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Assessment of Dynamics of Inter-Parameter Concatenation during Exercise Tests

E. Venskaityte, J. Poderys

Lithuanian Academy of Physical Education, Laboratory of Kinesiology,
Ausros str. 42-31, LT-44221, Kaunas, Lithuania, phone: +370 37 302650, e-mail: evenskaityte@yahoo.com

N. Balagué

Catalonian Academy of Physical Education, Barcelona University,
Laboratory of Kinesiology, Lithuanian Academy of Physical Education

L. Bikulciene

Institute of Cardiology, Kaunas University of Medicine,
Department of Applied Mathematics, Kaunas University of Technology,
Studentu str. 50-323, LT-51368, Kaunas, Lithuania, liepa.bikulciene@ktu.lt

Introduction

An existing control mechanism from subcellular to systemic levels ensures that information is constantly exchanged across all levels of organization, even at rest, and enables body to adjust to an ever-changing environment. The dynamic processes are evident in the complex fluctuations of physiologic output signals (heart rate, blood pressure and others) [3]. The outputs of physiologic systems under neural regulation exhibit high degree of variability, special and temporal fractal organization which remains invariant at different scales of observation, as well as complex nonlinear properties [10].

Considering body's general functional state and its adaptability, complex model allows evaluating its integrity and reflects the main functional interactions. Cardiovascular signals are largely analyzed using traditional time and frequency domain measures, but these measures fail to indicate the dynamics of inter-parametric concatenation which is related to multiscale organization and nonequilibrium dynamics. The complementary role of conventional signal analysis methods and emerging multiscale techniques is, therefore, an important frontier area of investigation [3]. Most electrocardiograms (ECG) lately were recorded by digital, automated machines equipped with software that measures ECG intervals and amplitudes, provides an instantaneous interpretation. However, different automated systems may have different technical specifications that result significant differences in the measurement of amplitudes, intervals, and diagnostic statements [7]. Consequently the collection and analysis of ECG data in the present research would provide additional insights regarding to body as a complex system performance during provocative exercise test and also enables analysis of inter-parametric concatenation within.

Previous researchers in order to find an explanation for the origin of fatigue during past decades suggested a few models and hypothesis that induces re-examine some of the classical theories. Predominant newly developed models of fatigue derivation are known as lactic acid hypothesis [2], cardiovascular anaerobiosis catastrophe model (CAC) [9], central governor model (CGM) [8], and task dependency model of fatigue (TDM) [5]. Lately most of researchers emphasize integrative approaches of the interaction between peripheral and central aspects of fatigue. Concerning the concatenation of parameters that point out the causes of fatigue, the non-linear dynamical systems theory (NDST) enables to reveal this phenomenon as a part of dynamic system processes. The dynamic systems approach indicates the existence of fluctuations under the presence of noise in the system and also predicts their enhancement as dynamic instability appears. Depending on previously mentioned objects, the purpose of this research is to asses dynamics of inter-parameter concatenation and to establish new features of body's fatigability.

Methods

12 sportsmen (Lithuanian (N=7) and Spanish (N=5) endurance athletes) (age (23,7±1,9, years), height (1,86±2,4, m), weight (74±2,1, kg)) were involved in this study. They performed provocative exercise test, which consisted of warm-up and maximal physical load (300 W), on bicycle ergometer. During all investigation were registered standard 12-lead ECG by „Kaunas-load" ECG analysis system. While analysis of separate phases of

research protocol, recorded parameters were distributed into five segments: steady state, warm-up, maximal load, beggining of recovery (1-2 min.) and the end of recovery (4-5 min.).

Theoretical background: the new method for assessment of inter-parameter concatenation during monitoring of vital signals has been developed. For investigation of two objects interaction two synchronous numerical time series $(x_n; n = 0,1,2,...)$ and $(y_n; n = 0,1,2,...)$ representing exploratory object must be formed. Here x_n and y_n are real numbers and its represent results of some measurements (in this case it is an ECG parameters of athletes involved in this research). When elements of series is determined variables, information about object of investigation can be described using mathematical relationships [1]. In this paper the method based on matrix theory is proposed.

