ALGORITHM FOR COMPUTER ANALYSIS OF THE ELECTROENCEPHALOGRAM

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An algorithm for plotting two-dimensinal EEG histograms in amplitude–frequency coordinates of the waves forming the curve with the aid of a computer is described. The EEG is presented for coding as a series of extrema, the times of their appearance being recorded. The appropriateness of the algorithm is confirmed by examples.

KEY WORDS: computer analysis of the EEG; algorithm.

Among the series of operations required for computer analysis of the EEG, its encoding is the most difficult. The difficulties arise, in particular, because of the large volume of information. In the course of one experiment (with recordings from 16 leads during 15 min, with a quantification frequency of f=200/ sec and with a number of amplitude quantification levels of n=64) it amounts to several million bits. Before the EEG can be led into the memory of the computer, it is therefore advisable to reduce the volume of information but without reducing its informativeness, so far as possible, at least in relation to modern methods of analysis.

This can be done if the EEG can be presented purely as readings taken at its extrema, with the times of their appearance being recorded simultaneously. With this method the segment of the EEG in the interval (O, T) is replaced by a series of digital pairs (u_i, t_i), the indices of which correspond to the serial number of the extremum in the segment recorded; the first number is the value of the EEG at the extremum, and the second number is the time of its appearance. The mean number of these pairs is eT, where e is the mean number of extrema of the EEG in unit time. The term t_i rises sharply toward the end of the segment, so that the recording would be more economical if the series (u_i, t_i) were replaced by the series (u_i, Δt_i), $\Delta t_i = t_{i+1} - t_i$. In that case the relative economy in the volume of information ξ is expressed as follows:

$$\xi = \frac{V_1}{V_2} = \frac{f}{e}\left(\log \sqrt[n]{f \cdot s + 1}\right)^{-1}, \qquad (1)$$

where V_1 and V_2 are the volume of information (bits) for uniform quantification and extremal presentation of the EEG respectively; s the maximal distance between the extrema (in seconds). For the EEG ξ=5-10; this does not, of course, solve the problem but it broadens the class of experimental situations for which the EEG, presented in this way, can be stored directly in the computer's memory.

Presentation of the EEG by extrema leads to virtually no loss of information from the point of view of methods at present used for its assessment. Some characteristics are retained completely. This applies to asymmetry of the EEG waves [1], to the Faure diagram [2, 3], and to many elements of the evaluatory matrix of the EEG [4]. The estimate of the correlation function of the EEG can be calculated from this presentation more accurately than, for example, from sign correlation, and so on.

The writers used presentation of the EEG by extrema in order to plot two-dimensional histograms in "EEG amplitude–wave duration" coordinates, which have proved themselves in programs of identification of specimens [5].

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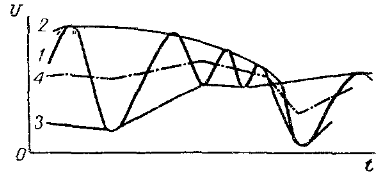

Fig. 1. Piecewise-linear approximation of EEG envelopes: 1) segment of EEG; 2) upper envelope (V_u); 3) lower envelope (V_l); 4) mean between them (V).

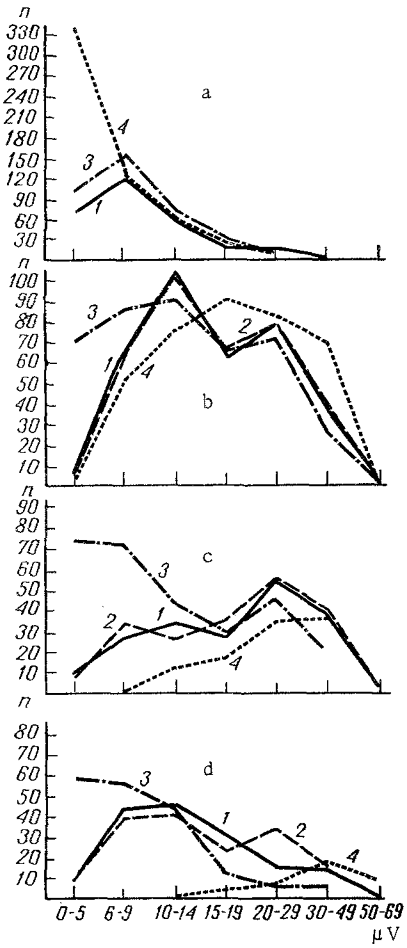

Fig. 2. Graphs showing two-dimensional histograms of EEG characteristics. 1) Histogram obtained manually; 2, 3, 4) histograms obtained by computer (variants with V_u, V_l, and V respectively): a) frequencies > 14 Hz; b) frequencies 8-13 Hz; c) frequencies 4-7.5 Hz; d) frequencies 1-3.5 Hz. Abscissa, amplitude of waves (in μV); ordinate, number of waves in 10 sec in 4 wavebands indicated above.

A scrutiny of the method of processing used by specialists during visual analysis of the EEG shows that it consists of three stages: a) measurement of the parameters of the waves; b) identification of low-frequency additive components; c) the plotting of two-dimensional histograms.

