Measuring-off of Time Intervals: Correlations Between Peculiarities of Their Estimation and Parameters of EEG Phenomena, and Influence of the Subjects' Personality Features

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Neirofiziologiya/Neurophysiology, Vol. 34, No. 6, pp. 451-461, November-December, 2002.

Received August 20, 2002.

In 76 healthy persons (right-handed men and women), we recorded background EEG and event-related potentials from the C3 and C4 sites; tests were performed within the framework of an experimental situation requiring internal measuring-off of the time intervals. To limit the interval, the tested person had to push a button; he/she did not know the precise value of the interval, which was preset by the experimenter, and was informed only of the lower and upper limits of this interval, 17 to 23 sec. The person obtained information about the coincidence/noncoincidence of the measured-off and preset intervals via visual feedback; the respective signal was presented 2 sec after measuring-off had been completed. In the case where the intervals coincided with each other, the person should confirm this by pushing the button next time (confirming push). We characterized the parameters of the measured-off time interval by the following indices: (i) measuring-off efficacy (accuracy of fitting the preset interval), (ii) estimation tendency (measured-off interval/preset standard interval ratio), and (iii) coefficient of variation (CV) of the measured-off interval. Features of the subject's personality were estimated using Eysenck's (PEN) and Cattell's (16PF) questionnaires. We found correlations of the powers of the background EEG rhythms (beta1, beta2, and alpha/theta ratio) and characteristics of the measured-off time interval. In addition, we observed significant positive correlations between the estimation tendency and "extraversion" index and between CV of the interval and "urge toward domination" and "protension" indices. Negative correlations were observed between the measuring-off efficacy and "protension" (suspiciousness), between the estimation tendency and "anxiety," and between the CV of the interval and age of the subjects. We support the conclusion that correlations between the patterns of EEG potentials, peculiarities of measuring-off of the time interval, and psychological features of the personality are to a noticeable extent mediated by the individual specificity of the neurodynamics.

Keywords: measuring-off of time intervals, electroencephalogram, event-related EEG potentials, psychological features of personality.

INTRODUCTION

In humans, perception of the time interval duration is the most important component in the temporal organization of vital functions. It has been hypothesized that time-setting reactions in the CNS are controlled mostly by cholinergic brain structures, temporal prediction is provided predominantly by dopaminergic systems, while aftereffects accompanying these reactions are related to the activity of GABA-ergic systems [1]. Acetylcholine neurotransmission is involved in transformation of the durations measured by an internal "clock" of the organism into values stored in the temporal memory [2]. Most brain structures involved in measuring-off of the time intervals are components of the hippocampal circle [3]. Among possible physiological phenomena underlying the intrinsic control of time-related behavior, the heart rhythm, alpha rhythm of EEG, theta activity in the hippocampus, negative fluctuations of slow brain potentials, and muscle sensations have been proposed [4]. Thus, there is no generally accepted viewpoint in this aspect. It cannot be ruled out that several of the above-mentioned factors can be involved in the measuring-off of the time intervals. It is supposed ([5], p. 135) that "... the brain, by

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functioning as a clock mechanism, measures flow of the time perceived by the individual using a step equal to its own value of the 'actual present.' "

Analysis of EEG potentials is one of the promising approaches in the studies of temporal perception and estimation of the time intervals. In this case, we should take into account that estimation of time intervals by a subject is inevitably related to changes in the levels of activation and attention [6]. Modifications of the current EEG and generation of event-related EEG potentials (ERP) are objective manifestations of processes of local activation of the brain; different specific phenomena (both external and internal) can be considered events in this context. A number of authors have demonstrated that such ERP can reflect functioning of brain structures related to the perception processes, processes of formation of motor acts, formation of realized and unrealized conditioned reflex connections, and selective attention, as well as dysfunctions of the above brain structures related to disorders in higher mental functions. In this respect, special attention is paid to such ERP as the readiness potential (RP), contingent negative variation (CNV), and P300 potential [7-9].

Despite evident progress in the studies of different aspects of the above-mentioned problem, questions on correlation of the EEG indices with individual psychophysiological peculiarities of personal time perception and reproduction of the time intervals by a subject still remain insufficiently studied, and the respective publications are scarce. In general, it was shown that the parameters of EEG activity (power and frequency of oscillations of background EEG and amplitude of some ERP components) show a certain relationship with the specificities of time measuring-off [6]. It was mentioned that individuals reproducing longer time intervals, as compared with the standard values (i.e., those who underestimate time), are characterized, as a rule, by a low level of activation (well-expressed alpha rhythm in the occipital recordings and a low power of the rolandic rhythm in the frontal recordings) [10]. The mean frequency of the alpha rhythm in the occipital and right frontal recordings was demonstrated to correlate with the duration of the measured-off minute-range intervals [11]. It was also shown that the character of motivation affects the accuracy of reproduction of the time interval. Introduction of a nociceptive punishment (unpleasant sensation after electrical stimulation) and the possibility to avoid it (defensive reaction) dramatically intensify depression of the alpha rhythm in the situation of estimation of the time interval and influence the accuracy of such estimation [12].

