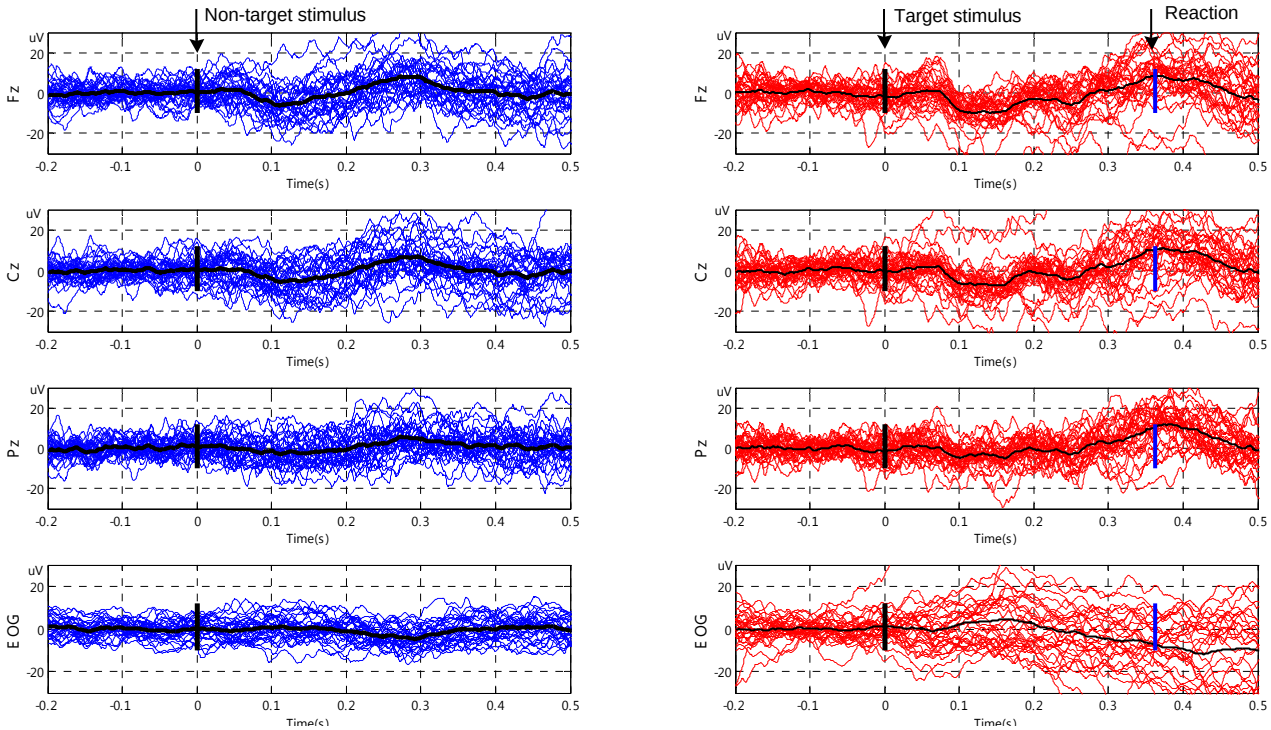

FIGURE 4. ERPS AVERAGED FOR BOTH GROUPS OF (A) NON-TARGET AND (B) TARGET STIMULI. ALL ERPS OBSERVATIONS ARE ILLUSTRATED. THE AVERAGED ERPS ARE SHOWN BY A THICK LINE.

