

Functional state assessment on the dynamics of interparametric concatenations during exercise tests

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Key words: exercise tests; cardiovascular system; muscular system; complex system.

Abstract. The aim of this study was to complement an analytical approach by new methodology of data sequences analysis of muscular and cardiovascular indices during the assessments of functional state. The participants of the study were 14 elite Greco-roman wrestlers and they underwent two exercise tests 30 squats per 45 s while 12-lead ECG was recorded continuously and 30-s vertical jumps test while the height, contact and flight times of each jump recorded. The parametric interactions parameters and their sequences analysis based on a mathematical method founded upon a matrix theory were applied.

The obtained results enabled to identify dynamical changes of the independence of parameters or an opposite phenomenon – interaction. The dynamics of ECG or performance parameters did not allowed to find out the moments of critical changes during the exercising. The dynamics of concatenation between the time of push-off and the height of jumps while performing repeated jumps has a tendency to increase in the values of discriminant and the fluctuations at some point of jumping task comes on. Analysis of concatenation between ECG or muscle performance parameters allows distinguishing the individual peculiarities which could be in value of discriminant, in time of exercising before the fluctuations occurs, in character how the body behave as to compensate fatigue. It was concluded that assessment the dynamics of inter-parametric concatenation of physiological parameters based on the data sequences analysis provide a new approach in the field of functional state assessment allowing to reveal features of functional preparedness and fatigability during workloads.

Introduction

Analytical approach has been successful in describing the physical world but it is not the same when we must handle with the treatment or coaching related issues, i.e. by applying it to living objects (1, 2). Human body during exercising in fact represents a much more complex phenomenon reflecting the nonlinear processes of body's general functional state and its fatigability in a fractal or chaotic manner. Interrelation mechanisms of body systems and component interactions are essential in determining how body functions as a whole as a complex dynamic adaptive system. The actual problem in medicine and sports science is how to catch very small changes in functional state of the body during the training, adaptation to sudden change of environmental conditions or peaking. Functional state could be recognized by assessing the reactions to exercise tests (3) but the chosen indices and criteria of assessment play an important role. The aim of this study was to complement an analytical approach by new methodology of data sequence analysis of muscular and cardiovascular indices during the assessments of functional state of elite athletes.

Material and methods

The data registered during the stage assessment of functional state of the muscular and cardiovascular systems in a cohort of elite athletes of Lithuanian Olympic Team were taken for analysis. The participants of the study were 14 elite Greco-roman wrestlers, and two months before taking part in the World championship they underwent two exercise tests: 1, Roufier test (30 squats per 45 s) while a 12-lead ECG was recorded continuously; 2, a half of Bosco Test (30-s vertical jumps) while the height, contact, and flight times of each jump were recorded. The individual assessment of functional changes was made by analytical approach and assessment of the dynamics of concatenation of registered indices by the use of a method based on matrix theory proposed by Vainoras et al. (4). According to this method two synchronous time series ($x_n := 0, 1, 2, \dots$) and ($y_n := 0, 1, 2, \dots$), which represent results of some measurements were structured and analyzed by using the numerical characteristics of second order matrix and main components of it:

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

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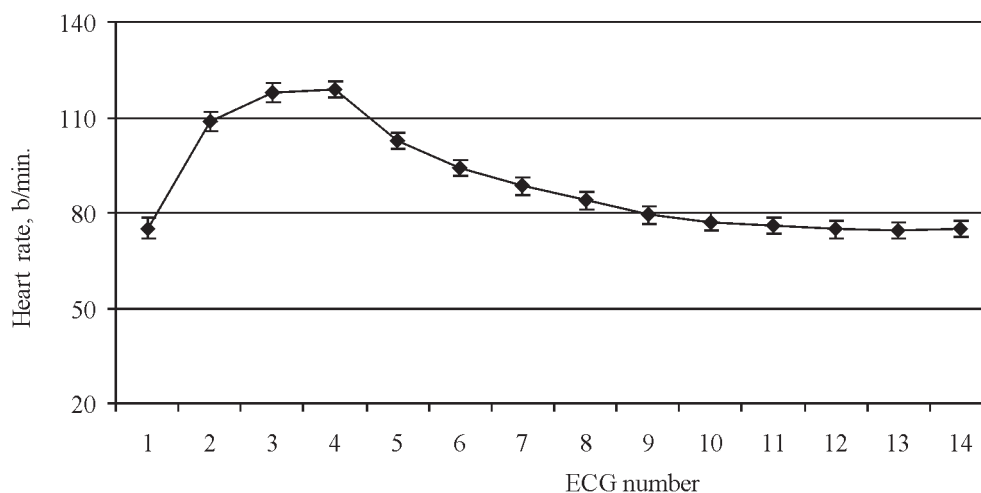


Fig. 1. Dynamics of heart rate during the Roufier test
1 ECG, before load; 2–4 ECG, Roufier test; 5–14 ECG, recovery.

