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 (VO₂peak), anaerobic power, isokinetic ankle eversion strength, while lower extremity function tests consisted of Y-balance and hop tests. In both groups, VO₂peak, 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. Conclusively, HIIT and HISST can simultaneously improve VO₂peak, 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 intervention 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 $d_z = 0.5$, $\alpha$ error $= 0.05$, and power $(1-\beta$ 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 ankle eversion 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 × 3)) × 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 unjured 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 ≥90% VO2peak, and the suitable exercise intensity was evaluated using a HR monitor interface (Polar RS400, Polar Electro OY, Kempele, Finland). A level of ≥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
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.

<table>
<thead>
<tr>
<th>Variables</th>
<th>HIIT (n = 28)</th>
<th>HISST (n = 28)</th>
<th>t-value or χ²</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>16.4 ± 1.3</td>
<td>16.0 ± 0.7</td>
<td>−1.670</td>
<td>0.624</td>
</tr>
<tr>
<td>Height, cm</td>
<td>176.6 ± 2.6</td>
<td>177.9 ± 3.5</td>
<td>−5.325</td>
<td>0.217</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>63.4 ± 3.1</td>
<td>63.7 ± 3.4</td>
<td>−2.976</td>
<td>0.538</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>22.7 ± 1.6</td>
<td>21.9 ± 1.8</td>
<td>0.631</td>
<td>0.501</td>
</tr>
<tr>
<td>Rehabilitation duration, weeks</td>
<td>6.3 ± 1.3</td>
<td>6.4 ± 1.7</td>
<td>3.075</td>
<td>0.392</td>
</tr>
<tr>
<td>Position, FW/MF/DF</td>
<td>2/14/12</td>
<td>3/16/9</td>
<td>0.762</td>
<td>0.683</td>
</tr>
<tr>
<td>Injury side, right/left</td>
<td>12/16</td>
<td>10/18</td>
<td>0.299</td>
<td>0.785</td>
</tr>
<tr>
<td>Recurrence AS injury</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>14</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recurrence 2 times</td>
<td>10</td>
<td>13</td>
<td>1.198</td>
<td>0.274</td>
</tr>
<tr>
<td>Recurrence ≥3 times</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group</th>
<th>Pretest</th>
<th>Posttest</th>
<th>% Difference</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂peak, mL/kg/min</td>
<td>HIIT</td>
<td>48.7 ± 1.7</td>
<td>51.7 ± 1.5</td>
<td>6.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>HISST</td>
<td>49.9 ± 1.2</td>
<td>51.4 ± 1.3</td>
<td>3.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.886</td>
<td>0.520</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exercise duration, s</td>
<td>HIIT</td>
<td>885.0 ± 84.9</td>
<td>997.6 ± 79.3</td>
<td>12.7</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td>HISST</td>
<td>900.9 ± 74.6</td>
<td>980.8 ± 90.2</td>
<td>8.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.098</td>
<td>0.120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilatory threshold, %</td>
<td>HIIT</td>
<td>63.5 ± 5.2</td>
<td>69.6 ± 8.9</td>
<td>9.6</td>
<td>0.039</td>
</tr>
<tr>
<td></td>
<td>HISST</td>
<td>62.9 ± 8.2</td>
<td>68.2 ± 10.2</td>
<td>8.4</td>
<td>0.044</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.603</td>
<td>0.158</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak HR, %</td>
<td>HIIT</td>
<td>93.6 ± 2.3</td>
<td>96.3 ± 1.8</td>
<td>2.89</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>HISST</td>
<td>92.7 ± 2.0</td>
<td>95.8 ± 2.2</td>
<td>3.34</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.509</td>
<td>0.411</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovery 1 min HR, %</td>
<td>HIIT</td>
<td>49.0 ± 9.0</td>
<td>60.8 ± 8.8</td>
<td>24.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>HISST</td>
<td>52.8 ± 6.5</td>
<td>59.2 ± 6.1</td>
<td>12.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.205</td>
<td>0.754</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

p < 0.05; Abbreviations: HIIT, high-intensity interval training; HISST, high-intensity sports specific training; HR, heart rate; VO₂peak: 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 sport 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; HIIT, high-intensity interval training; HISST, high-intensity sport 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 sport 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 sport 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_{peak} 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_{peak} improved by 7.2% after HIIT [45]. A 6 weeks’ study of sports specific training of basketball players suggested a significant improvement in VO_{peak} 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_{peak} 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 inversion 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_{peak} 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_{peak} 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\textsubscript{2peak} for VT of trained athletes [65]. The VT of the participating athletes in current study was VO\textsubscript{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\textsubscript{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.

ACKNOWLEDGMENT

We sincerely thank Gangneung-Wonju National University for volunteering and administrative support for this study.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES


