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Cointegration of Different ECG Parametres for Various Physical Tasks

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Introduction

Any physical load evokes systemic reaction of organism functions combining cardiovascular system, central nervous system and muscles. The activity of these systems is brought out during different physical tasks performed at different time points and to a different degree.

A great number of scientific studies deal with the analysis of ECG parameters, the mechanisms of their functioning. New methods of analysis of research results broaden the assessment possibilities of human functional state. There have already been presented some studies investigating the concatenation of ECG parameters [1,2] by applying algebraic method of data cointegration. The concatenation of different ECG parameters for various physical tasks with different muscle groups involved was decided to analyze, in order to accomplish further studies in this field.

The aim of the study - to analyze the concatenation of different ECG parameters during various physical tasks by applying new analysis technologies.

The contingent and methods of the research

The work is focused on the analysis of the concatenation of different ECG parameters. A healthy subject of the study performed 4 different physical tasks: 1) provocative bicycle ergometry test; 2) provocative bicycle ergometry test with a physical task for arms; 3) exercise test for evaluation of abdominal muscle endurance; 4) exercise test for evaluation of back muscle endurance.

Physical loads of global (bicycle ergometry test performed by legs and arms) and regional (exercises training abdominal and back muscle endurance) character was applied. About 2/3 of the whole muscle mass is activated during the global physical workload, whereas the regional workload comprises the functioning from 1/3 to 2/3 of the whole muscle mass.

During the workload and 5 minutes after it ECG was registered. The subject performed a gradually increasing provocative bicycle ergometry test by legs. The load was increased every 60 seconds. The workload was started by applying 50 W of intensity. Later, the power was increased every minute by 50 W. Cycling frequency was 60 times per minute. The initial power applied to the arm bicycle ergometry test was 20 W, and was increased every minute by 20 W. Cycling frequency was 60 cycles per minute. The workload was continued until submaximal rate of heart contraction or until clinical features limiting physical load. The exercises training abdominal (trunk flexion) and back (trunk extension) muscle endurance were performed as follows: physical load was performed 6 times for 20 seconds with the rest intervals of 20 seconds between each load.

The evaluation of the heart functional indices was performed by the electrocardiogram analysis system „Kaunas - load“ created at the Institute of Cardiology of Kaunas University of Medicine. With the help of this system the electrocardiogram of 12 synchronous standard leads during the workload and the first five minutes of recovery were registered. The following parameters of II standard leads: RR interval, JT interval, ST segment were chosen. All data were normalized from 0 to 1 according to the formula:

$$x_{new\,value} = \frac{x_{old\,value} - x_{\min}}{x_{\max} - x_{\min}}, \qquad (1)$$

($x_{\min}$ and x_{max} – minimal and maximal values of the parameters). The concatenation between ST segment and JT interval as well as between RR amplitude and JT interval by applying the analysis method of second order matrices were analysed.

The methodology of two numeric time series investigation is presented when values of elements are determined.

Using mathematical methods for investigation of two parameter concatenation it is necessary to form two synchronous numerical time series $(x_n; n = 0,1,2,...)$ and $(y_n; n = 0,1,2,...)$ which represent exploratory object. Here x_n and y_n are real numbers and they represent of some measurements. Usually these are electrocardiogram signals (or some parameters of signals). 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 $a_n := x_n$, $d_n := y_n$, $b_n := \alpha(x_{n-1} - y_{n-1})$, $c_n := \beta(x_{n+1} - y_{n+1})$ when parameters α, β are at choice dependent on properties of time series $(x_n; n = 0,1,2,...)$ and $(y_n; n = 0,1,2,...)$. So, in this case four time series $(a_n; n = 0,1,2,...)$,... $(d_n; n = 0,1,2,...)$ and one matrix time series $(A_n; n = 0,1,2,...)$ are obtained. Of course these series can be formed using other mathematical relationships. Different methods for analysis of obtained series can be used [4], [5]. For investigation of matrix time series the numerical characteristics of second order matrices and main components of matrices A_n were used: $\mathrm{Tr}A_n := a_n + d_n$ (trace of matrix A_n), $\mathrm{dfr}A_n := a_n - d_n$ (difference), $\mathrm{cdp}\,A_n := b_n \cdot c_n$ (co-diagonal product), $B_n := \begin{bmatrix} \frac{\mathrm{dfr}A_n}{2} & b_n \\ c_n & -\frac{\mathrm{dfr}A_n}{2} \end{bmatrix}$ (main component of matrix A_n).

