Assessment of Adaptation Processes in the Integrated Functional Diagnostic Monitoring of Highly Qualified Athletes in Various Types of Sports

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Abstract

Aim: To identify the universal parameters of the functional state of athletes in various sports, which lets more fully evaluate the effectiveness of training loads.

Methodology: Examining 103 highly qualified athletes aged 13-29, spiroergometry, Wingate test, electrocardiography, echocardiography, densitometry and biochemical parameters.

Experimental conditions: All the participants had a preliminary medical examination and were found healthy.

Participants: Athletes aged 13-29.

Basic measurements: Hemoglobin level, spiroergometric test parameters, maximum and peak power in the Wingate test (30 sec), bone mineral density, stroke and minute blood volumes, heart rate.

Result: a High prognostic correlation of hemoglobin parameters and anaerobic performance and the prevalence of the hypokinetic type of blood circulation in the subjects were revealed.

Conclusions: The results obtained can be considered as new markers in assessing the adaptation processes in the body of athletes and can be used to monitor the health status of athletes and optimize the training process.

Key-words: Body Reactions, Training Programs, Development, Sportsmen, Progress, Efficiency, Adaptation.

1. Introduction

For high-achievement sports, the priority today remains to monitor the physical condition of athletes, to conduct the necessary functional and diagnostic tests, as well as laboratory research, that allow quickly and accurately controlling the functional state of the body.

The tests used must allow a clear interpretation of the results to evaluate and predict the further physical capabilities of the athlete's body, to answer the questions of correctness and rationality of the existing training programs of the athlete, and to indicate the possibility of managing the training process as a whole [1]. The set of examinations and consultations of narrowly specialized medical scientists enables the sports medical scientist to give a complete conclusion both on the athlete's condition at the moment and to predict further progress or regression of their performance in the future [2, 3, 4, 5].

The present study consisted of evaluating and comparing indicators obtained after a series of laboratory and functional tests to better understand the athlete's health status.

The study focused on drawing practical conclusions based on the results of functional tests and biological indicators of athletes and to formulate recommendations for monitoring these indicators, as well as to emphasize the importance of testing to determine the true indicators of an athlete.

The objectives were as follows: to assess the correlation of biological indicators and the results of functional tests in athletes of various sports, to identify the most significant correlations and interpret their value, to determine the type of blood circulation of athletes and to evaluate the adaptive capabilities of the cardiovascular system, and to identify the error between the calculated and true indicators on the example of HRmax (maximum heart rate test).

2. Relevance

The study of factors affecting the functional state of athletes is crucial for managing the training process both in the preparatory stage and in the competitive stage. Optimizing physical qualities development implies identifying a clear relationship between sports and technical results and specific biological processes that occur in the athlete's body under the influence of physical activity, as well as registering and interpreting the results of recorded changes. Identifying correlations between sports and technical indicators and biomedical parameters will allow more efficient management of the training process to increase athletes' productivity and performance and to achieve the highest sports results.

3. Materials and Methods

The following equipment was used to obtain data on the health status of athletes:

1. Cosmed Quark CPET – a state-of-the-art, highly efficient system for performing cardiorespiratory stress tests and metabolic rates;

2. Katana Sport – a modern and reliable treadmill;

3. Excalibur Sport ergometer;

4. Schiller Cardiovit CS-200 electrocardiograph for assessing the functional state of the cardiovascular system;

5. Premium class ultrasonic system EPIQ 5;

6. Blood test was performed at the DIALAB laboratory";

7. STRATOS osteodensitometer (France). Densitometry is a body composition analysis according to the parameters of bone mass, adipose tissue and muscle mass.

On this equipment, athletes underwent Wingate testing (30 seconds) and MAC (maximal anaerobic capacity) testing (10 seconds); with the help of an echocardiograph, stroke and minute blood volumes were determined. To compare the values of stroke and minute blood volume in subjects with different height and body weight, the calculation of stroke and cardiac indices was performed [6, 7].

Heart index (hereinafter HI) = MBV/S, where MBV is the minute blood volume and S is the surface area of the body.

Athletes were tested for hemoglobin and underwent densitometry to determine bone mineral density.

Athletes' health data was statistically processed in the IBM SPSS Statistics program. The results were digitized and depersonalized, grouped by sports and analyzed to look into the relationship between the studied indicators of health and physical performance of athletes.

