CORRELATIONS AND STATISTICAL MEMORY EFFECTS AS MARKERS OF AGE-RELATED CHANGES IN COMPLEX SYSTEMS OF LIVING NATURE

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Annotation

In this paper, within the framework of Memory Function Formalism, 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 can serve as markers of age-related changes in the body of a person. As a result of analysis, we identify features of statistical memory of dynamometric signals of representatives of older age groups and young volunteers. In addition, age-related changes lead to deformation and stratification of the spatiotemporal structures of signals in the phase space and a change in their spectra.

Introduction

Presently, studies of the dynamics and evolution of complex systems of diverse nature have acquired particular relevance in the natural sciences. Complex systems have unique properties [1] and are considered as composite objects with a large number of interacting components. The study of living systems requires the development of new theoretical approaches, experimental methods due to the complex spatiotemporal organization.

In contrast, to the well-developed theoretical approaches to the search for diagnostic criteria for various diseases of the human body, in studies of age-related changes in living systems, questions remain, related to the search for ways to describe the physical aspects of the phenomenon of biological aging most fully [2]. 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 [3].

Authors

Kazan Federal University

D.E. Averkiev*,
S.A. Demin,
V.A. Yunusov,
N.Y. Demina

Kazan Federal University
Kazan, Russia

**Phone: +7 (909) 305-85-57;*
**E-mail: aver263@gmail.com*

Methods

MFF is a author's theoretical approach as applied to the discrete dynamics of complex non-Hamiltonian systems [3,4]. Correlations describe the relationship between two or more random variables in the absence of a direct functional relationship between them. Statistical memory reflects the hidden nature of the processes of creation, propagation and decay of correlations.

The frequency-dependent generalization of the first measure of memory for the discrete evolution of complex living systems has the form:

$$\varepsilon_i(\nu) = \left\{ \frac{\mu_{i-1}(\nu)}{\mu_i(\nu)} \right\}^{\frac{1}{2}}.$$

The power spectrum of the i-th order memory function *M(t)*:

$$\mu_i(\nu) = \left| \Delta t \sum_{j=0}^{N-1} M_i(t_j) \cos(2\pi\nu t_j) \right|^2 .$$

The value of the parameter at zero frequency contains information about long-range temporal correlations of the studied temporal signal. The special role of statistical memory effects in the behavior of complex living systems can also be detected using the second measure of memory [4]:

$$\delta_i(\nu) = \frac{\widetilde{M}'_i(\nu)}{\widetilde{M}'_{i+1}(\nu)},$$

The numerical value of the parameter allows evaluating the degree of manifestation of long-range correlations in the variability of the amplitude of the output force impulse of people of different age groups.

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 force of 5%, 10%, 20% and 40%.

Results

Fig. 1(a) shows phase portraits for the variability of the output force impulse of two dynamic orthogonal variables   for representatives of each age group with pressure force of 5, 10, 20 and 40 %. Phase clouds for a participant from the first age group have a centered shape, symmetrical with respect to the origin. In the case of representatives from group II and group III there is a noticeable deformation of the phase portraits, which is associated with more significant fluctuations in the dynamics of the output power pulse. In addition, an increase in the scale of phase clouds is noticeable.

Fig. 1(b) shows the power spectra of the first-order memory function   for three age groups of people (5% of the maximum pressing force value). In the frequency behavior of the function   for representatives of the first age group, spectral peaks are clearly observed at frequencies of 20 Hz, 40 Hz. They reflect the periodic features of the functioning of the human neuromuscular system. For the second and third age groups, the data of spectral bursts shift to higher frequencies. The change in periodic features in the power spectra of memory functions is a marker that characterizes the biological aging of the human neuromuscular system.

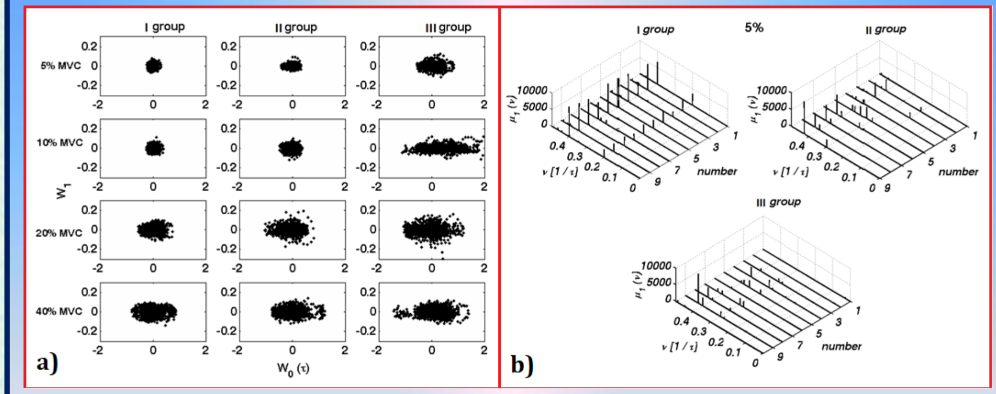

Fig. 1. Phase portraits compiled by two orthogonal dynamic variables for the variability of the output force impulse of representatives of three age groups at different levels of the pressing force (a), Power spectra of the first memory function for representatives of three age groups. As an example, the spectra are given for 5 % of the level of the maximum pressure on the sensor (b)

Results

Fig. 2(a) shows the average values of the first measure of memory at zero frequency at different pressure levels. Comparison of these values indicates a significant increase in this measure for representatives of the second and third age groups compared with the group of young volunteers. Noticeable decrease in the lifetime of memory in the studied physiological series is a marker of age-related changes in the human neuromuscular system.

Fig. 2(b) shows the average values of the second measure of statistical memory at zero frequency at four pressure levels. The lifetime of memory in the studied physiological signals for all age groups is much shorter than the relaxation times of the correlation function. The results obtained indicate a significant role of the effects of statistical memory in the signals of the human neuromuscular system during aging.

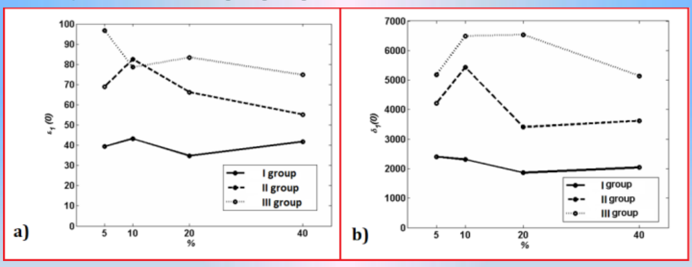

Fig. 2. Average values of the statistical memory measure for three age groups of volunteers at 5, 10, 20 and 40% of the maximum pressure on the dynamometric sensor (a),
Average values of the second measure of memory or three age groups of people (at different pressure levels) (b)

Conclusions

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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