EEG mapping,
histogram analysis,
isopotential areas

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HISTOGRAMS OF SELECTED EEG MAPS SEQUENCES

The aim of the study was analysis of histograms of selected sequences of EEG maps to assess variability of isopotential areas. In clinical practice this variability is evaluated using visual inspection that is subjective and may be difficult in revealing of subtle differences. Variability of isopotential areas is manifested by changes of isopotential areas as well as changes of their topolocalisation.

The histograms of total map areas include the information concerning the ispotential area variability, while histogram analysis of particular areas of map may be useful for evaluation of variability of isopotential areas configuration. Basing on the examples containing the period before, during and after generalized seizure activity, the variability of constellations of isopotential areas in EEG maps and related to that diversity of their histogram types were presented.

The work includes examples of series of EEG map histograms with their statistical analysis and the description of method used for the quantitative assessment of the histogram series variability for the maps sequences containing seizure activity.

1. INTRODUCTION

Brain Electrical Activity Mapping – BEAM (*Duffy FH, Burchfield JL, Lombroso CT: Brain electrical activity mapping (BEAM), a method for extending the clinical utility of EEG and evoked potential data. Ann Neurol* 1979,5) is a well established electroencephalographic (EEG) examinations method as utilizing imaging of the distribution of different values (parameters) characterizing bioelectrical brain activity measured on the scull surface [1,10,13]. In the development of the functional neuroimaging the different forms of the diagnostic images are available, e.g. momentary maps, instantaneous maps, significant probability mapping [2], differential maps [17], landscapes [9]. However, they are not commonly applied in practice.

Mapping of EEG activity amplitude is a routine method used in electroencephalography. Maps sequences are very useful for presentation of the variability of constellations depicted on maps. This may be of significance in the evaluation of different episodes like e.g. seizure activity and its dynamics. Evaluation of the consecutive maps changes requires, however, the quantitative methods [11,12,14-16].

The most important approach was done by Lehmann and coworkers [9,10] and concerned comparisons of 'potential landscapes' i.e. series of maps of the momentary spatial distributions of bioelectrical activity using Global Field Power function calculated as standard deviation of the momentary potential values. Two maps to be compared were average-referenced and scaled to unity Global Field Power. Then, one map was subtracted form the other one. The value of Global Field Power of the resulting difference map is the magnitude of Global Map Dissimilarity. Statistical comparison of potential landscapes between experimental conditions or between different groups of subjects uses as dependent measure Global Map Dissimilarity, or extracted parameters such as the location of the two centroid locations of the map's positive and negative potential areas or the electric gravity.

Despite various techniques described above there is lack of relatively simple method which could be helpful in clinical practice for estimation of the dynamic of changes visible in EEG maps sequences.

Presented in color scale EEG amplitude maps show areas with potential values contained in given ranges, those areas are called isopotential areas. The areas are filled with colors according to given color scale, the scale assigns the range of potential values to particular colors. The aim of the presented research

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was the qualitative assessment of the size, shape and topolocalization variability of isopotential areas in selected EEG map sequences.

Visual assessment of isopotential areas variability is performed basing on the analysis of their shape and topolocalisation changes. Quantitative variability assessment can concern the evaluation of shape, topolocalisation and configuration changes of selected isopotential areas and can be perform basing on the analysis of total map histograms. Analysis of histograms of the particular areas of maps can give information about spatial configuration of the areas with accuracy equals to the size of the selected area.

The presented work relates to methods of analysis of histograms of the total EEG maps, which only give information about the isopotential areas variability versus time. The application o these methods to the analysis of histograms of particular areas of map, e.g. of left and right hemispheres of frontal, temporal and occipital regions would provide information about isopotential areas variability in both the one map area, as well as in the sequence. The paper is an extended version of work presented at the conference CORES 2011 [5].

Fig. 1 presents selected sequences from exemplary series of 1000 EEG map containing the period before, during and after generalized seizure activity.

