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ORIGINAL RESEARCH

Effect of high-intensity sports specific training and high-intensity interval training on sprained ankle male adolescent soccer athletes before return-to-play

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Abstract

Ankle sprain is a highly observed injury in soccer due to repeated strenuous movements. Rehabilitation after injury leads to decreased physical strength and muscle-joint function. The ankle sprained patients need improved soccer specific fitness and ankle function simultaneously. Therefore, current study aimed to compare high-intensity sports specific training (HISST) with high-intensity interval training (HIIT) to identify effective training for fitness and lower-extremity functions. A total of 56 high school male soccer players (HIIT: 28, HISST: 28) who survived the acute phase due to ankle sprain participated the study. In the intervention period of 4 weeks, the HISST and HIIT groups were randomly assigned. Physical fitness and lower-extremity function tests were performed before and after the intervention. Physical fitness measurements included Volume Oxygen peak (VO_{2peak}), anaerobic power, isokinetic ankle eversion strength, while lower extremity function tests consisted of Y-balance and hop tests. In both groups, VO_{2peak}, exercise time, peak power, and eversion strength improved after the intervention, with significant improvement in all Y-balance subtests and hop tests ($p < 0.05$). Regarding the posteromedial and posterolateral directions of the Y-balance test, and the crossover of the hop tests, HISST was significantly higher ($p < 0.05$) than HIIT in the post-intervention test. Concludingly, HIIT and HISST can simultaneously improve VO_{2peak}, abductor strength, and lower extremity function in sprained ankle athletes before returning to competition. Additionally, HISST was slightly more effective than HIIT for mediolateral balance and crossover hopping.

Keywords

Ankle sprain; High-intensity sports specific training; High-intensity interval training; Fitness; Lower extremity function

1. Introduction

Ankle sprain (AS) is a common injury in sports such as soccer due to repeated strenuous movements such as running, jumping, spinning, sprinting, tackling, and physical contact [1]. The injury involves increased length or rupture of the anterior talofibular or calcaneofibular ligaments as the ankle is inverted [2]. Nearly 75% of high-activity sports players experience AS injuries, with repeated injuries rate of 12–47% [3, 4]. Proper management of AS is necessary since many athletes develop chronic ankle instability due to the high recurrence rate although the initial injury is [3, 5]. Approximately 40% AS cases are due to chronic ankle instability [6]. The AS is more prevalent in adolescents than in adults (1.94 *vs.* 0.72 per 1000 exposures) [7] as ligaments and muscle strength are still at developing stage in adolescents than in adults [8, 9]. Mandorino *et al.* [10] reported that AS injury chances are higher in highly skilled athletes especially with injured previously, fatigue accumulation, and limb asymmetry. Similarly, limited exposure to proper education and programs related to injury prevention increases risk of AS [11].

Non-serious injuries, are usually managed by conservative treatments, *e.g.*, immobilization, physical therapy, and rehabilitation [12]. In the early rehabilitation phase, athletes experience decreased fitness owing to the discontinuation of high-intensity training [13]. After 30 days discontinued training, optimum exercise potential of triathletes decreased by 4.7% [14]. Maximum aerobic speed decreased by 3.02% in a youth soccer player restricted from training for 9 weeks due to the COVID-19 lockdown [15].

Players preparing for a return to play after rehabilitation should be fit just like their pre-injury condition. In soccer, although the aerobic system is chief energy supplier, anaerobic fitness is also required due to the frequent high-speed running [16]. High-intensity interval training (HIIT) effectively addresses these requirements [17]. In HIIT, short-duration, high-intensity, explosive anaerobic exercise is exchanged with short recovery time until exhaustion effectively improving both aerobic and anaerobic ability [18]. In national soccer athletes, twice a week HIIT for 8 weeks led to a 5.7% increase in VO_{2peak}, *i.e.*, from 51.92 to 54.87 by [19].

For AS patients, fitness recovery is important to improve performance for playing soccer. Similarly, improved neuromuscular control of the ankle facilitates skill implementation and prevents re-injury [20, 21]. Training improving the neuromuscular control system consist of movements frequently seen during soccer, such as zigzags, turns, and jumps, and techniques that enhance proprioceptive nerve responses using tools such as BOSU® or balance boards [22]. Sports specific training for athletes' trains muscles and joints for soccer characteristics, including improvement of the neuromuscular system, proprioception, agility, and energy supply system [23, 24]. High-intensity sports specific training (HISST) was designed for this purpose. The HISST for soccer involves aerobic fitness by sports specific movements, and lower extremity strengthening exercises [24–26].

Less data exists about HISST than HIIT, and there are few studies comparing both types. Therefore, this study was designed to compare improvements in aerobic fitness, ankle strength, and function changes in the lower extremities by HISST and HIIT in adolescent soccer players preparing to return after sprained ankle. The hypothesis of this study is that fitness and function will improve in both trainings, and there will be a difference between the two groups in lower extremity function.

2. Materials and methods

2.1 Experimental process

The sprained ankle male adolescent soccer players of this study visited a sports rehabilitation center, completed a rehabilitation course, and were preparing to return to play. The player's participation in the study was voluntary through the center's bulletin board and internet notice and written informed consent was obtained from the players, their guardians, and the team coach. A consultation session of volunteer participants was arranged with the staff for their initial visit. The counseling content included ground position, injury location, injury frequency, mechanism, treatment history, rehabilitation participation period, and history of other injuries, and other diseases.

Participants were allowed to discontinue any time during the experiment without any penalty. This study received ethics approval and consent to participation.

The physical and mental fitness of participants were examined by a physician allowing only the fit athletes as study participants. Physical fitness and lower extremity function tests were conducted at baseline and interventional exercises were performed for 4 weeks. The physical fitness tests included graded exercise test (GXT) for aerobic fitness, Wingate test for anaerobic fitness, and isokinetic ankle eversion test for ankle strength. The Y-Balance test (YBT) and hop test were used to measure lower extremity function. All tests were conducted after sufficient explanation, demonstration, and practice by the measurer to enhance the understanding of the participants. Each test was conducted by the same measurer, and a break of at least 30–60 minutes was provided to block the mutual interference effect between tests.

2.2 Participants of the research

The sample size was derived using a dedicated software (G*Power 3.1, Universität, Düsseldorf, NRW, Germany). The calculation was based on Wilcoxon signed-rank test, effect size dz = 0.5, α error = 0.05, and power (1-β err prob) = 0.80. The results revealed that 28 samples were required for each group, leading to a total of 56 patients. Hence, 56 male adolescents (aged 15–17 years) were included in this study. After consulting with the players and guardians, 28 participants were randomly assigned both to the HIIT (n = 28) and HISST (n = 28) groups. The participants were young soccer players who suffered an AS injury and visited the rehabilitation center continuously. Players with AS injuries were excluded if the acute phase of the injury had passed long ago, and without ankle pain or swelling symptoms. General medical treatment was provided to participants during the acute phase. The inclusion criteria were patients with an AS injury by inversion mechanism, who had discontinued high-intensity training and team training for more than 1 month, capable of maximum running and cycling after the inflammatory and regenerative phases of the injured area. The volunteers with a history of lower limb surgery, severe pain (visual analog scale; VAS $\geq$6), eversion mechanism injury, inability to stand on one leg or hop at all, and with severe visual edema were excluded.

