



Article

Assessment of Functional Parameters in Young Swimmers

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Abstract: This study aimed to assess changes in cardiovascular functional parameters and adaptive capacity among young swimmers throughout an annual training cycle, considering different training periods and sex-related differences. The study involved 116 young swimmers, including 60 boys (11.8 ± 0.43 years) and 56 girls (11.6 ± 0.40 years), from the Andijan City Specialized Children's and Youth Sports School for Swimming. Cardiovascular function was evaluated using the Ruffier index, Robinson index, endurance coefficient, hemodynamic parameters, functional changes index, and adaptive potential. The results demonstrated improvements in physical performance and cardiovascular endurance throughout the training cycle, particularly during the basic and pre-competition periods. By the pre-competition stage, the Ruffier index decreased by 23.1% in boys and 18.1% in girls, indicating enhanced physical performance and cardiovascular adaptation. Endurance also improved, with favorable changes in the endurance coefficient observed in both groups. These findings suggest that systematic swimming training contributes to the development of cardiovascular functional reserves, although the magnitude and direction of adaptation vary according to sex and training period. The observed fluctuations in hemodynamic parameters indicate that cardiovascular responses to training are not uniform and may reflect differences in physiological maturation, individual adaptive capacity, and training demands. Furthermore, the relative stability of adaptive potential and functional changes indices suggests that the participants generally maintained satisfactory cardiovascular adaptation despite variations in training intensity. The study highlights the importance of comprehensive cardiovascular monitoring rather than relying exclusively on heart rate or individual functional indices. Regular assessment of cardiovascular parameters may help coaches and sports medicine specialists optimize training loads, identify early signs of functional strain, and promote safe physiological development in young athletes.

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1. Introduction

The According to numerous studies, sports performance largely depends on the functional parameters of the body. Each sport has specific model functional characteristics that facilitate the rapid, coordinated, and effective performance of physical actions; therefore, athletes should meet the functional requirements of a particular sport to achieve high sports performance. Functional criteria differ across periods of age-related maturation in both boys and girls [1]. The cardiovascular system of children and adolescents also has distinctive features compared with that of adults. In children, cardiac mass and volume increase, the proportions of the cardiac chambers and its position within the thorax change, and the histological structure of the myocardium and blood vessels undergoes differentiation. By the age of 10 years, cardiac mass is approximately six times greater than at birth, while by 13–14 years the thickness of the cardiac walls doubles [2].

Cardiac enlargement occurs predominantly through an increase in left ventricular mass. Age-related characteristics should therefore be taken into account when prescribing physical loads, with particular attention to excessive sports loads in children and adolescents. In children and adolescents, the heart readily adapts to physical exercise and recovers rapidly; however, its functional activity may be unstable, a feature that can be overlooked by coaches who consequently increase training loads [3]. It should also be remembered that the growing body of young athletes is more sensitive to external influences than that of adult athletes [4]. Knowledge of age-related characteristics and periods of maximal development of particular cardiovascular parameters can help identify signs of overtraining in a timely manner. Taking these data into account makes it possible to adjust the training process and prevent functional decompensation in the developing organism, allowing the child to continue sports participation safely [5].

Previously, many sports medicine physicians and coaches assessed cardiovascular function mainly by measuring heart rate (HR). As is well known, HR decreases with age and with increasing sports-training experience. Because this parameter is individual for each athlete, morning resting pulse should be monitored regularly with consideration of age [6]. A resting heart rate of 50 beats/min may represent sports-related adaptation in one athlete but marked bradycardia in another child. An increase in HR above an athlete's individual baseline may indicate fatigue in the absence of other somatic diseases, such as diffuse goiter or helminthic infestation. Knowledge of the athlete's pulse rate enables the coach to plan the training process or involve an appropriate medical specialist when necessary [7].

Numerous studies indicate that cardiovascular function is best assessed comprehensively. In the training setting, this can be achieved using standardized physical exercise and hemodynamic indices. Cardiovascular status can be evaluated using arterial pressure parameters systolic (SBP), diastolic (DBP), pulse pressure (PP), and mean dynamic pressure (MDP) as well as stroke volume (SV), cardiac output (CO), predicted cardiac output, peripheral vascular resistance, the Quass index, Kerdo autonomic index, Robinson index, Ruffier index, endurance coefficient, cardiac index, the functional changes index (FCI), and the type of circulatory self-regulation [8].