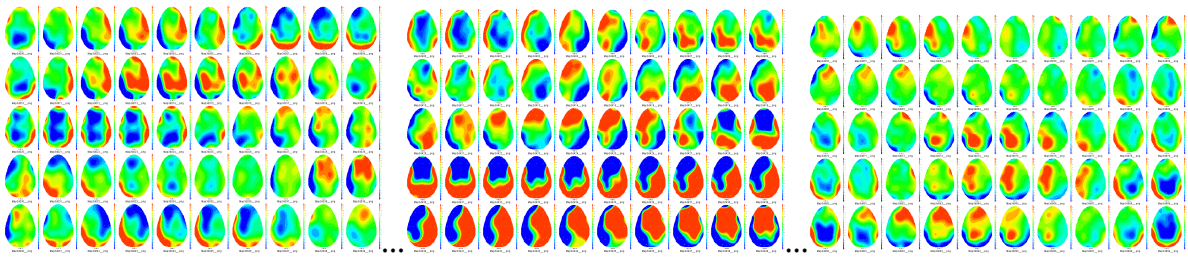


Fig. 1. Selected sequences form series of 1000 EEG map before (a), during (b) and after seizure activity (c) .

Fig. 2 shows a selection of sequences presented in Fig. 1. EEG maps can be characterized by a specific type of histogram like:

- quasi normal (Fig. 2a),
- bimodal (Fig. 2b),
- nearly two-valued (Fig. 2c),
- equalized (Fig. 2d).

Histograms series for the exemplary 1000 EEG map series containing the period before, during and after seizure activity are presented below.

In Fig. 3a the histograms for the selected sequence of 50 maps are presented in the 3D form and in so-called planar form (Fig. 3b) and Fig. 3b presents the histograms for the whole analyzed series in planar form. In histograms in planar form (Fig. 3b) the values of normalized area are presented in color scale according to legend in right side of diagram.

Qualitative assessment of the isopotential areas surface variability can be performed based on the visual analysis of consecutive map EEG histogram, presented in Fig. 3.

Quantitative assessment evaluation of isopotential areas surface variability can be made using histograms statistical features such as:

- variance,
- dispersion,
- asymmetry,
- entropy.

