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Original Article

Effect of high-intensity interval training on physical and biological indicators in individual sports Athletes

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Abstract
Objectives: This study aimed to determine to evaluate the impact of high-intensity interval training (HIIT) on physical and biological indicators among athletes in individual sports. **Methods:** We employed an experimental design involving 30 participants from Al-Adalah Club in the Kingdom of Saudi Arabia. The participants were divided into two groups: experimental group (n = 15; age: 18.67 ± 0.70 years; height: 171.87 ± 2.23 cm; weight: 68.67 ± 2.53 kg; training experience: 4.71 ± 0.62 years) and the control group (n = 15; age: 18.73 ± 0.80 years; height: 172.00 ± 2.30 cm; weight: 69.27 ± 2.87 kg; training experience: 5.27 ± 0.49 years). Physical performance was assessed using (SLJT) and Sergeant Jump Test (SJT). Lactic acid levels were measured with the Lactate Pro 2 blood lactate meter. Heart rate (HR) and blood pressure were assessed using the Beurer blood pressure monitor (model Bc28 | 57144), while hemoglobin (Hb) levels were analyzed in a medical laboratory by a qualified medical professional. The intervention program was implemented for 8 weeks, consisting of three training sessions per week**.** **Results:** The findings indicated significant improvements in physical performance as measured by the SLJT and SJT, with statistical significance ($p = 0.001$). Additionally, there were enhancements in HR, VO2 max, and systolic blood pressure (SBP), alongside a reduction in hemoglobin levels and lactic acid concentrations at designated times (0, 3-, 6-, 9-, and 12-minutes post-exercise), with p-values indicating significance ($p < 0.05$; $p = 0.001$) favoring the post-intervention assessments of the experimental group. The experimental group exhibited superior results compared to the control group, with improvement rates ranging from 2.7% to 19.61% ($p = 0.001$). **Conclusions:** The implementation of HIIT training is shown to be a more effective training method for athletes participating in individual sports. Future research should focus on the long-term effects of HIIT to better understand its implications for physical fitness and overall health among different populations.
Keywords: Hemoglobin, Heart rate, VO2 max, Lactic acid, HIIT, athletes

Introduction

Exercise is crucial for maintaining overall health, preventing chronic diseases, and improving mental well-being. Regular physical activity reduces the risk of conditions like heart disease, diabetes, and obesity while strengthening muscles and bones (Abdullah, 2023; Rooney et al., 2023). High-intensity interval training (HIIT) is characterized by several sets of short exercise with relatively high intensity separated by a lower intensity or a pause [2]. This training method has been studied extensively and has resulted in the creation of many protocols because it is efficient and fast ens. In the recent past, HIIT protocols encompassing low volume have been used since they offer appreciable fitness gains with minimal exercise time [Buchheit, M. et al. 2013; Batacan, R.B.J. et al. 2017]. HIIT Training has emerged as a highly effective exercise modality, providing comparable benefits to traditional exercise in enhancing cardiorespiratory fitness, metabolic health, and overall quality of life. Research suggests that HIIT can significantly improve cardiovascular health, insulin sensitivity, and psychological well-being, making it a viable option for various populations. HIIT has been shown to enhance VO2 max, reduce blood pressure, and improve endothelial function (Plizga et al., 2024).

The research papers discussed in the course of this paper reveal enhanced aerobic-place, muscle-energy, and total-body power. Some of the findings that have been found when HIIT is incorporated have been found to enhance maximal oxygen uptake (VO2max) in well-trained runners by 2.6%, coupled with improvements in running economy and performance in time trials (Possamai T. L. et al., 2024). In the wheelchair tennis players, HIIT training resulted in valuable positive changes in their cardiorespiratory fitness based on the improved performance on the yo-yo test as postulated by Latino F. et al., 2024. Regression to the different HIIT protocols yielded quantized blood lactate levels with higher lactate concentration when comparing ergometer-based ergometry to whole-body calisthenics and thereby highlighting distinctly differing physiological stress reactions (Schaun GZ. et al., 2024). HIIT also helped enhance lower-body strength and power, revealing significant enhancement in other parameters, such as the CMJ (Possamai T. L. et al., 2024). It is interesting to note that through the HIIT program, positive improvements in athletic performance have been noted in relation to its