Let two numerical time series $(x_n; n = 0,1,2,...)$ and $(y_n; n = 0,1,2,...)$ be given. Then the matrix time series $(A_n; n = 0,1,2,...)$ can be formed. Here $A_n := \begin{bmatrix} a_n & b_n \\ c_n & d_n \end{bmatrix}$ and coefficients $a_n := x_n$, $b_n := \alpha(x_{n-1} - y_{n-1})$, $c_n := \beta(x_{n+1} - y_{n+1})$, $d_n := y_n$, when parameters α, β are at choice dependent on properties of time series $(x_n; n = 0,1,2,...)$, $(y_n; n = 0,1,2,...)$. In the simplest case coefficients $\alpha = \beta = 1$. So, in this case four time series $(a_n; n = 0,1,2,...)$,... $(d_n; n = 0,1,2,...)$ and one matrix time series $(A_n; n = 1,2,3,...)$ are obtained. Though different methods for data analysis can be applied, in this investigation of matrix time series the numerical characteristics of second order matrices and main components of matrices A_n were used:

$$\mathrm{Tr}A_n := a_n + d_n \text{ (trace of matrix } A_n\text{)}, \quad (1)$$

$$\mathrm{dfr}A_n := a_n - d_n \text{ (difference)}, \quad (2)$$

$$\mathrm{cdp}\,A_n := b_n \cdot c_n \text{ (co-diagonal product)}, \quad (3)$$

$$B_n := \begin{bmatrix} \dfrac{\mathrm{dfr}A_n}{2} & b_n \\ c_n & -\dfrac{\mathrm{dfr}A_n}{2} \end{bmatrix}. \quad (4)$$

From these initial parameters follow characteristics which have more applicative sense:

$$\mathrm{dsk}\,A_n = (\mathrm{dfr}A_n)^2 + 4\,\mathrm{cdp}\,A_n \text{ (discriminate)}, \quad (5)$$

$$\det A_n = \frac{1}{4}\left((\mathrm{Tr}A_n)^2 - \mathrm{dsk}\,A_n\right) \text{ (determinant)}, \quad (6)$$

$$\lambda_{1,2} = \frac{1}{2}\left(\mathrm{Tr}A_n \pm \sqrt{\mathrm{dsk}\,A_n}\right), \quad (7)$$

From definitions of matrix characteristics the main interest have discriminates of matrices A_n, accordingly the time series $(\mathrm{dsk}A_n; n = 0,1,2,...)$ investigation is important. The elements of matrices can be formed in more complicated way:

$$b_n := \alpha_1(x_{n+1} - y_{n+1}) + \alpha_2(x_{n+2} - y_{n+2}), \quad (8)$$

$$c_n := \beta_1(x_{n-2} - y_{n-2}) + \alpha_2(x_{n-1} - y_{n-1}). \quad (9)$$

where $\alpha_1 + \alpha_2 = 1, \alpha_1 > \alpha_2 > 0$, $\beta_1 + \beta_2 = 1$, $\beta_1 > \beta_2 > 0$.

On purpose to escape noise influence, the elements can be averaging. Then terms of time matrices $a_n := \sum_{j=-k}^{l} \gamma'_j x_{n+j}$, $b_n := \sum_{j=1}^{l} \sigma'_j (x_{n+j} - y_{n+j})$, $c_n := \sum_{j=-k}^{-1} \sigma''_j (x_{n+j} - y_{n+j})$, $d_n := \sum_{j=-k}^{l} \gamma''_j y_{n+j}$.

If number of terms in sums increases, the sequence of discriminates become smoother, but its character is the same. From numerical investigation it is obtained that changing of parameters α, β has influence only to amplitude of sequence, but not for character, because in further calculations the simplest case of matrices formation were used. The initial data was normalized using formula

$$x_{new\,value} = \frac{x_{old\,value} - x_{\min}}{x_{\max} - x_{\min}}, \quad (10)$$

where $x_{\min}$ and $x_{\max}$ are minimal and maximal physiological values of parameter.

Research results

In order to evaluate the changeable inter-parametric concatenations and its dynamics during provocative exercise test, electrocardiogram parameters monitoring and its data sequences analysis were applied. According to the model of integral evaluation of body functioning during exercise, the following ECG indices were registered: RR and JT interval, QRS complex and ST segment.

With a view to the qualitative metabolic alteration in myocardium, the relationship between RR interval and ST segment was analyzed and it decreased during provocative workouts and respectively individuality of parameters increased. The opposite processes were observed in the period of body recovery (Fig. 1, Subject A).

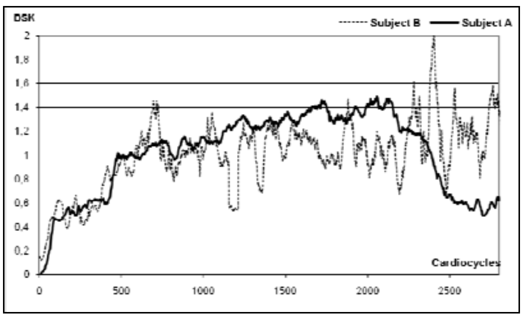

Fig. 1. Concatenation dynamics of RR interval and ST segment of subjects A and B

However, observation of same indices interaction in different subjects revealed diverse results. As many physiological time series such as the one is shown in (Fig. 1, Subject B), was extremely inhomogeneous and nonstationary, fluctuating in an irregular and complex manner.