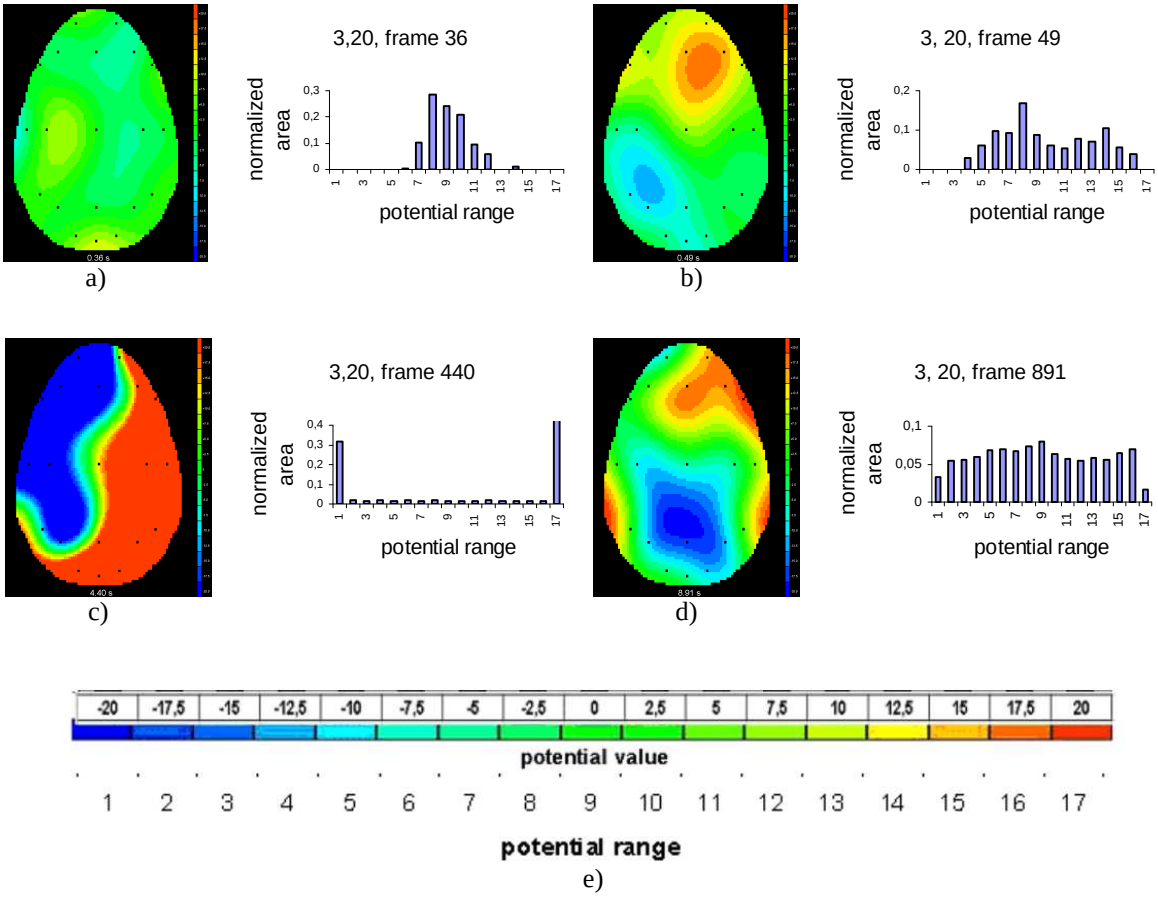
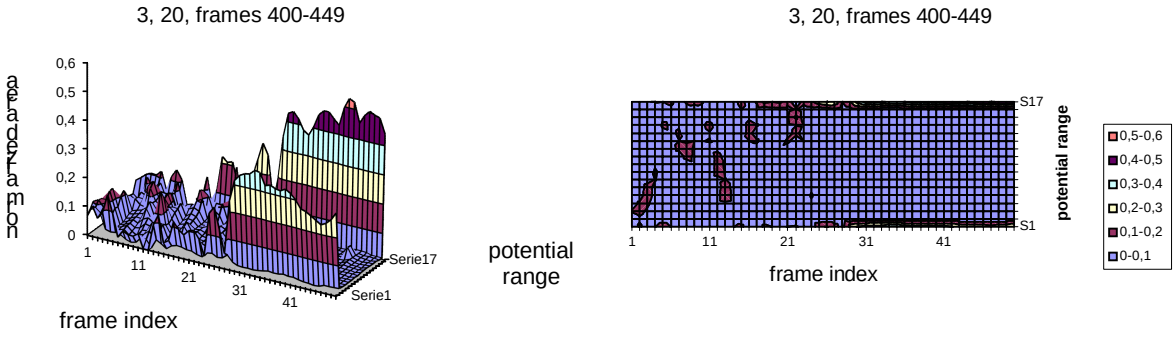
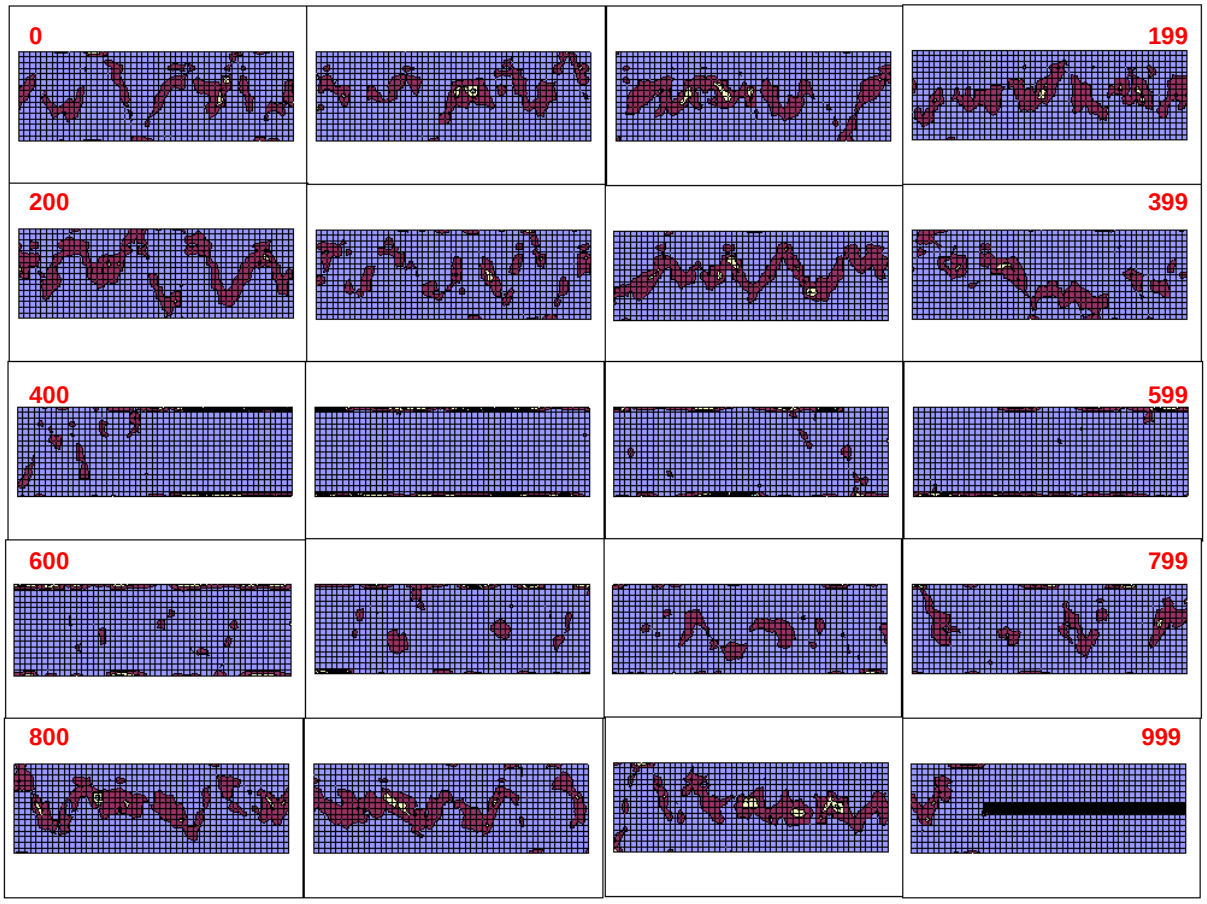


