

EEG Activity in the Process of Measuring-off of Time Intervals by Humans

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We recorded EEG from sites C3 and C4 in an experimental situation with internal counting-off of a 20-sec-long time interval, whose beginning and end were limited by the tested subject by pushing a button; 65 adult men and women took part in the tests. In the first experimental series, the subject obtained no real information on the accuracy in production of the interval. In the second series, such information was displayed by feedback visual signals. We calculated means of the measured intervals (\bar{t}), coefficient of variation of the realizations (CV), and, in the series with the real feedback, successfulness of measuring-off (normalized number of fits within an acceptable range of the standard interval, 19 to 21 sec). Analysis of the data obtained in the first experimental series for the entire tested group demonstrated the existence of a reverse dependence between the modal frequency of EEG beta rhythm recorded from the left hemisphere in the course of measuring-off of the interval and the \bar{t} value. In the second series, we found significant negative correlation between the beta rhythm power in both hemispheres and CV , that between the alpha rhythm power in the left hemisphere and \bar{t} , and positive correlation between the alpha rhythm frequency in the left hemisphere and successfulness of the interval counting-off. Analysis of the dynamics of EEG of each tested subject demonstrated the existence of mostly reverse dependences between the powers of a few EEG rhythms and duration of the produced interval. We hypothesize that the frequencies of the alpha and beta EEG oscillations play the role of significant indices reflecting the speed of the "internal clock" of the individual. We also emphasize a complex nature and the high individual variability of the EEG pattern in the course of measuring-off of time intervals.

Keywords: electroencephalogram, subjective time, production of time intervals.

INTRODUCTION

Studies of the temporal organization of activity and vital processes in humans are an important aspect of physiology and psychophysiology. Structures of the hippocampal circle, in particular the hippocampus itself, septum, mamillary bodies, and entorhinal cortex, have attracted the attention of investigators dealing with this problem. These structures form the framework of the system that estimates the duration of time intervals. The activity of these structures is responsible for switching on the mechanism of counting off the time that allows one to realize the respective effector reactions [1].

Humans probably do not possess a specific sensory system whose modality can be adapted to perception of

time. This is why subjective estimation of the duration of time intervals is realized based on signals from sensory transducers of other modalities. If we try to discuss the existence of an internal time counter, we should emphasize that this system does not estimate an objective time course but estimates a multitude of subjective time measurements [2, 3]. In addition, the modality of a given signal, whose duration serves as a standard of the time interval, inevitably significantly influences the pattern of measuring-off of such an interval. For instance, under the conditions of alternating presentations of visual and acoustic signals of the same duration the former signals are estimated as shorter compared with acoustic stimuli [4]. It was also shown that evaluation of the duration of visual stimuli is related to activation of the same brain systems that are involved in the analysis of "non-temporal" visual information [5]. In the case where the subject reproduces standard, as to their duration, acoustic signals, EEG activation is also manifested first of all in the temporal cortical regions [6]. If an experimental task includes determination of the moment of initiation

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of a motor act, the readiness potential, which precedes the movement, and the earliest signs of activation are observed in the accessory motor region, and only later on are they manifested in other subregions of the motor cortex [7, 8].

The specificities of spatial/temporal organization of brain potentials in healthy individuals and patients, who perform tasks involving production of time intervals show that subjective time estimation correlates with personality-related features of the brain functional state and pathological modifications of this state [6].

The EEG pattern demonstrates signs of activation in the course of estimation of the time intervals. This is why it seems that we can obtain adequate information on the mechanisms of time perception when analyzing this pattern, [9]. A few publications reported that amplitude and frequency parameters of the alpha activity are interrelated with the accuracy of estimation of the duration of time intervals [9]. This is indicative of some integrity of the neurophysiological mechanisms responsible for the above phenomena and supports the hypothesis of Winer. Winer proposed that the alpha rhythm reflects the activity of an internal biological clock, which realizes the function of strobing the impulses [10, 11]. In our earlier study [12], we showed that the efficacy of counting-off of 17- to 23-sec-long intervals is higher in persons with a greater ratio of the powers of alpha vs theta rhythm in the central regions of the right hemisphere (EEG was recorded in the resting state).

