Stratification of the phase clouds and statistical effects of the non-Markovity in chaotic time series of human gait for healthy people and Parkinson patients

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1. Introduction

A wide class of physical and biological systems exhibits complex dynamics, related to the presence of many factors interacting over a wide range of time or space scales [1–30], [31–34]. Physiologic signals generating by complex self-regulating systems are extremely inhomogeneous, unsteady and fluctuating in an irregular and chaotic manner. Among them the locomotion is active movements made by a person which considerably exceed the norm typical of the size of their body. Walking is the most widespread form of human locomotion. The study of locomotion dynamics of a human present great interest for modern biomedicine and physiology [11–30], [31–34]. The number of people with various infringements of locomotion activity increases annually. The basic actual problems connected with these researches of the human's gait dynamics and walking are considered in the papers of Hausdorff [9–15]. Here, we deal with the changes of the fractal dynamics of patients' gait [9,10], the increase of instability of elderly people's gait [9,11,15] the steady long-range correlation of fluctuations of young people's step interval [14] and the development of children's gait dynamics [16]. As a rule similar researches are carried out on the basis of the traditional biomechanical methods [1,2,18,21,22], for example, on the records of electric signals in the muscles of legs of a human at walking [17]. Though experimental techniques are well developed at present, the theoretical analysis of the measurements is inadequate so far. The dynamics of the electric signals of the muscle tremors is related to a class of nonlinear, nonstationary and nonergodic processes. While analyzing the electric activity of the muscle tremors, it is necessary to take into account the discrete non-Markov properties of time change of the signals as well as the sudden alternation of the behavioral regimes. This is the reason why traditional methods of nonlinear dynamics are not sufficiently sensitive for the purpose of distinction between different chaotic regimes. The use of the statistical method of discrete non-Markov random processes [35–38] in the similar researches allows to receive the more detailed characteristics of deflections in the central nervous system (CNS) and in the motor system and to differentiate the parameters for different age groups.

This method also allows to find out the predisposition to Parkinson's disease as early as possible even of young children. It is of great practical value as it allows to diagnose and prevent the development of the disease at its early stages and reduce the danger of more serious complications, that might set in without appropriate treatment.

Parkinson's disease is a chronic one, a slowly progressing disease caused by the lesion of the extrapyramidal system. The extrapyramidal system includes the system of nucleus of a brain and the motor ways which are responsible for involuntary automatic regulation and coordination of the complex motor acts, and also the regulation of a muscular tone, the maintenance of pose and the organization of impellent manifestation. It is impossible to establish the cause of the disease at an early stage. Therefore, the possibility to diagnose predisposition to the given disease at an early stage is very important. As a rule the disease reveals itself at the age of 50–60, but there are exceptions. A total of 160 in 100 000 people suffer from this disease.

Parkinsonism is a syndrome of progressing lesion of the nervous system. This syndrome reveals itself in the decrease of the general motor activity, the slowness of

movement, the tremor and the increase of muscular tone. The muscular tone has two components: a component related to the maintenance of a pose is a “pose tone”, another component related to reflexion is a “reflex tone”. The disease can be complicated with the syndrome of epidemic encephalitis, atherosclerosis of brain vessels caused by insufficiency of brain blood circulation, tumors of big hemispheres and craniocerebral traumas. Less often the disease is connected with intoxication caused by manganese, carbon monoxide, lead and other medical substances products.

The basic external attributes of the disease reveal themselves through limitation of the general motor activity. The movements of the patients are slowed down and performed with difficulty, their speech is monotonous and hardly audible, the face expression is unemotional. While walking the patients make short steps, there is no concomitant motion of their hands and the phenomenon of propulsia can be observed (inertia movement). The tone of skeletal muscles increases and as the result the movements are constrained. The characteristic pose of the patient is as follows: the body is bent forward, the chin dropped onto the chest, the hands are at the side of the body bent in elbows. Huntington’s disease also refers to the group under study as it is a certain kind of walking resembling a dancing gait.

Now more than 10 million people in the advanced countries suffer from Parkinson’s disease. The symptoms of the disease reveal themselves as tremor and rigidity, caused by mortification of cells in the certain area of human brain named substantia nigra. Neurons from this area transfer nerve impulses by means of doufamin mediator. Owing to the destruction of the nervous cages of substantia nigra changes take place in other areas of the brain responsible for motor activity. The condition of the Parkinson patient can be alleviated, if the lack of doufamin is filled up. However, the process of neuron destruction continues.

It is supposed, that the “cause” of disease is an unknown toxic substance contained in the environment. Later on narcotic substances, stimulating the phenomena very similar to the symptoms of Parkinson’s disease, were discovered. Even tea, mint and herbicides contain substances which in a combination with the natural loss of the nervous cages of substantia nigra can cause Parkinson’s disease. The effect of the substantia nigra is thought to have the effect similar to the effect of toxic substances. It is connected not only with the destruction of the brain caused by Parkinson’s disease, but comes as a natural “process” of human aging.