It was also noted that the role of psychophysiological features of personality in the perception of time still remains to a considerable extent obscure because of differences in the experimental approaches used [13]. The problem of estimation and reproduction of the time intervals is being studied mostly on a phenomenological level; techniques allowing experimenters to obtain absolute and relative estimates of reproduction, production, and comparison of such intervals are used in the respective studies [14]. The technique of measuring-off of the time intervals [5] (frequently called the technique of production of such intervals [14]), where the tested subject is asked to reproduce within definite temporal limits the interval duration determined by a descriptive instruction of the experimenter, is believed to be one of the most adequate techniques.

Our study was aimed at determining possible correlations between the peculiarities of estimation of the time intervals (using the technique of measuring-off), parameters of EEG potentials recorded in this experimental situation, and psychological characteristics of personalities of the tested subjects.

METHODS

Seventy-six subjects (right-handed, 21 men and 55 women, 19 to 35 years old) were involved in the tests. We recorded and analyzed background EEG and ERP using a computerized electroencephalographic set and routine techniques. The EEG potentials were recorded monopolarly from the C3 and C4 sites (according to the 10-20 international system), which corresponds to the projections of central regions of the associative cortex. Recording of EEG from these points is believed to allow experimenters to adequately detect the dominating EEG rhythms [15]. Standard Ag-AgCl electrodes were used; electrodes positioned above the *processes mastoidei* and connected with each other served as a reference electrode. An amplifier with a standard frequency band was used for background EEG recording: the upper limit of the frequency range was 70 Hz, and the time constant determining the lower limit was 0.3 sec. To record ERP, channels of the amplifier were modified to provide a time constant of 10 sec. The digitizing frequency was 100 sec^{-1}.

When we recorded ERP under conditions of internal time measuring-off, we used an experimental scheme based on a modification of the known paradigm [16], which allowed us to analyze the parameters of time intervals. The subject was in a dark shielded chamber, sitting in a convenient armchair. He/she had to perform a simple voluntary movement, to push a button by the index finger of the right hand in a voluntarily chosen time moment and, after this, to begin internal counting of the time interval. The precise value of the latter was not initially known to the tested subject; he/she was only told that this interval is within a 20 ± 3 sec range. A start push of the button provided generation of a synchroimpulse for ERP storage. When the subject finished measuring-off of a correct (according to his subjective opinion) interval, he/she pushed the button next time (a finishing push). The subject was preliminarily informed that if measuring-off of the interval is correct (± 5%), he/she will obtain the respective feedback signal produced by the computer and should perform the third confirming push. Such a situation provided a stable high level of attention throughout the entire testing period and a high level of uncertainty (at least within the beginning phase of the tests).

When analyzing the EEG, we considered the following frequency ranges of oscillations (Fig. 1B): 1-4, 4-8, 8-14, 14-25, and 25-30 Hz (delta, theta, alpha, beta1, and beta2 rhythms, respectively). Over a single experiment, we recorded EEG segments allowing us to obtain 40 power spectra for left- and right-hemisphere records (20 samples for closed and 20 for open eyes). An analyzed epoch for plotting one spectrum was 2.56 sec long.

Within the framework of our experimental situation, several endogenous ERP were generated. Before the finishing push of the button (as well before the initial push), an RP was generated. Before the feedback signal and the third, confirming push of the button (if necessary), we observed a CNV, and after the feedback signal, a P300 potential appeared (Fig. 1C). The P300 wave looked, as a rule, like a high-amplitude positive fluctuation generated 250-550 msec after the feedback signal had been presented [6]. The latency of the P300 wave was measured from the moment of beginning of the latter signal to the peak of this potential.

We measured the following indices of the measured time interval: (i) measuring-off efficacy calculated as a normalized number of successful hits within the limits of the preset time interval, %; the total number of trials was taken as 100%; (ii) estimation tendency, i.e., the mean time between two pushes of the button normalized with respect to the preset time interval, %; and (iii) coefficient of variation (CV) of the time interval between the pushes.

