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# N.A. BERNSTEIN HYPOTHESIS IN THE DESCRIPTION OF CHAOTIC DYNAMICS OF INVOLUNTARY MOVEMENTS OF PERSON

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**Abstract.** The features of chaotic dynamics of neuromuscular system parameters (tremor) of two groups of women have been studied using comparative analysis. The registration of tremor was performed in two groups of subjects (15 people in each group) with different physical fitness at rest and at a static load of 300 g. Each subject has been tested 15 times (number of series *N* = 15) in both states (with physical load and without) and each series contained 15 samples (*n* = 15) of tremorogram measurements (500 elements in each sample, registered coordinates $x_1(t)$ of the finger position relative to eddy current sensor) of the finger. Using non-parametric Wilcoxon test of each series of experiment, a pairwise comparison was made forming 15 tables in which the results of calculation of pairwise comparison matrix (15x15) for tremorograms are presented. The dynamics of involuntary micromovements of the limbs (tremor of fingers), with and without static physical loads manifested in the change of the number of “coincidences” of arbitrary pairs of samples (*k*), which (pairs) can be attributed to one general population. In this case, tremorograms showed the global statistical instability of the samples (their statistical distribution functions $f(x)$) as in state of rest and under physical load. The samples obtained in one experiment cannot be arbitrarily repeated in the next experiment (similar to homeostasis). This represents a quantitative measure of Eskov-Zinchenko effect in the analysis of randomly varying statistical distribution functions of samples of tremorograms. The average number of fits of random pairs of samples ($<k>$) and standard deviation σ were calculated for all 15 matrices without load and under the impact of physical load (300 g), which showed an increase almost in twice in the number *k* of pairs of matching samples of tremorograms at conditions of a static load. It was revealed change in number *k* of matches for arbitrary pairs of samples in a resting state for not athletes is 2.93, for athletes is 2.13.

**Key words:** tremor, pairwise comparison matrix, Eskov-Zinchenko effect, chaotic dynamics.

## INTRODUCTION

In 1947, N.A. Bernstein (in 2016, we celebrated 120 anniversary of N.A. Bernstein) presented a hypothesis of “repetition without repetition” in relation with organization any voluntary


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human movement. For the nearly 70 years since the release of his monograph and its transfer to Pergamon Press later [2], we have practically no accurate analytical models describing the dynamic behavior of the tremor (and tremorogram), which some scientists believe involuntary movements. N.A. Bernstein put forward the assertion of coherent structure in the organization of any activity of the neuromuscular system of a person and called for the development of systemic-structural approach to the study of the structure and functions of various systems of movement. It is obvious that it is possible under high differentiation of elements in the study of the diversity of electoral forms of relationship, between them in any movement [11, 13, 15, 17].

Note that the human brain and the motor system solve the challenging task of building a movement for which it is not enough simply counting the number of mechanical degrees of freedom (number of joints and muscles in the hand). Most of the actions are dynamic and require continuous and coordinated work of all elements of the system, which in the end, we will show, working chaotically [28]. In this regard, the relevance of the study one of the fundamental problems of motion control, namely, management of separate parts of the human body from the brain, from the point of view of biomechanical and functional characteristics, is obvious. Then, there is the problem of quantitative description of Eskov-Zinchenko effect [16, 18], in which there is statistical instability of the parameters of motion and who first gave a quantitative confirmation of N.A. Bernstein hypothesis [2, 5, 21, 22, 24, 25, 27], and not only in biomechanics but also in the study of the cardiorespiratory system [8, 10].

Now, it is obvious that the functional state of the human body in terms of performing specific motor tasks is of particular interest in the framework of theory of chaos and selforganization, as the stochastic approach gives a low efficiency in quantitative description of any movement. In our studies, the parameters of a neuromuscular system of the person has are to analyzed, such parameters characterize the change of the parameters of the chaotic neuromuscular system in women when performing regular exercise (when compared with the rest of the population, without physical training). Moreover, with purposeful management of physical activity (in sport), the majority of North of Russia inhabitants can ensure the prolongation of their lives. Objective assessment of neuromuscular system conditions with systematic physical activities requires new data processing techniques and the expansion of diagnostic features, this becomes possible now from the standpoint of the new theory of chaos and selforganization with respect to not only neuromuscular system, but also cardiovascular sysytem [1, 14, 19, 20], and other homeostasis systems [6].

