

## Event Differentiation in Averaged Signals by Method of the Credits

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**Abstract-** Presented Method of the Credits and its application are based on the determination of the statistically significant signal in the accumulated data. The method helps to determinate whether EEG signal is rather stimulus related than response related.

### I. Introduction

The brain activity is investigated from the various points of view. One of them studies the function of the different brain regions in the dependence on the type of repetitive stimulation paradigm (oddball, CNV, etc.). In each paradigm, stimuli of one modality (visual, auditory, somatosensory) are usually presented. Subjects are instructed to respond to given stimulus (e.g. marked as a target stimulus in oddball paradigm) by motoric response (e.g. hand movement) or some mental activity (e.g. counting) and apparent EEG changes occur (phase - locked ERP – event related potentials or non-phase-locked ERD/ERS – event related desynchronization/synchronization). The response can be either stimulus related or reaction related.

Event-related signals are repetitive biological signals characterised by low signal-to-noise ratio (SNR). The signal accumulation is used to increase SNR. Final results depend on a pre-processing, on the segmentation parameters and on a method of event detection. The aim of the presented study was to compare the signals processed either as stimulus or reaction related by the Method of Credits and to verify the statistical evaluation by an appropriate statistical method.

### II. Methods

Nine subjects participated in our study. They were requested to watch continuously a fixation point on the monitor screen. Two types of stimuli were presented - a non-frequent one (letter 'X', target stimulus) (Fig 1) and a frequent one (letter 'O', non-target stimulus). The subjects were instructed to respond by pressing a micro-switch button to the target X stimuli, not to respond to non-target O stimuli ("oddball" paradigm).

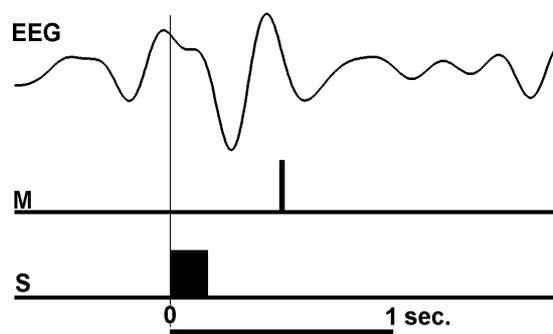


Figure 1. EEG – one EEG channel, pass band 0.5-5Hz, S – target stimulus ('X' letter on the screen), M – motoric reaction to a stimulus (switch pressing).

EEG repetitive signals with a motoric response at specified times were recorded with a sampling frequency of 256 Hz from the 45 depth intracerebral electrodes. The voltage level was from 10 $\mu$ V to 300 $\mu$ V and signals were highly contaminated by a noise. In neurology different frequency passbands

are explored. We concerned on 0.5-5 Hz passband where appropriate ERP signals were expected. Data were filtered using FFT and segmented with a trigger placed on the stimulus or on the reaction. The SNR was improved by signal accumulation in a time domain.

### A. Method of Credits

To distinguish the distortion of an accumulated signal by artefacts (Fig 2) the method of Credits (a mechanism of the statistical data analysis) was used.

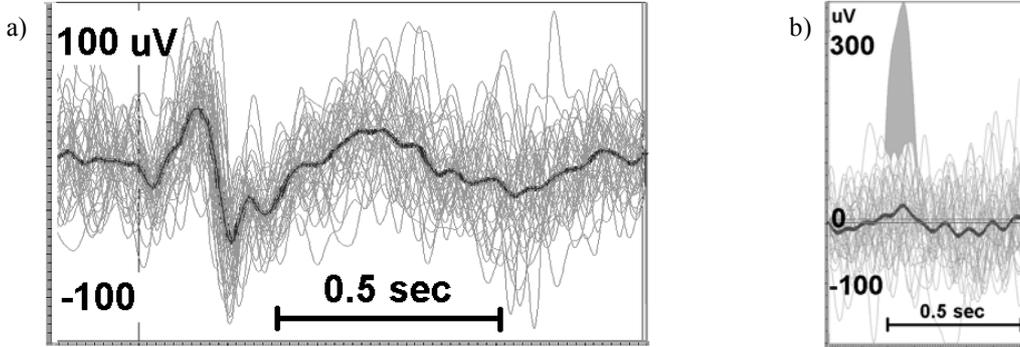


Figure 2. Error in averaging: EEG signal is filtered in 0.5-5 Hz passband and accumulated (dark). Number of segments is 53, all segments are redrawn in one slide (light). Trigger is marked by vertical line. a) Signal was accumulated without artefacts → correct result. b) An example of an artefact (shadow marked) contribution to the accumulated signal → incorrect result.