On April 16, 2002 “Decode Genetics” research company has declared that the define gene is responsible for Parkinson’s disease. If the results of the discovery are put into practice, the new means of combating this disease will appear.

It seems very curious and rather odd, that rats and mice are less sensitive to all the factors listed above, than people and primates. It is due to the special rodent brain structure.

In Refs. [11–30] various methods were offered for finding the distinction of motor functions of different age groups and differences between patients and healthy people. In this work we present a new method of detecting strong differences existing in different age groups and the means of diagnostics Parkinson’s disease at its early stages. A quantitative analysis of human gait dynamics show that the description of motor processes cannot be executed on the basis of the fundamental methods of statistical

physics. The most essential moments in time series describing the behavior of real-life systems are their discreteness, nonstationarity, nonergodicity and non-Markovity.

Therefore, for the description of the complex systems it is necessary to use the theory of random non-Markov discrete processes [35–38]. The approach proposed in these works allows to define a wide spectrum of dynamic characteristics for the majority of real objects. This method [35] is used in the given work for the research of non-Markov statistical effects in time discrete series of human gait. The generalization will consist in taking into account the nonstationarity of stochastic random processes and their further application to the analysis of human gait by means of time correlation function (TCF) method.

One of the key moments in the spectral approach in the analysis of stochastic processes is the use of normalized TCF

$$a_0(t) = \frac{\langle \mathbf{A}(T)\mathbf{A}(T+t)\rangle}{\langle |\mathbf{A}(\mathbf{T})|^2\rangle}\ , \tag{1}$$

where the time T is the beginning of a time serial, the angular brackets indicate a scalar product of vectors, and vector $\mathbf{A}(\mathbf{t})$ is a state vector of a complex system, $|\mathbf{A}(\mathbf{t})|$ is the length of vector $\mathbf{A}(\mathbf{t})$. The above-stated designation is true only for stationary systems. In a non-stationary case Eq. (1) is not true and should be changed. The concept of TCF can be generalized in case of discrete nonstationary sequence of signals. For this purpose, it is necessary to take advantage of the standard definition of the correlation coefficient for the two random signals X and Y in the probability theory

$$\rho = \frac{\langle \mathbf{XY}\rangle}{\sigma_X \sigma_Y}, \quad \sigma_X = |\mathbf{X}|, \quad \sigma_Y = |\mathbf{Y}|\ . \tag{2}$$

In Eq. (2) the multicomponent vectors $\mathbf{X}, \mathbf{Y}$ will be generated from fluctuations of signals x and y accordingly, σ_x^2, σ_y^2 is proportional to the dispersion of signals x and y, and values $|\mathbf{X}|$, $|\mathbf{Y}|$ represent the lengths of vectors $\mathbf{X}$, $\mathbf{Y}$, correspondingly. Therefore, the generalization of concept of TCF 1 for nonstationary processes can be served by the function [37]

$$a(T,t) = \frac{\langle \mathbf{A}(T)\mathbf{A}(T+t)\rangle}{|\mathbf{A}(T)||\mathbf{A}(T+t)|}\ . \tag{3}$$

For the quantitative description of nonstationarity with accordance to Eqs. (1) and (3), it is convenient to introduce the function of nonstationarity

$$\gamma(T,t) = \frac{|\mathbf{A}(T+t)|}{|\mathbf{A}(T)|} = \left\{\frac{\sigma^2(T+t)}{\sigma^2(T)}\right\}^{1/2}\ , \tag{4}$$

which one is equal to the ratio of lengths of the vectors of the final and initial states. In case of stationary process the dispersion does not vary with the time (or its variations are very weak).

In this work we consider only a few problems connected with the description of the human's gait dynamics. The most important of them are:

(1) What are the advantages of using the theory of discreteness and long-range memory effects for the description of locomotor dynamics?

(2) Is it possible to use the non-Markov statistical effects for revealing predisposition to motor system diseases?

The article is organized as follows. In Section 2 we consider the brief description of the statistical theory of nonstationary discrete non-Markov processes in complex systems [35–37]. Section 3 contains the description of the initial data about electric signals in muscles of legs of healthy people of various age groups and Parkinson patients. The received results and their analysis are given in Section 4. Section 5 is devoted to summary and conclusions of this work.

2. Statistical theory of nonstationary discrete non-Markov processes in complex systems. Basic concepts and definition

The brief description of the statistical theory of the discrete non-Markov nonstationary processes for the complex systems of wildlife is presented in this section. The theory and the description of quantities used here can be found in the works of authors published earlier [35–38].

While analyzing complex systems we obtain discrete equidistant series of experimental data, the so-called random variable

$$X = \{x(T), x(T+\tau), x(T+2\tau), \ldots, x(T+k\tau), \ldots, x(T+\tau N-\tau)\}\ . \tag{5}$$

It corresponds to a measured signal during the time $(N-1)\tau$, where τ is a temporary sampling interval of a signal.

