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Sport-Specific Cardiac Adaptations: A Comparative Echocardiographic Analysis of Basketball, Volleyball, and Handball Athletes

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Original Research

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Abstract

Purpose: This study aimed to compare central cardiovascular adaptations, both structural and functional, in elite male athletes from basketball, volleyball, and handball to identify sport-specific differences. **Method:** Thirty male athletes (aged 18-25; n=10 per sport group) participated in this cross-sectional study. All participants underwent comprehensive transthoracic echocardiography at rest and immediately following a maximal graded exercise test (GXT) on a treadmill. Key measured parameters included left ventricular (LV) dimensions, wall thickness, mass, ejection fraction (EF), stroke volume, and cardiac output. Data were analyzed using One-Way ANOVA or the Kruskal-Wallis test, with post-hoc analyses where appropriate. **Results:** While most parameters indicated a common adaptive athlete's heart profile across all sports, significant sport-specific differences were found. Handball players exhibited a significantly higher heart rate post-GXT (180.11±9.45bpm) compared to both basketball and volleyball players ($p<0.01$). Furthermore, ejection fraction was significantly different between all groups at rest ($p<0.05$), with handball players also demonstrating a superior EF post-GXT compared to the other groups ($p<0.05$). A significant difference in left ventricular end-systolic dimension was also observed at rest between all three sports ($p<0.001$). **Conclusion:** The findings confirm that basketball, volleyball, and handball athletes share a baseline of physiological cardiac remodeling. However, the significant differences in post-exercise heart rate and ejection fraction, particularly in handball players, suggest that the pronounced upper-body and isometric components of handball impose a unique hemodynamic stress, leading to distinct functional adaptations. This underscores the importance of sport-specific interpretation of cardiac parameters in athletes.

Keywords: Athlete's Heart; Echocardiography; Team Sports; Cardiac Remodeling; Exercise Test; Hemodynamic Adaptation.

Introduction

Engagement in regular physical activity induces significant physiological and morphological adaptations in the heart, a phenomenon often termed "athlete's heart" (1, 13). These adaptations vary considerably based on the nature of the exercise stimulus, primarily categorized into endurance (dynamic) and resistance (static) training [2]. Endurance sports, characterized by sustained aerobic output, typically promote volume-loading effects. These lead to physiological changes such as eccentric left ventricular (LV) hypertrophy, characterized by an increase in LV end-diastolic volume, stroke volume, and cardiac output, alongside a reduction in resting heart rate [1, 3]. In contrast, strength and power sports impose a significant pressure load on the heart, often resulting in concentric remodeling, where the ventricular walls thicken with only minor changes in chamber size [2, 4]. The clinical significance of understanding these adaptations is paramount, as they must be distinguished from pathological conditions such as hypertrophic cardiomyopathy (HCM). HCM is a leading cause of exercise-related sudden cardiac death in young athletes, and its presentation can overlap with physiological hypertrophy, though typically with key differentiating features like excessive, asymmetric wall thickness and a small LV cavity [5, 6]. This distinction underscores the critical importance of comprehensively characterizing the cardiac phenotype in athletes. While the cardiac adaptations to common endurance (e.g., running, cycling) and strength sports are well-documented [1, 2], less is known about the specific effects of intermittent, high-intensity team sports like handball, basketball, and volleyball. These sports present a unique hemodynamic challenge, combining dynamic aerobic elements with frequent bursts of high-intensity static exertion (e.g., jumping, pushing, and throwing). Furthermore, upper-body dominant sports like handball may impose a distinct stress profile. For a given oxygen consumption, arm exercise elicits a higher heart rate and blood pressure response compared to leg exercise due to a smaller active muscle mass, higher systemic vascular resistance, and greater afterload [7, 8]. This is often compounded by the Valsalva maneuver during intense efforts, further increasing intrathoracic pressure and myocardial oxygen demand [8, 14]. Despite these known physiological differences, a comparative analysis of the cardiac structure and function among athletes specializing in these distinct team sports is lacking. It remains unclear whether the specific demands of handball (with its pronounced upper-body component) produce cardiac adaptations that are measurably different from those seen in basketball and volleyball, which, while also involving the upper body, may have a different central and peripheral impact. Therefore, the primary aim of this study was to compare central cardiovascular adaptations in young elite athletes from handball, basketball, and volleyball. We specifically investigated structural parameters—including left ventricular wall thickness, end-diastolic and end-systolic dimensions, and mass—and functional parameters, such as resting heart rate, ejection fraction, stroke volume, and cardiac output. This research seeks to determine if sport-specific hemodynamic loads drive differential remodeling of the athlete's heart.

Methods

Study Design

This study employed a cross-sectional, comparative design to investigate cardiac structural and functional adaptations in athletes from three distinct team sports. The protocol was reviewed and approved by the Vice President for Research, Urmia University and was conducted in accordance with the ethical principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their inclusion in the study.

Participants

The statistical population comprised all male basketball, volleyball, and handball athletes in West Azerbaijan, Bukan city, Iran, who had competed at the county or provincial level. A simple random sampling method was used to select potential participants. Following coordination with team officials and coaches, eligible athletes were invited to a briefing session where the study's purpose, procedures, benefits, and potential risks were thoroughly explained. Inclusion criteria were: (1) male gender; (2) age between 18-25 years; (3) active participation in structured training and competition for at least the previous three seasons; and (4) absence of any known cardiovascular, pulmonary, or metabolic disease as confirmed by a health history questionnaire and medical screening. A final sample of 30 athletes (mean age: 22.87±2.28 years) was recruited and divided into three sport-specific groups: basketball (BB; n=10), volleyball (VB; n=10), and handball (HB; n=10).

Study Protocol

All testing was conducted in a controlled laboratory setting over two separate sessions to avoid fatigue. In Session A, which focused on familiarization and baseline assessment, participants completed the informed consent and health screening forms. Anthropometric measurements, including height and weight, as well as resting physiological data such as heart rate and blood pressure, were collected. A preliminary echocardiographic screening was performed to exclude any underlying pathological cardiac conditions. In Session B, which involved experimental testing, subjects abstained from caffeine and strenuous exercise for 24 hours before reporting to the lab. The session proceeded as follows: first, participants underwent pre-exercise resting measurements, where they rested in a seated position for 15 minutes, after which resting heart rate (RHR) and blood pressure (BP) were recorded. Next, a comprehensive resting echocardiogram was performed as part of the pre-exercise assessment. Following this, participants immediately underwent a maximal graded exercise test (GXT) on a treadmill. Finally, immediately upon termination of the

GXT, participants assumed the left lateral decubitus position for rapid post-exercise image acquisition via echocardiogram.

Measurements and Instrumentation

Anthropometric and basic measures included height (centimeter) and weight (Kg), which were measured using a stadiometer and a calibrated digital scale (Seca 803, Germany), respectively. Body Surface Area (BSA) was calculated accordingly. Resting Heart Rate (RHR, beat/min) was measured via Polar Pacer after 15 minutes of seated rest, while Resting Blood Pressure (BP, (mmHg) was measured using an automated digital blood pressure monitor (Omron M2, China) (Table 1).

Graded Exercise Test (GXT):

A symptom-limited maximal graded exercise test (GXT) was performed on a motorized treadmill (TechnoGym, Italy) with the following protocol: Stage 1 involved walking at 2.0 km/h (0% grade) for 3 minutes, followed by Stage 2, where participants ran at speeds ranging from 9.6 to 12.0 km/h (0% grade) for another 3 minutes. In subsequent stages, the treadmill incline was increased by 2.5% each minute until the participant reached volitional exhaustion, despite strong verbal encouragement. Heart rate was monitored continuously throughout the test using a telemetric system (Polar Pacer, Finland), and blood pressure was measured at the end of each stage using a clinically validated Yagami VG200 (Japan) sphygmomanometer. Maximal effort was considered achieved if the participant met at least two of the following criteria: (1) a respiratory exchange ratio (RER) greater than 1.10, (2) a plateau in heart rate despite increasing workload, or (3) volitional exhaustion (9).

Echocardiography:
A comprehensive transthoracic echocardiogram was performed at rest and immediately post-exercise by an experienced sonographer using a

commercial ultrasound system (KONTRON MEDICAL, France). All examinations followed the standardized views and techniques recommended by the American Society of Echocardiography (10, 11).

Cardiac Structure**:** M-mode echocardiography was used to measure left ventricular internal dimensions at end-diastole (LVIDd) and end-systole (LVIDs), interventricular septal thickness at end-diastole (IVSd), and left ventricular posterior wall thickness at end-diastole (LVPWd). Left Ventricular Mass (LVM) was calculated using the Devereux formula (12):
$LVM (g) = 0.8 \times \{1.04 \times [(IVSd + LVIDd + LVPWd)^3 - LVIDd^3]\} + 0.6$

Cardiac Function: Two-dimensional (2D) echocardiography and pulsed-wave Doppler were used. Left ventricular volumes at end-diastole (LVEDV) and end-systole (LVESV) were measured from the apical 4-chamber and 2-chamber views using the biplane method of discs (modified Simpson's rule). Stroke Volume (SV) was calculated as $SV = LVEDV - LVESV$. Cardiac Output (CO) was derived as $CO = SV \times HR$. Ejection Fraction (EF) was calculated as $EF = (SV / LVEDV) \times 100\%$. Stroke Volume was also validated using Doppler methods at the left ventricular outflow tract (LVOT): $SV = VTI\_LVOT \times \pi \times (D\_LVOT/2)^2$ (Table 2).

Analysis

All statistical analyses were performed using SPSS software (version 27, IBM Corp., USA). Descriptive data are presented as mean ± standard deviation (Mean±SD). The normality of data distribution was confirmed for all variables using the Kolmogorov-Smirnov test. To compare the effects of exercise (rest vs. post-GXT) across the three sport groups, a two-way (2 [time] × 3 [sport]) mixed-model analysis of variance (ANOVA) with repeated measures on the time factor was employed. Where significant interaction effects were found, pairwise comparisons were conducted using the Bonferroni post-hoc test. Statistical significance was set a priori at $p \leq 0.05$.

Results

Table 1. Anthropometric and physiological characteristics of the Athletes

Variable	Handball	Volleyball	Basketball
Age (yrs.)			
Pre	23.00±2.49	23.30±1.95	22.30±2.50
GXT	23.00±2.49	23.30±1.95	22.30±2.50
Height (Cm)			
Pre	186.20±3.19	189.30±1.49	189.30±2.36
GXT	186.20±3.19	189.30±1.49	189.30±2.36
Weight (Kg)			
Pre	88.50±3.84	89.60±2.27	91.20±3.76
GXT	87.90±3.81	89.00±2.49	90.50±3.13
BMI (Kg/m2)			
Pre	25.46±1.68	25.00±0.61	25.46±0.99
GXT	25.46±1.68	24.90±0.63	25.29±0.90

Heart Rate (beat.min)			
Pre	61.39±3.14	62.49 ± 3.79	61.79 ± 2.66
GXT	180.11±9.45	177.31±7.44	175.31±5.87

Data are presented as mean ± SD (standard deviation); GXT: Graded Exercise Test; Pre: 24 hours before GXT protocol; BMI: Body mass index (kg/m2);

Table 2. Average changes (Mean ± Standard Deviation) for cardiac variables in young male athletes (basketball, handball, and volleyball) at before GXT protocol and Post-GXT

Variable	Condition	SD± Mean
Cardiac Output (L/min)	Pre	6.84±1.17
	Post-GXT	23.90±5.51
Stroke Volume (mL)	Pre	104.05±19.03
	Post-GXT	126.26±21.78
Heart Rate (bpm)	Pre	61.89±3.15
	Post-GXT	177.58±7.72
Ejection Fraction (%)	Pre	0.61±0.04
	Post-GXT	0.71±0.07

End-Systolic Volume (mL)	Pre	49.70±7.54
	Post-GXT	40.53±17.93
End-Diastolic Volume (mL)	Pre	123.60±13.34
	Post-GXT	130.17±10.08
Posterior Wall Thickness (cm)	Pre	1.06±0.08
	Post-GXT	1.11±0.11
LV End-Systolic Dimension (cm)	Pre Post-GXT	2.85±0.34 2.20±0.31
LV End-Diastolic Dimension (cm)	Pre	4.59±0.37
	Post-GXT	4.28±0.49
Interventricular Septum Thickness (cm)	Pre	1.04±0.09
	Post-GXT	1.06±0.09

GXT: Graded Exercise Test; LV: Left Ventricular; Pre: 24 hours before GXT protocol.

The results of this research (Table 3 and Table 4) showed that at rest, the One-Way ANOVA revealed no statistically significant difference in resting cardiac output between the three sport groups ($F (2, 27) = 0.369$, $p = 0.692$). At Post-GXT protocol, similarly, no significant difference was found between groups following the graded exercise test ($F (2, 27) = 0.019$, $p = 0.981$). Also, at rest, no significant difference in resting stroke volume was observed between basketball, volleyball, and handball athletes ($F (2, 27) = 0.560$, $p = 0.572$). At Post-GXT protocol, the Kruskal-Wallis test indicated that stroke volume after GXT was not significantly different across the three groups ($\chi^2 (2) = 0.571$, $p = 0.751$). Heart Rate: At rest, the Kruskal-Wallis test showed no significant difference in resting heart rate among the groups ($\chi^2 (2) = 1.149$, $p = 0.488$). At Post-GXT conditions, a significant main effect of sport type was found for heart rate after maximal exercise ($\chi^2 (2) = 12.247$, $p = 0.001$). Post-hoc pairwise comparisons with a Bonferroni correction revealed that handball players had a significantly higher post-exercise heart rate compared to both basketball ($p = 0.008$) and volleyball ($p = 0.017$) players, while no significant difference was found between basketball and volleyball players ($p = 1.000$). In addition, at rest, the Kruskal-Wallis test identified a significant difference in resting ejection fraction between the groups ($\chi^2 (2) = 7.070$, $p = 0.029$). Post-hoc tests indicated that basketball players had a significantly higher resting EF than both volleyball ($p < 0.001$) and handball ($p = 0.046$) players, with volleyball players also having a significantly lower EF than handball players ($p = 0.001$). Post-GXT, a significant difference between groups was also maintained after exercise ($\chi^2 (2) = 6.814$, $p = 0.049$), with post-hoc analysis showing that the ejection fraction in handball players was significantly higher than in both basketball ($p < 0.001$) and volleyball ($p = 0.020$) players post-GXT (Table 3 and Table 4).

Table 3: Comparison of Cardiac Variables (Mean ± SD) in basketball, handball, and volleyball players (N=30) at rest and Post-Graded Exercise Test (GXT)

Variable	**Condition**	**Basketball (n=10)**	**Volleyball (n=10)**	**Handball (n=10)**	**Total (N=30)**
Cardiac Output (L/min)	Rest	-	-	-	6.84 ± 1.17
	Post-GXT	-	-	-	23.90 ± 5.51
Stroke Volume (mL)	Rest	-	-	-	104.05 ± 19.03
	Post-GXT	-	-	-	126.26 ± 21.78
Heart Rate (bpm)	Rest	-	-	-	61.89 ± 3.15
	Post-GXT	a*	a	b	177.58 ± 7.72
Ejection Fraction	Rest	a	b	c	0.61 ± 0.04
	Post-GXT	a	a	b	0.71 ± 0.07
End-Systolic Volume (mL)	Rest	-	-	-	49.70 ± 7.54
	Post-GXT	-	-	-	40.53 ± 17.93
End-Diastolic Volume (mL)	Rest	-	-	-	123.60 ± 13.34
	Post-GXT	-	-	-	130.17 ± 10.08
Posterior Wall Thickness (cm)	Rest	-	-	-	1.06 ± 0.08
	Post-GXT	-	-	-	1.11 ± 0.11
LV End-Systolic Dimension (cm)	Rest	a	b	c	2.85 ± 0.34
	Post-GXT	-	-	-	2.20 ± 0.31

LV End-Diastolic Dimension (cm)	Rest	-	-	-	4.59 ± 0.37
	Post-GXT	-	-	-	4.28 ± 0.49
Septal Thickness (cm)	Rest	-	-	-	1.04 ± 0.09
	Post-GXT	a	b	c	1.06 ± 0.09

*Note: Different superscript letters (a, b, c) within a row indicate a statistically significant difference ($p < 0.05$) between basketball, handball, and volleyball players based on post-hoc analysis. A dash (-) indicates no significant difference was found between groups for that variable and condition

Table 4: Between-Group Comparisons of cardiac variables (Mean ± SD) in basketball, handball, and volleyball players

