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The Effect of a Training Program Using High-Intensity Interval Training on Several Physiological Variables Among Young Wrestlers

Taha Ramadhan Taha

[1] Department of Physical Education and Sports Science, College of Education, University of Zakho- Kurdistan; taha.taha@visitor.uoz.edu.krd

* Corresponding author: Region – Iraq; taha.taha@visitor.uoz.edu.krd

ORCID ID: https://orcid.org/0009-0005-0568-4688

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This study aimed to examine the effects of a high-intensity interval training (HIIT) program on the physiological variables of young wrestlers. The significance of this study lies in its potential to identify effective training strategies to enhance the physiological capabilities of wrestlers, which are crucial for optimal performance. Despite the potential benefits of HIIT, research on its effects on young wrestlers is limited. The study utilized a pre- and post-test experimental design involving 14 young wrestlers from the Zakho Sports Club who were divided into control and experimental groups, each comprising seven wrestlers. The experimental group underwent a 9-week HIIT program, whereas the control group underwent a traditional training program. The physiological variables assessed included blood pressure, heart rate, lactic acid concentration, and anaerobic and aerobic powers. The results indicated significant improvements in the experimental group in terms of resting heart rate, heart rate after effort, lactic acid concentration, and aerobic power but not in blood pressure or anaerobic power. These findings confirm that HIIT can effectively enhance the physiological efficiency of young athletes and provide valuable methodological contributions to training programs for young wrestlers. This research demonstrates that HIIT effectively enhances athletes' physiological capacity and technical performance. This conclusion validates the idea that customized high-intensity and interval-based training can lead to substantial and advantageous physiological improvements in young wrestlers.

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Public Interest Statement

This study addresses a significant gap in sports science by investigating the effects of high-intensity interval training (HIIT) on young wrestlers, a population with limited research. These findings demonstrate HIIT's effectiveness of HIIT in enhancing critical physiological variables, such as heart rate, lactic acid concentration, and anaerobic and aerobic power. This study provides valuable insights for trainers and athletes, highlighting HIIT's potential of HIIT to optimize training programs and improve athletic performance in young wrestlers.

Introduction

Wrestling is a competitive sport that requires a variety of physical and physiological demands. This sport involves a set of combat techniques aimed at bringing the opponent down to the ground. Given the nature of this sport, wrestlers need high levels of muscular strength, power, endurance, agility, balance, and coordination, in addition to good aerobic and anaerobic capabilities (Mirzaei et al., 2009).

Previous research has shown that a set of physiological variables significantly affects the performance of wrestlers, the most important of which are maximal oxygen uptake (VO2max), anaerobic power, heart rate, blood lactate levels, and body composition (Barbas et al., 2011). Maximal oxygen uptake (VO2max) is considered to be one of the most important physiological indicators related to wrestling performance, as it reflects the capacity of the cardiorespiratory system to deliver oxygen to the working muscles and the ability of these muscles to utilize oxygen (Sterkowicz et al., 2013). In addition, anaerobic power plays an important role in wrestling, as this sport requires short periods of high-intensity performance interspersed with short recovery periods (Tønnessen et al., 2011).

While it is clear that these physiological variables play a significant role in wrestler performance, there is still much to be discovered in terms of the impact of effective training methods on improving these characteristics in young wrestlers. One training approach that has shown promising outcomes in enhancing physiological variables in athletes is high-intensity interval training (HIIT) (Buchheit & Laursen, 2013). Nevertheless, there is a lack of studies that specifically investigate the effects of HIIT on the physiological profiles of young wrestlers.

Therefore, the current study aimed to fill this research gap by investigating the effect of a training program using high-intensity interval training on several physiological variables in a sample of young wrestlers. The specific objectives of the study were: 1) to develop a training program using high-intensity interval training, 2) to reveal the statistical significance of the differences in physiological variables between the pre-test and post-test of the experimental and control groups, and 3) to investigate the extent of the effect of the training program on the selected physiological variables.

Considering these physical and physiological requirements, developing effective training programs to improve these variables in young wrestlers is of paramount importance. Among the training methods that have shown effectiveness in improving physiological variables in athletes is high-intensity interval training (HIIT) (Buchheit & Laursen, 2013). This training approach is characterized by alternating short periods of high-intensity exercise with short- or low-intensity recovery periods, leading to stimulation of desired physiological adaptations (Gibala & McGee, 2008).

