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Gender differences in integral indicators of adaptation of athletes' bodies to training in different energy modes

Adaptation to intense muscle activity leads to an increase in athletic performance. The task is not to bring an athlete to the stage of failure of adaptation mechanisms during training, which is accompanied by a drop in performance and other negative consequences, hence the need to have accessible and informative markers of the athlete's body condition in order to correct the training process. The study was conducted at the Olympic Training Center (OTC), city of Karaganda. The participants were athletes without health complaints. To determine the physical performance of athletes, a submaximal PWC $_{170}$ test was used, and the MOC was calculated by an indirect method. Based on the measurement of the main indicators of the cardiovascular system (HR, SBP, DBP) and the calculation of derivative indices (PP, SBV, MCV, DP, KEC) adopted in sports medicine and adaptology (ShI, IFC), a comparative analysis of the adaptation of the body of high-class athletes (46 people) to training in different energy modes (aerobic, anaerobic-aerobic, anaerobic) was performed. The study showed differences in the adaptation indicators of the cardiovascular system of the athletes depending on the energy mode of training and gender. Measurement and subsequent calculation of accessible and informative indicators of adaptation of the cardiovascular system of the athlete's body to training loads in different energy modes allows not only to monitor its current state, but also to identify the stress preceding the breakdown of adaptation mechanisms.

Keywords: athlete, gender, energy training regime, cardiovascular system adaptation, stress, adaptation failure, indices.

Introduction

The state of the system can be assessed by the final result of its action, by the output. At the output of the system, first of all, energy is released, due to which the impact on the environment is carried out. The amount of this energy correlates with viability, which, in turn, is associated with the concept of adaptability. In addition, the energy potential is an integral indicator of the system's operation; it can be calibrated and reflected in the integral indicators of the system's state [1]. In connection with the above, the integral indicators of the athlete's body adaptation (training) can be working capacity, as well as indicators of his physical development, assessed by the method of standards and the method of indices [2, 3].

The ability to adapt to an influencing factor (in our case, to intense muscular activity) without breaking down the adaptation mechanisms is possible only with sufficient adaptation potential. The "cost of adaptation" is determined primarily by the costs of maintaining the required level of functioning of the cardiovascular system [4].

The purpose of this study is to identify gender-specific features of the adaptive capabilities of the cardiovascular system of athletes training in various energy modes using generally available methods accepted in sports medicine and adaptology.

Materials and methods

The survey was conducted at the beginning of the annual training cycle at the Olympic Training Center (OTC), Karaganda. The surveyed high-class athletes (masters of sports, candidate masters of sports) were divided into 3 groups: 21 people training mainly in aerobic mode, 7 people in anaerobic mode, 18 people in mixed, aerobic-anaerobic mode. The study groups included athletes without health complaints. The following indicators were measured using standard methods: HR (heart rate), SBP (systolic blood pressure), DBP (diastolic blood pressure), PP (pulse pressure) were measured by generally accepted methods.

Based on the data obtained, the following integral indices were calculated: SBV — systolic blood volume; MCV — minute circulatory volume; KEC — Kvass endurance coefficient (the ratio of HR to PP, multiplied by 10); DP — "double product", characterizes the systemic work of the heart; ShI — Shaptala index, reflects the adaptive capabilities of the cardiovascular system; IFC — index of functional changes [4].

To determine the physical performance of athletes, the submaximal PWC_{170} test was used, and maximal oxygen consumption (MOC) was calculated using an indirect method [3].

The digital material obtained as a result of a comprehensive instrumental study was processed using the method of variation statistics with standard programs. In statistical processing of the obtained results, the method of finding the indicator of a significant difference from the arithmetic mean (M), the value of the square deviation (σ), and the average error (m) was used. The degree of reliability between the compared values was determined by the Student's t reliability criterion (Sepetliev D., 1968). Differences were assessed as reliable if the probability value P corresponded to a value of less than 0.05 (95 %).

Results

The results of the parameters of the cardiovascular system are presented in Table 1. The heart rate (HR) of men and women training in the same energy mode showed no significant differences. In the group of athletes training in the anaerobic mode, HR was 71.0±7.5 beats/min in men and 72.0±4.2 beats/min in women. In the anaerobic-aerobic mode, HR values were 64.0±2.1 and 62.0±2.5 beats/min, respectively, while in the aerobic mode they were 63.1±2.8 and 62.0±2.5 beats/min (Table 1).

