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ORIGINAL RESEARCH

Impact of short term high-intensity interval training on the aerobic and anaerobic fitness of young male football players in the final stages of rehabilitation

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Abstract

After rehabilitation, it is important for athletes to regain their previous fitness level in order to return to play. In this study, we sought to determine whether short-term HIIT and MICT improve the fitness in young male football players. Our analysis included 50 participants with a mean age of 16.4 $\pm$ 1.3 years (range: 15.5–17.7 years), a mean height of 174.7 $\pm$ 6.2 cm (163.1–191.0 cm), and a mean weight of 65.7 $\pm$ 6.5 kg (48.6–79.0 kg). Athletes who had almost completed their rehabilitation and were about to return to playing football were classified into high-intensity interval training (HIIT, n = 25) and moderate-intensity continuous training (MICT, n = 25), and underwent a 12-session intervention training program that lasted four weeks. We conducted graded exercise tests, as well as Wingate, isokinetic strength, and Y-balance tests. The Mann-Whitney test was used for between-group comparisons and Wilcoxon's test was used for comparisons before and after intervention. Volume of oxygen uptake peak, heart rate recovery and anaerobic threshold showed significant improvement in both groups following intervention but were significantly higher in the HIIT group than in the MICT group ($p < 0.05$). The Wingate anaerobic peak power and fatigue index showed significant increasement in the HIIT and MICT in first and second sets, but only for third set in the HIIT ($p < 0.05$). HIIT improved isokinetic strength at 60°/s, whereas both training methods provided improvement at 180°/s ($p < 0.05$). Results arising from the Y-balance test did not improve in either group. In conclusion, short-term HIIT and MICT are effective methods with which to improve fitness in young male football players preparing to return to play after injury. However, HIIT was slightly more effective than MICT in terms of improving aerobic and anaerobic fitness and strength.

Keywords

Football; Fitness; Adolescent; High-intensity interval training; Moderate-intensity continuous training

1. Introduction

Excellent performance in football requires a combination of fitness, skill, teamwork and strategy [1]. Maintaining fitness over long periods of time is important in football because it can directly influence the field performance of players [2]. Football games require high aerobic capacity; for example, to move 11.5 km, a midfielder must expend a large amount of energy [3]. Because of the nature of football, continuous running, jumping and changes of directions are required, and anaerobic power is necessary to facilitate intermittent short sprints [4]. Ultimately, footballers need to maximize both aerobic and anaerobic energy supply systems to fulfill the necessary requirements for muscle energy [5, 6]. During a game, the distance required for high-intensity running ranges from 1044 m for wide midfielders to 854 m for center forwards [7].

Even athletes who maintain high levels of physical fitness can suffer injuries which are accompanied by temporary reductions in fitness due to detraining [8]. A previous study investigated the effects of detraining in athletes and reported that volume of oxygen uptake peak (VO_2 peak), exercise time to exhaustion, and maximal stroke volume were all significantly reduced after two weeks of detraining [9]. Furthermore, the VO_2 of elite swimmers was found to decrease by 3.6 mL/kg/min when not engaging in high-intensity training during the five weeks of the off-season [10]. In the case of professional football players, stopping training for 6 weeks not only resulted in a reduction of 2.6 mL/kg/min, but also increased sprint time and body fat percentage [11].

For athletes, anaerobic energy metabolism and adapting to high-intensity sprints are crucial for fitness improvement. There are various training methods to improve anaerobic power, and one of the representative methods is high-intensity interval training (HIIT). The HIIT sequence consists of alternating short periods of high-intensity exercise with short periods of rest [12]. The goal of HIIT is to exert maximum effort during high-intensity intervals of approximately 20–90 s, followed by short periods of rest, in order to achieve the benefits of both aerobic and anaerobic training. Typically, athletes complete training by repeating a planned procedure [13]. In a study of Gökkurt *et al.* [12], training was designed three sessions per week for 8 weeks for youth soccer players under the age of 19. The control group performed general training, and the experimental group performed HIIT. As a result of comparison, HIIT achieved significant improvements in speed, acceleration, and agility compared to the control group. Grendstad *et al.* [14] reported that 8 weeks of high-intensity training in 12-year-old athletes significantly improved VO_2 compared to the control and strength conditioning groups.

Significant improvements in speed and acceleration have been reported in adolescents under the age of 19 years who performed HIIT for three days per week for eight weeks [12]. Another study reported that significant improvements of 15.9% in VO_2 peak, 16.6% in anaerobic threshold (AT), and 12.5% in anaerobic power were achieved in young football players after four weeks of HIIT using cycles; in addition, the benefits of HIIT were greater than those of traditional aerobic moderate-intensity continuous training (MICT) [15, 16].

