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Echocardiographic Insights into Left Ventricular Functional Adaptation in Track and Field Athletes: A Comprehensive Review

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Abstract

Scientific sports training is perquisite for excel in track and field athletes, which effects the changes of functional capacity of heart as well as circulatory system. The study investigates the intricate process of functional adaptation of the left ventricle in track and field athletes. Echocardiography is a vital tool for a non-invasive assessment of cardiac anatomy and function that can differentiate between normal and abnormal cardiac changes. In general, the athletes who participates in endurance events have bigger hearts, which aids in the assessment of left ventricular functional adaptation. Heart rate adaptation in athletes is influenced by age, gender, ethnicity, and level of sport. Exercise that is high in intensity alters the heart's structure, electrical activity, and overall functionality. The volume and intensity of endurance exercise influences the functional adaptations of the left ventricle. The present study systematically discussed the effects of different track and field events (isometric or isotonic training) on cardiac left ventricle of athletes and it focus the necessity of customized training and coordinated healthcare for the best possible cardiovascular health.

Keywords: Track and Field Athletes; Echocardiography and Left Ventricular Functional Adaptation

Abbreviations: LV: Left Ventricle; LVM: Left Ventricular Mass; EDV: End-Diastolic Volume; LVH: Left Ventricular Hypertrophy; SV: Stroke Volume; RES: Resistance Training; EDV: End Diastolic Volume; ET: Endurance Training; LVEDV: Left Ventricular Systolic Volume; SVI: Stroke Index; QI: Cardiac Index; FS : Fractional Shortening; EF: Ejection Fraction.

Introduction

Athletes perform a variety of activities such as throwing, jumping and running which requires a good amount of physical fitness. The main elements of fitness are speed, agility, muscular strength, muscular endurance, and cardiovascular fitness [1]. The dynamic interaction between physical activity and cardiovascular adaptation is an important factor influencing sports performance, especially in track and field. Acute exercise can cause anatomic and functional changes in the left ventricle (LV) of the heart. The increased need for oxygen supply as a result of physical activity can be compensated by our physiological system. A thorough understanding of the complex physiological changes that occur in the human body is necessary for the achievement of athletic performance. One of the main factors contributing to heart health is left ventricular function [2]. The adaptation of the cardiovascular system is one of the most important results of regular physical training. Competitive sports and public health are two areas that express the true meaning of the "athlete's heart" [3].

In the cardiovascular system, the left ventricle plays an important role in pumping blood throughout the body. Alteration of left ventricular function is necessary to improve athletic performance and cardiovascular fitness in track and field athletes [2]. Adaptive hypertrophy, or increased mass and size of the left ventricle, is a result of the left ventricle's response to exercise [3]. Training and stress can change the body and make it work better. Training based on training principles requires more work and results in greater adaptation to increased load. These adaptations include decreased resting heart rate, increased stroke volume, increased haemoglobin levels, increased oxygen consumption, muscle hypertrophy, and intramuscular changes [4]. Although there are many cardiovascular adaptation benefits from physical activity, there are still concerns about possible health effects, especially when engaging in vigorous or prolonged physical activity. Intensive training programs are associated with increased ventricular hypertrophy and other structural changes, which increases more concerns about the long-term effects and cardiovascular damage of maintaining high levels of exercise training [5]. Because echocardiography is non-invasive, accurate, and highly reproducible, it is an important method for assessing left ventricular function adaptation in track and field athletes. It assesses heart pain, ventricular size, wall thickness, systolic and diastolic function and provides suggestions for long-term health management and performance improvement [6].

The purpose of the study was to discuss critically the effects of different types of track and field events on left ventricular functional adaptations of athletes based on the echocardiographic findings of other researchers i.e. a review study was conducted.

Echocardiography and Sports

In contemporary sports, echocardiography is essential for non-invasively evaluating cardiac shape and function, helping to differentiate between normal and pathological alterations in the heart of the athletes, and improving medical assessments [7]. Echocardiography is a diagnostic cardiac ultrasound procedure that uses high-frequency ultrasound technology to produce images of the heart. These images show information about the anatomy and physiology of the heart, such as size, shape, wall motion, and valve function [8]. An athlete's left ventricular functional adaptation may be evaluated by echocardiographic screening; those who engage in endurance activity have the greatest dimensions and highest functionality, which are correlated with increased LV volume [9]. Before the development of new imaging techniques, the physiological consequences of cardiac adaptation in athletes were well documented. Morganroth and colleagues described the assessment of cardiac adaptation using current imaging techniques such as echocardiography to measure ventricular size and wall thickness [10]. According to Urhausen, et al. [11], sports activity, training volume, and body size should be considered when collecting ultrasound heart measurements in athletes. To evaluate the state and function of the athlete's heart, multi-imaging techniques such as cardiac CT, cardiac MR, and complex echo technology were introduced in 2014. On the other hand, sensors Wearables, compact trackers, and implantable devices make monitoring easy during training and competition, it is easier to assess electrophysiological changes in athletes [12].