Fig. 2. Examples of EEG maps of the sequence shown in Fig. 1 and their histograms (a - d) and the identification of their potentials for the scale ranges ±20 μV ; ranges 1 and 17 also include the values of potentials, respectively, below and above the ones assigned on a scale.

Selected variability features of isopotential areas, for example, the dominance of areas with positive or negative potential can be detected using the skewness of the maps histograms. To characterize the degree of dominant areas of given potentials one can use such histogram features as dispersion and entropy.





c)

Fig. 3. Histograms visualization of the sequence of EEG maps: 3-D histograms (a) and planar (b) for a sequence of 50 maps from Fig. 1b and planar histograms for sequences of 1000 maps in blocks of 50 histograms (c), description of axes as in diagram (b).

Fig. 4 shows the diagrams of values of histograms statistical parameters for the selected sequence of maps (range 200 - 249, Fig. 3). The diagrams presented in Fig. 4 allow tracing variability of selected parameters. Diagrams in Fig. 5 showing the histograms of statistical parameters for the entire 1000 series maps allow to specify the ranges found in a series of maps of the statistical histograms parameters, and thus find a map with configurations characteristic for a given series. The values determined for the four maps shown in Fig. 2 are marked in red dots.

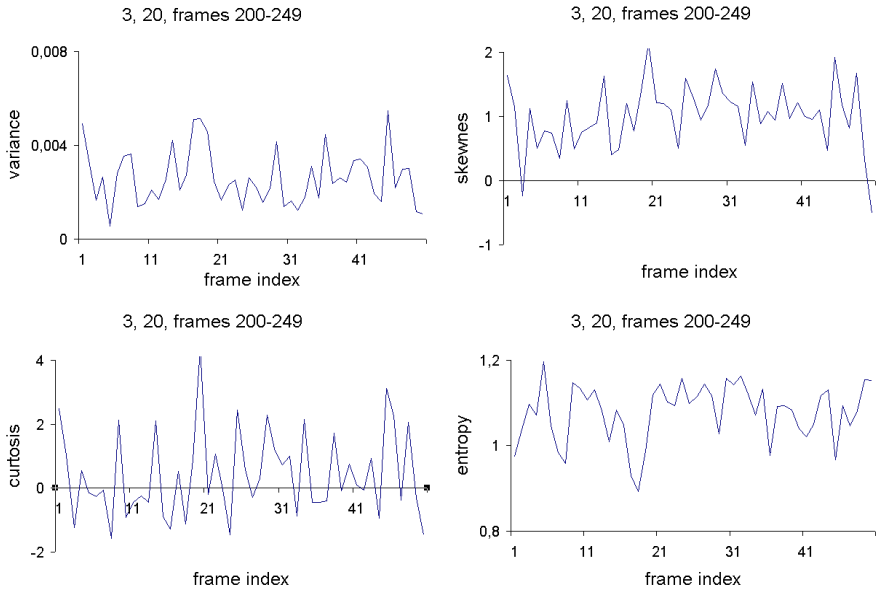


Fig. 4. Waveforms of statistical histogram parameters for the range of maps EEG equal to 200-249.