Table 1

Cardiovascular parameters of elite athletes training in different bioenergetic modes (M±m)

Training mode	**Heart rate, d /min**	**SBP, mm Hg**	**DBP, mm Hg**	**PP, mm Hg**	**DP, conventional units.**
men					
Anaerobic	71.0±7.5	123.3±4.2	80.0±1.0	43.3±4.2	87.7±9.3
Anaerobic-aerobic	64.0±2.1	116.7±1.8	74.2±3.5	42.5±4.4	74.5±2.5
Aerobic	63.1±2.8	126.2±3.3	82.5±2.0	42.1±3.3	76.0±4.6
women					
Anaerobic	72.0±4.2	117.5±8.6	72.5±2.8	40.0±5.7	81.0±5.9
Anaerobic-aerobic	62.0±2.5	103.3±4.2	70.0±8.4	33.3±12.6	64.0±2.5*
Aerobic	62.0±2.5	110.0±8.4	86.7±6.3	43.3±2.1	68.0±2.5*

Note.* Changes are statistically significant ($p < 0.05$) compared to the anaerobic training regimen (women). HR — heart rate, SBP — systolic blood pressure, DBP — diastolic blood pressure, PP — pulse pressure, DP — double product.

The relatively high pulse rate of athletes training in an anaerobic mode is noteworthy. A slowdown in the pulse rate at rest in athletes in the other two groups is a typical adaptation response to repeated physical exertion. As a result of systematic sports training, the central tone of the vagus nerve increases, which is known to be the main parasympathetic nerve innervating the heart. The balance between sympathetic and parasympathetic control over the activity of the sinus node of the heart changes towards the predominance of parasympathetic, slowing influences — bradycardia develops. At the same time, signs of fatigue in an athlete's body are considered to be a state when the pulse rate at rest exceeds 80–85 beats per minute.

The measurement of arterial pressure in the examined groups showed that the average figures of both systolic (SBP) and diastolic (DBP) pressure correspond to the standards accepted for athletes (Table 1). Thus, at present, it is accepted to consider the values of maximum pressure in athletes to be normal if they fluctuate in the range from 105 to 129 (mm Hg). The normal range for minimum BP is 60–89 (mm Hg). The values of SBP and DBP measured by us in female athletes are somewhat lower than in the examined male athletes.

Pulse pressure (PP), calculated as the difference between systolic and diastolic pressure, was approximately the same in all groups, from 40.0 to 43.3 (mm Hg). The exception was the group of athletes training in an anaerobic-aerobic mode, whose PP value was equal to 33, 3 mm Hg. The obtained value of PD is explained by the low figure of SBP (103, 3 mm Hg), registered in this group. According to various authors, arterial hypotension in athletes occurs in 10–16 % of cases and in women twice as often as in men [2]. With the growth of athletic skill and experience, the frequency of hypotonic conditions related to the physiological norm increases [3].

Calculation of the DP (double product), reflecting the systemic work of the heart, showed the following (Table 1). The highest value of this indicator was found in male athletes training in the anaerobic mode (87.7 ± 9.3). The DP of athletes training in mixed and aerobic modes is lower by 18 % and 15 %, respectively, but the difference is not statistically confirmed. A similar pattern is observed in female athletes, but the difference between the compared groups is more pronounced. In female athletes training in a mixed mode, the DP is significantly lower by 26 % ($p < 0.05$), and in aerobic mode — by 19 % ($p < 0.01$). In general, the DP figures calculated by us are lower in women than in men. It should be noted that the lower the specified index at rest, the higher the maximum aerobic capabilities of the athlete's body [5–8].

For a more in-depth characterization of the cardiovascular system's response to training loads with different energy characteristics, we calculated a number of indices characterizing adaptive shifts in the heart and blood vessels.

Thus, the systolic blood volume (SBV) in men and women of the examined groups (Table 2) fluctuated, on average, from 59.5±0.59 ml (in athletes training in anaerobic mode) to 65.4±9.1 ml (in athletes training for endurance), which corresponds to the average standards.

It is known that healthy untrained people may have this indicator with some changes within 40–90 ml, and athletes — in the range of 50–100 ml [3]. In our case, there is a tendency for the systolic blood volume to increase. This fact is explained, on the one hand, by the anthropometric characteristics of the athlete, since this indicator is directly proportional to the body weight and height of the athlete, and on the other hand on by general physical performance, which is most pronounced in athletes training for endurance. In our case, these are male athletes training mainly in aerobic mode. These athletes have the highest average SV, equal to 65.4 ±9.1 ml.