Left Ventricular Functional Adaptations

Adaptation is the process by which physical and psychological functional systems respond to training loads. Getting used to stress will lead to improved performance. Through the adaptation process, athletes' performance improves [13]. In sports, training adaptations refer to physiological and functional changes caused by physical training that are influenced by the amount of exercise, type of activity, and method. Adaptation involves a gradual increase in stress to maintain tissue overload and facilitate adaptation [14]. However, illness or injury can hamper the training program and require adjustments. Physiological adaptations are always specific to training and stress on the body. It is the adaptations that lead to improved performance after training. Adaptations in response to exercise include a decrease in resting heart rate, an increase in stroke volume and cardiac output, an increase in oxygen uptake, an increase in blood haemoglobin levels, muscle hypertrophy, and other changes in the muscles. These include a variety of changes: increased myoglobin, increased mitochondrial number, and increased aerobic fitness or use anaerobic enzymes depending on training specificity, increased lactate threshold, etc. [15].

Regular, intense physical training causes an increase in the mass, cavity size, and wall thickness of the left ventricle (LV), which is referred to as "athlete's heart." Depending on the type of exercise, strength, or endurance, these modifications can vary in degree [16]. Male middle-distance runners have alterations in their adaptive body responses to exercise, including variations in blood haemoglobin concentration and functional capacity of the body [17]. Adolescent male track and field athletes have varying performance characteristics across different sports, with boys beginning in early adolescence to perform better than girls [18].

Exercise and training-induced modifications to left ventricular mass (LVM), end-diastolic volume (EDV), stroke volume (SV), heart rate and cardiac output, are all part of the process of left ventricular functional adaptation. Extended periods of high-intensity exercise regimens induce cardiac adaptations, which raise the LVM and cavity width and satisfy the requirements for left ventricular hypertrophy (LVH) [19].

Marsh, et al., [20] reported that the effects of various exercise modalities on cardiac adaptation vary; for example, resistance training (RES) does not increase LVM and end diastolic volume (EDV), but endurance training (ET) does. Men experience higher increases in left ventricular systolic volume (LVEDV) and SV as a result of ET, although LVM augmentation is equivalent in both sexes [21]. These results emphasize the significance of exercise duration, type, and intensity in influencing functional adaptations of the left ventricle.

Cardiac muscles adjust functionally in response to sporting activity. These adaptations include alterations in left ventricular (LV) function during exercise, such as higher stroke index (SVI) and cardiac index (QI) in highly trained young athletes compared to their recreationally active contemporaries [19]. Diastolic function improves in young athletes during exercise, most likely because to improved preload determinants [22]. Aerobic training at a moderate level can contribute to left ventricular hypertrophy (LVH) by reducing the hemodynamic strain during daily activities [23]. Individuals with high aerobic fitness exhibit decreased LV strain at rest and during exercise, indicating improved systolic function [24].

SL No	Study/Topic Name & Authors	Objective	Methods	Findings
1	Left ventricular adaptations following short-term endurance training [25].	The study investigated the impact of short-term endurance training (ET) on left ventricular adaptation and functional response to exercise challenges.	Eight untrained men were studied before and after 6 days of ET, which involved cycling 2 hours/day at 65% peak aerobic power.	According to the study, brief exercise training raises exercise stroke volumes by improving heart rate, plasma volume, and Vo2max but not resting left ventricular function.
2	The impact of endurance exercise training on left ventricular systolic mechanics [26].	The study sought to evaluate LV systolic performance in competitive athletes before and after 90 days of EET, with an emphasis on tissue velocity, strain, and strain rate.	The study looked at the impact of competitive athletics among Harvard University undergraduates on their heart health. Data was collected over a 90-day period, including endurance and strength workouts. The statistical analysis comprised paired t-tests, Wilcoxon matched pair tests, and correlation analysis.	Exercise training (EET) lowers circumferential strain in left ventricular septal segments, probably due to ventricular interdependence. LV strain and tissue velocity are more sensitive measures of systolic adaptation. The study focuses on understanding EET-induced myocardial adaptation in healthy persons.