In the course of analysis, we calculated averaged integral values of the amplitude of the RP related to the finishing push and that of CNV (means of the current amplitudes of these waves measured every 10 msec). Zero level was determined as the mean value of the potential 1.5-2.0 sec before the second (finishing) push of the button. The amplitude of P300 was measured in a similar way, but in this case we took the average level of the potential 200 msec before switching-on of the feedback signal. Other details of the technique were described earlier [9].

Psychological characterization of the tested subjects was performed using Eysenck's PEN and Cattell's 16PF questionnaires.

Numerical data were quantitatively processed using Statistica software.

RESULTS AND DISCUSSION

A general pattern of the current (background) EEG and ERP recorded in our experimental situation is illustrated by Fig. 1. Averaged parameters and extreme values of the powers of EEG frequency components and amplitudes of ERP components recorded during realization of the experimental task (measuring-off of the time interval) are presented in Table 1. We should mention that we found no significant differences between the studied indices of EEG potentials for men and women; therefore, experimental data were analyzed for the entire studied group.

To find the presence or absence of correlations between indices of the measured time interval, powers of the EEG rhythms, parameters of the ERP components, and psychological personality features of the tested subjects, we calculated Spearman's coefficients of range correlation, r, between these indices. The results are presented in Tables 2 and 3.

We found significant positive correlation between the alpha/theta ratio in EEG recorded from the right hemisphere and the efficacy of measuring-off of the time interval (we have mentioned that the latter value was calculated as a normalized number of hits within the preset standard time interval) ($r = -0.27$ at $\rho = 0.021$). As Fig. 2 shows, subjects more successfully measured time intervals when the alpha rhythm dominated in their current background EEG, as compared with the cases of domination of the theta rhythm. This fact may be related to the well-known statement that clear expression of the alpha rhythm in the resting state is an EEG manifestation of the optimum balance between the main nervous processes [17].