Credits determinate the credibility of the useful signal in accumulated data using following equations:

$$C_{max} = \frac{(A_{max} - A_{mean})\sqrt{N}}{STD_{max}} \quad CB_{max} = \frac{(A_{max} - A_{mean})\sqrt{N}}{STD_{baseline}} \quad (1)$$

where  $C_{max}$  is a credit of a maximum related to the standard deviation of this maximum and  $CB_{max}$  is a credit of maximum related to the baseline deviation.  $A_{max}$  is a maximal amplitude of the accumulated signal,  $A_{mean}$  is a mean amplitude of the accumulated signal,  $STD_{max}$  is a standard deviation of all segments computed from all segments in points  $T_{max}$  ( $T_{max}$  is a time position of the  $A_{max}$ ),  $STD_{baseline}$  is a standard deviation of all segments in the baseline region.

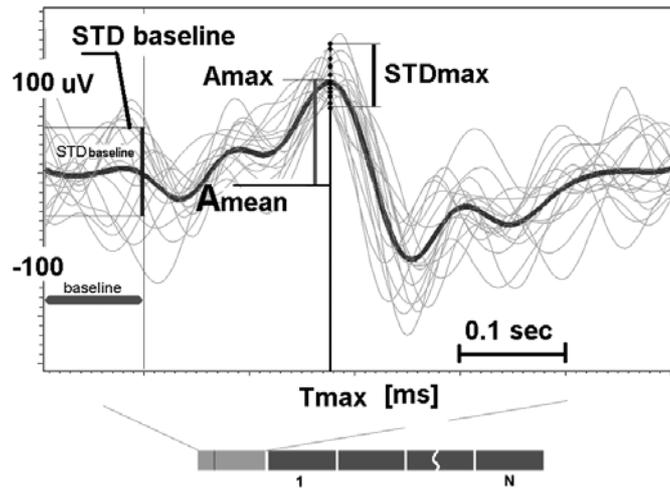


Figure 3. Computing of  $C_{max}$  and  $CB_{max}$  credits.  $C_{max}$  is related to the standard deviation  $STD_{max}$  of all segments in the intersection of  $T_{max}$  line,  $CB_{max}$  to the baseline deviation  $STD_{baseline}$ .  $A_{max}$  represents a maximal amplitude of the accumulated signal (dark line),  $A_{mean}$  a mean amplitude,  $STD_{baseline}$  a standard deviation of all segments in the baseline region and  $N$  a number of accumulated segments.

We proposed that the accumulated signal is credible with the probability of 99% if the corresponding credit is  $C_{max} > 3$  or  $CB_{max} > 3$ . The credits for minima are computed analogically to credits of maxima.

This method can be helpful for a decision whether a signal is stimulus related or not.

## B. Verification of Credits

To determine the significance probability that the medians of two matched vectors  $\mathbf{x}$  (before stimulation) and  $\mathbf{y}$  (after stimulation) (Fig 4) are equal/different standard pair-matched statistical tests were used. Vectors  $\mathbf{x}$  and  $\mathbf{y}$  contain values collected from all segments at the time position of the accumulated baseline maximum  $BL_{max}$  ( $\mathbf{x}$ ) and accumulated response maximum  $A_{max}$  ( $\mathbf{y}$ ).  $C_{max}$  credits were compared with results obtained from Wilcoxon Rank Sum Test (WRST), Wilcoxon Signed Rank Test (WSRT) and Sign Test (ST). These tests are suitable for not normally distributed data or data, whose distribution is not known. It is assumed that the data are distributed symmetrically around their median.

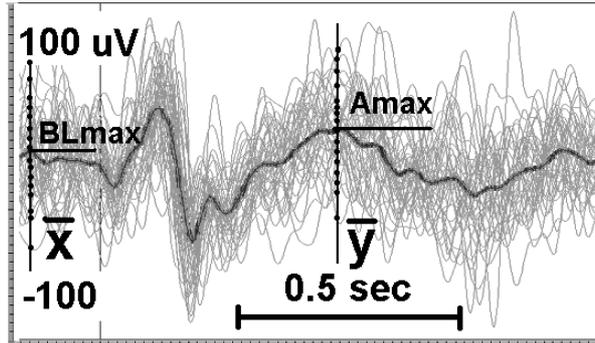


Figure 4. Statistical tests input data:  $BL_{max}$  is the maximal amplitude related to the accumulated baseline region.  $A_{max}$  is the maximal amplitude related to the accumulated signal region.  $\mathbf{x}$  and  $\mathbf{y}$  are vectors of values in all segments in the intersection of the line at the time position of the  $BL_{max}$  or  $A_{max}$ .