Many contemporary studies assess the cardiovascular system under clinical or laboratory conditions. However, cardiopulmonary exercise testing is not always feasible in 11-year-old children and may be difficult to perform in adolescents because some sports schools are located far from the capital. Not all parents consent to lactate testing because it is an invasive procedure. Therefore, empirical cardiovascular assessment—measurement of pulse and blood pressure at rest, at peak exercise, and during recovery—remains relevant and has become incorporated into a range of hemodynamic indices used to assess athletes' training status [9].

Monitoring functional parameters as a child grows and develops facilitates timely measures aimed at preserving and strengthening the health of the younger generation.

In adolescents, a mismatch may occur between cardiac size and the diameter of blood vessels and cardiac valves, with cardiac growth lagging behind the increase in overall body dimensions. These changes may result in functional murmurs and the so-called “drop heart.” They are associated with age-related morphological and physiological remodeling of the endocrine and nervous systems [10]. Such cardiovascular changes during adolescence may increase the risk of autonomic dysfunction and adolescent hypertension [11]. Comprehensive cardiovascular assessment is therefore necessary to prevent these undesirable phenomena. For example, mean dynamic arterial pressure is a relatively stable value reflecting the elasticity of the arterial wall and the coordination between cardiac output regulation and peripheral vascular resistance. The normal MDP value is 75–85 mmHg [12].

Total peripheral vascular resistance (TPVR) is the resistance of the vascular bed to blood flow resulting from blood viscosity, friction against vessel walls, and turbulent flow. TPVR is determined predominantly by the degree of constriction of resistance vessels, including arterioles and venules located in the pre- and post-capillary portions of the vascular bed. An increase in TPVR leads to a substantial increase in systolic and, particularly, diastolic blood pressure and a decrease in pulse pressure [13].

One of the principal indicators of cardiac function is cardiac output (CO), i.e., the volume of blood ejected into the systemic circulation per unit of time. CO may vary widely, from approximately 4–5 L/min at rest to 25–30 L/min during strenuous physical exercise. CO is determined by stroke volume and heart rate and depends on body position, sex, age, training status, environmental conditions, and many other factors. During exercise, the muscle-pump mechanism plays an important role in increasing cardiac output. Muscle contraction compresses the veins, immediately increasing venous blood return from the lower extremities [14]. Postcapillary vessels, predominantly veins, in the systemic vascular bed (liver, spleen, etc.) also act as part of the overall blood-reservoir system; contraction of their walls increases venous return. Together, these mechanisms increase blood flow to the right ventricle and facilitate rapid cardiac filling [15].

Aim

To study the functional parameters of the body of young swimmers during the annual training cycle.

2. Materials and Methods

The study was conducted at the Andijan City Specialized Children's and Youth Sports School for Swimming. The main study group comprised 60 boys aged 11.8 ± 0.43 years and 56 girls aged 11.6 ± 0.40 years who were engaged in swimming. The obtained results were compared with generally accepted reference values.

The Ruffier test was performed after 5–10 minutes of rest. Resting pulse was measured in the seated position (P1). The participant then performed 30 squats within 45 seconds, after which the pulse was recorded while seated during the first 15 seconds (P2). The third measurement (P3) was the number of heartbeats during the last 15 seconds of the first minute of recovery after squatting. The Ruffier index (I) was calculated using the following formula: $I = [4 \times (P1 + P2 + P3) - 200] / 10$. Interpretation of the Ruffier index for 11-year-olds was as follows: ≥ 18 , unsatisfactory; 14–18, poor physical performance; 9–13, satisfactory; 3.5–9, good; ≤ 3 , excellent.

Regional standards were used to assess the endurance coefficient (EC). According to these standards, the normal EC in preschool and younger school-age children is 22–24 conventional units, whereas in middle-school-age children it is 19–22 conventional units. An increase in this parameter indicates a reduction in cardiovascular functional capacity, whereas a decrease indicates improvement.

The Robinson index characterizes the regulation of the cardiovascular system and reflects the degree of adaptation to physical exercise. It was calculated using the formula: $DP = HR \times SBP / 100$. At rest, the level of physical health and functional cardiovascular status was characterized as low at $DP > 111$ conventional units, below average at 95–100 conventional units, and average at 85–94 conventional units.