For the dynamical analysis, it is more convenient to use a normalized TCF. For the discrete processes the TCF has its usual form $(t = m\tau, N-1 > m > 1)$

$$a(t) = \frac{1}{(N-m)\sigma(0)\sigma(t)} \sum_{j=0}^{N-1-m} \delta x(T+j\tau)\delta x(T+(j+m\tau))\ , \tag{6}$$

where $\sigma(0)$ and $\sigma(t)$ is the variances of the initial $(t=0)$ and final (at moment t) states of a systems, correspondingly. The properties of the TCF $a(t)$ are determined by the conditions of normalization and attenuation of correlations

$$\lim_{t\to 0} a(t) = 1, \qquad \lim_{t\to\infty} a(t) = 0\ . \tag{7}$$

If we take into account the nonstationarity and discreteness of complex systems for real processes, then the kinetic equation for the TCF $a(t)$ has the form of a closed set of the finite-difference equations of the non-Markov type [35–38]:

$$\frac{\Delta a(t)}{\Delta t} = \lambda_1 a(t) - \tau \Lambda_1 \sum_{j=0}^{m-1} M_1(j\tau) a(t-j\tau)\ . \tag{8}$$

Here Λ_1 is a relaxation parameter with the dimension of square of frequency, and parameter λ_1 describes an eigen-spectrum of Liouville's quasioperator $\hat{L}$

$$\lambda_1 = i\,\frac{\langle \mathbf{A}_k^0(0)\hat{L}\mathbf{A}_k^0(0)\rangle}{\langle |\mathbf{A}_k^0(0)|^2\rangle}, \qquad \Lambda_1 = \frac{\langle \mathbf{A}_k^0\hat{L}_{12}\hat{L}_{21}\mathbf{A}_k^0(0)\rangle}{\langle |\mathbf{A}_k^0(0)|^2\rangle}\ . \tag{9}$$

The function $M_1(j\tau)$ in the r.h.s. of Eq. (8) represents the first memory function

$$M_1(j\tau) = \frac{\langle \mathbf{A}_k^0(0)\hat{L}_{12}\{1 + i\tau\hat{L}_{22}\}^j\hat{L}_{21}\mathbf{A}_k^0(0)\rangle}{\langle \mathbf{A}_k^0(0)\hat{L}_{12}\hat{L}_{21}\mathbf{A}_k^0(0)\rangle}, \quad M_1(0) = 1\ . \tag{10}$$

In Eq. (9) and later operation $\hat{L}$ is a finite-difference operator

$$i\hat{L} = \frac{\triangle}{\triangle t}, \quad \triangle t = \tau\ ,$$

where τ is a discretization time step.

It is easy to see that in Eq. (10) we deal with the time correlation of new orthogonal dynamic variable $\hat{L}_{21}\mathbf{A}_k^0(0)$.

Eq. (8) represents the first equation in the chain of finite-difference kinetic equations with memory for the discrete TCF $a(t)$. It is easy to see that the memory function $M_1(t)$ takes into account the statistical memory about previous states of the system. By using the procedure of Gram–Schmidt orthogonalization [35] we receive the recurrent formula, in which the older dynamic variable $\mathbf{W}_n = \mathbf{W}_n(t)$ is connected to the younger one in the following way:

$$\mathbf{W}_0 = \mathbf{A}_k^0(0), \quad \mathbf{W}_1 = \{i\hat{L} - \lambda_1\}\mathbf{W}_0, \ldots,$$

$$\mathbf{W}_n = \{i\hat{L} - \lambda_{n-1}\}\mathbf{W}_{n-1} + \Lambda_{n-1}\mathbf{W}_{n-2}, \quad n > 1\ . \tag{11}$$

Introducing the corresponding projection operators we come to the following chain of connected non-Markov finite-difference kinetic equations ($t = m\tau$)

$$\frac{\Delta M_n(t)}{\Delta t} = \lambda_{n+1}M_n(t) - \tau\Lambda_{n+1}\sum_{j=0}^{m-1} M_{n+1}(j\tau)M_n(t - j\tau)\ . \tag{12}$$

Here λ_{n+1} is an eigen-value of the Liouville's quasioperator and the relaxation parameters Λ_{n+1} are determined as follows:

$$\lambda_n = i\,\frac{\langle \mathbf{W}_n\hat{L}\mathbf{W}_n\rangle}{\langle|\mathbf{W}_n|^2\rangle}, \quad \Lambda_n = -\frac{\langle \mathbf{W}_{n-1}(i\hat{L} - \lambda_{n+1})\mathbf{W}_n\rangle}{\langle|\mathbf{W}_{n-1}|^2\rangle}\ .$$

Eqs. (8)–(12) are written down in view of that in the present work we analyze short time series. In this case it is possible to not take into account the nonstationarity functions [37].

