DYNAMICAL PECULIARITIES OF CONCATENATIONAL CHANGES IN FUNCTIONAL CARDIOVASCULAR PARAMETERS

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ABSTRACT

Research background and hypothesis. Traditional time series analysis techniques, which are also used for the analysis of cardiovascular signals, do not reveal the relationship between the changes in the indices recorded associated with the multiscale and chaotic structure of the tested object, which allows establishing short-and long-term structural and functional changes.

Research aim was to reveal the dynamical peculiarities of interactions of cardiovascular system indices while evaluating the functional state of track-and-field athletes and Greco-Roman wrestlers.

Research methods. Twenty two subjects participated in the study, their average age of 23.5 ± 1.7 years. During the study standard 12 lead electrocardiograms (ECG) were recorded. The following ECG parameters were used in the study: duration of RR interval taken from the II standard lead, duration of QRS complex, duration of JT interval and amplitude of ST segment taken from the V standard lead.

Research results. Significant differences were found between inter-parametric connections of ST segment amplitude and JT interval duration at the pre and post-training testing. Observed changes at different hierarchical levels of the body systems revealed inadequate cardiac metabolic processes, leading to changes in the metabolic rate of the myocardium and reflected in the dynamics of all investigated interactions.

Discussion and conclusions. It has been found that peculiarities of the interactions of ECG indices interactions show the exposure of the functional changes in the body at the onset of the workload. The alterations of the functional state of the body and the signs of fatigue, after athletes performed two high intensity training sessions per day, can be assessed using the approach of the evaluation of interactions between functional variables. Therefore the evaluation of the interactions of physiological signals by using time series analysis methods is suitable for the observation of these processes and the functional state of the body.

Keywords: electrocardiogram, time series, functional state.

INTRODUCTION

Interactions of local complex adaptive system (CAS) components, which require exploring the processes of discovery and examination at a microscopic level, open the door to the global processes of the specific models or helps to predict the behavior of the global nature (Provata et al., 2008).

One or two digital time series contain information about the research object, and using certain mathematical methods this information can be expressed in the form of mathematical relationships. In this article we used analytical method developed by professor Z. Navickas and L. Bikulčienė (2008). This method enables the

evaluation of the dynamic relationships of the ECG parameters cointegrating primary data series into the second order matrix.

Signal dynamic interactions, characterising individual systems, are very significant to functional analysis of the human body as CAS. Identification of parameters, method sensitivity analysis and the understanding the physiological significance of final results still remains an actual problem (Beckers et al., 2001; Batzel, Bachar, 2010). Non-linear mathematical analysis methods and application integration solving a range of medical and sports science problems can be some of those solutions.

The aim of the study was to reveal the dynamical peculiarities of interactions of cardiovascular system indices while evaluating the functional state of track-and-field athletes and greco-roman wrestlers.

RESEARCH METHODS

Twenty two subjects participated in this study, their average age was 23.5 ± 1.7 years. Further characterization of the subjects is presented in Table 1. The study was divided into two investigations. The first investigation was designed to analyse the peculiarities of concatenational changes in the functional parameters of the cardiovascular system of elite Greco-Roman wrestlers (n = 12), when two high-intensity training sessions per day were carried out (wrestlers performed a typical Rouffier exercise test in the 4 stages of the investigation protocol: on the 1st day before the training session, after the 1st and the 2nd training sessions, and on the 2nd day before the training session). The second investigation allowed exploring peculiarities of concatenational changes in the functional parameters of the cardiovascular system of track-and-field athletes and Greco-Roman wrestlers (n = 10) during a dosed exercise test (Rouffier test).

Table 1. **Characteristics of the subjects**

Investigations	Number of participants	Stature, cm	Weight, kg
Investigation 1 Elite Greco-Roman wrestlers	12	180.0 ± 2.22	87.7 ± 5.72
Investigation 2 Elite Greco-Roman wrestlers and track-and-field athletes	10	181.5 ± 0.94	78.0 ± 1.55

During all investigations standard 12 lead electrocardiograms (ECG) were recorded using computerized analysis program "Kaunas–Load" (Institute of Cardiology, KMU, Lithuania). Discriminants of the parameters calculated from the following ECG time series were as follows: duration of RR interval taken from the II[nd] standard lead, duration of QRS complex, duration of JT interval and amplitude of ST segment taken from the V[th] standard lead.