The research objectives of this study are multifaceted and contribute significantly to the field of sports science and physical training. First, it sought to develop a training program specifically utilizing high-intensity interval training (HIIT). This approach was intended to optimize physical performance and physiological adaptations in participants. Second, the research aimed to reveal the statistical significance of the differences in various physiological variables between the pre-test and post-test measurements of both the experimental and control groups. This objective is crucial for understanding the effectiveness of the HIIT program compared with traditional training methods. Finally, the study intends to investigate the extent of the effect of the training program on several physiological variables, providing a comprehensive analysis of its impact on participants' physical health and performance. Through these objectives, this research aspires to offer valuable insights and evidence-based recommendations for enhancing athletic training protocols.

Literature Review

Wrestling is characterized by intense physical demands that require athletes to possess a robust combination of strength, power, and endurance (Franchini et al., 2011). To optimize the performance and ensure the continued success of young wrestlers, it is essential to explore effective training strategies. High-Intensity Interval Training (HIIT) has gained increasing attention in sports science. HIIT involves repeated bouts of high-intensity exercise interspersed with periods of rest or low-intensity exercise (Gibala & McGee, 2008).

HIIT training elicits a wide range of physiological adaptations including improved cardiovascular fitness, increased muscle strength and power, and enhanced metabolic efficiency (Gibala & McGee, 2008; Laursen & Jenkins, 2002). Given the intermittent nature of wrestling, HIIT may be particularly suitable for this type of sport.

Several studies have explored the effects of HIIT on various physiological variables in athletes including wrestlers. Franchini et al. (2013) found that a 12-week HIIT program significantly improved VO2max, time to exhaustion, and blood lactate concentration in Brazilian jiu-jitsu athletes. Amtmann et al. (2008) reported similar findings with a 6-week HIIT program for collegiate wrestlers, showing significant increases in VO2max, peak power output, and improved body composition.

HIIT elicits a wide range of physiological adaptations including improved cardiovascular fitness, increased muscle strength and power, and enhanced metabolic efficiency (Gibala & McGee, 2008; Laursen & Jenkins, 2002).

Alcaraz et al. (2008) demonstrated that a 6-week HIIT program improved power output, muscle strength, and endurance in elite junior wrestlers. Buchheit and Laursen (2013) reviewed the application of HIIT in various sports and highlighted its benefits in improving both aerobic and anaerobic fitness. They emphasized tailoring HIIT protocols to the specific demands of the sport and the needs of individual athletes.

Bazyler et al. (2017) and Mirzaei et al. (2009) also found that HIIT can enhance vertical jump height, isometric mid-thigh pull force, peak power output, VO2max, and time to exhaustion in youth- and national-level wrestlers, respectively. Chiodo et al. (2011) supported these findings by showing improvements in anaerobic power output and technical skills in elite adolescent wrestlers.

Applying HIIT to wrestling involves incorporating high-intensity intervals into wrestlers' conditioning programs to enhance their performance and physiological capabilities. Barbas et al. (2011) noted significant increases in VO2max, blood lactate concentrations, muscle glycogen content, and improved recovery kinetics following a 6-week HIIT program in Greek national-level wrestlers. Yoon (2002) and Horswill (1992) emphasized the importance of a well-rounded fitness profile and the potential benefits of incorporating HIIT into wrestling training regimens.

Callan et al. (2000) and Kraemer et al. (2001) showed that a 12-week training program with an HIIT component improved VO2max, time to exhaustion, upper-body muscular endurance, and technical skills in collegiate and elite wrestlers. Chaabene et al. (2015) conducted a systematic review and meta-analysis, concluding that HIIT is effective for improving aerobic fitness, anaerobic power, and muscle strength in combat sports athletes.

Although HIIT offers numerous benefits, it also has potential drawbacks, such as a higher risk of injury if not properly supervised. The demanding nature of HIIT may not be suitable for all athletes, particularly those with preexisting conditions or lower fitness levels.

In summary, existing literature suggests that integrating HIIT into training programs for young wrestlers can significantly impact their physiological variables and overall performance. Hoffman et al. (2009) and Utter et al. (2002) demonstrated significant improvements in VO2max, time to exhaustion, upper-body muscular endurance, and anaerobic power output in collegiate and elite junior wrestlers following a 4-week and 12-week HIIT program, respectively. HIIT effectively enhances aerobic and anaerobic capacities, muscular strength and power, and metabolic efficiency, which are essential for sports success. These findings highlight the potential of HIIT as a valuable training approach to optimize the physical and physiological profiles of young wrestlers, contributing to their continued development and competitive success.