4. Results

The study involved 103 athletes aged 13-29 who were divided into three groups:

Group 1 – 25 representatives of high-speed power sports and martial arts, 22 male and 3 female:

13 – judo

4 – weightlifting

2 – boxing

2 – short track

1 – Taekwondo

1 – freestyle wrestling

2 – downhill skiing

Group 2 – 33 representatives of cyclical sports, 18 male and 15 female:

23 – rowing

5 – swimming

2 – athletics

1 – kayaking

1 – skiing

1 – biathlon.

Group 3 – 45 athletes representatives of game sports, 25 male and 20 female:

23 – water polo

10 – curling

5 – handball

2 – badminton

2 – table tennis

1 – football

1 – eventing

1 – trampoline.

To analyze the data, a correlation table was compiled between the following indicators for each group of athletes: hemoglobin value (g/dl); spiroergometric test parameters (VO2 max/kg, ml/min/kg); maximum and peak power in the Wingate test (30 sec); maximal anaerobic capacity (MAC, 10 sec), bone mineral density (BMD, g/cm^2), and stroke and minute blood volumes (see Tables below).

Table 1- Correlations between Study Indicators, Group 2

	Hb g/dl (blood test)	BMD, g/cm^2 (densitometry)	W max (MAC'10)	Wmax, W (Wingate test'30)	minute blood volume (echo)	stroke blood volume (echo)	VO2 max/kg, ml/min/kg
Hb g/dl (blood test)	1	.757**	.601**	.718**	.085	.082	.370*
BMD, g/cm^2 (densitometry)	.757**	1	.783**	.792**	.062	.208	.301
W max (MAC'10)	.601**	.783**	1	.844**	.402*	.509**	.073
Wmax, W (Wingate test'30)	.718**	.792**	.844**	1	.446*	.505**	.214
minute blood volume (echo)	.085	.062	.402*	.446*	1	.743**	-.224
stroke blood volume (echo)	.082	.208	.509**	.505**	.743**	1	-.061
VO2 max/kg, ml/min/kg	.370*	.301	.073	.214	-.224	-.061	1

** Correlation is significant at the level of 0.01 (two-way)

* Correlation is significant at the level of 0.05 (two-way).

Table 2- Correlations between Study Indicators, Group 1

	Hb g/dl (blood test)	BMD, g/cm^2 (densitometry)	W max (MAC'10)	Wmax, W (Wingate test'30)	minute blood volume (echo)	stroke blood volume (echo)	VO2 max/kg, ml/min/kg
Hb g/dl (blood test)	1	.149	.454*	.331	-.004	-.002	-.233
BMD, g/cm^2 (densitometry)	.149	1	.749**	.745**	.251	.631**	.096
W max (MAC'10)	.454*	.749**	1	.961**	.384	.688**	-.187
Wmax, W (Wingate test'30)	.331	.745**	.961**	1	.417*	.706**	-.297
minute blood volume (echo)	-.004	.251	.384	.417*	1	.781**	-.190
stroke blood volume (echo)	-.002	.631**	.688**	.706**	.781**	1	-.105
VO2 max/kg, ml/min/kg	-.223	.096	-.187	-.297	-.190	-.105	1

**Correlation is significant at the level of 0.01 (two-way)

*Correlation is significant at the level of 0.05 (two-way).

Table 3 - Correlations between Study Indicators, Group 3

	Hb g/dl (blood test)	BMD, g/cm^2 (densitometry)	W max (MAC'10)	Wmax, W (Wingate test'30)	minute blood volume (echo)	stroke blood volume (echo)	VO2 max/kg, ml/min/kg
Hb g/dl (blood test)	1	.474**	.632**	.666**	.416**	.223	.336*
BMD, g/cm^2 (densitometry)	.474**	1	.749**	.761**	.510**	.155	.580**
W max (MAC'10)	.632**	.749**	1	.979**	.654**	.313	.484**
Wmax, W (Wingate test'30)	.666**	.761**	.979**	1	.637**	.295	.503**
minute blood volume (echo)	.223	.155	.313	.295	.725**	1	-.062
stroke blood volume (echo)	.416**	.510**	.654**	.637**	1	.725**	.350*
VO2 max/kg, ml/min/kg	.336*	.580**	.484**	.503**	.350*	-.062	1

** Correlation is significant at the level of 0.01 (two-way)

* Correlation is significant at the level of 0.05 (two-way).

