

The influence of sports-related factors on left heart chambers in young female athletes

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Abstract

Objective: Athletic heart syndrome (AHS) represents a physiological and morphological adaptation of the heart to long-standing intensive training. Left ventricular (LV) chamber sizes are primarily affected by the complex interplay of sports-associated factors. AHS in females substantially varies from males due to underlying physiological, hormonal, and anthropometric differences. This study aims to explore the influence of sports-related factors on left heart chambers in young female athletes (FA).

Methods: A cross-sectional study was conducted in 28 young FA, who undergo training for at least 3 months with a minimum of 3 times weekly sessions. They were divided in 2 groups: endurance (END) and mixed-training (MIX). We assessed using echocardiography: left atrial volume index (LAVI), end-diastolic (EDV) and end-systolic (ESV) LV volumes, LV mass index (LVMI). Comparisons were performed using t-tests or Mann-Whitney U tests. A MANCOVA was selected to determine the relationship between sports-related factors and left heart indices. Post-hoc contrast and margins tests were conducted to show a correlation with exact cardiac parameters.

Results: Groups were matched by age, body surface area, and total training duration. However, weekly training time (WTT) was higher in END athletes (12.7 (5.3) vs. 5.7 (0.8), $p < 0.001$) and left cardiac indices were greater in END athletes than in MIX counterparts: LAVI (28.8 vs. 18.7 ml/m², $p = 0.009$), EDV (81.1 (11.7) vs 66.1 (16.8) ml, $p = 0.01$), ESV (29.6 (10.8) vs. 20.5 (10) ml, $p = 0.01$) and LVMI (68.3 (11.7) vs. 59.2 (8.2) gr/m², $p = 0.02$). According to MANCOVA, higher WTT ($p = 0.03$, $\eta^2 = 0.44$), was associated with increased LAVI, EDV, and LVMI values. Mean differences obtained from contrast analysis showed significant variations of only LVMI between training groups (-13.17, $p = 0.04$). Post-hoc analysis revealed significantly higher values of all chamber parameters in END athletes ($p < 0.001$).

Conclusions: Young FA have distinct cardiac adaptations based on training type and training load time. END athletes exhibited greater volumetric indices and LVM compared to MIX athletes, emphasizing the significant influence of training intensity and modality on cardiac remodeling. Furthermore, the hypothetical moderating role of the WTT in the relationship between training type and left heart chamber sizes was observed. These findings emphasize the importance of individualized cardiac evaluation in FA for the adequate management of the AHS.

Key words: Athletic heart syndrome, female athlete, cardiac remodeling, training type, endurance training, mixed training, total training duration, weekly training load

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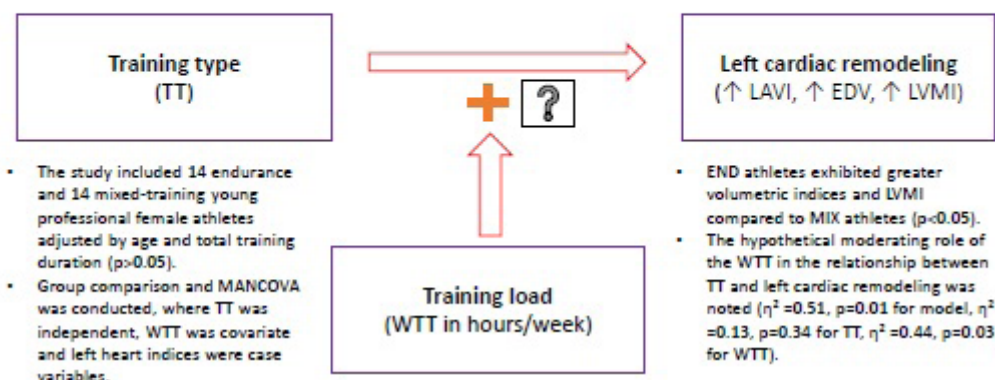
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Graphical abstract

The Influence of Sports-related Factors on Left Heart Chambers in Young Female Athletes



Introduction

Undoubtedly, long-standing physical training induces physiological adaptations in various organ systems, including the cardiovascular system. Among athletes, the heart undergoes specific structural and functional changes, often referred to as “athletic heart syndrome” (AHS) (1, 2). These adaptations are largely dependent on the type and intensity of training, with various training types (TT) eliciting different cardiac alterations. As accepted conventionally, endurance sports, such as field and track athletics or long-distance swimming, induce volume overload on the heart, leading to eccentric hypertrophy (3, 4).

