

# Individual Typological Features of Subjective Time Scales for Short Time Intervals

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## Abstract

**Introduction:** The present study analyzes the individual characteristics and typology of the basic properties of STS and the bioelectrical phenomena in the brain that arise when solving problems of separate and simultaneous scaling of STI of 5 and 15 sec.

**Methods:** In 40 conventionally healthy subjects of both sexes, the indicators of the average duration of subjective time intervals were assessed. The deviations of the subjective time from the objective time were compared, the stability of these indicators was determined in 5 repeated tests, and the spectral power density of the electroencephalograms recorded in a single system with measurements of time was calculated.

**Results:** The results showed that the STS for 5 sec has a smaller deviation of the subjective time intervals from the objective time and has a greater variability of indicators in repeated tests compared to the STS for 15 sec. With the interaction of STS, the duration of the subjective time increases and approaches the objective one for both scales.

**Conclusion:** We present individual characteristics of the subjects on the basis of cluster analysis of subjective time intervals deviations from the objective time are grouped into 2 psycho-physiological time scaling profiles. The profiles differ in the bioelectrical activity of the brain: The EEG spectral power in the studied frequency range is higher in representatives of the second profile both with separate and simultaneous time scaling.

**Keywords:** Spectral power • Human brain • Interaction of time scales • Time perception

## Highlights

1. STS for 5 and 15 seconds differ in accuracy and resistance to repeated scaling attempts.
2. With the interaction of STS, the deviation of subjective time from the objective time decreases.
3. Psycho-physiological profiles of STI scaling can be singled out.
4. STI scaling profiles differ in the bioelectrical activity of the brain.
5. STI scaling profiles appeared in all the study modes for 5 and 15 seconds.

## Introduction

The ability to assess periods of time that are not tied to circadian rhythms and are much shorter is the highest mental function [1,2]. The cognitive processes of working memory, attention, visual and auditory perception are realized due to psycho-physiological mechanisms associated with assessing Short Time Intervals (STI) [2,3]. Experimental studies reveal that STI processing is related to the peculiarities of choosing effective behavioral strategies [4], to the formation of feedback in behavioral and motor acts [5,6], to motor functions [7-9], and to emotional self-regulation [9,10]. Estimation of STI is necessary for performing a large number of daily activities [2] and therefore is of interest for interdisciplinary studies related to the physiology of sports and to the activity of a human operator [11-13]. Most authors believe that the sense of time is formed as a result

of synchronization of the activity of brain structures which include, for example, the entorhinal cortex and cerebellum [3,14]. The role of cellular and synaptic mechanisms and of genetic factors that determine individual differences in temporal perception [15] is investigated [3,5]. Nevertheless, there is no unified hypothesis about the mechanisms of STI perception [16-18] since a wide range of methodologies, of research paradigms, and the heterogeneity of samples make it difficult to compare and analyze the data obtained. In particular, a key question on the typology and properties of subjective scales for assessing STI remains open.

The Subjective Time Scale (STS) represents a group of mental functions implemented by a person while assessing the duration of events and the time costs necessary both for the actor themselves and for the auxiliary systems used for a particular activity [12,18].

Here, a large number of behavioral decisions are made in time intervals ranging from tens of milliseconds to tens of seconds. The STS for assessing STI are thought to be discreet and to have 8-9 gradations regardless of duration [18]. However, the description of the basic properties of the STS is far from complete and, therefore, these properties are not taken into account when organizing samples of subjects and analyzing the data obtained. According to a number of researchers, this significantly complicates the interpretation of the results obtained and hinders the development of studies of the sense of time [16]. Besides, the issue of the interacting STS that are synchronic when it is necessary to evaluate intervals of various durations has not been studied, although numerous activities require measuring several time periods simultaneously.

Among the proposed approaches to studying the STS properties, attention is drawn to the method for studying the duration of subjective

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time intervals (interval timing) [16]. In this case, the subject measures a time interval of a given duration. The method is used both in experimental psychophysiology and in clinical studies, and is considered sensitive and reproducible [16,18-21]. Its advantage is very accurate measurement of the subjective interval duration and a combination of time measurement and simultaneous registration of functional indicators of the bodily activity [12]. Obviously, the perception of time is based on the periodic processes occurring in the body. The central nervous system, and possibly the heart, is traditionally considered as an internal clock designed to assess STI not tied to circadian rhythms [12,22]. In case of the central nervous system, periodic processes are a proven phenomenon, reflected, for example, on the EEG. Thus, the search for correlates of periodic oscillations of the EEG with STS is promising for a greater insight into this function. However, there are few studies that link functional brain studies and time-sense parameters. In particular, correlations were found between the subjective assessment of time intervals and the bioelectric activity of the brain [21], changes in the amplitude of evoked potentials and EEG rhythms, which, according to most observations, are localized in the area of central and frontal electrodes [16].