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effect on the physical characteristics and physiological aspects of athletes of different sports disciplines. The following sections highlight various recent findings from existing literature. HIIT has brought significant improvements in physical skills such as sprinting, agility, and endurance. For instance, Shiraz S. 2024 noted the readiness of both basketball and soccer players to display a reduction of 6% in their sprint time and better agility calibration after HIIT. Volleyball players showed improvements in various physical assessment activities, such as throw force over long distances and sprinting, over the course of 9 weeks following HIIT training (Yue L. & Hong C., 2023). Young women enhanced their VO2max, sprint, and flexibility performance after 8 weeks of bodyweight HIIT exercise training (Uysal et al., 2024). HIIT has been associated with increased cardiorespiratory fitness and lower risk markers for CVD, including total and/or HDL- cholesterol in children and adolescents (Men et al., 2023). Youth players engaging in small-sided games and high-intensity training showed notable improvements in endurance without any reported injuries, suggesting that specific training methods can boost fitness levels effectively(Paul DJ. et al., 2019). It is important to note that there is evidence of HIIT enhancing several performance parameters; however, the changes in BMI, as determined by HIIT, may not be as significant (Men J. et al., 2023).

The existing literature (Shiraz S. et al. 2024; Kumari, A. et al. 2023; Arslan E. et al. 2022; Janowski M. et al. 2020; Chacón Torrealba T. et al. 2020; Kunz, P. et al. 2019;Mile C. et al. 2019; Batacan, R.B.J. 2017; Monks L. et al. 2017; Laursen P.B. 2010) supports the importance of HIIT. We have realized there is low performance for individual sports athletes and that coaches are not caring enough. The researchers surveyed the tests and then corroborated the low incidence of athletes in those tests, which led them to perform such a study using HIIT exercises by taking into consideration the impact on some of the physical and biological indices among the individual sports athletes (karate, kung fu, and kickboxing). It is for this reason that the physical and biological features of individual sports athletes under study were not measured as previously stated. We hypothesized that there are significant differences between the pre- and post-measurements of the experimental group and the control group of the physical and biological measurements of an individual sports athlete.

Materials and Methods

Participation, Study design:

The purpose of the study was to establish the impact that HIIT has on players, particularly those of individual sports, on physical and biological characteristics. The sample of 30 athletes was taken from El Adalla Club in Al-Ahsa, Saudi Arabia. The athletes were divided into the experimental group that performed high-intensity interval training (n = 15, mean ± SD, age = 21.24± 0.14 years) and the second group that did not perform high-intensity interval training (n = 15; mean ± SD, age = 21.24 ± 0.14 years). At least they had 5 years of experience with their playing fields, as shown in Table 1. Those with behavioral issues, medical conditions were not included. Moreover, the inclusion criteria used in the study did not permit anyone who had been involved in HIIT for the past six months before participating in this study. Participants were also aware of the possibility of a risk they may be subjected to while participating in the experiment. All subjects encountered in the research process arrived willingly and fully understood the reason for the study and the potential danger, and they filled in the informed consent in accordance with the principles mentioned in the Helsinki Declaration. The HIIT program that was employed in this study was developed from Zwetsloot, K. et al. 2014. To standardize the procedures, the participants were advised to avoid alcohol, caffeine, and rigorous physical activity for 48 hours before all the tests and HIIT sessions. Also, to overcome any variations in performance due to circadian rhythms, all the sessions were done at the same time of the day. Over the course of eight weeks, the full HIIT program included a total of 24 sessions, with three sessions scheduled on alternate days: Saturday, Monday and Wednesday. The study period was between September 2023 and December 2023, while the Pre- measurements for the study were taken from September 30 to the 2nd of October 2023. The eight-week HIIT program (see Appendix A) was between October 7 to November 29, 2023. The post-measurements were collected from November 30 to November 25, 2023.

Table 1. Descriptive statistics:

variables	Experimental				Control			
	Mean	Std.	Min	Max	Mean	Std.	Min	Max
age	18.67	0.70	18.00	20.00	18.73	0.80	18.00	20.00
height	171.87	2.23	170.00	176.00	172.00	2.30	169.00	177.00
WIGHT	68.67	2.53	64.00	72.00	69.27	2.87	64.00	72.00
Training	5.33	0.49	5.00	6.00	5.27	0.46	5.00	6.00

Min = Minimum; Max = Maximum

Tools, Devices and testing Procedures:

