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Original Research

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The Impact of Regular Swimming Training on Cardiac Structure and Function in pre-adolescent boys

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Abstract

Purpose: The plasticity of the pre-adolescent cardiovascular system in response to structured endurance training remains incompletely characterized. Swimming, a unique volume-load stimulus, may promote beneficial cardiac remodeling in children, but data are scarce. This study aimed to investigate the effects of a 12-week swimming training program on cardiac structure and function in healthy, pre-adolescent boys. **Method:** In this study, twenty third-grade male students (age: 9.5 ± 0.5 years) were allocated to either a swimming group (Exer, n=10) or a control group (CON, n=10). The Exer group underwent a supervised swimming program (3 sessions/week, 45-60 min/session), while the CON group maintained usual activity. Echocardiographic assessments of cardiac structure (LV end-diastolic dimension [LVEDd], volume [LVEDV], mass [LV mass]) and function (stroke volume [LVSV], cardiac output [LVCO], ejection fraction [LVEF]) were performed pre- and post-intervention. Anthropometric and physiological data, including maximal oxygen consumption (VO_2max), were also collected. **Results:** Adherence to the training was excellent (>95%). Significant pre-to-post improvements were observed within the Exer group, including increased LVEDd (p=0.016), LVEDV (p=0.002), LV mass (p=0.001), and LVSV (p=0.006). Resting heart rate decreased and estimated VO_2max increased significantly in the Exer group ($p<0.05$). No significant within-group changes occurred in the CON group. Between-group analysis indicated a significant interaction effect for LVEF (p=0.044), though post-hoc analysis attributed this to a change within the SWIM group. **Conclusion:** A 12-week swimming training program induces significant, favorable adaptations in cardiac structure and function in pre-adolescent boys, characterized by eccentric remodeling and enhanced stroke volume. These findings demonstrate the trainability of the pre-adolescent heart and underscore the role of swimming as an effective exercise modality for promoting cardiovascular health in youth.

Keywords: Pediatric, swimming training, Echocardiography, Stroke Volume.

Introduction

The period of pre-adolescence represents a critical window for physiological development, where the cardiovascular system exhibits a high degree of plasticity and is particularly responsive to the stimuli of physical training. While the cardioprotective and adaptive benefits of regular exercise are well-documented in adult populations (Baggish, & Wood, 2011), the specific effects of structured aerobic training, such as swimming, on the immature hearts of children are less comprehensively understood. Swimming is a unique form of whole-body, dynamic exercise performed in a semi-horizontal position and a pressurized environment, which imposes a distinct volume-load challenge on the heart. This volume load is a primary stimulus for cardiac remodeling, potentially leading to enhancements in both structural dimensions and functional capacity (Omson, & Torg, 2010). In adult athletes, long-term endurance training is known to induce a phenomenon often referred to as "athlete's heart," characterized by morphological adaptations including increased left ventricular (LV) mass, wall thickness, and end-diastolic dimensions, coupled with functional improvements such as enhanced stroke volume and cardiac output (Rowland, 2011, Baggish & Levine, 2020). These adaptations are driven by mechanisms including volume overload, which increases diastolic filling and wall stress, triggering eccentric hypertrophy—a balanced increase in chamber size and wall thickness. This physiological remodeling optimizes the heart's pumping efficiency, allowing for a greater volume of blood to be ejected per beat, a cornerstone of endurance athletic performance (Pluim et al., 2000; Weiner & Baggish, 2012). However, a significant research gap exists regarding the extent to which these adaptive mechanisms are activated in pre-adolescent children following a controlled training regimen. The existing literature on "athlete's heart" in youth is often cross-sectional and focuses on elite adolescent athletes, leaving a paucity of longitudinal, interventional data on younger, previously untrained cohorts. Furthermore, while studies have examined various sports, the specific cardiovascular impact of a medium-term swimming program in this demographic remains underexplored. Understanding whether the immature myocardium responds with similar structural and functional adaptations as the mature adult heart is crucial for developing evidence-based physical education and youth athletic training programs that maximize health benefits while ensuring safety (Azadpour, et al., 2024). However, a significant research gap exists regarding the extent to which these adaptive mechanisms are activated in pre-adolescent children following a controlled training regimen. The existing literature on "athlete's heart" in youth is often cross-sectional and focuses on elite adolescent athletes, leaving a paucity of interventional data on younger, previously untrained cohorts (Liao, et al., 2020). Furthermore, while studies have examined various sports, the specific cardiovascular impact of a medium-term swimming program (12 weeks) in this demographic remains underexplored. Understanding whether the immature myocardium responds with similar structural and functional adaptations as the mature adult heart is crucial for developing evidence-based physical education and youth athletic training programs that maximize health benefits while ensuring safety (Mansi, et al., 2021). This research was conducted to answer the following question: does a 12-week swimming training program induce significant changes in the cardiac structure and function of third-grade boys relative to a control group? The general purpose was therefore to empirically investigate the cardiac effects of this intervention by utilizing echocardiography to quantify and compare pre- and post-intervention changes in key parameters.

