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THE EFFECT OF CROSSFIT TRAINING ON THE CENTRAL HEMODYNAMIC PROFILE IN YOUTH WRESTLERS

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Wpływ treningu Crossfit na centralny profil hemodynamiczny u młodych zapaśników

Streszczenie

W celu określenia skuteczności opracowanego programu treningu Crossfit na centralny profil hemodynamiczny u młodych zapaśników, w eksperymencie pedagogicznym uczestniczyło 48 zapaśników w trakcie etapu specjalistycznego treningu podstawowego. Średni wiek badanych zapaśników wynosił $14,5 \pm 0,3$ roku. Grupa Crossfit składała się z 24 zapaśników uczestniczących w treningu Crossfit, którego celem było poprawienie funkcjonalnego stanu układu sercowo-naczyniowego. Natomiast grupa kontrolna składała się z 24 zapaśników, którzy realizowali standardowy program. Zapaśnicy uczestniczyli w treningach Crossfit trzy razy w tygodniu przez godzinę przez sześć miesięcy, w ramach przygotowania fizycznego. Po interwencji Crossfit zaobserwowano znaczący wzrost w grupie głównej: objętości wyrzutowej serca o $12,98$ ml/uderzenie ($p < 0,001$); pojemności minutowej serca o $0,92$ l/min; wskaźnika wyrzutowego o $0,43$ ml/uderzenie/ m^2 ($p < 0,001$); mocy lewej komory serca o $1,05$ W ($p < 0,01$). Porównanie wskaźników hemodynamiki układu sercowo-naczyniowego po treningu wykazało obecność istotnych różnic między badanymi

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grupami ($p < 0,05-0,001$). Przewaga była widoczna u zapaśników z grupy głównej we wszystkich wskaźnikach w porównaniu z zapaśnikami z grupy porównawczej. Wartość objętości wyrzutowej była lepsza u zapaśników z grupy głównej w porównaniu z grupą kontrolną o 10,26 ml ($p < 0,01$), pojemność minutowa serca – o 0,62 l/min ($p < 0,05$). Wyniki wskazują, że włączenie wielofunkcyjnych metod Crossfit o wysokiej intensywności podczas eksperymentu pedagogicznego skutkowało pozytywną dynamiką poziomu przygotowania zapaśników podczas etapu specjalistycznego treningu podstawowego.

Słowa kluczowe: funkcja sercowo-naczyniowa, przygotowanie, ćwiczenia Crossfit, sportowcy, hemodynamika centralna.

Abstract

To determine the effectiveness of CrossFit training on the central hemodynamic profile in youth wrestlers, intervention study was attended by 48 wrestlers during the specialized foundational training stage. The average age of the studied wrestlers was 14.5 ± 0.3 years. The CrossFit group comprised 24 wrestlers participating in the CrossFit training aimed at enhancing functional state of the cardiovascular system. Meanwhile, the control group comprised 24 wrestlers following the standard program. Wrestlers engaged in CrossFit workouts three times a week for one hour over a six-month period as part of their physical conditioning. After CrossFit intervention the significant increase was observed in the CrossFit group by actual stroke volume by 12.98 ml/beat ($p < 0.001$); cardiac output by 0.92 l/min; stroke index by 0.43 ml/beat/m² ($p < 0.001$); left ventricular power by 1.05 W ($p < 0.01$). Comparison of the post-training indicators of the rheography cardiovascular system showed the presence of probable differences between the studied groups ($p < 0.05-0.001$). Advantages were observed in the wrestlers of the CrossFit group by all indicators compared to the wrestlers of the comparison group. The stroke volume value was higher in the wrestlers from the main group compared to the control group by 10.26 ml ($p < 0.01$), while cardiac output was higher by 0.62 l/min ($p < 0.05$). The results have indicated that the incorporation of high-intensity multifunctional CrossFit methods during the study resulted in positive dynamics in the preparedness level of wrestlers during the specialized foundational training stage.

Keywords: cardiovascular function, preparedness, CrossFit regimen, athletes, central hemodynamics.