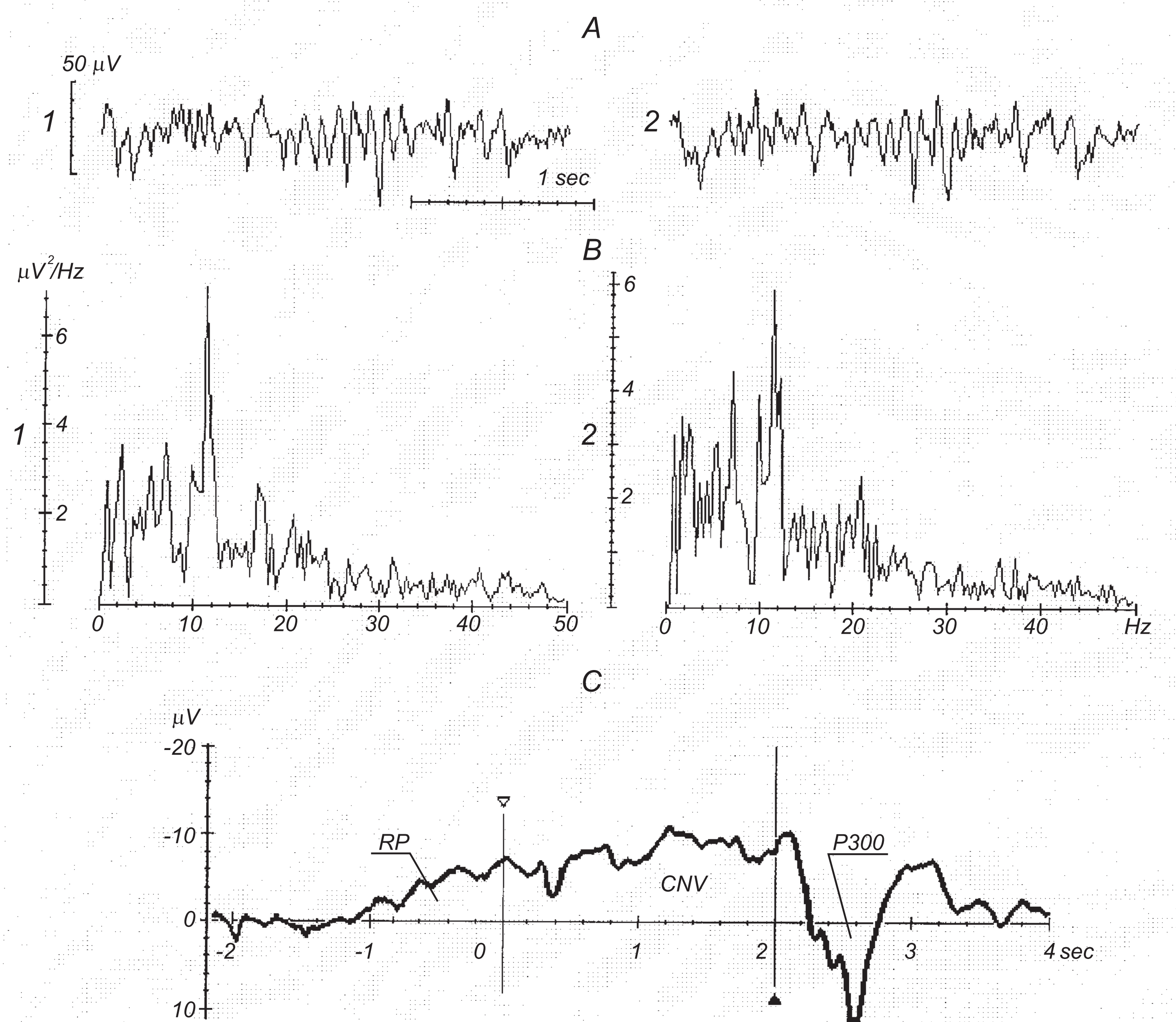

Fig. 1. An example of the background EEG and event-related potentials (ERP) generated in the experimental situation requiring measuring-off of the time intervals. A) Segments of EEG recorded in the resting state (with the eyes closed) from sites C3 and C4 (1 and 2, left and right hemisphere, respectively). B) The respective EEG frequency spectra. Abscissa) Frequency, Hz; ordinate) spectral power, μV^2/Hz. C) Complex of ERP accompanying measuring-off of the time intervals. Open arrow indicates the moment of push of the button; filled arrow indicates presentation of the feedback signal. RP is the readiness potential, CNV is the contingent negative variation, and P300 is the late positive wave.

We also found negative correlation of the power of the beta1 rhythm in the left hemisphere with the CV of the time between pushes of the button, which limited the produced interval (r = –0.27 at ρ = 0.021). In other words, when the beta1 EEG rhythm is well expressed, the subjects measure off the time interval with smaller variations of the values (more stably).

The expression of the beta2 rhythm in both hemispheres correlated positively with the estimation tendency for the time interval (r = 0.23 at ρ = 0.047 and r = 0.26 at ρ = 0.025 for the left and right hemispheres, respectively). It is obvious that if the mean time between pushes of the button (estimation tendency) exceeded the preset standard time interval, the subject underestimated the produced interval, and his “personal time flow” was relatively slower. These data to a certain extent contradict widespread concepts on the functional role of the beta2 rhythm. Many investigators assumed the presence of a direct relation between the expression and intensification of the beta2 rhythm in the EEG and the generalized activating influences on the cortex coming from the brainstem reticular formation (which, naturally, is reflected in the general level of mental activity in humans) [18]. The spectral power of the beta2 frequencies in the frontal cortical regions was shown to correlate with the dynamic characteristics of the behavioral activity (such as the individual rate and diversity of the behavioral acts); it is obvious that these characteristics can demonstrate certain relations with such typological property of a personality as lability of his/her nervous activity (the feature characterizing rates of initiation and termination of the nervous processes) [19]. It seems logical that the higher the level of activation, the stronger the excitation process and the later termination of an actualized (taken from memory) standard of the time interval occurs [6].

Considering that the beta2 rhythm of the background EEG correlates with the characteristics of the produced time interval, we believe that this frequency component of EEG may be related to the process of mobilization of an internal standard of the time interval. The fact that such correlation is more intimate for the beta2 rhythm in the right hemisphere can be considered proof of the hypothesis that mechanisms of estimation of the time intervals (in particular, those of a relatively long range) are localized just in the right brain hemisphere.

TABLE 1. Mean Intragroup Values of the Spectral Power (μV^2/Hz) of the Background EEG Frequency Ranges and Amplitudes of the Readiness Potential (RP), Contingent Negative Variation (CNV), and P300 Potential (μV) Recorded in the Experimental Situation Requiring Measuring-Off of the Time Intervals

