

## STRUCTURAL AND FUNCTIONAL REORGANIZATION OF THE HEART AND ITS RELATIONSHIP WITH PHYSICAL ACTIVITIES IN ELITE FOOTBALL PLAYERS

### STRUKTURALNE I CZYNNOŚCIOWE ZMIANY ZACHODZĄCE W MIĘŚNIU SERCOWYM ORAZ ICH ZWIĄZEK Z AKTYWNOŚCIĄ FIZYCZNĄ ELITARNYCH PIŁKARZY NOŻNYCH

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#### Summary

**Background.** The aim of the study was the evaluation of the structural and functional reorganization of the heart and their relationship with physical activity in elite football players.

**Material and methods.** Characteristics of the myocardium and physical activity were studied using the Catapult Vector S7 GPS-sport telemetry system, "Polar" heart rate monitor, and echocardioscope.

**Results.** Physical activity in the mode of high-speed running during games was found to contribute to an increase in playing activities of football players and structural and functional characteristics of the heart. A correlation ( $r=0.35-0.51$ ;  $p=0.021-0.043$ ) was obtained between the performance of football players, which was measured by distance, heart rate, cardiac output, stroke volume, stroke index, left ventricle mass. Statistically significant differences were found in the structural and functional characteristics of the myocardium: end-diastolic volume, end-systolic volume, stroke volume, stroke index, ejection fraction, myocardial contractility index, and left ventricle mass for groups of players with different gradations of distance in the mode of high-speed running.

**Conclusions.** It was found that there is a relationship between the physical activities of highly qualified football players in the mode of speed running with the characteristics of the pumping function of the heart.

**Keywords:** telemetry, football, echocardiography, physical activity

#### Streszczenie

**Wprowadzenie.** Celem pracy była analiza strukturalnych i czynnościowych zmian zachodzących w mięśniu sercowym oraz ich związku z aktywnością fizyczną elitarnych piłkarzy nożnych.

**Materiał i metody.** Charakterystykę mięśnia sercowego oraz aktywność fizyczną badano przy użyciu systemu telemetrii sportowej GPS Catapult Vector S7, monitora tętna „Polar” oraz echokardiografii.

**Wyniki.** Stwierdzono, że aktywność fizyczna w formie szybkiego biegu w trakcie gry przyczynia się do zwiększenia aktywności boiskowej piłkarzy nożnych oraz strukturalnych i czynnościowych zmian w mięśniu sercowym. Zaobserwowano korelację ( $r=0,35-0,51$ ;  $p=0,021-0,043$ ) pomiędzy wydolnością piłkarzy nożnych, którą mierzono długością dystansu, częstością skurczów serca, rzutem serca, objętością wyrzutową, wskaźnikiem objętości wyrzutowej oraz masą lewej komory serca. Stwierdzono istotne statystycznie różnice w strukturalnych i czynnościowych cechach mięśnia sercowego, tj. objętości końcoworozkurczowej i końcowoskurczowej, objętości wyrzutowej, wskaźniku objętości wyrzutowej, frakcji wyrzutowej, wskaźniku sercowym i masie lewej komory serca pomiędzy grupami zawodników o różnej długości dystansu przebytej w formie szybkiego biegu.

**Wnioski.** Stwierdzono, że istnieje związek między aktywnością fizyczną w formie szybkiego biegu wysoko wykwalifikowanych piłkarzy nożnych a cechami funkcji pompującej serca.

**Słowa kluczowe:** telemetria, piłka nożna, echokardiografia, aktywność fizyczna

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## Introduction

An objective assessment of the circulatory system's functional state in relation to the activities of football players is an important task in the theory and practice of sports, medicine, and physiology. This is due to the fact that football is a multi-component sport that requires a high level of aerobic training [1]. It is known that against the background of basic aerobic activity, football players perform intermittent actions of high intensity, characterized by accelerations, sprints, changes in direction, jumps, side steps, and specific technical movements [2]. The result of the game is dependent on the technical, tactical, psychological, functional training, and physical activities of players [3,4]. It should be noted that exceptional physical activity is considered an important component of achieving elite results in the sport. According to experts, the physical activities of football players depend on their morpho-functional characteristics, strength, endurance, and muscle coordination, as well as the power, capacity, and efficiency of energy supply mechanisms [5]. Elite results can only be achieved by players who possess a high level of physical activities and functional fitness [6,7].