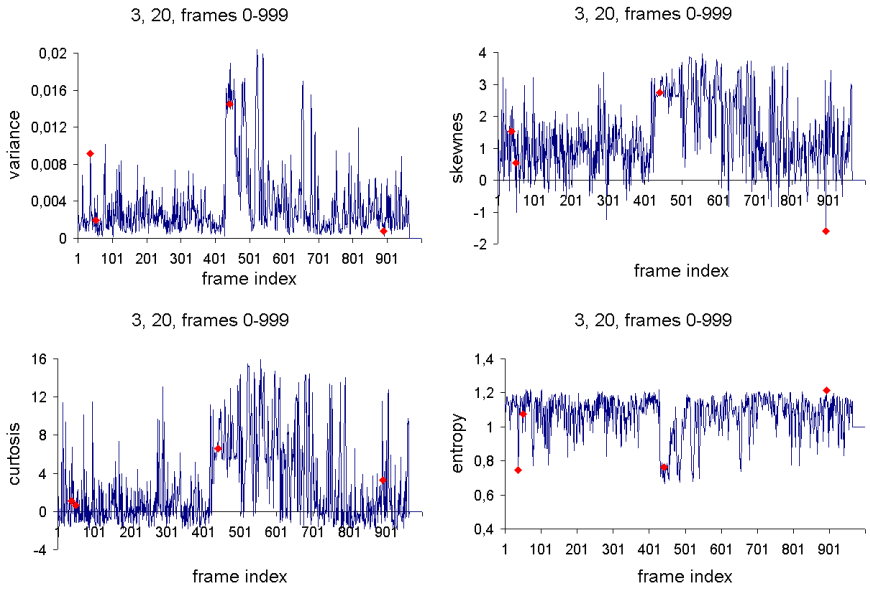


Fig. 5. Waveforms of statistical histogram parameters for the sequence of EEG maps equal to 0-999.

Quantitative assessment of the characteristics of the histogram indicates distinct distribution features, for example, maximum of entropy and minimum of variance indicates a map having the most equalized in the test series histogram (Fig. 5, map 891). In this case, each potential range covers an area of approximately similar value. A positive value of skewness indicates appearance of more areas with positive potential. Interpretation of the other histogram features is not so clear, but it can also be used to determine variability trends in the sequences of maps.

The changes of the histogram parameters such as skewness and kurtosis could also be estimated using EEG map series histograms as presented in Fig. 3.

For the histograms of the type shown in Fig. 2c, calculated for a sequence of maps in the seizure activity (approximately 400 - 699, Fig. 3) there are mainly two extreme values corresponding to areas with extreme ranges of potential. In this case, it is important to assess the dynamics of alternation of extreme isopotential areas i.e. extreme ranges of potential in time.

The method for qualitative assessment of the dynamics of these changes is presented below.

2. MATERIAL AND METHOD

The principle of the presented method is to compare the similarity of the shape of curves representing the changes of values of extreme isopotential areas in time. As a measure the ratio of extreme isopotential areas and the ratios of shape coefficients have been applied.

The material comprised sequences of amplitude maps consisting of pre, during and post- episode activity for selected subjects divided into two groups with episodes of different characteristics classified in previous works [6-8]. There is common numbering for both groups of subjects: 1 – 7 for group II and 8 – 17 for group I. Sequences of maps were generated in 17 levels color scale corresponding to 17 ranges of potential values $S1$ – $S17$ equals to ±20 μV. $S1$ denotes minimum potential range and $S17$ denotes maximum potential range.

Fig. 6 presents waveform time analysis of extreme values of histograms for sequence of maps illustrating seizure activity for two subjects from two groups. They correspond to isopotential areas for extreme values in used scale of potential ranges, respective isopotential areas are denoted as A_{-20} and A_{20}.