Table 4- Distribution of Heart Rate among Athletes (Number of Athletes by Sports)

Group	HI		
	<2.75	2.75-3.5	>3.5
High-speed power sports and martial arts	17	7	1
Cyclical	26	7	0
Game	29	13	3
Total	72	27	4

Table 5- HR Max Obtained for 1 Athlete in the Test with Maximum Physical Activity and based on the Mathematical Formula

HR beats/min	fat burning zone	recovery zone	compensation zone	adaptation zone	max working capacity zone
HRmax1	85-100	up to 115	115-165	165-175	over 175
HRmax2	100-118	up to 135	135-194	194-205	over 205

HR max – maximum heart rate

HR max1 – obtained in the test with maximum load

*HRmax2 – obtained mathematically by the formula 220-age*0.5, (the age of the athlete is 21 years).*

Figure 1- Diagram of Two Indicators of HRmax Obtained for 1 Athlete in the Test with Maximum Physical Activity and based on a Mathematical Formula (Same Athlete)
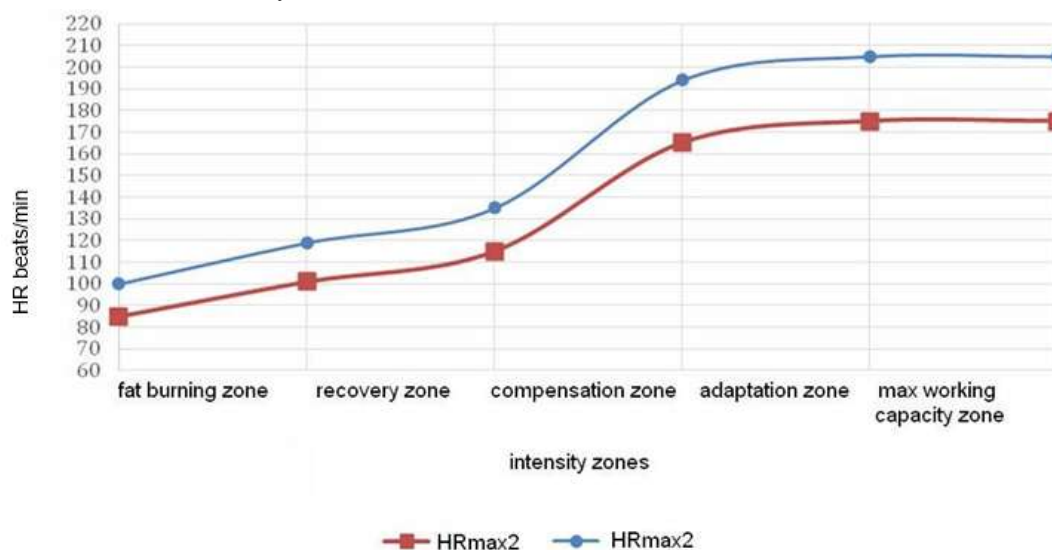
The Pearson correlation coefficient is interpreted as follows: less than 0.3 – weak; 0.3-0.5 – moderate; 0.5-0.7 – noticeable; 0.7-0.9 – high; over 0.9 – very high. Only the correlations that were significant at the level of 0.01 (confidence interval 1%) were analyzed.

The indicator of bone mineral density does not correlate with BMD; however, additional tests are required to study the effect of bone mineral density on a stable increase in the performance of the musculoskeletal system in achieving maximum results [8, 9, 10, 11].

The correlation between the maximum power and peak power obtained in the Wingate test (30 seconds) is explained by the fact that these indicators are a characteristic of the power that an athlete can develop [12, 13].

The study revealed a high correlation (coefficient 0.718) between hemoglobin concentration and maximum power (W) in group 2 and a noticeable correlation (coefficient 0.666) in Group 3. For Group 1, such correlation was not found.

The present study considers in more detail the reasons for the presence/absence of this correlation in different groups of athletes and explains its practical significance.

Of the entire sample (103 athletes), 70% have the hypokinetic type of blood circulation. These athletes have training and recovery programs designed most rationally for the development of high adaptive capabilities of the cardiovascular system. Moreover, training and rehabilitation programs provide an opportunity to further increase the adaptive abilities of the cardiovascular system [14, 15, 16, 17].

26% of athletes have the eukinetic type of blood circulation. This indicates rationally designed training and recovery programs that provide adequate adaptive capabilities of the cardiovascular system during exercise. However, the indicators of the sports training program do not provide further growth and development of the adaptive capabilities of the cardiovascular system [18].

4% of athletes have the hyperkinetic type of blood circulation, which indicates a decrease in the adaptive abilities of the cardiovascular system [19].

According to the HI index in the muscle resting state, 3 types of blood circulation are distinguished:

- HI <2.75 L/min/m^2, the *hypokinetic* type (reflects the high profitability of cardiac activity at rest, and of large dynamic range of adaptation during physical exertion);
- HI 2.75-3.5 L/min/m^2, the eukinetic type.
- HI over 3.5 L/min/m^2, the hyperkinetic type.