3. Experimental data and data processing

In our study we use the records of electric signals data in legs muscles at human's walking from the data base of physionet website [39]. The first group of the data describe the dynamics of children's gait, aged from 3 to 10, (I type), the second represents teenagers, 11 to 14, (II type), the third includes young people, 21 to 29, (III type), the fourth contains the data on elderly persons, 71 to 77, (IV type), the fifth characterizes Parkinson patients (V type) [39]. The obtained data were dealt with the help of the above-introduced technique. The set of the three memory functions

was calculated for each sequence of the data. The power spectra for each of these functions are obtained by the fast Fourier transform (FFT). Also, we will show the phase portraits in plane projections of the multidimensional space for the dynamic orthogonal variables. For a more detail diagnostics of the system we will consider the frequency dependence of the three first points of the statistical spectrum of the non-Markovity parameter. In this study we will use the frequency dependence of the non-Markovity parameter [33–38]

$$\varepsilon_i(\omega) = \left\{ \frac{\mu_{i-1}(\omega)}{\mu_i(\omega)} \right\}^{1/2} . \tag{13}$$

Here $i = 1, 2, \ldots$, and $\mu_i(\omega)$ is a power spectrum of ith level.

For a more detailed analysis of data we present a multiplicative power (MP) on the fixed frequency. This parameter allows to reveal the precise quantitative distinctions in the power spectra of different groups of the data

$$M = \prod_{i=0}^{3} \mu_i(\omega_{spec}), \quad \omega_{spec} = 10^{-2} \text{ f.u.}, \quad 1 \text{ f.u.} = 2\pi/\tau , \tag{14}$$

where τ is discretization time. In this work the MP is introduced only to account for $\mu_i(\omega_{spec})$, where $i = 0, \ldots, 3$. Further, it is possible to use senior memory functions to reveal a more precise distinction between the investigated groups of the data.

4. Discussion of results

In this section the quantitative and comparative analysis of the chaotic dynamics of healthy people's gait and the gait of Parkinson patients will be carried out on the basis of the theory presented in Section 3. In Figs. 1–5 the time series of the initial signals, the phase portraits of the dynamic variables, the power spectra of the TCF, the junior memory functions and the frequency dependence of the first three points of non-Markov parameter are considered.

The time series of the electric signals in leg muscles for all the five groups of the data are given in Fig. 1. The analysis of the first four orthogonal variables W_0 (Figs. 1a), W_1 (Figs. 1b), W_2 (Figs. 1c), W_3 (Figs. 1d) shows that the brightest fluctuations of the dynamic variables can be observed in case of Parkinson patients. The time series of the dynamic variables for the data of III type (young people) have the best organization. Pronounced fluctuations are observed in the development of the signals for all the groups of probationers. In Fig. 2 the phase portraits of the four first dynamic variables in six plane projections for the healthy young man (III type) are given. In this figure the symmetry of the phase clouds about the center of coordinates is appreciable. In all phase portraits one can see the centralized nucleus and a few separate points scattered on the perimeter. The interval of the dispersal is 0.1 τ. The completely different picture is observed in case of the Parkinson patients (V type) (see, Fig. 3).

In Fig. 3 the symmetry of the phase portraits about the center of coordinates is visible. But here another important feature namely the stratification of phase clouds can be observed. The stratification of the phase cloud results in the uniform distribution

