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Age-related alterations of relaxation processes and non-Markov effects in stochastic dynamics of R–R intervals variability from human ECGs

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Abstract

In this paper, we consider the age-related alterations of heart rate variability on the basis of the study of non-Markovian effects. The age dynamics of relaxation processes is quantitatively described by means of local relaxation parameters, calculated by the specific localization procedure. We offer a quantitative informational measure of non-Markovity to evaluate the change of statistical effects of memory. Local relaxation parameters for young and elderly people differ by 3.3 times, and quantitative measures of non-Markovity differ by 4.2 times. The comparison of quantitative parameters allows to draw conclusions about the reduction of relaxation rate with ageing and the higher degree of the Markovity of heart rate variability of elderly people.

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Keywords: Discrete non-Markov processes; Time-series analysis; Heart rate; Relaxation processes; Complex systems

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1. Introduction

The ageing of a human organism has been in the focus of attention in physics of live systems over the past years. One of the most significant systems of vital activity of a human body is its cardiovascular system. Today there are a number of scientific studies on the problems of biological ageing of the cardiovascular human system. The latter is extremely sensitive to age-related as well as pathological changes in a human organism. Thus not only physiologists, biologists and physicians have been involved in this studies but also experts from other natural-science areas. Conditions of a human heart are estimated by means of various parameters. Thus heart rate variability (HRV) represents one of the most frequently used parameters, in cardiology. Nowadays there are different methods of studying HRV dynamics. In recent years [1], fluctuations of heartbeat dynamics have been studied by means of several methods derived from nonlinear dynamics and statistical physics, such as detrended fluctuation analysis (DFA) [2,3], spectral analysis [4], entropy [5–7], correlation dimension [8]. In paper [9] authors illustrate the problems related to the physiological signal analysis with representative examples of human heartbeat dynamics under healthy and pathological conditions which is based on two methods: power spectrum and detrended fluctuation analysis. In this paper different characteristics of heartbeat: $1/f$ fluctuations, long-range anticorrelations (monofractal analysis), self-similar cascades, multifractality and nonlinearity are considered. By means of a wavelet-based multifractal formalism it is shown that healthy human heartbeat dynamics exhibits higher complexity which is characterized by a broad multifractal spectrum. In paper [10] multiresolution wavelet analysis has been used to study the HRV in a patient with different pathological conditions. Noise effects of abnormal heartbeats were considered in paper [11]. The correlation exceptions of heartbeat dynamics of different sleep stages often have been researched lately. In papers [12,13] correlation properties of the magnitude and the sign of increments in the time intervals between successive heartbeats during a light sleep, a deep sleep, a rapid eye movement sleep were discovered by means of the detrended fluctuation analysis. Multiscaled randomness [14], multifractal analysis [15], simulation by nonlinear oscillators [16], fractal approach based on scaling of a frequency spectrum on power law $1/\omega^{\alpha}$ [17], quantitative analysis [18] are also used to analyze HRV. The change of correlations and statistical memory effects is one of the most important questions [19] in HRV dynamics observed with ageing [1,4].

Among existing methods of researching HRV one can differentiate the methods of estimating HRV in a time area, spectral methods of estimating HRV in a frequency area, as well as nonlinear methods. The last group of methods has proved to be a powerful means to study various complex systems and has brought about significant achievements in processing biological and medical data. In recent years universal methods of statistical physics have been more often used in medicine and biology. The methods of statistical physics which have been used to research real complex systems [20–25], in the field of cardiology reveal essentially new opportunities for the analysis, diagnostics and forecasting the processes of biological ageing and diseases