3	Adaptation of heart to training: A comparative study using echocardiography & impedance cardiography in male & female athletes Yılmaz, et al. [16].	The purpose of the study is to assess how endurance training affects the hemodynamic parameters, left ventricular function, and heart shape of athletes, both male and female.	Transthoracic echocardiography and impedance cardiography were performed on 79 healthy athletes and 82 healthy adolescents, 49% of whom were male, at the age of 20.0 ± 2.6 years.	In comparison to inactive controls, endurance-trained male and female athletes had increased LV mass, LV cavity dimensions, and stroke volume. Male athletes' resting heart rates were lower and their mean arterial blood pressure was greater.
4	Regular endurance training in adolescents impacts atrial and ventricular size and function [27].	The purpose of the study was to look at the relationship between maximum oxygen consumption and the effects of long-term endurance exercise on adolescent atrial and ventricular growth and function.	A study measuring echocardiograms, Doppler investigations, and treadmill exercise VO2max was carried out with 27 endurance-trained teenagers between the ages of 13 and 19 and 27 controls.	Adolescents who engaged in physical activity displayed greater heart dimensions and better systolic function in comparison to controls. This shows increased atrial and ventricular dimensions, as well as functional remodelling, in the heart as a result of prolonged endurance exercise.
5	Left ventricular remodeling and the athlete's heart, irrespective of quality load training [28].	The study's objective was to monitor, for a minimum of five years, the effects of physical training on the morphology and function of the heart in a group of elite rugby and soccer players.	A total of 250 elite rugby and soccer players and 114 soccer players were studied between 1993 and 2015. Of them, 60 rugby and 78 soccer players were followed for five years and paired with a control group.	After a five-year follow-up, athletes' LV dimensions and LVMi were considerably higher than those of inactive subjects', but no significant changes in cardiac dimensions were noted. Frequent physical activity causes mild left ventricular hypertrophy, which is an adaptive response to stress-exercise.
6	The role of echocardiography in the evaluation of cardiac re-modelling and differentiation between physiological and pathological hypertrophy in teenagers engaged in competitive amateur sports [29].	This study aimed to identify cardiac re-modelling forms, differentiate between pathological and normal hypertrophy, and show left ventricular hypertrophy prevalence in sports-playing teens.	Echocardiographic measures of athletes and control subjects were acquired using M-mode, two-dimensional, and Doppler methods.	According to the study, cardiac re-modelling and left ventricular mass were considerably greater in healthy teens who played both dynamic and static sports. The prevalence of both forms of re-modelling was also higher. These results point to heart remodeling and physiological hypertrophy in sports.

7	Assessment of myocardial function in elite athlete's heart at rest - 2D speckle tracking echocardiography in Korean elite soccer players [30].	This study looked at the myocardial function of elite Korean soccer players by comparing the results with normal controls using both conventional and advanced speckle tracking imaging.	The study used tissue Doppler, STI, and conventional echocardiography together with 2D echocardiography speckle tracking echocardiography to evaluate LV regional strain in 29 elite soccer players compared to 29 healthy controls.	Soccer players exhibit distinct ventricular adaptation, including greater basal circumferential, apical radial, and apical circumferential strain, as well as higher rotation at the base and apex, which may help in cardiovascular adjustment to activity without major energy expenditure loss.
8	Left ventricular remodeling in elite and sub-elite road cyclists [31].	The purpose of this study was to use conventional and speckle tracking 2D echocardiography to characterize the mechanical, functional, and structural properties of left ventricular (LV) components in endurance athletes.	Male elite road cyclists, sub-elite cyclists, and healthy non-athlete university students and staff participated in this cross-sectional study.	Septal and lateral E' velocities, larger global circumferential strain, lower ejection percentage, dilated eccentric hypertrophy, higher chamber concentricity, and stronger LV structural adaptability were all seen in elite cyclists (34.7%). While lower E and E' velocities could suggest functional reserve in EC(Elite Cyclists), higher GCε might be a compensatory strategy to maintain stroke volume.
9	Ten-year follow-up of cardiac function and neural regulation in a group of amateur half-marathon runners.	Assessing the medium- to long-term impacts of moderate-to-intense physical exercise on cardiovascular neuronal regulation, cardiac function, and the incidence of cardiovascular illnesses was the goal of this follow-up.	To evaluate cardiovascular disease, neural control, and heart function, subjects received transthoracic echocardiography, physical exams, interviews, and standing tests.	Middle-aged sportsmen who engaged in regular physical training during a 10-year follow-up revealed normal echocardiographic measurements, a low incidence of cardiovascular disease, and decreased sympathetic and enhanced vagal modulation.
10	Training intensity influences left ventricular dimensions in young competitive athletes [32].	The purpose of the study was to assess how young competitive athletes' heart muscles have changed structurally and functionally in response to training duration, intensity, and output.	In the Munich Cardiovascular Adaptations in Young Athletes Study, which included 404 kids and teenagers, several tests were used to evaluate left ventricular anatomy, training intensity, aerobic capacity, and strength.	The study demonstrates that, in spite of anatomical alterations and a reduction in diastolic function, cardiac adaptations to exercise happen early in life and are impacted by exercise intensity and maximal aerobic capacity.