Although tendency of concatenation of RR interval and ST segment remained unaltered in both cases, but interaction of these parameters was incident to individual features of subject's body.

Profound examination of supplying (cardiovascular) system was carried out by evaluation of QRS complex and ST segment interaction, which allowed indicating endogenous, functional changes of heart.

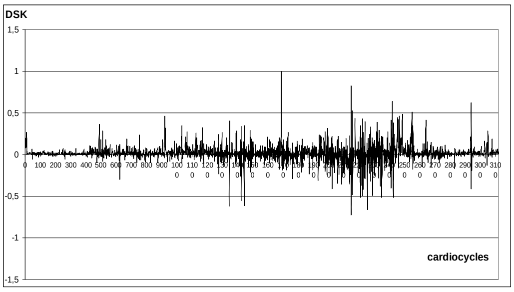

Fig. 2. Concatenation dynamics of DQRS complex and ST segment

The dynamics of concatenation of QRS complex duration and ST segment fluctuations were relatively high (see Fig. 2), and only in the end of maximal physical load the instability increased. The instant resumption of integrative processes between those parameters was noticed during recovery phase, but primary level was not restored.

Also was paid an attention to the average inter-parametric values dynamics during provocative exercise test. The average values of each test protocol phase of QRS complexes and ST amplitude interaction is shown in Fig. 3. The steady state mean values *(0,162±0,059)* altered onset of workout and peak of change was achieved during maximal physical load *(0,098±0,030)*.

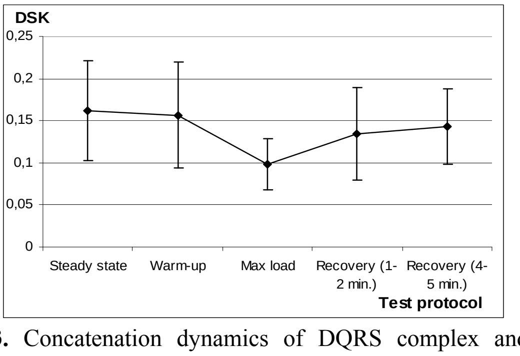

Fig. 3. Concatenation dynamics of DQRS complex and ST segment distributed in order of five phases of test protocol

Similar tendencies were obtained in other inter-parametric characteristics, which were analysed in this research. However, individual features of interactions between various parameters are shown in Fig. 4, where each subject's average values are illustrated separately. In some cases subjects, for instance, subject *No. 8*, demonstrated altered steady state values *(0,015±0,005)* from the values observed while subjects achieved the phase of maximal load *(0,066±0,005)* and after following abrupt recovery.

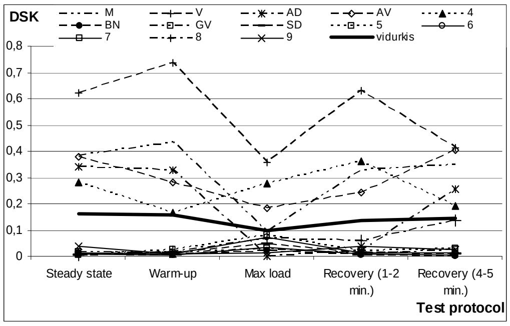

Fig. 4. Individual features of concatenation dynamics of QRS complex duration and ST segment

In the first recovery stage parameters' values returned to the level of steady state, but in some cases, after the 4th and the 5th minutes of recovery the values decreased.

Finally, the analysis of the typical individual behavior of the dynamic physiological system shows that provocative exercise test induced fluctuations increase as the fatigability enhances respectively. And concatenation of parameters often modulates the individual actions of the components, thus altering their local functionality by relaying global context.