Recent research has supported these conclusions. McHaffie et al. (2022) and Zhou et al. (2019) confirmed significant increases in VO2max, time to exhaustion, and technical performance in national-level wrestlers following HIIT programmes. Afonso et al. (2021) and Cortesi et al. (2020) provided further evidence of HIIT's effectiveness in improving physiological and performance variables in elite wrestlers.

These consistent findings across multiple studies and populations suggest that HIIT can be a valuable training approach to enhance the overall physical and technical capabilities of young wrestlers.

Materials and Methods

I used an experimental method, as it is appropriate for the nature and problems of the research. I adopted an experimental design with a pre-test and post-test, as the use of the appropriate experimental design is important in every experimental research because it helps to obtain answers to the research hypotheses, assists in experimental control, and helps prepare the means to reach the required results, as shown in Table 1(Creswell, 2014).

Table 1. Experimental design of the research

Group	Pre-test	Independent Variable	Post-test
Experimental	Physiological Variables	Training Program	Physiological Variables
Control			

The study community was purposefully selected from the wrestlers (Zakho Sports Club) in the city of Zakho, with a total of (14) young wrestlers. The study sample was distributed using a simple random method, as they were divided into two groups (control and experimental) with (seven) wrestlers in each group.

The study variables were determined with clear distinctions between independent and dependent variables. The independent variables comprised two groups: the control group and the experimental group. By contrast, the dependent variables encompass various physiological variables, which are the primary focus of the study's measurements and analyses. As outlined in Table 2, despite the random distribution of the research groups, tests for homogeneity and equivalence were conducted across several variables that might influence the dependent variables, specifically the physiological tests. This was done to ensure that any observed effects could be attributed to the independent variable, which in this context was the training program. By establishing this equivalence, this study aims to provide a robust analysis of the impact of the training program on physiological variables.

Table 2. Normal distribution of the research groups in variables of weight, height, age, and training age

Variables	Unit of Measurement	Group	d.f	Kolmogorov-Smirnov	Sig	Significance
Weight	kg	Experimental	7	0.1750	0.200	Not Significant
		Control	7	0.2040	0.200	
Height	cm	Experimental	7	0.1780	0.200	Not Significant
		Control	7	0.1450	0.200	
Age	Years	Experimental	7	0.2870	0.0840	Not Significant
		Control	7	0.2940	0.0970	
Training Age	Years	Experimental	7	0.3120	0.0670	Not Significant
		Control	7	0.2560	0.1820	

Table 2 shows that the probability values from the Kolmogorov-Smirnov test were greater than (0.05), suggesting that the research sample in the first and second experimental groups followed a normal distribution with respect to weight, height, age, and training age.

Table 3. Homogeneity and equivalence of the variables (weight, height, age, training age) between the research groups

Variables	Unit of Measurement	Group	M ± SD	Skewness	Kurtosis	t. test	Sig	Significance
Weight	kg	Experimental	67.1429 ± 8.19407	0.43	-0.92	0.213	0.8350	Not Significant
		Control	66.1429 ± 9.29926	0.54	-1.52			
Height	cm	Experimental	175.428 ± 6.34710	0.35	-0.74	0.835	0.4200	Not Significant
		Control	172.857 ± 5.11301	-0.052	-0.45			
Age	Months	Experimental	216.285 ± 60.1711	0.842	-0.67	0.229	0.8230	Not Significant
		Control	214.428 ± 51.7135	0.912	1.084			
Training Age	Years	Experimental	11.1429 ± 6.28301	0.678	-0.05	0.979	0.3470	Not Significant
		Control	8.4286 ± 3.77964	0.183	1.23			

Table 3 shows that the study succeeded in achieving both homogeneity and equivalence among the participants. In terms of homogeneity, the skewness values for the variables of weight, height, age, and training age were confined within the range of ±1, whereas the kurtosis values were within ±2, which suggests that the members of the experimental and control groups were homogeneous across all these variables. With regard to equivalence, the probability values of the t-test for weight, height, age, and training age were all greater than 0.05, indicating that there were no statistically significant differences between the experimental and control groups in these variables. Consequently, this study confirmed that the experimental and control groups were equivalent with respect to weight, height, age, and training age.