Studies of the above-mentioned topic are not numerous, and their results are in many cases contradictory. For example, some authors believe that the alpha rhythm is a crucial phenomenon responsible for the motion of the internal biological clock [10, 11]. At the same time, experimental results obtained by other authors seem to be indicative of the absence of any dependence between the duration of the produced time interval and the alpha rhythm power [13].

In our study, we tried to evaluate the probable level of involvement of the main EEG rhythms in the process of measuring-off of the preset time intervals within the framework of two experimental paradigms. The latter were based on the use of fundamentally different reference information for estimation of the efficacy of internal time counting-off by the tested subject.

METHODS

Sixty-five subjects (22 men and 43 women, 18 to 47 years old) were involved in the study. We used

standard techniques and a computerized set for EEG recording and analysis. The EEG potentials were recorded from C3 and C4 sites, according to the international 10-20 system. In the course of the tests, the subject was in a darkened shielded chamber, sitting in a soft armchair; a display was positioned 1.5 m in front of him/her. A verbal instruction asked the subject to continuously observe the display screen. The experimental task included repetitive (about 30 trials) measuring-off of a 20-sec-long time interval; the subject limited the latter by two consecutive pushes of a button by the right thumb. We used central EEG recording sites taking in account that the experimental task included motor components.

The tested subject was informed that he/she will be able to obtain computer-produced feedback signals on the monitor, which will inform him/her of the successfulness of the task performance. Yet, within the framework of the first experimental series the subject obtained no real information on the duration of the measured-off time intervals. The signals indicated the correctness of measuring-off, with no dependence on the quality of the performance (accuracy of the estimation). In such a way, we revealed a natural inclination of the individual to overestimate or to underestimate time. In the second experimental series, adequate feedback signals were displayed, and the subject obtained objective information on the accuracy of measuring-off of the produced interval. These signals were indicated by a plus ("overshoot") when the interval was more than 1.0 sec longer than the standard, by a minus ("undershoot") when the interval was more than 1.0 sec shorter, and by a vertical bar ("correct") when the interval was within a 19 to 21 sec range (in other words, a $\pm 5\%$ accuracy of measuring-off was believed satisfactory).

Recording of EEG was begun within the period of measuring-off of the time interval by the subject, 5 sec after he/she pushes the button. The analyzed EEG epoch was 5.12 sec long. In the course of analysis, we calculated the powers and estimated the modal frequencies of the following EEG frequency ranges: 4 to 8 Hz (theta rhythm), 8-14 Hz (alpha rhythm), and 14-30 Hz (beta rhythm). We took into account such characteristics of the time interval as its mean value for all trials of the series, \bar{t} , the coefficient of variation of its duration, CV (in the second experimental series), and, in the second series, the successfulness of counting-off (normalized number of fits within the acceptable range of durations).

Other details of the techniques were described earlier [12].

RESULTS AND DISCUSSION

We should emphasize that we focused on two directions of analysis of the obtained data. The first direction envisaged analysis of the averaged data within the total studied group; we calculated such parameters of the produced intervals as the coefficient of variation of these intervals and the number of fits within the preset standard range (for the series with the presence of real feedback). The second direction included calculation of the correlation matrices of the EEG parameters and counted-off intervals for each tested subject. In such a way, we studied the dynamics of the parameters of EEG activity immediately in the course of measuring-off of the duration by one individual or another.

