Journal of Physical Education and Sport ® (JPES), Vol. 25 (issue 4), Art 85, pp. 793 - 804, April 2025
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Effects of 8-Week HIIT short interval training with extensive intensity and change of direction (COD) on aerobic and anaerobic capacity of youth soccer players

ARBEN BICI[1], AGRON KASA[2]
Faculty of Movement Science, Sport Collective Department, Sports University of Tirana, ALBANIA

Published online: April 30, 2025
Accepted for publication: April 15, 2025
DOI:10.7752/jpes.2025.04085

Abstract:
The purpose of this study was to examine the effects of a high-intensity interval training (HIIT) program involving 30-second running intervals at intensities of 105%, 110%, 115%, and 120% of vVO₂max, interspersed with 30-second active recovery periods at 50% of vVO₂max. The program incorporated changes of direction (COD) at 45° and 90°. Eighteen 16-year-old soccer players from a football school participated in a single test group. The test group trained for 8 weeks on a running circuit of 115–130 meters, including COD at 45°–90°. Each running interval lasted 30 seconds, with 3-minute recovery periods between series. Aerobic capacity was measured using the Åstrand 6-minute cycle ergometer test (Monark 839), and anaerobic capacity was assessed with the Running-based Anaerobic Sprint Test (RAST, 6 × 35 m).The 12-minute Cooper test results showed a p-value (<0.0001) well below 0.05, with a t-statistic (11.36) exceeding the critical value (1.771). Participants improved their average distance by 215 meters (95% CI: [175, 255]), representing a 7.9% increase. All 14 participants demonstrated improvements, with gains ranging from 80 m to 350 m. The effect size (Cohen's d ≈ 3.04) indicates an extremely large effect (>0.8 is considered large). The Åstrand 6-minute test results were statistically significant, with a t-statistic (14.82) far exceeding the critical value (1.771) and a p-value (<0.001). Participants improved their VO₂max by an average of 8.96 units (95% CI: [7.59, 10.33]), a 18.89% increase, with all 14 participants showing significant gains. The RAST (6 × 35 m) results indicated statistical significance, with a t-statistic (-3.59) exceeding the critical value (±2.160) in magnitude and a p-value (<0.01). Participants improved their Fatigue Index (FI) by an average of 1.63 units (95% CI: [-2.58, -0.68]). Twelve of 14 participants improved, with two exceptions: Participant 9's FI value increased by 0.66 (pre: 2.70; post: 3.36), and Participant 11's FI value increased by 1.20 (pre: 1.53; post: 2.73). The effect size (Cohen's d ≈ 0.96) indicates a large effect. **Conclusion:** High-intensity interval training with 30-second intervals at 105%, 110%, 115%, and 120% of vVO₂max, interspersed with 30-second active recovery at 50% of vVO₂max and combined with COD at 45° and 90°, significantly improves the aerobic and anaerobic capacities of 16-year-old soccer players.

Key words: HIIT, vVO₂max, Åstrand 6-minute test , RAST 6 × 35 m test, Fatigue Index, Change of Direction (COD).

Introduction

Soccer is primarily characterized by acyclic running at varying intensities, engaging both aerobic and anaerobic energy systems. During a match, aerobic metabolism predominates, accounting for over 70% of low-intensity activities (Bangsbo et al., 2006). The average oxygen consumption is estimated at 70–75% of a player's maximum (VO₂max), corresponding to average and maximum heart rates of 85% and 98%, respectively (Krustrup et al., 2011; Mohr et al., 2016). However, blood lactate concentrations often exceed 12 mmol/L, indicating significant anaerobic metabolism during intense actions such as sprinting, shooting, or kicking, which are often decisive in matches (Krustrup et al., 2011). During high-intensity exercises lasting more than a few seconds, adenosine triphosphate (ATP) is resynthesized through both aerobic and anaerobic processes (Medbø et al., 1988). The ability to resynthesize ATP can limit performance in sports requiring high-intensity efforts. Therefore, training programs for such sports should aim to enhance athletes' capacity to generate energy aerobically and anaerobically. Recent reviews on high-intensity interval training (HIIT) in children and adolescents highlight its benefits for cardiorespiratory fitness. Research has explored the effects of short-interval HIIT (s-HIIT), a form of HIIT, on aerobic and anaerobic capacities in youth soccer players. Short-interval HIIT significantly improves VO₂max, with studies reporting increases of 5–10% after 6–8 weeks of training. The repeated high-intensity efforts followed by brief recovery periods enhance oxygen utilization and cardiovascular efficiency. Vollaard et al. (2017**)** in the meta-analysis of 34 studies showed SIT significantly improves VO2max (~8% on average).