Pulse pressure was calculated as: $PP = SBP - DBP$, where SBP is systolic blood pressure (mmHg) and DBP is diastolic blood pressure (mmHg). Mean dynamic pressure was calculated as: $MDP = DBP + 0.42 \times PP$, where DBP is diastolic blood pressure (mmHg) and PP is pulse pressure (mmHg). Total peripheral vascular resistance was calculated as: $TPVR = MDP \times 1333 \times 60 / CO$, where MDP is mean dynamic pressure (mmHg), CO is cardiac output (mL), 1333 is the conversion coefficient to dynes, and 60 is the number of

seconds per minute. Cardiac output was calculated as: $CO = SV \times HR$, where SV is stroke volume (mL) and HR is heart rate (beats/min). Stroke volume was estimated using: $SV = 100 + 0.5 \times PP - 0.6 \times SBP - 0.6 \times Age$, where PP is pulse pressure (mmHg), SBP is systolic blood pressure (mmHg), and Age is expressed in years.

The functional changes index (FCI) is an indicator of the adaptive potential of the circulatory system. It was calculated as: $FCI = 0.011 \times HR + 0.014 \times SBP + 0.008 \times DBP + 0.014 \times Age + 0.009 \times Body\ weight - 0.009 \times Height - 0.27$, where HR is resting heart rate (beats/min), SBP is systolic blood pressure (mmHg), DBP is diastolic blood pressure (mmHg), Age is years, body weight is kg, and height is cm. An FCI value ≤ 2.6 characterizes satisfactory circulatory function; 2.6–3.1 indicates functional strain; 3.1–3.5 indicates unsatisfactory function; and ≥ 3.5 indicates failure of circulatory-system function.

To calculate adaptive potential (AP), the equation of L.A. Konevskikh was used: $AP = 1.238 + 0.09 \times HR$. AP is expressed in conventional units (points), HR is heart rate (beats/min), and 1.238 and 0.09 are equation coefficients. Values below 7.2 points were considered satisfactory. Strain of adaptive mechanisms was recorded at 7.21–8.24 points; unsatisfactory adaptation at 8.25–9.85 points; and failure of adaptive mechanisms at >9.86 points.

Statistical analysis included frequency analysis (%), variation statistics (arithmetic mean, M ; standard error, $\pm m$), and Student's t-test for assessing the significance of differences between mean values. Differences were considered statistically significant at $p \leq 0.05$.

3. Results and Discussion

the Functional tests make it possible to assess the general condition of the body, its reserve capacity, and the characteristics of adaptation of different systems to physical exercise [16]. One of the simplest tests is the Ruffier test, which evaluates adaptive reserves and functional performance of the cardiovascular system using a single standardized physical load and heart-rate measurements at different stages of recovery. Changes in HR reflect adaptation of the circulatory system to the body's requirements and environmental conditions. The increase in HR follows an approximately linear relationship: the better the heart is adapted to exercise, the smaller the post-exercise tachycardia, and vice versa [17]. Accordingly, an inverse relationship can be demonstrated between the Ruffier index and physical performance: the higher the Ruffier index, the poorer the adaptive capacity of the cardiovascular system. High physical performance is an indicator of stable health, whereas low performance may represent a health-risk factor [18].

At both the beginning and the end of the preparatory training period, the Robinson index in boys and girls was within the below-average range. However, in boys it increased by 0.56% by the end of the preparatory period, whereas in girls it decreased by 0.6%. Thus, systolic cardiac function and overall functional capacity improved during the preparatory period in girls, in contrast to boys.

During the preparatory period, the Ruffier index was rated as satisfactory in both boys and girls at both the beginning and end of the period. By the end of the preparatory period, the index decreased by 0.55% in boys, indicating an increase in physical performance, whereas in girls it remained stable.

The endurance coefficient decreased dynamically from the beginning to the end of the preparatory period in all athletes: by 1.58% in boys and by 3.67% in girls, indicating improved cardiovascular functional capacity (Table 1).

Table 1. Characteristics of physical performance and endurance indicators of young swimmers during the preparatory training period ($M \pm m$).

No.	Sex	Age, M±m	years	Parameter	Beginning of period M±m	End of period M±m
1	Boys	11.83±0.44		Robinson index	95.6±0.58	96.14±0.61
1	Boys	11.83±0.44		Ruffier index	10.95±0.49	10.89±0.49
				Endurance coefficient	22.05±0.68	21.7±0.66
2	Girls	11.61±0.40		Robinson index	98.5±0.76	97.9±0.68
2	Girls	11.61±0.40		Ruffier index	11.6±0.45	11.6±0.44
				Endurance coefficient	24.5±0.71	23.6±0.74

Note: $p<0.05$, comparison between the beginning and end of the corresponding training period.

Table 2. Characteristics of physical performance and endurance indicators of young swimmers during the basic training period (M±m).