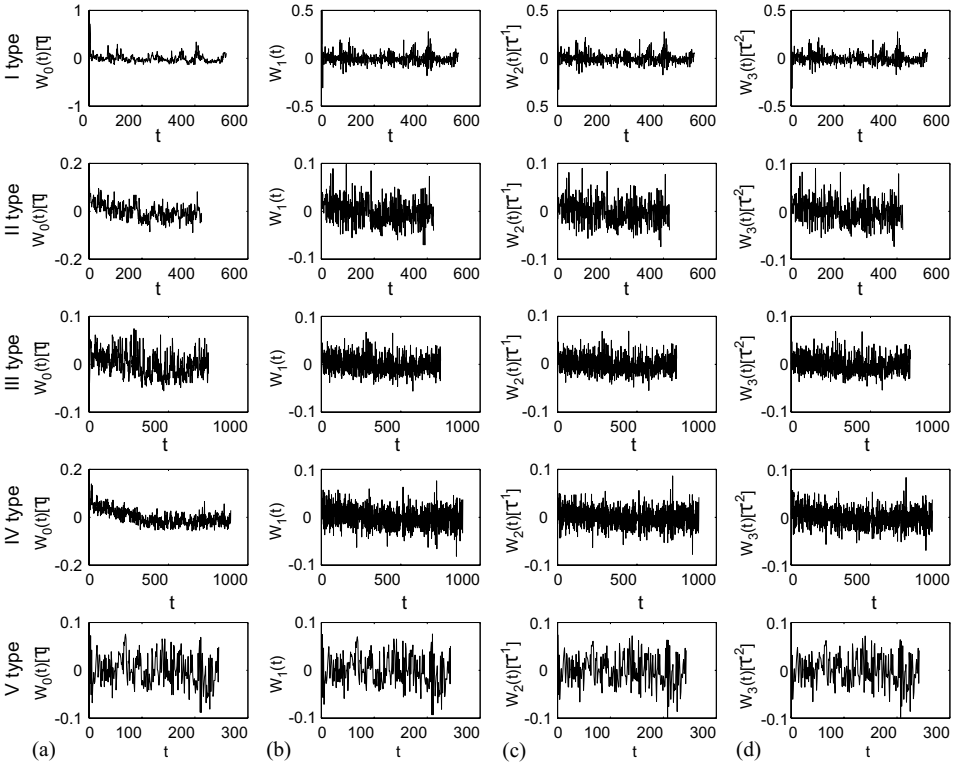

Fig. 1. The time record of the fourth first orthogonal variables W_0 (a), W_1 (b), W_2 (c) and W_3 (d) for the child of 4 (I type), for the teenager of 12, 4 (II type), for the young man of 26 (III type), for the elderly person of 75 (IV type), for the Parkinson patient (V type).

of all the points all over the space and the disappearance the well-defined nucleus. The interval of the dispersion of the points increases up to 0.175τ. Such stratification is typical only of the data of V type. This kind of phase clouds corresponds to the condition of Parkinson's disease. The analysis of the data of other groups shows that even the small stratification of the phase clouds demonstrates the failure of the system and makes it possible to predict Parkinson's disease at early stages.

It is necessary to note that certain stratification of the phase clouds similar to the data of V type is observed for 5–6.5 year old children and for 12–13 year old teenagers. This phenomenon is related to physiological changes of this age. Infringements of the gait dynamics are caused by age changes of the brain regulator functions. Thus, it is difficult to predict predisposition to Parkinsonism at these age periods. In Fig. 4 the power spectra of the TCF $\mu_0(\omega)$ and the three younger memory functions of $\mu_i(\omega)$, $i = 1, 2, 3$ for all five groups of the data are given. The low-frequency spectra are submitted for a more detailed analysis of the data on a double-log scale. The spectra for the data of I–IV types have a specific fractal dependence. The brightest fractality is observed for the initial TCF $\mu_0(\omega)$.

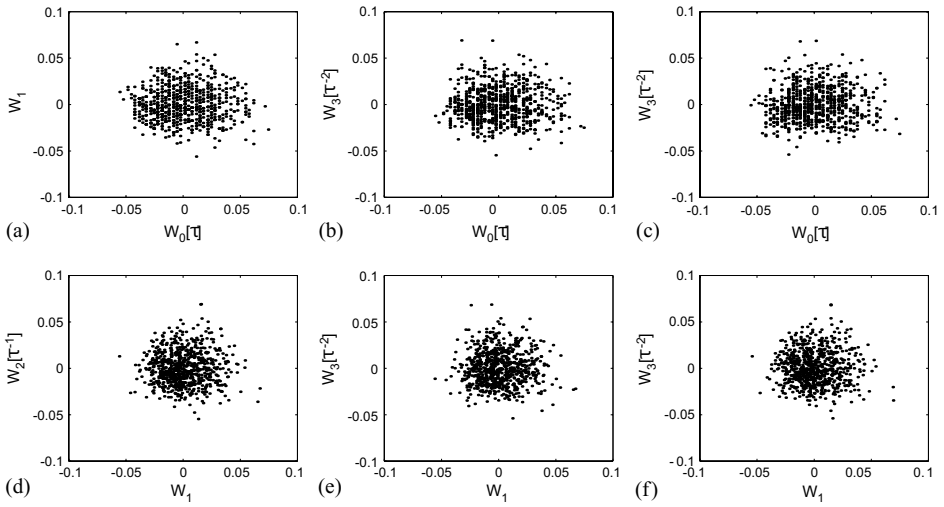

Fig. 2. (a–f) The phase portrait of the dynamics of human gait in the plane projections of two various orthogonal variables (W_i, W_j) for the probationer of type III.