No dose-response relationship between the number of sprints (2–10) and VO2max gains; low-volume SIT (2–3 sprints) is as effective as higher volumes. SIT is a time-efficient method for enhancing

Corresponding Author: ARBEN BICI, E-mail: abici@ust.edu.al

cardiorespiratory fitness. Willoughby et al. (2016) in protocol training 4 weeks of running SIT (4–6 × 30-second sprints, 4-minute rest, 3 sessions/week) increased VO2max (~7–10%) in young and middle-aged adults. No significant age-related differences in VO2max gains. Improved anaerobic performance (e.g., peak power output). McKie et al. (2017) study report that manipulating SIT work and rest durations influenced aerobic (VO2max) and anaerobic outcomes. Shorter rest periods likely enhanced anaerobic benefits, while longer rest favored aerobic improvements (specific findings unclear due to abstract format). Islam et al. (2017**)** compared three SIT protocols (30-second sprints/4-minute rest, 15-second sprints/2-minute rest, 15-second sprints/1-minute rest) over 4 weeks. All protocols improved VO2max (~6–8%) and anaerobic power, with no significant differences between groups. Shorter rest intervals increased metabolic stress (higher lactate) but maintained aerobic benefits. Koral et al. (2018) study shows that, 6 SIT sessions (4–6 × 30-second sprints, 4-minute rest) over 2 weeks improved 3-km running time (~2–3%) and running economy in trained athletes. Modest VO2max increase (~3–5%); no significant change in anaerobic capacity. SIT enhances performance beyond aerobic capacity. McKie et al. (2018) study report that, 4 weeks of three SIT protocols (30-second sprints/4-minute rest, 15-second sprints/2-minute rest, 15-second sprints/1-minute rest) improved VO2max (~7–9%) and anaerobic power. Shorter rest intervals increased perceived exertion but not adherence or enjoyment. High enjoyment across protocols supports psychological sustainability. Gist et al. (2014) found that s-HIIT improved VO$_2$max more effectively than moderate-intensity continuous training (MICT). Additionally, s-HIIT increases the lactate threshold, enabling players to sustain higher intensities without fatigue by improving lactate clearance and buffering capacity (Iaia et al., 2015). Short-interval HIIT also enhances time to exhaustion, allowing players to maintain high-intensity efforts for longer durations due to improved aerobic and anaerobic energy system efficiency (Ferrari Bravo et al., 2016). Furthermore, s-HIIT significantly improves repeated sprint ability (RSA), which is critical for soccer players who must perform multiple high-intensity efforts during matches. This improvement is attributed to enhanced phosphocreatine recovery and glycolytic system efficiency (Mendez-Villanueva et al., 2018). Short-interval HIIT also increases peak power, essential for explosive actions like sprinting and jumping, by improving recruitment of Type II muscle fibers and neuromuscular coordination (Buchheit & Laursen, 2014). Moreover, s-HIIT enhances mean power, enabling players to sustain high-intensity efforts over time through improved anaerobic energy system efficiency and muscle endurance (Rampinini et al., 2019). Short-interval HIIT uniquely targets both aerobic and anaerobic systems, making it highly effective for soccer players who require a blend of endurance and power.

The high-intensity efforts stress both energy systems, leading to comprehensive physiological adaptations. Lloyd et al. (2021) emphasized the importance of age-appropriate training but did not specifically address short-interval high-intensity interval training (s-HIIT) with changes of direction (COD). HIIT in children and adolescents is less studied than in adults. Meta-analyses and literature reviews indicate that research on HIIT for youth is limited, particularly for s-HIIT protocols (Clemente et al., 2021; Engel et al., 2018; Kunz et al., 2019; Hall et al., 2022). Several studies on young, healthy athletes have shown that VO$_2$max is associated with performance in sprints, repeated sprints, and jumps in the context of HIIT. Recent reviews on HIIT in children and adolescents focus on cardiorespiratory fitness. However, most meta-analyses of youth HIIT studies examine long-interval (e.g., 4 min × 4 min) or short-interval protocols (e.g., 30 s with 4 min recovery). Few studies focus on youth HIIT protocols with 30 s work and 30 s rest (Barker et al., 2014; Buchan et al., 2012, 2014; Burns et al. 2012). Even fewer studies have investigated HIIT protocols with 30 s intervals at extensive running speeds of 105%, 110%, 115%, or 120% of vVO$_2$max with 30 s rest. Berthoin et al. (1995) conducted a study with 10 s runs at 120% of vVO$_2$max in 14- to 17-year-olds. Arslanoğlu et al. (2024) examined running intensities from 80% to 110% of vVO$_2$max, while Agostino (2019) used 10 s × 10 s and 5 s × 5 s protocols at 120% of vVO$_2$max. Hall et al. (2022) noted that most HIIT protocols with 30 s sprints involve recovery periods of 180–300 s. Research by Billat et al. (1999) investigated interval training with 30 s high-intensity runs alternating with 30 s complete rest. Åstrand et al. (1960) reported that interval training with 15 s runs at vVO$_2$max alternating with 15 s rest was insufficient to elicit maximal VO$_2$, whereas 30 s runs at vVO$_2$max with 30 s rest achieved 65% of VO$_2$max with low blood lactate concentrations (2.2 mmol·L^{-1}) (Billat et al., 1999). HIIT protocols performed for a few minutes at intensities around 90% of VO$_2$max improve aerobic power and capacity, as seen in aerobic high-intensity training (Hostrup et al., 2022; Impellizzeri et al., 2005; Clemente et al., 2014).

