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Assessment of middle-distance runners cardiovascular system in rest and load conditions

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Abstract
Purpose: Assessment of cardiovascular response of qualified middle-distance runners to aerobic and anaerobic physical loads.
Methods: Qualified middle-distance runners at the stage of sportsmanship improvement (n = 20) were studied. Sports qualification - 2 and 1 categories. The analysis of Heart Rate Variability was carried out using the application "CardioMood" with "Polar h10" and "Polar M430". A 5-minute electrocardiogram recording was performed. Only normal NN cardio cycles were studied. When analyzing Heart Rate Variability, the following parameters were obtained: HR, SDNN, pNN50, TP, entropy (H), modes (Mo), AMo, stress index. The complex "vegetative indicator" was calculated. Statistical processing of obtained research results was carried out by "EXCEL" program. In random samples of study, the following were calculated: arithmetic mean (M±), standard deviation (±a). Normality of distribution was determined by statistical test. The significance of the differences between indicators was determined using the Student's t-test (assuming a normal distribution). Correlation analysis was performed using the simple correlation method.
Results: Athletes Heart Rate and Heart Rate Variability indicators are significantly differed, Heart Rate mechanism regulation was characterized by restructuring to an autonomous regulation loop, activity indicator is respiratory sinus arrhythmia with minimal centralization of control and an increase to parasympathetic nerve system. This was reflected in SDNN indicators characterizing the "scatter function" of cardio intervals durations. The shift of vegetative balance towards parasympathetic, and AMo value, less than 30%, is due to an excess of adaptation resources.
Conclusion: The results showed that nowadays, while building an effective training program, it is necessary to use modern technologies for correction and operational control of training process, as well as rational distribution of the volume and intensity of loads in preparatory period. The data of the research work can be useful for both: specialists in middle-distance running, and for athletes involved in other sports that are similar in performing of physical work.

Keywords: Heart Rate Variability, Stress Index, Middle distance running, Intensity zones, Loads, Functional state, Training process.

Introduction

Stress plays an important role in middle-distance runners exercising in zone of submaximal intensity. Competition results often depend on stress level (Cassirame et.al., 2019; Cottin et.al., 2006; Gronwald et.al., 2019).

Stress can be caused by various factors that irritate the nervous system, which affects Heart Rate Variability. Since development stagnation of middle-distance running in Uzbekistan, an attempt was made to revise the volume and intensity of training loads at the stage of improving sportsmanship and optimize individually, for a gradual improvement in the functional state of athletes body. Turning to the scientific works of the authors who devoted their professional activities to the study of problems in the development of middle-distance running, we came to the conclusion that the authors opinions do not coincide, and each study and has its own results (Giles et.al., 2018; Gronwald et.al., 2019).

Each specialist is looking for his own way to achieve success in this discipline, which in turn pushes to revise training methods, as well as purposeful preparation for important competitions. Training at different stages of the preparatory period has a huge impact on the performance of athletes, which is an urgent problem in the integral system of training qualified middle-distance runners. Having determined the Heart Rate Variability and the stress index, it becomes possible to timely correct the real functional state of athletes. (Gronwald et.al., 2020; Ivanov et.al., 2001; Kannankeril et.al., 2002) .

Methods

The experiment was organized and conducted on the basis of the Uzbek State University of Physical Culture and Sports and the object of the pedagogical experiment was qualified middle-distance runners. Qualified middle-distance runners in the number of 40 people were divided by 20 people into the Experimental Group and the Control Group.

The control group trained according to the training plan drawn up by athletes' trainers

and trained according to the traditional methodology approved by either the Athletics Federation of Uzbekistan or the Athletics Department of the Uzbek State University of Physical Culture and Sports, which has its own student track and field team. We did not adjust the training process of the Control group. From our side, only pedagogical observation was carried out to obtain indicators and compare them with Experimental group.

In experimental group, there was an attempt to implement several tasks to achieve the set goal and a training program was developed based on the obtained data on Heart Rate Variability and stress index, the reaction of the cardiovascular system to physical loads in different intensity zones, as well as duration of the recovery process after completed, so called "distances". To obtain indicators of the functional state of athletes, as well as the level of the functional state, it was carried out using a chest monitor based on electrocardiogram "POLAR h10" technology and a wrist watch "POLAR M430" based on photoplethysmography technology (Jamnick et.al., 2020). The functional features of these devices are all indicators are displayed on smartphone's screen and monitored online, where the trainer can quickly adjust the training process. There are system requirements for software compatibility with a smartphone or tablet, with Android + 4.3 operating system, and iPhone 4C +, with support for the bluetooth smart function: 4.0 Low Energy.