Variable	Condition	Test Statistic	p-value	Post-Hoc
Cardiac Output	Rest	$F(2,27) = 0.369$	0.692	-
	Post-GXT	$F(2,27) = 0.019$	0.981	-
Stroke Volume	Rest	$F(2,27) = 0.560$	0.572	-
	Post-GXT	$\chi^2(2) = 0.571$	0.751	-
Heart Rate	Rest	$\chi^2(2) = 1.149$	0.488	-
	Post-GXT	$\chi^2(2) = 12.247$	0.001	HB > BB, HB > VB
Ejection Fraction	Rest	$\chi^2(2) = 7.070$	0.029	BB > VB, BB > HB, HB > VB
	Post-GXT	$\chi^2(2) = 6.814$	0.049	HB > BB, HB > VB
End-Systolic Vol. (ESV)	Rest	$\chi^2(2) = 0.457$	0.465	-

	Post-GXT	-	>0.05	-
End-Diastolic Vol. (EDV)	Rest	$F(2,27) = 0.033$	0.977	-
	Post-GXT	$\chi^2(2) = 0.192$	0.119	-
LV End-Systolic Dimension	Rest	$F(2,27) = 47.89$	<0.001	BB ≠ VB ≠ HB
	Post-GXT	$\chi^2(2) = 0.795$	0.672	-
LV End-Diastolic Dimension	Rest	-	>0.05	-
	Post-GXT	-	>0.05	-
Posterior Wall Thickness	Rest	$\chi^2(2) = 1.149$	0.176	-
	Post-GXT	-	>0.05	-
Septal Thickness	Rest	$\chi^2(2) = 0.264$	0.877	-
	Post-GXT	$\chi^2(2) = 6.553$	<0.05	.

Abbreviations: BB = Basketball, VB = Volleyball, HB = Handball. LV = Left Ventricular. Note: The p-value column is bolded when the result is statistically significant. χ^2: Kruskal-Wallis test; F: One-Way ANOVA test.

Structural Adaptations:

For End-Systolic Volume (ESV), no significant differences were found between the three sports either at rest (χ^2 (2) = 0.457, p = 0.465) or post-GXT (p > 0.05). Similarly, for End-Diastolic Volume (EDV), no significant differences were found between groups at rest (F (2, 27) = 0.033, p = 0.977) or post-GXT (χ^2 (2) = 0.192, p = 0.119). This is while, a significant difference was found between groups for LV End-Systolic Dimension at rest (F (2, 27) = 47.89, p < 0.001), with post-hoc analysis confirming that all pairwise comparisons (basketball vs. volleyball, basketball vs. handball, volleyball vs. handball) were significantly different ($p < 0.05$ for all). In contrast, no significant differences were found between the groups for LV End-Diastolic Dimension, either at rest ($p > 0.05$) or post-GXT ($\chi^2(2) = 0.795$, $p = 0.672$). On the other hand, the Kruskal-Wallis test showed no significant differences in posterior wall thickness among basketball, volleyball, and handball athletes, either at rest (χ^2 (2) = 1.149, $p = 0.176$) or post-GXT ($p > 0.05$). For Interventricular Septum Thickness, no significant differences were found between the three groups at rest (χ^2 (2) = 0.264, $p = 0.877$); however, a significant difference emerged post-GXT (χ^2 (2) = 6.553, $p < 0.05$), with post-hoc tests indicating that the nature of these differences was specific to the sport groups (Table 4).

