METHOD OF DISTINGUISHING ELECTROENCEPHALOGRAPHIC RESPONSES TO DIFFERENT TYPES OF MENTAL ACTIVITY

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Statistical characteristics of the EEG were obtained by means of which its responses to performance of various types of mental work can be distinguished without regard to the pattern of the background EEG or to its changes produced by mental activity. The α-rhythm of differentiation is based on the probability ratio of a two-dimensional probability density. An analysis was made of the EEG recorded during 37 arithmetical calculations and 29 examinations of a picture made by 22 subjects. The results of differentiation in trained and control groups were approximately the same (91% of correct responses). The results are regarded as evidence of the coding in the EEG of neurophysiological processes playing a role in the organization of mental work.

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The development of reliable methods of distinguishing between different mental states by means of the EEG would provide a convenient means for the solution of complex psychophysiological and neurophysiological problems.

The first reports of the possibility of such differentiation appeared in my earlier paper [1]. By examining coefficients of correlation of 3 bipolar recordings of the EEG with electrodes placed in the inferior parietal, occipital, and temporal regions, I found slight yet statistically significant differences between the coefficients of correlation during arithmetical calculation, verbal description of a picture, and certain other types of activity. However, the coefficients of correlation enable differentiation to be performed only when the mental activity evokes a certain degree of inhibition of the α-rhythm.

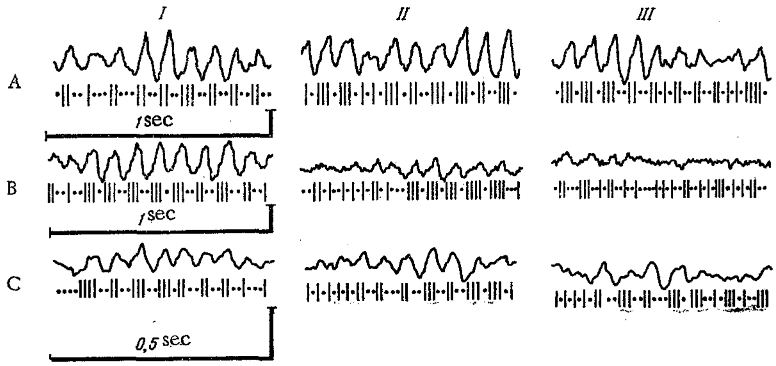

Fig. 1. Principal types of inferior parietal—occipital recording of spontaneous EEG, during arithmetical calculation, and during description of picture. A) Stable α-rhythm, B) desynchronization of α-rhythm during activity, C) stable β-rhythm; I) background; II) arithmetical calculation, III) description of picture; II and III) 5th second after final instruction. Discrete transformation shown below EEG, by means of which duration of EEG phases was assessed. Calibration 25 μV.

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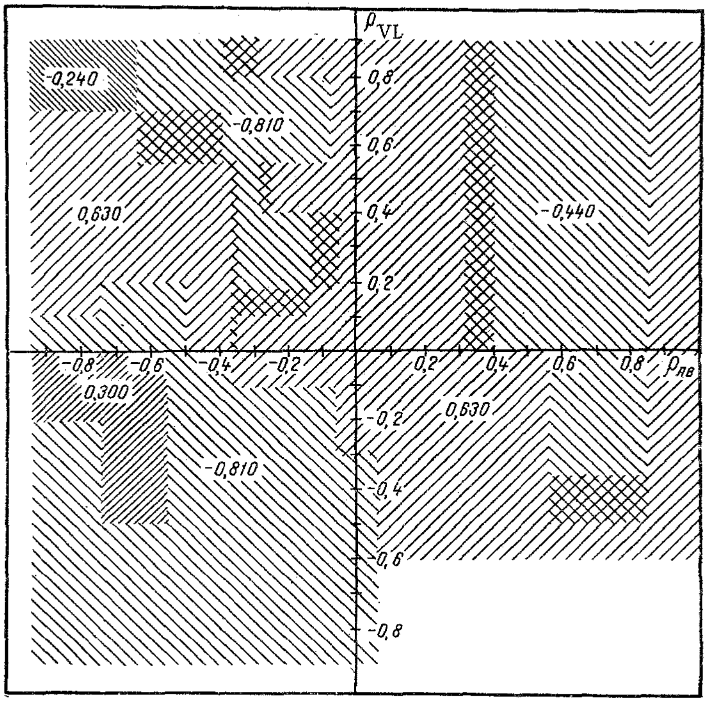
TABLE 1. Discriminant 2-Dimensional Table (ρ_{AB}, ρ_{VL}) for Distinguishing Two Types of Mental Work (Arithmetical calculation and verbal description of a picture) from Parieto-Occipital Recording of EEG



Legend: numbers represent diagnostic coefficients ($\log\frac{p}{q}$). Regions with the same diagnostic coefficient are shaded in the same way; double shading denotes boundary between regions. When points (ρ_{AB}, ρ_{VL}) fall on the boundary, half the sum of the diagnostic coefficient of neighboring regions should be taken.