Analyzing the performances of the strongest teams at the last World and European Championships, it should be noted that modern football is characterized by high-intensity matches, a high density of technical and tactical actions, and their increased significance in the last minutes of the sport when the activities of the football players become especially important [4,8]. They excel in the latter, a high level of cardiorespiratory capacity is required of the football player's body [9]. This demonstrates the important role muscle blood supply through heart function plays to ensure maximal oxygen consumption ( $\dot{V}O_2 \text{ max}$ ) and maintain the elite performance of football players [10]. Therefore, building a rational training process requires knowledge of the functional state of a player's cardiovascular system. This system, under certain conditions, can be a weak link in the transport of oxygen to muscles and can limit the playing activities of players. According to the results of our research and that of other authors, playing football is accompanied by an increase in heart rate (HR) to 190-210 beats per minute, an increase in oxygen consumption to 90-100% of  $\dot{V}O_2 \text{ max}$ , and an increase in blood lactate concentrations to 8.34-14.0 mmol·l<sup>-1</sup> [11,12]. It has also been shown that skilled football players possess a high level of aerobic capacity. The level of  $\dot{V}O_2 \text{ max}$  for Premier League players is 61.27 ml·kg·min<sup>-1</sup> and 67.05 ml·kg·min<sup>-1</sup> for players of leading foreign teams and are similar to the levels of  $\dot{V}O_2 \text{ max}$  in high-level athletes specializing in cycling, rowing, cross-country skiing, and middle- and long-distance racing [13-16]. Research has shown that an increase in cardiac output (CO), due to the maximum mobilization of the cardiovascular system's reserve capacity, is important in providing oxygen to the football player's body [17]. Thus, modern football is characterized by a high level of playing activities and cardiorespiratory capabilities [3,9,10].

In light of some studies [4,12,18], which examined the features of the cardiovascular system in skilled football players, there are many unresolved issues. The relationship between physical activity and functional indicators of the heart is established in some studies [2]. Characteristics of playing activities, considering the structural and functional changes of the heart, remain insufficiently studied and rarely used in training and competitive activities. We assume that the playing activities and physical performance of football players may be determined by the structural and functional capabilities of pumping by the myocardium. A number of issues are unclear, including the relationship between the structural and functional characteristics of the heart and the playing activities of football players in different positions [6,9,16]. How significant from a prognostic point of view are structural and functional changes in the myocardium to influence the training process? Finally, is it possible to use the results of a study of physical activities and features of structural and functional characteristics of the heart in the selection and staffing of a team? To clarify these issues, we need research using telemetry systems to analyze motor activity using an automated multi-channel GPS system. Such knowledge is necessary to establish the patterns and features of the cardiovascular system's adaptation to intense physical activity. This is the basis for further increasing the playing activities of football players and the basis for preventing the development of pathological conditions. It is also an urgent problem in sports theory, medicine, and physiology in avoiding fatigue, depletion of energy sources, and achieving high sports results.

This article focuses on the peculiarities of structural and functional reorganization of the myocardium in elite football players with different gradations of physical activities. It was necessary to establish a relationship between the distance players ran during a game and echocardiography findings of the heart.

## Material and methods

Guided by the principles of biomedical ethics and based on personal consent and norms of bioethics, we studied the structural and functional characteristics of the heart at rest, and during general and special game-

related physical activities in 41 professional football players. The average age of the players was  $23.1 \pm 0.9$  years old.

Physical activities were studied during national championship games in Ukraine in 2020-2021 using the "GPS-sport system Catapult Vector S7" telemetry system. Physical activities were determined by the distance (m) players ran during the game and at different speeds. Speed modes were determined as the following: walking — 0.7-7.1 km/h, jogging — 7.2-14.3 km/h, aerobic running — 14.4-19.7 km/h, high-speed running — 19.8-25.1 km/h, and sprinting —  $>25.1$  km/h [2,9].

We documented cardiography findings and the HR of players on an empty stomach after 10 minutes of lying down to allow a return to registration conditions. Background indicators were recorded during the last 5 minutes. Later, cardio intervals were recorded during games using a telemetry system and a Polar heart rate monitor (Elecnro OU, Finland). We analyzed the structural and functional state of the heart at rest using an echocardioscope on the SIEMENS ACUSON X 300 device. We measured indicators of the heart's pump function, namely: end-diastolic diameter (EDD, mm), end-systolic diameter (ESD, mm), end-diastolic volume (EDV, ml), end-systolic volume (ESV, ml), ejection fraction (EF, %), CO (l), cardiac index (CI,  $l \cdot \text{min}^{-1} \cdot \text{m}^{-2}$ ), stroke volume (SV, ml), stroke index (SI,  $\text{ml} \cdot \text{m}^{-2}$ ), myocardial contractility index (MCI, %), and left ventricle mass (LVM, g) [10].

Data analysis was performed using statistical packages for medical and biological research (SPSS, version 21, IBM, USA). Verification of the data's normality that fell under the law of normal distribution was carried out using the Shapiro-Wilk test. The differences between normally distributed samples were determined using the Student's T-test. The differences between non-normally distributed samples using the Mann-Whitney criteria. The calculations of correlation coefficients ( $r$ ) were performed using the Spearman method. A  $p$ -value for statistical significance was set at a level of less than 0.05.

## Results

The anthropometric and functional indicators of the elite football players are presented in Table 1.

**Table 1.** Anthropometric and functional indicators in football players ( $n=41$ ), presented as the median and lower and upper quartiles [Me (Q25-Q75)]

Researched indexes	Median	Lower quartile, 25%	Upper quartile, 75%
Age, years old	23.4	19.3	28.7
Height, m	1.85	1.69	1.93
Weight, kg	78.5	69.3	74.6
BMI, $\text{kg}/\text{m}^2$	22.3	20.7	23.6
Fat mass, %	11.6	8.6	12.8
BP max, mmHg	122.4	116.5	128.7
BP min, mmHg	78.4	67.4	83.3
HR, beats/min	63.3	59.8	66.5

Table 1 shows that anthropometric and functional indicators are in accordance with the literature and are typical for elite players [19].

### *Research of physical activity in game activities*

The physical activity of football players was studied with the help of the "GPS-sport system Catapult Vector S7" GPSports-system and "Polar" heart rate monitor during the 2020-2021 championship games of the Premier League of Ukraine. In accordance with recommendations [2,9], speed gradations during activities in the match were established. According to the indicators of distance during the match, playing time was determined in absolute and relative values for different speeds, average HR, and peak HR (Table 2).

**Table 2.** Distance (m) and HR per game and in different speed modes of football players during game activities (n=41)

Investigated indicator	Per game	Speed modes				
		Walking: 0.7-7.1 km/h	Jogging: 7.2-14.3 km/h	Aerobic running: 14.4- 19.7 km/h	High-speed running: 19.8- 25.1 km/h	Sprint: >25.1 km/h
Distance (m)	11069.8 ±121.4	4012.3 ±88.5	4475.6 ±93.8	1841.0 ±44.3	611.3 ±18.4	129.6 ±11.7
Game time in different speed modes (min.)	90.0	32.9	34.0	14.6	6.8	1.7
Relative time indicators in different speed modes (%)	100	36.6	37.8	16.2	7.5	1.9
HR (min. <sup>-1</sup> )	158.8 [124; 171]	104.9 [89;114]	134.7 [124;139]	156.4 [151; 160]	170.9 [163; 179]	178.6 [168; 191]

The results obtained using a telemetry system showed that the amount of work performed and the distance per game was 11069.8±121.4 m. The majority of playing time (34.0 minutes) was spent jogging (37.8%) with a speed of 7.2-14.3 km/h. The football players covered 4475.6±93.8 m while in this speed mode. The players spent a slightly lower amount of time (36.6%) walking, at a speed of 0.7-7.1 km/h, and covered a distance of 4012.3±88.5 m. In the mode of aerobic running (14.4-19.7 km/h), the amount of time in this mode was less (16.2%) covering a distance of 1841.0±44.3 m. The mode of high-speed running (19.8-25.1 km/h) was only performed for a distance of 611.3±18.4 m which corresponded to 7.5% of playing time. In the sprint mode (more than 25.1 km/h), the players ran 129.6±11.7 m (1.9% of playing time) per game.