No.	Sex	Age, M±m	years	Parameter	Beginning of period M±m	End of period M±m
1	Boys	11.83±0.44		Robinson index	96.14±0.61	94.65±0.59
1	Boys	11.83±0.44		Ruffier index	10.89±0.49	10.83±0.46
				Endurance coefficient	21.7±0.66	21.4±0.65
2	Girls	11.61±0.40		Robinson index	97.90±0.68	97.33±0.72
2	Girls	11.61±0.40		Ruffier index	11.62±0.44	11.57±0.43
				Endurance coefficient	23.65±0.74	22.58±0.68

Note: $p<0.05$, comparison between the beginning and end of the corresponding training period.

Table 3. Characteristics of physical performance and endurance indicators of young swimmers during the pre-competition training period (M±m).

No.	Sex	Age, M±m	years	Parameter	Beginning of period M±m	End of period M±m
1	Boys	11.83±0.44		Robinson index	94.65±0.59	95.43±0.55
1	Boys	11.83±0.44		Ruffier index	10.83±0.46	8.44±0.38
				Endurance coefficient	21.38±0.64	21.4±0.65
2	Girls	11.61±0.40		Robinson index	97.33±0.72	97.23±0.65
2	Girls	11.61±0.40		Ruffier index	11.57±0.43	9.50±0.40
				Endurance coefficient	22.58±0.68	18.29±0.54

Note: $p<0.05$, comparison between the beginning and end of the corresponding training period.

Table 4. Characteristics of general hemodynamic parameters of young swimmers during the preparatory training period (M±m).

No.	Sex	Age, years M±m	Parameter	Beginning of period M±m	End of period M±m
1	Boys	11.83±0.44	PP (mmHg)	41.83±0.814	42.17±0.808
1	Boys	11.83±0.44	MDP (mmHg)	82.153±0.388	83.043±0.38
			TPVR (mmHg)	1476±4.46	1513±4.29
			CO (mL)	4568.89±6.50	4483.3±5.59
			SV (mL)	50.07±0.39	49.5±0.40
2	Girls	11.61±0.40	PP (mmHg)	39.01±0.84	40±0.92
2	Girls	11.61±0.40	MDP (mmHg)	83.17±0.62	83.5±0.58
			TPVR (mmHg)	1481.43±5.58	1514.05±5.52
			CO (mL)	4568.89±6.50	4490.682±6.37
			SV (mL)	49.06±0.57	48.96±0.56

Note: p<0.05, comparison between the beginning and end of the corresponding training period.

Table 5. Characteristics of general hemodynamic parameters of young swimmers during the basic training period (M±m).

No.	Sex	Age, years M±m	Parameter	Beginning of period M±m	End of period M±m
1	Boys	11.83±0.44	PP (mmHg)	42.17±0.808	42.17±0.78
1	Boys	11.83±0.44	MDP (mmHg)	83.04±0.38	83.04±0.34
			TPVR (mmHg)	1513±4.29	1546.5±3.38
			CO (mL)	4483.3±5.59	4344.1±4.81
			SV (mL)	49.5±0.40	49.23±0.32
2	Girls	11.61±0.40	PP (mmHg)	40±0.92	41.2±0.90
2	Girls	11.61±0.40	MDP (mmHg)	83.58±0.58	83.39±0.54
			TPVR (mmHg)	1514.05±5.52	1522.8±5.24
			CO (mL)	4490.6±6.37	4448.3±6.16
			SV (mL)	48.96±0.56	49.02±0.50

Note: p<0.05, comparison between the beginning and end of the corresponding training period.

Table 6. Characteristics of general hemodynamic parameters of young swimmers during the pre-competition training period (M±m).

No.	Sex	Age, years M±m	Parameter	Beginning of period M±m	End of period M±m
1	Boys	11.83±0.44	PP (mmHg)	42.17±0.78	47.17±0.75
1	Boys	11.83±0.44	MDP (mmHg)	83.04±0.34	86.14±0.39
			TPVR (mmHg)	1546.5±3.38	1644.6±4.9
			CO (mL)	4344.1±4.81	4023.1±5.08
			SV (mL)	49.23±0.32	47.78±0.39

2	Girls	11.61±0.40	PP (mmHg)	41.2±0.90	47.9±0.83
2	Girls	11.61±0.40	MDP (mmHg)	83.3±0.5	85.04±0.4
			TPVR (mmHg)	1522.8±5.2	1644.6±4.9
			CO (mL)	4448.3±6.1	4183.5±5.3
			SV (mL)	49.02±0.50	48.5±0.41

Note: $p<0.05$, comparison between the beginning and end of the corresponding training period.