Restameter used in determination of height/weight where the candidate had no shoes, no upper clothes, and shorts of certain weight on to get naked weight 12 hours after meal. The subject remained standing in the center of the weighing machine with his eyes forward during the exercise. Height was measured in centimeters, while body weight was measured in kilograms (HASSAN AK. et al. 2023). The Lactate Pro 2 test strips were used for all the lactate measurements. Heart rate (HR) and blood pressure were assessed using the Beurer blood pressure monitor (model Bc28 | 57144), while hemoglobin (Hb) levels were analyzed in a medical laboratory by a qualified medical professional. The reliability of the device used was also tested by comparing it with other devices, such as the Lactic Acid V-5000 VIS visible spectrophotometer made in Italy and M&A Instruments, Inc. VO2 max was measured using a direct method with the aid of an AD instrument gas analyzer (model ML206): subjects were supposed to come in the morning or 2-3 hours after the last meal. Before the test, the subjects were first introduced to the general nature and specific details of the classified exercise test protocols, which were then shown to them. Patients were asked to put on a face mask that is linked to a gas meter that will measure the total amount of gas inhaled and expelled during the test. For the assessment, a progressive treadmill stress test protocol was being used where initially the subject was asked to walk for three minutes on a horizontal surface and then run at a specific speed for the next three minutes on an inclined plane, then for further consistent speed of the treadmill, the incline was increased by 2.5% every minute until the subject was not able to do the exercise any further. The device was connected to a monitor that showed certain values, such as VO2 volume of oxygen, VCO2 volume of carbon dioxide, RER (respiratory exchange ratio), MET, etc., every 10 seconds (Buttar K. K. et al. 2022). We assessed the physical variables for the standing broad jump-vertical jump tests (see Appendix A). We used an exploratory study by applying the measurements to a sample outside the original sample to ensure the validity and reliability of those measurements. All the research variables were predetermined before initiation of the programme and the players did not engage in any rigorous physical activities for the next 48 hours of the test. First, venipuncture was done by drawing blood sample from the subject's right or left thumb and placed in test strips, then the pre- and post-lactic acid exercise of the players were measured using Lactate Pro 2. The measurement was done after (0 min,3 min,6 min,9 min,12 min) of the exercise (HASSAN AK. et al. 2023). The measurement was done through the device; a special needle was pricked; the sample was placed on the test strips; and the reading was obtained directly from the device (Appendix B). Second, before data collection there was a 15-minute warm-up session. This included stepping and short distance running. In physical assessments, standing broad jump test as well as vertical jump assessment was done and the assessment tests were done to all participants without bias.

Training Program Protocol:

The program was designed based on HIIT exercises to enhance the physical and biological parameters of individual sports athletes. High-intensity interval training program was conducted with the experimental group which included training sessions three a week for 8 weeks with the session duration being (60-90 minutes). In the given HIIT training, the actual time spent on training ranged from (20-35 minutes) and the load intensity was (60-85% of the max HR). The training was then set to be done in phases. The first part was the preparation and lasted for 15 minutes while the main part of the exercise (lasting between 40 and 75 minutes) entailed physical preparation exercises combined with HIIT training. The closing part took 5 minutes (see Appendix B). It included stretching and swing exercises as shown in table 2.

Table 2. Time distribution of the HIIT program

Week	session	*HIIT*	*Group*	*Rest*		*intensity %*
				B ex	***B G***	
First	*1*	*1,22,32, 29, 2*	*4*	*60 s*	*40 s*	*65%*
	2	*13,16,17,30,40*	*4*	*60 s*	*65 s*	*65%*
	3	*3,30,14,25,40*	*5*	*60 s*	*60 s*	*60%*
Second	*4*	*11,13,17,22,37*	*4*	*60 s*	*40 s*	*65%*
	5	*1,22,16,25,38*	*5*	*60 s*	*45 s*	*60%*
	6	*15,18,19,25*	*4*	*60 s*	*45 s*	*60%*
Third	*7*	*19,20,24,37,38*	*5*	*65 s*	*40 s*	*60%*
	8	*33,37,21,30,43*	*4*	*60 s*	*45 s*	*75%*
	9	*2,28,11,27,42*	*4*	*60 s*	*55 s*	*60%*
Fourth	*10*	*16,26,12,33,43*	*4*	*55 s*	*45 s*	*75%*
	11	*10,19,25,32,9*	*5*	*60 s*	*45 s*	*805*
	12	*21,22,23,29,38*	*5*	*65 s*	*45 s*	*60%*
Fifth	*13*	*29,20,22,34,43*	*5*	*65 s*	*50 s*	*80%*
	14	*17,18,31,23,40*	*4*	*60 s*	*50 s*	*70%*
	15	*7,8,30,27,30*	*4*	*60 s*	*45 s*	*60%*
Sixth	*16*	*33,36,25,37, 41*	*5*	*60 s*	*45 s*	*65%*
	17	*23,34,28,31,41*	*4*	*60 s*	*55 s*	*60%*
	18	*12,14,32,20,39*	*4*	*60 s*	*60 s*	*75%*
Seventh	*19*	*2,18,17,24,40*	*4*	*65 s*	*40 s*	*75%*