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

$$\begin{cases} \mathrm{dsk}\,A_n = (\mathrm{dfr}A_n)^2 + 4\,\mathrm{cdp}\,A_n, \\ \lambda_n^{1,2} = \frac{1}{2}\left(\mathrm{Tr}A_n \pm \sqrt{\mathrm{dsk}\,A_n}\right), \\ \det A_n = \frac{1}{4}\left((\mathrm{Tr}A_n)^2 - \mathrm{dsk}\,A_n\right). \end{cases} \quad (2)$$

Two important types of matrices in matrix analysis are important. The matrix $\boldsymbol{I}$ is called idempotent (matrix of stable power), if $I^2 = I$ and the $\boldsymbol{N}$ - nilpotent (matrix losing power), if $N^2 = \mathbf{0}$, where $\mathbf{0} := \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$.

For instance, the main component B_n is nilpotent if $\mathrm{dsk}A_n = 0$, and the matrices $I_n := \frac{1}{2}E + \frac{1}{\sqrt{\mathrm{dsk}\,A_n}}B_n$ and $E - I_n$ are idempotent if $\mathrm{dsk}A_n \neq 0$. If discriminants of matrices A_n become to zero then matrices A_n from idempotent become to nilpotent.

Mathematically, if the limits $\mathrm{dsk}A_n \to 0$, $b_n \to \bar{b}, c_n \to \bar{c}$, satisfying condition $\bar{b} \cdot \bar{c} \leq 0$ exists, then $B_n \to \begin{bmatrix} \pm\sqrt{|\bar{b} \cdot \bar{c}|} & \bar{b} \\ \bar{c} & \mp\sqrt{|\bar{b} \cdot \bar{c}|} \end{bmatrix} := \bar{B}$ and $\bar{B}^2 = \mathbf{0}$. It shows that chosen time series $(x_n; n = 0,1,2,...)$ and $(y_n; n = 0,1,2,...)$ become similar and it describes more associated system. The sequence of idempotent matrices $\left(\sqrt{\mathrm{dsk}A_n} \cdot I_n; n = 0,1,2,...\right)$ if the limit transitions $\left|\lambda_n^1 - \lambda_n^2\right| \to 0$, $\sqrt{\mathrm{dsk}A_n} \cdot I_n \to \bar{B}$ exists can be formed, and this sequence shows evolution of matrix sequence $(A_n; n = 0,1,2,...)$. When functional complexity of any structures are analyzed the most important problem is evaluation of inter element links and interaction between them. In 1983 V. I. Arnold presented the methods for assessment the dynamic characteristics of such interaction [3] but usage of those methods is problematic in case of living objects because many troubles start up in formalizing of physiologic processes. Methods for visualization of interaction of human physiologic processes have been developed in HeartMath Institute (USA) [4].

The dependency of presented parameters was measured by applying Spearman's rank correlation coefficient:

$$R = 1 - \frac{6\sum D^2}{N(N^2 - 1)}, \quad (3)$$

where R – rank correlation coefficient, D – difference between the ranks of two items, N – the number of observations. Correlation is strong when $-1 \leq R \leq 1$.

Results

The concatenation (2) of the parameters between ST segment and JT interval was analysed in order to study the inner heart functional changes.

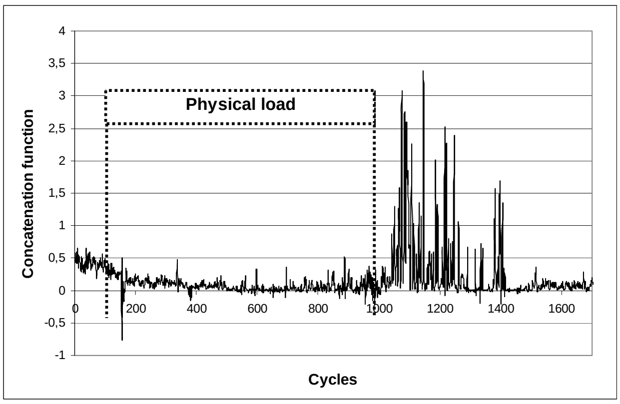

Fig. 1. The concatenation of the parameters between ST segment and JT interval during the workload performed by legs

The observation of the changes of the relation of these parameters during the workload performed by legs (Fig. 1) reveals obvious intensification of the concatenation during the load. The changes occurring with the beginning of recovery can indicate a certain changes of the heart function, which allows the returning to general work.