Thus, the present research aimed to analyze the properties, individual characteristics and typology of the STS of the subjects when assessing STI in two modes—the scaling mode (assessing one and the same time interval) and the interaction mode (when the subject measures 2 intervals of different duration from the same initial time point). Besides, the phenomena that serve as markers of time intervals scaling (and their manifestation in the interaction mode) were identified based on the data analysis of the brain bioelectrical activity.

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## Methods

40 healthy subjects (22 male boys and 18 female, right-handers) aged 18-19 took part in the study; voluntary informed consent was obtained from all the subjects. None of the participants had a burdened neurological and psychiatric history, used psychoactive substances and/or alcohol, or had complaints at physical or mental condition. The experiments were carried out for one month at the same time of day (11-14 AM-PM). After literature data analysis, the method of interval timing (determining the duration of the time interval) was chosen as sensitive and reproducible, adopted in psychophysiological and clinical studies [12,16,19]. The subjects measured the time intervals in the samples of 5 and 15 seconds by clicking the left mouse button, 5 attempts for each sample.

As mentioned above, the work was carried out in two modes. In the separate scaling mode, the subjects sequentially measured identical intervals of a given duration one after another (Figure 1), while the end of one measured time interval served as the beginning for measuring the next one. In the interaction mode, the subjects measured simultaneously 5 sec and 15 sec from one initial time point. To accomplish the assigned task, the subjects clicked the mouse button twice: After 5 and after 15 subjective seconds from one starting point (Figure 1). The mode received its name because previously performed experiments [23] suggested that STI of different durations can be scaled by different STS. The subjects received no preliminary training and were not allowed to count when measuring the

time either aloud or silently. The experiment determined:

- Average duration of the subjective time intervals;
- Individual characteristics when scaling time (the tendency to under measure or over measure the time in comparison with the objective duration of a given interval);

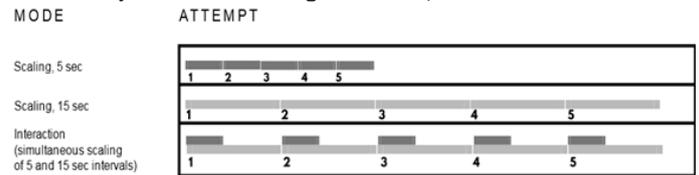


Figure 1. Experiment scheme.

In studying the STS parameters, the subjects' bioelectrical activity of the brain was recorded by EEG with a Neocortex electroencephalograph (Neurobotics LLC, Zelenograd, RF) monopolarly according to the 10-20 scheme in frontal (F3,F4), parietal (P3,P4), temporal (T3,T4), central (C3,C4) and occipital (O1,O2) leads. The EEG was recorded with the notch filter on (50 Hz) and the high and low frequency filters off; the sampling frequency was 1 kHz, and the ADC bit depth was 16 bits. The relatively small number of channels

from which the EEG was recorded was explained by the need to minimize the time for placing the electrodes in order to minimize the subject's fatigue which could potentially affect the STS. Pooled reference electrodes were positioned on the earlobes. EEG recording and interval timing were carried out in a unified technical system: A mouse button click was applied to the EEG as a mark. The time intervals were calculated in ms from the distance between the marks. The spectral density of signals was calculated in the period of 3 seconds after the mark in the frequency ranges of theta rhythm (4 Hz-7 Hz), alpha rhythm (7 Hz-14 Hz), lower and upper beta rhythms (14 Hz -24 Hz and 24 Hz -40 Hz, respectively) after the classical Fourier transform. The results were processed using the STATISTICA v.10.0 and Impulse software packages [24]. To assess the differences between the indicators after a preliminary analysis of the distribution and the effect of multiple comparisons, the following statistical criteria were used: The Wilcoxon signed-rank test, the Friedman test, two-tailed Fisher's exact test, McNemar's test, Kolmogorov-Smirnov two-sample test, and the Mann-Whitney U test (see below). Cluster analysis was performed using the k-means method. Differences were considered significant at  $p < 0.05$ .

## Results and Discussion

The average duration of the subjective time intervals was evaluated under the conditions of separate scaling. For 5 seconds, it was  $4373 \text{ ms} \pm 109 \text{ ms}$ , for 15 seconds— $11996 \text{ ms} \pm 335 \text{ ms}$ . Repeated 5 second scaling tests found differences between individual attempts. The subjective time in the first attempt was the shortest, while in the second and third attempts it was longer (Table 1). The measurement of 15 seconds turned out to be resistant to the number of attempts: there were no differences between their duration.