In this report the introduction of traditional and new physical methods in biological research based on the method of multidimensional phase spaces [3, 14] has been presented to study the characteristics of the reaction of neuromuscular system in response to dosed static loads.

Instead of the traditional understanding of stationary regimes of biological systems in the form $dx/dt = 0$, where $x = x(t) = (x_1, x_2, ..., x_n)^T$ is a vector of system state, or when calculating the distribution functions $f(x)$ when the stationary regime requires the immutability of these $f(x)$ obtained for consecutive samples of a parameter $x$, we use the pairwise comparisons matrix of samples [11–15]. These movements are chaotic, i.e. $dx/dt \neq 0$ constantly, i.e. it is almost impossible to obtain two adjacent samples $f_j(x_i(t)) = f_{j+1}(x_i(t))$. In this regard, authors proposed new methods for the calculation of chaotic dynamics of tremor (as alleged involuntary movements) [1, 9, 23, 26, 28].

The aim of this study is to assess the peculiarities of chaotic dynamics of tremor of micro-movements of the human upper limb with different physical preparedness without load and under conditions of static load from the position of theory of chaos and selforganization and Eskov-Zinchenko effect [18, 23].

## METHODS AND ORGANIZATION OF RESEARCH

**Contingent.** The study involved women living within the county (Yugra, Russia) not less than 5 years. The average age of the surveyed was 31. Depending on the degree of physical activity, 2 groups of women for 15 people have been formed. The first group took women who exercise regularly (not-athletes), at least 3 times a week. The second group included women who are professionally involved in sports (athletes), with sports qualifications not lower than the 1st adult category and continues to engage in systematic physical exercise more than 3 times a week.

**Research methods.** The subjects were recorded parameters of tremor using biophysical measuring complex, developed in the laboratory of biocybernetics and biophysics of complex systems in Surgut State University (Figure). The installation includes a metal plate (2) which is fixed rigidly to the finger test, eddy-current sensor (1), the amplifier together with an analog-to-digital converter (3) and the computer with the original software (4).

As a phase coordinate in addition to coordinates $x_1 = x_i(t)$ of the moving limbs, it was used to coordinate the speed of movement of the finger $x_2 = dx_1/dt$ [4, 6]. Every subject had the task to hold the finger in a given area consciously controlling his immobility at a given point in space.

Each subject took 15 episodes of the experiment ($N = 15$), in each of which the registration of tremor was performed 15 times ($n = 15$) at rest and similarly ($N = 15$, $n = 15$) under a load of 300 g (load attached to the index finger).