Table 4. Normal distribution of the research sample in physiological variables

Functional Variables	Unit of Measurement	Group	d.f	Kolmogorov-Smirnov	Sig	Significance
Systolic Blood Pressure	mmHg	Experimental	7	0.274	0.121	Not Significant
		Control	7	0.238	0.200	
Diastolic Blood Pressure	mmHg	Experimental	7	0.168	0.200	Not Significant
		Control	7	0.250	0.200	
Resting Heart Rate	bpm	Experimental	7	0.190	0.200	Not Significant
		Control	7	0.199	0.200	
	bpm	Experimental	7	0.303	0.052	Not

Heart Rate after Effort		Control	7	0.222	0.200	Significant
Lactic Acid Concentration	mmol/L	Experimental	7	0.190	0.200	Not Significant
		Control	7	0.253	0.194	
Anaerobic Power	reps/min	Experimental	7	0.204	0.200	Not Significant
		Control	7	0.187	0.200	
Aerobic Power	m/min	Experimental	7	0.258	0.173	Not Significant
		Control	7	0.214	0.200	

Table 4 indicates that the probability values from the Kolmogorov-Smirnov test are greater than 0.05, suggesting that the research sample in both the experimental and control groups is normally distributed in all specified functional variables.

Table 5. Homogeneity and equivalence of the research groups in the physiological variables

Physiological Variables	Group	M ± SD	Skewness	Kurtosis	t. test	Sig	Significance
Systolic Blood Pressure	Experimental	137.857 ± 13.4217	0.91	-0.39	0.40	0.696	Not Significant
	Control	135.142 ± 11.9223	0.29	-1.69			
Diastolic Blood Pressure	Experimental	76.4286 ± 13.4642	0.47	0.05	0.92	0.282	Not Significant
	Control	82.1429 ± 6.81734	0.83	0.92			
Resting Heart Rate	Experimental	72.4286 ± 5.19157	-0.90	1.07	0.23	0.987	Not Significant
	Control	73.2857 ± 7.38725	-0.92	0.70			
Heart Rate after Effort	Experimental	107.428 ± 7.04408	-0.91	-0.91	0.67	0.511	Not Significant
	Control	104.142 ± 10.7149	0.83	-1.09			
Lactic Acid Concentration	Experimental	18.2000 ± 1.65831	-0.23	-1.22	1.68	0.097	Not Significant
	Control	19.9143 ± 1.84520	0.82	1.30			
Anaerobic Power	Experimental	18.6714 ± 4.11004	-0.51	0.23	0.20	0.842	Not Significant
	Control	19.1143 ± 4.02798	-0.49	0.38			
Aerobic Power	Experimental	1902.85 ± 178.858	-0.99	-0.41	1.38	0.192	Not Significant
	Control	1800.00 ± 81.6496	0.00	1.2			

Table 5 shows that the study successfully established both homogeneity and equivalence among participants concerning physiological variables. In terms of homogeneity, the skewness values for all specified physiological variables were within the range of ±1, and the kurtosis values were within ±2. These indicators confirmed the homogeneity of the experimental and control groups across all physiological variables. Regarding equivalence, the probability values of the t-test for all functional variables were greater than 0.05, indicating no statistically significant differences between the experimental and control groups. This result demonstrates the equivalence of the two groups in terms of specified physiological variables.

2.1 Research Instrument

The physiological tests in this study were determined through scientific references and previous studies that dealt with physiological indicators, which were then presented in the form of a questionnaire to obtain the approval of experts and specialists in the fields of training physiology, sports training, and wrestling. A consensus rate of (85%) was obtained for the measurement of the specified physiological variables. As shown in Table 6.

Table 6. Percentage of agreement of the experts on the physiological tests

Physiological Tests	Experts Agreed	Experts Disagreed	Agreement Percentage	Chi-Square	Sig	Significance
Systolic Blood Pressure	15	0	100%	15	0.000	Significant
Diastolic Blood Pressure	15	0	100%	15	0.000	Significant
Resting Heart Rate	13	2	86%	8.06	0.001	Significant
Heart Rate after Effort	15	0	100%	15	0.000	Significant
Lactic Acid Concentration	15	0	100%	15	0.000	Significant
Anaerobic Power	14	1	93.33%	11.26	0.001	Significant
Aerobic Power	15	0	100%	15	0.000	Significant

2.2 Data Collection Methods

The methodology for data collection in this study was meticulously planned to ensure the comprehensive coverage and reliability of the results. Sources of data included a blend of Arabic and international literature, physiological tests designed to assess participants, interviews with sports training experts to validate the training units, and questionnaires to verify the validity of these physiological tests.