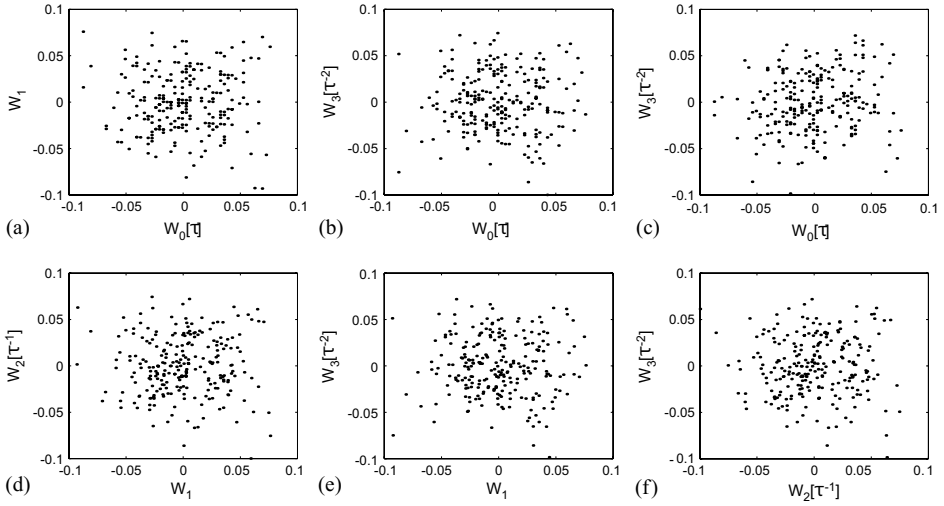

Fig. 3. (a–f) The phase portrait of the dynamics of human gait in the plane projections of two various orthogonal variables (W_i, W_j) for the patient of type V.

The frequency spectra of Parkinson patients (V type) considerably differ from the spectra of the healthy people. In this case the fractal dependence disappears. Sharp breaks of the linear sites of spectra on all frequencies are characteristic for all memory functions. Sharp spectral peaks are especially appreciable on low frequencies. The

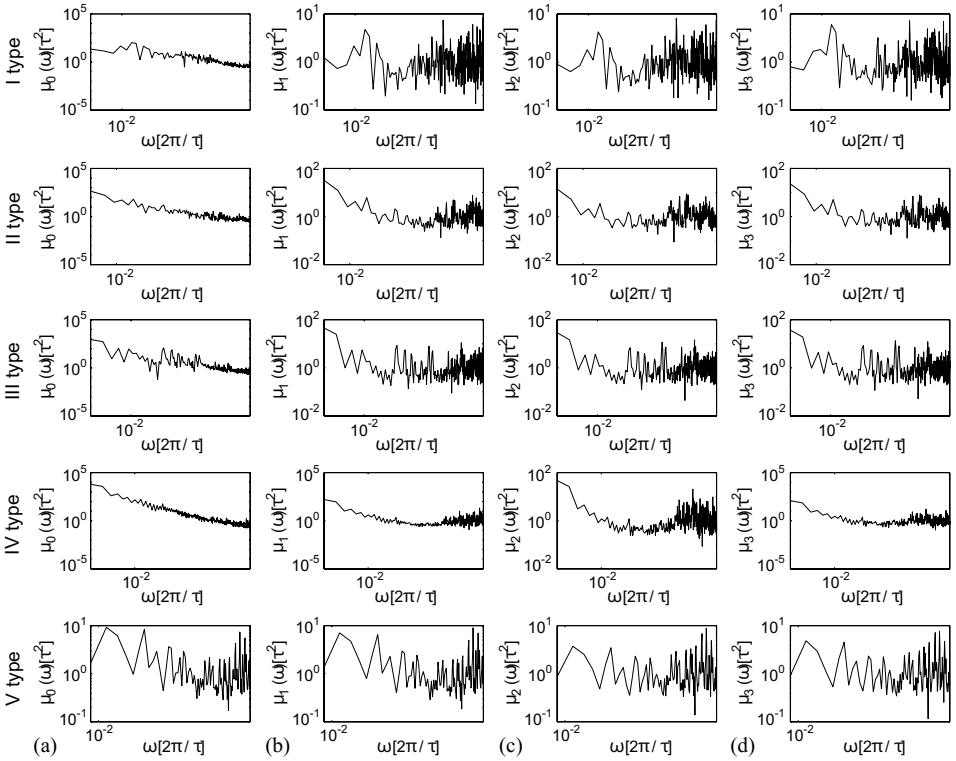

Fig. 4. The power spectra $\mu_i(\omega)$, for fourth first junior memory function of the dynamics of human gait for the all five types of the probationers ($i = 0$ (a), $i = 1$ (b), $i = 2$ (c), $i = 3$ (d)).

similar peaks are also observed in case of probationers of the I type, the phenomenon is caused by insufficiently "mature" coordination and regulation of the locomotor activity. It is necessary to note, that the distribution of power spectra of the memory functions on high frequencies for all the groups of the data is almost identical. It is easy to see condensation of spectral lines as well as spectral noise. It means that the most trustworthy information can be obtained only on low frequencies.

There are power spectra of the $\mu_i(\omega_{spec})$, $i = 0, \ldots, 3$, where $\omega_{spec} = 10^{-2}$ f.u., 1 f.u. $= 2\pi/\tau$, and of the multiplicative power on the fixed frequency (MP) for the five types of probationers in Table 1. The spectrum of $\mu_0(\omega_{spec})$ presents the greatest interest. The value of this parameter (in units of τ^2) has the order from 10^1 for children and teenagers (I–II type) up to 10^2 for young and elderly persons (III–IV type). For patients (V type) this parameter is minimal and has the order of the unit. The increase of this parameter means extension of long-range memory and long-range order in the system. The values of other parameters $\mu_i(\omega_{spec})$, $i = 1, 2, 3$ for the data of all the types are of order of unit and are almost identical.