From definitions of matrix characteristics, the main interest has discriminants of the matrix:

$$dsk A_n = ((x_n - y_n)^2 + 4((x_{n-1} - y_{n-1}) * (x_{n+1} - y_{n+1})))$$

The initial data for analysis of muscular performance indices was the time of contact and the time of flight in seconds and for cardiovascular system – normalized ECG parameters of RR and JT intervals, ST-segment depression, and duration of QRS complex. All parameters were interpolated using cubic splines, because numbers of terms in data sequences were not equal. Then discriminants of all investigated relationships were defined. If discriminants of matrices become near to zero, then matrices from idempotent become to nilpotent, i.e. concatenation comes close to maximal and conversely. Individual features of the relationship between the registered ECG or muscle performance parameters were analyzed in the study.

Results

Fig. 1 presents the dynamics of heart rate while performing the Roufier exercise test (30 squats per 45 s) and during the recovery after exercising. The dosed exercise test did not caused changes of heart rate to a very large degree, i.e. at the end of exercising the heart rate increased up to 118.6 ± 2.5 b/min. Fast recovery was an essential feature of highly skilled athletes and after one minute of recovery the heart rate was close to the initial data (75.2 ± 3.3 b/min). There were no significant differences in values of HR and their dynamics between individuals during exercising or recovery in respect to training experience.

The results obtained during the data sequences analysis of cardiovascular indices upon a matrix theory showed that the sequence of discriminants

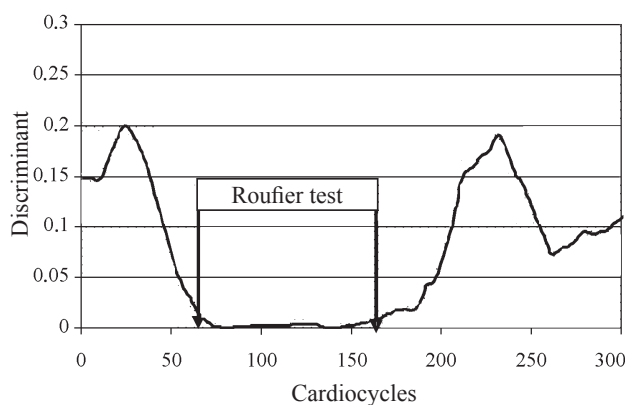


Fig. 2. Interaction between the dynamical changes of the length of the RR interval and duration of the QRS complex
Note: arrows indicate the beginning and the end of the applied workload.

for some ECG parameters was very sensitive to changing of functional state before, during exercising and during the recovery. Firstly, the decrease of discriminant between the length of the RR interval and duration of the QRS complex started before the exercising and it was a typical feature in for all participant of the study. Secondly, fast decreases of discriminant were observed during the exercise stress and in period of recovery the inverse dynamic of relationships were observed (Fig. 2).

During the physical stress, when the sympathetic system of nerves dominates, a concatenation between JT interval and QRS complex increased, i.e. independence of parameters decreased. The concatenation of some parameters, i.e. duration of QRS complexes and ST-segment depression, did not show significant changes. An observation of the interaction of the same indices (the amplitude of the