11	Concentric and Eccentric Remodelling of the Left Ventricle and Its Association to Function in the Male Athletes Heart: An Exploratory Study [33].	The study compared left ventricular (LV) functional parameters, peak strain and strain rate, and temporal strain and strain rate curves in 45 male athletes with concentric, eccentric, and normal LV geometry.	Based on LV geometry, 45 elite male athletes between the ages of 18 and 35 were included in the research. They had a thorough cardiovascular evaluation that included 2DSTE, TTE, and ECG to measure global myocardial distortion.	The study discovered that whereas normal left ventricular function is often linked with these remodeling patterns, concentric remodeling in athletes' hearts raises ejection fraction (EF) and temporal myocardial strain.
12	Biventricular mechanical pattern of the athlete's heart: comprehensive characterization using three-dimensional echocardiography [34].	This study aimed to characterize biventricular morphology and function in elite athletes using three-dimensional (3D) echocardiography.	Athletes' left ventricular and RV end-diastolic volumes (EDVi) and ejection fractions were found to be considerably greater than controls' in a research including top athletes and healthy individuals. The reductions in LV GLS(Global Longitudinal Strains) and RV GCS(Global circumferential strains) brought on by exercise were greater.	Athletes' left ventricular and RV end-diastolic volumes (EDVi) and ejection fractions were found to be considerably greater than controls' in a research including top athletes and healthy individuals. The reductions in LV GLS(Global Longitudinal Strains) and RV GCS (Global circumferential strains) brought on by exercise were greater.
13	Cardiac cycle timing intervals in university varsity athletes [35].	This study set out to characterize the contractility characteristics and cardiac cycle timing intervals in varsity athletes competing at the university level.	In a study with 152 male and 93 female athletes, the researchers discovered that although men's heart rates were lower, women's isovolumic relaxation times, systolic times, and heart rates were shorter. Timing interval variations were also observed in sports, with football players having shorter diastole periods and basketball players having longer systolic times.	These findings suggest that male and female athletes exhibit distinct cardiac features and contribute reference cardiac cycle timing data to the literature. Team differences imply that distinct training regimens for various sports may produce distinct alterations in heart function; yet, they seem to be correlated with the players' sex. These cardiac cycle timing intervals provide a useful comparison tool to enhance our comprehension of heart physiology in varsity sports groups.
14	Cardiac functional adaptation to resistance and endurance exercise training: a randomized crossover study [36].	This study examined the impact of endurance and resistance training on changes in left ventricular (LV) systolic and diastolic function in healthy participants.	The study involved 64 participants in a 12-week crossover design trial, with echocardiograms assessing systolic function, diastolic function, and left atrial volume indexed to body surface area.	Results showed that LV mass increased with both RES and END training, but remained significant after END. The adaptation in LVM and LA volumes, as well as diastolic function, was exercise mode specific. Twelve weeks of intensive END increased LVM, LA volumes, and increased diastolic function. However, after RES, LVM increased, although this was attenuated after accounting for changes in lean body mass.

Table 1: Research findings of Cardiac Functions in response of training by different researchers.

Results and Discussion

Our thorough review research provide insight into the complex connection between athletic training for track and field and left ventricular (LV) functional adaptation. The findings of the different researchers demonstrate the profound physiological alterations in the heart that result from consistent physical training, particularly for track and field competitors.

The finding of the other researchers indicated that the training routine of track and field athletes, especially endurance athletes, causes significant left ventricular adaptations. Enhanced LV performance, larger cavity size, thicker walls, and greater LV mass are some of these modifications. These modifications are sometimes referred to as the "athlete's heart," which symbolizes the heart's capacity to adjust and function at its best in response to demands placed on it by sports.

Athletes' left ventricular adaptations and cardiac function were examined in depth in the research summarized in Table - 1. Studies such as those conducted by Goodman, et al. [25], for example, have shown that short-term endurance training can raise exercise stroke volumes without appreciably compromising resting left ventricular function. Other research, like Baggish, et al. [26], demonstrated how endurance exercise training may affect LV strain and tissue velocity and emphasized the significance of LV systolic mechanics in competitive athletes. Maximizing cardiac performance during exercise depends on these adaptations, which are regulated by age, genetics, training style, intensity, and duration. Improved cardiac efficiency, higher left ventricular compliance, concentric and eccentric hypertrophy, and increased left ventricular mass (LVM) are among the main alterations seen in the left ventricles of athletes. More force production and stroke volume are possible with increased left ventricular mass brought on by exercise. When it comes to hypertrophy, athletes that train for endurance are more likely to experience eccentric hypertrophy than strength training athletes. Higher cardiac output and stroke volume are the results of continuous exercise's improvement in left ventricular compliance. More output is produced at lower heart rates is the indication of more efficient hearts of athletes than non-athletes [2,37].

The subject of left ventricular functional adaptation in sprinters and distance runners of track & field has been studied extensively. The findings imply that both sprinters and distance runners undergo physiological adjustments in their left ventricles as a result of training. These adaptations include increased left ventricular internal dimensions, mass, and ejection fractions [38].

Track and field throwers and master resistance-trained athletes may have distinct somatotypes. They are bigger people with more absolute power, somatotypes like those from "Strongmen" competitions. Younger competitors in the Strongmen competition, who have trained for ten years and are between the ages of twenty and forty-five, had smaller diastolic function but larger absolute heart dimensions than controls [39].

Sports-related exercise training has an impact on left ventricular function; isotonic training improves diastolic function, but isometric exercise usually results in normal or slightly diminished function. Training of any kind has little effect on left ventricular systolic performance at rest [26].

LV systolic function is represented by stroke volume (SV), LV ejection fraction (EF), fractional shortening (FS), cardiac output (Q), cardiac index, peak systolic myocardial velocity (S'), LV myocardial performance index (Tei index), concentricity, and sphericity index. Endurance athlete's EF was significantly increased in the study by Rundqvist, et al. [27]. Divided into dynamic and static types of sport, Sulovic, et al. [40] reported a significantly higher ejection fraction (EF) in dynamic exercising athletes and a significantly reduced EF in static exercising athletes. Contrary to these findings, three studies did not report significant differences [41-43]. The same is reported for Fractional Shortening (FS) [41,42].

The underlying stimuli for cardiac adaptation have been identified as being factors like the training history, training volume and intensity, the types of sports [44], genetics [45] and pubertal and hormonal status [46-48].

Impact of Training Intensity and Duration

The importance of training time and intensity in determining left ventricular adaptations was also highlighted in our review study. Research conducted by Weberruss, et al. [32] showed that the volume and intensity of training, affect the anatomical and functional changes of young competitive athletes' hearts. High intensity and low volume repetitive exercises such as resistance training elicit morphological increment of the left ventricle of an athlete which is termed as concentric hypertrophy. In case of concentric hypertrophy, left ventricular septum, posterior wall and interventricular septum thickness may chronically increase workload on the heart, most commonly resulting from pressure overload. On the other hand, moderate intensity and high-volume exercises such as marathon run elicit cardiac hypertrophy which is known as eccentric hypertrophy. In case of eccentric hypertrophy, the heart responds by increasing left ventricular internal diameter and left ventricular wall thickness. Ventricular dilation is caused by volume overload. The significance of echocardiography in recognizing cardiac remodelling types and differentiating between normal and pathological hypertrophy in athletes was brought to light by studies such as Šulović, et al. [29].

Gender and Age Variations

We also reviewed age and gender differences in left ventricular adaptations in athletes. Research has shown that the LV shape, functional characteristics, and adaptive responses to training may differ between male and female athletes [33]. Age-related variations in cardiac adaptability and function were also noted, highlighting the necessity of customized training regimens based on personal traits [49-51].

Clinical Implications and Future Directions

Healthcare practitioners need to know the information regarding sports specific cardiac hypertrophy in order to diagnose, treat, and prevent cardiac problems. Future studies should concentrate on investigating cardiac adaptation mechanisms, creating individualized training strategies, and evaluating the long-term effects of training on heart function. The analysis highlights the intricate connection between cardiac function, long-term health outcomes, and athletic training, underscoring the necessity of customized training regimens and cardiac monitoring in the treatment of athletes.

Conclusion

The study of left ventricular (LV) functional adaptation in track and field athletes is a complex and dynamic field that intersects sports science, cardiology, and exercise physiology [52-56]. Through our comprehensive review, we have discussed the intricate mechanisms and adaptations that occur within the athlete's heart, shedding light on the physiological changes that accompany rigorous athletic training.