Although endurance and power training are well-documented to cause specific cardiac changes such as eccentric and concentric morphological alterations, the effects of mixed training, which combines both endurance and strength elements, remain less understood. Most of the studies were conducted in a comparative mode in Caucasian and Black ethnicities (5, 6). It is unclear whether athletes engaging in mixed sports develop cardiac adaptations more similar to endurance athletes or those engaging in strength training.

Studies have demonstrated that at least three or four months of vigorous training is sufficient for the development of AHS (2). Differences in hormonal levels, body composition, and training responses can cause female athletes to exhibit different cardiac adaptations compared to their male counterparts. Studies have shown that female athletes generally develop less pronounced concentric cardiac remodeling and hypertrophy than males, despite engaging in similar training intensities (7, 8). However, little is known about the AHS in young female athletes.

This study aims to elucidate the functional and structural cardiac remodeling through transthoracic echocardiography (TTE) in young female athletes of endurance (END) and mixed (MIX) training. We hypothesize that END athletes will display greater changes in left ventricular dimensions than MIX counterparts. Furthermore, training load along with TT might exert a significant impact on cardiac remodeling in professional athletes.

Methods

Study population and design

Twenty-nine female athletes from the Republican Sports College of the Olympic Reserve were enrolled in this cross-sectional study conducted during September and October of 2022.

Athletes of track and field, swimming, and football disciplines were selected through a convenient sampling method. Athletics (field and track sports) and swimming disciplines were considered as END training, whereas football was accepted as a form of MIX training. This matching of sports disciplines with training types was based on European Society of Cardiology Guidelines criteria (9). Inclusion criteria for the study were female athletes of either endurance or mixed training, aged between 14 and 20 years, at least 3 months of regular exercise with a minimum of 3 training sessions or 6 hours per week (2), and lack of prior history of cardiovascular disease or other chronic medical conditions.

The study was approved by the Institutional Review Board of the Ala-Too International University. All participants provided informed consent before participating in the study. Data was collected anonymously and stored securely to ensure confidentiality.

Anthropometric, hemodynamic and sports-related indices

All subjects were evaluated for basic anthropometric indices, such as age, body weight, height and body surface area (BSA) (according to Mosteller formula), pre-procedure systolic (SBP) and diastolic blood pressures (DBP) in mmHg, heart rate in beats per minute (bpm). Sports-related indices included overall training time duration (TTD) expressed in months, weekly training time (WTT) a surrogate marker of training load expressed in hours, and number of participated competitions (CP) regardless of the level (local, republic, international).

Echocardiographic Assessment

All athletes underwent a comprehensive TTE evaluation using a standardized protocol recommended by EACVI/ASE guidelines (9). Echocardiograms were performed by a single experienced cardiologist from the Research Institute of Heart Surgery and Organ Transplantation to ensure consistency in measurements. Philips CX50 with both adult and pediatric phased-array probes were used for the investigation procedure.

The following morphological echocardiographic parameters of the left heart were evaluated: left ventricular end-diastolic diameter (LVEDD), end-systolic diameter (LVESD), end-diastolic volume (LVEDV), end-systolic volume (LVESV), ejection fraction (LVEF), interventricular septum thickness (IVS), left ventricular posterior wall thickness (LVPW), left ventricular mass index (LVMI), relative wall thickness (LVRWT), left atrial anteroposterior diameter (LA) and volume index (LAVI), and aortic diameters at four levels as recommended by guidelines: aortic fibrous annulus (AFA), sinuses of Valsalva (SV), sino-tubular junction (STJ) and proximal ascending aorta (PAA) (10,11).