By analogy with the frequency spectrum of TCF MP parameter (in units of τ^2) has the order from 10^2 for children and teenagers (I–II type) up to 10^3 for young and

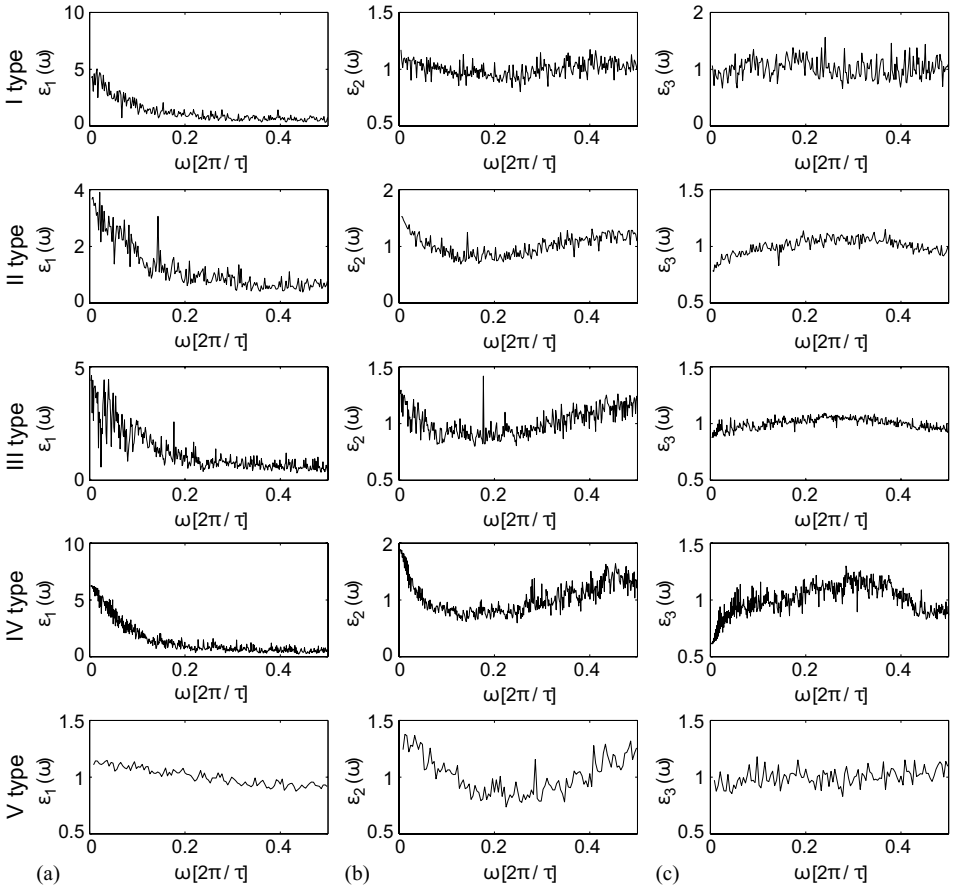

Fig. 5. The frequency dependence of the first three points of non-Markovity parameter $\varepsilon_i(\omega)$ of the dynamics of human gait for all the five underlying types (1st point (a), 2nd point (b) and 3rd point (c)).

Table 1
The power spectra $\mu_i(\omega_{spec})$ (in units of τ^{-2}) and multiplicative power on the fixed frequency (MP) (in units of τ^{-8}) for all the five types (where $\omega_{spec} = 10^{-2}$ f.u., 1 f.u. $= 2\pi/\tau$)

	$\mu_0(\omega_{spec})$	$\mu_1(\omega_{spec})$	$\mu_2(\omega_{spec})$	$\mu_3(\omega_{spec})$	M(MP)
I type	3×10^1	2	1.5	2	1.8×10^2
II type	4×10^1	2	2	2	3.2×10^2
III type	10^2	4	2	2	1.6×10^3
IV type	2×10^2	7	1.5	3	6.3×10^3
V type	4	4	2	2	6.4×10^1

Table 2
The three first points of non-Markovity parameter for all the five types (when $\omega = 0$)

	$\varepsilon_1(0)$	$\varepsilon_2(0)$	$\varepsilon_3(0)$
I type	4.2	1.2	1.1
II type	3.95	1.5	0.75
III type	4.5	1.3	0.87
IV type	6.2	1.8	0.6
V type	1.1	1.25	0.95

elderly persons (III–IV type). For Parkinson patients (V type) this parameter has the minimal value of the order about 10^1. The numerical value MP means the presence of long-range memory and order in a healthy system. It is necessary to notice, when the top index in a product of $\mu_i(\omega_{spec})(i > 3)$ increases then the values of the MP in Eq. (14) for different groups get greater distinctions.