Using a chest Heart Rate Monitor with a Heart Rate sensor - Polar h10 in experimental group during the training process, tests of the organism's functional state were taken at the current moment at various distances (30m, 60m, 100m, 200m, 400m, 600m, 800m, 1000m, 1200m, 1500m, 2000m, 3000m, 8km, 10km, 12km, 14km, 16km.). And also a questionnaire survey of athletes was made on external stimuli, which, as it turned out later, are an obstacle in competitive activity. Visualization training was applied before the races. The training was conducted by a qualified sports psychologist in the field at the stadium. The athletes were given the task to visualize their movements in the race. Also, the indicators of the sympathetic and parasympathetic nervous systems were taken before the races and after training process, before the race during the race and after. After each training process and competitive activity, corrective work was carried out by the psychologist for readiness to the next trainings and competitions.

Results and discussion

According to the results of the research study, we found that during the preparatory stage, the training process is chaotic, training distances are built not logical, athletes' functional state is at a low level and requires intervention and correction towards the development of aerobic and aerobic-anaerobic capabilities of qualified middle-distance runners (Karapetian et.al., 2008; Lipponen et.al., 2019). In distances requiring high-intensity training loads and performing exercises in submaximal and maximal zones, athletes often overtrained and the next training session came unrecovered and could not withstand the training loads according to the preplanned training plan. Note that work in abovementioned intensive zones takes place in a near-limit and almost oxygen-free mode of energy supply and requires the athlete, first of all, to resist the production of lactic acid, which leads to a disorder of motor skills and improper execution of the running technique in the so-called "acidified state" (Karasik et.al., 2002; Reis et.al., 2011). But having correctly estimated the reaction of the cardiovascular system to physical loads of aerobic, anaerobic and aerobic-anaerobic skills (Naranjo-Orellana et.al., 2021), we managed to rationally distribute the volume and intensity of training loads over the microcycles of preparatory and competitive mesocycles and summarize the quantitative indicators of the volume and intensity of training loads in a six-month macrocycle of training runners for average distances at the stage of improving sportsmanship.

For a better understanding of the Heart Rate Variability and stress index during loads and rest conditions, the following electrocardiogram is clearly shown, where program converts into a rhythmogram graph and calculates the R-R interval variability (Rogers et.al., 2021) (Figure 1).

What is Heart Rate Variability. Where does it come from? If you completely cut the sympathetic and parasympathetic nerves leading to the heart and isolate the endocrine heart from the environment, then the heart will contract at the same frequency, there will be an isoline. But in reality, the pulsogram does not look like a straight line, but a toothed wave, (Graph 1.), since there are direct and feedback systems

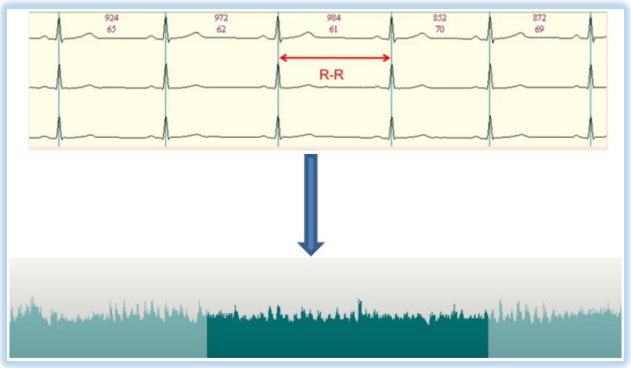


Figure 1. Conversion of an electrocardiogram into a Rhythmogram.

of self-regulation in the body. Here is a graph of the pulsogram, where the "X" is the number of R-R intervals, and the "Y" is the value of the R-R intervals. Where do the R-R intervals come from. On the classic electrocardiogram (ECG), where we can clearly see the distance between the contractions of the ventricle. So the distance between contractions is the R-R intervals and is measured in milliseconds. If we translate this into the number of contractions in seconds, then we get 65 beats per minute. The next distance can be 62, 67, 70, etc. The mismatch difference between adjacent R-R beats is Heart Rate Variability. The cardio strap itself measures the difference between the R-R teeth, the program itself builds the pulsogram, namely the mathematical model, and there will always be a different distance between the R-R teeth, that is, a different period of time, then the pulse rate, the distance between the R-R teeth will fluctuate. This is Heart Rate Variability. It can be analyzed and a lot of information about the current state of the cardiovascular system can be obtained. The advantage of this program is that it converts an electrocardiogram into a pulsogram. The Heart Rate will be influenced by the respiratory system, the oxygen content in the blood, the carbon dioxide content in the blood, the pH of the blood, and blood pressure through forward and backward connections of the central and autonomic nervous systems (Rogers et.al., 2021; Rosenwinkel et.al., 2001)