To conclude, this analysis offers significant understanding into the complex connection between left ventricular functional adaptation and endurance training in track and field athletes [57-60]. The intricate relationship among cardiac remodelling, athletic demands, and long-term health outcomes, we may improve the performance, well-being, and care of athletes in a variety of sports. In order to focus on further understanding and promote cardiovascular health in the athletic community, it is crucial to engage in more research, education, and cooperation [61-64].

References

1. Katsagoni CN, Kokkinos P, Sidossis LS (2023) Definition of Fitness and Its Components, Chapter 4. Wiley pp: 61-67.
2. Pluim BM, Zwinderman AH, Laarse A, Wall VV (2000c) The athlete's heart A meta-analysis of cardiac structure and function. Circulation 101(3): 336-344.
3. Kneffel Z (2008) Morphological and functional characteristics of the left ventricle in athletes of various ages, and performing at various levels. Orvosi Hetilap 149(23): 1085-1094.
4. Jackson D (2023) Physiological Adaptations. HSC PDHPE.
5. Keefe JH, Patil HR, Lavie CJ, Magalski A, Vogel RA, et al. (2012) Potential adverse cardiovascular effects from excessive endurance exercise. Mayo Clinic Proceedings 87(6): 587-595.
6. Lang RM, Badano LP, Avi VM, Afilalo J, Armstrong A, et al. (2015) Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. Journal of the American Society of Echocardiography 28(1): 1-39.
7. D'Ascenzi F, Oxborough D (2020) Medical evaluation of athletes: Echocardiography. Textbook of Sports and Exercise Cardiology pp: 135-151.
8. Echocardiogram (ECho) (2023) Heart Attack and Stroke Symptoms. American Heart Association.
9. Sharykin AS, Badtieva V, Ivanova Iu M, Usmanov DM (2022) Possibilities of echocardiographic screening in athletes. Part 1. Normal values. Sports medicine: research and practice 12(3): 72-83.
10. Morganroth, J, Maron BJ, Henry WL, Epstein SE (1975b) Comparative left ventricular dimensions in trained athletes,' Annals of Internal Medicine 82(4): 521-524.
11. Urhausen A, Kindermann W (1992) Echocardiographic Findings in Strength- and Endurance-Trained Athletes. Sports Medicine 13(4): 270-284.
12. Kovacs RJ, Baggish AL (2016) Cardiovascular adaptation in athletes. Trends in Cardiovascular Medicine 26(1): 46-52.
13. Mukhopadhyay, K. (2022) Load dynamics, recovery and adaptation for better sporting events. Journal of Advances in Sports and Physical Education 5(8): 180-190.
14. Fister I, Fister D, Fister Jr I (2019) Adaptation of training plans in Adaptation, learning, and optimization pp: 181-

200.

15. Dan J (2016) Examine the relationship between physiological adaptations and improved performance resulting from aerobic training. HSC PDHPE.

16. Yilmaz D, Buyukakilli B, Gurgul S, Rencuzogullari I (2013) Adaptation of heart to training: a comparative study using echocardiography & impedance cardiography in male & female athletes. PubMed 137(6): 1111-1120.

17. Roda O, Kalytka S, Vashchuk L, Demianchuk O (2017) The changes in the adaptive processes of the male organism during training physical exercises. Physical Activity Review 5: 10-18.

18. Nikolaidis PT, Sonkin VD (2023) Sports Physiology in Adolescent Track-and-Field Athletes: A Narrative review. Open Access Journal of Sports Medicine 14: 59-68.

19. Pittaras A, Faselis C, Doumas M, Grassos C, Kokkinos P (2023) Physical activity and cardiac morphologic adaptations. Reviews in Cardiovascular Medicine 24(5): 142.

20. Marsh CE, Thomas HJ, Naylor LH, Dembo LG, Scurrah KJ, et al. (2022) Left Ventricular Adaptation to Exercise Training via Magnetic Resonance Imaging: Studies of Twin Responses to Understand Exercise Therapy. Medicine & Science in Sports & Exercise 54(7): 1095-1104.

21. Diaz-Canestro C, Montero D (2020) The Impact of Sex on Left Ventricular Cardiac Adaptations to Endurance Training: a Systematic Review and Meta-analysis. Sports Medicine 50(8): 1501-1513.

22. Unnithan VB, Beaumont A, Rowland T, George K, Sculthorpe N, et al. (2022) Left Ventricular Responses during Exercise in Highly Trained Youth Athletes: Echocardiographic Insights on Function and Adaptation. Journal of Cardiovascular Development and Disease 9(12): 438.