Furthermore, left ventricular global longitudinal strain (GLS) was evaluated offline by an experienced operator. The QLAB pack of speckle-tracking echocardiographic modality based on a 17-segment model was applied for offline strain analysis.

Evaluation and interpretation of reports guided under current guidelines (12).

Statistical analysis

All tests were performed using Stata 16.1 software (StataCorp, Texas, USA). Categorical variables are highlighted via absolute count (%) and continuous variables are reported as mean (standard deviation) in case of normal distribution whereas median (interquartile range) in case of the violation of normality assumption. Comparison of variables between groups was achieved by independent samples t-test or Mann-Whitney U test, depending on the results of the Shapiro-Wilk test for normality of distribution. To investigate the potential correlations between TT, confounders, and cardiac chamber indices we conducted multiple analysis of covariance (MANCOVA) test. After the MANCOVA test, post-hoc contrast and margin analyses were performed. Partial eta square (η^2) was calculated for the estimation of effect size after MANCOVA. The statistical significance was adjusted for the p-value of less than 0.05 and a confidence interval of 95%.

Results

Demographic, anthropometric, hemodynamic and sports-related findings

Due to the accidental finding of a congenital bicuspid aortic valve with significant ascending aortic dilatation during TTE evaluation, one endurance athlete was excluded from the study. Overall distribution according to sports disciplines is presented as follows: eight track and field athletes, six swimmers, and fourteen football players. Thus, both training groups equalized by absolute count (n=14 for each END and MIX group).

Groups were comparable by age and anthropometric parameters (Table 1). The mean age of athletes was 16.5 (2.3) years without significant differences by groups (p=0.25). None of the weight, height, BSA showed statistical differences by groups (p=0.78, p=0.88, p=0.97, respectively).

Parameter	Total (n=28)	END (n=14)	MIX (n=14)	p
Age, years	16.5(2.3)	17(2.7)	16(1.7)	0.25
Weight, kg	52.9(6.9)	52.5(3.8)	53.3(9.1)	0.78
Height, cm	164.9(5.05)	165.07(4.9)	164.7(5.3)	0.88
BSA, m ²	1.55(0.11)	1.55(0.06)	1.55(0.15)	0.97
SBP, mm Hg	103.4(7.5)	101.9(8.4)	105(6.5)	0.29
DBP, mm Hg	62.3(7.1)	60(8.7)	64.6(4.1)	0.08
HR, bpm	70.3(11.1)	65.7(12.6)	74.9(7.2)	0.02
TTD, months	48 (16-60)	48 (12-54)	36 (24-60)	0.67
WTT, hours	9.2(5.2)	12.7(5.3)	5.7(0.8)	<0.001
CP	3.5 (1.5-10.5)	9.5 (0-11)	2 (2-5)	0.12

Table 1. Comparison analysis of clinical, sport and echocardiographic variables by training groups (continued from page 495)

Parameter	Total (n=28)	END (n=14)	MIX (n=14)	p
AFA, mm	17.6 (16.8-18.2)	18.2 (17.1-19.5)	17.1 (16.8-17.8)	0.01
SV, mm	26.9(1.7)	27.6(2.02)	26.2(2.2)	0.08
STJ, mm	23.5(1.7)	24.1(1.5)	22.9(1.7)	0.07
PAA, mm	23.8 (22.4-24.7)	24 (23.3-24.9)	23.1 (21.9-24.6)	0.34
LA, mm	29.7(2.9)	30.1(3.2)	29.3(2.8)	0.46
LAVI, ml/m2	21.2 (17.7-28.8)	28.8 (21.6-32.4)	18.7 (17.6-20.9)	0.009
LVEDD, mm	45.3(3.07)	45.7(3.6)	44.9(2.4)	0.48
LVESD, mm	27 (25.4-29.3)	26.2 (25.4-28.2)	28.1 (25.5-29.4)	0.42
IVS, mm	7.4(0.93)	7.9(0.88)	7.03(0.77)	0.009
LVPW, mm	7.5(0.87)	7.8(0.79)	7.2(0.84)	0.03
LVMI, gr/ m2	63.8(10.9)	68.3(11.7)	59.2(8.2)	0.02
RWT	0.32(0.04)	0.33(0.04)	0.31(0.03)	0.13
EDV, ml	73.6(16.2)	81.1(11.7)	66.1(16.8)	0.01
ESV, ml	24.7 (20.05-30.45)	29.6 (22.1-32.9)	20.5 (18.7-28.7)	0.01
EF, %	65.4(3.5)	64.8(3.6)	65.9(3.4)	0.41
GLS, %	20.9(2.8)	20.9(2.7)	20.9(2.9)	0.95