This chart shows the results of a qualified middle-distance runner during a race, whose Heart Rate Variability and stress index were determined before and after the race. It can be seen from the graph that the level of energy consumption before the race for the athlete is quite high. This phenomenon indicates that the athlete has excessive excitement, which leads to additional energy consumption without even starting the exercise in the intense zone. Video

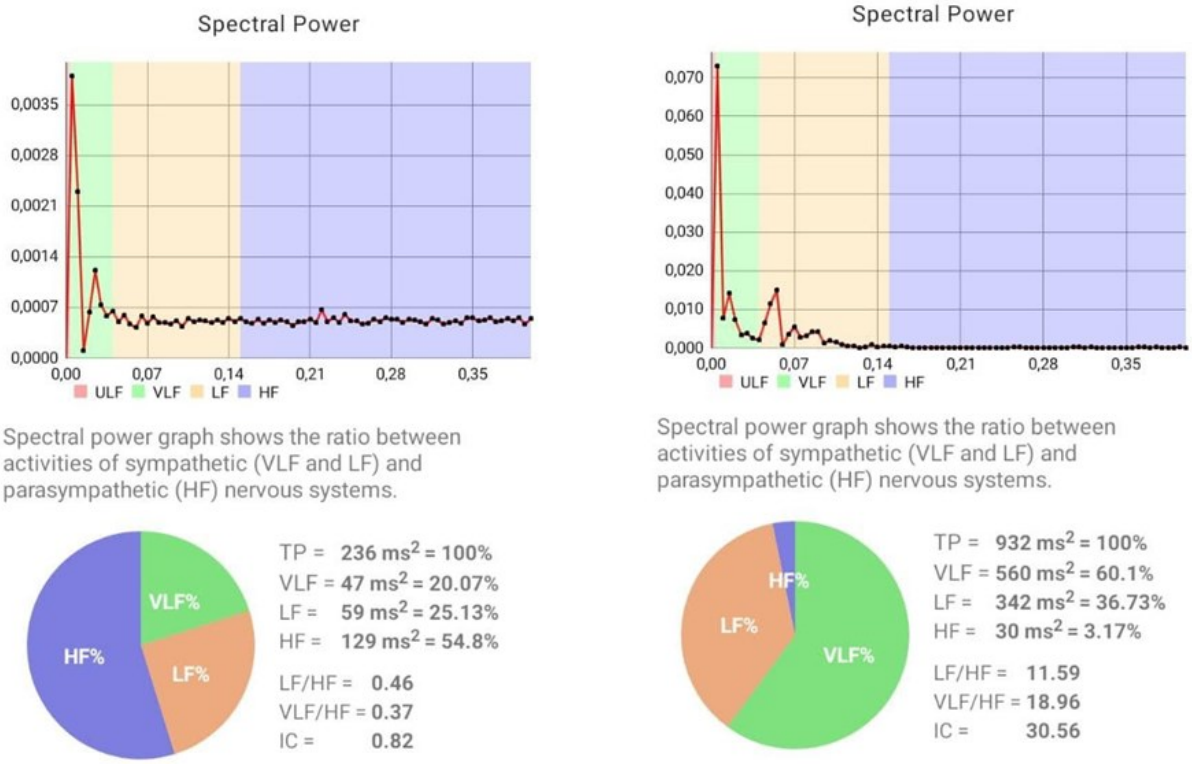


Figure 2. Determination of Heart Rate Variability and stress index on example of a qualified middle-distance runner.

Table 1. Indicators of heart rate variability in athletes from the control and experimental groups (M ± SD).

