Prospects for using indicators of non-linear analysis of heart rate variability as markers of the functional state of the athlete's body when performing training and testing loads

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Abstract

Objective of the study was to identify modern approaches to the use of indicators of non-linear analysis of heart rate variability as markers of the functional state of the athlete's body when performing training and testing loads, indicators of the readiness of body systems to perform a load of a given intensity, criteria for assessing the quality of recovery processes within the framework of operational and routine control measures.

Methods and structure of the study. The scientific work used a computerized systematic search for relevant articles from the electronic databases PubMed, Scopus, ResearchGate, Web of Science, eLibrary. Among the initially selected 196 articles met the inclusion criteria and were used for the analysis of 62 papers.

Results and conclusions. The prospects of using and potential advantages of non-linear analysis methods as tools for monitoring the functional state of the athlete's body have been studied, and possible limitations of their use in the practice of sports training have been identified. It is shown that one of the most promising methods of nonlinear analysis is the method of detrended fluctuation analysis (DFA), which makes it possible to evaluate the multifractal spectrum of time series and calculate the DFA α1 index; intensity zones, when assessing the functional state of the athlete's body in the pre- and post-load period.

Keywords: *heart rate variability; nonlinear analysis; DFA index α1, functional state marker.*

Introduction. The rhythmocardiography method is increasingly used and widely used not only in medicine (clinical, space, experimental) [6], but also in the field of scientific, methodological and medical-biological support of sports training. This is due to the confirmed importance of studying and analyzing the characteristics of the heart rhythm when assessing the functional state of an athlete's body as a key physiological indicator characterizing the processes of autonomic, neurohumoral and central regulation [2, 3]. The advantages of using HRV indicators when assessing the functional state of the body include the non-invasiveness of the method, a high level of reliability and insignificant variability, objectivity and accuracy of statistical processing of the electrocardiographic signal, the ability to visualize data and analyze them in real time, during dynamic observations, the integrity of the indicator, which is the basis for an objective assessment of the autonomic support of the cardiovascular and respiratory systems, and the mechanisms of humoral regulation [5]. To solve research and applied problems of sports training, the feasibility of a comprehensive assessment of the functional state of an athlete within the framework of operational control in natural conditions of the training process is also very important.

Objective of the study was to identify modern approaches to the use of indicators of non-linear analysis of heart rate variability as markers of the functional state of the athlete's body when performing training and testing loads, indicators of the readiness of body systems to perform a load of a given intensity, criteria for assessing the quality of recovery processes within the framework of operational and routine control measures.

Methods and structure of the study. To solve the research problems, a search was carried out for relevant articles posted on the electronic databases PubMed, Scopus, ResearchGate, Web of Science, and eLibrary. Of the initial selection, 196 articles met the inclusion criteria and 62 papers were used for analysis.

Results of the study and discussion. In publications by domestic and foreign experts that reveal the capabilities of the method of rhythmocardiography and HRV monitoring in athletes at rest, after test or physical exercise at the stages of the training process, the choice of the evaluated indicators and the methods used (frequency and spectral analysis) is based on the assumption of the linearity of the recorded ECG signal. However, the diverse influences on HRV, in particular, the neurohumoral mechanisms of higher autonomic centers, predetermine the nonlinear nature of changes in heart rate, which, in turn, requires the use of appropriate methods [7, 10, etc.]. It is noted that the traditional methods of analyzing variability usually consider heart rate as a linear stochastic system and do not take into account the “chaotic component” inevitably present in the rhythm of even a healthy heart [1], it is emphasized that the mechanism that controls heart rate is inherently refers to chaotic processes [8]. As part of solving this problem, the concept of studying HRV time series based on chaos theory is being actively developed using nonlinear methods for analyzing the structure of the heart rhythm, which, unlike more common methods for assessing HRV, make it possible to evaluate not the magnitude of variability, but the quality, scaling and correlation properties signals, providing a detailed understanding of the properties of heart rate time series caused by physiological processes [10]. Nonlinear methods, compared to linear HRV indicators, are able to detect more subtle changes in heart rate behavior [11].

One of the most promising approaches to the analysis of such characteristics is the nonlinear method of analyzing detrended (with detrending) fluctuations DFA (Detrended Fluctuation Analysis), which makes it possible to identify and localize the moment of change in the functional state by fluctuations in the values of the short-term scaling indicator DFAα1.

Research results have confirmed its low dependence on heart rate and its suitability for characterizing the complex autonomic regulation of the heart when performing exercises of varying intensity, modality and under different environmental conditions [12, 19].

The analysis made it possible to identify promising areas for using DFA analysis indicators in the field of scientific, methodological and medical-biological support of sports training: as a criterion for assessing the functional state of the body and the level of adaptation to environmental conditions [4]; as a marker of readiness for the load of a training session [22] and the level of recovery after exercise [11], including taking into account gender differences [20]; to identify threshold values of load and heart rate during testing of athletes [13, 15, 21, etc.]; when monitoring the intensity of the training load, including in real time [9,14,17, etc.]. The experiments carried out are not only of a research nature, but also of a clearly applied nature, which allowed the authors to develop specific methodological recommendations for use in practical work.

So, M.M. Lapkin et al. [4], having studied the potential of fractal-fluctuation analysis of nonlinear components of the heart rate as a tool for parameterizing the functional state of a person, developed a scale for assessing the values of the DFA α1 indicator with the following interpretation of the ranges of values: from 1.5 to 1.7 – failure of adaptation; from 1.1 to 1.5 – voltage; from 0.8 to 1.1 – relative physiological rest; from 0.5 to 0.8 – state of fatigue or sleep. The boundary values of these ranges correspond to transient processes.

M. Schaffarczyk et al. [22] experimentally established the feasibility of using the level and dynamics of DFA α1 as a biomarker of readiness for the load of a training session: measured during a standardized low-intensity warm-up, this indicator can be used to assess the physiological status, taking into account which the training program of athletes should be promptly adjusted.

The fact that the DFA α1 index, based on fractal correlation properties, is characterized by a wide dynamic range, covering all areas of exercise intensity [12], allowed a number of authors to recommend its use as a biomarker when distributing exercise load across intensity zones. The potential of this method, "sensitive" to moderate loads, for characterizing the level of internal load of the body, which is critical for ensuring real individualization of training programs, for providing "polarization training" in sports with a predominant manifestation of endurance, is assessed quite highly [9, 18, 23]. An analysis of the kinetics of the DFA α1value during physical activity of increasing intensity revealed its decrease as the external load increases. In this case, achieving the aerobic threshold level corresponds to a DFA α1value of 0.75 (a value occupying an "intermediate" position between well-correlated fractal patterns and uncorrelated behavior), achieving an anaerobic threshold - 0.5 (a value indicating random patterns of contractions, indicating a vegetative state of instability and reflecting a further loss of fractal correlation properties).

It is important for use in sports-specific conditions that a relatively short recording time is acceptable for this index, while a steady state is not required [12, 16]. The range of potential advantages of the method expands with the use of software and hardware systems that allow real-time monitoring of the DFA-alpha1 index in field conditions, which provides information on the intensity of exercise without preliminary testing of the athlete with lactate measurement or gas analysis.

Conclusions. Nonlinear methods of HRV analysis reveal aspects of heart rate regulation that are not available in amplitude and frequency analysis. The most effective tool is multifractal signal analysis (DFA), in which the DFA α1 marker is used as a marker. Being an indicator of "training stress", quite sensitive even to loads of moderate intensity, it can be used as a marker of internal load, a criterion for assessing readiness for the load of a training session and the level of post-exert recovery.

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