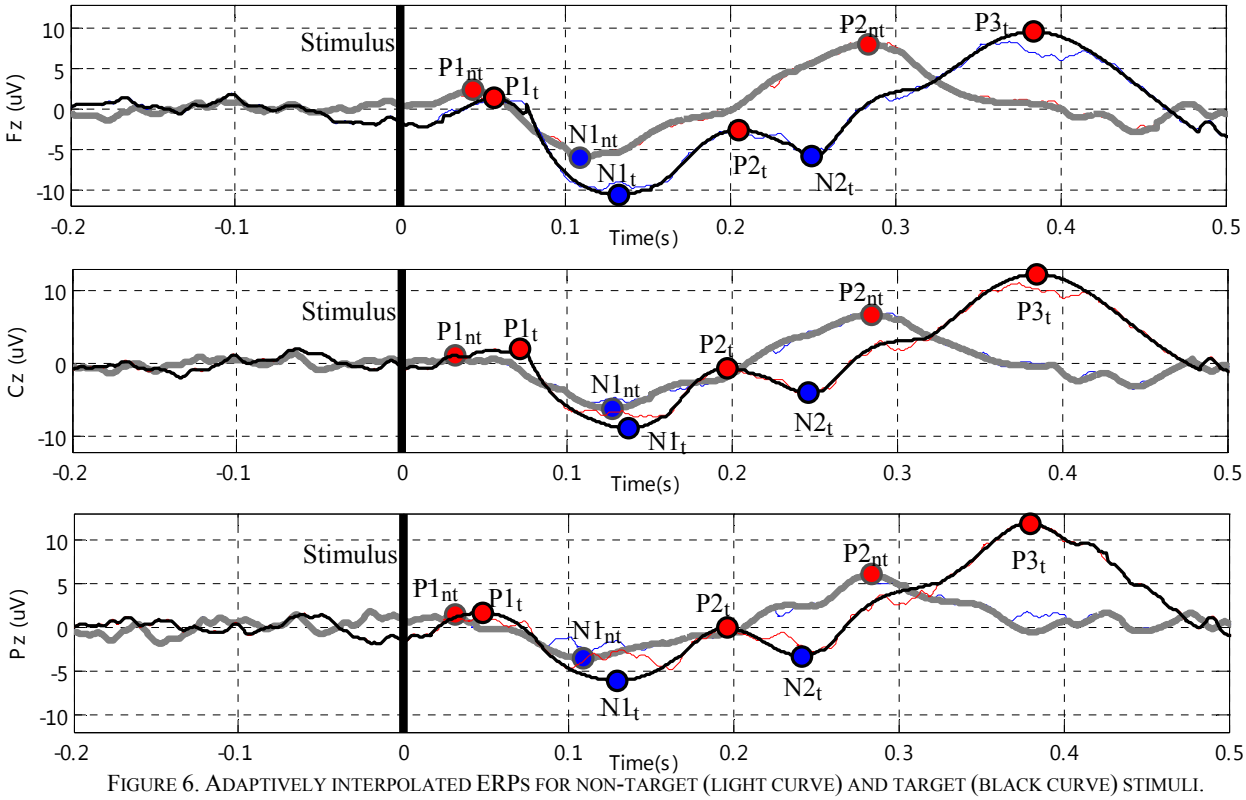

FIGURE 6. ADAPTIVELY INTERPOLATED ERPS FOR NON-TARGET (LIGHT CURVE) AND TARGET (BLACK CURVE) STIMULI. THE 'O' MARKS SHOW THE DETECTED PEAKS P1, N1, P2, N2, P3 OF TARGET (t) AND NON-TARGET (nt) ERPS COMPONENTS.

Method 2 was developed as a technique for adaptive interpolation to reconstruct only the slow regions around the ERPs extrema where the artifacts influence is crucial. The idea is that high-gradient slopes represent stable ERPs components with high signal-to-noise ratio. Therefore they are eligible to derive polynomials used then to reconstruct the slow regions around the ERPs extrema.

Method 2 was designed in five steps:

(1) Detection of all peaks (positive and negative), which are extrema for at least 5 ms around them.

(2) Validation of slopes between the extrema, which last more than 20 ms and have an amplitude difference of more than 1 μV. The begin-end points of such slopes are marked with '+' in figure 5.

(3) Calculation of a polynomial fitted to all samples of both slopes (falling and rising) surrounding the

extremum. Our tests showed that small number of coefficients (5) is enough to fit well the data.

(4) The derived polynomial is used to reconstruct the signal between the two slopes, coinciding with the slow zone around the extremum.

(5) Smoothing the edge effects in the zones of transition between 2 polynomials.

Figure 6 illustrates the adequately interpolated target and non-target ERPs in the three Fz, Cz, Pz channels, according to Method 2.

D. Measurements

The interpolated ERPs were subjected to measurements of the components P1,N1,P2,N2,P3 (figure 6). The interpolated waveforms were smoothed enough to apply a simple iterative algorithm for detection of significant peaks (extrema for at least 30 ms) in a sequence of positive extrema (P1,P2,P3) and a sequence of negative extrema (N1,N2) searched up to 400 ms after the stimulus.