In the first experimental series, we studied a natural inclination of the tested individual to overestimate or underestimate time intervals in the course of their measuring-off. In other words, the subject itself decided what interval he/she supposes as correct, using some internal, endogenous reference points, with no real via-feedback information on the accuracy of his/her own counting-off. Correlation analysis, by Spearman, revealed a significant ($P = 0.047$) negative correlation ($R = -0.244$) between the modal frequency of the beta rhythm recorded from the central region of the left hemisphere and the mean value of the produced time intervals (Table 1, Fig. 1A).

In this relation, we should mention a special direction in the study of the temporal properties of nervous activity in humans. This direction originated from an idea on the discrete nature of time. An English researcher, Stroud, first proposed such a concept in 1955. In general, this hypothesis suggests the existence of some brain mechanism that measures off time and works with a characteristic frequency of 8 to 10 Hz. This allowed the author to suppose that there is a psychological time unit equal to 50-100 msec; Stroud called this hypothetical unit “a moment.” According to this author, bursts of excitation in the CNS structures, when coinciding in time with critical durations (“moments”), should be most effective. These critical durations are discrete and are limited by successive digressions of a cortical mechanism that realizes “surveying” and “comparing.” It was supposed that this process is manifested in the brain activity as an alpha rhythm. Such a concept also agrees with Winer’s hypothesis on the reflection of the work of the internal biological clock, which functions as a strobing device for the impulses, and this process is reflected in the alpha activity. A unitary “quantum” of psychological

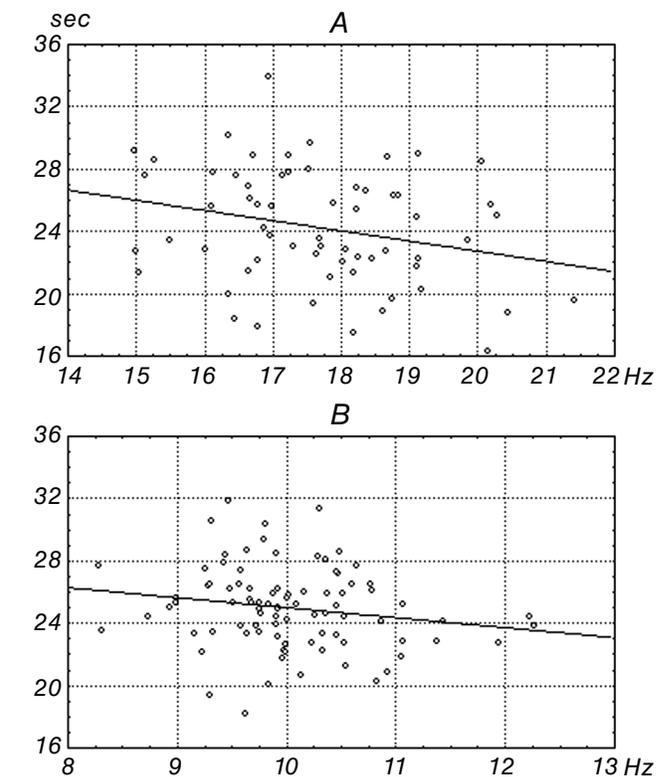


Fig. 1. Correlation fields of modal frequencies of EEG rhythms (abscissa, Hz) vs averaged values of the measured-off duration (ordinate, sec) in the studied group of subjects ($n = 65$). A) For the beta rhythm in the series of tests without informative feedback; B) for the alpha rhythm in the series with such a feedback.

time represents the common divisor; all time intervals observed in the studies of mental processes should be divisible by this value.

It is obvious that our experiments do not support Stroud’s hypothesis on the specific role of the alpha frequency in strobing psychological time. Yet, they allow us to suppose that the beta rhythm can play such a role. In other words, we can assume that a longer duration of the “subjective second” can correspond to a greater period of the beta rhythm (i.e., to a smaller value of its modal frequency); this results in “expansion” of the counted-off interval as a whole.