2.3 Graded exercise test (GXT)

The GXT used was the Bruce protocol on a treadmill as a measure of aerobic fitness (Volume Oxygen peak, VO_{2peak}) [27], with incremental advancements in speed and incline every 3 minutes. Inspiratory oxygen and expiratory carbon dioxide were measured with ventilation sensors (Quark CPET, COSMED, Rome, Italy). The peak test proceeded until the participants requested to stop, and the peak moment was when the participant gained rate of perceived exertion (RPE) $\geq$17, $\geq$1.10 respiratory exchange ratio, and 90% expected peak heart rate [28]. Data of participants who did not meet these criteria were excluded from the analysis. Blood pressure and electrocardiography (ECG) were continuously monitored and documented, and the chest pain scale, RPE, heart rate (HR), and blood pressure (mmHg) were recorded at each stage. The VO_{2peak}, exercise duration, and peak HR (formula = 220 - age, %) were evaluated by the GXT [29], and ventilatory thresholds and HR recovery rates during the 1-min recovery period were analyzed. At ventilatory threshold (VT), the energy supply system changes from aerobic to anaerobic due to increased exercise intensity, and lactate accumulation and ventilation suddenly increases [30]. For VT confirmation, a printed result sheet was used having every 10 s record of VO_2, Volume Carbon dioxide (VCO_2), and ventilation. The VT was determined at the inflection point of the rising slope of these values. The HR at that point was also noted [31].

2.4 Isokinetic ankle eversion strength

The objective ankle strength of players was assessed by Humac Norm isokinetic (CSMI, Stoughon, MA, USA) equipment [32] (Fig. 1a). In the test mode, ankle inversion and eversion indicated angular velocity of 30 and 120°/s of concentric contraction. To familiarize with the equipment, observations of other players' measuring, explanations, and demonstrations by the measurer and four practice repetitions were allowed. The test was conducted after confirming players consented for the test with sufficient understanding. The applicant was positioned supine with both hands held together. The feet with sneakers were lifted making 90° between hip and knee joint. The chest, waist, knees, and feet were banded with pads and belts to prevent body movements during the test. The athletes performed four practice sessions and four test measurements. The measured values were analyzed as the absolute peak value (Nm) and relative peak value (Nm/kg) using the highest value. Only eversion strength was used during analysis due to substantially weak eversion muscles by the inversion mechanism.

2.5 Wingate test

The Wingate test using a bicycle ergometer is widely used to evaluate anaerobic power in athletes [33]. A Monark bicycle ergometer (Model 864, Varberg, Sweden) was used. The participant's weight was multiplied by 0.075 for a starting load, and the maximum ability test was applied for 30 s.

By repeating three sets, the anaerobic ability during the fatigued state was confirmed. The bicycle handle was adjusted properly based on the upper body, and the saddle height was adjusted according to the leg length, making a 25°–35° knee angle during extension. The participants performed a 5-min warm-up at 80 revolutions per minute (RPM). When the participants were ready, the inspection coordinator provided a "start" sound and simultaneously applied the starting load (body weight (kg) multiplied by 0.075 (constant)). The participants resisted the load for 30 s to exert the maximum RPM, and the examiner recorded the RPM every 5 s. Three sets were performed, with 2 min rest between sets for incomplete rest [34]. The fatigue index was calculated as the difference between the highest and lowest RPM. The higher the peak power and fatigue index indicated the better fitness of the athlete.

2.6 Y-balance test as lower extremity function test

The YBT device (Move2Perform, Evansville, IN, USA) was used to measure lower extremity postural control ability during dynamic one-leg balance test [35] (Fig. 1b). The participants were tested on the uninjured and the AS side respectively. The initial position involved standing with the test foot on the central platform maintaining the central position on one leg. In the test protocol, the foot on the test side was placed in the center of platform and the marker was sent as far as possible in the anterior, posteromedial, and posterolateral directions with the opposite foot (outstretched foot). When the volunteer's outstretched foot touched the ground, it was not recorded, and the test was repeated. After measuring each direction twice, the higher distance was analyzed. Bilateral leg length was measured from the anterior superior iliac crest to the medial malleolus. The YBT score was calculated as follows: YBT score = ((sum of the three directions, cm)/(leg length, cm $\times$ 3)) $\times$ 100.

2.7 Hop tests as lower extremity function test

The hop tests, being lower extremity function tests, measure the distance and duration of one leg jumping. There are four inspection configurations: single, triple, crossover and 6-m [36]. Single, triple, and crossover were recorded as distances (cm) and 6-m was recorded as time (s). The uninjured leg was tested first followed by the AS side. All tests were performed with the participants standing on one leg at the starting line, and the maximum hop test was conducted after the "start" signal. In the single-hop test, the participants jumped forward simultaneously, and in the triple-hop test, the participants jumped forward thrice continuously. The crossover hop test was conducted similarly to the triple test but moving left and right based on the centerline. Finally, the 6-m hop test helped measure the fastest time to pass 6-m, regardless of the number of jumps. The tests were performed twice, and the higher value was used for analysis.

2.8 Intervention program

Training was arranged for 60–70 min, including a 10–15 min warm-up, 40-min main intervention (HIIT or HISST), and a 10–15 min cool-down. Twelve intervention sessions were performed for 4 weeks, 3 days per week.

HIIT: Running-based HIIT for soccer players was constructed as reported earlier [37, 38]. Interval training consisted of a total of 5 sequences, for 40-min. To reflect the characteristics of a soccer game with frequent short sprints, one sequence was 6-min, and a 10-s sprint and a 20-s incomplete break were repeated 12 times. Complete rest between sequences was provided for 2 minutes. For the target exercise intensity, HR was measured when GXT indicated $\geq$90% VO_{2peak}, and the suitable exercise intensity was evaluated using a HR monitor interface (Polar RS400, Polar Electro OY, Kempele, Finland). A level of $\geq$50% was maintained even during an incomplete break between intervals. A treadmill or field track was used, and the researcher managed using a stopwatch.

HISST: The HISST aimed to improve overall athleticism, agility, speed, power, endurance, and muscle strength while specifically targeting movements required in soccer. HISST was designed and implemented similarly to the intensity, time, and volume of HIIT. HISST consists of side steps, zigzag runs, ladder runs, shuttle run, and plyometrics instead of HIIT sprints [24–26]. However, this sequence was conducted for 30 minutes, and strength training was conducted for 10 minutes, making up a total of 40 minutes. For strength training to improve strength and power, five lower extremity machines were mainly used: leg extension, leg press, leg curl, inner thigh, and hip abduction. According to the training principle of American College of Sports Medicine (ACSM) [28], 12