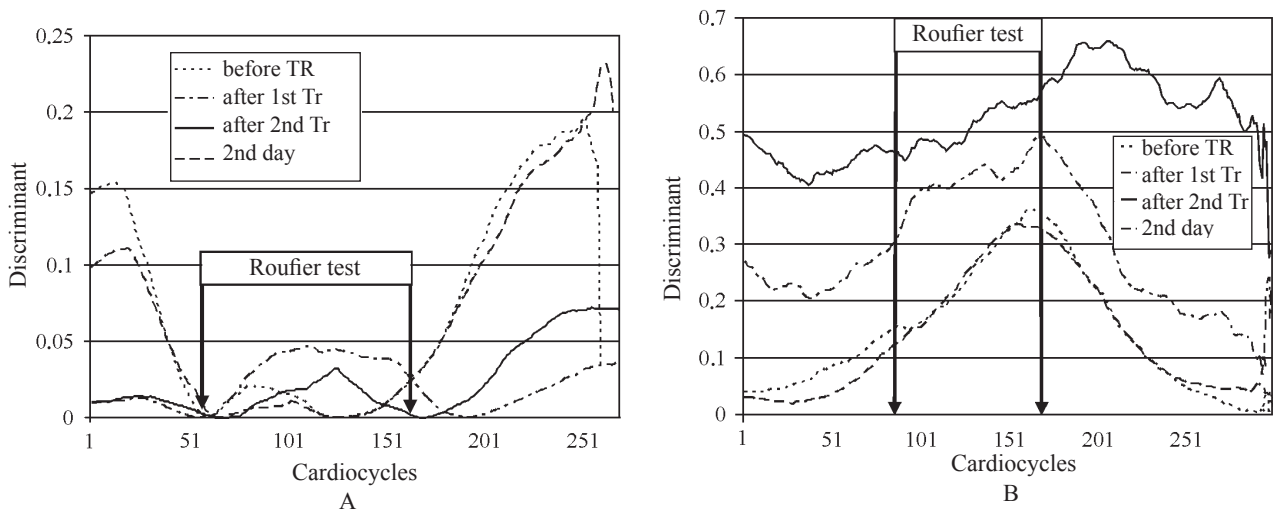


Fig. 3. Individual features (subject S.A. and subject A.P.) of the interaction between the dynamical changes of the amplitude of the ST segment and the duration of the JT interval

Note: arrows indicate the intervals of the beginning and the end of the applied workload.
*An opposite response observed in the subject A who attended training for a longer time.

ST-segment and the duration of the JT interval) in different subjects revealed diverse results. As many physiological time series, one shown in Fig. 3 was extremely inhomogeneous and unstable concerning the stage of the investigation and the duration of subject's active training as opposite response was observed in the other subject who attended training for a longer time than his counterpart. Although similar tendencies were revealed in most of the examined wrestlers interparametric characteristics, interaction of these parameters was specific to the individual subject.

Fast development of fatigue and decrease of muscular power and the height of jumps is an essential feature while performing all-out exercise test why the decrease the height of jumps, and muscular power was significant. The analysis of dynamics of muscular power, time of push-ups or height of jumps did not allow to find out the critical changes of muscular performance, i.e. the moments in time of exercising. The dynamics of concatenation between the time of push-off and the height of jumps while performing repeated jumps has a tendency to increase the values of discriminant and fluctuations at some point of jumping task comes on. The averaged data of cohort (Fig. 4) hide individual peculiarities in changes of functional performance and allows revealing the tendencies of changes only. Individual dynamics of muscular functional performance during the vertical jumps test allows distinguishing individual peculiarities and these differences could be in value of discriminant; in time of exercising before the fluctuations occurs; in character how the participant trying to compensate fatigue (Fig. 5).

Discussion

At onset of exercise all body systems adapts it-

self with a series integrated response to meet the metabolic demands of exercising muscles (5) and all physiological systems appear to show similar non-monotonic activity at all times and at all functional levels (6). We tried to assess this interaction as part of complex system integration. In this study the changing parametric interactions and their dynamical changes during exercise tests, monitoring of the electrocardiographic or performance parameters, and their data sequences analysis based on a mathematical method founded upon a matrix theory were applied. The results obtained during the study enabled us to identify the dynamical changes of the independence of parameters, and analyze an opposite phenomenon – interaction. The complexity of a dynamic system also decreases (7) with the loss of parametric independence. The variability of the registered signals accompanied by alterations according to the dosed exercise test results does not provide comprehensive information about the creation of a new stable state through fluctuations.

The variability of the registered signals or conventional parameters during the performance a dosed exercise test does not provide comprehensive information about the hidden changes in functional state while the new analysis allowed to observe the creation of a new and relatively stable state through fluctuations.