The correlation coefficient results between running work per game and the number of points the team scored during the game did not reveal a statistically significant relationship. Therefore, we cannot say that the physical activities of the players and the amount of running work affected the outcome of the game. However, it should be noted that we found a weak correlation  $r=0.38$  ( $p=0.045$ ) between the team's points scored during the season and the average distance covered in high-speed running (19.8-25.1 km/h). For other running modes, the correlation between the number of points per season and distance did not reach statistical significance. So, the effectiveness of the game depends on the physical activities (volume of running work) in which players spent in the high-speed running mode with a speed of 19.8-25.1 km/h.

Since we found a relationship between the number of goals scored during national championship games and the distance covered in the high-speed running mode gave us reason to analyze the dependence of average HR values per game and different speed modes. Thus, the average HR for the team per game, which was obtained by the Polar heart rate monitor, was 158.8 [124; 171] min<sup>-1</sup>. The greatest amount of running activities by football players was spent in the jogging mode (7.2-14.3 km/h). In this speed mode, players ran 4475.6±93.8 m, spent 37.8% of the game, and achieved a HR of 134.7 [124; 139] min<sup>-1</sup>. Higher HRs (170.9 [163; 179] min<sup>-1</sup>) were detected in the high-speed running mode with an intensity of 19.8-25.1 km/h. This speed mode was present for only 7.5% of playing time. Additionally, players achieved a HR of 178.6 [168; 191] min<sup>-1</sup> for a small share of playing time (1.9 %) in the speed mode of sprinting. Low HR values during games (104.9 [89; 114] min<sup>-1</sup>) were recorded in the slow running and walking mode. In this mode, the players spent 32.9 minutes, 36.6% of playing time, and covered a distance of 4012.3±88.5 m.

Statistical analysis did not reveal a significant correlation between average HR and distance per game ( $r=0.32$ ;  $p=0.071$ ). There was no statistically significant correlation between HR and distance in different running modes ( $p>0.05$ ). We can argue that the average HR is not related to the result of playing activities. However, a weak correlation was found ( $r=0.38$ ;  $p=0.045$ ) between the average distance covered in high-speed running (19.8-25.1 km/h) and HR. For other running modes, the correlation between distance and HR did not reach statistically significant values ( $p>0.05$ ).

Thus, it has been proved that the effectiveness of the game, amount of running work, and HR are related to the physical activities that the players performed in the high-speed running mode (19.8-25.1 km/h).

#### *Study of structural and functional characteristics of the heart*

Since we found a statistically significant relationship between the number of points in the championship games and distance ( $r=0.42$ ;  $p=0.034$ ) in the mode of speed running gave us reason to analyze the relationship between the structural and functional characteristics of the myocardium and physical activities in football

players. It was logical to assume that footballers with different levels of physical endurance would have different structural and functional changes in the myocardium.

As part of this study, an in-depth analysis of physical activities and adaptive changes in the pumping function of the heart was conducted using echocardiography. To do this, the method of cluster analysis (method K averages) divided the players into three clusters according to the average distances (611.3±18.4 m) covered in the mode of speed running (19.8-25.1 km/h). The first group included football players with an average of 742.2±16.3 m, the second averaged 629.6±24.4 m, and the third averaged 570.3±15.1 m. The findings of structural and functional reorganization of the heart in the three groups are presented in Table 3.

**Table 3.** Structural and functional characteristics of the heart ( $\bar{X}\pm m$ ) of football players (n=41) with different gradations of distance in the speed running mode

Echocardiographic indicators	Groups of football players, depending on the distance in high-intensity running		
	1 (n=13)	2 (n=16)	3 (n=12)
Distance in high-intensity running mode, m	742.2±16.3	629.6±24.4	570.3±15.1***
Heart rate (HR), min. <sup>-1</sup>	58.3±1.8	60.4±0.9	64.9±1.9*
Stroke volume (SV), ml	102.1±2.4	98.1±3.7	91.2±2.3***
Cardiac output (CO), l·min. <sup>-1</sup>	6.2±0.2	6.3±0.4	6.1±0.4
Stroke index (SI), ml·m <sup>2</sup>	60.5±2.4	58.4±1.7	54.4±2.1**
Cardiac index (CI), l·min. <sup>-1</sup> ·m <sup>2</sup>	3.2±0.1	3.1±0.1	3.1±0.1
Left ventricular end-diastolic diameter (LVDd), cm	5.4±0.1	5.3±0.2	5.2±0.2
Left ventricular end-systolic diameter (LVSd), cm	3.1±0.2	3.6±0.1	3.8±0.2***
Left ventricular end-diastolic volume (LVDV), ml	133.7±2.5	129.6±3.4	121.2±3.6*
Left ventricular end-systolic volume (LVSV), ml	69.6±2.9	45.1±4.6	40.1±4.6***
Ejection fraction (EF), %	70.5±2.4	68.0±1.2	58.1±1.2***
Myocardial contractility index (MCI), %	42.1±2.0	41.5±1.3	34.6±1.4***
Left ventricular myocardial mass (LVM), g	154.7±3.0	151.4±4.5	145.8±3.0*