Such a dependence, however, was found in the second series, with the informative feedback, but for the modal frequency of the alpha rhythm of the EEG activity in the central cortical region of the left hemisphere ($R = -0.204$, $P = 0.049$) (Table 1, Fig. 1B). A process of active search for and estimation of the preset time interval based on reliable information, coming via feedback from outside, probably increases the role of the alpha rhythm in the time measuring-off. In principle, this agrees well with Stroud’s hypothesis, but with the reservation that this mechanism functions

TABLE 1. Coefficients of Correlation between Mean Values of the Measured-Off Intervals (\bar{t}), Coefficients of Variation of the Responses (CV), and Normalized Numbers of Fits within an Acceptable Range of the Interval (%), on the One Hand, and Modal Frequency (F) and Power (P) of the EEG Theta, Alpha, and Beta Rhythms, on the Other Hand

| Series with no feedback | | | | | | | | | | | | |
|-------------------------|-----------------|------------|------------|------------|-----------|-----------|------------------|------------|------------|------------|-----------|-----------|
| Indices | Left hemisphere | | | | | | Right hemisphere | | | | | |
| | F_θ | P_θ | F_α | P_α | F_β | P_β | F_θ | P_θ | F_α | P_α | F_β | P_β |
| \bar{t} | -0.083 | -0.042 | -0.039 | -0.016 | -0.244* | -0.143 | -0.077 | -0.003 | -0.023 | 0.071 | -0.146 | 0.022 |
| CV | -0.029 | -0.063 | 0.080 | -0.060 | -0.101 | 0.015 | -0.014 | -0.106 | 0.040 | -0.092 | -0.122 | -0.050 |
| Series with feedback | | | | | | | | | | | | |
| Indices | Left hemisphere | | | | | | Right hemisphere | | | | | |
| | F_θ | P_θ | F_α | P_α | F_β | P_β | F_θ | P_θ | F_α | P_α | F_β | P_β |
| \bar{t} | 0.073 | -0.100 | -0.204* | -0.010 | -0.047 | -0.197 | 0.060 | -0.004 | -0.154 | 0.098 | -0.127 | 0.001 |
| CV | 0.069 | -0.181 | -0.152 | -0.079 | 0.111 | -0.250* | 0.144 | -0.180 | -0.096 | -0.088 | -0.046 | -0.230* |
| % | -0.052 | 0.066 | 0.274** | 0.420 | -0.104 | 0.194 | -0.173 | 0.073 | 0.180 | 0.076 | -0.045 | 0.154 |

Footnote. One and two asterisks show cases with significant correlation coefficients with $P < 0.05$ and $P < 0.01$, respectively.

only under conditions of active self-regulation of the “temporal” activity of the human brain with the use of external reference points. Thus, in such an experimental situation the duration of the “subjective” second directly correlates with the alpha rhythm frequency in the central region of the left hemisphere.

The successfulness of fitting the preset time interval in the second experimental series also correlated significantly ($P < 0.009$) with the alpha rhythm frequency in the left hemisphere ($R = 0.275$; Table 1). In other words, the subject who displays a higher frequency of the alpha rhythm generally measures off the preset duration most accurately.

In addition, we should mention that the variability of the subjects’ responses correlated negatively with the power of the beta rhythm in both brain hemispheres. The values of the correlation coefficients were -0.250 ($P < 0.018$) and -0.231 ($P < 0.030$) for the left and right hemispheres, respectively. Therefore, those subjects who manifested a higher power of the beta EEG components showed the most “even” responses. The following assumption can be proposed for interpreting this fact. Considering the generally accepted concept that intensification of the beta rhythm corresponds to an excited and strained state of the subject, we believe that there is a more intense effort to control the measured-off duration, and this corresponds to intensification of the beta rhythm. This situation provides a more successful and accurate performance of the experimental task.