	20	*23,24,25,36,40*	*4*	*60 s*	*40 s*	*80%*
	21	*3,9,12,33,38,37*	*5*	*60 s*	*75 s*	*75%*
Eighth	*22*	*4,5,29,33,41*	*4*	*60 s*	*50 s*	*70%*
	23	*20,23,28,22,43*	*4*	*60 s*	*60 s*	*80%*
	24	*13,20,21,26,39*	*4*	*65 s*	*75 s*	*85%*

B ex: Between Exercises; B G: Between groups.

Statistical Analysis:

Normality and sphericity were examined using the Shapiro Wilk and the Mauchly tests, both with positive outcomes. Other quantitative indices like mean, standard error, t-test, 95% confidence interval and Cohen's d were computed on the quantitative data obtained from the study. In this case, all the variables were analysed using a two-way repeated measures ANOVA. Main effects that were statistically significant were subjected to Post hoc tests using the Bonferroni corrections. The measure of the effect size was partial eta-squared (ηp2) obtained from F statistics of ANOVA. The effect size measure of pairs was in terms of Cohen's d by comparing the standardized differences. In all the analyses, significant differences were determined to be at $p < 0.05$ level. Means are displayed as mean ± SD or mean difference with 95% CI. Statistical analysis was done using SPSS software version 26 for windows.

Results:

The results presented in the form of figures 1,2 represents the experimental and control group before and after taking the measurements. The post measurements proved that the experimental group improved significantly compared to the Control group even at $p<0.05$.

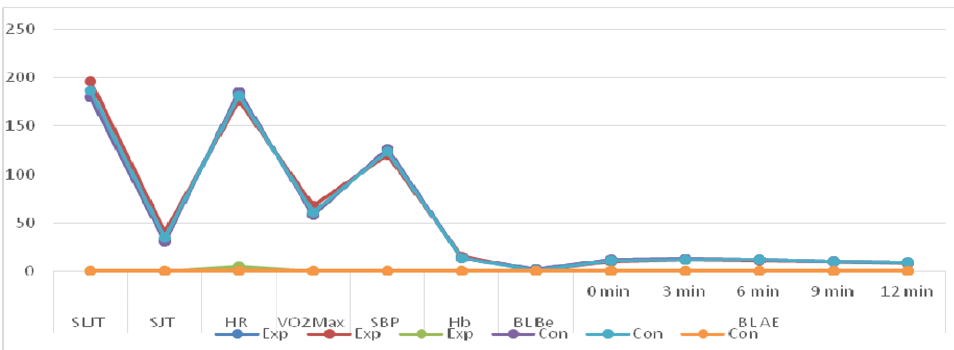

Figure 1. pre and post- measurements of the control group.

Table 2. Descriptive statistics for experimental and control group variables

variables		experimental					control				
		Pre		post		Imp.	Pre		post		Imp.
		Mean	Std.	Mean	Std.		Mean	Std.	Mean	Std.	
SLJT (cm)		179.80	2.27	196.47	3.50	9.27%	180.87	2.45	186.93	2.02	3.35%
SJT (cm)		30.67	0.62	40.40	1.18	31.72%	30.80	0.56	34.53	0.74	12.11%
HR (bpm)		185.13	1.60	176.27	1.83	4.79%	185.20	2.21	181.33	2.06	2.09%
VO2Max (ml/kg/min)		58.39	0.92	67.96	1.10	16.39%	58.54	0.99	60.48	0.50	3.31%
SBP (mmHg)		126.67	2.61	120.33	1.05	5.01%	126.53	2.36	123.93	1.83	2.05%
Hb (g/dL)		13.45	0.22	14.88	0.06	10.63%	13.41	0.06	13.89	0.19	3.58%
BL Be (mmol/L)		1.74	0.07	1.48	0.04	14.94%	1.74	0.05	1.67	0.07	4.02%
BL AE	**0min (mmol/L)**	11.41	0.15	10.31	0.09	9.64%	11.42	0.06	11.17	0.03	2.19%
	3min (mmol/L)	12.33	0.25	11.39	0.10	7.62%	12.34	0.04	12.20	0.03	1.13%
	6min (mmol/L)	11.51	0.20	10.68	0.19	7.21%	11.52	0.05	11.35	0.09	1.48%
	9min (mmol/L)	10.32	0.07	9.79	0.04	5.14%	10.33	0.03	10.18	0.05	1.45%
	12min (mmol/L)	9.35	0.09	8.21	0.07	12.19%	9.37	0.05	9.12	0.06	2.67%

SLJT — Standing Long Jump Test; SJT — Sergeant Jump Test; HR—Heart rate; SBP— Systolic blood pressure; BL Be—Blood lactate concentration Before effort; BL —Blood lactate concentration After effort; Hb—Hemoglobin; Imp. — percentage improvement.

Table 2. displays the percentage of improvement and the variations between the pre- and post-measurement averages for the experimental and control groups. It is evident that in the experimental group, the percentage improvement rates for the physical indicators (SLJT, SJT) and the biological indicators (HR, VO2Max, SBP, Hb) were 9.27%, 31.72%, 4.79%, 16.39%, 5.01%, and 10.63%), as well as the percentages for

the lactic acid (BE, AE 0min, AE 3min, AE 6min, AE 9min, and AE 12min) were 14.94%, 9.64%, 7.62%, 5.21%, 5.14%, and 12.19%), while in the control group, the percentage improvement rates for the physical indicators (SLJT, SJT) and the biological indicators (HR, VO2Max, SBP, Hb) were (3.35%, 3.31%, 2.05%, and 3.58%). and lactic acid for (BE, AE 0min, AE 3min, AE 6min, AE 9min, and AE 12min) respectively at percentages of (4.02%, 2.19%, 1.13%, 1.48%, 1.45%, 2.62%).

The results of the ANOVA are presented in Table 3, the F-statistic for the main effects for measurement and group and for the interaction between measurement and group is reported, along with the partial eta squared (ηp2). The results of the Bonferroni post hoc tests indicated that the experimental group had a higher increase in the incremental values of all the variables than the control group. As shown in Table 3, the ANOVA analysis of each of the study variables produced significant effects at a $p < 0.05$ level.

Table 3. The results of the Repeated Measures ANOVA.

variables		Measurement			Group			Group ×Time Interaction		
		F	P	ηp^2	F	P	ηp^2	F	P	ηp^2
SLJT (cm)		447.97	0.001	0.941	28.547	0.001	0.505	97.395	0.001	0.777
SJT (cm)		1005.73	0.001	0.973	190.338	0.001	0.872	199.648	0.001	0.877
HR (bpm)		463.461	0.001	0.943	15.932	0.001	0.363	71.461	0.001	0.718
VO2Max (ml/kg/min)		774.152	0.001	0.965	199.102	0.001	0.877	341.182	0.001	0.924
SBP (mmHg)		148.397	0.001	0.841	7.055	0.013	0.201	25.917	0.001	0.481
Hb (g/dL)		553.319	0.001	0.952	195.010	0.001	0.874	136.498	0.001	0.830
BLCR Be (mmol/L)		203.783	0.001	0.879	30.872	0.001	0.524	64.421	0.001	0.697
BL AE	**0 min (mmol/L)**	587.866	0.001	0.954	437.446	0.001	0.940	236.367	0.001	0.894
	3 min(mmol/L)	258.791	0.001	0.902	125.621	0.001	0.818	143.760	0.001	0.837
	6 min (mmol/L)	172.295	0.001	0.860	77.704	0.001	0.735	74.961	0.001	0.728
	9 min (mmol/L)	622.777	0.001	0.957	264.241	0.001	0.904	181.274	0.001	0.866
	12min(mmol/L)	1558.729	0.001	0.982	642.207	0.001	0.958	655.827	0.001	0.959