Subsequently, to detect responses associated with human mental and psychological activity in general, a method of statistical analysis of the durations of waxing and waning phases of single EEG waves was used [2, 3]. It was found that the level of asymmetry of phase duration for parieto-occipital recording in persons with a stable α-rhythm changes in a regular manner during various types of mental work, but these responses are not a linear function of the original level of asymmetry but are characteristic of the particular subject investigated, and they cannot therefore enable reliable differentiation to be made in the general case.

In this paper an account is given of a study of the informativeness of certain statistical indices characterising the duration of phases and their connection with the amplitude of the EEG, as a result of which EEG characteristics were selected which, even with the use of a single channel and a suitable rule for solution, could distinguish the EEG responses to arithmetical calculation (AC) and verbal description of a picture (DP) for a group of persons irrespective of other characteristics of the background EEG or its changes evoked by mental activity.

EXPERIMENTAL METHOD AND RESULTS

In the experiments 22 subjects aged 17–35 years were instructed to multiply two-figure numbers or to describe a picture in their own words. Altogether 37 AC and 29 DP performances were analyzed. Some of the instructions required the performance of arithmetical operations with assigned numbers and description of a particular picture (28 × 26, 56 × 37, "describe the picture' The Ninth Rampart'," and so on). In other cases the subject was instructed to multiply any two figure numbers at will and to describe any pic-

TABLE 2. Results of Classification for EEG Patterns Corresponding to Arithmetical Calculation and to Verbal Description of a Picture in Training Groups (10 persons)

Results of discrimination	In reality	
	Calculation	Picture
Calculation	18 (13)	0 (0)
Picture	2 (1)	14 (14)
Indefinite	0 (6)	0 (0)

TABLE 3. Results of Classification of EEG Patterns Corresponding to Arithmetical Calculation and Verbal Description of a Picture in Control Group (12 persons)

Results of discrimination	In reality	
	Calculation	Picture
Calculation	14 (10)	1 (1)
Picture	3 (3)	14 (10)
Indefinite.	0 (4)	0 (4)

ture with which he was familiar. The subjects were placed in a screened, half-lit room in a sitting or lying position with their eyes closed. Subjects were chosen at random. Two of them had no α-rhythm in their background EEG and no changes could be perceived visually during activity (Fig. 1C), while in 13 subjects a definite α-rhythm was observed both on the background EEG and during performance of the tests (Fig. 1A), and in 7 other subjects definite inhibition of the α-rhythm developed during activity (Fig. 1B). The EEGs were recorded on a "Kaiser" electroencephalograph. The filter was in the mean position and the time constant 0.3 sec.

A statistical analysis was made of the EEG in inferior parietal–occipital leads from the left hemisphere. The occipital electrode was 2-3 cm above a horizontal line passing through the occipital tuberosity and 4-5 cm to the left of the midline.

The interelectrode distance was 4 cm. Commutation of the electrodes was so arranged that upward deflection corresponded to an increase in negativity of the occipital region relative to the parietal.

Analysis of EEG and procedure of selection of informative characteristics. The following measurements were made for each second of the tracing: A) duration of ascending phase; B) duration of descending phase, $L=A+B$ (period), $\Delta=A-B$ (asymmetry), and V (amplitude).

The mean values of these indices and also their coefficients of correlation in pairs were calculated for successive intervals of 5-8 sec:

$$\bar{A},\ \bar{B},\ \bar{L},\ \bar{\Delta},\ \bar{V},\ \rho_{AB},\ \rho_{AV},\ \rho_{BV},\ \rho_{VL},\ \rho_{\Delta V},\ \rho_{\Delta L},\ \rho_{A\Delta},\ \rho_{B\Delta},\ \rho_{AL},\ \rho_{BL}\ (*).$$

The basis of the method of analysis and the method of measurement and calculation of these values as used in this case is described in earlier papers [3, 4].

The performance time (AC or DP) was 30-100 sec, i.e., it consisted of several 5-8 sec intervals. For each performance of the activity there was thus a corresponding table with rows of (*); the number of these rows was equal to the number of 5-8 sec intervals. By combining the values of all corresponding columns for all performances of a particular activity and for all subjects, unidimensional histograms were constructed for AC and DP separately.

These histograms were found to contain insufficient information for correct conclusions to be drawn either by Wald's homogeneous procedure of probability ratio for each criterion separately, or by a heterogeneous sequential procedure using all characteristics. Assessment of two-dimensional probability densities for values of statics belonging to different columns, however, revealed pairs which appear sufficiently informative for the solution to the problem. The information contained in a pair of statistics $(\bar{A}, \rho_{AB})$ $(\bar{L}, \Delta)$, (ρ_{AB}, ρ_{AV}), (ρ_{AB}, ρ_{VL}) and so on will be called the two-dimensional characteristic. In this paper only the characteristic (ρ_{AB}, ρ_{VL}), which has the greatest informativeness for separation of AC and DP, will be considered.

The informativeness of 1- and 2-dimensional characteristics was measured by the Kullback–Wald interval [5].