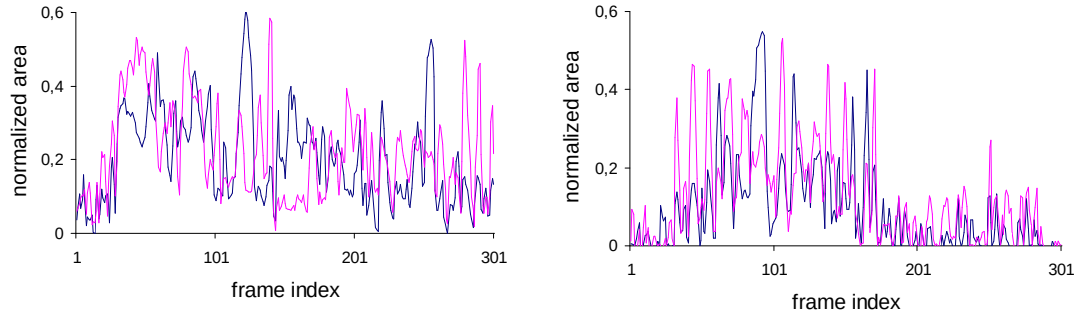


Fig. 6. Waveforms of extreme histogram values for the range 400-699 EEG maps corresponding to the values of time series $A_{-20}(t)$ (in blue) and $A_{20}(t)$ (in red) for subjects no. 3 (a) and no. 9 (b).

The Fig. 6a presents the lower variability of the areas A_{-20} and A_{20} which were distinctive for group II, while the areas A_{-20} and A_{20} in group I presented higher variability (Fig. 6b).
The principle of the method for estimation of variability of the areas A_{-20} and A_{20} in EEG maps sequence consist of:

- analysis of the plot of ratio of time series $A_{-20}(t)$ and $A_{20}(t)$ for the frequency of areas variability evaluation,
- analysis of the similarity of the shape of time series $A_{-20}(t)$ and $A_{20}(t)$ using the measures of asymmetry and flattening and comparing the results for both time series.

Fig. 7 shows the waveforms of ratio of both time series (the extreme values of histograms) for the map corresponding to values of time series $A_{-20}(t)$ and $A_{20}(t)$ for sequences of 300 EEG maps (range 400-699), for subjects no. 3 (a) and no. 9 (b).

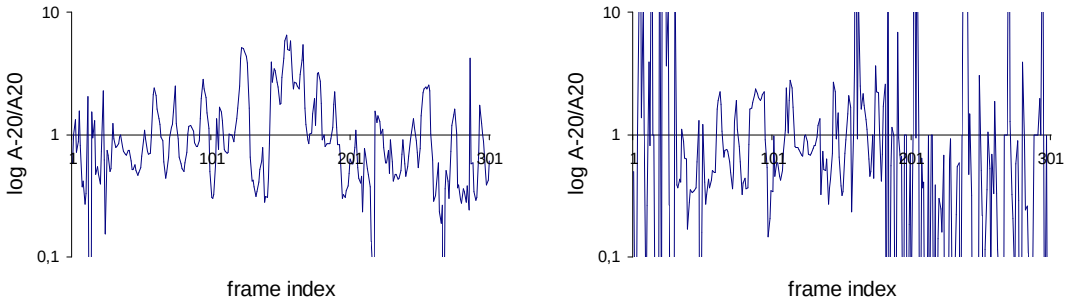


Fig. 7. Values of ratios of time series $A_{-20}(t)$ and $A_{20}(t)$ in logarithmic scale for sequence of 300 EEG maps for subjects no. 3 (a) and no. 9 (b).

Changing the values of areas A_{-20} and A_{20} (estimated as number of passing through level 1 and time between successive passings) is lower in group II than in group I.

The analysis of shape of time series $A_{-20}(t)$ and $A_{20}(t)$ for seizure episode has been applied for estimation of the similarity of both series.

Different time of duration of episode in each map sequence is a reason that the values of shape coefficients of time series incomparable for different subjects. So, only the ratios of the coefficients for both time series were analyzed for estimation of their similarity.

Two coefficients for time series $A_{-20}(t)$ and $A_{20}(t)$ shape have been calculated:

- normalized moment of 3rd order μ_3 describing the asymmetry,
- normalized moment of 4th order μ_4 describing the flattening.