The first stage – measurement of the parameters of the waves – can be expressed variously. In a paper by Kozhevnikov and Meshcherskii [6] several definitions are given for the concepts of "wave," "amplitude of the wave," and "duration of the wave." In the algorithm to be examined below the wave is the region between neighboring minima and its duration τ is

$$\tau = \Delta t_{i+\eta} + \Delta t_{i+\eta-1}, \qquad (2)$$

and its amplitude u is

$$u = 0{,}5\,(-u_{i+\eta} + 2u_{i+\eta-1} - u_{i+\eta-2}) = -0.5\Delta^2 u_{i+\eta}. \qquad (3)$$

Here $\{\Delta t\}$ is the first difference of the series (t_i); $\{\Delta^2 u\}$ is the second difference of the series (u_i), and

$$\eta = \begin{cases} 1, & \text{if the series begins with an ascending phase,} \\ 0, & \text{if the series begins with the descending phase.} \end{cases}$$

The second stage is connected with the concept of the EEG as the result of superposition of different potentials on each other. The problem here is to distinguish the slow components of the EEG.

At this stage the simplest approximation would evidently be to distinguish the envelopes of the EEGs or, because of the shortness of the segment analyzed, their piecewise-linear approximations, the nodal points of which are the extrema of the EEG. There are three possibilities: to plot the upper envelope V_u (from the maxima of the original curve), to plot the lower envelope V_l (from the minima), or the means V between them (Fig.1).

In a paper by Nikiforov and Bochkarev [7], in which they discuss problems similar to those now being considered, a method of EEG processing analogous to the plotting of V_u was used. It can be shown that V_u and V_l reflect not only the additive but also the multiplicative components (such as the spindles of the α-rhythm). In the method of evaluation of the EEG as it has evolved in practice, its multiplicative slow components are not considered to be "slow waves." It is therefore better to use the mean V, which is not sensitive to them.

Finally, the third stage, the plotting of histograms, is done in the usual way. Boundaries of the intervals (U_1, U_2, ..., U_k ..., ..., U_n and T_1, T_2, ..., T_l, ..., T_n) are chosen along the u (amplitude of the waves) and τ (duration of the waves) axes, and in each two-dimensional region

$$U_{k-1} < u \leq U_k, \quad T_{l-1} < \tau \leq T_l \qquad (4)$$

the number of waves from the segment of the EEG being processed, and whose parameters satisfy this inequality, is stored.

On the basis of these determinations the algorithm of histogram formation from the series (u_i, Δt_i) was developed and used for programing the Minsk-32 computer.

The number of intervals along the τ axis was chosen to be four (corresponding to durations of the α-, β-, θ-, and Δ-waves), and ten intervals along the u axis (5 to 50 μV). The program included construction of the series (u_i, Δt_i) from the uniformly quantified EEG obtained with the "Silhouette" apparatus (time quantization increment 5 msec, accuracy of measurement of EEG ordinates 8 bits). The program was compiled from the following units:

a) formation of the series (u_i, Δt_i) from the original EEG (i.e., distinguishing the extremal points);

b) measurement of the parameters of the EEG waves according to equations (2) and (3) and filling in the histograms in accordance with equation (4);

c) distinguishing the low-frequency components of the EEG, for which V_u, V_l, or V were used in different variations of the program;

d) processing of the low-frequency components by the same method as the EEG, as in paragraph b.

It was first supposed that the number of low-frequency components to be distinguished would be fairly large and that the components themselves would require low-frequency filtration. The experiments were carried out in accordance with variant 21 (different combinations of components and different parameters of the filtration operator). They showed that the best approximation to the results of visual analysis is given by the use of only two unsmoothed components – the initial EEG and its envelope.

Let us consider an example which shows how computer analysis of the EEG by reference to its extrema can be carried out.

Patient Sh-i. Eight bipolar recordings were taken from the basic regions of both hemispheres. Epoch of analysis 10 sec.

The construction of two-dimensional histograms on the basis of computer data obtained in three variants (HC) and on the basis of manual processing of the same curve as a control (HM) is illustrated in Fig. 2. Histograms of the eight recordings in this case were plotted so that the state of the subject over a period of 10 sec was characterized by a single histogram. Comparison shows that agreement between HC and HM within the α- and θ-rhythm bands is almost complete.

Within the β-rhythm band, the number of waves in HC was lower than in HM. This evidently happened because of defects in the encoding of the primary EEG by the "Silhouette" system. In the region of low values of u and τ, the number of θ- and Δ-waves is larger in HC than in HM, indicating that the HM method is more sensitive. In order to approximate HC and HM, thresholds must therefore be introduced so that low-frequency and low-amplitude regions in HC are excluded from the histogram.

EEGs of 12 subjects altogether were analyzed by the method described above. The results confirmed the usefulness of the computer algorithm for the plotting of two-dimensional histograms of the EEG between coordinates of "amplitude–frequency" of its waves.

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