We should note that the observed dependences between the inclination to overestimate or underestimate time intervals and the frequency characteris-

tics of the EEG alpha and beta rhythms in the central cortical regions do not always apply to separate individuals (especially so considering that the above values of the correlation coefficients are in general not very high). These dependences, however, probably reflect a general tendency, which is statistically significant for the total human population. Despite the probable variability of the realizations, a certain individual is characterized by a more or less manifested inclination to overestimate or underestimate time segments. Indices of the EEG activity for a given subject in standard situations are also relatively stable. Probably, the vector distribution of EEG frequency indices for the entire population corresponds to a reverse vector of the distribution of values characterizing the rate of flow of subjective time. In other words, a rightward shift along the frequency axis of the indices of alpha and beta rhythms (toward greater values) corresponds to a decrease in the duration of the “subjective” second.

As was mentioned above, we also analyzed the matrices of relations between produced time intervals and frequency/amplitude EEG characteristics for each separate person. In such a way, we studied the interdependences between modal frequencies and powers of the EEG frequency components, on the one hand, and dynamics of the duration measuring-off, on the other hand. This was performed in the presence and absence of information feedback.

In contrast to our expectations, the obtained results were extremely variable. We did not find significant dependences in a number of subjects, while other subjects demonstrated dissimilar and opposite cor-

relations. General patterns of the numbers of calculated positive and negative correlations between the EEG rhythms and measured-off intervals for separate individuals, which were observed in the first and second experimental series, are shown in Fig. 2A and B, respectively.

Despite the above-mentioned heterogeneity of correlations, one can clearly notice that negative correlations between the produced intervals and powers of the EEG rhythms were most frequently observed in the first experimental series. In other words, some general tendency was found. Increases in the powers of the EEG rhythms under study corresponded to a more rapid run of the “internal clock” in humans, i.e., such a shift resulted in shortening of the measured-off interval. At the same time, indices of the powers of various EEG rhythms in separate subjects correlated with the duration of the measured-off time segment in a variable manner.

For example, in a woman of the studied group significant correlations were found between durations of the produced interval and modal frequencies of the theta, alpha, and beta rhythms ($R = -0.350$, $R = -0.430$, and $R = -0.373$, respectively). Figure 3 illustrates the pattern of significant dependences between the values of produced intervals and ratios of the powers of alpha vs beta and alpha vs theta rhythms (A and B, respectively). As can be seen, simultaneous decreases in the powers of the alpha and beta ranges were accompanied by a more or less stable increase in the measured-off duration of the interval. It seems that a “subjective second” expanded due to the arrival of some additional generators of neuronal activity, which was reflected in EEG desynchronization. The observed regularity was less single-valued for the relation between alpha and theta rhythms. With increase in the power of the alpha rhythm, the value of the produced interval could occur rather long both at low and high powers of the theta rhythm. At a high power of the alpha rhythm, the interval noticeably increased if this was accompanied by a rise in the theta rhythm power.

Under conditions of our experimental paradigm, significant correlations with the parameter of the interval were more frequently found for the rhythms of EEG recorded from the central region of the left hemisphere. The high level of involvement of just the left hemisphere in the tasks with measuring-off of the time intervals can be explained by considering the existing information on interhemisphere asymmetry. According to these data [15], a lateralized activation of that hemisphere, which is specialized for a defi-

nite type of cortical activity, develops within separate phases of performance of some integral neural/mental function. The left hemisphere is believed to freely operate with numerical data and mathematical formulas within the framework of formal logic and earlier learned rules [16]. Probably, the process of measuring-off of the time intervals, which consists of successive counting-off of the “subjective seconds,” belongs to just such a type of activity.

The second experimental series was characterized by the EEG pattern recorded from the left hemisphere close to that observed in the first series. Reverse dependences between the produced duration of the interval and amplitude of the beta rhythm were more frequently observed. In addition, a positive correlation between the interval duration and beta-range frequency and a negative correlation between the duration and frequency of the alpha rhythm were observed for the right hemisphere.