EEG frequency ranges and components of event-related potentials	Mean ± s.e.m.	Minimum	Maximum
$Delta_s$	6.88 ± 0.28	1.78	18.89
$Delta_d$	6.94 ± 0.24	1.93	14.94
$Theta_s$	5.95 ± 0.31	1.48	18.39
$Theta_d$	5.90 ± 0.30	1.43	17.11
$Alpha_s$	15.76 ± 1.12	2.11	52.19
$Alpha_d$	16.01 ± 1.08	2.34	49.82
$Beta1_s$	1.68 ± 0.08	0.37	4.95
$Beta1_d$	1.74 ± 0.09	0.25	4.71
$Beta2_s$	0.66 ± 0.04	0.13	2.71
$Beta2_d$	0.64 ± 0.03	0.14	2.13
RP_s	–4.03 ± 0.56	–17.34	7.73
RP_d	–3.37 ± 0.52	–14.77	6.49
CNV_s	–1.56 ± 1.08	–25.01	24.69
CNV_d	–2.33 ± 0.97	–21.95	19.42
$P300_s$	17.00 ± 0.65	5.29	33.75
$P300_d$	17.23 ± 0.65	6.06	34.44

Footnote. Subscripts “s” and “d” indicate the potentials recorded from the left and right hemispheres, respectively.

The right-side asymmetry of the amplitudes of the CNV and P300 in our situation with measuring-off of the time intervals (Table 1) can be another proof of such a statement [9].

We believe that brain hemispheres are in a dissimilar manner involved in the process of formation of temporal relations and creation of standards for the time intervals. It was reported that persons with a lower alpha index in the left hemisphere and a higher alpha index in the right one, i.e., subjects with domination of the left hemisphere, measure off intervals of about 0.5 sec more accurately. At the same time, longer intervals (2-12 sec) are measured off more accurately by subjects with right-hemisphere domination [20]. In the cases of subjective underestimation of the time intervals, the characteristic EEG frequency (position of the maximum in the power spectrum) is lower in the right hemisphere, as compared with the left one, while the above relation is opposite in the cases of correct estimation of the time intervals or overestimation of the latter [21].

Therefore, interrelations between the indices of the produced time interval, on the one hand, and spectrum power of the beta2 rhythm and alpha/theta spectral power ratio in the background EEG, on the other hand, can be an indication that neuronal mechanisms responsible for generation of the high-frequency beta and alpha rhythms are most actively involved in the processes of measuring-off of the time intervals.

There are different viewpoints on the content of the informational process underlying repro-

TABLE 2. Correlations between Indices of Background EEG and Parameters of the Produced Time Intervals in the Tested Group of Subjects

EEG frequency ranges	Coefficients of correlation		
	efficacy of measuring-off of the time interval	coefficient of variation of the time interval	estimation tendency for the time interval
$Delta_s$	0.07	–0.02	0.07
$Delta_d$	–0.06	0.14	0.17
$Theta_s$	0.004	0.10	0.05
$Theta_d$	–0.09	0.10	0.09
$Alpha_s$	0.15	–0.01	0.16
$Alpha_d$	0.05	–0.01	0.18
$Beta1_s$	0.21	–0.27*	0.17
$Beta1_d$	0.20	–0.13	0.14
$Beta2_s$	0.18	–0.21	0.23*
$Beta2_d$	0.20	–0.20	0.26*
$Alpha/theta_s$	0.22	–0.13	0.16
$Alpha/theta_d$	0.27*	–0.19	0.17

Footnotes. Cases of significance of the coefficients of correlation ($P > 0.95$) are shown by asterisks. Other designations are similar to those in Table 1.

TABLE 3. Correlations between Parameters of the Produced Time Intervals, Indices of Psychological Characterization of the Personality, and Age of the Tested Subjects

Indices	Coefficients of correlation		
	efficacy of measuring-off of the time interval	coefficient of variation of the time interval	estimation tendency for the time interval
Extraversion (by Eysenck)	–0.03	–0.01	0.24*
Factor E “domination” (by Cattell)	–0.20	0.32**	–0.01
Factor L “protension” (by Cattell)	–0.32**	0.35**	0.08
Factor Q2 “anxiety” (by Cattell)	–0.11	0.20	–0.27*
Age	0.04	–0.29*	–0.02

Footnotes. Two asterisks show the cases of significance of the coefficients of correlation with $P > 0.99$. Other designations are similar to those in Table 2.

duction of a preset time interval. According to one concept, reproduction of the interval is related to impression of its duration limited by external signals, while according to another viewpoint, this reproduction is based on estimation of the measured-off interval using internal temporal standards pre-existing in the nervous system. According to the third interpretation, reproduction of the interval can be realized using either the former or the latter principle, depending on the duration of the interval [6].