Despite the positive effects of HIIT training, the disadvantage of HIIT is that athletes may be exposed to injury due to the accumulation of joint and muscle fatigue if they continue training at high intensity over a long period [17]. Thus far, studies have mostly been conducted over 8 to 12 weeks of training [12, 14]. However, shorter-term HIIT studies aimed at the improvement of fitness lost due to injury are relatively rare. Therefore, there is an urgent need to develop an efficient training method to improve the fitness of adolescent players who are preparing to return to play.

In this study, we investigated the specific effects of short-term HIIT, performed over four weeks, on performance-related fitness in young football players preparing to return to play in the final stages of rehabilitation. In addition, we directly compared HIIT to traditional MICT to determine an effective fitness recovery program. Our research hypothesis was that both training methods would be beneficial and that the effect of HIIT would be superior, at least to some extent.

2. Materials and methods

2.1 Participants

The participants were male high school football players who visited a rehabilitation training center for various injuries. Participants were recruited from the Internet, center bulletin boards, and announcements. Final participation was confirmed by consultation with the coaches and relevant parents or guardians. Fifty athletes who were scheduled to return to play football after injury improved were enrolled.

The allocation of training programs was based on the order of registration: odd numbers were assigned to HIIT, and even numbers were assigned to MICT. Participants who were unable to fully perform running and various other movements due to knee, ankle and back injuries were classified into a rehabilitation group and were excluded from this study. The final HIIT (n = 25) and MICT (n = 25) groups underwent training and data were analyzed for each group.

Researcher interviewed players about their daily training prior to injury. Typically, they trained for two sessions per day. The first session lasted approximately three hours after school, with two hours of training on soccer skills, systems and one hour of fitness improvement. The second session was a personal training session after dinner and was conducted autonomously for approximately one hour. During personal training, we mainly performed football techniques such as dribbling, passing, trapping and kicking.

2.2 The graded exercise test

The testing procedure and criteria for maximum exercise capacity conformed to the guidelines published by the American College of Sports Medicine [18]. The graded exercise test (GXT) measures changes in VO_2 peak, anaerobic threshold (AT), and heart rate, collectively representing cardiorespiratory fitness. The GXT involved the use of a treadmill, gas analyzer (Vmax229, Sensormedics Co., Yorba Linda, CA, USA), and the Bruce protocol [19]. To ensure safety during the test, an electrocardiogram device (Case8000, GE Marquette Co., Milwaukee, WI, USA) was analyzed the electrical activity of the myocardium. In addition, the purpose of the test and the measurement method were explained to the participants. Because this test measures maximum capacity, we continued this test until the participant requested to stop. A perceived rating of exertion $\geq$17 was considered as the condition during which the heart rate and VO_2 did not change under high exercise load. Data on early finishes below 90% of predicted maximum heart rate (220 − age) were not included in the statistical process [20].

2.3 The Wingate anaerobic test

The Wingate test uses a bicycle ergometer to measure anaerobic power and fatigue and is performed by applying a load based on an individual's body weight followed by sprinting for 30 s (Load (0.075 $kg \cdot kg^{-1}$ weight) [21]. A friction-braked cycle ergometer (Monark model 864 Crescent AB; Varberg, Sweden) was adopted to acquire measurements. The bicycle seat and handlebars were adjusted individually according to the length of the legs and arms of each participant. First, the athlete was asked to sit on the saddle and extend his legs; then, the knee angle was set to approximately 25–35°. Warm-up was performed for 4 min at a load of 50 watts and a speed of 80 rpm. The actual measurement was tested as follows. The main tester counted 5-s before the start and gave with the "start" sound. The assistant tester increased the load on the bicycle to reach the target intensity, and the athlete pedaled at maximum capacity for 30 s. The revolution per minute (RPM) was recorded every 5 s, and the tester calculated the peak power and fatigue index using the maximum RPM and minimum RPM and used this data to calculate load, as follows: Peak Power/Weight = (maximum RPM/12 × kp × 6/0.0833/6.123)/Body Weight; Fatigue Index = (maximum

RPM − minimum RPM)/100. The test was completed by repeating three sets, with an interval of 2 min between sets [22].