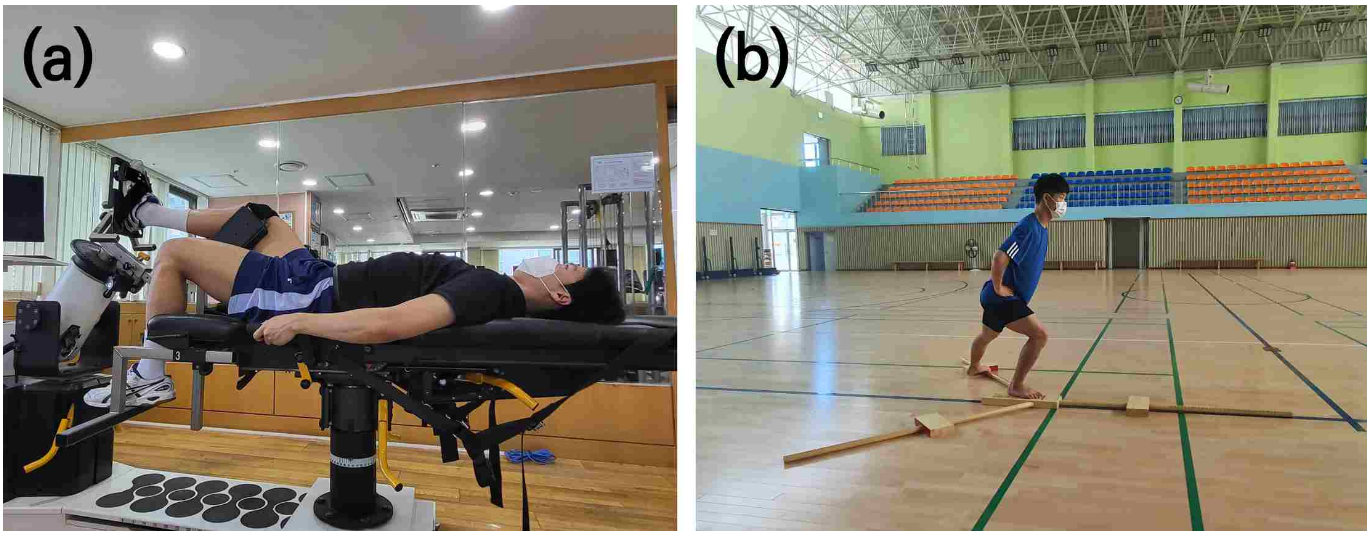

FIGURE 1. Testing position. (a) isokinetic eversion strength, and (b) Y-balance test.

repetitions were performed at a fast pace with 80% weight of 1RM (maximum value of 1 repetition), and 3 sets were repeated.

2.9 Data analysis

IBM SPSS 25.0 Statistics software for Windows (IBM Corp., Armonk, NY, USA) was used for analysis. Numerical data are presented as means and standard deviations, while category data are expressed as numbers and percentages. Shapiro-Wilk tests were used for normality. As the main variables analyzed in this study were not normally distributed, a non-parametric analysis was performed. The Wilcoxon test was performed before and after intragroup comparisons, and the Mann-Whitney U test was used for intergroup comparisons. The significance level was set at $p < 0.05$.

3. Results

3.1 General characteristics

Table 1 summarizes the differences in the general characteristics of HIIT and HISST. There were no significant differences in age, weight, height, BMI, position or injured side of either group. Recurrent AS injuries accounted for approximately half of all cases. No significant differences were observed between the groups.

3.2 Graded exercise test

Table 2 details the GXT. The VO_{2peak}, exercise duration, ventilatory threshold, peak HR and HR recovery at 1 min significantly improved in both groups.

3.3 Isokinetic ankle eversion strength

Fig. 2 denotes the effects of the isokinetic eversion muscle strength test on the participants' ankles. Both types of training showed a significantly improved muscle strength after training. These significant changes were observed in absolute values (Nm), and relative values (%), considering body weight. An independent t-test was conducted to compare both groups. However, there was no significant difference between the groups in the pre- and post-intervention tests.

3.4 Wingate test

Both groups showed improved peak power and fatigue in sets 1–3. However, HIIT showed significantly decreased peak power and fatigue in 3rd set compared to 1st set, whereas HISST did not exhibit any significant change. This indicates that the anaerobic potential of the HISST group was well maintained up to the 3rd set as compared to the 1st set, whereas the HIIT group maintained up to the 1st and 2nd sets and decreased in the 3rd set (Fig. 3).

3.5 Lower extremity function test

Fig. 4 shows the YBT results, as variables of lower extremity function. In the YBT, the anterior, posterior medial, and posterolateral distances and YBT scores significantly improved after the intervention in both groups. In the posteromedial and posterolateral directions, no significant difference between the groups in the pretest was observed. However, the posttest value was significantly different in both groups.

Single, triple, crossover, and 6 m hop tests significantly improved after the intervention in both groups. However, the HISST group showed a significantly higher crossover test value than the HIIT group in the post-intervention test (Fig. 5).

4. Discussion

This study aimed to confirm the effect of HISST and compare HIIT and HISST for improving fitness and lower-extremity function in adolescent soccer athlete participants of AS rehabilitation. HISST training is distinct from HIIT and includes complex and dynamic movements maximizing muscles and joints performance in any sports *e.g.*, soccer, basketball, and baseball [39, 40]. Since the program can be configured according to the type of sports, HISST is not standardized and can be more easily adapted to sports-specific movements than HIIT. HISST can include a combination of aerobic and anaerobic trainings, dynamic balance and jumps training, and neuromuscular and

TABLE 1. Differences in general characteristics of both groups.

Variables	HIIT (n = 28)	HISST (n = 28)	t-value or χ^2	p-value
Age, yr	16.4 ± 1.3	16.0 ± 0.7	−1.670	0.624
Height, cm	176.6 ± 2.6	177.9 ± 3.5	−5.325	0.217
Weight, kg	63.4 ± 3.1	63.7 ± 3.4	−2.976	0.538
BMI, kg/m^2	22.7 ± 1.6	21.9 ± 1.8	0.631	0.501
Rehabilitation duration, weeks	6.3 ± 1.3	6.4 ± 1.7	3.075	0.392
Position, FW/MF/DF	2/14/12	3/16/9	0.762	0.683
Injury side, right/left	12/16	10/18	0.299	0.785
Recurrence AS injury				
First	14	13		
Recurrence 2 times	10	13	1.198	0.274
Recurrence ≥3 times	4	2		

HIIT, high-intensity interval training; HISST, high-intensity sports specific training; BMI, body mass index; FW, forward; MF, midfielder; DF, defender; AS, ankle sprain.

TABLE 2. Comparison of changes in graded exercise test of both trainings.

Variables	Group	Pretest	Posttest	% Difference	p-value
VO_{2peak}, mL/kg/min					
	HIIT	48.7 ± 1.7	51.7 ± 1.5	6.2	<0.001
	HISST	49.9 ± 1.2	51.4 ± 1.3	3.0	<0.001
	p-value	0.886	0.520		
Exercise duration, s					
	HIIT	885.0 ± 84.9	997.6 ± 79.3	12.7	0.009
	HISST	900.9 ± 74.6	980.8 ± 90.2	8.9	<0.001
	p-value	0.098	0.120		
Ventilatory threshold, %					
	HIIT	63.5 ± 5.2	69.6 ± 8.9	9.6	0.039
	HISST	62.9 ± 8.2	68.2 ± 10.2	8.4	0.044
	p-value	0.603	0.158		
Peak HR, %					
	HIIT	93.6 ± 2.3	96.3 ± 1.8	2.89	0.015
	HISST	92.7 ± 2.0	95.8 ± 2.2	3.34	0.004
	p-value	0.509	0.411		
Recovery 1 min HR, %					
	HIIT	49.0 ± 9.0	60.8 ± 8.8	24.1	<0.001
	HISST	52.8 ± 6.5	59.2 ± 6.1	12.1	<0.001
	p-value	0.205	0.754		

$p < 0.05$; Abbreviations: HIIT, high-intensity interval training; HISST, high-intensity sports specific training; HR, heart rate; VO_{2peak}: Volume oxygen peak.