Modes		Scaling,5 sec	Scaling,15 sec	Interaction,5 sec	Interaction,15 sec
Attempt no	1	4075 ± 232 (3120;4880)	12048 ± 653 (8760;14860)	4786 ± 313 (3300;5480)*	13314 ± 750 (9560;16700)
	2	4439 ± 253 (3420;5520)**	11740 ± 706 (7840;14900)	4934 ± 331 (3460;5880)	13358 ± 788 (9420;16700)***
	3	4462 ± 223 (3460;5580)***	12264 ± 801 (7820;15400)	5051 ± 283 (3800;6040)*	13494 ± 788 (10200;17320)

	4	4342 ± 245 (3200;5180)	11387 ± 777 (7100;15320)	5332 ± 329 (3860;6340)* ***	13631 ± 779 (10280;16680) ***
	5	4532 ± 265 (3340;5540)	12587 ± 825 (8360;16880)	5436 ± 458 (3600;6440)**	13516 ± 822 (9760;17280)

Note: \*: p<0.05; \*\*: p<0.01; \*\*\* : p<0.001

**Table 1.** Duration of subjective time, M ± m (p25%; p75%).

Significance of differences between the 1st attempt and subsequent attempts: "-p<0.01, ""-p<0.001; between the scaling and the interaction mode: \*-p<0.05, \*\*-p<0.01, \*\*\*-p<0.001.

In the interaction mode, when the subjects measured two intervals of different duration from one time point, the average duration of subjective time intervals increased for both 5 sec and 15 sec (p<0.001). For 5 sec, it was 5108 ms ± 155 ms, for 15 seconds–13463 ms ± 348 ms. In repeated scaling tests of 5 seconds, the same as in the scaling mode, differences were found between individual attempts. The subjective time was lengthened from the first to the fifth attempt (Table 1). The 15-second scale proved to be resistant to the number of attempts: no differences were

found between their duration. Thus, in the interaction mode, the subjects showed a tendency to lengthen the subjective time which was approximate to the objective values. The 15 second scale was resistant to the number of attempts, as in the scaling mode.

Next, the individual characteristics of assessing the STI duration were studied; it was found that when working in the scaling mode, some subjects measured the specified intervals as longer than the objective time (over measured the time). Others measured the given intervals as shorter (under measured the time) (Table 2). Studying these features in repeated tests revealed their resistance to the number of attempts: In most cases, the subjects similarly measured the time both in the first and fifth attempts.

5 <sup>th</sup> attempt			
Interval	Attempt	Over measured (ppl)	Under measured (ppl)
5 sec p<0.01	1st attempt	Overmeasured 7	2
		Under measured 6	23
p<0.001	1st attempt	Over measured 8	1
		Under measured 5	23
5 sec p<0.05	1st attempt	Over measured 6	3
		Under measured 3	25
	5th attempt	Over measured 7	5
		Under measured 6	19

**Note:** In the table, p values are calculated for 2x2 tables, highlighted with fill of different intensity.

**Table 2.** Individual features of STS in 5 scaling attempts 5 and 15 seconds in the scaling mode.

A similar phenomenon was observed in the subjects in the interaction mode (Table 2). At the same time, the tendency of a person to under measure or over measure time intervals was most often traced in both modes. Thus, of 29 participants who did not measure 5 seconds in the first attempt of the scaling mode, 20 did not measure it in the interaction mode. Of 30 participants who did not measure 15 seconds in the first attempt of the scaling mode, 22 did not measure it in the interaction mode (p<0.01, Fisher).

The stability of the scaling profile when measuring time intervals of different duration was compared, revealing that in the scaling mode, up to 42% of the subject's measure intervals of 5 and 15 seconds in different directions (Table 2). Differences in the direction of the assessment of STI of 5 and 15 seconds were also found in the interaction mode. Thus, despite some similarities, the characteristics of the scales for 5 and 15 seconds differ.

Previous works show that the criteria for STS in different conditions can be formed in different ways [12]. For example, their properties may depend on the ergonomics of devices with which a person interacts when performing actions [12]. In the present experiment, the STI scaling devices were identical, and the duration of the measured time interval was different. Taking into account the results obtained, it can be assumed that the STS for 5 and 15 seconds belong to the same group of time scales, which,

nevertheless, are modified independently of each other.