2.4 Measurement of isokinetic strength and dynamic balance in the knee

Next, we measured the extensor and flexor muscle strengths of the knee joints with an isokinetic device (Humac Norm; CSMi, Stoughton, MA, USA), a computer-controlled device that adjusts both resistance and speed [23]. Measurements were set at angular velocities of 60 and 180°/s with concentric contraction; muscle strength was 60°/s and muscle power was 180°/s. Extension measured the strength of the quadriceps while flexion measured the strength of the hamstrings. First, the athlete was asked to sit in an examination chair. Then, the examiner aligned the anatomic axis with that of the machine and the lateral epicondyle of the femur. Next, the examiner explained the test method, conducted various exercises, and provided demonstrations to aid participant understanding. The range of motion in the joint being tested was from 0° extension to 90° flexion, and the test was only conducted after the participant had gained adequate practice. Tests were initiated in the flexed state. On the initiation of a signal, extension was performed, and flexion was performed in the extended state. The actual test was repeated four times. Newton meters (Nm) were recorded at 60°/s, and watts were recorded at 180°/s. Values for extension and flexion were summed and divided by the body weight, as shown in the following formula: (extension + flexion)/body weight [24].

Next, we measured dynamic balance ability with a Y-balance test (YBT) equipment (Y Balance Test™, Ceder Park, TX, USA) [25]. The tester explained the test process, and provided an appropriate opportunity for practice. The athlete stood on an examination table with one leg and was asked to maintain balance. Using the tips of the toes of the other foot, the athlete then pushed the measuring device as far as possible in the anterior (ANT), posterior, posteromedial (PM), and posterolateral (PL) directions. If the foot touched the ground or balance was lost, the test was a failure and it was retested. Measurements were tried twice in each of the three directions, and the highest value was recorded finally [26].

2.5 Intervention training

2.5.1 High-intensity interval training (HIIT)

In this study, we used a HIIT program that involved a running-based sprint protocol [27, 28]. Three sessions per week were conducted during 12 sessions over four weeks. The sprint protocol used a 400-m track, and featured running for 30 s at maximum effort followed by 30 s of slow running with incomplete rest intervals. During exercise intervals, the heart rate per minute was set in the range of a minimum of 80% to a maximum, and during incomplete rest, the heart rate was not allowed to fall below 50% to 65%. One set of training was completed after repeating the procedure five times and taking a complete rest for 10 min. Approximately one hour of HIIT was conducted, and a total of four sets were repeated. The heart rate was monitored with an electric device (Polar H10, Polar Electro, Bethpage, NY, USA) (Table 1).

2.5.2 Moderate intensity continuous training (MICT)

The MICT program consisted of 12 sessions over 4 weeks, similar to that of the HIIT group. The MICT group exercised continuously at moderate intensity using a trek and trained in the range of 65–75% of the maximum heart rate predicted using a heart rate monitor [29]. The test consisted of two sets of 20 min each, with a complete rest period of 10 min. The heart rate was monitored using equipment similar to that used for the HIIT, thus enabling the athletes and trainers to monitor progress (Table 1).

2.5.3 Resistance training

In addition to intervention training, the HIIT and MICT groups underwent core training and body weight strength training equally. Following intervention training and a period of sufficient rest, all participants gathered in a professional room and conducted the training together for 30 min under specific instructions and monitoring by the trainer. Training included squats, lunges, exercise balls, conservative training, crunches and lunges (Table 1).

2.6 Data analysis

Statistical analyses were performed using SPSS (version 21.0; IBM, Armonk, NY, USA). All continuous variables are expressed as the mean and standard deviation, and data relating to the position and injured area are expressed as numbers and percentages. First, a normality test was performed using the Shapiro-Wilk test; variables were found not to conform to the normal distribution. Therefore, Mann-Whitney non-parametric analysis was used to compare the two interventions, and the Wilcoxon test was used to compare groups before and after each intervention. The significance criterion was adopted at $p < 0.05$.

3. Results

3.1 The participant's profiles

Participants were divided into two intervention and general profiles were compared. Although the two groups were randomly allocated, there were no significant differences in age, height, weight, rehabilitation period, athletic career period or injury site ($p > 0.05$) (Table 2).

3.2 GXT comparison

The VO_2 peak increased after intervention in both the HIIT and MICT groups ($p < 0.05$). Furthermore, both intervention training sessions exerted a significant effect on AT ($p < 0.05$). The ratio of 1-min heart rate during the recovery period was significantly higher in the HIIT ($p < 0.05$) than MICT ($p < 0.05$) groups. There was no significant change in VO_2 peak, AT, exercise duration, and the 1 min heart rate during recovery when compared between the groups before training ($p > 0.05$); however, there was a significant difference in the measured parameters after training ($p < 0.05$) (Table 3).