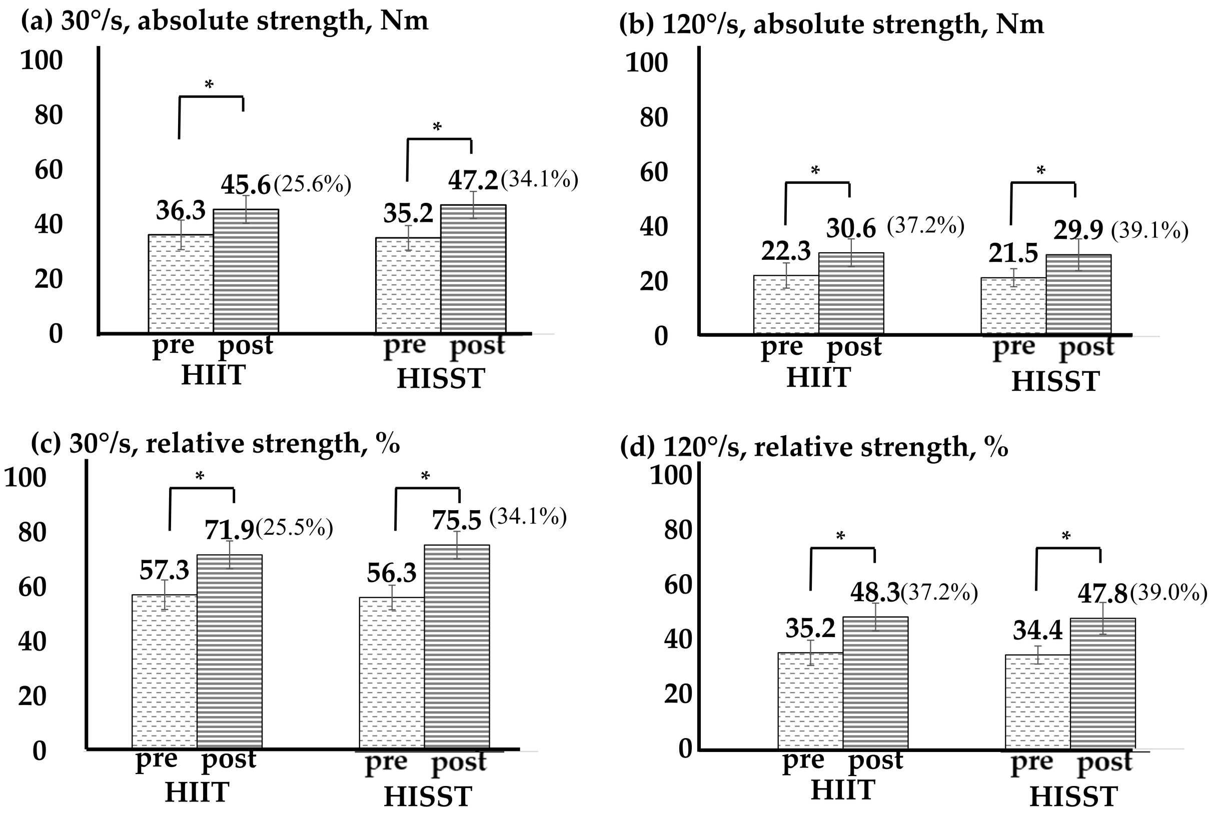

FIGURE 2. Comparison of changes in ankle isokinetic eversion strength in both groups. $*p < 0.05$; HIIT, high-intensity interval training; HISST, high-intensity sports specific training. (a) absolute strength of ankle eversion in angular velocity 30°/s; (b) absolute strength of ankle eversion in angular velocity 120°/s; (c) relative strength of ankle eversion in angular velocity 30°/s; (d) relative strength of ankle eversion in angular velocity 120°/s.

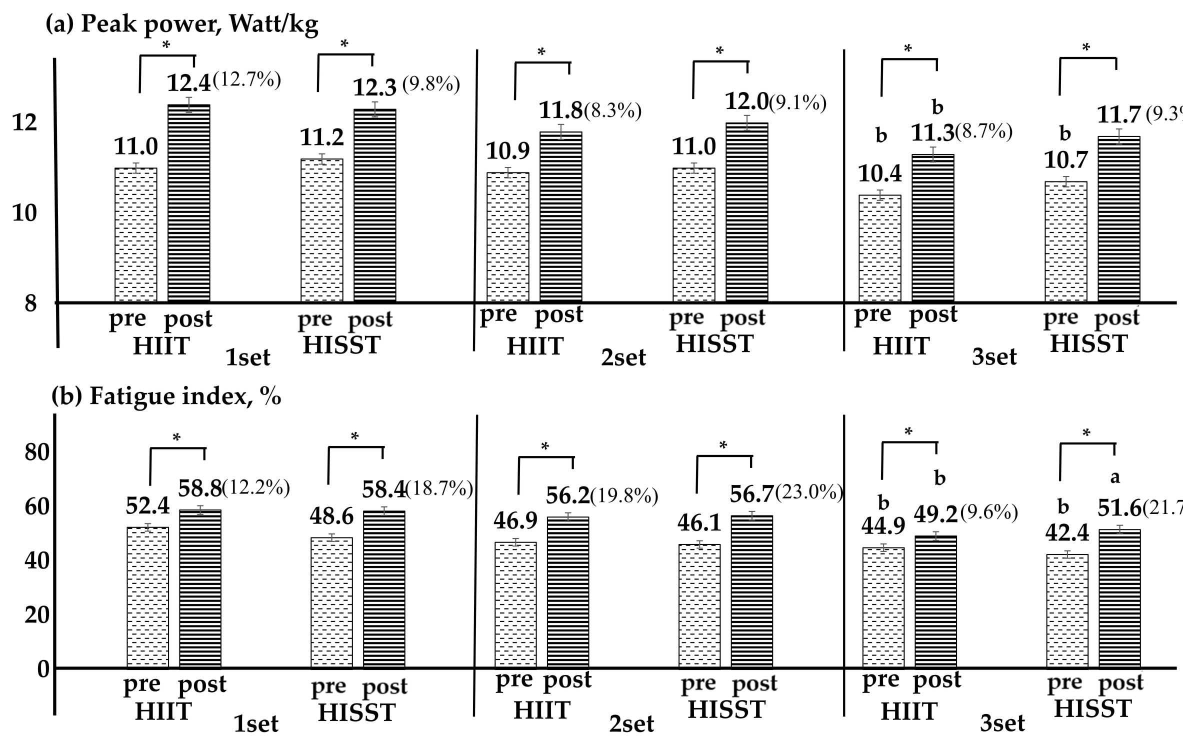

FIGURE 3. Changes in anaerobic power and fatigue in both trainings. $*p < 0.05$; a, comparison of HIIT and HISST; b, 1 set *vs.* 3 sets; HIIT, high-intensity interval training; HISST, high-intensity sports specific training. (a) peak power from 1st set to 3rd set; (b) fatigue index from 1st set to 3rd set.