№	Indicator	Control Group *n* = 20	Experimental group *n* = 20
1.	HR (b./min)	**63,35 ± 5,49** *P* < 0,001	**58,12 ± 6,02** *P* < 0,001 *P* > 0,05
2.	SDNN (mc)	**60,07 ± 12,61** *P* < 0,065	**99,51 ± 27,34** *P* < 0,001 *P* < 0,001
3.	pNN50 (%)	37,04 ± 14,68	63,13 ± 15,83
4.	TR (ms^2)	**7298 ± 1474** *P* > 0,05	**9695 ± 6156** *P* < 0,001
5.	LF/HF	**1,487 ± 0,861** *P* > 0,05	**0,567 ± 0,48** *P* < 0,001
6.	VLF (%)	**39,63 ± 11,27**	**26,64 ± 14,18**
7.	LF (%)	**32,23 ± 8,37** *P* > 0,05	**21,92 ± 8,75** *P* < 0,001
8.	HF (%)	**26,92 ± 11,86** *P* >0,05	**51,54 ± 13,28** *P* < 0,001
9.	Entropy	**5,56 ± 0,380** *P* < 0,03	**5,34 ± 0,362** *P* < 0,001 *P* < 0,001
10.	Mo (ms)	**1,102 ± 0,28**	**0,996 ± 0,34**
11.	AMo (%)	**23,58 ± 8,67** *P* > 0,05	**21,53 ± 9,03** *P* < 0,001
12.	VR (ms)	**0,425 ± 0,15**	**0,498 ± 0,16**
13.	IVR	**68,42 ± 16,57** *P* < 0,001	**42,65 ± 14,51** *P* < 0,001
14.	PAPR	**23,49 ± 7,27**	**23,38 ± 7,54**
15.	VPR	**1,61 ± 0,68**	**1,83 ± 0,63**
16.	SI	**22,17 ± 11,52**	**22,58 ± 11,46**

analysis of the athlete's running showed that in the second half of the distance, the athlete greatly slowed down the pace of running, there was clearly a disorder in the running technique at the finish. In this wave structure, three types of waves are distinguished, depending on their duration.

As we can see in Table. 1, the values unambiguously indicate a shift in the vegetative balance in athletes towards the predominance of the parasympathetic division influence of the autonomic nervous system on the heart, and the AMo values less than 29% - on the excess of adaptation resources. The athletes showed a

decrease in cardiac activity. This can be seen from the data of Heart Rate Values in the compared groups (Table 1).

The study showed that in both groups the total effect of regulation can be characterized as "moderate bradycardia" (Seely et.al., 2004; Stöggl et.al., 2019). It is known that with such effects, circulatory disorders do not develop, the heart contracts with sufficient force (Gronwald et.al., 2020).

In the experimental group of athletes, there was a decrease in heart rate compared to the control group. The lowest Heart Rate Variation were observed in the control group: 63.35 ± 5.49 bpm (P <0.001). The heart rate was less than 58.12 ± 6.02 beats / min in the experimental group (P <0.001). Such a rare heart rhythm can be attributed to a mild degree of bradycardia. Bradycardia is considered as a manifestation of the economy of cardiac activity at rest. It occurs as a result of an increase in the tone of the parasympathetic nervous system with a simultaneous decrease in the activity of the sympathoadrenal system (Tarvainen et.al., 2014; Tulppo et.al., 1996). This type of bradycardia can be considered a sign of a high functional state of the body (Seely et.al., 2004; White et.al., 2014). In the process of sports training, the total power of the spectrum grows mainly due to the increase in the power of respiratory waves (HF-component) (Jamnick et.al., 2020). From the data table. 1 shows that the athletes of the control group at rest had moderate sinus arrhythmia, and the athletes of the experimental group had a pronounced change in the automatism of the heart. This was evidenced by the data of the TR indicator. The highest total activity of regulatory mechanisms in terms of TR was noted in the experimental group (9695 ± 6156 ms2).

At the same time, the vegetative balance in athletes of both groups was shifted towards prevalence of parasympathetic division of the autonomic nervous system. This can be clearly seen in the values of the stress index. According to the power of the spectrum of low frequency waves (LF), the activity of the vasomotor center in the control group did not statistically significantly differ from the experimental group.

According to many researchers, VLF reflects the level of basal metabolism, thermoregulation, ergotropic functions (Rosenwinkel et.al., 2001). We have calculated the total assessment of the regulatory systems in the groups. According to this approach, the Heart Rate Variability of control group was assessed as a "regular" ("zero" assessments were recorded for all parameters). The minimum tension of regulation systems is noted, which is characteristic for the satisfactory adaptation of the organism to the conditions of the external environment. In general, the control group had a balanced activity of the sympathetic and parasympathetic divisions of the autonomic nervous system.

Athletes of experimental group showed the optimal activity of regulation systems. The functional capabilities of heart are high. There is a reserve of cardiovascular system.