The performance of the workload by arms resulted in similar change of the concatenation of the parameters between ST segment and JT interval as compared to the change of the physical task performed by legs. However, greater fluctuations during the whole workload for arms were noticed, especially noticeable with the beginning of the maximum load. This may be caused by different flow of blood into the vessels of arms and legs. Arm veins have no valves, which causes higher arterial blood pressure and heart contraction rate during the arm work. This has an impact on the concatenation of the parameters specifying the functioning of the heart.

The scientists analysing the complexity of organism functions [5], determined a functional relation between supplying and regulatory systems reflecting the relation between JT and RR intervals. A strong concatenation of these parameters during the physical loads performed by arms and legs was observed. However, the fluctuations appeared at different points of time, i.e. during the tasks for arms the fluctuations emerged at the maximum of the workload, whereas during the tasks for legs they were noticed at the beginning of recovery.

The relation of ST segment and JT interval while performing the tasks for back muscle exercise is presented in Fig. 2. The subject underwent the task 6 times. Great fluctuations of the amplitude are noticed at the beginning of each load. However, after several seconds they tend to decrease. It is interesting to observe, that each repetition of the load reduces the amplitude of this initial fluctuation.

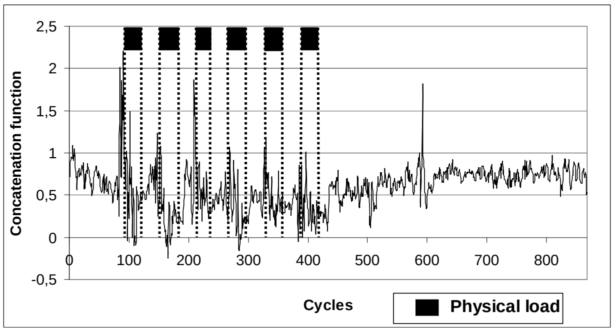

Fig. 2. The concatenation of the parameters between ST segment and JT interval during the exercises for back muscles

Fig. 3 presents the relation of ST segment and JT interval during the first and last load. During the first load the cointegration coefficient rises to 2 and during the last load it hardly reaches 1. This indicates the intensification of the heart and its adaptation to the load given. Yet, there is no strong concatenation of the parameters of ST segment and JT interval observed during the workload and rest. The absence of it may be influenced by the fact that the physical task and rest last only for 20 seconds. The parameters specifying the inner changes of the heart do not have enough time to adjust to each other.

The change of the concatenation of the parameters between ST segment and JT interval during the exercise for abdominal muscle endurance test is similar to the one for the back muscle exercise. However, it contains fewer fluctuations.

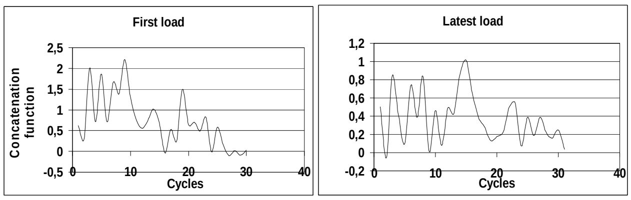

Fig. 3. The concatenation of the parameters between ST segment and JT interval during the first and last repetition of the exercise for back muscles

The concatenation of the parameters between JT and RR intervals of the exercise for abdominal muscle is presented in Fig. 4. Great fluctuations during the load and a strong concatenation of the parameters during the rest are noticed again. Even the period of recovery revealed greater fluctuations of the concatenation of these parameters than during the exercise for the back muscle.