Table 7. Characteristics of functional changes index and adaptive potential during the preparatory training period (M±m).

No.	Sex	Age, years M±m	Parameter	Beginning of period M±m	End of period M±m
1	Boys	11.83±0.44	FCI	1.88±0.06	1.89±0.07
1	Boys	11.83±0.44	AP	2.24±0.06	2.25±0.07
2	Girls	11.61±0.40	FCI	1.92±0.11	1.92±0.10
2	Girls	11.61±0.40	AP	2.29±0.10	2.28±0.09

Note: $p<0.05$, comparison between the beginning and end of the corresponding training period.

Table 8. Characteristics of functional changes index and adaptive potential during the basic training period (M±m).

No.	Sex	Age, years M±m	Parameter	Beginning of period M±m	End of period M±m
1	Boys	11.83±0.44	FCI	1.89±0.07	1.88±0.06
1	Boys	11.83±0.44	AP	2.25±0.07	2.24±0.07
2	Girls	11.61±0.40	FCI	1.92±0.10	1.92±0.10
2	Girls	11.61±0.40	AP	2.28±0.09	2.28±0.09

Note: $p<0.05$, comparison between the beginning and end of the corresponding training period.

Table 9. Characteristics of functional changes index and adaptive potential during the pre-competition training period (M±m).

No.	Sex	Age, years M±m	Parameter	Beginning of period M±m	End of period M±m
1	Boys	11.83±0.44	FCI	1.88±0.06	1.91±0.06
1	Boys	11.83±0.44	AP	2.24±0.07	2.24±0.06
2	Girls	11.61±0.40	FCI	1.92±0.10	1.95±0.07
2	Girls	11.61±0.40	AP	2.28±0.09	2.29±0.07

Note: $p<0.05$, comparison between the beginning and end of the corresponding training period.

Among young swimmers, within-group changes in the indices were heterogeneous. During the preparatory period, an increase in the Robinson index was observed in 16.6%

of boys, a decrease in 30%, and no change in 53.3%; among girls, the corresponding proportions were 21.4%, 66%, and 12.5%. The endurance coefficient also showed heterogeneous dynamics: among boys it increased in 8.3%, decreased in 38.3%, and remained unchanged in 53.3%; among girls the corresponding proportions were 8.92%, 78.5%, and 12.5%. From the beginning to the end of the preparatory period, the Ruffier index showed positive dynamics in 3.33% of boys, negative dynamics in 33.3%, and no change in 63.3%; among girls, it increased in 44.6%, decreased in 25%, and remained unchanged in 30.3% (Figure 1).

Figure 1. Proportion of athletes demonstrating positive, negative, or no change in hemodynamic indices during the preparatory training period.

Our analysis of the basic training period showed satisfactory physical performance in both boys and girls at the beginning and end of the period. However, by the end of the basic period, all indicators decreased, which was interpreted as evidence of increased training status.

The Robinson index (RI), or “double product,” is also used to assess myocardial metabolic and energetic processes. An increase in this criterion indicates enhanced myocardial contractile function and improvement of the circulatory system during physical exercise. In boys, the index increased from a below-average to an average value during the basic period, whereas in girls it remained within the below-average range. A decrease in the Robinson index from the beginning to the end of the basic period was 1.55% in boys and 0.58% in girls, indicating improved cardiac adaptation to physical exercise during this period.

The endurance coefficient is an integrated measure incorporating HR and systolic and diastolic blood pressure. An increase indicates reduced cardiovascular functional activity, whereas a decrease indicates enhanced activity.

As shown in Table 2, the endurance coefficient in boys corresponded to age-specific norms at both the beginning and end of the basic period and decreased over time, indicating enhanced cardiovascular activity. In girls, the EC exceeded the age-specific value at the beginning of the basic period but returned to the normal range by the end, suggesting good cardiovascular adaptation.

Figure 2. Proportion of athletes demonstrating positive, negative, or no change in the Robinson index during the basic training period.

During the basic period, the Ruffier index showed the following pattern in boys: it increased in 16.6% of swimmers, decreased in 45%, and remained unchanged in 38.3%. Among girls, the corresponding proportions were 10.7%, 35.7%, and 53.5% (Figure 3).

Figure 3. Proportion of athletes demonstrating positive, negative, or no change in the Ruffier index during the basic training period.