2.3 Pilot Studies

This research involved conducting two pivotal pilot studies. The first pilot study, conducted on October 8, 2023, involved a sample of five players from the research community. The aim was to verify the accuracy of the physiological tests. This initial pilot study focused on assessing the competence of the assistant team, ensuring their understanding of the measurement processes and result recording, evaluating the devices and tools used, confirming the test sequence from easier to more challenging, checking the suitability of the tests for the sample and their interactive response, as well as measuring the spatial logistics required between tests.

The second pilot study was conducted on August 11, 2023, with another set of five players from the same research sample. This study aims to apply a training protocol to identify potential obstacles and refine the training process. Key aspects tested included the coach's adherence to the training program, players' responsiveness to the training, challenges in implementation, spatial arrangement of exercises, timing suitability for each segment of the training session, and effectiveness of the tools and equipment used.

The training program was critically evaluated by a panel of experts in training science and wrestling. These specialists reviewed the exercises and provided insights on the validity of their application, time allocation for different segments of the training units, and the alignment of exercises with the training objectives. The program comprised 27 training units for the experimental group, spread over nine weeks with three sessions per week, ensuring a structured and consistent delivery aimed at maximizing the training outcomes.

2.3 The Training Program

This study involved presenting a training program to a group of specialists in the fields of training science and wrestling. These experts provided their opinions and observations regarding the exercises, focusing on verifying the validity of their application, time allocation for different parts of the training units, and alignment of the exercises with the overall training objectives.

The time plan for the training program was structured meticulously. The program consisted of 27 training units, designed specifically for the experimental group. The implementation of this training program spanned nine weeks, with the training units distributed at a rate of three sessions per week. This structured approach ensured that the training was consistent and comprehensive, aiming to maximize the effectiveness and outcomes of the program.

2.4 The Final Research Experiment

First, the exercises for the experimental group were meticulously distributed in a specific sequence to maximize their impact on the working muscle groups and the cardiorespiratory system. The exercises began with the full squat targeting the leg and back muscles, followed by the parallel exercise for the shoulder girdle muscles; abdominal exercise with a medicine ball for the dynamic abdominal muscles; hammer on the frame for the arm, shoulder, and back muscles; the arch with the dummy for flexibility and speed of the back muscles; rope climbing for the hand, arm, and shoulder muscles; and deadlift focusing on the thigh and lower back muscles. Each training unit was concluded with a jogging session of 10-15 minutes to enhance cardiorespiratory endurance, which is crucial for wrestlers. In this study, I ensured variation in the muscle workload to prevent overloading of specific muscles by incorporating exercises with low repetitions performed within short periods.

Second, the loading principles were carefully considered when designing the training units. The load was applied using either body weight or additional weights, and the intensity, volume, and duration of rest were calculated precisely. The rest period was set to twice the effort period while maintaining a 1:2 ratio. The intensity for the experimental group was calculated based on the highest achievement for each exercise using a specific equation for exercises such as the full squat and deadlift to determine the appropriate load and intensity. This structured approach ensured that the training was effective, safe, and aligned with the study objectives.

Required weight to be used at a certain intensity= $\frac{\text{Required intensity} \times \text{Best achievement}}{100}$

For abdominal, hammer, and arch exercises, the calculation of the training load is based on the highest number of repetitions achieved within a specific time period. This was determined by calculating the highest repetition count in one minute, considered as 100%, and then multiplying this count by the required intensity to determine the necessary number of repetitions. This method ensures that the training load is accurately tailored to the athlete's capabilities and the specific demands of each exercise, promoting optimal adaptation and performance improvements.

The interval training method in strength exercises incorporates the use of additional weights that can reach up to approximately 75% of an individual's maximum capacity. In this approach, the volume of exercises is inversely related to their intensity; as the intensity increases, the volume of exercises decreases, and rest periods between exercises become relatively longer. However, these rest periods are incomplete, allowing the heart to return to a partial resting state while maintaining a level of readiness for the subsequent set of exercises. This strategy effectively manages the physiological demands of athletes, ensuring that they can sufficiently recover while still preparing for the next exercise set.

Pre-tests were conducted on August 15, 2023, to assess the initial physiological status of the participants. Following the completion of the training program on October 27, 2023, post-tests were administered on October 28, 2023, to evaluate the effects of the training regimen. During these post-tests, heart rate and lactic acid concentration in the blood were measured after a recovery period of five minutes post-exercise.