Notes: The values of the first group reached statistical significance when compared to the third group (\*  $p<0.05$ ; \*\*  $p<0.01$ ; \*\*\*  $p<0.001$ ).

The data given in Table 3 shows that the values of structural and functional characteristics of the heart were different in the three groups with different gradations of distance covered in the mode of high-speed running (19.8-25.1 km/h) are different. Thus, the football players in the first group, which ran higher distances in the mode of speed running, had statistically significant higher values of SV, SI, EDV, ESV, EF, CI, and LVM. These values reflect the altered structural and functional reorganization of the heart compared to the third group ( $p<0.05-0.001$ ). This resulted in high systolic blood volumes. In addition, in the first group, we found that the proportion of total systole was 40% on average and diastole was 59.9%. Players in the third group had a total systole proportion of 44% and diastole of 55.5%. The HR and ESD of the first group were lower compared to the third group ( $p<0.05-0.001$ ). However, other structural and functional indicators such as CO, CI, and EDD were similar in the three groups ( $p>0.05$ ).

LVM is one of the most important characteristics of football players' hearts. For the first group of football players with higher values of distance and physical activities, LVM was higher (154.7±3.0 g) compared to the group with less running work (145.8±3.0 g;  $p<0.05$ ).

Studies of structural and functional reorganization of the myocardium were necessary to fuel reserves and increase the playing activities of football players. The distance each team ran per game (on average, 11069.8±121.4 m) and HR (159.8 [153; 167] min<sup>-1</sup>) were obtained with the help of a GPSports-system and Polar heart rate monitor. Echocardiography revealed changes in the structural and functional characteristics of the heart in football players. We should mention an interesting fact that the correlation analysis did not reveal statistically significant relationships between the mean distance and HR for the game ( $p>0.05$ ). Additionally, there were no statistically significant findings in the characteristics of echocardiography for CO, CI, EDD, ESV, EDV, and LVM ( $p>0.05$ ). Statistically significant correlations were found between SV and SI and mean distances during high-speed running (19.8-25.1 km/h). The following indicators, HR, CO, SV, SI, and SV mass were analyzed for correlation to the mean distance run in the various running modes (Table 4).

**Table 4.** Correlation coefficients of distance (m) in different running modes with echocardiography (n=41)

Echocardiography indicators	Correlation coefficients (r) in different speed modes				
	Walking: 0.7-7.1 km/h	Jogging: 7.2-14.3 km/h	Aerobic running: 14.4- 19.7 km/h	High-speed running: 19.8- 25.1 km/h	Sprint: >25.1 km/h
HR, min. <sup>-1</sup>	0.21	0.21	0.42	0.51	0.31
SV, ml	0.32	0.37	0.37	0.38	0.34
SI, ml·m <sup>2</sup>	0.21	0.23	0.29	0.43	0.39
CO, l·min. <sup>-1</sup>	0.18	0.20	0.35	0.38	0.24
CI, l·min. <sup>-1</sup> ·m <sup>2</sup>	0.23	0.22	0.28	0.29	0.23
LVM, g	0.26	0.29	0.47	0.46	0.31

Notes: Statistically significant correlations  $p < 0.05$  are highlighted in bold.

A statistically significant correlation ( $r=0.51$ ;  $p=0.034$ ) between the distance covered in high-speed running and HR was established. Besides, a close relationships between mean distance in the mode of high-speed running and SV ( $r=0.38$ ;  $p=0.021$ ), CO ( $r=0.38$ ;  $p=0.037$ ), and LVM ( $r=0.46$ ;  $p=0.043$ ) were found. A slightly weaker relationships ( $r=0.42$ ;  $p=0.034$ ) between distance in the aerobic running mode (14.4-19.7 km/h) and HR ( $r=0.42$ ;  $p=0.033$ ), SV ( $r=0.37$ ;  $p=0.021$ ), CO ( $r=0.35$ ;  $p=0.037$ ), and LVM ( $r=0.47$ ;  $p=0.043$ ) were found. This makes us think that there is a dependence of physical activities in football players on the state of structural and functional characteristics of the heart not only in the aerobic mode but also in high-speed running (19.8-25.1 km/h).