By analogy it is possible to use the frequency dependence of the first three points of the statistical non-Markov spectrum $\varepsilon_i(\omega)$, where $i = 1, 2, 3$ (Fig. 5) to diagnose the diseases of the motor system. The fractality is most appreciable in the behavior of the $\varepsilon_1(\omega)$ and $\varepsilon_2(\omega)$ for I–IV types of probationers. The spectra of the third point non-Markov parameter $\varepsilon_3(\omega)$ for all probationers are almost identical and take the shape of a straight line $\varepsilon_3(\omega) = 1$ with small fluctuations. It means strong non-Markovity. In frequency spectrum $\varepsilon_1(\omega)$ the condensation of the spectral lines in the region of $0 < \omega < 0.2$ f.u. for I–IV types and their absence for V type is appreciable. For the probationer of I–III types the spectral discharges close to the characteristic frequency of 0.2 f.u. is observed.

The spectral lines for all points of the $\varepsilon_i(\omega)$ for V type of probationers take a shape of straight line $\varepsilon_i(\omega) = 1$ (where $i = 1, 2, 3$) with a feebly marked bursts. For all the groups of the data the behavior of the spectra of non-Markov parameter $\varepsilon_i(\omega)$ means the possibility to describe the dynamics of human gait with the help of the non-Markovity process with feebly marked splashes of Markovity on low frequencies.

In Table 2 the frequency dependence of the first three points of the non-Markovity parameters $\varepsilon_i(\omega)$, $i = 1, 2, 3$ where $\omega = 0$ is given. The results for the $\varepsilon_1(0)$ present a great interest. The comparative analysis of the this parameter allows to define the evolution of the dynamics of human gait. The value of this parameter for the healthy people varies from 4 up to 7 (according to the age group). The probationers of type V have the order of a unit. The decrease or increase of this parameter concerning the average value of 5.5 for the healthy people means the degree of predisposition to the diseases of human motor system. The values of others parameters $\varepsilon_2(0)$ and $\varepsilon_3(0)$ change within an interval of 1–2. This means long-range order and the statistical memory of the system.

In Table 3 the quantitative data of some kinetic and relaxation parameters λ_1, λ_2, λ_3, Λ_1 and Λ_2 are given. We notice, that all the parameters for V type accept the least values.

Table 3
The some kinetic and relaxation parameters for the I–V types

	$\lambda_1(\tau^{-1})$	$\lambda_2(\tau^{-1})$	$\lambda_3(\tau^{-1})$	$\Lambda_1(\tau^{-2})$	$\Lambda_2(\tau^{-2})$
I type (4 y)	−0.29847	−1.0573	−1.0403	−0.02819	0.046063
II type (12 y)	−0.42744	−1.1251	−1.0324	−0.13742	0.07488
III type (26 y)	−0.35072	−1.091	−1.0112	−0.079744	0.047017
IV type (75 y)	−0.27593	−1.2192	−1.0646	−0.1436	0.1365
V type (PD)	−0.91981	−1.0136	−1.0193	−0.19034	0.0062973

5. Conclusions

In this work the dynamics of human gait is considered as the random non-Markov process. The statistical theory of discrete non-Markov processes for real objects and live systems is the best way to investigate this phenomenon. This theory [35–38] allows to define essential distinctions between the parameters for healthy people and the people with infringements of locomotor activity. On the basis of processing of the experimental data of the electric signals in legs muscles the time series of the dynamic variables $W_i(t)$ were obtained and memory functions as well as the first three points of non-Markov parameter were calculated. For the analysis of the time functions we used the power spectra received by the FFT. The numerical parameters, given in Tables 1–3, demonstrate essential distinctions between the five groups of the data (I–V).

It is possible to make the following conclusions based on the long-range memory conception. There are, at least, the two age periods (5−6.5 and 12–13 years), when it is difficult to diagnose predisposition to the infringement of the locomotor activity. These periods are connected with the age of physiological changes in young human organism. Within other age periods the predisposition to the infringement of the locomotor activity is possible to be diagnosed. The diseases of such sort are closely connected to general infringements of human CNS. This is very important for preventive diagnostics.

The organization of gait is different for various age groups of the healthy probationers (I–IV groups) and for the Parkinson patients (V group). Random movement dynamics is characteristic of the healthy probationers. Organization and rigidity in gait dynamics is inherent in the Parkinson patients.

The received results can present practical value in different studies of other diseases of human motor system (for example, Huntington's disease) and in diagnosing various infringements of human CNS.

In this paper we have clearly demonstrated that the set of relaxation, kinetic and spectral parameters as well as the characteristics of discrete non-Markov stochastic processes are valuable for the diagnosis of Parkinson's disease.

Since the similar situation is typical for the majority of the phenomena in live systems our conclusions is of profound importance for live sciences.

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