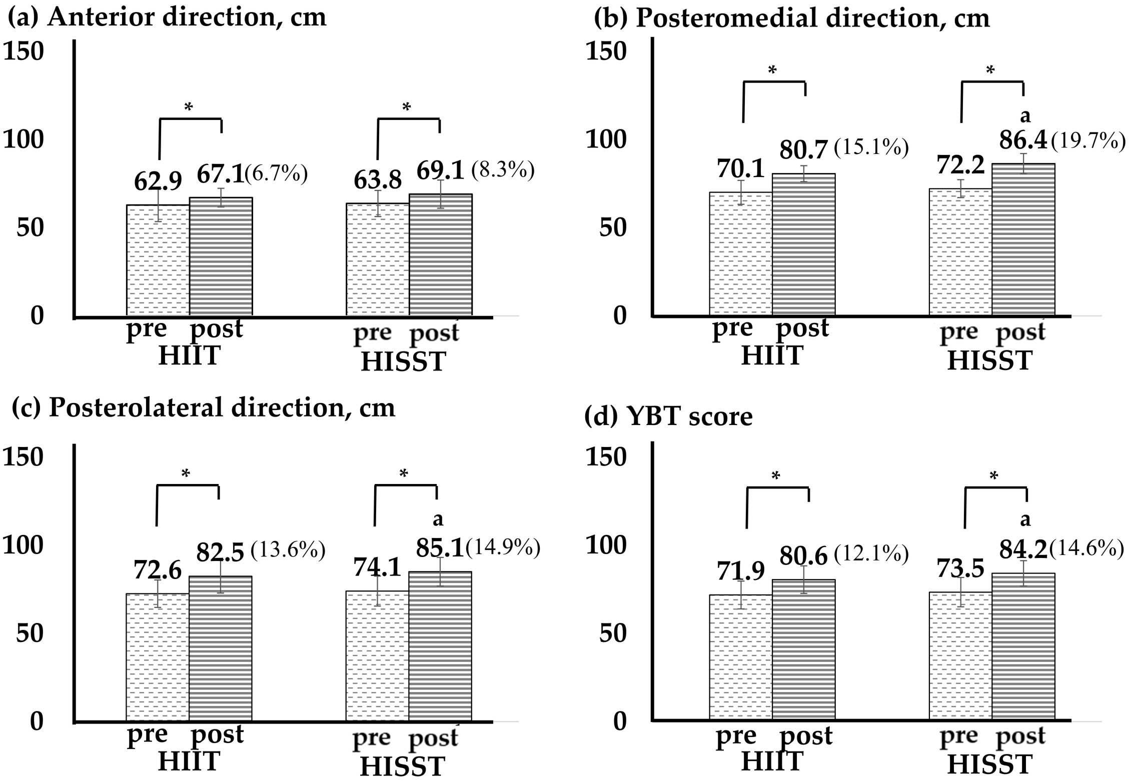

FIGURE 4. Changes in Y-balance test in HIIT and HISST. *$p < 0.05$; a, comparison of HIIT and HISST; HIIT, high-intensity interval training; HISST, high-intensity sports specific training; YBT, Y-balance test. (a) distance of anterior direction; (b) distance of posteromedial direction; (c) distance of posterolateral direction; (d) YBT score.

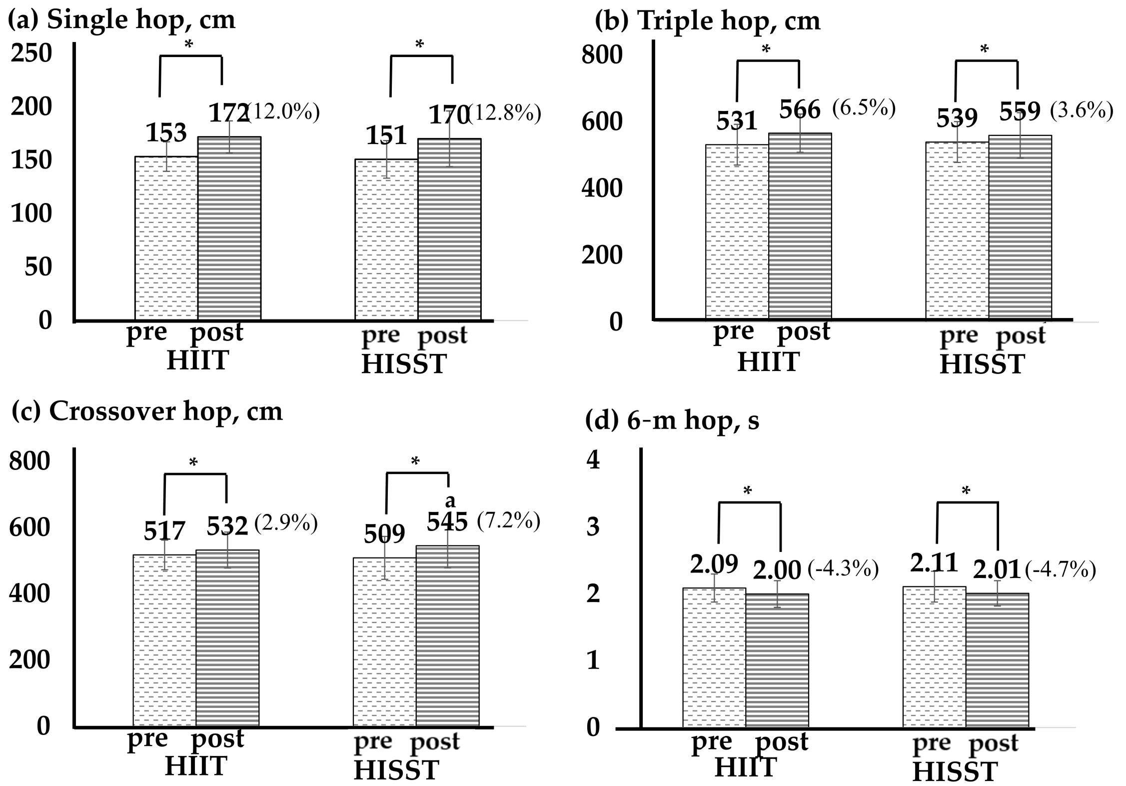

FIGURE 5. Changes in hop tests in HIIT and HISST. *$p < 0.05$; a, comparison of HIIT and HISST; HIIT, high-intensity interval training; HISST, high-intensity sports specific training. (a) distance of single hop; (b) distance of triple hop; (c) distance of crossover hop; (d) time of 6-m hop.

sports drills training. Hence, HISST has been traditionally used to restore playing in the final stages of rehabilitation [41]. Due the unique characteristics of HISST, some results of current study may have more effect as compared to HIIT.

The main finding of this study is that aerobic fitness increased in both the HIIT and HISST groups. Aerobic fitness is also known as VO_{2peak} and is the most representative value of physical fitness, expressing endurance capacity. This is the main benefit of high-intensity training as reported in many studies [42–44]. A meta-analysis of 24 studies on adolescent athletes revealed that VO_{2peak} improved by 7.2% after HIIT [45]. A 6 weeks' study of sports specific training of basketball players suggested a significant improvement in VO_{2peak} from 59 to 62 mL/kg/min [46].