However, HIIT at higher intensities, such as all-out efforts or sprints of 10–40 s with longer recovery periods (e.g., sprint interval training or speed endurance training), promotes adaptations in anaerobic energy systems and ion handling (Hostrup et al., 2019, 2022). These high-intensity protocols impose significant psycho-physiological stress and physical performance demands, potentially leading to prolonged neuromuscular depression, muscle micro-tears, and increased risk of performance decline or injury if not properly dosed or if recovery is inadequate (Hostrup et al., 2019, 2022). Younger populations have lower aerobic capacity due to smaller body size (e.g., reduced heart size) and lower maximal cardiac output compared to adults (Atan et al., 2014; Stølen et al., 2005). Youth athletes also have limited glycogen stores (50–60% of adult levels), leading to faster depletion (Atan et al., 2014; Alvarado et al., 2005; Boisseau et al., 2000). Their anaerobic power is approximately 50% lower than that of adults, resulting in limited ATP supply during high-intensity exercise, reduced phosphofructokinase (PFK) activity, and lower glycolysis rates (Atan et al., 2014; Nikolaidis et al., 2001; Riddell, 2008). Immature muscle fiber distribution further limits performance (Atan et al., 2014;

Naughton, 2002). Consequently, young players exhibit less sprinting, slower speeds, and reduced distances covered in high-intensity activities during match play (Atan et al., 2014; Alvarado et al., 2005). Despite these limitations, Billat (2000) noted that interval training with 30 s high-intensity runs alternating with 30 s complete rest efficiently improves VO_2max and is well-tolerated even by untrained individuals. The question of the problem is to identify a training protocol that is not overly intensive, mirrors the characteristics of soccer, requires less time in daily and weekly training programs, and simultaneously enhances aerobic and anaerobic capacities in youth soccer players. Therefore, this study aimed to evaluate the effects of an 8-week short-interval high-intensity interval training (s-HIIT) protocol on the aerobic and anaerobic capacities of youth soccer players. The protocol consisted of 3 sets of 3 repetitions (30 s work: 30 s rest) with a 1:1 work-to-rest ratio between repetitions and 180 s recovery between sets. The running speeds were set at extensive intervals of 105%, 110%, 115%, and 120% of vVO_2max, alternating with 30 s active recovery at 50% of vVO_2max, and incorporated changes of direction (COD) at 45° and 90°.

Methodology

Participants

This study recruited 18 male soccer players aged 16 years from the Football Master's High School "Loro Boriçi" in Tirana, Albania. The team participated in the Albanian Football Federation (AFF) amateur category for the U-17 age group during the 2017–2018 season. The study was conducted with permission from the school director of "Loro Boriçi" and approval from the team's coach. It was approved by the Ethics Committee of the Sports University of Tirana and adhered to the Declaration of Helsinki. All participants were informed, and consent forms were obtained from all.

Study Design and Procedures

Three test protocols were conducted seven days before and seven days after an 8-week training intervention. A rest day was provided between consecutive tests to minimize fatigue. The tests included the 12-minute Cooper Test, the 6-minute Åstrand Test on a cycle ergometer, and the Running-based Anaerobic Sprint Test (RAST, 6 × 35 m). These tests were performed in a laboratory (Åstrand Test) and on a soccer field with artificial grass (Cooper Test and RAST). Prior to data collection, participants were familiarized with the test procedures to ensure accurate execution.

Tests

- Anthropometric measurements (height, weight, and body mass index [BMI])
- 12-minute Cooper Test (running)
- 6-minute Åstrand Test (cycle ergometer)
- Running-based Anaerobic Sprint Test (RAST, 6 × 35 m)

Protocol and Test Administration

12-minute Cooper Test

The Cooper Test was conducted on a soccer field with artificial grass (105 m × 68 m) at the training facilities of the Albanian National Football Team. The field's perimeter was modified into a 300 m runway (Figure 1). Participants, each assigned a number from 1 to 18, ran as far as possible in 12 minutes around the designated perimeter. At the end of the test, distances were recorded, and VO_2max was calculated for each player using standard Cooper Test formulas. The Cooper Test was also used to determine each participant's maximum aerobic speed (vVO_2max).

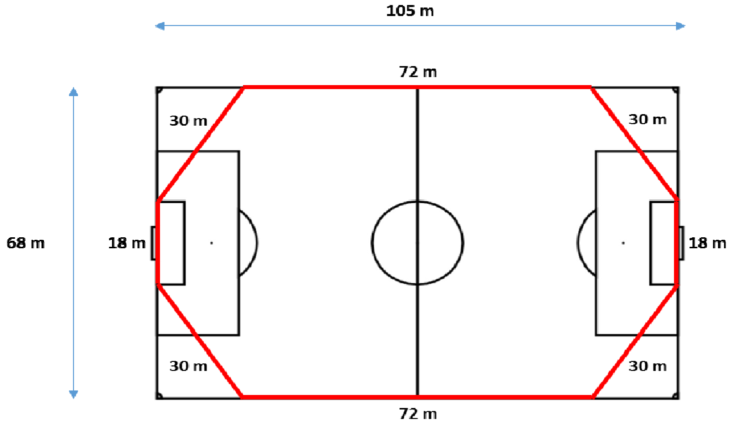
Determining Maximum Aerobic Speed (vVO_2max)

The vVO_2max was calculated using the following formula:

vVO_2max = Running Distance (m) / Time (s)

This value represented 100% of the maximum aerobic speed for each participant.

Figure 1. Cooper Test 12' Runway perimeter



During the test the participant were encouraged to perform the run as much as thye can till to the end of the 12 minute run test.