The endurance coefficient did not increase in boys; a negative trend was observed in 80%, while 20% showed neither an increase nor a decrease. Among girls, the corresponding proportions were 5.3%, 67.8%, and 26.7% (Figure 4).

Figure 4. Proportion of athletes demonstrating positive, negative, or no change in the endurance coefficient during the basic training period.

Comparison of the two training periods showed a decrease in the Ruffier index from the beginning of the preparatory period to the end of the basic period in boys. In girls, the Ruffier index remained stable during the preparatory period but decreased by the end of the basic period, indicating improved physical performance. Regarding the Robinson index, boys demonstrated an increase during the preparatory period and a decrease during the basic period, suggesting improved endurance by the end of the basic period. In girls, a decrease was observed from the preparatory period through the end of the basic period, indicating good adaptation and endurance. The endurance coefficient decreased

dynamically in both boys and girls across the two periods, indicating a noticeable increase in endurance.

In male swimmers, the Robinson index was within the average range at the beginning of the pre-competition period but fell into the below-average range by the end, which was interpreted as increased cardiovascular strain immediately before competition. In girls, the index remained below average at both time points but decreased progressively beginning in the basic period. Notably, the Robinson index in boys followed a wave-like pattern: it increased by the end of the preparatory period, decreased by the end of the basic period, and tended to increase again immediately before competition.

During the pre-competition period, the Ruffier index in boys changed from satisfactory to good, indicating increased physical performance toward competition. Considering all three periods, physical performance in boys increased by 23.1%. In girls, although the Ruffier index remained within the satisfactory range throughout training, it decreased by 18.1% by the competition stage, which the authors considered a favorable result.

The endurance coefficient remained within normal limits in all athletes during the pre-competition period, except for girls at the beginning of that period, when reduced functional capacity was observed. From the beginning of the preparatory period, endurance increased by 2.9% in boys and by 25.3% in girls.

Within-group dynamics during the pre-competition period were heterogeneous. In boys, the Robinson index increased in 53.36%, decreased in 31.6%, and remained unchanged in 15%; in girls, the corresponding proportions were 41.07%, 58.9%, and 0%. The endurance coefficient increased in 0% of boys, decreased in 98.3%, and remained unchanged in 1.6%; among girls the corresponding proportions were 5.3%, 94.6%, and 0%. The Ruffier index decreased in 98.3% of boys, remained nearly unchanged in 1.6%, and showed positive dynamics in none. Among girls, positive dynamics were observed in 1.78%, a decrease in 98.2%, and no unchanged cases were reported.

In physiological practice, after HR and blood pressure have been determined, particular interest is given to the calculation of pulse pressure, mean dynamic pressure according to Hickam's formula, total peripheral vascular resistance according to Poiseuille's formula, and cardiac output.

The end of the preparatory period was associated with an increase in PP by 0.8%, MDP by 1.1%, and TPVR by 2.5% in boys, with decreases in CO by 1.8% and SV by 1.14%. In girls, PP increased by 2.53%, MDP by 0.39%, and TPVR by 0.15%, while CO decreased by 1.73% and SV by 0.2% (Table 4).

Within-group changes in general hemodynamic parameters during the preparatory period were heterogeneous. In boys, PP increased in 10%, decreased in 8.33%, and remained unchanged in 81.6%; among girls the corresponding proportions were 16.07%, 1.78%, and 82.14%. Positive, negative, and unchanged MDP dynamics were observed in 12.2%, 3.33%, and 76.6% of boys, respectively, and in 16.07%, 1.78%, and 85.7% of girls. TPVR increased in 43.3% of boys, decreased in 3.33%, and remained unchanged in 53.3%; in girls the corresponding proportions were 76.78%, 10.7%, and 12.5%. CO increased in 1.66% of boys, decreased in 27.45%, and remained unchanged in 53.3%; among girls the proportions were 10.7%, 76.78%, and 12.5%. Cardiac output increased in 3.33% of boys, decreased in 20%, and remained unchanged in 76.6%; among girls it increased in 1.78%, decreased in 16.7%, and remained unchanged in 82.1%.

Figure 5. Proportion of athletes demonstrating positive, negative, or no change in general hemodynamic parameters during the preparatory training period.

By the end of the basic period, PP and MDP in boys changed little; TPVR increased by 2.21%, while CO decreased by 3.10% and SV by 0.54%. In girls, PP increased by 3%,

TPVR by 0.57%, and SV by 0.125, whereas MDP decreased by 0.22% and CO by 0.94% (Table 5).