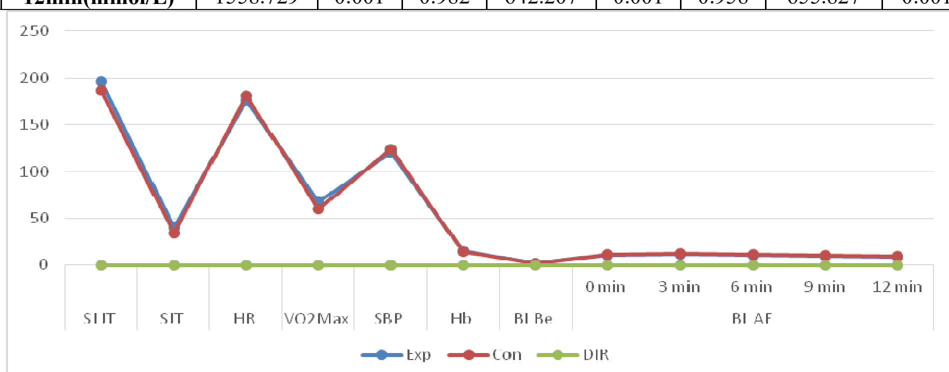

Figure 2. Subsequent measurements of the experimental and control groups.

Table 4. Experimental and Control groups measurements

variables		Levene's Test for Equality of Variances		t-test for Equality				95% CI		DIR
		F	Sig.	t	Sig.	Mean Difference	Std. Error Difference	Lower	Upper	
SLJT (cm)		2.97	0.10	9.14	0.001	9.53	1.04	7.40	11.67	5.92%
SJT (cm)		2.40	0.13	16.26	0.001	5.87	0.36	5.13	6.61	19.61%
HR (bpm)		0.01	0.93	-7.12	0.001	-5.07	0.71	-6.52	-3.61	2.7%
VO2Max (ml/kg/min)		7.06	0.01	23.91	0.001	7.48	0.31	6.84	8.12	13.08%
SBP (mmHg)		6.74	0.01	-6.61	0.001	-3.60	0.54	-4.72	-2.48	2.96%
Hb (g/dL)		10.10	0.001	19.66	0.001	0.99	0.05	0.89	1.10	7.05%
BLCR Be (mmol/L)		1.14	0.29	-9.51	0.001	-0.19	0.02	-0.23	-0.15	10.92%
BL A E	0 min (mmol/L)	21.23	0.001	-33.64	0.001	-0.87	0.03	-0.92	-0.81	7.45%
	3 min (mmol/L)	4.97	0.03	-30.72	0.001	-0.81	0.03	-0.87	-0.76	6.49%
	6 min (mmol/L)	18.33	0.001	-12.36	0.001	-0.67	0.05	-0.78	-0.56	5.73%
	9 min (mmol/L)	0.39	0.54	-23.87	0.001	-0.39	0.02	-0.42	-0.35	3.69%
	12min(mmol/L)	0.12	0.74	-38.23	0.001	-0.91	0.02	-0.96	-0.86	9.52%

95% CI — 95% Confidence Interval of the Difference; DIR= Differences improvement rates.

Table 4. presents the statistical comparisons between the post-measurement values of the experimental and control groups for various physical and biological indicators. The experimental group exhibited significantly higher percentage improvement rates in all indicators compared to the control group, as shown by the t-values ($p < 0.005$). Specifically, the experimental group had higher improvement rates in physical indicators (SLJT, SJT) by 5.92% and 19.61%, respectively, and in biological indicators (HR, VO2Max, SBP, Hb) by 2.7%, 13.08%, 2.96%, and 7.05%, respectively. Additionally, the experimental group demonstrated greater improvements in lactic acid levels (BE, AE 0min, AE 3min, AE 6min, AE 9min, AE 12min), with percentage increases ranging from 3.69% to 10.92%."

Discussion

The study sought to investigate the impact of high-intensity intermittent training (HIIT) on individual sports athletes' physical and biological indicators. The findings revealed that the experimental group, which implemented HIIT, significantly outperformed the control group. This superior performance can be attributed to HIIT's effectiveness in enhancing lower body strength and endurance, as evidenced by the improvements in the single-leg jump test (SLJT) and squat jump test (SJT). Additionally, HIIT positively influenced physiological and biochemical indicators, including heart rate (HR), maximal oxygen uptake (VO2max), systolic blood pressure (SBP), hemoglobin (Hb), and blood lactate (BL). These results collectively demonstrate the efficacy of HIIT in improving the physical and biological indicators of individual athletes. Studies have shown that high-intensity interval training (HIIT) can be beneficial for taekwondo and karate athletes. A study found that 12 weeks of HIIT led to improvements in strength, endurance, and flexibility, although speed and agility remained unchanged (Liu & Jia, 2023). Additionally, research has demonstrated that specific HIIT techniques can enhance lower limb performance, particularly in kick-related metrics, suggesting improved explosive power for taekwondo (Ojeda-Aravena et al., 2021). HIIT has been found to significantly increase arm and leg muscle power, agility, and anaerobic endurance in Kumite athletes, highlighting its effectiveness in developing the essential physical attributes for competitive success (Hadi & Yudhistira, 2023).