Data are presented as mean (SD), median (interquartile range) or %,
 AVA – aortic valve annulus, BSA – body surface area, CP – competition participation, DBP – diastolic blood pressure, EDV – end-diastolic volume, ESV – end-systolic volume, GLS – global longitudinal strain, HR – heart rate, IVS – interventricular septum, PAA – proximal ascending aorta, LA – left atrium, LAVI – left atrial volume index, LVEDD – left ventricular end-diastolic diameter, LVESD – left ventricular end-systolic diameter, LVMI – left ventricular mass index, LVPW – left ventricular posterior wall, RWT – relative wall thickness, SBP – systolic blood pressure, SV – sinus Valsalva size, STJ – sino-tubular junction, TTD – total training duration, WTT – weekly training time

Average SBP and DBP values were observed to be slightly higher in MIX than END group without statistical significance ($p=0.29$, $p=0.08$, respectively). Resting heart rate was higher in MIX ($p=0.02$) than in END group.

Sports-related parameters were found with some extent of differences by groups. Overall median of TTD was 48 (16-60) months without significant differences by groups (48 (12-54) vs 36 (24-60), $p=0.67$). On the other hand, WTT was noted higher in END athletes than MIX ones (12.7 (5.3) vs 5.7 (0.8)h/wk, $p<0.001$). The median CP also differed by groups, however, the comparison test did not reveal statistical significance ($p=0.11$).

Comparison of left heart indices according to TT

TTE measurements of the left cardiac chambers were presented with unequivocal findings. Among aortic diameters, only AFA size was found to be significantly varied between groups ($p=0.01$). Despite the relatively larger aortic sizes at the SV, STJ, and PAA levels in END, no statistical significance was reached ($p>0.05$).

LA size was found to be indifferent whereas LAVI revealed a significant difference, i.e. END athletes showed larger values of LAVI (28.8 vs 18.7 ml/m², $p=0.009$) as compared to MIX athletes. Similar findings were presented by left ventricular indices, where B-mode sizes were indifferent, and volumetric indices were higher in the END group (81.1(11.7) vs 66.1(16.8) ml, $p=0.01$ for EDV and 29.6 (22.1-32.9) vs 20.5 (18.7-28.7) ml ($p=0.01$) for ESV, as compared to MIX group.

Both IVS and LVPW diameters had higher values in END group ($p=0.009$ for IVS; $p=0.03$ for LVPW). Furthermore, it was confirmed by LVMI values in athletic groups (68.3(11.7) vs 59.2(8.2) gr/m², $p=0.02$ respectively for END and MIX). Interestingly, functional indices were presented without statistical variations ($p=0.41$ for EF; $p=0.95$ for GLS).

Relationship analysis of sports-related factors and echocardiographic athletic heart syndrome

A MANCOVA model consisted of training type as an independent or grouping variable, WTT as a covariate, and LAVI, EDV, and LVMI as continuous test variables (Table 2).