The most significant differences of heart rate variability indicators in comparison with control group were found in qualified middle-distance runners of the experimental group. A pronounced predominance of parasympathetic activity of autonomic nervous system was noted. This option is typical for well-trained athletes.

The runners of experimental group trained once a day. Obviously, each subsequent training in the microcycle takes place against the background of recovery. Therefore, as shown above, they had a balanced activity of sympathetic and parasympathetic divisions of autonomic nervous system with decreased heart rate and increased beats volume of heart.

Analyzing athletes' functional state, it is important to assess the activity of parasympathetic link of autonomic nervous system. Balance shift of autonomic nervous system towards parasympathetic division provides an optimal supply of oxygen to the athlete's body at rest and recovery after exertion, saving the activity of the cardiovascular system, characterizes the functional reserve of the body for performing intense physical activity (Reis et.al., 2011). Among the indicators characterizing parasympathetic influences, the most acceptable is the pNN50 indicator, which is highly correlated with other high-frequency indicators of temporal and spectral analysis, is not very sensitive to random phenomena, and is not distorted by rare breathing and other artifacts (Lipponen et.al., 2019). A new complex indicator - "vegetative indicator", based on which the pNN50 and AMo indicators are calculated by the formula: vegetative indicator = pNN50 ÷ 10 + (100 - AMo) ÷ 10 (rel. Units). In our work, we performed the calculation of this indicator, its value of control group was 11.09 ± 2.01

units. This value of vegetative indicator characterizes the current functional state of those who doing sports as "satisfactory", the influence of the parasympathetic nervous system was balanced by other mechanisms of heart rhythm control and, accordingly, was equal to 11.24 ± 2.02. and 11.37 ± 1.91. This level characterizes the current functional state of middle-distance runners of control group as "good" - with a moderate predominance of the parasympathetic nervous system in heart rate control. In experimental group, the vegetative index was 13.59 ± 1.63. with the same interpretation of the functional state, but statistically significant (P <0.001) by the greater influence of parasympathetic department.

When all athletes were combined into one group (n = 40) and the correlation analysis was carried out, the following was revealed. The strongest correlations of the vegetative index were found to be with the stress index and the entropy index (the correlation coefficient was 0.91 and 0.87, respectively, at P <0.01), with the HF spectrum (0.63; P <0.01) and the centralization index. (–0.63; P <0.01). Significant correlations were noted with indicators: heart rate (–0.61; P <0.01), TP (0.61; P <0.01), LF / HF (–0.62; P <0.01).

Conclusion

Based on the results of the research and experiment, we made the following conclusions:

1) The effectiveness of heart rate variability and stress index analysis lies in operational management of qualified middle-distance runners' training process at the stage of sportsmanship improving, since it is possible to timely correct training loads based on the reaction of the cardiovascular system to loads and the recovery process.

2) It is possible to objectively measure with mathematical precision the level of stress, the level of energy, the adaptive reserves of the body, measure the activity of sympathetic and parasympathetic nervous systems in stress and at rest conditions.

3) Application for the Heart Rate Variability analysis CardioMood Expert, which, in conjunction with any bluetooth cardio strap, allows to monitor the level of qualified middle-distance runners' functional state at any stage of training, protecting athletes from overtraining.

4) Allows to objectively calculate certain factors of cardiac activity that reduce the level of performance and energy supply, although the opposite may seem subjectively, this is a common situation when athletes use substances that stimulate performance and sports nutrition. All of the above creates the illusion of a fitness effect.

5) By Heart Rate Variability and stress index it is possible to objectively find out in figures how exactly affects training distances in middle-distance running. Allows finding out the biological age of the cardiovascular system. Heart Rate Variability is a good biomarker of aging. It is very easy to find out. As the body ages, the Heart Rate Variability decreases. Allows knowing 20-40 hours in advance with a high degree of probability about the onset of arrhythmia's first symptoms, tachycardia and bradycardia and to take measures in advance to prevent a pathological state of cardiovascular system. With pathological symptoms of cardiovascular system, the stress level always increases, and the Heart Rate Variability decreases. Allows accurately dosing physical activity during training, to know the exact time when it is necessary to finish the training process. Allows identifying individual indicators of autonomic and nervous system and train on the basis of individual indicators, and not by the average value for all and by the stopwatch.

6) Can help to find out whether it makes sense to train at the moment according to a training plan written in advance, or the body has not yet recovered and requires rest. Also, using the CardioMood application, can help to determine how the load and overstrain in sports increases the number of arrhythmias and extrasystoles.

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