We test the null hypothesis  $H_0=0$  that the difference ( $\mathbf{x}$ ,  $\mathbf{y}$ ) in medians (WSRT, ST) / populations (WRST) are equal. The result of the test is marked zero if the difference of  $\mathbf{x}$  and  $\mathbf{y}$  is not significantly different from zero or one if they are significantly different.

## III. Results

Some examples of evaluated data are presented in Fig 5 and Fig 6. Credits for selected channels (Fig 6) correspond to the same data set segmented according to a trigger related to the stimulus (Fig 5a, Fig 6 dots) or according to a trigger related to the reaction (Fig 5b, Fig 6 squares).

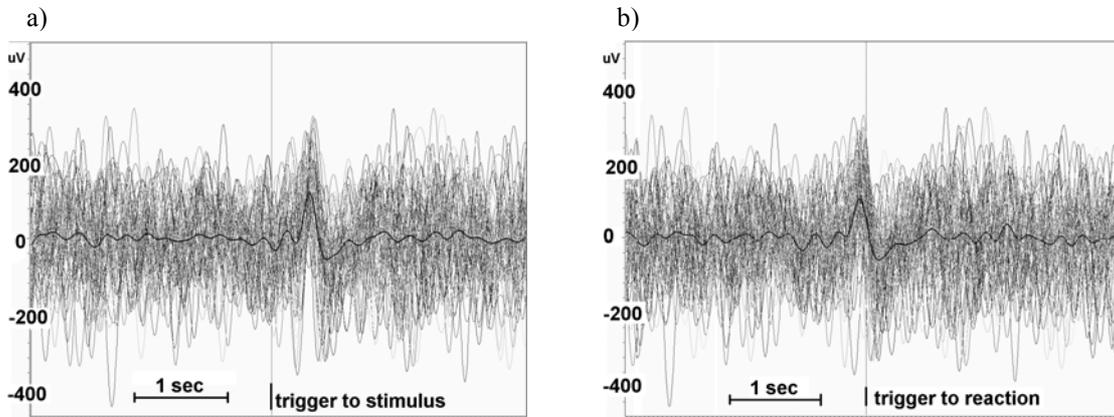


Figure 5. EEG signal (channel 17) filtered in 0.5-5 Hz passband and accumulated (dark). Signal was segmented according to a trigger related to the stimulus (a) and according to a trigger related to the reaction (b). Number of segments is 53, all segments are redrawn in one slide (light).

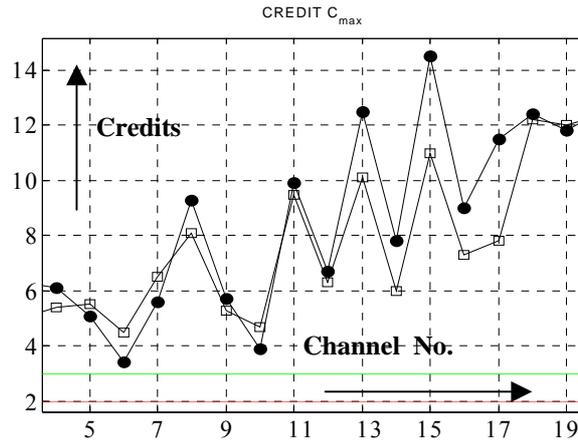


Figure 6. Credits for selected channels, the same data set segmented according to a trigger related to the stimulus (dots) or to the reaction (squares).

Credits denote the signal credibility and also indicate the convenience of a selected segmentation method. In the case of the channel no. 17, the probability of a better accumulation results is higher for segmentation on a trigger related to the stimulus (Fig 5a) then on the reaction (Fig. 5b).

Results obtained by Credits were confirmed for all subjects and channels by pair-matched statistical tests. Table 1 shows typical results of evaluation. Same EEG data sets as in Figs 5 and 6 were analysed.

