COMPUTER CLASSIFICATION OF TWO-DIMENSIONAL POINT DIAGRAMS DISPLAYING VARIOUS TYPES OF HUMAN EEG

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UDC 612.172.4+616.12.12-073.97] : 681.31

Experiments are described in which the algorithm developed by V. K. Maslov for seeking informative criteria (for use in problems of form recognition) was used for automatic classification by computer of the various types of EEG previously distinguished by E. A. Zhirmunskaya on the basis of qualitative evaluation. The possibility of computer classification of EEG types marks a new advance in clinical electroencephalography.

Evaluation of the EEG by plotting point diagrams in a system of two-dimensional coordinates was first suggested in 1953 [1]. Later this method of evaluation of brain electrical activity has been used in several investigations [2, 3] in which, however, only a qualitative relationship was established between the statistical characteristics of the diagrams and the various types of human EEG.

In the investigation described below an attempt was made to find a quantitative expression for the correlations established previously and to undertake the automatic classification of human EEG types by computer. Algorithms of search for informative criteria [4] as applied to problems of form identification were used.

## EXPERIMENTAL METHOD AND RESULTS

The aim of the experiments was to find, by means of algorithms, the significant criteria (factors) within the space of which the types of EEG studied are clearly distinguishable, and also to arrange the area of the Faure diagrams in order of their relative contribution to the differentiating power of the algorithmic factors.

The human EEG was recorded on an Alvar ink-writing electroencephalograph. The period in Hz and the amplitude in V of the waves forming the EEG curve were measured (with the aid of a ruler and calipers) on the records thus obtained. Taking into account all waves (both large and the smaller waves superposed on them) found on a cut of the EEG 10 sec in length, found in eight synchronously recorded bipolar leads (occipital-parietal, occipital-temporal, temporal-frontal, central-frontal, from the left and right cerebral hemispheres). A full account of the procedure is given elsewhere [2, 3].

EEGs of the five types corresponding to the accepted classification were analyzed: type I) normal; II) hypersynchronized; III) desynchronized; IV) disorganized; V) severely disturbed.

The EEGs for analysis were regarded as realizations of a stochastic process in a certain period of time. The two-dimensional density of distribution $(a, \tau)$ of the EEG waves in coordinates of amplitudes $(a)$ and periods $(\tau)$ (or frequency $f = 1/\tau$) in the interval T is the mathematical expression of what is called the Faure diagram. To evaluate the diagram its density $(a, f)$ is quantified at five levels of amplitude along the $a$ axis (5-24; 25-49; 50-69; 70-99; 100-150 V) and in four frequency bands along the $f$ axis (1-3.5;

Institute of Neurology, Academy of Medical Sciences of the USSR, Moscow. (Presented by Academician of the Academy of Medical Sciences of the USSR E. V. Shmidt.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 77, No. 1, pp. 17-20, January, 1974. Original article submitted July 31, 1972.

TABLE 1. 20-Dimensional Space of Original Description X

| Amplitude (in $\mu$V) | Frequency (in Hz) | | | |
|---|---|---|---|---|
| | 1—1½ | 4—7 ½ | 8—13 | 14—30 |
| 100—150 | 20 | 15 | 10 | 5 |
| 70—99 | 19 | 14 | 9 | 4 |
| 50—69 | 18 | 13 | 8 | 3 |
| 25—49 | 17 | 12 | 7 | 2 |
| 5—24 | 16 | 11 | 6 | 1 |

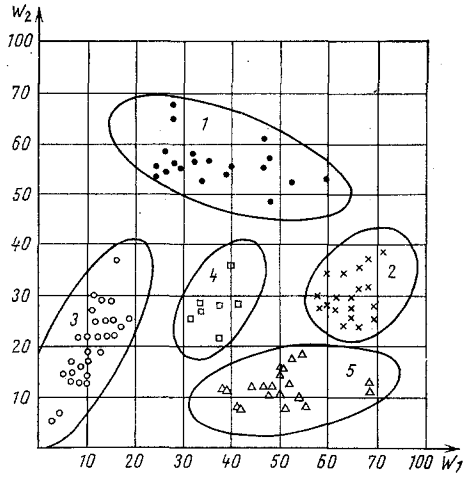


Fig. 1. Realization of types of EEG in space of algorithmic factors. $w_1$, $w_2$) axes corresponding to factors found by criterion (1); 1-5) Nos. of types of EEG; O) realization of type 1; ×) of type 2; □) of types 3 and 4; Δ) of type 5; circled regions represent regions of space of factors in which individual representatives (realizations) of the corresponding type of EEG are grouped.