The assessment of inter-parameter relationships obtained while monitoring vital signals was developed by Z. Navickas and L. Bikulčienė (2008). Two synchronous time series (xn : = 0, 1, 2,…) and (yn : = 0, 1, 2,…), which represent the ECG parameter measurements were structured and analysed using the numerical characteristics of the second order matrix (Formula 1) and the main components of it (Berškienė et al., 2009):

$$A_n := \begin{bmatrix} x_n & x_{n-1} - y_{n-1} \\ x_{n+1} - y_{n+1} & y_n \end{bmatrix} \quad (1)$$

The most informative characteristics rose from matrix definitions and they were discriminants (D) of matrix:

$$D\,A_n = ((x_n - y_n)2 + 4((x_{n-1} - y_{n-1}) * (x_{n+1} - y_{n+1}))) \quad (2)$$

Complexity measure reflecting the degree of coupling between heart electrophysiological variables was expressed as the value of D (see Formula 2). If the value of D decreases and is close to zero, the interaction between two synchronous numerical time series (ECG signals) increases, but the complexity of the adaptive system decreases.

A statistical difference was tested applying the nonparametric Mann-Whitney test for independent samples and the nonparametric Wilcoxson test for related samples (*SPSS for Windows 17.0*). The difference when p value was lower than 0.05 was regarded as statistically significant.

RESEARCH RESULTS

The concatenation of ST segment amplitude and JT interval duration analysis allowed indicating endogenous functional changes in heart (Figure 1). Statistically significant ($p < 0.05$) differences were indicated between pre and post-training testing. ST-segment and JT interval discriminant values in the range of change were much smaller compared to the

higher fractal levels (systemic level and subsystemic level relating to the heart regulatory processes).

The analysis of the interactions of all investigated parameters showed that the fatigability enhanced fluctuations induced by dosed exercise test trials, and it increased respectively to the number of training sessions. These results confirm the dynamic sensitivity of the complex adaptive system to initial conditions and attractor distribution or transition from one attractor to another leading to fluctuation.

We also observed changes at different hierarchical levels of the body systems. These changes revealed inadequate cardiac metabolic processes, leading to changes in the metabolic rate of the myocardium and reflected in the dynamics of interactions. Such kind of the dynamic development of interactions indicates the occurrence of fatigue which is not observed at the systemic level (Figures 2 A and B).

Figure 1. **Dynamics of ST segment and JT interval interaction during Rouffier test before and after training sessions (subject M. E.)**

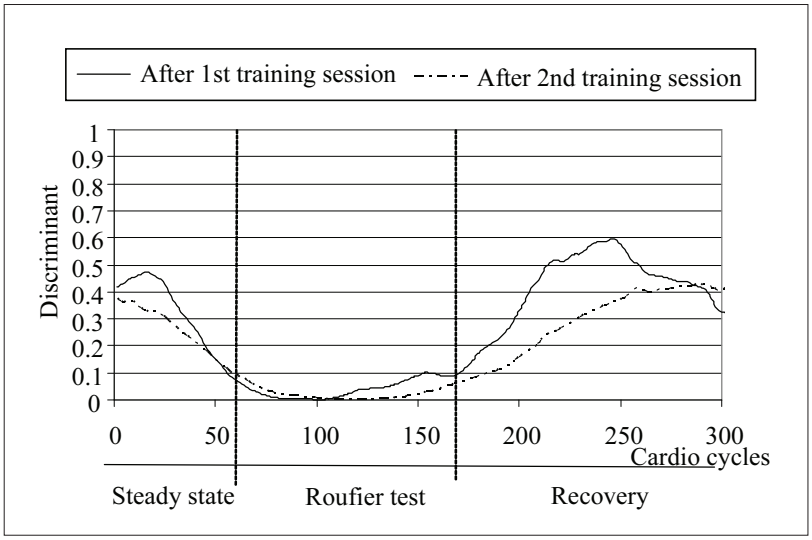
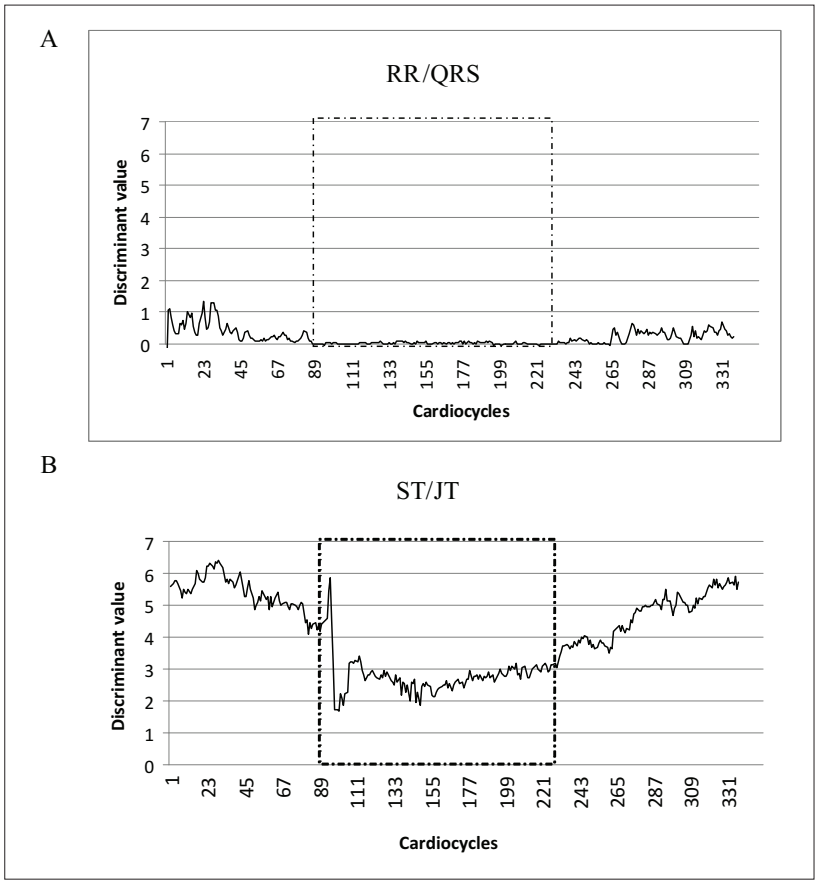