TABLE 1. Training program of high-intensity interval training and moderate-intensity continuous training.

	HIIT			MICT
	Training target HR		Resting HR	Training target HR
Set 1	5 min 80% HR		50% HR	
		10 min recovery		20 min 65–75% HR
Set 2	5 min 85% HR		55% HR	
		10 min recovery		10 min recovery
Set 3	5 min 90% HR		60% HR	
		10 min recovery		20 min 65–75% HR
Set 4	Maximum HR		65% HR	
		10 min recovery		10 min recovery
	End of intervention training and complete rest			
Group training	Core stability strength training, squats, lunges, exercise ball and conservative training, crunches frank training			

HIIT: high-intensity interval training; MICT: moderate-intensity continuous training; HR: heart rate.

TABLE 2. The participant's profiles of both groups.

Variables	HIIT (n = 25)	MICT (n = 25)	t or χ^2	p-value
Age, yr	16.2 ± 1.4	16.5 ± 1.2	−0.250	0.713
Height, cm	174.9 ± 6.3	174.3 ± 6.0	0.155	0.877
Weight, kg	64.7 ± 6.2	66.7 ± 7.0	−1.066	0.291
BMI, kg/m^2	21.1 ± 1.1	21.2 ± 1.6	−1.861	0.068
Player history, yr	4.4 ± 2.1	4.7 ± 2.7	0.321	0.851
Rehabilitation duration, weeks	6.5 ± 2.6	6.1 ± 1.9	0.341	0.669
Position, n				
Defender	8	10		
Midfielder	14	11	0.670	0.716
Forward	3	4		
Injury site, n				
Lower extremity	20	19		
Low back and trunk	3	5	0.584	0.430
Shoulder and arm	2	1		

HIIT: high-intensity interval training; MICT: moderate-intensity continuous training; BMI: body mass index.

3.3 Anaerobic power and fatigue index

Peak power, a parameter that refers to anaerobic power as determined by the Wingate test, increased significantly after intervention compared to before in both groups in sets 1 and 2 ($p < 0.05$). However, in set 3, only the HIIT group exhibited an increase; however, there was no significant change in the MICT group. The fatigue index before and after training improved significantly in all sets in the HIIT group ($p < 0.05$); however, no significant changes were detected in three sets in the MICT group ($p > 0.05$) (Table 4).

3.4 Isokinetic strength and dynamic balance

We identified a significant improvement in isokinetic knee strength only in the HIIT group at 60°/s. At 180°/s, there was a significant improvement in muscle power after training in both the HIIT and MICT groups ($p < 0.05$). However, there was no significant changes in the YBT before or after intervention in either group (Table 5).

4. Discussion

High football performance requires on both the endurance and sprint capacities of athletes. During the rehabilitation period following injury it is very difficult to maintain performance-related fitness due to detraining [10]. Therefore, we compared the effects of running-based sprint HIIT and MICT in young football players over a period of four weeks. We observed improvements in cardiorespiratory fitness, AT, and exercise duration in both intervention groups (Table 3). In addition, we found that HIIT improved both anaerobic power and fatigue in

TABLE 3. Comparison of changes in the graded exercise test following both training protocols.

Variables	Group	Pretest	Posttest	% Difference	*p*-value
VO_2 peak, mL/kg/min					
	HIIT	50.8 ± 5.8	56.9 ± 5.0	12.0	<0.001
	MICT	51.3 ± 4.5	54.6 ± 4.6	6.4	0.004
	p-value	0.283	0.007		
Exercise duration, s					
	HIIT	15.5 ± 1.2	17.1 ± 1.2	10.3	<0.001
	MICT	15.6 ± 1.6	16.7 ± 1.7	7.1	0.008
	p-value	0.201	0.031		
AT, %					
	HIIT	58.0 ± 5.2	67.9 ± 5.3	17.0	<0.001
	MICT	57.7 ± 3.5	64.5 ± 4.3	11.8	0.006
	p-value	0.793	0.011		
Peak HR, %					
	HIIT	183.3 ± 8.3	180.0 ± 9.6	−1.8	<0.001
	MICT	185.5 ± 8.2	182.1 ± 8.4	−1.8	<0.001
	p-value	0.320	0.379		
Recovery 1 min HR, %					
	HIIT	52.7 ± 5.4	63.3 ± 4.3	20.1	<0.001
	MICT	54.2 ± 6.8	59.7 ± 5.8	10.1	0.002
	p-value	0.360	0.010		

Abbreviations: HIIT: high-intensity interval training; MICT: moderate-intensity continuous training; HR: heart rate; VO_2 peak: volume oxygen peak; AT: anaerobic threshold.