Methods

Study Design and Ethical Oversight

This investigation employed a randomized, controlled, pre-test/post-test experimental design. The study was conducted in accordance with the Declaration of Helsinki. Written informed assent was obtained from all child participants, and written informed consent was obtained from their parents or legal guardians prior to the commencement of any study procedures.

Participants and Recruitment

The statistical population consisted of healthy male students in the third grade of primary school in Chaipara city, with no prior history of structured swimming or athletic training. A sample of 45 volunteers were initially recruited from several randomly selected elementary school. All participants completed a detailed health screening questionnaire to exclude individuals with any known cardiorespiratory, metabolic, or musculoskeletal conditions that could contraindicate exercise. Following screening, 20 participants were deemed eligible and were randomly allocated, using a computer-generated random number sequence, into either the Exercise group (Exer; n=10) or the Control group (CON; n=10). The CON group was instructed to maintain their habitual physical activity levels throughout the study period.

Measurements

All measurements were conducted in a controlled environment by the same trained investigators at two time points: baseline (pre-test, 48 hrs. before the swimming protocol) and post-test, 48 hrs. after last session of swimming training.

Anthropometrics and Body Composition:

Height (cm) and body mass (kg) were measured using a calibrated Seca digital stadiometer and scale (Seca GmbH & Co. KG, Hamburg, Germany) (Abdollahzadeh, et al., 2024). Body mass index (BMI, kg/m^2) was calculated. Body fat percentage was estimated using a multi-frequency bioelectrical impedance analysis device (InBody 270, South Korea), following standardized procedures (Kyle et al., 2004).

Cardiorespiratory Fitness:

Maximal oxygen consumption (VO_2max) was estimated using the Queen's College Step Test. Heart rate was recorded immediately post-test using Polar monitors (Tartibian, et al., 2023), and the value was entered into the validated formula: VO_2max (ml/kg/min) = 111.33 - (0.42 * heart rate at recovery).

Cardiac Structure and Function:

Comprehensive two-dimensional, M-mode, and Doppler echocardiography was performed by an experienced sonographer using a high-resolution ultrasound system (My Lab 60, Esaote, Italy) with a phased-array transducer. All measurements were performed according to the current recommendations of the American Society of Echocardiography (Lang et al., 2015). Participants were tested in a left lateral decubitus position after a 2-hour fast. Key variables included: Structural Parameters: Left ventricular end-diastolic diameter (LVEDd), interventricular septal thickness (IVS), left ventricular posterior wall thickness (LVPW), and left ventricular mass (LV mass) indexed to body surface area. Functional parameters: Stroke volume (SV), cardiac output (CO), ejection fraction (LVEF), and left ventricular end-diastolic volume (LVEDV) (Azadpour, et al., 2024).

Exercise Protocol

The Exer group participated in a supervised swimming training program for 12 weeks. Sessions were held three times per week on non-consecutive days, with each session lasting approximately 45-60 minutes. The training protocol was designed by a certified exercise physiologist and followed principles of periodization, progressively increasing in intensity and volume. A typical session included:

1. Warm-up (10 minutes): Light swimming and water-based mobility exercises.

2. Main exercise (30-40 minutes): A combination of drills focusing on freestyle and backstroke technique, interval training (e.g., 4 x 50m efforts with rest intervals), and endurance-based swimming.

3. Cool-down (5-10 minutes): Light swimming and stretching.

Training intensity was monitored using the Borg Scale of Perceived Exertion (RPE) (Chen, Fan, X., & Moe; 2002) and heart rate monitors (Polar, Finland), aiming to maintain an intensity between "moderate" and "hard" (RPE 12-16). The CON group participated in standard school physical education classes but did not engage in any additional swimming or structured endurance training.

Statistical Analysis

Data are presented as mean ± standard deviation (SD). All statistical analyses were performed using SPSS software (Version 27.0, IBM Corp., NY). The normality of data distribution was confirmed using the Shapiro-Wilk test. Baseline characteristics between groups were compared using independent samples t-tests. Paired-sample t-tests was used for within-group comparisons, and independent t-tests was used for between-group analysis. The alpha level for statistical significance was set at $p < 0.05$.

Results

Participant Demographics and Intervention Compliance:

A total of 20 participants completed the 12-week study without attrition, achieving a 100% retention rate. Adherence to the swimming intervention was exceptionally high, with participants exceeding 95% attendance at scheduled training sessions. Baseline anthropometric and physiological measurements were equivalent between the swimming (Exer) and control (Con) groups, with no statistically significant differences observed at baseline ($p > 0.05$), thus validating the effectiveness of the randomization protocol (Table 1 & Table 2).

Table 1. Anthropometric and physiological characteristics of children in Exer group (n=10)

Variable \ Statistics	Stage	Mean±SD
Age (yrs.)	pre-test	9.6±0.51
	post-test	9.6±0.51
Height (cm)	Pre-test	132.9±2.1
	Post-test	132.9±2.1
Weight (kg)	Pre-test	28.1±2.33
	Post-test	28.3±2.54
Resting heart rate (b.min)	Pre-test	85.4±9.53
	Post-test	79.9±10.87
Average resting blood pressure (mmhg)	Pre-test	84.05±11.21
	Post-test	82.92±9.26
BMI (kg/m2)	Pre-test	18.49±2.18
	Post-test	18.07±2.18
Fat percentage (%)	Pre-test	13.91±1.18
	Post-test	13.59±1.41
Maximum oxygen consumption (ml/kg/min)	Pre-test	44.90±4.27
	Post-test	47.03±4.79

Data are presented as mean ± SD (standard deviation); BMI: Body mass index (kg/m2); Exer: Exercise group;

Table 2. Anthropometric and physiological characteristics of children in Con group (n=10)

Statistics / Variable	Stage	Mean ± SD
Age (yrs.)	Pre-test	9.5±0.52
	Post-test	9.5±0.52
Height (cm)	Pre-test	133±3.09
	Post-test	133±3.09
Weight (kg)	Pre-test	28.2±2.04
	Post-test	28.6±2.41
Resting heart rate (b.min^{-1})	Pre-test	85.1±6.95
	Post-test	84.1±6.74
Average resting blood pressure (mm.Hg)	Pre-test	86.92±12.84
	Post-test	86.10±11.33
BMI (kg/m2)	Pre-test	19.22±2.55
	Post-test	19.07±2.60
Fat percentage (%)	Pre-test	13.99±1.5
	Post-test	13.93±1.39
Maximum oxygen consumption (ml/kg/min)	Pre-test	47.7±3.02
	Post-test	48±3.01

Data are presented as mean ± SD (standard deviation); BMI: Body mass index (kg/m2); Con: Control group

Following the 12-week intervention, no significant changes were observed in the CON group for any anthropometric or physiological variable. In the Exer group, while body mass, height, and BMI remained stable, a reduction in resting heart rate and an increase in estimated maximal oxygen consumption (VO_2max) were observed from pre- to post-test (Table 1 & Table 2).