RAST Test 6 x 35 m (Anaerobic Capacity Measurement)

Figure 2. Configuration for the RAST Test

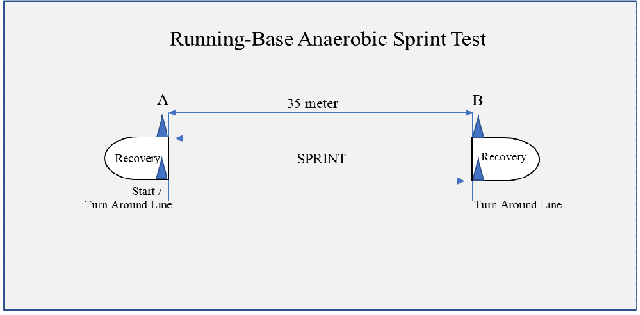


Figure 2. RAST TEST CONFIGURATION

Testing procedure

Prior to the test, body mass (in kilograms) was measured and recorded.

Formula: Body Mass Index (BMI), it’s calculated as:

$$\mathrm{BMI} = \frac{\text{weight (kg)}}{\text{height (m)}^2}$$

Measurements

All participants were subjected to anthropometric measurements (Figure.3) and tests related to the VO2 max RAST Test 6x35 m evaluation prior to the study protocols.

Figure 3. Anthropometric measurements average data

Gender	Masculin
Number	15
Age (year)	16.4
Weight (Kg)	65
Height (cm)	176
BMI (Kg*m2)	21

The RAST test was conducted on a soccer field with artificial grass, using a 35 m sprint track marked by cones (Cone A and Cone B; Figure 2). Participants completed a warm-up prior to the test, followed by 3–5 minutes of recovery to ensure readiness. Each participant began from a standing start position, 50 cm behind the start line, alternating between Cone A and Cone B for each sprint. The test commenced with a countdown (“3 – 2 – 1 – GO!”), and on the “GO” signal, participants sprinted at maximal effort through the timing gate at Cone A to Cone B (35 m). They were verbally encouraged to maintain maximal effort. Upon crossing the timing gate at Cone B, the sprint duration was recorded, and a 10-second recovery period began. During recovery, participants prepared to sprint back to Cone A. This procedure was repeated for a total of six sprints (five 10-second recovery periods). After the test, participants rested for 2–3 minutes to minimize fatigue or discomfort.

6-minute Åstrand Test

The Åstrand Test was conducted on a cycle ergometer (Monark 839) in a laboratory. Participants were informed that the test would last 6 minutes, during which they must maintain the prescribed pedaling pace. They were advised they could stop the test at any time, particularly if experiencing chest pain, shortness of breath, dizziness, or blurred vision. **Protocol**: Participants completed a 3–5 minute warm-up to achieve a heart rate above 120 beats per minute. The workload progressed as follows: First minute: 300 kgm/min (50 watts). Second minute: 600 kgm/min (100 watts). Minutes 3–6: 900 kgm/min (150 watts). Heart rate was monitored to estimate VO_2max using standard Åstrand Test nomograms.

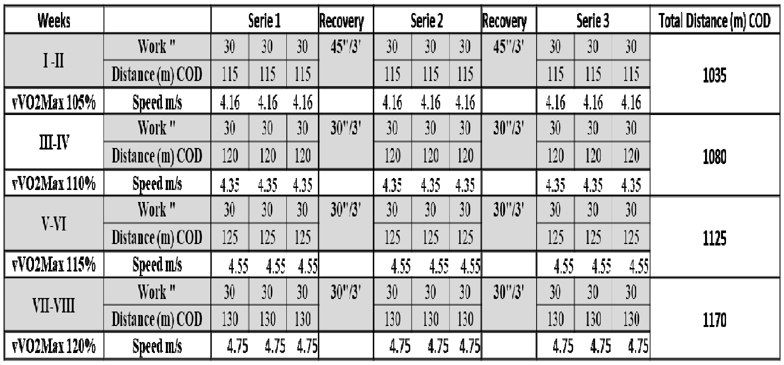
Statistical Procedures

A paired-sample t-test was used to compare pre- and post-intervention assessments for each test (Cooper Test, Åstrand Test, and RAST). The statistical significance level was set at $p < 0.05$.

Training Intervention

The 8-week training intervention utilized a short-interval high-intensity interval training (s-HIIT) protocol with changes of direction (COD) at 45° and 90°, conducted on a soccer field with artificial grass. Training sessions occurred twice weekly (Monday and Wednesday or Tuesday and Friday at 10:00 a.m.), each starting with a 10-minute warm-up. The s-HIIT protocol consisted of 3 sets of 3 repetitions (30 s work: 30 s active recovery) with a 1:1 work-to-rest ratio and 180 s recovery between sets. Running speeds were set at 105%, 110%, 115%, and 120% of each participant’s vVO_2max, determined from the 12-minute Cooper Test, with active recovery at 50% of vVO_2max. Due to the COD at 45° and 90°, individual sprint distances were reduced by 7% based on recommendations by Laursen and Buchheit (2019) to account for the increased physiological demand of directional changes. Consequently, running distances ranged from approximately 115 m to 130 m per 30 s interval, depending on the prescribed intensity (105–120% vVO_2max). The circuit design and progression are illustrated in Figure 4. To ensure accurate execution, sprint distances were adjusted before the intervention, and participants began each interval 3 seconds apart following a starting command.

Figure 4. Training Intervention Program



Weeks		Serie 1			Recovery	Serie 2			Recovery	Serie 3			Total Distance (m) COD
I -II	Work "	30	30	30	45"/3'	30	30	30	45"/3'	30	30	30	1035
	Distance (m) COD	115	115	115		115	115	115		115	115	115	
vVO2Max 105%	Speed m/s	4.16	4.16	4.16		4.16	4.16	4.16		4.16	4.16	4.16	
III-IV	Work "	30	30	30	30"/3'	30	30	30	30"/3'	30	30	30	1080
	Distance (m) COD	120	120	120		120	120	120		120	120	120	
vVO2Max 110%	Speed m/s	4.35	4.35	4.35		4.35	4.35	4.35		4.35	4.35	4.35	
V-VI	Work "	30	30	30	30"/3'	30	30	30	30"/3'	30	30	30	1125
	Distance (m) COD	125	125	125		125	125	125		125	125	125	
vVO2Max 115%	Speed m/s	4.55	4.55	4.55		4.55	4.55	4.55		4.55	4.55	4.55	
VII-VIII	Work "	30	30	30	30"/3'	30	30	30	30"/3'	30	30	30	1170
	Distance (m) COD	130	130	130		130	130	130		130	130	130	
vVO2Max 120%	Speed m/s	4.75	4.75	4.75		4.75	4.75	4.75		4.75	4.75	4.75	

The training progression over the 8 weeks was as follows:

- **Weeks 1–2**: Sessions on Monday and Wednesday, with 3 sets of 3 repetitions (45 s work: 45 s active recovery at 50% vVO_2max). Recovery between sets was 3 minutes. Total session distance was approximately 1035 m.
- **Weeks 3–4**: Sessions on Monday and Wednesday, with 3 sets of 3 repetitions (30 s work: 30 s active recovery at 50% vVO_2max). Recovery between sets was 3 minutes. Total session distance was approximately 1080 m.
- **Weeks 5–6**: Sessions on Monday and Wednesday, with 3 sets of 3 repetitions (30 s work: 30 s active recovery at 50% vVO_2max). Recovery between sets was 3 minutes. Total session distance was approximately 1125 m.
- **Weeks 7–8**: Sessions on Monday and Wednesday, with 3 sets of 3 repetitions (30 s work: 30 s active recovery at 50% vVO_2max). Recovery between sets was 3 minutes. Total session distance was approximately 1170 m.

Every two weeks, running speed and total session distance increased to progressively overload the participants, as detailed in the training protocol (Table 1). Each training session lasted approximately 12 minutes, excluding the warm-up. The intervention period spanned 8 weeks.

Results

Of the 18 participants initially recruited, 4 were unable to complete the 8-week intervention due to injuries sustained during official matches. The remaining 14 participants attended all training sessions and completed pre- and post-intervention assessments. A limitation of this study was the inability to control participants' nutrition, daily regimen, and sleep patterns, particularly bedtime, which may have influenced performance outcomes. The results of the pre- and post-intervention tests are presented below. The main findings indicated significant improvements in performance: **Cooper Test**: Distance covered increased by 7.69% post-intervention ($p < 0.05$, Table 1). **Åstrand Test**: VO_2max improved by 18.89% ($p < 0.05$, Table 2). **RAST**: Fatigue Index improved by 35.40% ($p < 0.05$, Table 3).

Table 1. Results of Pre-test ans Post- test of Cooper Test 12 minute

COOPER TEST 12 Minute RUNNING				
No.	Distance (m) Pre-test	Distance (m) Post-test	Difference (Post - Pre)	Percentage Change
1	2630	2910	280.00	10.65
2	2810	3050	240.00	8.54
3	2570	2810	240.00	9.34
4	2730	2950	220.00	8.06
5	2850	3000	150.00	5.26
6	2700	2850	150.00	5.56
7	2860	3100	240.00	8.39
8	2770	2850	80.00	2.89
9	2690	2970	280.00	10.41
10	2800	2980	180.00	6.43
11	2800	2930	130.00	4.64
12	2400	2750	350.00	14.58
13	2700	2950	250.00	9.26
14	2680	2910	230.00	8.58

Table 2. Results Pre-test and Post-test of Astrand Test 6 minute Ergometric Bicycle

ASTRAND TEST 6 Minute Ergometer Bicycle				
No.	**Vo2 Max Pre-test**	**Vo2 Max Post-test**	**Difference (Post - Pre)**	**Percentage Change**
1	41.70	48.20	6.50	15.59
2	53.33	62.45	9.12	17.10
3	37.50	47.00	9.50	25.33
4	44.00	50.00	6.00	13.64
5	50.91	65.23	14.32	28.13
6	42.00	50.00	8.00	19.05
7	57.00	66.00	9.00	15.79
8	50.08	57.00	6.92	13.82
9	47.00	54.00	7.00	14.89
10	53.33	62.00	8.67	16.26
11	49.64	60.00	10.36	20.87
12	48.75	59.00	10.25	21.03
13	38.50	50.00	11.50	29.87
14	45.10	52.40	7.30	16.19

Table 3. Results Pre-test and Post-test of RAST Test 6x35m

RAST TEST 6 x 35 meter				
No.	**FI Pre-test**	**FI Post-test**	**Difference (Post - Pre)**	**Percentage Change**
1	6	4.22	-1.78	-29.67
2	6.23	1.69	-4.54	-72.87
3	3.73	2.74	-0.99	-26.54
4	5.66	2.79	-2.87	-50.71
5	7.7	4.29	-3.41	-44.29
6	5.72	2.04	-3.68	-64.34
7	2.48	0.89	-1.59	-64.11
8	3.25	2.69	-0.56	-17.23
9	2.7	3.36	0.66	24.44
10	4.5	4.08	-0.42	-9.33
11	1.53	2.73	1.2	78.43
12	6.8	3.6	-3.2	-47.06
13	3.55	3.11	-0.44	-12.39
14	4.48	3.3	-1.18	-26.34