The tools used in this study included a Restameter device for measuring height and weight, measuring tape for distance measurement, 3 kg medicine balls, a wrestling mat, climbing ropes, a stopwatch, a polar watch for heart rate monitoring, a Lactat Pro device for measuring lactic acid levels, and training dummies of various weights. These tools were integral to ensuring precise and consistent measurements throughout the study, thereby enhancing the reliability and validity of the research findings.

Results and Discussion

Table 7 shows the significant findings regarding the measured physiological variables. The mean difference values for the physiological variables—Resting Heart Rate, Heart Rate after Effort, Lactic Acid Concentration, Anaerobic Power, and Aerobic Power—were 1.28, 6.57, 0.68, 5.37, and 190.85, respectively, with corresponding standard deviations of 0.75, 3.82, 0.67, 3.71, and 90.90. The calculated t-values for these variables were 4.5, 4.54, 2.69, 3.83, and 5.55, respectively, with probabilities (sig) less than 0.05. These results indicate statistically significant differences between the pre-test and post-test measurements of the experimental group for these physiological variables, favoring the post-test results. Consequently, the null hypothesis was rejected and an alternative research hypothesis was accepted.

On the other hand, the mean difference values for Systolic Blood Pressure and Diastolic Blood Pressure were 0.85 and 1.57 respectively, with standard deviations of 1.34 and 3.45. The calculated t-values for these variables were 1.68 and 1.20, with probabilities (sig) greater than 0.05. This indicates that there were no significant differences between the pre- and post-test measurements for Systolic and Diastolic Blood. Therefore, the null hypothesis is accepted and the alternative research hypothesis is rejected for these variables. These results provide a nuanced understanding of the impact of the training program, highlighting specific areas of significant improvement, while also identifying variables that remain unchanged.

Table 7. Difference between Pre-test and Post-test of the experimental group in physiological variables

Physiological Variables	Test	M ± SD	Difference M	Difference ± SD	t-test	Sig	Significance
Systolic Blood Pressure	Pre-test	137.8571 ± 13.42173	0.85	1.34	1.68	0.143	Not Significant

	Post-test	137.0000 ± 13.71131					
Diastolic Blood Pressure	Pre-test	76.4286 ± 13.46424	1.57	3.45	1.20	0.274	Not Significant
	Post-test	74.8571 ± 11.03674					
Resting Heart Rate	Pre-test	72.4286 ± 5.19157	1.28	0.75	4.5	0.004	Significant
	Post-test	71.1429 ± 4.84522					
Heart Rate after Effort	Pre-test	107.4286 ± 7.04408	6.57	3.82	4.54	0.004	Significant
	Post-test	100.8571 ± 5.75698					
Lactic Acid Concentration	Pre-test	17.2000 ± 1.65831	0.68	0.67	2.69	0.036	Significant
	Post-test	16.5143 ± 1.35576					
Anaerobic Power	Pre-test	18.6714 ± 4.11004	5.37	3.71	3.83	0.009	Significant
	Post-test	13.2971 ± 1.75148					
Aerobic Power	Pre-test	1902.8571 ± 178.85882	190.85	90.90	5.55	0.001	Significant
	Post-test	2093.7143 ± 175.50566					

Table 7 for the experimental group trained according to the training program regarding the functional variables under study shows that heart rate, lactic acid concentration, short-term anaerobic power, and aerobic power were statistically significant between the pre-test and post-test, in favor of the post-tests because the probability (sig) was less than 0.05. Thus, the training program had a biological effect on heart rate over time, as the heart rate decreased in the post-test. The existing literature provides strong evidence for the use of high-intensity interval training (HIIT) in training programs for young wrestlers. The integration of HIIT can have a significant impact on the physiological variables and overall performance of athletes.

Several recent studies have explored the benefits of HIIT for young wrestlers. Chaabene et al. (2015) found that HIIT was highly effective for improving aerobic fitness, anaerobic power, and muscle strength. Similarly, Bazyler et al. (2017) reported significant improvements in vertical jump height, isometric mid-thigh pull force, and peak power output during the Wingate test in youth wrestlers following a 6-week HIIT program. McHaffie et al. (2022) demonstrated that a 4-week HIIT program significantly increased VO2max, time to exhaustion, and blood lactate concentrations during high-intensity exercise as well as improved technical and tactical performance.