4-7.5; 8-13; 14-30 Hz). The method of quantification of the Faure diagram is shown in Table 1. The squares are numbered. The results obtained by measurement of the EEG waves are applied to the quantified diagram. The number of waves falling in each square of the diagram is counted. After this procedure each cut of the EEG (realization of the EEG in time T) is presented as 20 numbers; i.e., it is represented in a 20-dimensional space X.

To carry out the experiment, training material was fed into the computer to the amount of 80 realizations (16 cases for each of the five types of EEG).

The content of the factor-searching algorithms concentrating the information distinguishing the types of EEG consists essentially of finding the subspace of least dimension $Y \subset X$, in which the distance between the realization families of the different types of EEG would be large enough in a certain sense.*

The basic vectors $w_i$ of the subspace Y will be called factors and the projections of the Faure diagrams on these vectors the values of the factors. For a fixed dimension $K < I$ of the subspace of the factors $Y \subset X$, the solution was obtained to the problem

$$\max_{\{\tilde{W}\}} \min_{q<p} \min_{n,\, m} \rho(\tilde{W}x_{qn}, \tilde{W}x_{pm}), \tag{1}$$

where $x_{qn}$ represents the n-th vector of realization of the q-th type (the n-th Faure diagram of the q-th type); w is the matrix of the dimension factors K × 20; K the number of factors (the dimension of the subspace of the factors Y); q, p are the indices of the EEG types ($q = 1$; $p = 2, \ldots, 5$).

The results of operation of the algorithm by criterion (1) are shown in Fig. 1, where the realization of all types of EEG are shown in space 2 of the linear factors $w_1$ and $w_2$ found. The coordinates of these factors $w_1(w_1^1, w_1^2 \ldots . w_1^j)$ and $w_2$ $(w_2^1, w_2^2, \ldots . w_2^j)$, regarded as the basis of the subspace $Y \subset X$, give the relative weight of each of the 20 areas of the plane $(a, \tau)$. It is clear from Fig. 1 that the types of EEG are clearly distinguished in the space of the separate factors.

A histogram of the relative contributions (weights) of individual squares of the Faure diagram is shown in Fig. 2. Clearly the greatest contribution is made by squares Nos. 6, 7, 8, and 13, a smaller con-

* The authors did not have sufficient arguments to give preference to any particular measure. The ordinary, euclidean measure was therefore used, according to which

$$\rho(x_{qn}, x_{pm}) = \sqrt{\sum_{i=1}^{J} (x_{qni} - x_{pmi})^2}\ .$$

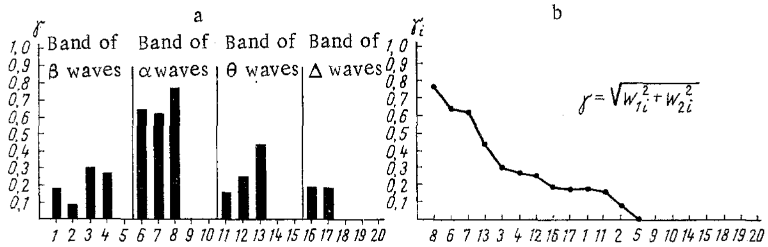


Fig. 2. Graph of relative contributions of squares of the Faure diagram matrix: a) successive values of contributions; b) values of contributions in order; ordinate, contribution $\gamma i$; abscissa, No. of square on Faure diagram.

tribution is given by Nos. 1, 2, 3, 4, 11, 12, 16, and 17, while the other squares (Nos. 5, 9, 10, 14, 15, 19, 20) make no contribution.

Squares with numbers giving the greatest contribution correspond on the Faure diagram to the frequency band of alpha waves with an amplitude of 5-70 $\mu$V and theta waves with an amplitude of 50-70 $\mu$V; squares with numbers making a smaller contribution correspond to beta waves with an amplitude of 5-100 $\mu$V and also to theta and delta waves of low amplitude (5-50 $\mu$V).

During visual (qualitative) classification of the EEG into types it was this same difference in the informativeness of the different frequencies and amplitudes of the waves, which was used. The results of the present investigation confirmed these ideas on the basis of a quantitative evaluation of the EEG components. It can accordingly be concluded that the principles lying at the basis of the EEG classification reflect the actual principles which govern its structure.

In conclusion it may be noted that computer analysis of the EEG, with the use of Faure diagrams, has several indisputable advantages over the methods of spectral analysis. This follows from the non-gaussian nature of the EEG and the consequent need for using characteristics with greater capacity than spectral for its evaluation, such as two-dimensional distributions or functionals of multivariate distributions.

The possibility of automatic identification of the various types of EEG recognized in clinical neurology, demonstrated by this investigation, gives a fresh impetus to the use of electroencephalography in clinical medicine.

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