For each subject two ratios *S* and *K* have ben calculated:

$$S = \frac{\mu_3(A_{-20})}{\mu_3(A_{20})} \tag{1}$$

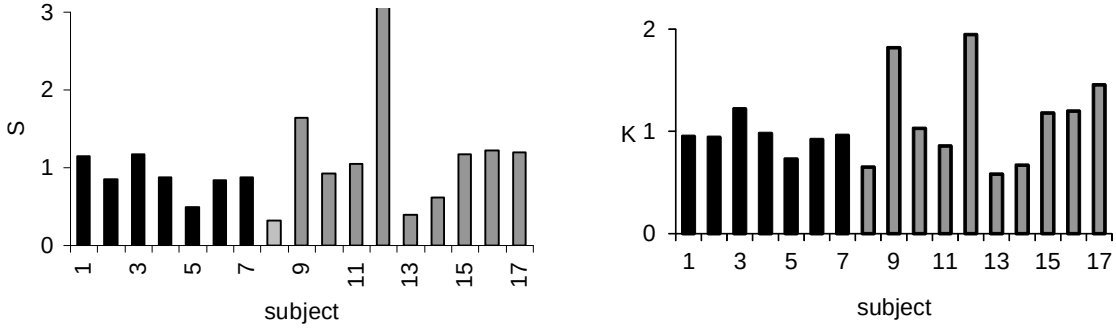
and

$$K = \frac{\mu_4(A_{-20})}{\mu_4(A_{20})} \tag{2}$$

The results of the coefficients *S* and *K* values for two groups of subjects are presented below.

3. RESULTS

The results of quantitative estimation of the similarity of the time series $A_{-20}(t)$ and $A_{20}(t)$ using asymmetry and flattening coefficients are presented. The ratios of asymmetry coefficients and the ratios of flattening coefficients for time series $A_{-20}(t)$ and $A_{20}(t)$ for both groups of subjects are presented in Fig. 8.



a) b)

Fig. 8. Values of ratios of *S* (a) and *K* (b) coefficients for time series $A_{-20}(t)$ and $A_{20}(t)$ for both groups of subjects**.**

The ratios of both coefficients for the group II are about 1. It indicates the similar in the sense of asymmetry and flatting of series $A_{-20}(t)$ and $A_{20}(t)$ for group II, while for the group I the values of the respective ratios indicate the differences of series $A_{-20}(t)$ and $A_{20}(t)$.

Visual evaluation of presented results confirms that examined coefficients may be useful for describing the variability of the areas A_{-20} and A_{20} estimation: ratios of asymmetry coefficients and flattening coefficients for the time series $A_{-20}(t)$ and $A_{20}(t)$.

4. COMMENTS AND CONCLUSIONS

Results of this work as well as our previous studies [3-5] indicate usefulness of EEG maps histograms analysis for evaluation of isopotential areas dynamics. Analysis of EEE map histogram sequences allows for qualitative and quantitative assessment of isopotential areas size variability.

Visualization in so-called planar form histograms of series EEG map, presented in Fig. 4 allows for qualitative assessment of analyzed series variability.

In Section I the examples of EEG map histograms heterogeneity and waveforms of standard statistical parameters for selected map sequences are presented.

Analyzing histograms presented in Fig. 1a,b,d, one can use standardized statistical measures of histogram assessment (Fig. 5), but for histogram types such as presented in Fig. 1c the variability assessment can be mainly related to two extreme values and relations between those values are important.

For map sequences characterized with bi-modal histograms, like those presented in Fig. 3 (range 400-699), presenting generalized seizure activity, the method of analysis of mutual change in time of both extreme histogram values has been presented. The extreme values correspond to areas with extreme potential ranges.

The results of variability estimation obtained in present as well as previous [3-5] study were affected by the following factors:

- a topolocalisation changes were not taken into consideration,
- the scale of generated maps was constant.

Quantitative estimation of the shape of the time series $A_{-20}(t)$ and $A_{20}(t)$ were performed using asymmetry and flattening coefficients.

Similarity of the time series $A_{-20}(t)$ and $A_{20}(t)$ in the sense of asymmetry and flattening value for group II are bigger than the respective time series for group I.

Presented method for analysis of isopotential areas values in sequences of EEG maps based on map histograms allows for evaluation of one of the alternation features, i.e. dynamics of extreme isopotential areas changing.

For evaluation of the spatio-temporal trends of isopotential areas dynamics in EEG maps sequences it is necessary to perform more studies consisting on applying this method to particular regions of EEG maps, e.g. left and right hemispheres or frontal, temporal and occipital regions.

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