Discussion and conclusions

Natural systems so far are exhibiting components with relatively elementary features (mass, chemical activity, wavelength, frequency ect.), but there are also cases where complex state occurs in systems with more sophisticated components. When system performance is pushed up, there exists a threshold above which interaction between components overtake outside interaction [4]. Concatenation of inter-parametric variables of complex system, causes an integration considering their time and space characteristic into an organized whole. The variability of the registered signals accompanied by alterations [3], [12], according to provocative physical load, provide all the requirements for the creation of a new stable state through fluctuations

Obtaining the results of exercise test enables to identify the dynamics of independence of parameters and analyse an opposite phenomena – concatenation. The complexity of dynamic system also decreases [3] with the loss of parametric independence. An increase of the concatenation of the parameters responsible for qualitative metabolic alteration in myocardium (RR interval and ST segment) and respectively, lower independence of the same indices regarding to the dominance of the sympathetic nervous system were revealed during provocative exercise test. The concatenation of duration of QRS complex and ST segment analysis allowed to indicate endogenous, functional changes of heart (inter-parametric connections within supplying (cardiovascular) system). An investigated ratio decreased when subjects were close to task failure and it is associated with internal functional changes of cardio processes.

In period of body recovery the inverse dynamic of relationships were observed compare it to the alteration of signals interactions during exercise test. Fatigue arises through the interaction of the component processes and causes the reduction of low activity in neurobiological system. Although specific physiological mechanisms are probably highly task-dependent [5] there is non-linear dynamic system theory that enables to indicate specific causes of fatigue and provides knowledge about the phenomena of critical instability. Lately an integrative point of view [10] to the process of fatigue suggests that fatigue origin is related to the interaction between regulation (CNS) and peripheral system (muscular system). However, it is a very few possibilities to find a single mechanism able to explain the genesis of fatigue [6]. Also it can be considered as the consequence of an underlying mechanism – dynamic instability.

Due to summing-up an investigation it must be denoted that evaluation of body processes as a complex system mechanisms interaction, affords ground not only for an exposure of inter-parameter concatenation dynamics, but also allows indicating new features of body's fatigability. Furthermore, more research is required to understand the factors of inter-parameter concatenation dynamics and mechanisms of fatigue.

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The dynamic system components' interactions are essential in determining how system functions as a whole. Research based on complex model, which integrates the main functional systems, enables to reveal inter-parameter concatenation and allows indicating new features of body's fatigability obtained during provocative exercise tests. The analytical method was applied for the assessment of physiological system interactions in different fractal levels by electrocardiogram parameters monitoring and its data sequences analysis. The dynamics of inter-parametric concatenation provide new approach of electrocardiogram data sequences analysis and propose usefulness of the analytical methods in the field of complex systems. Ill. 4, bibl. 11 (in English; abstracts in English, Russian and Lithuanian).

Е. Венскайтите, И. Подерис, Н. Балагю, Л. Бикулчене. Оценка динамики между параметрическими взаимодействиями во время физических нагрузок // Электроника и электротехника. – Каунас: Технология, 2009. – № 6(94). – С. 89–92.

Динамическая система компонентов взаимодействия имеет важное значение при определении того, как система функционирует когда она воспринимается как одно целое. Исследование основано на комплексной модели, которая объединяет основные функциональные системы, даёт возможность выявить взаимодействие между параметрами и позволяет раскрыть новые особенности утомляемости организма, полученные в ходе осуществления провокационных тестов. Аналитический метод был применен для оценки физиологической системы взаимодействия в различных фрактальных уровнях, анализируя параметры электрокардиограммного мониторинга. Оценка динамики между параметрическими взаимодействиями представляет возможности создания новых методов анализа последовательности электрокардиограммных данных и подтверждает целесообразность применения аналитических методов в области сложных систем. Ил. 4, библ. 11 (на английском языке; рефераты на английском, русском и литовском яз.).

E. Venskaitytė, J. Poderys, N. Balagué, L. Bikulčiene. Tarpparametrinių sąsajų kaitos vertinimas atliekant fizinio krūvio mėginius // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 6(94). – P. 89–92.

Dinaminės sistemos komponentų tarpusavio sąsajos yra itin svarbios, nustatant kaip sistema funkcionuoja, kai ji yra vertinama kaip visuma. Tyrimas pagrįstas kompleksiniu modeliu, kuriame integruojamos pagrindinės organizmo funkcinės sistemos, suteikiančios galimybę analizuoti žmogaus organizmo tarparametrines sąsajas ir nustatyti naujas nuovargio pasireiškimo ypatybes, atliekant provokacinį fizinio krūvio mėginį. Analitiniai metodai buvo taikomi vertinant fiziologinių sistemų tarpusavio sąsajas skirtinguose fraktaliniuose lygmenyse, atliekant elektrokardiogramos rodiklių analizę. Šis tarpparametrinių sąsajų kaitos vertinimas atveria galimybes kurti naujus elektrokardiogramos rodiklių laiko eilučių analizės metodus ir rodo, kad analitinius metodus tikslinga taikyti tiriant kompleksines sistemas. Il. 4, bibl. 11 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).