The data obtained on the division of subjects according to the tendency to lengthen or shorten the time interval are consistent with the observations of other specialists made in different age groups [20,25,26]. The fact that the subjects demonstrated stable properties of time scales can be explained by the sufficient maturity of the individual characteristics of time perception which are formed after 15 years [20]. Thus, the division of the subjects into those who over measure the time intervals and those who under measure them allows clarifying the population structure of the individual characteristics of the STS.

The deviation of the subjective time intervals from the objective duration was assessed when the subjects worked in the scaling and the interaction modes. For this, the results were normalized: The difference between the duration of the objective time interval in ms (5000 ms,15000 ms) and the subjective time interval was calculated and divided by the value of the corresponding objective interval: (Objective time interval–subjective time interval)/objective time interval. The results obtained (Table 3) showed that in the scaling mode, the subjects measured the interval of 5 seconds with a smaller deviation from the objective value of the interval compared to 15 seconds. The greatest difference was found in the first attempt (Wilcoxon and Friedman). The 15-second scale was more resistant to the number of attempts, and there were no significant differences between attempts when scaling 15 seconds.

Modes		Scaling, 5 sec	Scaling, 15 sec	Interaction, 5 sec	Interaction, 15 sec
Average		0.13 ± 0.02 (-0.08;0.34)	0.20 ± 0.02 (-0.03;0.47) <sup>°°°</sup>	-0.02 ± 0.03 (-0.21;0.28) <sup>***</sup>	0.10 ± 0.02 (-0.12; 0.34) <sup>°°°</sup> <sup>***</sup>
	1	0.19 ± 0.05 (0.02;0.38)	0.2 ± 0.04 (0.01;0.42) <sup>°°</sup>	0.04 ± 0.06 (-0.1;0.34) <sup>**</sup>	0.11 ± 0.05 (-0.11;0.36)
	2	0.11 ± 0.05 (-0.1;0.32) <sup>**</sup>	0.22 ± 0.05 (0.01;0.48) <sup>°°</sup>	0.01 ± 0.06 (-0.18;0.31)	0.11 ± 0.05 (-0.11;0.37) <sup>**</sup> <sup>°°</sup>
Attempt no	3	0.11 ± 0.04 (-0.12;0.31) <sup>***</sup>	0.18 ± 0.05 (-0.03;0.48) <sup>°</sup>	-0.01 ± 0.06 (-0.21;0.24) <sup>•</sup>	0.1 ± 0.05 (-0.15;0.32) <sup>°°</sup>
	4	0.13 ± 0.05 (-0.04;0.36)	0.24 ± 0.05 (-0.02;0.53) <sup>°°</sup>	0.07 ± 0.07 (-0.27;0.23) <sup>***</sup>	0.09 ± 0.05 (-0.11;0.31) <sup>**</sup> <sup>°°°</sup>

Note: •: p<0.05; \*\*: p<0.01; \*\*\*: p<0.001; °: p<0.05; °°: p<0.01; °°°: p<0.001

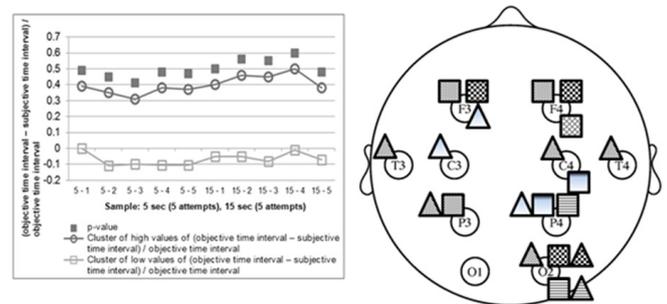
**Table 3.** Values of (objective time interval–subjective time interval)/objective time interval, M ± m (p25%; p75%).

Significance of differences between the 1st attempt and subsequent attempts: °-p<0.01, °°-p<0.001; between samples of 5 and 15 seconds: °-p<0.05, °°-p<0.01, °°°-p<0.001; between scaling and interaction modes: •-p<0.05, \*\*-p<0.01, \*\*\*-p<0.001.

In the interaction mode, the scaling of 5 sec was also closer to the objective time than that of 15 sec. This is evidenced by the lower value of (objective time interval–subjective time interval)/objective time interval (Table 3). At the same time, the scaling accuracy decreased from the first to the fifth. For 15 seconds, no differences were found between attempts in (objective time interval–subjective time interval)/objective time interval. An analysis of the deviation of the subjective time interval from the objective time duration indicates that in the interaction mode, the subjective time approaches the objective one for both 5 and 15 seconds.