The results obtained during the analysis of concatenation between analyzed parameters during the jumping task showed the importance and informativeness of individual assessment of the data. Averaged data showed the character and tendencies of changes during exercising but individual assessment the dynamics of discriminant values suggest about usefulness of such assessment in the field of func-

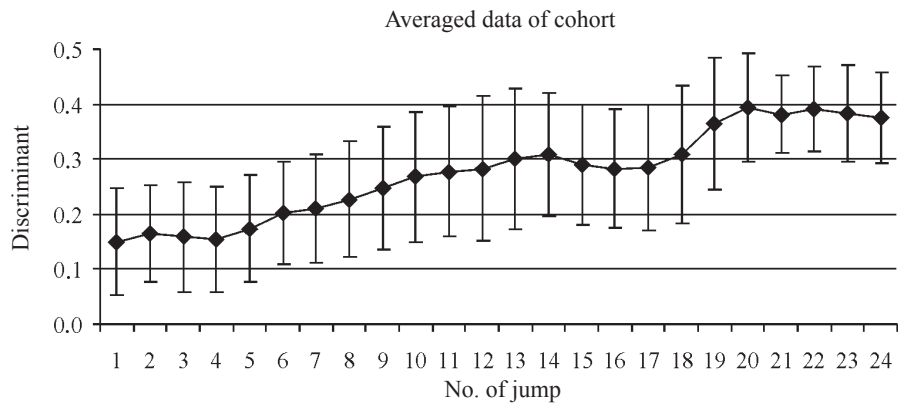


Fig. 4. Dynamics of muscular functional performance during the vertical jumps test (concatenation between the time of contact and the time of flight)

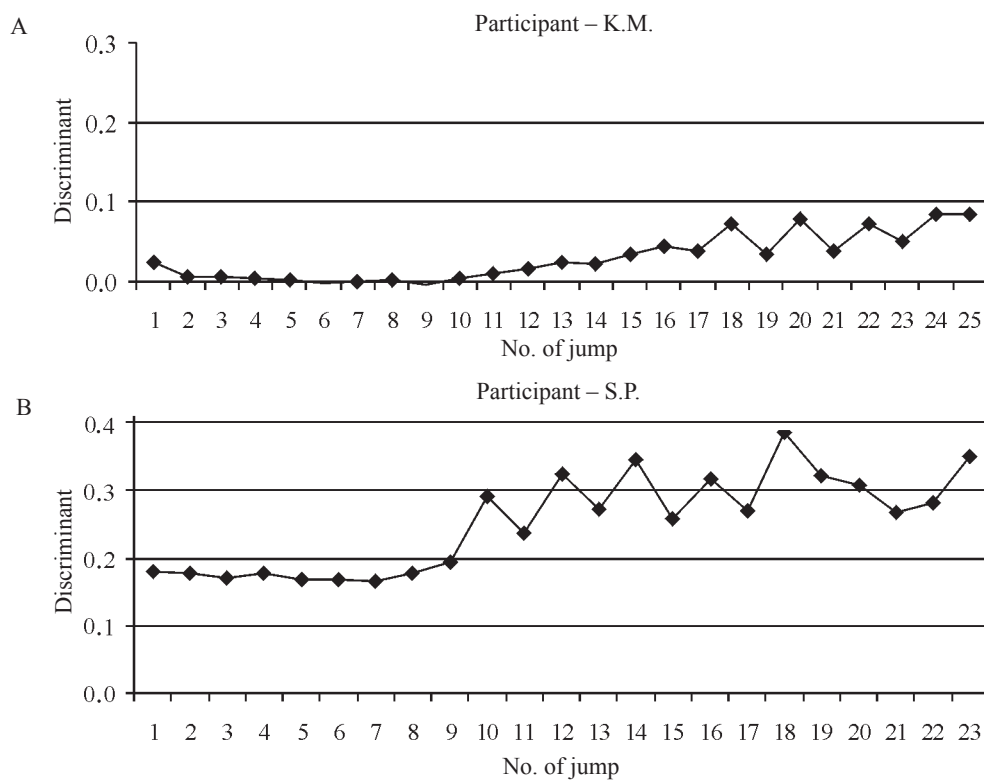


Fig. 5. Examples of individual dynamics of muscular functional performance during the vertical jumps test. Individual differences could be in value of discriminant; in time of exercising before the fluctuations occurs; in character how the participant trying to compensate fatigue.

tional state assessment during exercise tests.