Introduction

Contemporary wrestling imposes rigorous requirements on multiple facets of an athlete's training, encompassing functional conditioning and the enhancement of specific physical skills. These factors significantly impact subsequent success in technical and tactical training for athletes (Sazonov, 2017). While existing research primarily delves into the technical and tactical actions of wrestlers (Cieśliński et al., 2021; Demirkan et al., 2014), the ongoing challenge of improving the cardiovascular functional state during the initial basic training stage for youth wrestlers remains crucial and requires attention.

Modern pedagogical monitoring of athletes' readiness allows for timely implementation of necessary corrective interventions aimed at ensuring maximum

compliance of monitored indicators with their model values. However, pedagogical control should be carried out during training sessions at various stages of preparation (Chaabene et al., 2017; Cieśliński et al., 2021).

Cardiovascular health can be a key factor in achieving higher performance levels in wrestlers. Wrestling requires a combination of aerobic and anaerobic endurance. The cardiovascular system of wrestlers adapts to sustain prolonged periods of moderate activity during training sessions and sudden bursts of high-intensity effort during matches (Voronyi et al., 2020).

Theoretical analysis of contemporary publications (Zadorozhna, 2015; Monks, 2017) has indicated that the cardiovascular functional state has a significant impact on the performance of competitive activities for wrestlers. Additionally, it is a determining factor in ensuring physical performance and adaptive capabilities of athletes to physical loads (Voronyi et al., 2020).

During the specialized basic preparation stage, means are widely employed to significantly enhance the athlete's functional potential without the application of extensive loads and training work. These means closely resemble the nature of competitive activities (Voronyi et al., 2020).

In numerous works, e.g. by Pityn, 2015; Korobeynikov et al., 2020, it has been demonstrated that sports loads lead to the disturbance of homeostasis. The adaptation of the organism to muscular activity involves both immediate and prolonged adaptive processes, mobilization of energy resources, transportation of oxygen and oxidation substrates, energy metabolism reactions, and the creation of conditions for the plastic support of muscle work.

Simultaneously, Franchini et al. (2019) recommend integrating supplementary high-intensity interval training into the regular training regimen to improve wrestlers' anaerobic performance.

Experts emphasize the importance of individualizing and differentiating methods and approaches in sports training. Additionally, there is a focus on developing new strategies to enhance the effectiveness of training processes for qualified athletes during the specialized basic preparation stage. This stage is characterized by the orientation of the training process toward maximizing the realization of an athlete's potential in competitive activities.

In the context of wrestling, high-intensity functional training, such as CrossFit, has emerged as a potential method to enhance performance by improving the anaerobic energy supply system. It should be noted that many experts incorporate models of high-intensity interval training into their practice, performed over a short period, contributing to the enhancement of the anaerobic system (Gierczuk et al., 2018; Maia, 2019).

However, despite the documented benefits in terms of power and dynamic balance (Özbay et al., 2019; Voronyi et al., 2020), the impact of such training on the central hemodynamic profile of young wrestlers remains insufficiently ex-

plored. Central hemodynamics, which includes parameters such as cardiac output, stroke volume, and heart rate, plays a critical role in determining cardiovascular efficiency during both training and competitive performance.

Wrestling places significant cardiovascular demands on athletes due to its high-intensity and intermittent nature. This can result in elevated strain on the cardiovascular system, potentially affecting recovery and long-term health. While CrossFit training has been shown to improve functional preparedness and reduce recovery times (Caloglu & Yüksel, 2020), its specific effects on central hemodynamic parameters in young wrestlers are not well understood. Understanding these effects is crucial, as optimizing the central hemodynamic profile could lead to improved endurance, enhanced training efficiency, and better overall performance.

Wrestlers are encouraged to engage in individual CrossFit training to uphold their athletic performance and mitigate the decline in performance during the transitional phases of the annual training cycle. CrossFit workouts are considered a favorable alternative due to their practicality and the flexibility they offer in terms of time and space (Klimek, 2018; Maia, 2019).

There are also individual publications that emphasize the positive impact of individual CrossFit workouts among wrestlers during the transitional period of the training cycle and the rest period between competitions to maintain productivity and sports form (Caloglu & Yüksel, 2020).

The current gap in research highlights the need to investigate how CrossFit training influences the central hemodynamic profile of young wrestlers. This study seeks to fill this gap by exploring the effects of CrossFit on central hemodynamic parameters, providing a foundation for more targeted and effective training interventions for young wrestlers.