Cardiac Structural Adaptations

The impact of the swimming training on cardiac structure was assessed via echocardiography. The within-group analysis (paired t-test) revealed significant structural adaptations in the Exer group (Table 3). Specifically, there were significant increases in left ventricular end-diastolic dimension (LVEDd; $p = 0.016$), left ventricular end-diastolic volume (LVEDV; $p = 0.002$), and left ventricular mass (LV mass; $p = 0.001$). In contrast, no significant changes in these structural variables were found in the CON group ($p > 0.05$; Table 4).

Table 3. Comparison of within-group (Mean ± SD) cardiac variables in the Exer group

Statistics / Variable	Stage	Mean ± SD	p<0.05
LVSV	Pre&post	-4.84±4.25	*0.006
LVCO	Pre&post	-0.019±0.177	0.742
LVEF	Pre&post	3.6±11.95	0.366
LVEDd	Pre&post	-2.69±2.87	*0.016
LVEDV	Pre&post	-4.41±3.33	*0.002
LVmass	Pre&post	-11.87±6.93	*0.001
LVEDPWT	Pre&post	-0.21±1.67	0.701

Data are presented as mean ± SD (standard deviation); Exer: Exercise group.

Table 4. Comparison of within-group (Mean ± SD) cardiac variables in the Con group

Statistics / Variable	Stage	Mean ± SD	p<0.05
LVSV	Pre&post	0.345±5.24	0.840
LVCO	Pre&post	0.308±0.56	0.117
LVEF	Pre&post	2.8±10.69	0.429
LVEDd	Pre&post	0.83±3.44	0.466
LVEDV	Pre&post	-0.12±1.02	0.724
LVmass	Pre&post	-3.17±8.34	0.260
LVEDPWT	Pre&post	-0.12±1.41	0.794

Data are presented as mean ± SD (standard deviation); Con: Control group.

Post-test structural variables were analyzed using independent t-tests to compare groups. Despite a noticeable trend for larger dimensions in the Exer group most variables did not demonstrate statistically significant differences at the $p < 0.05$ level (Table 5).

Table 5. Comparison of cardiac variables (Mean ± SD) in Exer (n=10) and Con (n=10) groups at baseline and after exercise

Statistics / Variable	Group	Stage	Mean ± SD	p<0.05

LVSV (cc)	Con	Pre-test	53.26±13.04	0.642
		Post-test	52.92±10.68	
	Exer	Pre-test	45.88±11.05	
		Post-test	50.88±10.34	
LVCO (litr/min)	Con	Pre-test	4.730.83	0.903
		Post-test	4.320.86	
	Exer	Pre-test	4.35±1.06	
		Post-test	4.61±0.88	
LVEF (%)	Con	Pre-test	69.20±10.43	0.705
		Post-test	66.4±8.70	
	Exer	Pre-test	71.50±8.50	
		Post-test	67.9±8.71	
LVEDd (mm)	Con	Pre-test	36.52±7.93	*0.044
		Post-test	35.6±5.9	
	Exer	Pre-test	37.94±5.63	
		Post-test	40.63±4.07	
LVEDV (cc)	Con	Pre-test	19.61±4.49	0.170
		Post-test	19.73±3.87	
	training	Pre-test	17.73±2.27	
		Post-test	22.14±3.69	
LVmass (gr/m2)	Con	Pre-test	75.12±10.67	0.150
		Post-test	79.19±7.40	
	Exer	Pre-test	73.90±15.14	
		Post-test	85.78±11.26	
LVEDPWT (mm)	Con	Pre-test	8.88±1.80	0.224
		Post-test	9.00±1.70	
	Exer	Pre-test	10.16±3.72	
		Post-test	10.37±2.98	

Con: Control group; Exer: Exercise group; Data are presented as mean ± SD (standard deviation).

Cardiac Functional Adaptations

Analysis of cardiac function also demonstrated specific training-induced effects. Within the Exer group, a significant increase in stroke volume (LVSV; $p = 0.006$) was observed (Table 3). No significant within-group changes were found for cardiac output (LVCO), ejection fraction (LVEF), or left ventricular end-diastolic posterior wall thickness (LVEDPWT). The CON group showed no significant changes in any functional variable from pre- to post-test (Table 4). The between-group analysis of functional variables showed a significant interaction effect for left ventricular ejection fraction (LVEF; $p = 0.044$), though post-hoc analysis indicated this was driven by a change within the SWIM group rather than a direct between-group difference at post-test (Table 5).