Among girls, PP increased in 19.6% and remained nearly unchanged in 80.3%. MDP increased in 10.7%, decreased in 16.07%, and remained nearly unchanged in 73.2%. TPVR increased in 95% of boys, with no decrease reported and no change in 3.5%; in girls the corresponding proportions were 53.5%, 19.6%, and 26.7%. CO did not increase in boys: it decreased in 96.6% and remained unchanged in 3.33%. In girls the corresponding proportions were 19.6%, 53.5%, and 26.7%. Cardiac output decreased in 50% of boys and remained nearly unchanged in 50%; in girls it increased in 16.07%, decreased in 32.1%, and remained unchanged in 51.7%.

Figure 6. Proportion of athletes demonstrating positive, negative, or no change in general hemodynamic parameters during the basic training period.

By the end of the pre-competition period, PP in boys did not change, MDP increased by 3.73%, TPVR by 0.41%, while CO decreased by 7.38% and SV by 2.94%. In girls, PP increased by 16.26%, MDP by 2.08%, and TPVR by 7.99%, while SV decreased by 1.06% and CO by 0.13% (Table 6).

Within-group changes during the pre-competition period were heterogeneous. PP increased in 66% of boys, decreased in 3.57%, and remained unchanged in 30.3%; the same proportions were reported for girls. MDP increased in 57.1% of boys, decreased in 17.8%, and remained unchanged in 25%; the same distribution was reported for girls. TPVR increased in 91.07% of boys and decreased in 8.9%; the corresponding proportions in girls were also 91.07% and 8.9%. No unchanged cases were reported. CO increased in 7.14% of boys and decreased in 92.8%; the same proportions were reported for girls, with no unchanged cases. Cardiac output increased in 23.2% of boys, decreased in 60.7%, and remained unchanged in 16.07%; the same proportions were reported in girls.

Figure 6. Proportion of athletes demonstrating positive, negative, or no change in general hemodynamic parameters during the pre-competition training period.

By the end of the preparatory period, FCI in boys changed minimally, increasing by 0.53%, while AP increased by 0.44%. In girls, FCI did not change, whereas AP increased by 0.44% (Table 7). Within-group FCI increased in 20% of boys, decreased in 21.6%, and remained unchanged in 58.3%; among girls the corresponding proportions were 21.4%, 53.5%, and 14.25%. AP increased in 20% of boys, decreased in 18.3%, and remained unchanged in 61.6%; among girls the corresponding proportions were 21.4%, 60.7%, and 17.85%.

Figure 7. Proportion of athletes demonstrating positive, negative, or no change in adaptation indices during the preparatory training period.

By the end of the basic period, FCI decreased by 0.53% and AP by 0.44% in boys, whereas neither FCI nor AP changed in girls (Table 8). Within-group FCI increased in 11.6% of boys, decreased in 43.3%, and remained unchanged in 45%; among girls the proportions were 35.7%, 44.6%, and 19.6%. AP increased in 3.3% of boys, decreased in 56.6%, and remained unchanged in 40%; among girls the proportions were 30.3%, 44.6%, and 25%.

Figure 8. Proportion of athletes demonstrating positive, negative, or no change in adaptation indices during the basic training period.

By the end of the pre-competition period, FCI increased by 1.59% in boys, while AP did not change. In girls, FCI increased by 1.56% and AP by 0.44% (Table 9). Within-group FCI increased in 53.3% of boys, decreased in 31.6%, and remained unchanged in 15%; among girls the proportions were 50%, 41%, and 8.9%. AP increased in 46.6% of boys, decreased in 38.3%, and remained unchanged in 15%; among girls the proportions were 42.8%, 51.7%, and 5.3%.

Figure 8. Proportion of athletes demonstrating positive, negative, or no change in adaptation indices during the pre-competition training period.

4. Conclusion

Analysis of the dynamics of hemodynamic indices showed that, during training, all athletes demonstrated increased physical performance, endurance, and cardiovascular adaptation to physical exercise. Sex-related differences in swimmers' adaptation were identified: the increase in endurance was more pronounced in girls, whereas the increase in physical performance across the three preparation periods was more pronounced in boys.