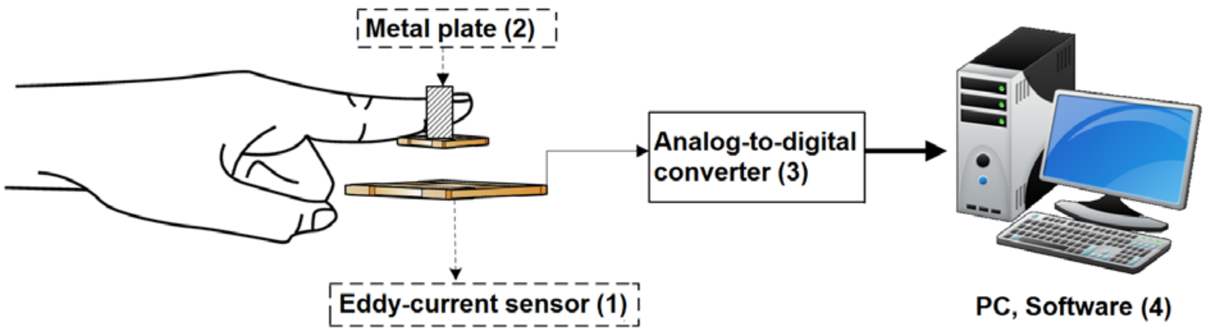


Fig. Scheme of measuring complex for tremor to be recorded

**Statistical and chaotic analysis.** Statistical data processing was carried out using the software package “Statistica 10”. Analysis of compliance of distributions of received data to a normal distribution was based on calculation of the Shapiro-Wilk test. A Wilcoxon test has been used to perform non-parametric pairwise comparison of tremorograms and 15 tables for each test subject in a resting state and 15 in the conditions of a static load of 300 grams for each test subject (a total of 225 samples of tremorograms) has been built.

Using analog-to-digital converter (3), a tremorograms have been recorded in the file with sampling rate $t = 0.01$ seconds (total time of registration of the $i$-th sample of $T = 5$ sec, the number of points in the expanded file $z = 500$). It was then produced pairwise comparison of segments of tremorograms for tremorograms sample of each test subject in order to classify all these samples as samples of the one general population (for the same test subject under a certain homeostatic state) [28].

## RESULTS OF THE STUDY

A particular chaotic dynamics of involuntary micromovements of the limbs (tremor of the fingers), as a reaction to the static load, manifested in the change in the number of matches of arbitrary pairs of samples ($k$), (pairs) include one of the general population. For this case the matrix of pairwise comparisons has been calculated. Note that Eskov-Zinchenko effect declares the lack of statistical robustness (there are no coincidences in a row of the received samples $x_i$) for any of homeostasis parameters of biological systems. We deal with neuromuscular system, for which we identify tremor as an involuntary movement.

Let us demonstrate this claim in the mode of multiple repetitions of registration of tremor in the form of 4 matrices of all 60 obtained matrices (as a model) [9, 11–13].

Paired comparisons of samples of tremorograms obtained in each series ($N = 1$) of $n = 15$ iterations of tremorograms registration (500 points – the values of $x_i(t)$ coordinates of the finger in relation to the eddy current sensor of check tremor) are presented in tables 1–4. Specific ($N = 1$) examples of calculation results of matrices (15×15) for pairwise comparison of tremorograms (coordinate $x_i(t)$) of subjects with different physical training showed that the number of pairs of identical samples is small ($k_{11} = 3$, $k_{12} = 6$, $k_{21} = 2$, $k_{22} = 4$), but they differ greatly an athlete and person without physical training.

As an example, the Table 1 presents the typical matrix for not-athlete test, subject $A$ (according to 225 tremorogram samples using this method, 15 matrices has been built for each test subject) in case of the resting state (free state). At the same time, for each such resting state, the experiment was repeated, but with physical load of 300 grams, 225 tremorogram samples of the same test subject have been recorded. Physical load on the finger (static load, 300 grams) allowed us to calculate 15 matrices (with physical load). A typical example of this (the second parallel) experiment has been shown in Table 2.

A pairwise comparisons of tremorogram samples of athlete test subject have been made. A typical example of pairwise matrices calculation presented in Tables 3 and 4. A comparison of the data for this test subject showed an increase in the number of matches in $k$ pairs of samples 2 times at a physical load (300 grams): $k_{21} = 2$ (no physical load) and $k_{22} = 4$ (with load of 300 grams). In this case, there is no element in top-diagonal set $p$, where $p < 0.05$.