Discussion

This study is the first to investigate a novel short-interval high-intensity interval training (s-HIIT) protocol incorporating changes of direction (COD) at 45° and 90° in youth soccer players, distinguishing it from prior studies that primarily utilized linear running protocols (e.g., Dupont et al., 2002, 2003, 2004; Billat et al., 2002; Helgerud et al., 2007). The aim was to evaluate the effects of an 8-week s-HIIT protocol (3 sets of 3 repetitions, 30 s work at 105–120% vVO$_2$max: 30 s active recovery at 50% vVO$_2$max, except weeks 1–2 with 45 s intervals) on aerobic and anaerobic capacities during the competitive season in 16-year-old soccer players. The protocol, applied twice weekly with a 5% biweekly increase in vVO$_2$max intensity, significantly improved performance: Cooper Test distance by 7.69% ($p < 0.05$, Table 1), Åstrand Test VO$_2$max by 18.89% ($p < 0.05$, Table 2), and RAST Fatigue Index by 35.40% ($p < 0.05$, Table 3). These findings align with previous research demonstrating that high-intensity interval training enhances aerobic and anaerobic capacities in soccer players. For instance, (Daussin et al. 2007, 2008) reported that HIIT improves VO$_2$max, enabling better on-field performance due to enhanced aerobic capacity. Similarly, (Balsom et al. 1994) found that HIIT reduces lactate production and increases creatine phosphate utilization, supporting anaerobic performance during high-intensity efforts. Study published in Journal of *Physical Education and Sport (JPES)* by Agostino et al. (2019) 15 s × 15 s and 5 s × 5 s at 120% vVO$_2$max, in comparison to related studies published in (JPES) of Salazar-Martínez et al. (2023): Used 3–4 x 30-second all-out sprints (100% effort, ~120–130% MAS), achieving a 10% VO$_2$max increase (5.3 mL/kg/min) in 6 weeks. Agostino's protocol, possibly using shorter intervals, may yield slightly smaller aerobic gains but similar anaerobic improvements. Clemente and Sarmento (2021) Reported MAS-related VO$_2$max gains of 3.2–5.1 mL/kg/min with 30–60-second intervals at 90–95% HRmax, suggesting Agostino's protocol is comparable but more focused on shorter, supramaximal efforts. Rabbani et al. (2019): Used longer intervals (4 x 4 min at 90–95% HRmax), improving VO$_2$max by 4.8 mL/kg/min. Agostino's shorter intervals likely prioritize anaerobic power over aerobic endurance.

The quantitative results from previous studies highlight HIIT's ability to elicit significant physiological adaptations in youth soccer players. Specifically, VO2max improvements ranged from 3.2–5.3 mL/kg/min (7–10% increase), sprint times decreased by 0.12–0.15 seconds (2–4.5% improvement), and RSA improved by up to 0.22 seconds (~3%) (Clemente & Sarmento, 2021; Rabbani et al., 2019; Salazar-Martínez et al., 2023). These outcomes are driven by HIIT's high-intensity, intermittent structure, which closely mimics the physiological demands of soccer matches, characterized by repeated bouts of high-intensity efforts interspersed with brief recovery periods. HIIT's effectiveness in improving VO2max is particularly critical, as aerobic capacity underpins a player's ability to sustain high-intensity efforts over a 90-minute match. The 5.3 mL/kg/min increase reported by Salazar-Martínez et al. (2023), published in JEPS Journal, reflects the potency of all-out sprint protocols (30-second sprints at 100% effort), which maximize cardiovascular stress and stimulate mitochondrial biogenesis. Similarly, Rabbani et al. (2019) demonstrated that HIIT protocols with 4-minute intervals **at** 90–95% HRmax enhanced VO2max by 4.8 mL/kg/min when performed before small-sided games (SSGs), suggesting that exercise order amplifies aerobic adaptations by increasing metabolic demand early in the session. Sprint performance and RSA improvements are equally significant, given soccer's reliance on repeated high-speed actions (e.g., sprints to intercept or attack). The 0.15-second reduction in 20-m sprint time and 0.22-second improvement in RSA mean time (Salazar-Martínez et al., 2023) indicate that HIIT enhances anaerobic power and neuromuscular efficiency.

These adaptations are likely due to HIIT's ability to increase muscle fiber recruitment, improve lactate threshold, and enhance recovery kinetics, all of which are critical for maintaining performance during intense match scenarios. The numerical data provide actionable insights for coaches designing training programs for youth soccer players. HIIT's efficiency—delivering significant improvements in 4–6 weeks with 2–3 sessions per week—makes it ideal for pre-season or in-season phases where rapid fitness gains are needed. Protocols such **as** 30–60-second intervals at 90–100% effort with 1–3-minute recovery (Clemente & Sarmento, 2021; Salazar-Martínez et al., 2023) are practical, requiring minimal equipment and space. Coaches can implement these on a track or field, using sprints or shuttle runs to replicate match-like intensities. The findings from Rabbani et al. (2019) suggest structuring sessions to prioritize HIIT before SSGs, especially when targeting aerobic and endurance outcomes. For example, a session could begin with 4 x 4-minute intervals at 90–95% HRmax, followed by 15–20 minutes of SSGs to integrate technical and tactical elements. This approach maximizes physiological stress while maintaining game-specific training, aligning with the demands of competitive soccer. HIIT's adaptability also allows tailoring to different age groups and fitness levels. For younger players (e.g., U12–U14), shorter intervals (e.g., 15–30 seconds) with longer recovery periods may reduce fatigue and injury risk, while older players (e.g., U16–U18) can handle more intense protocols like those in Salazar-Martínez et al. (2023). Monitoring HRmax or perceived exertion (RPE) during HIIT sessions can ensure appropriate intensity, **with** 90–95% HRmax **or** RPE of 8–9/10 as benchmarks. Beyond immediate performance gains, HIIT's role in youth soccer has long-term implications. Improved VO2max and sprint performance enhance players' resilience to match demands, potentially reducing fatigue-related errors and injuries.