So, the aim of the study is to determine the effectiveness of CrossFit training on the central hemodynamic profile in youth wrestlers.

Material and Methods

Participants

This study was approved by the Bioethics Committee for Clinical Research and conducted according to the Declaration of Helsinki. All participants gave their written consent to research and were informed about the purpose and test procedures and about the possibility of withdrawal of consent at any time for any reason.

The intervention study was attended by 48 wrestlers during the specialized foundational training stage. The average age of the studied wrestlers was 14.5

± 0.3 years. The CrossFit group comprised 24 wrestlers participating in the CrossFit program aimed at enhancing functional state of the cardiovascular system. Meanwhile, the control group comprised 24 wrestlers following the standard program at Children's and Youth School No. 16 (Zaporizhzhia).

Measurement Methods

Using impedance cardiography, the following parameters were evaluated: stroke volume (ml/beat), cardiac output (l/min), stroke index (ml/beat/m²), systemic vascular resistance (dyn·s/cm⁵), left ventricular work (m/beat), left ventricular power (W). Impedance cardiography parameters were assessed with the electrocardiographic complex KARDIOLAB (Scientific and Technological Centre of Radio-Electronic Medical Equipment and Technologies XAI-Medica of the National Aerospace University, Kharkiv, Ukraine, registration certificate number 6037/2007, conformity certificate number UA-MI/2p-2765-2009). The bioimpedance operator was thoroughly trained and had extensive experience in performing such measurements. This ensured the reliability and accuracy of the data collected during the study.

Statistical Analysis

The recorded data (mean and standard error of the mean) underwent analysis using Statistica for Windows (version 8.00). Prior to concluding the analysis, we assessed the data for normality, homogeneity, and the presence of extreme scores. The distribution of recorded data was tested using the Shapiro-Wilk test. This preliminary analysis was conducted before parametric calculations for the analysis of differences. A dependent t-test was employed to examine cardiovascular parameters within a group between baseline and post-training. Independent sample t-tests were utilized to compare post-training cardiovascular parameters between two groups of wrestlers. A $p < 0.05$ was considered statistically significant.

Study Design

When designing the program, we considered the initial functional capabilities of the CrossFit group's wrestlers, which formed the basis for determining the volume and intensity of physical activity. The program adhered to the principles of gradually increasing physical activity and maintaining the unity of general, special, and technical training while considering long-term biological adaptation of body systems to external training stimuli. The wrestlers engaged in CrossFit workouts three times a week for one hour over a six-month period as part of their physical conditioning.

The structure and content of CrossFit sessions for wrestlers with different levels of physical fitness is presented in Table 1.

Table 1

Structure and content of CrossFit sessions for wrestlers with different levels of physical fitness

Levels of physical fitness	General preparatory stage			Special preparatory stage		
	training duration	intensity	training mode	training duration	intensity	training mode
low level	50 min	50-60 % of the reserve heart rate	AMRAP CHIPPER	60 min	60-70 % of the reserve heart rate	AMRAP CHIPPER
below average	55 min	60-70 % of the reserve heart rate	AFAP EMOM	60 min	70-80 % of the reserve heart rate	AFAP EMOM
average	60 min	70-80 % of the reserve heart rate	TABATA	60 min	80-85 % of the reserve heart rate	TABATA

For wrestlers exhibiting lower physical fitness, the general preparatory stage involved 50-minute CrossFit sessions. Those with below-average fitness levels had sessions lasting 55 minutes, while wrestlers with average fitness trained for 60 minutes. During the special preparatory stage, the duration for all groups was standardized to 60 minutes. The intensity of the training for wrestlers with low fitness during the general preparatory stage was set at 50-60% of the heart rate reserve (determined by the Karvonen formula). For wrestlers with below-average fitness, the intensity was 60-70%, and for those with average fitness, it was 70-80%. In the special preparatory stage, the intensity levels were adjusted to 60-70% for low fitness, 70-80% for below-average fitness, and 80-85% for average fitness.