Under conditions of our experiments, integral activation of brain neuronal systems should be composed of components determined by the necessity, on the one hand, to measure-off the time interval and, on the other hand, to process the feedback signal. In our tests, correlations of the ERP amplitude parameters with the indices of the produced time interval did not reach significance levels, whereas in some reports it was mentioned that the individual variability of the CNV and P300 wave practically coincided with the variability of determination of the time interval [6]. We can only state that the efficacy of counting-off of the time interval was related to a certain extent to the expression of the RP and P300 wave (Fig. 3); nonetheless, individual variability of the respective values was so high that the coefficients of correlation were below the significance level. As can be seen in Fig. 3, subjects demonstrating an ERP complex, which simultaneously included a well-expressed negative RP and a "most positive" P300 wave, demonstrated the highest efficacy of measuring-off of the time segments.

Other authors also emphasized the existence of some relations between certain types of behavioral activity and generation of high-amplitude negative RP. It was reported that the tested subjects successfully and more rapidly performed the test task in the case of generation of intensive negative RP, while incorrect performances were preceded by low-amplitude negative or even positive RP [22]. As to the P300

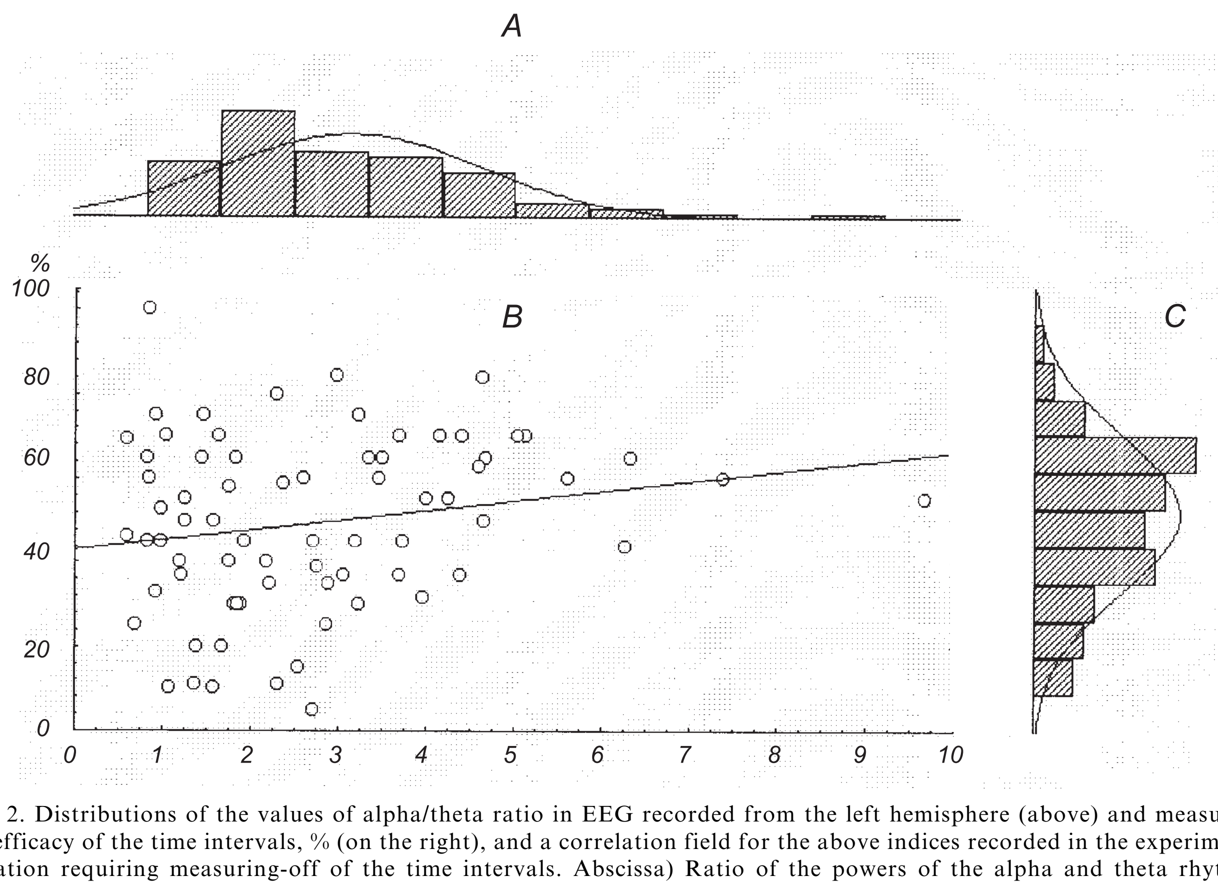

Fig. 2. Distributions of the values of alpha/theta ratio in EEG recorded from the left hemisphere (above) and measuring-off efficacy of the time intervals, % (on the right), and a correlation field for the above indices recorded in the experimental situation requiring measuring-off of the time intervals. Abscissa) Ratio of the powers of the alpha and theta rhythms; ordinate) measuring-off efficacy, %; the regression line is also shown. Thin lines on the histograms show approximation of the experimental distributions by Gaussians.

wave, its generation is assumed to be related to the distribution of the attention resources with respect to the stimulus, to the processes of coming to a decision, and also to cognitive processes and memory actualization [23]. The amplitude characteristics of this wave probably correlate mostly with the level of difficulty of solving a concrete task, but not with the peculiarities of determination of the temporal parameters [6].