Figure 2. **Dynamics of RR interval and QRS complex interaction (systemic level – regulatory processes) (A) and concatenation of ST segment amplitude and JT interval duration (subsystemic level – cardiac metabolism processes) (B) during dosed exercise test (subject M. E.)**



Note. Dotted-line square indicates physical load during the exercise test.

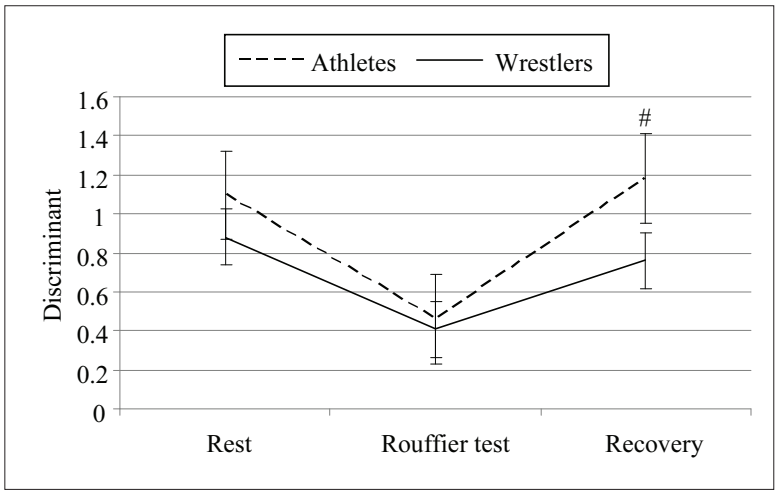


Figure 3. **Dynamics of QRS complex and JT interval interaction (subsystemic level–regulatory processes) during dosed exercise test**

Note. # – significant difference ($p < 0.05$) between groups.

Our results showed that the analysis of the alteration in cardiovascular functional parameters in the body readiness for the upcoming load starts even before the load begins and the performance is typical for each athlete (Figure 3). However, statistically significant difference ($p < 0.05$) was observed just at the recovery period.

DISCUSSION

The results of this study show that conventional Heuristic evaluation has proved to be less sensitive to relatively small changes in the evaluation of the functional state in terms of the body function inter-parametric links and their synergistic properties. Currently, the approach analysis – complexity – is becoming more and more popular (Rickards et al., 2010).

Elite Greco-Roman wrestlers who have two high-intensity training sessions per day have been studied in detail. This study sought to identify indicators of susceptibility to cardiovascular function and the wealth of information in assessing relatively small changes in the functional state (Krstacic et al., 2007). The overall effect of the influence of the functional state characteristics change because of fatigue changes at different levels of functional inter-parametric concatenations.