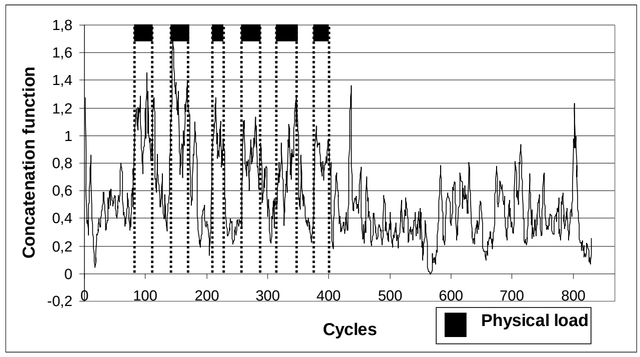

Fig. 4. The concatenation of the parameters between JT and RR intervals during the exercise for abdominal muscle training

Spearman's correlation coefficient (3) was calculated in order to measure the interdependency between ST segment and JT interval, as well as between JT and RR intervals Diagrams reveals that there is no difference among the stages of load, rest and recovery. A strong relation between the present parameters is absent as well.

Discussion of the results

Each analysed concatenation of parameters was observed due to its dynamics, which depends upon the stage of the test and the physical task. Each exercise is distinguished by an individual interrelation of ECG parameters. This interrelation depends on the group of muscles participating in the exercise.

The increase of fluctuations at the maximum of the physical load, or during the transitional stage from the rest to the load and vice versa reveals the idea of a chaotic process where the attractors are readjusted for further cooperation.

In the features of ECG parameters cointegration is clearly seen adaptation of the heart to the load. The dynamic of this adaptation can help to reveal important heart functional peculiarities.

In conclusion it can be asserted that the calculation of the concatenation of the parameters by applying the second order matrices analysis method better reveals the inner processes and changes of the organism than the calculation based on the correlation of the given parameters.

Acknowledgement

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Any physical load evokes systemic reaction of organism functions combining cardiovascular system, central nervous system and muscles. ECG parameters, their variations and mechanism of action/functioning reflect the peculiarities of the activity of these systems. The algebraic method of data cointegration, applied to the current work, allows observing the ways of chosen parameter concatenation during various physical tasks. The calculation of the concatenation of the parameters by applying the analysis method of second order matrices better reveals the inner processes and changes of the organism than the calculation based on the correlation of the given parameters. Each analysed concatenation of parameters was observed due to its dynamics, which depends upon the stage of the study and the physical task. Ill. 4, bibl. 5 (in English; abstracts in English, Russian and Lithuanian).

I. Мунтьянайте-Дулкиниене, В. Пошкайтис, А. Вайнорас, Г. Ярушявичус, Л. Бикулчене, З. Навицкас. Коинтеграция параметров ЭКГ во время различных физических задач // Электроника и электротехника. – Каунас: Технология, 2009. – № 6(94). – С. 77–80.

Любая физическая нагрузка вызывает системную реакцию функций организма, обусабливающую сердечно-сосудистую систему, центральную нервную систему и мышцы. Парамеры ЭКГ, их изменения и механизм действия отображают характер активности этих систем. В данной работе использован алгебраический метод коинтеграции данных, который позволяет видеть, как избранные параметры взаимодействуют между собой при разных физических нагрузках. Подсчитанная при помощи метода анализа матриц второго ряда межпараметрическая связь более четко выявляет внутренние процессы организма и их изменения. По каждой разбираемой межпараметрической связи наблюдалась динамика, зависящая от соответствующего этапа исследований и физической задачи. Ил. 4, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

I. Muntianaitė-Dulkinienė, V. Poškaitis, A. Vainoras, J. Jurevičius, L. Bikulčienė, Z. Navickas. EKG parametrų sąsajos įvairių fizinių užduočių metu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 6(94). – P. 77–80.

Bet koks fizinis krūvis sukelia sisteminę organizmo funkcijų reakciją, apimančią širdies kraujagyslių sistemą, centrinę nervų sistemą ir raumenis. EKG parametrai, jų pokyčiai ir veikimo mechanizmas atspindi šių sistemų aktyvumo ypatybes. Darbe taikomas algebrinis duomenų kointegracijos metodas leidžia matyti, kaip pasirinkti parametrai sąveikauja tarpusavyje esant skirtingam fiziniam krūviui metu. Tarpparametrinis ryšys, apskaičiuotas naudojantis antros eilės matricų analizės metodu, labiau nei parametrų koreliacija išryškina vidinius organizmo procesus ir jų kitimus. Buvo stebima kiekvienos nagrinėtos tarparametrinės sąsajos dinamika, priklausanti nuo tyrimo etapo ir fizinės užduoties. Il. 4, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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