The 15% improvement in YYIR1 **distance** (Rabbani et al., 2019) reflects enhanced intermittent endurance, critical for maintaining performance in the latter stages of a game. Moreover, HIIT's time efficiency supports its integration into holistic training programs, allowing coaches to allocate time for technical drills, strength training, and recovery. HIIT also fosters mental toughness and discipline, as the high-intensity efforts require significant effort and focus. For youth players, this can translate to improved work ethic and resilience, qualities essential for progression to higher competitive levels. However, coaches must balance HIIT's intensity with adequate recovery to prevent overtraining, particularly in adolescents with developing musculoskeletal systems. Macpherson and Weston (2015) demonstrate that a 6-week low-volume SIT program (2x/week, 6–10 x 6 s all-out sprints) significantly improves VO_2max by 5.9% (+3.1 mL/kg/min) and YYIR1 performance by 13.7% (+280 m) in semi-professional soccer players, with gains maintained after 6 weeks of regular training. Son'kin and Tambovtseva (2012) offer a comprehensive review of energy metabolism in children and adolescents, emphasizing aerobic dominance in pre-pubertal youth and enhanced anaerobic capacity post-puberty. These findings inform HIIT protocols for soccer, supporting the efficacy of short, high-intensity intervals (e.g., 6–30 s at 100–120% MAS) in adolescents.

The study of Berthoin et al. (1995), a 12-week program with one weekly intense session (90–120% MAS) increased MAS by 5.4–5.7% in 14–17-year-olds, suggesting Agostino's more frequent sessions (2–3x/week) could yield larger gains. (Berthoin et al. 1995) 10 s runs at 120% vVO_2max in 14–17-year-olds and (Arslanoğlu et al. 2024) 80–110% vVO_2max, and corroborate that s-HIIT with extensive intervals improves both aerobic and anaerobic capacities in youth athletes, consistent with our results. The inclusion of COD in our protocol addresses a critical gap in the literature, as soccer involves frequent directional changes not well-represented by linear running (Cavar et al., 2018). Léger et al. (1988) and Buchheit et al. (2011) emphasized the need for sport-specific locomotion in endurance training, advocating for tests like the 20-m shuttle run (Beep Test) that incorporate COD. Our s-HIIT protocol, with distances adjusted by 7% for COD (Laursen & Buchheit, 2019), mimics soccer's movement patterns, enhancing its ecological validity. The significant improvements in RAST Fatigue Index (35.40%) suggest that COD training may particularly benefit anaerobic performance, enabling players to sustain repeated sprints during matches. The 1:1 work-to-rest ratio (30 s: 30 s) in our protocol, except for the initial 45 s intervals in weeks 1–2, likely contributed to its effectiveness. De Frutos et al. (2021) suggested that frequent rest intervals in short-interval HIIT reduce physical exertion, allowing sustained effort over time. Zuhl and Kravitz (2012) noted that a 1:1 ratio targets specific energy systems, optimizing adaptations in both aerobic and anaerobic pathways. Our findings support their assertion that HIIT can yield significant improvements in shorter training periods, as the 12-minute sessions (excluding warm-up) improved performance metrics comparable to or better than longer protocols in prior studies (e.g., Helgerud et al., 2007). Despite these strengths, limitations must be acknowledged. Four participants dropped out due to match-related injuries, reducing the sample to 14 and potentially affecting statistical power. Additionally, we could not control nutrition, daily regimens, or sleep patterns, which may have influenced performance outcomes.

Future research should incorporate dietary and sleep monitoring and explore the protocol's effects in larger, more diverse samples, including female players. Further studies could also compare COD-based s-HIIT with linear HIIT to isolate the specific benefits of directional changes. In conclusion, this novel s-HIIT protocol with COD significantly enhanced aerobic and anaerobic capacities in youth soccer players, offering a time-efficient, soccer-specific training method. Its twice-weekly implementation during the competitive season makes it practical for coaches, aligning with the need for effective, low-stress training in adolescent athletes. Meta-analyses indicate that research on high-intensity interval training (HIIT), particularly short-interval HIIT (s-HIIT) protocols, in youth athletes is limited (Clemente et al., 2021; Engel et al., 2018; Kunz et al., 2019; Hall et al., 2022). In their meta-analysis on HIIT effects in male soccer players' physical fitness, Clemente et al. (2021) reported that "HIIT (overall) was found to produce significant improvements in VO_2max, field-based aerobic performance, RSA, and sprinting." Specifically, they noted VO_2max improvements ranging from 2.2% to 7.5% (average 4.8%) for short-interval HIIT (s-HIIT) and 3% for s-HIIT protocols. Engel et al. (2018) concluded that young athletes performing HIIT may improve key aerobic and anaerobic performance variables. Our study's findings align with these results. In the 12-minute Cooper Test, the t-statistic (11.36) exceeded the critical value (1.771), with a p-value < 0.0001, indicating high statistical significance. Participants increased their distance by a mean of 215 m (95% CI [175, 255]), a 7.69% improvement from the pre-test mean of 2714 m. All 14 participants improved, with gains ranging from 80 m to 350 m. The effect size (Cohen's $d \approx 3.04$) suggests an extremely large practical impact ($d > 0.8$ is considered large), highlighting the intervention's effectiveness in enhancing aerobic performance.