*Table 1*

**The matrix of pairwise comparison of the test tremorogram in *A* subject (no load, number of repetitions $n = 15$), the Wilcoxon test was used (significance $p < 0.05$, the number of matches $k_{11} = 3$)**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | **.63** | .00 | .00 | .00 | .00 | .00 | .00 |
| 2 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 3 | .00 | .00 | | **.69** | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 4 | .00 | .00 | **.69** | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 5 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 6 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 7 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 8 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 9 | **.63** | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 |
| 10 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 |
| 11 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | **.70** |
| 12 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 |
| 13 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 |
| 14 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 |
| 15 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | **.70** | .00 | .00 | .00 | |

*Table 2*

**The matrix of pairwise comparison of the test tremorogram 1 (with physical load 300 g), the number of replications $n$ = 15), the Wilcoxon test was used (significance level $p$ < 0.05, number of coincidences $k_{12}$ = 6)**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | **.47** | .00 | **.24** |
| 2 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 3 | .00 | .00 | | **.33** | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 4 | .00 | .00 | **.33** | | .00 | **.71** | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 5 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | **.65** | .00 | .00 | .00 |
| 6 | .00 | .00 | .00 | **.71** | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 7 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | **.52** | .00 | .00 | .00 |
| 8 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 9 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 |
| 10 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 |
| 11 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 |
| 12 | .00 | .00 | .00 | .00 | **.65** | .00 | **.52** | .00 | .00 | .00 | .00 | | .00 | .00 | .00 |
| 13 | **.47** | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .02 |
| 14 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 |
| 15 | **.24** | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .02 | .00 | |

*Table 3*

**The matrix of pairwise comparison of the test tremorogram 2 (athlete, without physical load, number of repetitions $n$ = 15), the Wilcoxon test was used (significance level $p$ < 0.05, the number of matches $k_{21}$ = 2)**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .02 |
| 2 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 3 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 4 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 5 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | **.60** | .00 | .00 | .00 | .00 |
| 6 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 7 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .04 | .00 | .00 | .00 | .00 | .00 | .00 |
| 8 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 9 | .00 | .00 | .00 | .00 | .00 | .00 | .04 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 |
| 10 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | **.71** |
| 11 | .00 | .00 | .00 | .00 | **.60** | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 |
| 12 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 |
| 13 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 |
| 14 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 |
| 15 | .02 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | **.71** | .00 | .00 | .00 | .00 | |

It means a sharp decline in the share of stochastics in tremorogram evaluation (there is no possibility to register two consecutive tremorogram samples with $p$ > 0.05) Adjacent pairs of tremorograms are stochastically unique in case of athletes $f_j(x_i) \neq f_{j+1}(x_i)$.

The number of matches of $k$ pairs of samples in Table 2 ($k_{12}$ = 6) is greater in 2 times than the number of pairs of comparison samples of the same test subject (without physical load, as in Table 1), since $k_{11}$ = 3. These examples belong to the case of test subjects without physical training and they show the diagnostic value of calculating the number of $k$ on the background of statistical instability of distribution functions $f(x)$. Indeed, this example demonstrates that for 105 independent pairs of comparisons of tremorogram samples only two matched – 3rd and 4th samples ($p = 0.69$) in Table 1. In Table 2 we have only one such pair. Moreover, it is impossible to obtain matching pairs of tremorograms randomly. However, for all 60 matrices, the probability of this pair coincidence (in a row) was even less. Everything happens according to N.A. Bernstein principle of "repetition without repetition" and it forms a quantitative estimation of Eskov-Zinchenko effect.

Obviously, all this demonstrates a two-fold excess of $k_{12}$ and $k_{22}$ in relation to $k_{11}$ and $k_{21}$ respectively, and it describes the differences between state of rest and tremorograms at a static physical load of test subjects. Moreover, the difference in values of $k$ do not depend on physical fitness, which affects $k_{11}$ and $k_{22}$.

*Table 4*

**The matrix of pairwise comparison of the test tremorogram of subject *B* (athlete, with physical load (300 g.), the number of replications $n = 15$), the Wilcoxon test was used (significance $p < 0.05$, the number of matches $k_{22} = 4$)**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | **.56** |
| 2 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 3 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 4 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 5 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | **.30** | .00 | .00 | .00 | .00 | .00 |
| 6 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 7 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 8 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | .00 | **.98** | .00 |
| 9 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 | **.16** | .00 |
| 10 | .00 | .00 | .00 | .00 | **.30** | .00 | .00 | .00 | .00 | | .00 | .00 | .02 | .00 | .00 |
| 11 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 | .00 |
| 12 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | | .00 | .00 | .00 |
| 13 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .02 | .00 | .00 | | .00 | .00 |
| 14 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | **.98** | **.16** | .00 | .00 | .00 | .00 | | .00 |
| 15 | **.56** | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | |

However, this is only a single series of experiments on 15 samples of tremorograms. If we increase the number of series, which was done, there has been a marked statistical regularity, which presented in Table 5. From this table, it follows that for a test subject without physical training $\langle k_{12} \rangle \approx 2 \langle k_{11} \rangle$, but for an athlete, this ratio decreased slightly ($\langle k_{21} \rangle$=2.13 and $\langle k_{22} \rangle$=3.13, and their ratio less than two).

## DISCUSSION

The result of comparison of 15 series of tremorograms samples from two different groups of test subjects at the state of rest and 15 series with physical load (300 grams) shows that there is no statistical stability of samples of tremorograms for an athlete and not-athlete. The repetition occurs without statistical "repetition", and tremorogram samples are nearly all different, and it is impossible to obtain two consecutive identical samples (randomly). We have a chaotic kaleidoscope of distribution functions $f(x)$ for tremorograms. The average number of coincidences of random pairs of tremorogram samples of test subjects – not-athlete $\langle k_{11} \rangle = 2.93$, which is significantly less than under physical load $\langle k_{12} \rangle = 5.67$.

A different situation was observed for tested athlete, where $\langle k_{21} \rangle = 2.13$, that is less than $\langle k_{22} \rangle = 3.13$, but these differences are smaller (in size), than are the differences for the athlete. The same tendency was observed in all subjects in the mode 225 repetitions of the measurement tremorogram with a load (300 g) and without a load, however, the values of $k_1$ and $k_2$ had individual character (in some subjects, $\langle k_1 \rangle = 4$ and $\langle k_2 \rangle = 7.4$, etc.).

This proves significant individual differences in the parameters of the tremor and questioned the appropriateness of combining different people in the statistical group at all. We now turn to a personalized medicine, where each person has its phase portrait in a limited (in size) of the phase space of states is just vector of homeostasis $x = x(t) = (x_1, x_2, ..., x_m)^T$, where $m$ can be very large: $m > 10$ or $m > 100$, etc. For tremor such phase coordinates are: $x_1(t)$ – the coordinate, $x_2(t) = dx_1/dt$ – the velocity, $x_3(t) = dx_2/dt$ – the acceleration of the limb in space.

It was also revealed that the average number of coincidences $\langle k \rangle$ for not-athlete and for athlete in conditions of a rest differ somewhat (table 5), which is a marker of fitness of female population of Yugra. The number of coincidences $\langle k_{11} \rangle$ (not-athlete) is initially greater than $\langle k_{21} \rangle$ (athlete): $k_{11} = 2.93 > k_{21} = 2.13$. Accordingly increases the average number of coincidences $\langle k \rangle$ in terms of static load (300 g): $k_{12} = 5.67 > k_{22} = 3.13$. Thus, the number of matches of arbitrary pairs of samples ($k$) of women athletes remains less than women with low physical activity at all stages of the experiment. This pattern was observed in all test subjects (15 non-athletes, 15 athletes).

Overall, this is an appropriate time to talk about the chaotic dynamics of tremor, although postural tremor occurs with the participation of consciousness (central nervous system) and it can be considered as a voluntary movement, but the reaction occurs randomly