These results suggested that both trainings sessions are effective, but some researchers have conducted psychological research for variety of programs. Functional trainings consisting of CrossFit®, HIIT and moderate interval continuous training (MICT) were conducted to compare subjective perceived hardship with RPE. Participants identified HIIT as the most difficult, followed by CrossFit® and MICT. Therefore, the actual training intensity experienced by those participating in CrossFit® may be lower than in HIIT [47]. Rather than HIIT and MICT performing the same movements of the running base, training consisting of multiple movements such as CrossFit® could reduce the phenomenon whereby the fatigue index is concentrated on some muscles due to the involvement of various muscles.

In soccer, playing time is mainly influenced by aerobic potential. Anaerobic capacity is specifically important when short runs, late game sprints, or jumps require continuous power generation while the individual is in a very exhausted state [48]. The Wingate test confirmed that anaerobic power increased in both the HIIT and HISST groups in current study, which is consistent with the results of earlier studies. Previously reported improved anaerobic threshold after 3-weeks of short-term HIIT in high school soccer players is consistent with results of current study [49]. Significant improvement in anaerobic capacity and VO_{2peak} after 8 weeks of plyometric training was observed in young soccer players [50]. High-intensity training increases the lactate threshold by increasing mitochondrial enzyme activity and reducing nonoxidative ATP generation, leading to a decreased lactate accumulation [51, 52].

Sports specific training adapts the muscle joints and muscle nerves for smooth performance during sports. Soccer specific drills of current study includes multi-directional running, landing, jumping, and sprinting. These movements sensitively activate proprioceptors such as muscle spindles and Golgi tendons in tissues and muscles around joints. Resultingly, improved neuromuscular control leading to the stable performance of movements is observed [53]. This study combined sports specific training with HIIT. Therefore, the evaluation included the hop test and YBT, which measures lower extremity function. Since dynamic leg balance enables dynamic sports activities, body movements such as dribbling, changing direction, and landing can be performed in soccer [54, 55]. This study revealed that the anterior YBT improved in both groups, but posteromedial and posterolateral YBT in the left and right directions improved only with HISST. Hence HISST would be more advantageous in inducing lower-extremity functional changes than the forward-running-based HIIT. The hop test and YBT of this study were similar to each other. Although the hop tests were significantly improved in both groups, the crossover hop requiring left and right movements was significantly higher in the HISST group than in the HIIT group after the intervention. Traditionally, one leg jump training has been widely used to activate proprioception in patients with ankle pain. A 6 weeks hop stabilization training of college basketball athletes with chronic ankle instability significantly improved the preparatory and reactive muscle activation, and muscle contraction onset time in the experimental group [56].

In the present study, isokinetic eversion strength was evaluated to objectively assess athletic muscle strength. In both HIIT and HISST groups, improved absolute value (Nm), and relative value (Nm/kg) were observed since both training sessions included weight-bearing high-intensity training leading to continuous muscle activity [57]. During the kinematics analysis in sports, the high angular velocity at the moment of "inversion injury" or "giving way" is more than 800°/s [58]. In current study, it was 30 and 120°/s, and both training groups improved significantly. Strength measurement at higher angular velocity is required in future studies when considering the injury and a training method increasing ankle stability at high angular velocity should be devised.

Although this study compared two different types of training, the same high-intensity training routine was used in both groups. The 4 weeks study duration is a relatively short period to improve fitness. Exercise physiologists reported that 2 weeks of high-intensity training can increase endurance exercise potential by increasing the maximum activity of the mitochondrial enzyme cytochrome c oxidase, leading to a 10–15% improvement [59, 60].

A typical characteristic of high-intensity training is superior time efficiency. Since the target HR during training is achieved by high-intensity training in a relatively short period of time, it is more effective in achieving a fitness level than endurance training with moderate intensity [47]. Previous study involving sessions thrice per week, similar to this study significantly improved VO_{2peak} and strength [61]. A study conducted twice weekly for 8 weeks positively improved the aerobic fitness [19]. Appropriate trainings should be imparted to growing adolescents highlighting the repetitive high-intensity trainings as a potential cause of injury.

Despite these valuable results, this study has several limitations. This study reported improvements in fitness and lower extremity function following short-term training, however, the durability of this effect is unknown. Flockhart *et al.* [62] physiologically analyzed the limits of high-intensity training and revealed that 3 weeks training increased mitochondrial function but decreased it after 4 weeks of recovery. Subsequently, repetition of HIIT for 4 weeks, quickly restored the function. These studies indicated that high-intensity training effects lasted for 4 weeks after the training ceased, although to a limited extent. Further studies are required to comprehend the long-term effects of these results on the VO_{2peak} and anaerobic power. Although many studies on short-term effects of sports specific or drills training with a duration of 3–16 weeks are often reported, studies investigating the effects of long-term training over 6 months are rare [63, 64].

This study has limitations in terms of sampling. The exercise physiologists, report a 65–80% of VO_{2peak} for VT of trained athletes [65]. The VT of the participating athletes in current study was VO_{2peak} 62.9–63.5%, which is low for athletes, possibly due to exclusion from high-intensity training for medical treatment. Current study included only male players hence female soccer participants is necessary for a complete picture. Regarding the research methodology, this study did not consider the respiratory compensation point at the time of VT or the maximum heart rate. Since the rehabilitation center staff combined the measurements and athlete training of the participants, bias possibility of regarding the participant groups can't be overruled.

Frequent visits of rehabilitation centers can be challenging for adolescent athletes since they need to exercise besides their academic commitments. Since individual training conducted outside the center was not completely controlled, hence team or self-monitoring training is useful. In this study, training was imparted in consultation with the players and guardians, however, a random sampling case-controlled design should be adopted in future research. In the results of YBT and hop tests, the HISST outcomes were more positive. Although efforts were made to maximally match HIIT and HISST using heart rate, training volume, and time, the results may have been diverse due to inherently diverse nature of HISST in training configuration design than HIIT.

5. Conclusions

The 4 weeks HIIT and HISST improved the VO_{2peak}, anaerobic ventilatory threshold, and anaerobic power in adolescent soccer players. The YBT anterior and hop tests (single-, triple- and 6-m hop) significantly improved post-intervention in both HIIT and HISST groups. The post-intervention comparison of posteromedial and posterolateral YBT and cross-hop test indicated a significantly higher value of HISST than HIIT. Hence, both HIIT and HISST can be appropriate training for improving a player's fitness and function prior to return-to-play. However, HISST was slightly more effective for balance and hop in medial and lateral directions.

AVAILABILITY OF DATA AND MATERIALS

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

AUTHOR CONTRIBUTIONS

YC and YK—Conceptualization, writing-review and editing; YC—methodology, formal analysis, investigation, writing–original draft preparation, supervision.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Institutional Review Board (IRB) of Gangneung-Wonju National University (approval number: GWNUIRB-2021-1-13), and all study procedures were in accordance with the relevant guidelines. Informed consent was obtained from all participants, their parents or legal guardians.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Watson A, Mjaanes JM, LaBella CR, Brooks MA, Canty G, Diamond AB, *et al*. Soccer injuries in children and adolescents. Pediatrics. 2019; 144: e20192759.