5. Comparative Analysis of HR Max

A comparative analysis of HR max obtained during the test with maximum load and HRmax calculated by the mathematical formula gave the following results:

In 100% of cases, HRmax calculated by the mathematical formula exceeds the indicator obtained in the test with maximum load. HRmax mathematically calculated on average exceeds the rate of true HRmax by 12.7% (approximately 25 beats/min).

6. Discussion

Hemoglobin is a protein of red blood cells consisting of non-protein (heme) and protein (globin) part and performing the transport function (delivery of oxygen from the lungs to the tissues), and as known, oxygen is a substrate involved in the aerobic pathway of energy production.

With regular physical exertion, the number of red blood cells and the amount of hemoglobin in them increase; as a result, the oxygen capacity of the blood increases. N. I. Medvedkova, M. Yu. Nohrin and V. D. Medvedkov showed the dependence of the skill level of 17-18-year-old athletes and the parameters of their hemograms. These authors found that with an increase in sports skills, the hemoglobin content in the blood increases [20].

Testing the maximum anaerobic power is performed due to the almost exclusively anaerobic method of energy supply of working muscles (the anaerobic component in the total energy production is from 90% to 100%) [21]. It can be assumed that an increase in the oxygen capacity of the blood due to an increase in hemoglobin during the maximum anaerobic load is important for the energy supply of the body, despite the fact that the energy basis of these exercises is anaerobic metabolism [22, 23, 24].

The correlation between the maximum power level and the level of hemoglobin in the blood suggests that an athlete involved in a cyclical sport with a high level of hemoglobin is able to demonstrate higher results, since the higher the level of hemoglobin in the blood, the more oxygen is transported to the oxidizing muscle fibers, where aerobic glycolysis occurs – the most effective way to generate energy, and the body can synthesize more ATP molecules during oxidative phosphoryzation without the formation of by-products such as lactate which causes acidosis in the muscles and blood and reduces the activity of oxidative enzymes, which complicates muscle activity [19, 25].

In cyclical sports, energy is provided mainly by aerobic mechanisms. The energy supply of athletes during training in high-speed power sports, on the contrary, occurs mainly due to the anaerobic path of energy production, therefore, there is no correlation between the level of maximum power and the level of hemoglobin in athletes of this group [8, 26].

Determining the type of hematopoiesis allows evaluating the adaptive capabilities of the cardiovascular system. Determination the indicators in dynamics lets control training and recovery programs to achieve high rates of adaptive capabilities of the body.

96% of athletes have satisfactory training and recovery programs, and only 73% of them have programs for the growth and development of adaptive capabilities of the cardiovascular system, which ensures the achievement of higher rates in a particular sport. The present study allows understanding the importance of systematic functional and diagnostic monitoring of the athlete's body for a rational analysis of training and recovery programs.

A large error in calculating the final HRmax when using the formula HRmax = 220-age * 0.5 (ACSM.2006) gives reason to limit the use of the mathematical formula for calculating HRmax for athletes, as this leads to *further inconsistency in the calculation of the intervals of bioenergetic training zones* to achieve certain goals.

An error of 12.7% is unacceptable, since it leads to designing irrational training programs that will not produce the desired results and may negatively affect the athlete's state of health. For the

correct preparation of training and recovery programs, it is necessary to use the HRmax obtained as a result of functional testing [27, 28].

7. Conclusion

Personalized biomedical correction protocols become crucial in building a highly effective training process.

In functional diagnostic testing, enough markers are obtained to assess the state of athletes' performance, to identify patterns of change in the performance of ongoing training and rehabilitation programs, and to evaluate the training programs themselves based on the level of adaptive abilities of the body.

The present study allows objectifying the assessment of the cardiovascular system and the mechanisms of its adaptation, and allows quickly and efficiently changing the orientation of training programs to achieve optimal sports and technical results of athletes.

The following pattern was revealed: the level of hemoglobin is one of the factors affecting the performance of the body and the achievement of a potentially high sports result. Based on this, it is proposed to control the level of hemoglobin in the blood of athletes in order to prevent its decline which may adversely affect results.

For athletes of cyclic sports with predominantly aerobic energy supply, it is important to control the level of hemoglobin in the blood, since a lack or decrease in the amount of oxygen entering the muscles reduces muscle performance [29]; for athletes involved in high-speed and power sports, monitoring this indicator is not so crucial.

Contributions

All the authors provided equal contributions to the present research.

Conflict of Interest

The authors would like to declare no conflict of interest.

Informed Consent

All the athletes participating in the present research gave their informed written consent.

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