A variety of interpretations can be proposed for our results. We believe that neurophysiological mechanisms providing effective functioning of the entire complex of temporal properties of the human brain are formed in the course of ontogenesis under the influ-

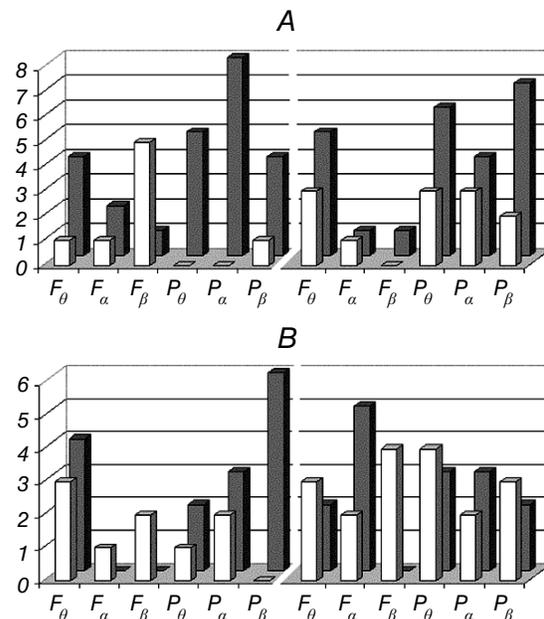


Fig. 2. Existence of significant correlations between the parameters of EEG rhythms and values of the measured-off time intervals in separate persons (existence of intraindividual correlations) within the examined group ($n = 65$). Vertical scale) Number of subjects with statistically significant positive and negative correlations (open and filled columns, respectively) between the modal frequencies (F) and powers (P) of the theta, alpha, and beta rhythms (θ , α , and β , respectively) in EEG recorded from the left and right hemispheres, on the one hand, and the interval duration, on the other hand. A and B) In the absence (A) and presence (B) of informative feedback.

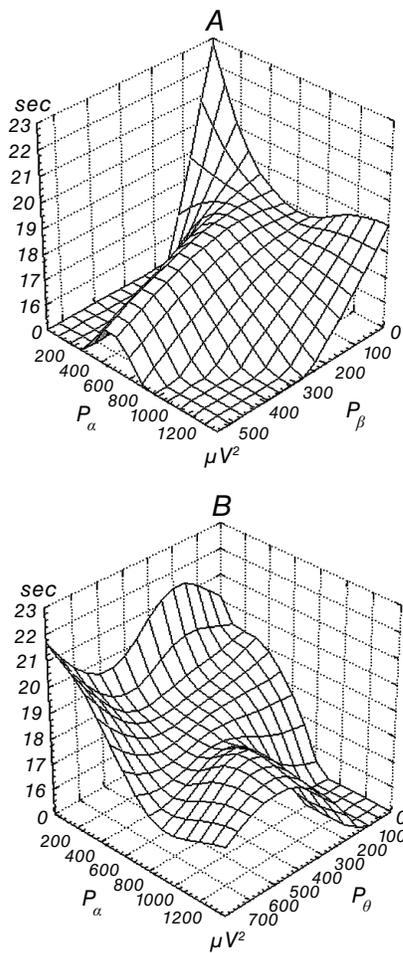


Fig. 3. Interrelations among the powers of EEG rhythms and durations of the measured-off time interval in one of the subjects. A) Interrelations among the power of alpha activity (P_α , μV^2), power of beta activity (P_β , μV^2), and duration of the interval (t , sec); B) those among the powers of alpha and theta activity (P_α and P_θ , μV^2) and duration of the interval (t , sec).

ence of multiple factors, which frequently differ fundamentally from each other. This is why we are faced with a very complex multilevel system of temporal self-regulation, whose activity can be reflected in the EEG pattern in different modes, depending on a number of the additional factors (both internal and external). In particular, our analysis of the EEG pattern shows that electrophysiological mechanisms, which seem to be involved in the operation of the “internal clock” within the framework of two of our experimental situations, differ significantly from each other.

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