23. Monte IP, Mangiafico S, Buccheri S, Bottari VE, Lavanco V, et al. (2014) Myocardial deformational adaptations to different forms of training: a real-time three-dimensional speckle tracking echocardiographic study. Heart and Vessels 30(3): 386-395.

24. Stöhr EJ, McDonnell B, Thompson J, Stone K, Bull T, et al. (2012) Left ventricular mechanics in humans with high aerobic fitness: adaptation independent of structural remodelling, arterial haemodynamics and heart rate. The Journal of Physiology 590(9): 2107-2119.

25. Goodman JM, Liu PP, Green HJ (2005b) Left ventricular adaptations following short-term endurance training. Journal of Applied Physiology 98(2): 454-460.

26. Baggish AL, Yared K, Wang F, Weiner RB, Hutter Jr AM, et al. (2008) The impact of endurance exercise training on left ventricular systolic mechanics. American Journal of Physiology-heart and Circulatory Physiology 295(3): H1109–H1116.

27. Rundqvist L, Engvall J, Faresjö M, Carlsson E, Blomstrand P (2016) Regular endurance training in adolescents impacts atrial and ventricular size and function. European Heart Journal Cardiovascular Imaging 18(6): 681-687.

28. Galanti G, Stefani L, Mascherini G, Tante VD, Toncelli L (2016) Left ventricular remodeling and the athlete's heart, irrespective of quality load training. Cardiovascular Ultrasound 14(1): 46.

29. Sulovic LS, Mahmutovic M, Lazic S, Sulovic N (2016) The role of echocardiography in the evaluation of cardiac re-modelling and differentiation between physiological and pathological hypertrophy in teenagers engaged in competitive amateur sports. Cardiology in the Young 27(4): 706-712.

30. Eun LY, Chae HW (2016) Assessment of myocardial function in elite athlete's heart at rest - 2D speckle tracking echocardiography in Korean elite soccer players. Scientific Reports 6: 39772.

31. Brown B, Millar L, Somauroo J, George K, Sharma S, et al. (2020) Left ventricular remodeling in elite and sub-elite road cyclists. Scandinavian Journal of Medicine & Science in Sports 30(7): 1132-1139.

32. Weberruß H, Baumgartner L, Mühlbauer F, Shehu N, Oberhoffer-Fritz R (2022) Training intensity influences left ventricular dimensions in young competitive athletes. Frontiers in Cardiovascular Medicine 9: 961979.

33. Johnson C, Sculthorpe N, George K, Stout M, Procter W, et al. (2023) Concentric and eccentric remodelling of the left ventricle and its association to function in the male athletes heart: an exploratory study. Journal of Cardiovascular Development and Disease 10(7): 269.

34. Fabian A, Ujvari A, Tokodi M, Lakatos BK, Kiss O, et al. (2022) Biventricular mechanical pattern of the athlete's heart: comprehensive characterization using three-dimensional echocardiography. European Journal of Preventive Cardiology 29(12): 1594-1604.

35. Singh J, Ellingson CJ, Ellingson CA, Scott P, Neary JP (2023) Cardiac cycle timing intervals in university

varsity athletes. EJSS/European Journal of Sport Science 23(7): 1457-1462.