To confirm the hypothesis about the different profiles of STI scaling, the values (objective time interval– subjective time interval)/objective time interval of both STS were processed by cluster analysis. The sample was divided into 2 clusters: High and low values of the indicator (objective time interval–subjective time interval)/objective time interval, which were characterized by statistically significant differences (Figure 2A), Mann-Whitney, Kolmogorov-Smirnov. An increase in the number of clusters led to a more detailed picture without revealing new features. The subjects of the cluster of low values of (objective time interval–subjective time interval)/objective time interval (17 people) showed a tendency to over measure the time while being more accurate in its assessment. The subjects of the cluster of high values of (objective time interval–subjective time interval)/objective time interval (17 people) under measured the time while overestimating its duration: Objective time interval<subjective time interval, therefore, (objective time interval–subjective time interval)/objective time interval had negative values. Thus, the results of the cluster analysis confirmed the presence of two profiles of STI scaling.

To analyze brain biorhythm differences in the subjects of both clusters, the spectral density indicators of 4 EEG frequency ranges were calculated and compared. It was found that in the subjects of the cluster of low values (objective time interval–subjective time interval)/objective time interval, the spectral density was higher in all the studied frequency ranges when scaling both time intervals on all the studied channels, with the exception of the left occipital leads (p<0.05) (Figure 2B). An exception was found at the frequency of the upper beta rhythm in the frontal lead on the right: The spectral density in the subjects of the cluster of high values in this lead was higher (objective time interval–subjective time interval)/objective time interval (p<0.05).



**Figure 2.** Clusters of high and low values of objective time interval.

- 5 seconds, theta rhythm; ▲ 15 seconds, theta rhythm;
- ▣ 5 seconds, alpha rhythm; ▲ 15 seconds, alpha rhythm;
- ▤ 5 seconds, beta lower rhythm; ▲ 15 seconds, beta lower rhythm;
- ▥ 5 seconds, beta upper rhythm, clu>cli;
- ▦ 5 seconds, beta upper rhythm; ▲ 15 seconds, beta upper rhythm.

Differences valid: p<0.05

In the interaction mode, the differences in the spectral density between the subjects of the cluster of high and low values (objective time interval–subjective time interval)/objective time interval for the interval of 5 seconds were detected at the frequency of the theta rhythm in leads C3 and T4, and at the frequency of lower and upper beta rhythms in leads T3 and T4, respectively (p<0.05) in the smaller number than in the scaling mode. When scaling 15 seconds, the differences between the clusters in the interaction mode were detected practically as often as in the scaling mode and in a greater number than for the 5 seconds scale. They were recorded at the frequency of theta rhythm in lead C4, alpha rhythm in lead C3, beta lower rhythm in leads O2, C4, T4, and beta upper rhythm in leads O2, C3, C4, T3, T4. At the same time, the subjects of the cluster of low values had higher spectral density than of the cluster of high values (p<0.05).

Today, it is widely believed [2,5,27] that orientation in time and estimation of intervals of various durations are a result of a complex time reflection system operating which is based on rhythmic processes occurring in various structures of the brain. These rhythmic processes have different periods and form a scale of nervous activity, which displays the duration

of the estimated time interval [28]. The experimental data obtained show that the selected time scaling profiles are characterized by different temporal organization of the rhythmic activity of the brain structures. Taking into account the isolated information available in the literature that individual differences in temporal perception can be associated with genetic mechanisms [15,29], the results obtained suggest differences in gene expression in representatives of different time scaling profiles in interval timing tests and ask for further research in this direction.

## Conclusion

The present paper (based on the experimental data obtained by the authors) analyzes the subjective time scales formed during the assessment of short time intervals of 5 and 15 seconds. Typological features of the 5-second STS are the smaller deviation of the subjective time intervals from the objective time duration (greater accuracy) and less resistance to repeated scaling attempts. The 15 second scale is less accurate and more resistant to repeated scaling attempts. A possible reason is the dependence of the STS of 5 sec on internal factors, including fatigue during repeated tests. In the interaction mode with simultaneous measurements of intervals of 5 and 15 seconds from one starting point, the properties of both time scales change: the duration of the subjective time interval increases and approaches the objective value of the time interval. Based on the cluster analysis of subjective time interval deviations from the objective time, the individual characteristics of the subjects when measuring the given intervals can be grouped into 2 psycho-physiological time scaling profiles. The first is characterized by a tendency to under measure intervals and a large deviation from the objective time. The second profile is characterized by a tendency to over measure the time and a more accurate assessment of its duration. The profiles differ in the bioelectrical activity of the brain structures, which is expressed in higher indicators of the spectrum power in the studied frequency range in the representatives of the second profile. Time scaling profiles can be traced both with separate and simultaneous operation of the STS.

The results show that studying the STS parameters is a promising direction in terms of developing additional criteria for assessing and predicting the functional state of an organism.

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