The proportion of CrossFit exercises varied according to the wrestlers' physical fitness levels and stages of preparation. During the general preparatory stage, wrestlers with a low fitness level performed 50% monostructural exercises, 30% gymnastics, 10% weightlifting, and 10% stretching. For those with below-average fitness, the distribution was 40% monostructural, 40% gymnastics, 10% weightlifting, and 10% stretching. Wrestlers with an average fitness level had a regimen of 30% monostructural, 40% gymnastics, 20% weightlifting, and 10% stretching. In the special preparatory stage, the breakdown for wrestlers with low fitness was 30% monostructural, 30% gymnastics, 30% weightlifting, and 10% stretching. For those with below-average fitness, it was 20% monostructural, 40% gymnastics, 30% weightlifting, and 10% stretching. Finally, wrestlers with average fitness levels had a routine consisting of 25% monostructural, 30% gymnastics, 40% weightlifting, and 5% stretching.

Wrestlers with lower physical fitness levels were engaged in both AMRAP and CHIPPER regimens throughout both the general preparatory and special preparatory stages of their training. For those with a below-average level, the AFAP and EMOM regimens were applied, and for those with an average level, a highly intensive TABATA regimen was used. These choices were influenced by the peculiarities of cardiovascular system and the necessity to improve physical fitness.

Results

The results of the evaluation of the impact of the developed experimental program on the functional state of the cardiovascular system in wrestlers are detailed in Table 2.

Table 2
Changes in cardiovascular system function indicators ($M \pm m$) between wrestlers in the CrossFit and control groups during the specialized foundational training stage

		CrossFit group (n=24)			Control group (n=24)		
		Beginning	After 6 months of training	p	Beginning	After 6 months of training	p
Stroke Volume, ml/beat	Actual	48.33±2.11	61.31±2.27 **	<0.001	48.08±1.88	51.05±1.81	>0.05
	% of predicted	69.58±3.41	93.37±2.37 ***	<0.001	68.99±2.44	72.98±2.54	>0.05
Cardiac Output, l/min		3.18±0.16	4.10±0.15 *	<0.001	3.21±0.13	3.48±0.14	>0.05
Stroke Index, ml/beat/m ²		1.82±0.08	2.25±0.07 **	<0.001	1.80±0.06	1.82±0.07	>0.05
Systemic Vascular Resistance, dyne·s·cm ⁵	Actual	1707.44±48.56	1689.76±47.53	>0.05	1709.09±53.17	1718.00±52.18	>0.05
	% of predicted	97.81±1.52	96.76±1.44	>0.05	99.36±3.44	99.92±3.18	>0.05
Left Ventricular Power, W	Actual	1.97±0.07	3.02±0.08 ***	<0.001	1.95±0.06	2.12±0.09	>0.05
	% of predicted	74.54±2.81	90.66±2.21 **	<0.001	72.85±2.77	77.88±2.55	>0.05

According to the table, both dependent and independent t-test analyses demonstrated a significant enhancement in the cardiovascular function of the CrossFit group. Following the CrossFit intervention, notable increases were observed in the CrossFit group's actual stroke volume by 12.98 ml/beat ($p < 0.001$), cardiac output by 0.92 l/min, stroke index by 0.43 ml/beat/m² ($p < 0.001$) and left ventricular power by 1.05 W ($p < 0.01$). Predicted values for stroke volume and

left ventricular power also showed significant improvements in the CrossFit group, increasing by 23.79% ($p < 0.001$) and 16.12% ($p < 0.001$), respectively. On the positive side, it is also necessary to note the increase in the minute volume of blood flow mainly due to the increase in the stroke volume and stable values of the total peripheral resistance of the vessels: in the CrossFit group systemic vascular resistance decreased by 20 $\text{dyne}\cdot\text{s}\cdot\text{cm}^5$ ($p > 0.05$).

Positively, it is important to highlight the increase in minute blood flow volume, primarily attributed to the rise in stroke volume, alongside stable total peripheral resistance values in vessels. Specifically, in the CrossFit group, systemic vascular resistance decreased by 20 $\text{dyne}\cdot\text{s}\cdot\text{cm}^5$ ($p > 0.05$).