The validity of this assumption was confirmed by the results of the structural and functional characteristics in groups of football players with different gradations of physical performance. It was found that the distance ran during a game in the mode of high-speed running (19.8-25.1 km/h) was on average  $611.3 \pm 18.4$  m. Players were then divided into groups with the first group of players having high values ( $742.2 \pm 16.3$  m), the second with medium values ( $629.6 \pm 24.4$  m), and the third with low values ( $570.3 \pm 15.1$  m) of distances (Table 3). The results showed that the structural and functional characteristics of SV, SI, EF, CI, EDV, ESV, and LVM ( $p < 0.001-0.05$ ) in the first group were higher compared to players in the third group. Conversely, the third group of football players with low values of physical activity had higher structural and functional indicators on echocardiography in HR and ESD ( $p < 0.05-0.001$ ) than the first group. At the same time, the indicators of CO, CI, and EDD did not differ in players separated by distance in the high-intensity running mode. We found the biggest differences in the analysis of the duration of total systole and diastole for the duration of the cardiac cycle. The proportion of total systole was 40.0% and diastole was 59.9% on average in the first group. At the same time, it was 44.0% and 55.5%, respectively for players in the third group.

## Discussion

The high level of physical activity and structural and functional characteristics of the heart in the first group of football players can be explained by the greater volume and intensity of running work performed during the game. The high level of physical activity in the first group was ensured by more pronounced structural and functional changes in the hearts of football players than in those with lower levels. It is possible to speak about the formation of more expressed functional hypertrophy of the myocardium in football players in the first group who had a high level of physical activity [17]. Most authors, including those who used direct research methods [10,18], noted an increase in SV and CO in athletes due to high-intensity physical activity. Studies presenting results obtained with the help of X-ray examinations have shown that football players have an increased heart size. In some works [20-22], echocardiographic characteristics of individual structures of the heart in football players are described. It is believed that long-term training promotes an increase in the size of the left atrium and ventricle, myocardial mass, ventricular thickness, EDV, ESV, and SV. Increasing SV and CI in response to training promotes the development of physical endurance in football players and is of paramount importance for the growth of CO. According to researchers [4,15,16], an increase in SV in elite players is observed both at rest and during physical load occurring at the level of  $VO_2$  max. Under conditions of intense work in football players, oxygen absorption can exceed  $6-7$  l·min<sup>-1</sup> and SV can exceed 200-220 ml [3,23]. Such changes can occur due to aerobic physical activity and are stipulated by an increase in the number of capillaries in the muscles and the opening of collateral vessels. This leads to increased blood flow and the ability of muscles to utilize oxygen under strenuous work [24].

Based on the results of our study, it is also possible that the high level of physical activity and morpho-functional characteristics of the heart in the first group could be stipulated by the peculiarities of selection to the team of masters, when, in addition to a high level of special training, genetically determined adaptive responses of the cardiovascular system were taken into account [25]. The validity of such considerations is confirmed by the high values of SV in the first group which was characterized by a greater amount of running work than in the third group. Usually, an indicator of SV in elite players at rest can reach 115-135 ml. In addition, we found a relationship between the diastolic volume of the ventricular cavity and the SV. The larger the volume of the ventricular cavity in a football player, the greater the SV. Additionally, the EDV of the ventricular cavity in the examined football players increased, and therefore, we do not exclude sarcomere lengthening. This is especially true in the first group of football players who were characterized by a higher level of physical activity. The football players of the first group ran in the speed running mode of 742.2 m per game which was statistically more than the players in the second and third groups. This allows us to identify the structural and functional characteristics of the heart as high for the first group compared to the groups with low levels of physical activity.