36. Green D, Marsh CE, Thomas HJ, Maslen BA, Collis J, et al. (2024) Cardiac functional adaptation to resistance and endurance exercise training: a randomized crossover study. American Journal of Physiology Heart and Circulatory Physiology 326(4): H929-H937.
37. Sharma S, Drezner JA, Baggish A, Papadakis M, Wilson MG, et al. (2017) International recommendations for electrocardiographic interpretation in athletes. European Heart Journal 39(16): 1466-1480.
38. Churchill TW, Groezinger E, Loomer G, Guseh JS, Weiner RB, et al. (2020) Training-Associated changes in ventricular volumes and function in elite female runners. Circulation: Cardiovascular Imaging, 13(6): e010567.
39. Venckūnas T, Vasiliauskas D, Marcinkeviciene JE, Grizas V, Stasiulis A, et al. (2011) Strongmen Sport is Associated with Larger Absolute Heart Size and Impaired Cardiac Relaxation. The Journal of Strength and Conditioning Research 25(10): 2919-2925.
40. Sulovic LS, Mahmutovic M, Lazic S, Sulovic N (2017) The role of echocardiography in the evaluation of cardiac re-modelling and differentiation between physiological and pathological hypertrophy in teenagers engaged in competitive amateur sports. Cardiology in the Young 27(4): 706-712.
41. Zdravkovic M, Perunicic J, Krotin M, Ristic M, Vukomanovic V, et al. (2010) Echocardiographic study of early left ventricular remodeling in highly trained preadolescent footballers. Journal of Science and Medicine in Sport 13(6): 602-606.
42. Binnetoğlu FK, Babaoğlu K, Altun G, Kayabey Ö (2014) Effects that different types of sports have on the hearts of children and adolescents and the value of two-dimensional strain-strain-rate echocardiography. Pediatric Cardiology 35(1): 126-139.
43. Simsek Z, Hakan Tas M, Degirmenci H, Gokhan Yazici A, Ipek E, et al. (2013) Speckle tracking echocardiographic analysis of left ventricular systolic and diastolic functions of young elite athletes with eccentric and concentric type of cardiac remodelling. Echocardiography 30(10): 1202-1208.
44. Beaumont A, Grace F, Richards J, Hough J, Oxborough D, et al. (2017) Left Ventricular Speckle Tracking-Derived Cardiac Strain and Cardiac Twist Mechanics in Athletes: a Systematic Review and Meta-Analysis of Controlled Studies. Sports Medicine 47(6): 1145-1170.
45. Guth LM, Roth SM (2013) Genetic influence on athletic performance. Current Opinion in Pediatrics 25(6): 653-658.
46. Handelsman DJ, Hirschberg AL, Bermon S (2018) Circulating Testosterone as the Hormonal Basis of Sex Differences in Athletic Performance. Endocrine Reviews 39: 803-829.
47. Bergeron MF, Mountjoy M, Armstrong N, Chia M, Côté J, et al. (2015) International Olympic Committee consensus statement on youth athletic development. British Journal of Sports Medicine 49(13): 843-851.
48. Kraemer WJ, Ratamess NA (2005) Hormonal Responses and Adaptations to Resistance Exercise and Training. Sports Medicine 35(4): 339-361.
49. Arce A (2018) Adaptations of the heart to chronic exercise.
50. Augustine JA (2018) Sex differences in cardiovascular adaptations to chronic endurance exercise. SciSpace.
51. Caselli S, Cicconetti M, Niederseer D, Schmied C, Jost CA, et al. (2022) Left ventricular hypertrophy in athletes, a case-control analysis of interindividual variability. International Journal of Cardiology 348: 157-162.
52. De Maria B, De Oliveira Góis M, Catai AM, Marra C, Lucini D, et al. (2021) Ten-year follow-up of cardiac function and neural regulation in a group of amateur half-marathon runners. Open Heart 8(1): e001561.
53. De Sante C, De Sante C (2023) Comparing the Physiological Differences Between Sprinters and Long-distance runners. casa de santa.
54. Demdeo D (2013) Physical fitness and physiological parameters of sport persons. A Comparative Study between Sprinters and Football Players.
55. Farrell C (2023) Normal versus chronic adaptations to aerobic exercise.
56. Fister I Iglesias A, Osaba E, Mlakar U, Brest J (2018b) Adaptation of sport training plans by Swarm Intelligence. In Advances in intelligent systems and computing pp: 56-67.
57. Franzen E, Mangold S, Erz G, Claussen CD, Andreas M, et al. (2012) Comparison of morphological and functional adaptations of the heart in highly trained triathletes and long-distance runners using cardiac magnetic resonance imaging. Heart and Vessels 28(5): 626-631.
58. George K, Whyte GP, Green DJ, Oxborough D, Shave RE, et

al. (2012) The endurance athletes heart: acute stress and chronic adaptation. British Journal of Sports Medicine 46(S1): I29-I36.

59. Major Z, Csajági E, Kneffe ZS,Kováts T, Szauder I, et al. (2015) Comparison of left and right ventricular adaptation in endurance-trained male athletes. Acta Physiologica Hungarica 102(1): 23-33.

60. Ozo U, Sharma S (2020) The impact of ethnicity on cardiac adaptation. European Cardiology 15.

61. Schmied C, Wilhelm M (2020) Athlete's heart: basic physiology and adaptation to exercise. Springer eBooks pp: 29-51.

62. Todd J (2020) The history of track and field – FloTrack. FloTrack pp: 25.

63. Wilson MG, Périard JD, Adamuz C, Farooq A, Watt V, et al. (2019) Does passive heat acclimation impact the athlete's heart continuum. European Journal of Preventive Cardiology 27(5): 553-555.

64. Witard OC, Garthe I, Phillips SM (2019) Dietary protein for training adaptation and body composition manipulation in track and field athletes. International Journal of Sport Nutrition and Exercise Metabolism 29(2): 165-174.