In the control group of wrestlers, there was a notable yet statistically non-significant trend towards improvement in the functional indicators of the cardiovascular system. Specifically, there was a modest increase in actual stroke volume by 2.97 ml/beat ($p > 0.05$), cardiac output by 0.27 l/min, stroke index by 0.02 ml/beat/ m^2 ($p > 0.05$) and left ventricular power by 0.17 W ($p > 0.05$). Predicted values for stroke volume and left ventricular power in the control group also exhibited improvements, albeit not statistically significant, with increases of 3.99% ($p > 0.05$) and 5.03% ($p > 0.05$), respectively.

A comparison of central hemodynamic parameters between groups at the end of the study is presented in Table 3.

Table 3

Comparison in cardiovascular system function indicators ($M \pm m$) between CrossFit and control group wrestlers after 6 months of training

		Groups		p
		CrossFit group	Control group	
Stroke Volume, ml/beat	Actual	61.31±2.27	51.05±1.81	<0.01
	% of predicted	93.37±2.37	72.98±2.54	<0.001
Cardiac Output, l/min		4.10±0.15	3.48±0.14	<0.05
Stroke Index, ml/beat/ m^2		2.25±0.07	1.82±0.07	<0.01
Systemic Vascular Resistance, $\text{dyne}\cdot\text{s}\cdot\text{cm}^5$	Actual	1689.76±47.53	1718.00±52.18	>0.05
	% of predicted	96.76±1.44	99.92±3.18	>0.05
Left Ventricular Power, W	Actual	3.02±0.08	2.12±0.09	<0.001
	% of predicted	90.66±2.21	77.88±2.55	<0.001

Comparative analysis of post-training rheography indicators of the cardiovascular system revealed statistically significant differences between the studied groups ($p < 0.05$ -0.001). The wrestlers in the CrossFit group demonstrated su-

perior performance across all indicators compared to those in the control group. Specifically, stroke volume was significantly higher in the CrossFit group wrestlers by 10.26 ml ($p<0.01$), cardiac output by 0.62 l/min ($p<0.05$), stroke index by 0.43 ml/beat/m² ($p<0.01$) and left ventricular power by 0.90 W ($p<0.001$). Relative indicators for stroke volume and left ventricular power were also notably greater in the athletes of the CrossFit group, showing increases of 20.39% ($p<0.001$) and 12.78% ($p<0.01$), respectively.

Discussion

The primary findings of this study demonstrate that CrossFit training significantly improves the central hemodynamic profile in young wrestlers. Specifically, we observed enhancements in parameters such as cardiac output and stroke volume, which are critical indicators of cardiovascular efficiency. These changes likely result from the combined effects of sustained high-intensity efforts and dynamic recovery periods inherent to CrossFit training, which stimulate both myocardial adaptation and vascular responsiveness.

From an athletic perspective, these adaptations hold significant importance. Enhanced cardiac output and stroke volume can improve oxygen delivery to working muscles, thereby supporting greater endurance and recovery during high-intensity bouts. For wrestlers, this translates into sustained performance in competitive settings characterized by intermittent bursts of maximal effort. From a health-related standpoint, such improvements may reduce cardiovascular strain during training and competitions, potentially lowering the risk of exercise-induced cardiovascular complications.

These findings emphasize the dual role of high-intensity functional training in optimizing athletic performance and promoting cardiovascular health, offering a promising approach for the structured development of young athletes.

Specifically, our results show statistically significant increases in stroke volume, cardiac output, stroke index, and left ventricular power in the CrossFit group compared to the control group. These findings indicate enhanced cardiovascular efficiency, which is critical for athletic performance and overall cardiovascular health.

The observed 10.26 ml increase in stroke volume ($p<0.01$) and 0.62 l/min increase in cardiac output ($p<0.05$) suggest that CrossFit training enhances the heart's ability to pump blood more effectively per beat and per minute. Additionally, a 0.43 ml/beat/m² increase in stroke index ($p<0.01$) and a 0.90 W rise in left ventricular power ($p<0.001$) further support the notion that high-intensity functional training stimulates myocardial adaptation, likely through a combination of sustained high-intensity efforts and dynamic recovery periods.

The functional state of the cardiovascular system in wrestlers is a complex interplay of various physiological adaptations influenced by their rigorous training, intense physical activity, and overall health. Wrestlers often exhibit increased cardiac output, the volume of blood pumped by the heart per minute. This is partly due to elevated stroke volume, the amount of blood ejected by the heart in each contraction. These adaptations support the increased demand for oxygen and nutrients during intense physical exertion.