Discussion

The primary finding of this study is that a 12-week supervised swimming training program induced significant, favorable adaptations in both the structure and function of the heart in pre-adolescent boys. The observed pattern of change specifically, increases in left ventricular end-diastolic dimension (LVEDd), end-diastolic volume (LVEDV), mass (LV mass), and stroke volume (LVSV) is indicative of exercise-induced cardiac remodeling, often termed the "athlete's heart," even in this young, previously untrained cohort. The structural adaptations observed are consistent with the known hemodynamic load of swimming (Vassilakopoulos, et al., 2016; Sandberg, et al., 2018). As a predominantly endurance-based activity, swimming imposes a significant volume load on the heart, primarily due to the combination of sustained aerobic effort and the hydrostatic pressure of water, which increases central blood volume and venous return (Baggish & Levine, 2020). This chronic volume overload during diastole increases wall stress, stimulating eccentric hypertrophy—a proportional increase in chamber volume and wall mass (Weiner & Baggish, 2012). Our results, showing significant increases in LVEDd, LVEDV, and LV mass without a concomitant increase in wall thickness (LVEDPWT), perfectly align with this eccentric remodeling pattern. This finding is crucial as it demonstrates that the plastic response of the myocardium to endurance training is already present in pre-adolescence, challenging the notion that such adaptations are exclusive to mature athletes (Magalhaes, et al., 2015). Functionally, the significant increase in stroke volume is a direct and expected consequence of the structural remodeling (Lund, et al., 2007). A larger left ventricular chamber allows for a greater end-diastolic volume, which, by the Frank-Starling mechanism, results in a more forceful contraction and a higher volume of blood ejected per beat (Pluim et al., 2000; Mazzilli & Bar-Or, 2006). The improvement in estimated VO_2max further supports this, as a higher stroke volume is a primary determinant of maximal cardiac output and thus aerobic capacity. The absence of significant change in ejection fraction is also characteristic of a physiological adaptation; in athlete's heart, the enhanced pumping capacity comes from a larger chamber size, not an increase in the fractional shortening of the muscle fibers, which remains normal or may even slightly decrease. It is noteworthy that while within-group changes in the Exer group were robust, the between-group comparisons at post-test did not always reach statistical significance. This is a common challenge in short-term training studies with small sample sizes and can be attributed to the high degree of individual variability in cardiac adaptation and the relatively short intervention period. The significant change in LVEF between groups should be interpreted with caution, as the clinical relevance of a change within the normal range is likely limited.

Limitations:

This study has several limitations. The sample size was small, limiting statistical power for some between-group comparisons. The participants were all boys from a specific geographic location, which may affect generalizability. Furthermore, the use of a step test to estimate VO_2max, while practical, is less accurate than direct gas analysis. Future research should employ larger, more diverse cohorts, include female participants, and utilize longer follow-up periods to track the longitudinal development of these cardiac adaptations.

Conclusion

In conclusion, this study provides empirical evidence that a 12-week swimming training program is a sufficient stimulus to initiate significant cardiac remodeling in pre-adolescent boys. The observed pattern of eccentric hypertrophy, coupled with an enhanced stroke volume, mirrors the classic "athlete's heart" phenotype seen in adult endurance athletes. These findings underscore the remarkable plasticity of the pre-adolescent cardiovascular system and highlight the importance of introducing regular, structured aerobic exercise, such as swimming, during childhood to promote optimal cardiovascular development and long-term health. From a public health perspective, these adaptations form a foundational basis for enhanced cardiovascular efficiency and aerobic fitness, potentially setting a trajectory for a healthier life.

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S.J.F, wrote the paper and drafted the manuscript; R.V, critically reviewed the manuscript; A.A, and A.H.F, collected the data and analysis.

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Conflicts of Interest:

The author declares no conflict of interest.

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