TABLE 4. Peak power and fatigue index, as determined by the Wingate test.

Variables	Group	Pretest	Posttest	% Difference	*p*-value
P.P 1set					
	HIIT	11.1 ± 0.8	12.4 ± 1.2	11.5	<0.001
	MICT	10.7 ± 1.0	12.1 ± 0.8	12.4	<0.001
	p-value	0.304	0.241		
P.P 2set					
	HIIT	11.0 ± 1.0	11.9 ± 0.9	8.4	<0.001
	MICT	11.1 ± 0.8	11.6 ± 1.1	4.4	0.036
	p-value	0.678	0.220		
P.P 3set					
	HIIT	9.4 ± 0.8	11.3 ± 0.9	20.2	<0.001
	MICT	9.0 ± 1.1	9.1 ± 1.6	1.2	0.661
	p-value	0.120	<0.001		
F.I 1set					
	HIIT	57.1 ± 7.7	52.0 ± 5.7	−8.9	0.042
	MICT	58.2 ± 8.0	52.5 ± 9.0	−9.8	0.009
	p-value	0.196	0.792		
F.I 2set					
	HIIT	62.7 ± 9.2	57.1 ± 7.1	−8.9	0.037
	MICT	62.5 ± 8.3	56.8 ± 4.7	−9.2	<0.001
	p-value	0.449	0.832		
F.I 3set					
	HIIT	66.9 ± 9.8	61.3 ± 6.9	−8.3	0.045
	MICT	67.0 ± 8.6	65.3 ± 7.6	−3.0	0.536
	p-value	0.249	0.044		

Abbreviations: HIIT: high-intensity interval training; MICT: moderate-intensity continuous training; P.P: peak power; F.I: fatigue index.

TABLE 5. Comparison of isokinetic strength and Y-balance test for both methods.

Variables	Group	Pretest	Posttest	% Difference	*p*-value
Knee 60°/s, Nm/kg					
	HIIT	391.8 ± 42.1	431.9 ± 37.2	10.2	<0.001
	MICT	388.8 ± 51.2	401.7 ± 44.4	3.3	0.370
	p-value	0.629	0.019		
Knee 180°/s, Nm/kg					
	HIIT	645.9 ± 72.4	695.1 ± 72.8	7.6	0.022
	MICT	636.6 ± 80.8	671.6 ± 82.8	5.5	<0.001
	p-value	0.155	0.026		
Anterior direction, cm					
	HIIT	69.6 ± 7.0	71.7 ± 5.7	3.0	0.301
	MICT	71.9 ± 7.7	73.9 ± 5.2	2.8	0.281
	p-value	0.240	0.409		
Posterolateral direction, cm					
	HIIT	82.2 ± 8.5	82.6 ± 7.1	0.5	0.816
	MICT	82.7 ± 7.1	84.5 ± 8.7	2.2	0.187
	p-value	0.239	0.956		
Posterolateral direction, cm					
	HIIT	84.1 ± 6.2	84.8 ± 5.3	0.8	0.656
	MICT	85.0 ± 8.4	86.9 ± 8.3	2.2	0.282
	p-value	0.891	0.140		

Abbreviations: HIIT: high-intensity interval training; MICT: moderate-intensity continuous training.

set 3 (Table 4).

In addition, we compared VO_2 peak between the HIIT and MICT groups over a long period. Our results were similar to those of previous studies. Both training programs led to improvement, although athletes in the HIIT group tended to perform slightly better. Russomando *et al.* [30] reported that HIIT was more effective in decreasing body fat ratio (−5.7 *vs.* −8.2%) and increasing VO_2 peak (+3.2 *vs.* +5.7 mL/kg/min) than MICT with 6 weeks of training 3 times a week. A similar soccer player study conducted interval training and continuous training sessions three times a week for soccer players in their 20s, for a total of 16 sessions. The results reported that interval training was not only a more suitable training method for improving performance than continuous training but also led to a greater improvement in VO_2 peak [31]. Moreover, the effects of HIIT were noticeable even in the general public. HIIT and MICT were performed on untrained people for 8 weeks, and the effects of the two trainings were compared after stopping training for 4 weeks. The results showed that HIIT showed significant improvement in VO_2 and 7 cardiovascular indices (lipids, blood pressure, glucose, *etc.*), but MICT improved only 3 variables, and the effect of HIIT tended to persist even after training was stopped [32]. However, Andreato *et al.* [29] reported important concerns relating to these results, including the fact that it was difficult to provide the same exercise and rest volumes for these two training programs; therefore, the superior effect of HIIT described in this previous study could potentially be attributed to design challenges.