Thus, summarizing the above-mentioned features of applying CrossFit functional training to enhance athletes' physical preparedness, the following conclusions can be drawn:

- the issue of scientific justification and development of training programs with an optimal ratio of physical training means requires further refinement, considering the specifics of the chosen sport and individual athlete characteristics;
- among the means of physical training, it is advisable to frequently use those that are structurally as close as possible to combat practice, varying the load by changing volume and intensity;
- contemporary challenges in wrestlers' physical preparation determine the modernization of CrossFit means, incorporating aerobic and anaerobic exercises performed at high intensity;
- CrossFit prioritizes exercises of moderate and high intensity, promoting the balanced development of athletes' physical attributes such as endurance, strength, flexibility, speed, and coordination;
- most experts identify the positive characteristics of CrossFit as accessibility, flexibility, diversity, quick results, functionality, the possibility of individual and group sessions, and time efficiency.

There are individual publications providing scientifically grounded data on the potential use of the CrossFit exercise system in wrestlers' training processes, which requires further study and analysis (Caloglu & Yüksel, 2020; Maia, 2019).

Our research findings support the assertions of researchers (Sazonov, 2017; Voronyi et al., 2020), emphasizing the critical importance of contemporary high-performance sports standards and the individual characteristics of wrestlers, particularly their functional state and level of physical fitness.

This underscores the imperative to revamp current training programs for Greco-Roman wrestlers during the specialized foundational training stage.

The results of our research confirm the views of the researchers such as Caloglu & Yüksel (2020), Gierczuk & Sadowski (2021), Lisenchuk et al. (2019), Omelchenko et al. (2020), Voronyi et al. (2020), Odynets et al. (2024). In the development of new training programs for wrestlers, it is crucial to consider modern elite sports standards and the individual characteristics of wrestlers, including their functional state and level of physical preparedness.

Our research is also supplemented by the findings of Dehnou et al. (2020) regarding strength-focused exercises tailored to varying volumes and intensities according to physical fitness levels, and findings from Özbay et al. (2019) on the dynamics of functional indicators of key physiological systems (cardiovascular and respiratory) during CrossFit training among wrestlers.

Understanding the hemodynamics of wrestlers is essential for optimizing training programs, enhancing performance, and safeguarding the overall cardiovascular health of athletes. Regular health assessments, individualized training plans, and a focus on recovery contribute to a comprehensive approach to managing hemodynamics in the context of wrestling. Factors such as age, fitness level, and previous health conditions should be considered when developing personalized cardiovascular training programs.

The findings of Akcan and Olmez (2024) demonstrate that a four-week program of high-intensity sprint training, conducted twice weekly, significantly enhances both aerobic and anaerobic power in athletes. These results provide valuable insights into the optimization of high-intensity training protocols, particularly regarding rest interval duration. In the future, our research will focus on investigating the effects of training-induced changes with different rest intervals in wrestlers, aiming to enhance our understanding of how rest interval duration influences physiological adaptations and performance outcomes.

This study has several limitations that should be considered when interpreting the results. First, the focus on young athletes restricts the generalizability of the findings to other age groups or populations with different training backgrounds. Additionally, while the study provides valuable insights into the hemodynamic adaptations induced by training, it lacks direct performance measures that could establish whether these changes translate into improved exercise capacity during competitive activities. Furthermore, potential variations in biological age among participants may have influenced the observed outcomes, given the physiological differences that can exist even within a narrow age range. These factors highlight the need for future studies to include diverse age groups, incorporate comprehensive performance metrics, and account for individual developmental differences to enhance the applicability of the findings.

Conclusions

The results have indicated that the incorporation of high-intensity multi-functional CrossFit methods during the intervention study resulted in positive dynamics in cardiovascular functional state of wrestlers during the specialized foundational training stage.

STATEMENT OF ETHICS

This study was conducted in accordance with the World Medical Association Declaration of Helsinki. The study protocol was reviewed and approved by the Ethical Committee of Khortytsia National Academy, Zaporizhzhia, Ukraine (№ 847/OD, April 08, 2023). All participants provided written informed consent to participate in this study.

DECLARATION OF CONFLICTING INTERESTS

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