*Table 5*

**The number of matches ($k_1$ and $k_2$) matrices for pairwise comparison of tremorogram of test subjects in 15 series of experiments (Wilcoxon test, $p < 0.05$)**

| № | Subject 1 (not athlete) | | Subject 2 (athlete) | |
|---|---|---|---|---|
| | without load | at load 300 g | without load | at load 300 g |
| 1 | 2 | 5 | 4 | 2 |
| 2 | 2 | 8 | 4 | 3 |
| 3 | 1 | 8 | 2 | 4 |
| 4 | 2 | 6 | 2 | 2 |
| 5 | 1 | 7 | 3 | 1 |
| 6 | 4 | 6 | 1 | 5 |
| 7 | 4 | 4 | 6 | 4 |
| 8 | 4 | 4 | 2 | 3 |
| 9 | 3 | 2 | 1 | 6 |
| 10 | 9 | 5 | 1 | 3 |
| 11 | 3 | 10 | 1 | 4 |
| 12 | 1 | 5 | 0 | 2 |
| 13 | 2 | 5 | 0 | 1 |
| 14 | 5 | 4 | 3 | 6 |
| 15 | 1 | 6 | 2 | 1 |
| $\langle k \rangle$ | 2.93 | 5.67 | 2.13 | 3.13 |
| σ, ± | 2.13 | 1.99 | 1.64 | 1.68 |

(without statistical stability) and then there are two fundamental problems of biomechanics and physiology of movements in general: 1) what is considered as voluntary movement (?); 2) what is the difference between voluntary and involuntary movements and how they can be measured (?).

We came in this direction to another fundamental problem of physiology and biomedicine: how quantitatively describe homeostasis (we are talking about homeostasis neuromuscular system) and what is homeostasis in general, if we do not have stationary states of neuromuscular system in the form $dx/dt = 0$ ($x(t)$ varies continuously) and there is no statistical stability of distribution functions $f(x)$ for parameters of neuromuscular system. The solution to this problem is based on the test evaluations of the chaos of the parameter vector $x(t)$ [11, 13, 15, 23]. Recall that we have calculated the average number of coincidences of random pairs of samples ($<k>$) and standard deviation σ for all the 15 matrices with no load and under the impact of physical load (300 g) of each of 30 test subjects.

Generally speaking, multiple repetitions of sampling of tremorograms always demonstrate the lack of statistical robustness of such samples. This was manifested when it is almost impossible to get two consecutively registered tremorograms where we would observe coincidences of $f(x)$, i.e., as a rule $f_j(x_i) \neq f_{j+1}(x_i)$ for any number of samples $j$. In case of tremor of any person (trained and untrained) the probability $p$ of coincidence of these features (i.e. $f_j(x_i) = f_{j+1}(x_i)$) does not exceed $p \leq 0.001$. This is an extremely small value and it proves existence of Eskov–Zinchenko effect and restricts the possibility of statistical description of the movements (in biomechanics). It requires a different mathematical apparatus and other methods to describe constant movements (or their changes), so the statistical functions $f_j(x_i)$ will not match (at a random sample $x$). This mathematical analysis tool is introduced in Proceedings of the Russian Academy of Sciences [3] and in Moscow University Physics Bulletin [11, 13, 15].

## Conclusions

We conclude the dynamics of increasing in number of pairs of matching samples of tremorograms at conditions of static load, which can be a quantitative measure of differences in organization of tremor in two different physiological conditions (with and without physical load). The average number of pairs of matching samples (i.e. samples with no statistically significant difference) does not exceed $k \leq 5$ for the tremor of a person who is resting and this proves the low efficiency of stochastic in evaluation of the tremor. It is impossible twice in a row to repeat two (same) tremorograms. We will always observe an Eskov–Zinchenko effect ("repetition without repetition" by N.A. Bernstein), which represent the uncertainty of the 2nd type in theory of chaos and selforganization (two adjacent samples, randomly obtained, cannot be attributed to the same general population).

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## References

1. Beresten D.K., Chernikov N.A., Poskina T.Y., Potetyrina E.S. Khaoticheskaya dinamika amplitudno-chastotnykh kharakteristikakh tremorogram pri mnogokratnykh povtorakh izmerenii [Chaotic dynamics of amplitude-frequency characteristics of tremorogram at multiple repetitions of the measurement]. *Complexity. Mind. Postnonclassic*. 2016, no. 1, pp. 71-78. DOI: 10.12737/18815 (*in Russian*).
2. Bernstein N.A. The co-ordination and regulation of movements. Oxford: Pergamon Press, 1967.