In the present study, the anaerobic power test revealed that the peak power and fatigue index only improved in the HIIT group in set 3. An earlier trial stated that HIIT leads increased glycolytic activity following the accumulation of lactate, thus favoring a higher rate of adenosine triphosphate production [33]. However, another study reported that HIIT did not improve anaerobic power in well-trained cyclists; the authors further considered that 6 weeks of training would have been too short to provide meaningful improvements [34].

In football, the quadriceps enable jumping, sprint, and shooting, whereas the hamstrings act as antagonist muscles of quadriceps, controlling running activities and improving the stability of the lower extremities during turns and tackles. The roles of these two muscle groups of knee require greater function for joint stability in the situation of high speed of performance [35]. In this study, knee strength at 60°/s only changed in the HIIT group, whereas improvement was detected in both training groups at 180°/s (Table 5). Previous study reported that high intensity training does not thicken the cross-sectional area of the muscle but increases the cross-sectional area ratio of type II muscle fibers, which are fast-twitch fibers [36]. In addition, HIIT increases muscle strength by inducing coordination in both the muscular and nervous systems [37]. However, if the goal is to improve muscle function, HIIT may be more dominant, although the positive effects of MICT training should not be overlooked.

The findings of this study revealed improvements in football-related physical fitness following HIIT as well as

MICT, thus demonstrating the superior efficacy of HIIT. However, the YBT revealed no improvement in either group (Table 5). This test requires improvement in the close interaction between the central and motor nerves of the knees and the lower extremities. Running-based training, which focuses on straight running, is limited by its ability to provide balance stability at various angles and under fast and dynamic conditions. Similar results have also been reported in previous studies. For example, in one study, youth football players were trained using HIIT for eight weeks and were evaluated for both speed and agility; analysis revealed that HIIT improved both speed and acceleration, but did not improve agility [12]. These findings revealed that as with balance, agility requires a mechanism that connects the receptors that receive sensory information, the transmission of information from the central nervous system, and the rapid interpretation of information following stimulation of the motor nerves. It is possible that the 4-week period was not sufficient for the development of stimuli [38]. However, existing data providing evidence for improvements in dynamic stability and agility after four weeks of aerobic training in young men suggest the need for additional research [39].

Previous studies have reported the benefits of HIIT, although there is clear inconsistency in previous findings [40, 41]. The present study had several limitations that need to be considered. Since our study involved injured athletes, the reduction in fitness may have been temporary; therefore, natural recovery was possible. As such, caution is required against overinterpretation of the findings because there was no control group. Furthermore, our analysis was limited to male adolescents and only investigated a short-term effect over four weeks. In 4 weeks training of two bicycle training methods for youth football players, HIIT achieved greater levels of improvement than MICT [15]. Nevertheless, we cannot rule out the possibility of more positive results arising from the long-term effects of MICT. Furthermore, it was not possible to fully control the training conducted individually in addition to the specific intervention training or the potential effects of different football positions. Nevertheless, confirming the short-term effects of HIIT in adolescents can positively influence issues related to injury prevention by avoiding HIIT failure, and can provide useful information to leaders and rehabilitation experts.

5. Conclusions

Four weeks of short-term HIIT and MICT resulted in improvements in VO_2 peak, exercise duration, AT, anaerobic power, fatigue index, and lower limb strength. Following intervention and compared to MICT, HIIT led to a significantly higher VO_2 peak, exercise duration, anaerobic threshold, peak power, fatigue index of set 3, isokinetic strength, and muscle power. Collectively, these results show that short-term running-based HIIT can effectively improve performance-related fitness in young football players and may represent a particularly useful training strategy for athletes returning to play during the final stages of rehabilitation.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the authors.

AUTHOR CONTRIBUTIONS

YK and JL—conceptualization; supervision. GFZ and YK—methodology; formal analysis; review and editing. JL—investigation. GFZ and JL—original draft writing. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Research Ethics Committee of the Gangneung-Wonju National University (GWNUIRB-R2020-16). All participants and their parents gave their written consent for examination and publication for the purpose of the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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