Table 2. Characteristics of variables included into the MANCOVA model

Variable role	Variable name	Variable type	Distribution
Group variable	Training type	Categorical	
Confounder variable	Training load	Continuous	Normal
Test variable	LAVI	Continuous	Normal
Test variable	LV EDV	Continuous	Normal
Test variable	LVMI	Continuous	Normal

LAVI – left atrial volume index, LV EDV – left ventricular end-diastolic volume, LVMI – left ventricular mass index

All test variables presented normal distribution without significant outliers. The obtained results are highlighted in Table 3, where the overall model fit was acceptable with appropriate statistical significance ($p=0.03$, $\eta^2=0.51$). Despite the non-significant results of training type ($p=0.34$, $\eta^2=0.13$), WTT clearly showed a significant effect on left heart chamber indices ($p=0.03$, $\eta^2 = 0.44$). According to these findings, training type had 13%, WTT had 44%, and cumulatively 51% of the impact on chamber variations in these athletic subjects.

Table 3. MANCOVA test results

	Wilk's lambda	F	p	Effect size
Overall model fit	0.09	2.16	0.01	0.51
Training type	0.81	1.19	0.34	0.13
Training load	0.14	1.83	0.03	0.44

Post-estimation contrast analysis revealed a significant difference in LVMI between MIX and END groups while controlled by WTT (-19.16 and $p=0.007$). However, the mean differences of EDV and LAVI did not reach statistical significance ($p=0.44$ and $p=0.06$, respectively). The results of contrast analysis are highlighted in Table 4.

Table 4. Post-hoc contrast test results

Test variable	Mean difference ¹	Standard error	F	p
LAVI	-7.6	3.98	3.64	0.06
LV EDV	-7.08	9.05	0.61	0.44
LVMI	-13.17	6.37	4.27	0.04

LAVI – left atrial volume index, LV EDV – left ventricular end-diastolic volume, LVMI – left ventricular mass index
¹Mean difference was calculated as mixed-endurance

Post-hoc margin analysis confirmed the findings of contrast analysis where the predicted mean in LAVI for END athletes was higher than MIX athletes (27.35 vs. 19.7 ml/m², $p<0.001$), and equivocal results were obtained for EDV (77.18 vs. 70.09 ml, $p<0.001$) and LVMI (70.4 vs. 57.23 gr/m², $p<0.001$) when controlled by WTT (Table 5).

Table 5. Post-hoc linear prediction (margins) of test variables

Test variable	Margins*	Standard error	t-test*	p
LAVI	27.35/19.75	2.32	11.75/8.48	<0.001
LV EDV	77.18/70.09	5.28	14.59/13.25	<0.001
LVMI	70.40/57.23	3.72	18.90/15.36	<0.001

LAVI – left atrial volume index, LV EDV – left ventricular end-diastolic volume, LVMI – left ventricular mass index;
 *Values were calculated for END/MIX respectively

According to these findings, we created a hypothetical independent-covariate-dependent or x-y-z variable interaction diagram (Fig. 1). Given the increase of cumulative effect size of the MANCOVA model when the effect of training

type was adjusted for WTT, we hypothesized the moderating effect of WTT in the interaction of training type and cardiac chamber indices.