3. Betelin V.B., Eskov V.M., Galkin V.A., Gavrilenko T.V. Stochastic volatility in the dynamics of complex homeostatic systems. *Doklady Mathematics*, 2017, vol. 472, no. 6, pp. 1-3. DOI: 10.1134/S1064562417010240
4. Eskov V.M., Filatova O.E., Ivashenko V.P. *Computer identification of compartmental neuron circuits. measurement techniques*, 1994, vol. 37, no. 8, pp. 967-971.
5. Eskov V.M., Filatova O.E. Respiratory rhythm generation in rats: The importance of inhibition. *Neurophysiology*, 1995, vol. 25, no. 6, pp. 348-353.
6. Eskov V.M. Hierarchical respiratory neuron networks. *Modelling, Measurement and Control*, 1995, vol. 48, no. 1-2, pp. 47-63.
7. Eskov V.M., Kulaev S.V., Popov Yu.M., Filatova O.E. Computer technologies in stability measurements on stationary states in dynamic biological systems. *Measurement Techniques*, 2006, vol. 49, no. 1. pp. 59-65.
8. Eskov V.M., Eskov V.V., Braginskii M.Ya., Pashnin A.S. Determination of the degree of synergism of the human cardiorespiratory system under conditions of physical effort. *Measurement Techniques*, 2011, vol. 54, no. 7, pp. 832-837.
9. Eskov V.M., Gavrilenko T.V., Kozlova V.V., Filatov M.A. Measurement of the dynamic parameters of microchaos in the behavior of living biosystems. *Measurement Techniques*, 2012, vol. 55, no. 9, pp. 1096-1101.
10. Eskov V.M. Evolution of the emergent properties of three types of societies: the basic law of human development. *Emergence: Complexity and Organization*, 2014, vol. 16, no. 2, pp. 107-115.
11. Eskov V.M., Gavrilenko T.V., Vokhmina Y.V., Zimin M.I., Filatov M.A. Measurement of chaotic dynamics for two types of tapping as voluntary movements. *Measurement Techniques*, 2014, vol. 57, no. 6, pp. 720-724.
12. Eskov V.M., Eskov V.V., Gavrilenko T.V., Zimin M.I. Uncertainty in the quantum mechanics and biophysics of complex systems. *Moscow University Physics Bulletin*, 2014, vol. 69, no. 5, pp. 406-411.
13. Eskov V.M., Eskov V.V., Gavrilenko T.V., Vochmina J.V. Biosystem kinematics as evolution: Stationary modes and movement speed of complex systems: Complexity. *Moscow University Physics Bulletin*, 2015, vol. 70, no. 2, pp. 140-152.
14. Eskov V.M., Filatova O.E., Provorova O.V., Khimikova O.I. Neural emulators in identification of order parameters in human ecology. *Human Ecology*, 2015, vol. 5, pp. 57-64.
15. Eskov V.M., Eskov V.V., Vochmina J.V., Gavrilenko T.V. The evolution of the chaotic dynamics of collective modes as a method for the behavioral description of living systems. *Moscow University Physics Bulletin*, 2016, vol. 71, no. 2, pp. 143-154.
16. Eskov V.M., Eskov V.V., Gavrilenko T.V., Vochmina Yu.V. Fopmalizatsiya effekta “povtopenie bez povtopeniya” N.A. Bernshteina [Formalization of the effect of “Repetition without Repetition” by N.A. Bernstein]. *Biofizika*, 2017, vol. 62, no. 1, pp. 168-176. (*in Russian*).
17. Eskov V.V., Filatov M.A., Filatova D.Yu., Prasolova A.A. Granitsy determinizma i stokhastiki v izuchenii biosistem - complexity [The boundaries of determinism and stochastics in the study of biological systems – complexity]. *Complexity. Mind. Postnonclassic*, 2016, no. 1, pp. 83-91. DOI: 10.12737/18817 (*in Russian*).
18. Filatov M.A., Filatova D.Yu., Poskina T.Y., Veraksa A.N. Ponyatie proizvolnykh dvizhenii s pozitsii effekta Eskova-Zinchenko v psikhofiziologii dvizhenii [The voluntary movements according to effect Eskov-Zinchenko in psychophysiology of movements]. *Complexity. Mind. Postnonclassic*, 2016, no. 1, pp. 17-24. DOI: 10.12737/18811 (*in Russian*).
19. Filatova O.E., Provorova O.V., Volokhova M.A. Assessment of vegetative status of oil-and-gas industry workers from perspective of chaos and self-organization theory. *Human Ecology*, 2014, vol. 6, pp. 16-19.
20. Garaeva G.R., Eskov V.M., Eskov V.V., Gudkov A.B., Filatova O.E., Khimikova O.I. Chaotic dynamics of cardiointervals in three age groups of indigenous people of Ugra. *Human Ecology*, 2015, vol. 9, pp. 50-55.
21. Gavrilenko T.V., Es'kov V.M., Khadartsev A.A., Khimikova O.I., Sokolova A.A. The new methods in gerontology for life expectancy prediction of the indigenous population of Yugra. *Advances in Gerontology*, 2014, vol. 27, no. 1, pp. 30-36.
22. Karpin V.A., Filatova O.E., Soltys T.V., Sokolova A.A., Bashkatova Yu.V., Gudkov A.B. Comparative analysis and synthesis of the cardiovascular system indicators of representatives of arctic and alpine adaptive types. *Human Ecology*, 2013, vol. 7, pp. 3-9.
23. Khadartsev A.A., Filatova O.E., Zinchenko Y.P. Vvedenie v biofiziku gomeostaticheskikh sistem [Introduction to the biophysics of homeostatic systems (complexity)]. *Complexity. Mind. Postnonclassic*, 2016, no. 3, pp. 6-15. DOI: 10.12737/22107 (*in Russian*).
24. Kravchenko I.V., Pavlova E.V., Sinelnikova Yu.M., Rusak, S.N., Murashko Yu.A., Bashkatova Yu.V. Evaluation of hair chemical composition in patients with chronic skin diseases on territory of Khanty-Mansi Autonomous Okrug - Yugra. *Human Ecology*, 2015, vol. 2, pp. 16-19.