Channel	Segmentation on	P (H <sub>0</sub> ) / H (Significance Level Alpha=0.05)			Credit C <sub>max</sub>
		Wilcoxon Rank Sum Test	Wilcoxon Sign Rank Test	Sign Test	
4.	<b>Stimulus</b>	0.0036 / 1	0.0035 / 1	0.0925 / 0	<b>6.2</b>
	Reaction	0.1285 / 0	0.0785 / 0	0.8013 / 0	5
10.	Stimulus	0.09 / 0	0.0668 / 0	0.0519 / 0	4
	<b>Reaction</b>	0.0426 / 1	0.0252 / 1	0.0226 / 1	<b>4.6</b>
15.	<b>Stimulus</b>	0 / 1	0 / 1	0 / 1	<b>14.8</b>
	Reaction	0 / 1	0 / 1	0 / 1	11.5
17.	<b>Stimulus</b>	0 / 1	0 / 1	0 / 1	<b>11.6</b>
	Reaction	0 / 1	0 / 1	0.0001 / 1	7.9

Table 1. Results of pair-matched statistical tests are compared with the method of Credits. P is the probability of hypothesis H<sub>0</sub>. If the P value is small, the population has a median  $\bar{x}$  distinct from the median  $\bar{y}$ . H is a result of the hypothesis test on the level of significance 0.005. H is zero/one if the populations of  $\bar{x}$  and  $\bar{y}$  are not/are significantly different. The same data set was segmented according to a trigger related to the stimulus and according to a trigger related to the reaction.

Results obtained using the method of Credits correspond to the results obtained by statistical tests (WSRT, WRST, ST).

- Channel No. 4 – a segmentation on the stimulus is preferred, in the other case results are not statistically significant (Alpha=0.05).
- Channel No. 10 – a segmentation on the reaction is preferred, in the other case a) results are not statistically significant on Alpha=0.05, b) results are statistically significant on Alpha=0.1 (Fig 7).
- **Channels No. 15, 17 – hypothesis probability for both variants of segmentation is 0. A preferred method of segmentation can be selected properly only by Credits.**

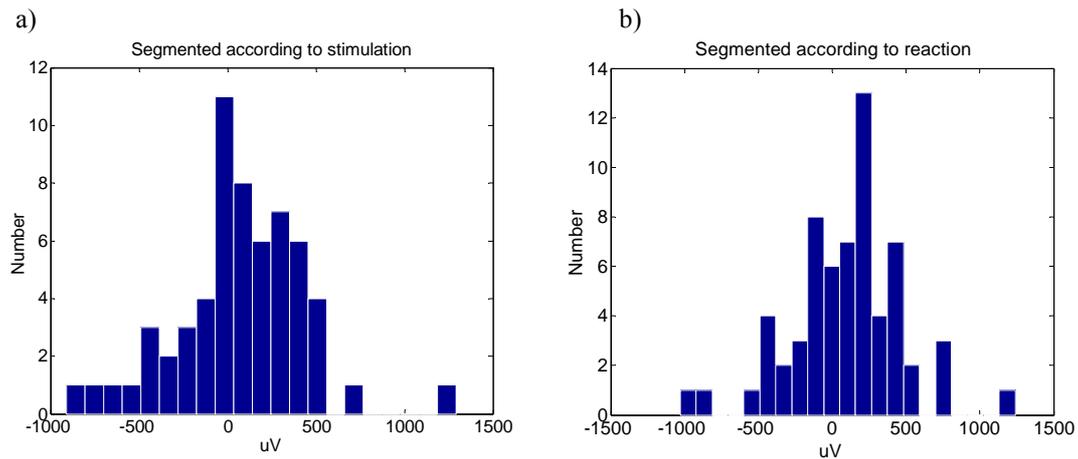


Figure 7. Histograms of statistically analysed data (channel 10). Signals were segmented according to a trigger related to the stimulus (a) and to the reaction (b). Although maximal amplitudes of an accumulated signal  $A_{max}$  are the same in both cases, the statistical distributions are different. A statistically significant is on the level of significance 0.05 only (b).

#### IV. Conclusion

The method of Credits helps to evaluate the signal credibility. This method has a simpler computation and is more sensitive than robust statistical tests (Wilcoxon Rank Sum Test, Wilcoxon Signed Rank Test and Sign Test). In all processed data only this method was able to distinguish clearly the convenience of the segmentation to a trigger related to the stimulus or to the reaction. Credits do not replace the pair-matched statistical tests, but they can better clarify our view on the significance of the processed EEG data.

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