[2] Halabchi F, Hassabi M. Acute ankle sprain in athletes: clinical aspects and algorithmic approach. World Journal of Orthopedics. 2020; 11: 534–558.

[3] Herzog MM, Kerr ZY, Marshall SW, Wikstrom EA. Epidemiology of ankle sprains and chronic ankle instability. Journal of Athletic Training. 2019; 54: 603–610.

[4] Donovan L, Hetzel S, Laufenberg CR, McGuine TA. Prevalence and impact of chronic ankle instability in adolescent athletes. Orthopaedic Journal of Sports Medicine. 2020; 8: 2325967119900962.

[5] Jagim AR, Luedke J, Fitzpatrick A, Winkelman G, Erickson JL, Askow AT, *et al*. The impact of COVID-19-related shutdown measures on the training habits and perceptions of athletes in the United States: a brief research report. Frontiers in Sports and Active Living. 2020; 2: 623068.

[6] Miklovic TM, Donovan L, Protzuk OA, Kang MS, Feger MA. Acute lateral ankle sprain to chronic ankle instability: a pathway of dysfunction. The Physician and Sportsmedicine. 2018; 46: 116–122.

[7] Doherty C, Delahunt E, Caulfield B, Hertel J, Ryan J, Bleakley C. The incidence and prevalence of ankle sprain injury: a systematic review and meta-analysis of prospective epidemiological studies. Sports Medicine. 2014; 44: 123–140.

[8] Gruskay JA, Brusalis CM, Heath MR, Fabricant PD. Pediatric and adolescent ankle instability: diagnosis and treatment options. Current Opinion in Pediatrics. 2019; 31: 69–78.

[9] Lin C, Houtenbos S, Lu Y, Mayer F, Wippert P. The epidemiology of chronic ankle instability with perceived ankle instability—a systematic review. Journal of Foot and Ankle Research. 2021; 14: 41.

[10] Mandorino M, Figueiredo AJ, Gjaka M, Tessitore A. Injury incidence and risk factors in youth soccer players: a systematic literature review. Part II: intrinsic and extrinsic risk factors. Biology of Sport. 2022; 40: 27–49.

[11] Hanlon C, Krzak JJ, Prodoehl J, Hall KD. Effect of injury prevention programs on lower extremity performance in youth athletes: a systematic review. Sports Health. 2020; 12: 12–22.

[12] Ortega-Avila AB, Cervera-Garvi P, Marchena-Rodriguez A, Chicharro-Luna E, Nester CJ, Starbuck C, *et al*. Conservative treatment for acute ankle sprain: a systematic review. Journal of Clinical Medicine. 2020; 9: 3128–3145.

[13] Chen Y, Hsieh Y, Ho J, Lin T, Lin J. Two weeks of detraining reduces

cardiopulmonary function and muscular fitness in endurance athletes. European Journal of Sport Science. 2022; 22: 399–406.

[14] Eastwood A, Bourdon PC, Snowden KR, Gore CJ. Detraining decreases Hb_{mass} of triathletes. International Journal of Sports Medicine. 2012; 33: 253–257.

[15] Silva AF, Clemente FM, Badicu G, Zangla D, Silva R, Greco G, *et al*. Analysis of the sustainability of long-term detraining caused by COVID-19 lockdown: impact on the maximal aerobic speed of under-16 soccer players. Sustainability. 2022; 14: 7821–7829.

[16] Jemni M, Prince MS, Baker JS. Retraction Note: Assessing cardiorespiratory fitness of soccer players: is test specificity the issue?—A review. Sports Medicine—Open. 2019; 5: 42.

[17] MacInnis MJ, Gibala MJ. Physiological adaptations to interval training and the role of exercise intensity. The Journal of Physiology. 2017; 595: 2915–2930.

[18] Atakan MM, Li Y, Koşar ŞN, Turnagöl HH, Yan X. Evidence-based effects of high-intensity interval training on exercise capacity and health: a review with historical perspective. International Journal of Environmental Research and Public Health. 2021; 18: 7201.

[19] Belegišanin B. Effects of high-intensity interval training on aerobic fitness in elite Serbian soccer players. Exercise and Quality of Life. 2017; 9: 13–17.

[20] Watabe T, Takabayashi T, Tokunaga Y, Kubo M. Individuals with chronic ankle instability exhibit altered ankle kinematics and neuromuscular control compared to copers during inversion single-leg landing. Physical Therapy in Sport. 2021; 49: 77–82.

[21] Lee AC, Tan LG. The effectiveness of neuromuscular training program to improve balance among female futsal players. European Journal of Molecular & Clinical Medicine. 2020; 7: 6060–6070.

[22] Wang H, Yu H, Kim YH, Kan W. Comparison of the effect of resistance and balance training on isokinetic eversion strength, dynamic balance, hop test, and ankle score in ankle sprain. Life. 2021; 11: 307–319.

[23] Karagianni K, Donti O, Katsikas C, Bogdanis GC. Effects of supplementary strength-power training on neuromuscular performance in young female athletes. Sports. 2020; 8: 104–115.

[24] Chtara M, Rouissi M, Haddad M, Chtara H, Chaalali A, Owen A, *et al*. Specific physical trainability in elite young soccer players: efficiency over 6 weeks' in-season training. Biology of Sport. 2017; 34: 137–148.

[25] Morgans R, Orme P, Anderson L, Drust B. Principles and practices of training for soccer. Journal of Sport and Health Science. 2014; 3: 251–257.

[26] Silva JR, Nassis GP, Rebelo A. Strength training in soccer with a specific focus on highly trained players. Sports Medicine—Open. 2015; 1: 17.

[27] Armstrong N. Youth aerobic fitness. Pediatric Exercise Science. 2019; 31: 137–143.

[28] Liguori G, American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. 11th edn. Lippincott Williams & Wilkins: Philadelphia, PA. 2020.

[29] Pedroni AS, Schiavo A, Macedo ED, de Campos NE, Winck AD, Heinzmann-Filho JP. Predictive maximal heart rate equations in child and adolescent athletes: a systematic review. Physical Therapy in Movement. 2018; 31: e003131–e003139. (In Portuguese)

[30] Dafoe W. Principles of exercise testing and interpretation. The Canadian Journal of Cardiology. 2007; 23: 274.

[31] Powers SK, Howley ET. Exercise physiology: theory and application to fitness and performance. 11th edn. McGraw Hill: New York, USA. 2020.

[32] van Cingel R, van Melick N, van Doren L, Aufdemkampe G. Intra-examiner reproducibility of ankle inversion-eversion isokinetic strength in healthy subjects. Isokinetics and Exercise Science. 2009; 17: 181–188.

[33] Castañeda-Babarro A. The wingate anaerobic test, a narrative review of the protocol variables that affect the results obtained. Applied Sciences. 2021; 11: 7417–7436.

[34] Maicas-Pérez L, Hernández-Lougedo J, Heredia-Elvar JR, Pedauyé-Rueda B, Cañuelo-Márquez AM, Barba-Ruiz M, *et al*. Effects of creatine supplementation after 20 minutes of recovery in a bench press exercise protocol in moderately physically trained men. Nutrients. 2023; 15: 657–676.