Zhou et al. (2019) observed that a 12-week HIIT program led to significant enhancements in VO2max, time to exhaustion, and anaerobic power output, along with improved technical and tactical skills in elite adolescent wrestlers. Afonso et al. (2021) also found significant increases in VO2max, blood lactate concentrations, and muscle glycogen content after a 6-week HIIT program. Cortesi et al. (2020) reported improvements in VO2max, time to exhaustion, and upper-body muscular strength following a 12-week training program that included an HIIT component.

These consistent findings across multiple studies and wrestler populations suggest that HIIT can be a valuable training approach to enhance the overall physical and technical capabilities of young wrestlers. In practical terms, HIIT can be incorporated into training programs through short bursts of high-intensity exercises, such as sprints or plyometric exercises, interspersed with periods of active recovery or lower-intensity exercises. The duration and intensity of the HIIT bouts, as well as the work-to-rest ratios, can be tailored to the specific demands of the sport and individual athletes' needs.

While the existing literature provides strong evidence for the efficacy of HIIT, most studies have relatively small sample sizes, and findings may be limited to specific populations, such as elite or national-level wrestlers. Further research with larger and more diverse samples would strengthen confidence in the application of HIIT and explore potential individual differences in responses to this training approach.

Overall, the integration of HIIT into training programs for young wrestlers is a valuable strategy for enhancing physiological and performance capabilities crucial for sports success. Further research with larger and more diverse samples is needed to elucidate the optimal implementation and generalizability of HIIT for training young wrestlers.

Table 8 shows that the study identified significant differences in several physiological variables between the pre- and post-test measurements of the experimental group. The mean differences in Resting Heart Rate, Heart Rate after Effort, Lactic Acid Concentration, and Aerobic Power were 0.85, 8.57, 0.38, and 273.28, respectively, with corresponding standard deviations of 0.58, 5.56, 0.34, and 102.29. The calculated t-values for these variables were 3.88, 4.07, 2.96, and 7.06, all of which had probabilities (sig) less than 0.05. These results indicate statistically significant differences between the pre-test and post-test measurements in favor of the post-test for these physiological variables. Consequently, the null hypothesis was rejected, and the alternative research hypothesis was accepted, confirming that the training program had a significant positive impact on these physiological measures.

Table 8. Difference between Pre-test and Post-test of the control group in physiological variables

Physiological Variables	Test	M ± SD	Difference M	Difference ± SD	t-test	Sig	Significance
Systolic Blood Pressure	Pre-test	135.1429 ± 11.92237	0.28	1.60	0.47	0.654	Not Significant
	Post-test	134.8571 ± 11.96423					
Diastolic Blood Pressure	Pre-test	82.1429 ± 6.81734	1.42	1.79	2.10	0.081	Not Significant
	Post-test	81.7143 ± 6.87300					
Resting Heart Rate	Pre-test	72.2857 ± 7.38725	0.85	0.58	3.88	0.009	Significant
	Post-test	71.4286 ± 7.09124					
Heart Rate after Effort	Pre-test	104.1429 ± 10.71492	8.57	5.56	4.07	0.007	Significant
	Post-test	95.5714 ± 8.30376					
Lactic Acid Concentration	Pre-test	19.0143 ± 1.84520	0.38	0.34	2.96	0.035	Significant
	Post-test	18.6286 ± 1.53700					
Anaerobic Power	Pre-test	19.1143 ± 4.02798	1.23	1.69	1.92	0.102	Not Significant
	Post-test	17.8800 ± 2.73250					
Aerobic Power	Pre-test	1800.0000 ± 81.64966	273.28	102.29	7.06	0.000	Significant
	Post-test	2073.2857 ± 111.34289					

Table 9 shows that the effect size values extracted for the functional variables (Resting Heart Rate, Heart Rate after Effort, Lactic Acid Concentration, Aerobic Power) were (1.46, 1.54, 1.12, and 2.66) respectively, and these values are greater than the specified criterion value in the effect size table, which is (0.8), indicating that the effect size of the training program was large. However, the effect size for the variables of (Diastolic Blood Pressure and Anaerobic Power) were (0.79 and 0.72) respectively, and they are greater than (0.5) and less than (0.8), indicating that the effect size of the training program was at a medium level in the variables of (Diastolic Blood Pressure and Anaerobic Power). The value of the effect size for Systolic Blood Pressure reached (0.18), which is less than the criterion (0.5) and greater than (0.2), indicating that the effect size of the training program was at a small level in Systolic Blood.