As can be seen in Table 3, the efficacy of measuring-off of the time interval was greater in subjects with low values of the L factor (protension, or suspiciousness) of Cattell's questionnaire (r = –0.32 at ρ = 0.005). The CV also correlated with the L factor, but positively (r = 0.35 at ρ = 0.002), i.e., persons with high values of the L factor demonstrated greater variability of estimates of the time interval. At one time, Cattell hypothesized that high values of the above factor indicate that suspiciousness is a mechanism defending the personality from sensations of anxiety, i.e., such a situation is a form of compensatory behavior [24].

The CV of the time interval also positively correlated with the E factor value (independence, domination, aggression, obstinacy, self-confidence) of the Cattell's questionnaire (r = 0.32 at ρ = 0.006). It is believed that when a rigid temporal framework of the action is preset, a subject can successfully fit the respective limits either by increasing the general level of CNS activation (increased attention), or through successful learning. High values of the E factor probably interfere with rapid involvement of the person in the complex perceptive activity and the use of an adequate strategy for the solution of one task or another. This situation embarrasses accurate estimation of the time interval; as a result, the CV of the latter is greater, and the mechanism of time estimation demonstrates some instability. We should mention that a few authors reported earlier on the existence of a correlation between the estimation accuracy for 1-min-long time intervals and the E factor of the Cattell's questionnaire [25].

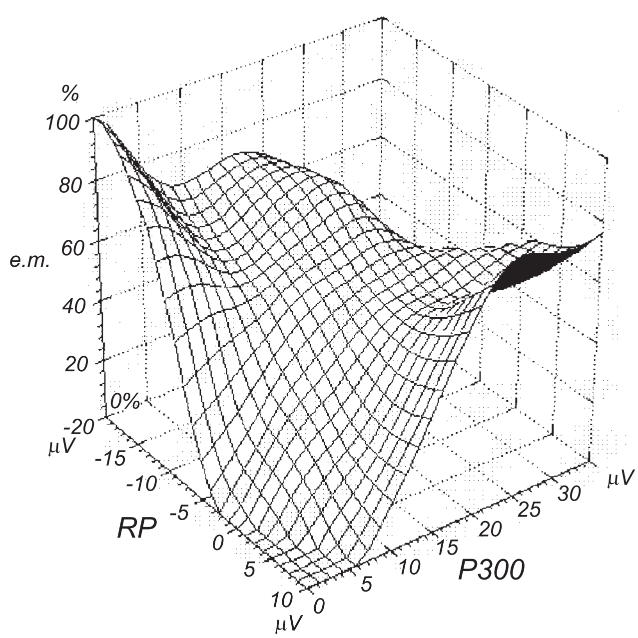

Fig. 3. Correlations between the amplitude of the readiness potentials, RP (recording from the right hemisphere), μV, amplitude of the P300 potential (recording from the left hemisphere), μV, and efficacy of measuring-off (e.m.), %, in the respective experimental situation. The plane of the 3D graph was plotted using a least-squares technique.

We also found a negative correlation of the CV of the produced time interval with the age of the tested subjects (r = –0.29 at ρ = 0.014). Such a dependence shows that the variability of the intervals between limiting motor events (pushes of the button) decreases with age. It seems that the stability of mechanisms of temporal estimation improve with age due to optimization of the balance between excitation and inhibition in the CNS.

The estimation tendency for the time interval correlated positively with the values in the extraversion scale of the PEN (Eysenck's) questionnaire (r = 0.24 at ρ = 0.037). As is known, the accuracy in reproduction of a preset interval and dispersion of the respective values depend on the general intensity of activation of the nervous system (in particular, on the individual level of such activation) [26]. Individuals with a "slow" internal clock (those who underestimate time) are obviously characterized by a relatively low level of CNS activation [10]. In our study, subjects with low values in the extraversion scale (i.e., introverts) overestimated the produced time interval, which can be related to domination of the activatory processes in the CNS of these persons [27]. It was supposed earlier that a temporal increment in the intensity of excitatory processes can play the role of the substrate for time measuring-off by an individual [28].