Statistically significant ($p < 0.05$) differences were found between inter-parametric connections of ST segment amplitude and JT interval duration at the pre and post-training testing. ST-segment and JT interval discriminant values in the range of change were much smaller compared to the higher fractal levels (systemic level and subsystemic level relating to the heart regulatory processes). These changes revealed inadequate cardiac metabolic processes leading to changes in the metabolic rate of the myocardium and reflected in the dynamics of interactions (Enoka, Duchateau, 2008; Šmidtaitė et al., 2009).

The last study analyzed the peculiarities of concatenational changes in the functional parameters of the cardiovascular system during dosed aerobic exercise test more precisely. It is known that the cerebral cortical motor centers of the signals at parallel with the motor impulses sent to muscles and autonomic nervous system, which reduces cardiac parasympathetic inhibition (Costa et al., 2008).

Track-and-field athletes exhibited lower degree perturbations than wrestlers ($p < 0.05$) in the period of body recovery, but an inverse dynamics of relationships was observed compared to the alteration of signal interactions before and during the exercise test. Corresponding oscillations were obtained during the analysis of different fractal levels (systemic, subsystemic) of the system (Peng et al., 2009; Šmidtaitė et al., 2009).

Likewise, in assessing functional fitness test results of the complex and the relative performance of high-performance athletes is better than Heuristic evaluation, and it allows the individual indicators reveal relatively small differences and changes in the individual skills of athletes and thus should be used for more sports studies. The obtained results of the exercise test enabled us to identify the dynamical changes of the independence of parameters, and analyse an opposite phenomenon – their interaction (Costa et al., 2008).

CONCLUSIONS AND PERSPECTIVES

1. Individual features are observed at different hierarchical levels of the body, therefore individual and all-levels observation scale involving evaluation enable a more detailed understanding of the functional characteristics of the body.

2. Evaluation of interaction changes in electrocardiographic parameters indicates that when the body starts the exercise, a natural preparation for the next workout is in progress.

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ŠIRDIES IR KRAUJAGYSLIŲ SISTEMOS FUNKCINIŲ RODIKLIŲ DINAMINIAI POKYČIAI

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SANTRAUKA

Tyrimo pagrindimas ir hipotezė. Tradiciniai laiko eilučių analizės metodai, taikomi širdies ir kraujagyslių sistemos (ŠKS) signalams tirti, neatskleidžia registruojamų rodiklių tarpusavio sąsajų kaitos, susijusios su tiriamojo objekto daugiaskale struktūra ir chaotiškumu, kurie leidžia nustatyti trumpalaikius bei ilgalaikius nagrinėjamos sistemos struktūrinius, funkcinius pokyčius.

Tikslas: nustatyti širdies ir kraujagyslių sistemos funkcinių rodiklių sąsajų kaitos ypatumus vertinant lengvaatlečių ir graikų-romėnų imtynininkų organizmo būsenas.

Metodai. Tirti 22 graikų-romėnų imtynininkai ir lengvaatlečiai, kurių amžiaus vidurkis 23,5 ± 1,7 metų. Visų testavimų metu buvo registruojamos standartinės 12 derivacijų elektrokardiogramos (EKG). Buvo vertinama šių EKG rodiklių dinaminiai tarpusavio sąsajų pokyčiai: RR intervalo trukmė (II derivacija), QRS komplekso trukmė, JT intervalo trukmė ir ST segmento amplitudė (V derivacija).

Rezultatai. Reikšmingai skyrėsi ST segmento amplitudės ir JT intervalo trukmės tarpusavio sąsajų pokytis prieš pratybas ir po jų. Stebint įvairių organizmo sistemų pokyčius nustatyta nepakankama širdies metabolinė veikla, dėl kurios pakito miokardo medžiagų apykaita. Šias ypatybes parodė tirtų rodiklių sąsajų kaita.

Aptarimas ir išvados. EKG rodiklių sąsajų kaitos vertinimas atskleidė: dar prieš krūvį organizme vyksta funkciniai pokyčiai. Organizmo funkcinės būklės kaita ir nuovargio požymiai, sportininkams atliekant dvejas intensyvias pratybas per dieną, gali būti vertinami naudojant funkcinių rodiklių tarpusavio sąsajų kaitos vertinimo metodą. Šiuos pokyčius rodo skirtingų organizmo sistemų funkcijų lygmenų rodikliai, todėl individualus visų sistemų stebėjimas ir vertinimas leidžia pagerinti sportininkų treniruotės vyksmo eigą ir valdymą.

Raktažodžiai: elektrokardiograma, laiko eilutės, funkcinė būklė.

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