Table 9 The effect size between the pre-test and post-test of the experimental group in the physiological variables

Physiological Variables	t-test	Sample Size	Cohen's d	Effect Size
Systolic Blood Pressure	0.47	7	0.18	Small
Diastolic Blood Pressure	2.10	7	0.79	Medium

Resting Heart Rate	3.88	7	1.46	Large
Heart Rate after Effort	4.07	7	1.54	Large
Lactic Acid Concentration	2.96	7	1.12	Large
Anaerobic Power	1.92	7	0.72	Medium
Aerobic Power	7.06	7	2.66	Very Large

Table 9 indicates that the effect size values for Resting Heart Rate, Heart Rate after Effort, Lactic Acid Concentration, and Aerobic Power were 1.46, 1.54, 1.12, and 2.66, respectively, all of which were greater than the criterion value of 0.8, indicating a large effect size. However, the effect sizes for Diastolic Blood Pressure and Anaerobic Power were 0.79 and 0.72, respectively, indicating a medium effect size. The effect size for Systolic Blood was 0.18, indicating a small effect size.

These findings provide strong evidence of the effectiveness of the high-intensity interval training (HIIT) program implemented in the experimental group. The statistically significant differences observed in the post-test measurements for key physiological variables, such as heart rate, lactic acid concentration, and aerobic power, suggest that the HIIT program led to significant improvements in the physiological efficiency of the participants.

The researcher's explanation aligns with the current understanding of literature. Recent studies have confirmed the benefits of HIIT in enhancing the physiological capabilities of athletes, particularly in sports with high-intensity and intermittent demands such as wrestling. Chaabene et al. (2015) conducted a systematic review and meta-analysis that found HIIT to be one of the most effective training methods for improving aerobic fitness, anaerobic power, and muscle strength in combat sports athletes, including wrestlers. This is in line with the current findings, which demonstrate the positive effects of HIIT on both the aerobic and anaerobic energy systems.

The decrease in heart rate observed in the results can be attributed to improved cardiovascular efficiency, as supported by the study by Aubert et al. (2003). As an individual's physical fitness increases through training, their heart rate at rest and during exercise tends to decrease, which is an advantageous adaptation that allows for more economical performance. The increase in lactic acid concentration was likely a result of the high-intensity nature of the HIIT program. This adaptation is not necessarily negative, as it can reflect the wrestler's improved capacity to tolerate and buffer lactate, which is crucial for sustained high-intensity effort during matches.

In terms of practical implementation, HIIT can be integrated into training programs for young wrestlers in several ways. For example, wrestlers may perform high-intensity exercises such as sprints, plyometrics, or wrestling-specific drills, interspersed with periods of active recovery or lower-intensity work. The duration, intensity, and work-to-rest ratios of the HIIT intervals can be tailored to the specific needs and characteristics of individual wrestlers, as well as the demands of the sport.

It is important to note that while the current findings provide strong evidence for the benefits of HIIT, the sample size and specific population (young wrestlers) may limit the generalizability of the results. Further research with larger and more diverse samples of young wrestlers would be beneficial to corroborate these findings and examine potential individual differences in physiological responses to HIIT.

Overall, the integration of HIIT into training programs for young wrestlers has been shown to be an effective strategy for enhancing their physiological capabilities, which are crucial for success in sports. The current findings, combined with recent literature, highlight the value of HIIT as a training approach that can improve the cardiovascular, respiratory, and metabolic efficiency of these athletes, ultimately contributing to their overall physical and performance capabilities.

Conclusions

This study found that a high-intensity interval training (HIIT) program led to significant improvements in physiological variables such as resting heart rate, heart rate after effort, lactic acid concentration, and aerobic power in the experimental group. These findings confirm that HIIT can effectively enhance the physiological efficiency of young athletes, particularly in sports such as wrestling, which require high-intensity and intermittent efforts.

The primary contribution of this study was the methodological application of HIIT in training programs for young wrestlers. This study provides empirical evidence supporting the effectiveness of HIIT in improving the physiological capacity and technical performance of athletes. This finding supports the concept that tailored high-intensity and interval-based training can yield significant and beneficial physiological adaptations in young wrestlers.

This study has some limitations, including a relatively small sample size and a specific population (young wrestlers). These limitations may restrict the generalizability of the findings. Future research with larger and more diverse samples is needed to strengthen confidence in the application of HIIT and explore potential individual differences in responses to this training approach. Future studies could also include long-term evaluations of the effects of HIIT and adjustments to HIIT programs to accommodate athletes of different skill levels and age groups.

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