Correlations and statistical memory effects as markers of age-related changes in complex systems of living nature

Sergey Demin
Institute of Physics
Kazan Federal University
Kazan, Russia
serge_demin@mail.ru

Dmitry Averkiev
Institute of Physics
Kazan Federal University
Kazan, Russia
aver263@gmail.com

Valentin Yunusov
Institute of Physics
Kazan Federal University
Kazan, Russia
valentin.yunusov@gmail.com

Natalya Demina
Institute of Physics
Kazan Federal University
Kazan, Russia
vnu_357@mail.ru

***Abstract*—In this paper, we study the physical mechanisms of the biological aging phenomenon of complex systems of living nature. We show that the correlations and effects of statistical memory, established within the framework of the Memory Functions Formalism, can serve as markers of age-related changes in the neuromuscular system and visual-motor coordination of a person. The dynamometric signals of representatives of older age groups are characterized by a shorter lifetime of statistical memory and an increase in the scale of fluctuations compared to the signals of young volunteers. The aging of an organism leads to a distinct deformation of the spatiotemporal structures represented in the phase space and to a change in the spectral behavior of the signals. The results obtained will be of interest to data sciences, complex systems physics and gerontology.**

Keywords—data sciences, complex systems, biological aging, time series analysis, correlations, effects of statistical memory, dynamometric signals, markers

1. Introduction

Starting from the second half of the 20th century, studies of the dynamics and evolution of complex systems of diverse nature have acquired particular relevance in the natural sciences. Complex systems are considered as composite objects represented by a significant number of interacting components. Such interaction leads to unique properties of complex systems, such as openness, nonlinearity, adaptability, emergence, self-organization, and critical transitions [1]. Living systems have the most complex spatiotemporal organization, the study of which requires the development of new theoretical approaches, experimental methods, as well as their combination using artificial intelligence technologies (classical learning, neural networks, and deep learning) [2].

Each of the biomedical signals (electroencephalograms, electrocardiograms, electromyograms, etc.), fixed at a certain time interval with a given sampling rate, is a manifestation of a complex set of physiological processes and can contain a large amount of information about the state of both an individual organ and an organism.

While theoretical approaches to the search for diagnostic criteria for various diseases of the human body have been developed to a sufficient extent, in studies of age-related changes in living systems, questions remain, primarily related to the search for ways to describe the physical aspects of the phenomenon of biological aging most fully [3]. To solve such issues, the authors propose to use the Memory Functions Formalism (MFF) – a theoretical approach to the study of correlations and effects of statistical memory in the dynamics of complex systems [4, 5].

2. The study of the evolution of complex systems within the Memory Functions Formalism

MFF is a theoretical approach developed by the Kazan school of statistical and computational physics as applied to the discrete dynamics of complex non-Hamiltonian systems of various nature [4, 5]. Here we will not dwell on the basic mathematical relations introduced into the MFF. It should be noted that this approach allows extracting a significant amount of information hidden in time signals by studying auto- and cross-correlations, statistical memory and synchronization effects, relaxation and kinetic parameters, orthogonal dynamic variables.

Correlations describe the relationship between two or more random variables in the absence of a direct functional relationship between them. At higher levels of the statistical description of correlations in a hierarchical way, the idea of the effects of statistical memory arises. Statistical memory reflects the hidden nature of the processes of creation, propagation and decay of correlations. The possibility of a quantitative and qualitative description of statistical memory appears due to the consideration of internal interactions and aftereffects that occur between parts or components of a complex system.

Here, by analyzing the dynamometric signals of healthy subjects of different age groups, we demonstrate the key role of correlations and effects of statistical memory in describing the phenomenon of biological aging of living systems.

3. Correlations and statistical memory effects as markers of biological aging

The dynamics of the output power impulse of people in different age groups was recorded by a group of American physiologists led by D.E. Vaillancourt [6, 7]. The variability of the output power pulse of the human index finger was recorded using a dynamometric sensor. Representatives of three age groups participated in the experiment: Group I (20-24 years old), Group II (64-69 years old), Group III (75-90 years old).

Subjects of all age groups had moderate muscle activity. The wrist and unused fingers of the right-hand during registration were fixed in a motionless state. The volunteer pressed the dynamometric sensor with the side of his index finger (Fig. 1).

In the first part of the experiment, for each participant was the maximum pressing force was identified. In the second part of the experiment, volunteers pressed the sensor with a pressing force of 5%, 10%, 20% and 40%. The required force was achieved by matching the theoretically calculated signal displayed on the screen and the dynamometric signal obtained by pressure on the sensor. Such registration makes it possible to consider the complex mechanisms of synergy of the neuromuscular system and visual-motor coordination of a person.

Fig. 1. Demonstration of an experiment on registration of a dynamometric signal

Here we cannot present all the results of the analysis of these biomedical signals. Let us dwell only on fixing the effects of statistical memory. The MFF uses the measure $\varepsilon=\varepsilon_1(0)$ [4, 5] to detect these effects. In the case of ε»1, the lifetime of the memory in the system is much shorter than the propagation time of the correlations. The temporal evolution of the system is characterized by weak statistical memory. A decrease in the parameter characterizes the lengthening of the memory lifetime in dynamics. For the case ε~1 the process is characterized by long-term (strong) statistical memory. An intermediate variant is associated with the manifestation of moderate statistical memory.

An increase in the average values of the measure of statistical memory from group I to group III indicates an obvious suppression of statistical memory during biological aging of the human neuromuscular system (Fig. 2).

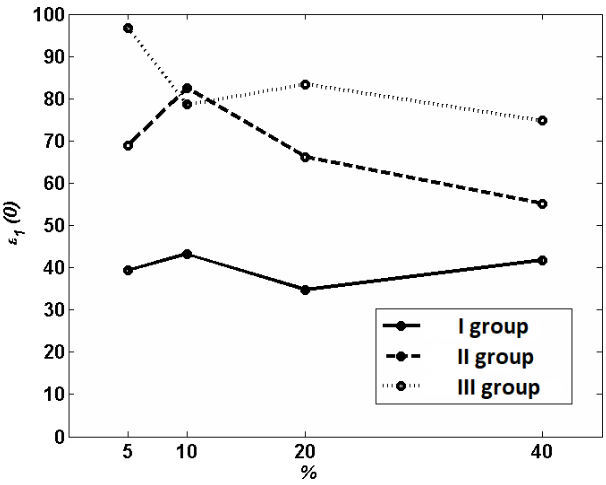

Fig. 2. Average values of the statistical memory measure for three age groups of volunteers at 5, 10, 20 and 40% of the maximum pressure on the dynamometric sensor

4. Conclusion

In this work, we discovered a weakening of the effects of statistical memory during biological aging of the human neuromuscular system. The dynamics of the output power pulse of elderly and old people is characterized by a shorter memory lifetime and an increase in the scale of fluctuations compared to the signals of young volunteers. The weakening of statistical memory is a kind of indicator of functional changes in the neuromuscular activity of a person during aging. In addition, age-related changes lead to an obvious deformation and stratification of the spatiotemporal structures of signals in the phase space and a change in their spectral behavior.

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