It was shown that the fluctuations of performance during the motor task could be registered even in a single joint. Hristovski and others (8) analyzed the time series in the frequency and time domain as well as the time dependent variability of the elbow angle states. The fluctuations of the elbow angle states enhanced drastically close to the point of task failure. The results from the time series analysis suggest an interaction dominant dynamics, that is, a dynamics whose variance is dominantly influenced by

the inter and intra level as well as time interactions between the components rather than by component processes alone. The enhancement of fluctuations close to the failure point suggest that the task failure may be produced by a task specific constellations of constraints which destabilize the previous state and give a way to self-organization and transition to a more stable state (8). The vertical jumps test, as a maximal all-out exercise requires maximal voluntary efforts and a good coordination as well. The perception and control of action are influenced by

stimulation of multiple perceptual systems and these include vision, audition, haptics/kinesthetics, and the vestibular system (9). Behavior causes simultaneous changes in multiple forms of ambient energy, including kinematics of inertial forces. Therefore, the dynamic systems theory is helpful to explain the organization and emergence of fluctuations while performing repetitive jumps with maximal efforts. The complex system model of fatigue suggests that activity during fatiguing exercise occurs in an integrative manner, where internal signals from a number of different physiological systems, which are in a constant state of flux, are used by an integrative “governor system” to continuously modulate exercise by regulating power output, and therefore pacing strategy, to levels appropriate to the capacity of each different physiological system relative to the level of intensity of the fatiguing exercise being performed (6). Each adjustment in power output results in changes to all physiological systems, and therefore a specific period of time is required for afferent information to be able to assess the result of these changes in the physiological systems that will enable further adjustments in power output. This time lag requirement creates fluctuations in power output, and in the different physiological systems (6).

When the system performance is pushed up, there exists a threshold above which interaction between its

components overtakes the outside interaction (10). The results of different stages of investigation (before; during workload; during the recovery) altered values of inter-parameter relationships remained in all cases of posttraining monitoring. In the 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 the neurobiological system. Although specific physiological mechanisms are probably highly task-dependent (11), there is the nonlinear dynamic system theory that enables to indicate specific causes of fatigue and provides knowledge of the phenomenon of critical instability. Lately, an integrative point of view (12) on the process of fatigue suggests that the origin of the fatigue or optimal functional state is related to the interaction between the physiological systems, between various physiological mechanisms.

Conclusion

The assessment dynamics of interparametric concatenation of physiological parameters based on the data sequences analysis provide a new approach in the field of functional state assessment allowing revealing features of functional preparedness and fatigability while performing exercise tests.

Funkcinės būsenos vertinimai pagal tarpparametrinių sąsajų kaitą atliekant fizinio krūvio mėginis

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Raktažodžiai: fizinio krūvio mėginys, širdies ir kraujagyslių sistema, raumenų sistema; kompleksinė sistema.

Santrauka. *Tyrimo tikslas.* Praplėsti širdies ir kraujagyslių sistemos bei raumenų funkcinės būsenos tyrimo rezultatų analitinio vertinimo galimybes nauja vertinimo metodologija grindžiama dviejų laiko eilučių kointegracijos metodu. Tyrime dalyvavo 14 aukšto sportinio meistriškumo graikų romėnų imtynininkų, kurie atliko du fizinio krūvio mėginis, t. y. 30 pritūpimų per 45 sek., nepertraukiamai registruojant 12 standartinių EKG derivacijų ir 30 sek. trukmės vertikalaus šuoliavimo maksimaliomis pastangomis pratimą. Registruotų rodiklių sąsajos kaitai vertinti buvo pasirinkti antros eilės matricų analizės metodai, t. y. dviejų laiko eilučių kointegracijos analizė.

Tyrimo rezultatai parodė, kad pagal pasirinktą duomenų analizės metodą galima vertinti rodiklių sąsajos arba priešingai – jų tarpusavio nepriklausomumo kaitą. Pagal įprastus EKG ar raumenų darbingumo rodiklių kaitos vertinimus negalima stebėti ir išskirti kritinių paslėptų funkcinės būsenos pokyčių. Atliekant vertikalaus šuoliavimo pratimą, atsispyrimo ir lėkimo fazių trukmių sąsaja turėjo tendenciją mažėti ir tam tikru pratimo atlikimo momentu atsiradavo reikšmingų vertinamo rodiklio svyravimų (fluktuacijos). Sąsajos tarp EKG rodiklių ar raumenų darbingumo rodiklių kaitos vertinimas leidžia išskirti individualius organizmo funkcinės būsenos kaitos ypatumus, pastebėti slapto nuovargio atsiradimo momentus ir būdą, kaip organizmas bando kompensuoti didėjantį nuovargį. Daroma išvada, jog fiziologinių rodiklių tarpparametrinių sąsajų kaitos vertinimas grindžiamas laiko eilučių kointegracija yra naujas metodinis požiūris, praplečiantis funkcinės būsenos vertinimo galimybes, leidžiantis vertinti funkcinį parengtumą ir nuovargį atliekant fizinis krūvis.

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