Many investigators mentioned that the estimation tendency of the time interval depends on the emotional state of the subjects. It was reported that temporal intervals begin to be overestimated with an increase in the anxiety level, while when the above level drops, they are underestimated [29]. In other words, the subjective time flows more rapidly for persons with a high anxiety level. The mechanism of this phenomenon can be based on a stress-related increase in the level of dopamine in the brain, which increases the "rate of motion" of the internal clock [30]. Our data support such a supposition. The estimation tendency of the time interval correlated negatively with the second-order factor Q2 "anxiety" (r = –0.27 at ρ = 0.029) of the Cattell's questionnaire.

Time perception is a complex process, which depends on the experimental situation and individual characteristics of the tested persons. The value of the produced interval depends on the state of the subject's CNS (in particular, on the level of activation), parameters of the motion of his/her "internal clock," and on the acquired experience. Initially, under conditions of an unknown experimental situation and clearly expressed orientation reaction, we observed a high variability of the values of time intervals. Later on, produced intervals were concentrated around the preset standard value (Fig. 4).

Note that the values of correlation coefficients between the parameters analyzed are rather low (they should be considered statistically significant, but, as a rule, they do not exceed 0.3). We think that such a result is not paradoxical but, on the contrary, expected. All indices that we recorded and measured (both parameters of the electrophysiological phenomena and psychological characteristics of the personality) are in each case subjected to a number of extremely variable influences, and, naturally, interrelations between these indices should be manifested only as certain trends but not as rigid dependences.

Therefore, the parameters of the time intervals produced within the framework of our experimental situation correlated significantly with some characteristics of the background EEG and psychological characteristics of the subjects (tested according to Eysenck's PEN and Cattell's 16PF questionnaires). We also observed some,

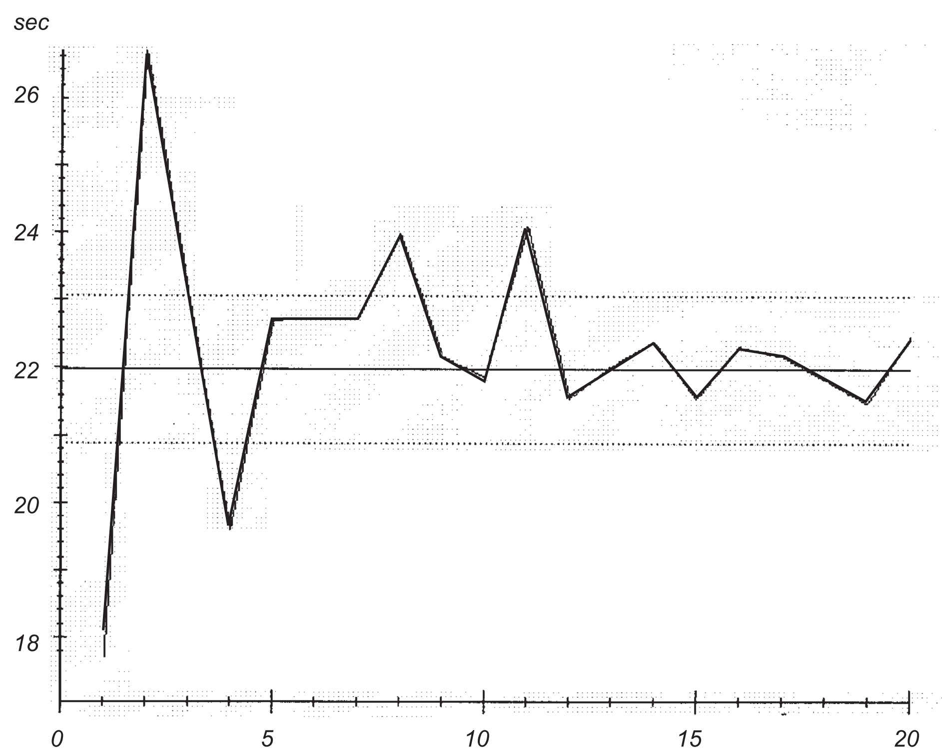

Fig. 4. Variability of the values of the time interval produced by one of the tested subjects. Abscissa) Number of realization; ordinate) value of the time interval, sec. Solid horizontal line shows the standard time interval preset in the experimental series (22 sec); dashed horizontal lines show the band, including acceptable errors (± 5 % of the preset interval).

but weaker, correlations of these parameters with the characteristics of the ERP accompanying realization of the experimental task. These data agree with the general statement that processes of measuring-off of the time intervals and their estimation depend on the individual neurodynamic and psychological characteristics of the person, and that neurodynamic processes play the role of the connecting link in this aspect.

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