Construction of the discriminant table. The algorithm of separation was based on tests of the probability ratio. The necessary estimates of two-dimensional probability density were obtained initially for a group of 10 persons in which the various patterns of background and evoked EEG were represented. Twenty performances of AC gave 102 points (ρ_{AB}, ρ_{VL}), forming a set M on a plane surface, and 14 performances of DP gave 77 points (ρ_{AB}, ρ_{VL}) giving a set N. The line intersection of M and N contained many points, but they could be combined together by subdividing them into sub-sets, in nearly all of which points of one of the sets—M or N—were definitely predominant. All the planes were subdivided into regions containing such sub-sets. After experimental variation of the different subdivisions, it was found that 7 regions were sufficient: σ_1, σ_2, σ_3, σ_4, σ_5, σ_6, σ_7.

If m_i points from the set M and n_i points from the set N fell in the region σ_i (i = 1, 2, 3, 4, 5, 6, 7), then

$$\lambda_i = \lg \frac{p_i}{q_i},$$

where $P_i = \frac{m_i}{102}$ and $q_i = \frac{n_i}{77}$ measure the degree of this predominance.

The result of subdivision into sub-sets and corresponding logarithms of the probability ratios are given in Table 1, which is called a discriminant (diagnostic) table.

Because of the limited amount of material, a precise line could not be drawn between the regions. Parts of the plane where points of sets M and N were absent are shown in Table 1 by double shading and are classified as boundaries between the corresponding regions.

Rule for solution. Suppose that in the course of performance of the activity pairs of values of characteristics ρ_{AB} and ρ_{VL} appeared, represented by the points $R_1 = R_1$ (ρ_{AB}, ρ_{VL}), $R_2 = R_2$ (ρ_{AB}, ρ_{VL}) . . . $R_s = R_s$ (ρ_{AB}, ρ_{VL}). This can be compared with the corresponding sequence of numbers μ_1, μ_2, μ_3. . . . μ_s, which can be defined as follows: if a point R_j, when j = 1, 2, 3. . . . . s, belongs to region σ_i, where i = 1, 2, 3, 4, 5, 6, or 7, let $\mu_j = \lambda_i$. If, on the other hand, R_j belongs to the boundary between regions σ_{i_1} and σ_{i_2}, then

$$\mu_j = \frac{\lambda_{i_1} + \lambda_{i_2}}{2}.$$

Two rules for solution were used in the classification. Rule A: sequential analysis of Wald's probability ratios [6] with thresholds −1.28 and 1.28, corresponding to errors of classification $\alpha = \beta = 0.05$. Rule B: if the available information is insufficient for reaching a decision by means of rule A, the two thresholds are replaced by one, namely zero. If, therefore, $\sum^{s}\mu_j > 0$ the decision is taken that the EEG corresponds to performance of AC, but if, on the other hand, $\sum^{s}\mu_j < 0$, then it corresponds to DP.

The results of discrimination for a training group, i.e., for a group of persons whose EEGs were used as material for compiling the diagnostic table (Table 1), are given in Table 2 (use of Rule A is shown in parentheses).

For this group, rule A gives the correct discrimination in 27 of 34 performances, including all 14 performances of DP. A mistake was made in only one case. The use of rule B in the remaining 6 indefinite answers gave one fresh mistake. Both mistakes were made in persons whose EEG had a stable α-rhythm.

For the new group of persons (control group) the results of classification were somewhat worse (Table 3).

It follows from Tables 2 and 3 that the results of discrimination of AC were slightly worse than those of DP. In earlier investigations [2, 3], in which different information was used—the distribution of durations of ascending and descending phases of the EEG, enabling AC and DP to be differentiated only for a particular subject (or a small group of persons having similar distributions),—it was found, on the contrary, that the diagnosis of AC was more precise. This contradiction can be understood if it is assumed that the AC algorhythm for one person is more definite than the DP, in view of possible differences in the meaning of visual images and in the emotional background arising during their presentation. On the other hand, for a group of persons a load placed on the visual system, associated with DP, gives rise to more stable changes in the characteristics examined in parieto-occipital recordings of the EEG than does AC, performance of which is more indivudalized in different persons.

On the whole, it can be concluded from the results of the procedure as described—60 correct answers in 66 cases (91%)—are convincing evidence of coding of neurophysiological processes in the EEG which participate in the organization of mental work.

LITERATURE CITED

1. A. A. Genkin, Vopr. Psikhol., No. 6, 114 (1961).
2. A. A. Genkin, Dokl. Akad. Ped. Nauk. RSFSR, No. 6, 117 (1962).
3. A. A. Genkin, Duration of Ascending and Descending Phases of the Electroencephalogram as a Source of Information About Neurophysiological Processes, Candidate's Dissertation, Leningrad (1964).
4. A. A. Genkin, in: Mathematical Analysis of Electrical Phenomena of the Brain [in Russian], Moscow (1965), p. 72.
5. S. Kullback, Information Theory and Statistics, New York (1959).
6. A. Wald, Sequential Analysis, Wiley.