IV. RESULTS

Our results (figure 6) confirm the normal auditory ERPs morphology known from the literature [1,2,4]. The ERPs for the target stimuli to which the subject has to press the mouse button consist of exogenous (P1t, N1t, P2t) and endogenous (N2t and P3t) components. The ERPs for the non-target stimuli, which have to be ignored are formed predominantly from exogenous components (P1nt, N1nt, P2nt) ending with an afterdischarge. Tables 1 and 2 summarize the amplitudes and latencies of the auditory ERPs components for both type of stimuli as measured by the signal processing technique described above.

TABLE 1. AMPLITUDES AND LATENCIES MEASURED FOR THE NON-TARGET (nt) ERPS EXOGENOUS AND ENDOGENOUS COMPONENTS

	Amplitude [μV]			Latency [ms]		
ERPs interp	EEG1 (Fz)	EEG2 (Cz)	EEG3 (Pz)	EEG1 (Fz)	EEG2 (Cz)	EEG3 (Pz)
P1nt	2.3	1.1	1.4	45	32	31
N1nt	-6.1	-4.7	-2.5	109	127	109
P2nt	8.1	6.7	6.0	283	284	283

TABLE 2. AMPLITUDES AND LATENCIES MEASURED FOR THE TARGET (t) ERPS EXOGENOUS AND ENDOGENOUS COMPONENTS

	Amplitude [μV]			Latency [ms]		
ERPs interp	EEG1 (Fz)	EEG2 (Cz)	EEG3 (Pz)	EEG1 (Fz)	EEG2 (Cz)	EEG3 (Pz)
P1t	1.4	2.0	1.6	57	71	48
N1t	-10.7	-8.8	-6.1	132	137	129
P2t	-2.6	-0.6	-0.1	205	197	196
N2t	-5.8	-3.9	-3.3	250	247	241
P3t	9.6	12.2	11.9	383	384	379

V. DISCUSSION AND CONCLUSIONS

As expected our results confirm the known literature, showing that in normal subject the exogenous auditory ERPs components (especially N1 and P2) are with fronto-centro-parietal amplitude distribution over the middle (z) line of the scalp [1,2]. These components reflect the brain activity related to the processing of the physical parameters of the stimuli and correlate with the activation of primary and secondary auditory cortex, situated around Brodmann area 41 and in dept of the posterior-up temporal lobe (see figure 7). The endogenous auditory N2 and P3 components are with centro-parietal amplitude distribution over the z-line and correlate with the activation of higher order brain areas in the parietal lobe, related with the processing of stimulus information in the context of the experimental task.

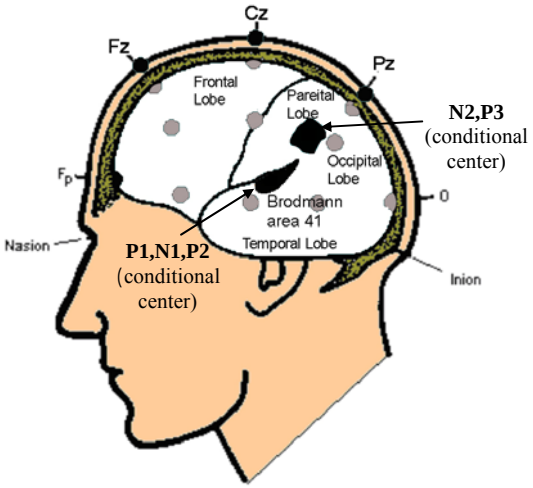

FIGURE 7. HUMAN HEAD WITH FZ,CZ,PZ ELECTRODES OVER THE MIDDLE (Z) LINE OF THE SCALP, AND CONDITIONAL ILLUSTRATION OF SOME ZONES GENERATING EXOGENOUS (P1,N1,P2) AND ENDOGENOUS (N2,P3) COMPONENTS.

In respect to signal processing, the proposed adaptive interpolation provided ERP waveforms with clearly defined peaks corresponding to the components of interest (shown in figure 6). The appropriate reconstruction of these components is crucial for the diagnostic interpretation based on their amplitudes and latencies. In non-automated methods, the experienced eye of the physician is the best interpolator of the ERP waveform. The proposed automated method was designed according to the basic consideration taken by the physician to interpolate visually the waveform, i.e. to follow the two fast slopes surrounding the component of interest and to fit them together by a single global peak, thus skipping several local peaks with artifacts. Following this idea, adaptive coefficients were derived to interpolate each couple of surrounding slopes. Adequate interpolations of the ERPs waveforms were obtained with a relatively small order of the polynomial.

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