High-Intensity Interval Training (HIIT) has been shown to significantly impact lactic acid levels and heart rate in both individual and combat sports athletes. HIIT training leads to improved lactic acid clearance and tolerance, enhancing performance in athletes. HIIT has been linked to increased anaerobic power, with a notable effect on blood lactate concentration, particularly in grappling athletes (Vasconcelos BB. et al., 2020). A study found significant correlations between post-exercise blood lactate concentration and peak heart rate during HIIT sessions (Piero WD.et al., 2018). Combat sports athletes experience heart rate responses that align with the intermittent nature of their sport, emphasizing the need for sport-specific HIIT protocols to optimize training outcomes (Franchini E., 2020). High-intensity interval training (HIIT) has been shown to effectively reduce lactic acid levels in athletes. The continuous and consistent nature of HIIT, combined with its reliance on high-intensity training loads, enables athletes to develop resilience against fatigue caused by lactic acid buildup. Regular HIIT training leads to physiological and biochemical adaptations in the blood and muscles, enhancing the body's ability to cope with fatigue from rapid and repetitive muscle contractions. Studies have demonstrated that HIIT can significantly decrease lactic acid accumulation during rest and post-exercise (Šimonek et al., 2017). Furthermore, HIIT has been shown to lo Research has consistently found that regular exercise, including HIIT, can lead to lower blood lactate levels at static loads (Suszter et al., 2020; Zhao et al., 2021). Thus, the results showed statistically significant differences between the pre- and post-measurement values for all variables in both the experimental and control groups.

Study Limitations

Despite the important findings, there are certain methodological limitations of this study that should be pointed out: Firstly, the number of the samples included was comparatively small, so that the findings of the study cannot be readily generalized to vast populations. Having more participants in future works may offer a precise view of the impact of HI on the different groups of people. Next, it would be important to pay attention to external conditions including meals, sleep and stress as all of them affect both training performance and physiological results. Differences in these conditions may explain the differences in participants' responses to the training program. However, the process of implementing the HIIT program in participants faced challenges in measuring other activities that they perform physically apart from HIIT program. These external activities can at times affect individual improvement levels and thus raises questions on changes that may be attributed to the HIIT intervention alone. Mastery of these limitations in future research activities will improve the credibility of findings and add to the liter on HIIT effects in various categories.

Conclusion

In conclusion, the results of the study showed positive increases in muscle capacity due to the completion of the 8-week High-Intensity Training (HIIT program as identified by the increases in the Squat Lateral Jump Test (SLJT) and the Squat Jump Test (SJT). Furthermore, the autonomic markers of cardiac frequency (HR), aerobic capacity (VO2 max), systolic blood pressure (SBP), and hemoglobin amounts (Hb) were recorded better enhancements; nonetheless, there was a low level of lactic acid at rest and after exercise for

0min, 3min, 6 min, 9 min, and 12 min. These outcomes support the HIIT program as a method for increasing total athletic performance, implying effectiveness of this type of training for athletes in all types of sports. Thus, the present study corroborated with the earlier findings that showed differences in the measured variables where the experimental group had a better result, although they were statistically non-significant; nonetheless, the HIIT effectiveness in limiting lactic acid build-up was established. Such reduction has a, therefore, positive effect of enhancing athlete's physical and functional fitness. In addition, because of the use of HIIT, training programs can be developed in such a way that HIIT coaches can increase the training of different groups of athletes.

Further research needs to be conducted on the long-term impact of HIIT to be able to fully appreciate the effects of this workout regime on physical fitness and people's health as well. Future research in the existent literature should invite a larger population of participants to ordinated sample data, and a deeper understanding of various characteristics that may influence HIIT responses will be achieved. Moreover, research into the specifics of how HIIT programs can be tailored to the specific age, sex, and fitness profile of the particular athlete remains.

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