Thus, we associate the increase in SV and SI as a response to training and competitive loads aimed at developing endurance and special physical performance to the reorganization of the structure and function of the heart, increasing heart size due to dilatation and hypertrophy, and increased strength of heart contractions [13,17,24]. The dilatation of the heart chambers caused by an increase in EDV, according to Frank-Starling's law, causes a more powerful myocardial contraction [10,18]. The obtained results show that the structural and functional characteristics of the heart are most closely linked and provide special physical activity to football players in a high-speed running mode, and not only in an aerobic running mode, as shown earlier [26]. Later, it was proved [27] that the greatest changes in muscular and neuromuscular regulation of the cardiorespiratory system occurred during an activity level near the anaerobic threshold (AT) and in the lactic acid mode of energy supply. It can be assumed that the accumulation of lactate during work in the mode of high-speed running (19.8-25.1 km/h) stimulates the structural and functional reorganization of the heart to a greater extent.

The myocardial mass of the heart can be an important indicator for assessing a player's physical activity. LVM was  $154.7 \pm 3.0$  g in football players of the first group and  $145.8 \pm 3.0$  g in groups with less running in the high-intensity mode ( $p < 0.05$ ). This indicates a relationship between myocardial mass and the level of physical activity in football players. It is known that myocardial hypertrophy is formed in the process of systemic adaptation to specific physical activities as a biologically determined process that enhances the functionality of the heart [25]. Our research has shown that the physical activity of football players with higher myocardial mass (first group) is greater than that of persons with lower heart mass (third group). Moreover, higher values of CO, SV, SI, EDV, and physical activity were recorded in individuals with higher myocardial mass. It is known from the literature [3,17] that the increase in myocardial mass is accompanied by the preservation of the normal proportions of fibers and nuclei and an increase in the number of functioning capillaries per unit area. Improving the functional state of the myocardium is confirmed by an increase in the level of physical activity of the first group. At the same time, due to the increase in the number of capillaries and active elements the number of mitochondria in myocardial fibers increases. This leads to hyperfunctioning, and, as a consequence, severe myocardial hypertrophy in the football players of the first group. This is evidenced by the results comparing players in the first group to the other groups in terms of playing activities in the mode of speed running. The values of myocardial mass in the first group were statistically higher than that of the second and especially the third group ( $p < 0.05$ ).

Thus, long-term adaptations in skilled football players with a predominance of high-intensity running revealed changes in the structural and functional reorganization of the heart. These results suggest that systematic physical activity during training and competitions leads to a pronounced structural and functional reorganization of the heart. Resulting in a significant increase in the efficiency of its work. We noted a decrease in the volume of the heart cavities in systole and an increase in its pumping function due to increased heart muscle contractility, HR, and blood output which has also been confirmed by other researchers [2,12,18,24,28].

The results of this study show the dependence of structural and functional capabilities of the myocardium on the amount of work that a football player runs at a speed of 19.8-25.1 km/h. Thus, training sessions should focus on the use of high-speed running exercises to further increase physical activity and game readiness.

## Conclusions

1. The influence of systematic physical activities in the mode of high-speed running (19.8-25.1 km/h) on the structural and functional reorganization of the heart aimed at ensuring a high level of special physical activities in football players has been proven.

2. We found statistically significant differences in the mean values of morpho-functional characteristics such as HR, SV, SI, EDV, ESV, EF, CI, and LVM in groups with different gradations of distances of high intensity running during games. The football players with higher values of high-intensity distance running were characterized to have enhanced structural and functional indicators of the pumping function of the heart. They had more pronounced increases in EDV, ESV, EF, and CI of the heart, and increases in indicators of SV and SI hemodynamics than footballers with medium and low grades of physical activities.
3. The relationship between the distance covered by football players per game in the high-speed running mode (19.8-25.1 km/h) indicated by structural and functional reorganization of the heart has been established. A statistically significant correlation ( $r=0.37-0.56$ ;  $p=0.024-0.036$ ) has been shown between indicators of physical activity, distance in a high-speed running mode, and the characteristics of HR, CO, SV, SI, and LVM.
4. No correlation was found between the distance players ran during games in other running modes and HR  $\text{min}^{-1}$  ( $r=0.32$ ;  $p=0.061$ ) and some structural and functional characteristics of the pumping function of the heart ( $r=0.21-0.27$ ;  $p=0.063-0.078$ ).
5. Training sessions should focus on exercises in a high-speed running mode to further increase physical activity, game readiness, and structural and functional characteristics of the heart of football players.

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