[35] Powden CJ, Dodds TK, Gabriel EH. The reliability of the star excursion balance test and lower quarter y-balance test in healthy adults: a systematic review. International Journal of Sports Physical Therapy. 2019; 14: 683–694.

[36] Peebles AT, Renner KE, Miller TK, Moskal JT, Queen RM. Associations between distance and loading symmetry during return to sport hop testing. Medicine & Science in Sports & Exercise. 2019; 51: 624–629.

[37] Buchheit M. Managing high-speed running load in professional soccer players: the benefit of high-intensity interval training supplementation. Sport Performance & Science Reports. 2019; 1: 1–5.

[38] Arslan E, Orer GE, Clemente FM. Running-based high-intensity interval training *vs.* small-sided game training programs: effects on the physical performance, psychophysiological responses and technical skills in young soccer players. Biology of Sport. 2020; 37: 165–173.

[39] Boudreau SL, Mattes LL, Lowenstein NA, Matzkin EG, Wilcox RB. Customizing functional rehabilitation and return to sport in the female overhead athlete. Arthroscopy, Sports Medicine, and Rehabilitation. 2022; 4: e271–e285.

[40] Kelly DM, Gregson W, Reilly T, Drust B. The development of a soccer-specific training drill for elite-level players. Journal of Strength and Conditioning Research. 2013; 27: 938–943.

[41] Dhillon H, Dhilllon S, Dhillon MS. Current concepts in sports injury rehabilitation. Indian Journal of Orthopaedics. 2017; 51: 529–536.

[42] Atakan MM, Li Y, Koşar ŞN, Turnagöl HH, Yan X. Evidence-based effects of high-intensity interval training on exercise capacity and health: a review with historical perspective. International Journal of Environmental Research and Public Health. 2021; 18: 7201–7227.

[43] Del Giudice M, Bonafiglia JT, Islam H, Preobrazenski N, Amato A, Gurd BJ. Investigating the reproducibility of maximal oxygen uptake responses to high-intensity interval training. Journal of Science and Medicine in Sport. 2020; 23: 94–99.

[44] Menz V, Strobl J, Faulhaber M, Gatterer H, Burtscher M. Effect of 3-week high-intensity interval training on VO_{2max}, total haemoglobin mass, plasma and blood volume in well-trained athletes. European Journal of Applied Physiology. 2015; 115: 2349–2356.

[45] Engel FA, Ackermann A, Chtourou H, Sperlich B. High-intensity interval training performed by young athletes: a systematic review and meta-analysis. Frontiers in Physiology. 2018; 9: 1012–1029.

[46] Mallesh A, Suresh TN, Sivakumar VPR. Effectiveness of sports specific circuit training and high intensity interval training on aerobic capacity in male basketball players. International Journal of Clinical Skills. 2017; 11: 177–184.

[47] Heinrich KM, Crawford DA, Johns BR, Frye J, Gilmore KEO. Affective responses during high-intensity functional training compared to high-intensity interval training and moderate continuous training. Sport, Exercise, and Performance Psychology. 2020; 9: 115–127.

[48] Dolci F, Hart NH, Kilding AE, Chivers P, Piggott B, Spiteri T. Physical and energetic demand of soccer: a brief review. Strength & Conditioning Journal. 2020; 42: 70–77.

[49] Lee KH, Lee K, Choi YC. Very short-term high-intensity interval training in highschool soccer players. Journal of Men's Health. 2020; 16: 1–8.

[50] Tahsin İ, Daglioglu Ö. The effect of the plyometric training program on sportive performance parameters in young soccer players. Turkish Journal of Sport and Exercise. 2018; 20: 184–190.

[51] Fiorenza M, Lemminger AK, Marker M, Eibye K, Marcello Iaia F, Bangsbo J, *et al*. High-intensity exercise training enhances mitochondrial oxidative phosphorylation efficiency in a temperature-dependent manner in human skeletal muscle: implications for exercise performance. The FASEB Journal. 2019; 33: 8976–8989.

[52] Calbet JAL, Martín-Rodríguez S, Martin-Rincon M, Morales-Alamo D. An integrative approach to the regulation of mitochondrial respiration during exercise: focus on high-intensity exercise. Redox Biology. 2020; 35: 101478.

[53] Lee JH, Jung HW, Jang WY. Proprioception and neuromuscular control at return to sport after ankle surgery with the modified Broström procedure. Scientific Reports. 2022; 12: 610.

[54] Lee S, Ahn S. Effects of balance evaluation comparison of dynamic balance and Y balance. Journal of Exercise Rehabilitation. 2018; 14: 939–943.

[55] Ringhof S, Stein T. Biomechanical assessment of dynamic balance: specificity of different balance tests. Human Movement Science. 2018; 58: 140–147.

[56] Minoonejad H, Karimizadeh Ardakani M, Rajabi R, Wikstrom EA,

Sharifnezhad A. Hop stabilization training improves neuromuscular control in college basketball players with chronic ankle instability: a randomized controlled trial. Journal of Sport Rehabilitation. 2019; 28: 576–583.

[57] Vechin FC, Conceição MS, Telles GD, Libardi CA, Ugrinowitsch C. Interference phenomenon with concurrent strength and high-intensity interval training-based aerobic training: an updated model. Sports Medicine. 2021; 51: 599–605.

[58] Li Y, Ko J, Zhang S, Brown CN, Simpson KJ. Biomechanics of ankle giving way: a case report of accidental ankle giving way during the drop landing test. Journal of Sport and Health Science. 2019; 8: 494–502.

[59] Gibala MJ, Little JP, van Essen M, Wilkin GP, Burgomaster KA, Safdar A, *et al*. Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. The Journal of Physiology. 2006; 575: 901–911.

[60] Hurst C, Scott JPR, Weston KL, Weston M. High-intensity interval training: a potential exercise countermeasure during human spaceflight. Frontiers in Physiology. 2019; 10: 581–587.

[61] Fang B, Kim YH, Choi MY. Effects of high-intensity aquatic or bicycling training in athletes with unilateral patellofemoral pain syndrome. International Journal of Environmental Research and Public Health. 2022; 19: 4675–4687.

[62] Flockhart M, Nilsson LC, Tais S, Ekblom B, Apró W, Larsen FJ. Excessive exercise training causes mitochondrial functional impairment and decreases glucose tolerance in healthy volunteers. Cell Metabolism. 2021; 33: 957–970.e6.

[63] Padrón-Cabo A, Rey E, Kalén A, Costa PB. Effects of training with an agility ladder on sprint, agility, and dribbling performance in youth soccer players. Journal of Human Kinetics. 2020; 73: 219–228.

[64] Bouguezzi R, Chaabene H, Negra Y, Ramirez-Campillo R, Jlalia Z, Mkaouer B, *et al*. Effects of different plyometric training frequencies on measures of athletic performance in prepuberal male soccer players. Journal of Strength and Conditioning Research. 2020; 34: 1609–1617.

[65] Tasew DG. Overview of major physiological factors affecting athletes' aerobic fitness level. International Journal of Physical Education, Sports and Health. 2020; 7: 293–297.

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