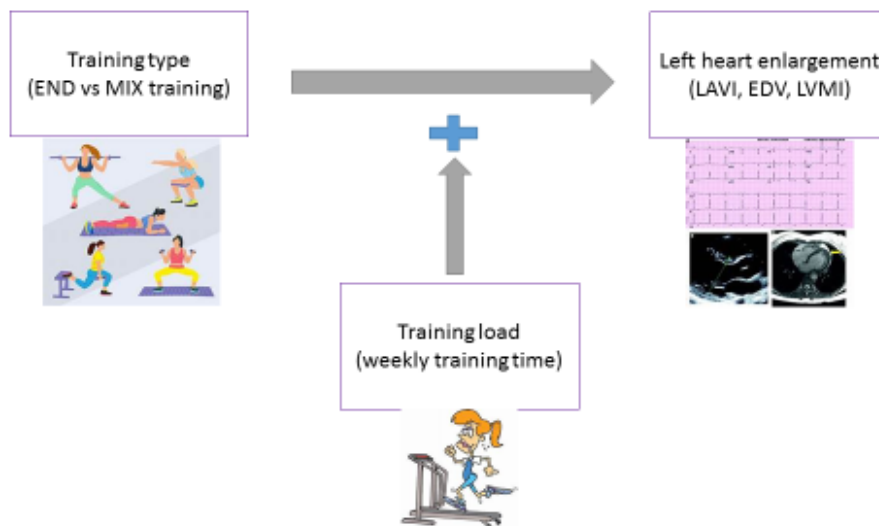


Figure 1. Hypothetical interaction model of sports-related and cardiac parameters

Discussion

Notably, in our study, END athletes were found with both dilation and hypertrophy of left heart chambers, as evidenced by literature (2, 9, 13). AHS typically manifests differently among athletes, with key factors such as training type, sports discipline, athlete's career, and other several factors influencing these variations (2, 14). Some reports based on the Morganroth hypothesis insisted on the development of eccentric remodeling in the case of endurance and concentric resistance training (3, 4). On the other hand, dynamic and static components of exercise play a crucial role besides aerobic components (14, 15).

Doronina et al. (16) reported that athletes on predominantly static training characterized by concentric remodeling, whereas athletes of high dynamic endurance resulted in eccentric remodeling. Despite the limited information about the training programs of athletes, we assume that cardiac remodeling in END groups resulted from both complex impacts of static-dynamic and aerobic components of field and track sports, as well as swimming.

The observed interaction between TT and WTT on cardiac chamber indices suggests the possible moderating role of WTT. While training type alone explained only 13% of the variability in left heart chamber indices, adjusting for WTT increased the model's explanatory power to 51%. This highlights the complex interplay between intrinsic (e.g., TT) and extrinsic (e.g., WTT) factors in shaping cardiac adaptations. Such moderating effects have been underexplored in the context of AHS and warrant further investigation (17). Additionally, post-hoc contrast analysis highlighted the significant changes

in the LVMI. Post-hoc margin analysis further reinforced these findings, showing significant differences in LAVI, LVMI, and EDV between END and MIX athletes after adjusting for WTT. These results underscore the importance of considering training intensity and duration when evaluating the impact of sports-related factors on cardiac structure.

Strikingly, functional indices such as EF and global GLS did not show significant differences between groups. This suggests that despite structural remodeling, functional adaptations remain preserved, consistent with the physiological nature of AHS in well-trained athletes. The findings from this study provide valuable insights into the cardiac adaptations in female athletes. They emphasize the need for gender-specific research in sports cardiology, as AHS in females can vary substantially from males due to differences in hormonal, physiological, and anthropometric factors (8).

From a clinical perspective, these results can help in the differentiation of physiological AHS from pathological conditions, particularly in female athletes who might present with remodeling patterns mimicking earlier manifestations of cardiomyopathies (8, 18). Additionally, the observed relationship between WTT and cardiac chamber indices highlights the importance of monitoring training loads to optimize athlete performance while minimizing potential risks of overtraining (19).

Study limitations

The cross-sectional design precludes causal inferences, and the small sample size limits the extrapolation of the findings. Additionally, the lack of sedentary controls and the absence

of detailed data on training programs restrict the robustness of these TTE findings. Future longitudinal studies with larger samples and detailed sports-associated parameters with complex regression models are needed to validate these findings and explore potential long-term implications of AHS in female athletes.

Conclusion

In summary, this study demonstrates that endurance training is associated with greater cardiac remodeling effects in young female athletes compared to mixed training, with WTT playing a significant role in these adaptations. The findings underscore the importance of tailored training strategies and the need for further research into gender-specific cardiac remodeling patterns in athletes.

Ethics: The study was approved by the Institutional Review Board of the Ala-Too International University. All participants provided informed consent before participating in the study. Data was collected anonymously and stored securely to ensure confidentiality.

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Conflict of interest: None to declare

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Availability of data and material: For collaboration requests contact authors in frame of ethics.

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