25. Rusak S.N., Eskov V.V., Molyagov D.I., Filatova O.E. Annual dynamics of climatic factors and population health in Khanty-Mansiysk autonomous area. *Human Ecology*, 2013, vol. 11, pp. 19-24.
26. Vokhmina Yu.V., Burykin Yu.G., Filatova D.Yu., Shumilov S.P. Stokhasticheskie i khaoticheskie otsenki neproizvol'nykh dvizhenii cheloveka [Stochastic and chaotic assessment of human involuntary movements]. *Journal of New Medical Technologies*, 2014, vol. 21, no. 2, pp. 10-15. DOI 10.12737/4988 (*in Russian*).
27. Zilov V.G., Eskov V.M., Khadartsev A.A., Eskov V.V. Eksperimentalnoe podtverzhdenie effekta «Povtorenie bez povtoreniya» N.A. Bernshteina [Experimental confirmation of "repetition without repetition" effect by N.A. Bernstein]. *Bulletin of Experimental Biology and Medicine*, 2017, no. 1. pp. 4-9. (*in Russian*).
28. Zinchenko U.P., Filatova O.E., Eskov V.V., Streltsova T.V. Obektivnaya otsenka soznatelnogo i bessoznatelnogo v organizatsii dvizhenii [Objective evaluation of conscious and unconscious parts of movement organization]. *Journal of New Medical Technologies*, 2016, vol. 23, no. 3, pp. 31-39. DOI:10.12737/21745 (*in Russian*).


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