Discussion

The primary aim of this study was to compare central cardiovascular adaptations in elite male athletes from three distinct team sports—basketball, volleyball, and handball—to determine if their specific hemodynamic demands induce differential cardiac remodeling. The key findings indicate that while most structural and functional parameters were similar across all athletes, confirming the general "athlete's heart" phenotype, significant sport-specific differences emerged in post-exercise heart rate, ejection fraction (both at rest and post-exercise), and left ventricular (LV) end-systolic dimension (14, 19). These nuances highlight the importance of considering the unique physiological profile of each sport. The majority of our findings align with the well-established literature on the athlete’s heart, a syndrome of cardiac adaptation characterized by physiological remodeling in response to chronic exercise training (1, 19). The absence of significant differences in resting cardiac output, stroke volume, end-diastolic volume, and wall thickness (posterior wall and septum) between the three groups suggests a common adaptive pathway to the overarching demands of high-intensity intermittent team sports. All three sports combine elements of dynamic and static exercise, leading to a mixed phenotype of eccentric and concentric hypertrophy (2). The increased LV mass and dimensions observed across all groups, though not statistically different between them, are classic hallmarks of this adaptation, serving to enhance pumping efficiency and reduce cardiac workload at rest, as evidenced by the lowered resting heart rate common to all athletes (3). Despite the overall similarities, several critical differences underscore the influence of sport-specific training. Firstly, post-exercise heart rate was significantly higher in handball players compared to both basketball and volleyball players. This finding is particularly intriguing and may be attributed to the greater upper-body dominance and sustained isometric contractions inherent in handball, such as throwing, blocking, and holding off opponents. Arm exercise elicits a higher heart rate and blood pressure response for a given oxygen consumption than leg exercise due to higher sympathetic nervous system activation, greater peripheral vascular resistance, and a smaller active muscle mass (8). The frequent use of the Valsalva maneuver during powerful throws or defensive actions further increases intrathoracic pressure and afterload, demanding a higher myocardial oxygen cost and consequently a higher heart rate to maintain cardiac output (8, 13, 18). This suggests that handball imposes a unique cardiometabolic strain that is distinctly different from the more lower-body-dominated and dynamic movements of basketball and volleyball. Secondly, significant differences were found in ejection fraction (EF). At rest, basketball players exhibited a higher EF than both other groups, with handball players also showing a higher EF than volleyball players. This pattern was reinforced post-exercise, where handball players maintained a significantly higher EF than both other groups. Ejection fraction is a measure of contractility and the heart's efficiency in ejecting blood. The superior EF in handball athletes, especially under the stress of exercise, could be interpreted as an enhanced contractile function, potentially adapting to the chronic pressure overload from intense upper-body work. However, it is crucial to differentiate this physiological enhancement from pathological conditions. The fact that this occurred alongside normal chamber dimensions and wall thickness is reassuringly physiological (15, 17, 18). The reason for the difference between basketball and volleyball, which share more similar movement patterns, is less clear and may warrant further investigation into subtle differences in training intensity, playing position, or game dynamics. Thirdly, the left ventricular end-systolic dimension (LVESD) at rest was significantly different between all three groups. LVESD is a key indicator of ventricular contractility and afterload; a smaller dimension often indicates a more forceful contraction or a higher pressure load (16, 17, 18). The specific pattern of difference (Basketball ≠ Volleyball ≠ Handball) suggests a fine-tuning of cardiac mechanics specific to each sport's demand. Handball's pressure-overload component may lead to a smaller LVESD as the ventricle adapts to eject blood against a higher resistance, consistent with a more concentric adaptation pattern

Implications and Applications:

These findings have practical implications for sports medicine and athlete care: Cardiologists screening athletes should be aware that "normal" cardiac dimensions and function can have sport-specific variations. The higher EF and post-exercise heart rate in a handball player should not be immediately misconstrued as abnormal without considering the sport's specific physiology. Coaches and trainers can use this information to better understand the cardiovascular demands of their sport. Handball coaches, now aware of the significant strain on the heart, might incorporate more specific cardiac recovery strategies into their programs.

Limitations of the Research:

While this study provides valuable insights, several limitations must be acknowledged. First, the relatively small sample size (n=10 per group) limits the statistical power of the study and increases the risk of Type II errors, which is the failure to find a difference that actually exists. A larger cohort might have revealed more subtle differences in other parameters. Second, the cross-sectional design of our study provides only a snapshot in time; a longitudinal study tracking athletes from the beginning of their career would provide stronger evidence for causal relationships between training type and cardiac adaptation. Third, while the training regimen was described, it was not precisely quantified using tools like GPS tracking, heart rate monitors, or session RPE (Rating of Perceived Exertion) for each individual, meaning that differences in individual training load within each sport could be a confounding variable. Finally, our study did not differentiate between different playing positions (e.g., goalkeeper vs. field player in handball), which can have vastly different physiological demands.

Conclusion

In conclusion, this study demonstrates that male athletes from basketball, volleyball, and handball share a common foundation of the athlete's heart syndrome, characterized by physiological remodeling to enhance performance. However, beyond this generalized adaptation, significant sport-specific differences exist. Handball, with its pronounced upper-body and isometric components, appears to drive a distinct adaptive response, characterized by a higher post-exercise heart rate and a superior ejection fraction, both at rest and under stress, alongside differences in LV end-systolic dimension. These findings advance our understanding of the intricate relationship between sport-specific hemodynamic loads and cardiac adaptation. They emphasize the need for a nuanced approach in the cardiovascular assessment of athletes, moving beyond a one-size-fits-all concept of the athlete's heart and towards a more sport-specific model. Further research seems necessary to better understand these changes.

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