Table 2

Integral indicators of the cardiovascular system of high-class athletes training in various bioenergetic modes (M±m)

Training mode	SBV, ml	MBV, l /min	ShI, conditional units	KEC, conditional units	FCI, points
men					
Anaerobic	59.5±0.59	3.27±0.5	21.7±1.6	16.4±0.7	2.22±0.13
Anaerobic-aerobic	64.3±2.4	3.12±0.47	15.8±2.3	15.5±3.9	2.15±0.05
Aerobic	65.4±9.1	3.47±0.3	17.9±2.9	9.5±0.9	2.50±0.3
women					
Anaerobic	62.3±1.7	3.31±0.2	16.6±2.4	19.6±2.7	2.04±0.19
Anaerobic-aerobic	62.7±10.1	2.69±1.2	12.9±5.7	21.7±8.8	1.78±0.09
Aerobic	64.5±1.5	3.33±0.3	10.7±3.5	12.5±0.8*	1.77±0.58

*Note**. Changes are statistically significant compared to men in this group ($p < 0.025$). SBV — systolic blood volume, MBV — minute blood volume, ShI — Chaptal index, KEC — endurance coefficient, FCI — functional change index.

The main hemodynamic indicator is cardiac output measured by MBV coefficient. It characterizes the level of tissue blood supply and the associated delivery of oxygen to cells and removal of carbon dioxide from them. Under resting conditions, the body's need for blood supply is relatively low. In healthy untrained people, this indicator (recorded in an upright body position) most often fluctuates between 2.5 and 5 l/min. In athletes, MBV value varies in a wider range, from 3 to 10 l/min. In approximately 60 % of athletes, MBV values correspond to normal standards recorded in healthy untrained people [3, 5].

The MBV values calculated in our study can be represented within the range of figures typical for athletes, with the highest values of MBV observed in men training for endurance (3.47±0.3 l/min), and the lowest in women training in an aerobic-anaerobic mode (2.69±1.2 l/min).

Shaptala Index (ShI) reflects the "mobilization readiness" of the cardiovascular system. We have not found any studies interpreting the ShI in high-class athletes. Thus, the value of this index in healthy young people before the exam was 23.1 ± 0.8 for boys and 14.2 ± 0.9 for girls. Psycho-emotional stress led to an increase in the ShI by 12 and 21 %, respectively [9]. We obtained ShI values at rest that are close to these values (Table 2). Thus, in athletes training mainly in an anaerobic mode, the ShI is, on average, 21.7 ± 1.6 for men and 16.6 ± 2.4 for women. A mixed training regimen leads to significantly lower ShI values: in men — 15.8 ± 2.3, which is 37 % lower than in the previous group ($p < 0.1$); in women — 12.9±5.7. Aerobic training is also accompanied by low values of the ShI, both in men (17.9±2.9) and in women (10.7±3.5) (Table 2).

The endurance coefficient (KEC) calculated in our study for all the examined groups of athletes, to a certain extent, reflects the functional capabilities of the cardiovascular system and should not exceed 16 conventional units at rest. Calculations showed that men in all three groups have the KEC which does not exceed the specified value: the average values were 16.4 ± 0.7 in anaerobic athletes, 15.5 ± 3.9 in the anaerobic-aerobic athletes, and 9.5 ± 0.9 in the aerobic athletes (all in conventional units). Women have higher values of this indicator compared to male athletes by 19 % (anaerobic mode), 40 % (aerobic-anaerobic mode) and 31 % (aerobic mode) ($p < 0.025$). To interpret the obtained data on the ShI and KEC, additional measurements using testing physical load are required.

It is known that there is a certain relationship between the values of the systolic blood volume (SBV) and the level of performance of an athlete, while the value of the MCV at rest is practically not related to athletic performance. This is explained by the fact that the MCV depends not only on the value of the systolic volume, but also on the heart rate. Both of these components, which determine the value of the MCV, are differently related to the level of physical performance. There is a direct proportional relationship between the level of physical performance and the systolic blood volume, and an inverse relationship between the value of physical performance and the heart rate. As a result of such multidirectional trends, the value of the MCV does not depend on the level of physical performance [9, 10]. Thus, judging by the hemodynamic data described above, in high-class athletes who train mainly in aerobic mode, the economization of the heart's work is more pronounced, in female athletes of the same group — to a greater extent.

Next, we measured the index of functional changes (IFC) in the examined athletes, proposed by Berseneva A.P. for the general population [4]. The advantage of this approach is the identification of the preclinical state of the organism, which, in turn, manifests itself in the following stages: 1-expressed functional stress, 2-acute functional stress, 3-overstrain of regulatory mechanisms. Only then does a breakdown of adaptation occur with exhaustion and breakdown of the regulatory systems of the organism.

The IFC reflects the relationship between myocardial-hemodynamic and structural-metabolic homeostasis. As a sensitive indicator of the adaptive reactions, the cardiovascular system is the first to respond to the action of intensive muscular loads; a regulator of the internal environment of the organism, maintaining the homeostasis of its organs and systems by their adequate blood supply.

The obtained IFC values in the athletes of the studied groups are shown in Table 2. Thus, in the group of athletes training mainly in the anaerobic mode, the average IFC value in men was 2.22±0.13 points, in women — 2.04±0.19 points. In martial artists, the IFC was also similar: 2.15±0.05 points, in women of the same group, the functional change index was 1.78±0.09 points, which is significantly lower than in men by 21 % ($p < 0.002$). The same average IFC value was demonstrated by female athletes training in the aerobic mode: 1.77±0.58 points. The average IFC figure for male athletes training in the aerobic mode was 2.50±0.3 points.

According to the authors, the level of functioning of the cardiovascular system (adaptation potential) according to the IFC up to 2.59 points reflects satisfactory adaptation, from 2.60 to 3.09 — tension of adaptation mechanisms, 3.10–3.49 — unsatisfactory adaptation, 3.50 and above — failure of adaptation [4]. We can state that the IFC values in female athletes are significantly lower than in men, and these IFC values reflect satisfactory adaptation. The IFC value for characterizing the adaptive capabilities of an athlete is relevant when considering individual indicators, which is reflected in Table 3 using the example of athletes training in an aerobic mode.

In this group, we recorded the highest values of performance and maximum oxygen consumption (Table 3). Thus, athlete A has a PWC_{170} test result of 2728 kgm /min, and MOC is 5878 ml/min, although the relative values of these indicators are higher for athlete P.: 30.0 kgm /min x kg^{-1} and 66.9 ml/min x kg^{-1}, respectively.

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Table 3

Individual performance indicators, maximal oxygen consumption and adaptation potential of high-class athletes training in aerobic mode

№	Gender	PWC 170 kgm min -1	PWC 170 kgm min 1 kg -1	MOC ml min -1	MOC ml min -1 kg -1	IFC, points
Aerobic energy supply						
1	Woman	1452	17.5	3705	44.7	2.53
2	Woman	1097	18.6	3105	52.6	1.63
3	Man	2728	28.1	5878	60.6	3.25
4	Man	2343	29.3	5224	65.3	2.20
5	Man	2340	30.0	5218	66.9	2.30
6	Man	2593	28.2	5649	61.4	3.46
7	Woman	1176	18.1	3239	49.8	2.15

Calculation of the index of adaptation changes (IAC) showed that two athletes (A. and L.), who showed the first two results in absolute values of the PWC $_{170\ test}$ and MOC, are in the stage of unsatisfactory adaptation, their IFC is 3.25 and 3.16 points, respectively. It should be noted that deviations from the average statistical values of the measured indicators in these athletes were also noted by us in other measurements. The remaining athletes have sufficient adaptation potential according to the IAC.

Conclusion

The studies showed that the values of both systolic and diastolic pressure measured by us in female athletes were slightly lower than those of the examined male athletes, while female athletes training in an anaerobic-aerobic mode had arterial hypotension. The figures of DP, reflecting the systemic work of the heart, were lower in women than in men in all energy modes of training, which indicates higher aerobic capabilities of the athletes' body. At the same time, the average value of the systolic blood volume (SBV) was the highest in male athletes training mainly in an aerobic mode. We also noted that the highest values of the minute blood volume (MBV), characterizing the level of tissue blood supply and gas exchange, are observed in men training for endurance, the lowest — in women training in an aerobic-anaerobic mode.

The Shaptala Index (ShI) reflects the "mobilization readiness" of the cardiovascular system, is within the statistical norm for athletes, both men and women, and the endurance coefficient (KEC), reflecting the functional capabilities of the cardiovascular system, was higher for women in all training modes. This is confirmed by the calculated values of the IFC, which reflect satisfactory adaptation of the body of the examined athletes, however, for female athletes the figures are significantly lower than for men. Also, reserve capacity of the cardiovascular system (according to the DP and KEC indices) in female athletes in all energy modes is higher compared to male athletes. It should be added that we have not encountered any comprehensive studies of the adaptation of the cardiovascular system in athletes in the gender aspect, training in different energy modes.

Thus, measurement and subsequent calculation of integral indicators of adaptation of the cardiovascular system to training loads allows not only to judge its current state, but also to identify the tension of adaptation mechanisms in the process of monitoring the state of the athlete's body, taking into account its gender.

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