REFERENCES

- [1] R. A. Abzalov, A. I. Ziyatdinova, and N. I. Abzalov, "Regulation of cardiac pump function in the developing organism," *Russian Journal of Physiology Named After I. M. Sechenov*, vol. 90, no. 8, p. 174, 2004.
- [2] V. A. Alekseeva and A. B. Guryeva, "Functional state of the cardiovascular system in Yakut combat-sport athletes aged 14–19 years," *Human. Sport. Medicine*, vol. 22, no. S2, pp. 30–36, 2022, doi: 10.14529/hsm22s204.
- [3] L. Kh. Garkavi, E. B. Kvakina, and T. S. Kuzmenko, *Antistressor Reactions and Activation Therapy*. Moscow, Russia: Kniga po Trebovaniyu, 2015, 559 pp.
- [4] T. R. Zulkarnaev, A. I. Agafonov, A. A. Kazak, I. I. Khisamiev, E. A. Povargo, and A. T. Zulkarnaeva, "Hygienic assessment of hemodynamic parameters in schoolchildren and students with different levels of physical activity," *Hygiene of Children and Adolescents*, no. 2 (311), pp. 19–25, 2019.
- [5] A. I. Ikramov, *Medical Foundations of Physical Education and Sport in the Formation of a Harmoniously Developed Generation*. Tashkent, Uzbekistan, 2011.
- [6] V. K. Kozukova, "Dynamics of total peripheral vascular resistance during the year in women," *Eurasian Union of Scientists*, vol. 2, no. 64, 2019, doi: 10.31618/ESU.2413-9335.2019.2.64.242.
- [7] I. E. Korelskaya and E. N. Vorontsova, "Assessment of the cardiovascular system in young athletes engaged in cross-country skiing and permanently residing in the northern region of Russia," *Scientific Review. Biological Sciences*, no. 2, pp. 15–20, 2018, doi: 10.17513/srbs.1097.
- [8] S. N. Kolomeichuk, R. V. Alekseev, A. A. Putilov, and A. Yu. Meygal, "Association of ACE and BDKRB2 gene polymorphisms with heart-rate variability parameters in athletes of the Republic of Karelia," *Bulletin of Russian State Medical University*, no. 4, pp. 50–58, 2017, doi: 10.24075/brsmu.2017-04-08.
- [9] E. N. Kuzina, L. I. Mozzhukhina, and G. Kondratyeva, "Assessment of physical health indicators in preschool and school-age children with acute and chronic respiratory pathology using functional research methods," *Perm Medical Journal*, vol. 30, no. 1, p. 81, 2013.
- [10] S. I. Chebanu, R. D. Deleu, A. V. Tabyrtse, O. I. Tafuni, and G. E. Friptulyak, "Functional state of the body of young athletes during participation in sports games," *Hygiene and Sanitation*, vol. 100, no. 3, pp. 268–273, 2021, doi: 10.47470/0016-9900-2021-100-3-268-273.
- [11] N. L. Chernaya, G. S. Ganuzina, and L. A. Lebedeva, *Assessment of the Effectiveness of Children's Health Improvement in Suburban Residential Recreational and Health Institutions: Methodological Recommendations*. Yaroslavl, Russia, 2009.
- [12] M. F. Bergeron, "Healthy and sustainable youth sports: The future of youth athlete development," *Sports Science Exchange*, vol. 28, no. 176, pp. 1–6, 2017.
- [13] L. S. Chutko, T. L. Kornishina, S. Yu. Surushkina, et al., "Syndrome of autonomic dysfunction in children and adolescents," *S. S. Korsakov Journal of Neurology and Psychiatry*, vol. 118, no. 1, pp. 43–49, 2018, doi: 10.17116/jnevro20181181143-49.
- [14] N. N. Larionova and I. N. Zhmyrko, "Determination of functional indicators of students as a factor of readiness to pass physical-education assessment standards," *Academic Bulletin of the Rostov Branch of the Russian Customs Academy*, vol. 1, no. 18, pp. 77–81, 2015.
- [15] V. P. Lupanov and E. Yu. Nuraliev, *Functional Exercise Tests in the Diagnosis of Ischemic Heart Disease*. Petrozavodsk, Russia: IntelTek Grupp LLC, 2012, 224 pp.
- [16] M. I. Rakhimov, "Peculiarities of chronotropic cardiac response in children and adolescents after physical exercise," *Fundamental Research*, no. 2–16, pp. 3536–3538, 2015.
- [17] T. N. Shutova, "Planning health-improving physical-education technologies for economics students based on analysis of cardiac muscle performance," *Plekhanov Scientific Bulletin*, vol. 1, no. 11, pp. 199–204, 2017.

[18] InfoUrok, "Ruffier test: Assessment of cardiac performance during physical exercise," *InfoUrok*, n.d. [Online]. Available: [InfoUrok – Ruffier Test](#).