The 6-minute Åstrand Test results were similarly robust. The t-statistic (14.82) far exceeded the critical value (1.771), with a p-value < 0.001. Participants improved their VO_2max by a mean of 8.96 units (95% CI [7.59, 10.33]), an 18.89% increase. All 14 participants showed gains, confirming the intervention's consistent effectiveness in improving aerobic capacity. The large, statistically significant improvement underscores the protocol's reliability and robustness. In the RAST (6 × 35 m), the t-statistic (-3.59) exceeded the critical value (±2.160) in magnitude, with a p-value < 0.01. Participants reduced their Fatigue Index (FI) by a mean of 1.63 units (95% CI [-2.58, -0.68]), a 35.40% improvement. Twelve of 14 participants improved, with two exceptions: Participant 9's FI increased by 0.66 (pre: 2.70, post: 3.36), and Participant 11's FI increased by 1.20 (pre: 1.53, post: 2.73). The effect size (Cohen's $d \approx 0.96$) indicates a large impact. The intervention significantly reduced fatigue, with consistent improvements across most participants, supported by a narrow confidence interval and strong correlation. However, the slightly higher standard deviation in post-test measurements suggests some participants benefited more than others, warranting further investigation into individual variability. Concerns about maximal effort in field tests (e.g., Cooper Test, RAST) compared to controlled laboratory tests (e.g., Åstrand Test) are common. However, benchmarking field and laboratory results validates the intervention's effectiveness. Our results demonstrate that the s-HIIT protocol (30 s work: 30 s active recovery for 8 weeks, with progressive increases in running distance and intensity) significantly improved the aerobic and anaerobic capacities of the 14 participants.

Conclusion

This study represents a pioneering effort in evaluating the efficacy of a novel short-interval high-intensity interval training (s-HIIT) protocol incorporating changes of direction (COD) at 45° and 90° in 16-year-old male soccer players during the competitive season. Conducted over 8 weeks with twice-weekly sessions, the protocol consisted of 3 sets of 3 repetitions (30 s work at 105–120% vVO_2max: 30 s active recovery at 50% vVO_2max, with 45 s intervals in weeks 1–2) and a 5% biweekly increase in intensity. The intervention, designed to mimic soccer's movement demands, significantly enhanced both aerobic and anaerobic capacities, addressing a critical gap in the limited literature on s-HIIT for youth athletes. This study's implications are profound for youth soccer training. The s-HIIT protocol with COD offers coaches a low-stress, soccer-specific method to enhance performance during the competitive season, aligning with the need for developmentally appropriate training. Its twice-weekly implementation minimizes time demands while delivering significant aerobic and anaerobic gains, supporting its adoption in youth academies.

The findings also contribute to the sparse literature on s-HIIT in adolescents, providing a foundation for future research to compare COD-based versus linear HIIT, include female players, and incorporate dietary and sleep monitoring to optimize outcomes. In conclusion, this novel s-HIIT protocol with COD significantly improved aerobic and anaerobic capacities in 16-year-old soccer players, demonstrating its efficacy and practicality. By addressing soccer's unique movement patterns and delivering robust performance gains in a time-efficient manner, this intervention holds substantial promise for enhancing youth soccer training and advancing exercise science research. Further exploration of its long-term effects and broader applicability will solidify its role in optimizing athletic development.

Practical Recommendations

Based on the results the intervention was highly effective. The large effect size and statistically significant results suggest that the intervention had a meaningful impact. Consistency across subjects. The narrow confidence interval and strong correlation indicate that the intervention worked well for most subjects. Consider individual variability. While the overall results are positive, the slightly higher standard deviation in the "Post" measurements suggests that some subjects may have benefited more than others. Further investigation into why this occurred could help optimize the intervention.

Future Research Directions

Key Finding and Recommendation

Need for more studies because there is a significant research gap in the effects of S-HIIT with COD on aerobic and anaerobic capacities in youth soccer players. Future studies should investigate the integration of COD into s-HIIT protocols, focusing on both physiological and technical outcomes. Longitudinal studies are needed to assess the long-term effects of s-HIIT with COD on growth, development, and injury risk in youth players. Studies should track players over multiple seasons to evaluate the sustainability of training effects. Individualized training protocols and advanced monitoring tools (e.g., GPS, accelerometers) are essential for optimizing s-HIIT with COD. Future research should focus on developing and validating individualized COD-based s-HIIT protocols.

References

Agostino, S. (2019). The improvement of the maximum aerobic speed in football through high intensity interval training. *Journal of Physical Education and Sport, 19*(S2), 305–313. https://doi.org/10.7752/jpes.2019.s2046

Alvarado, M. U. (2005). Nutrition for young soccer players. *International Journal of Soccer and Science, 3*(1), 12–20.

Arslanoglu, C., Celgin, G. S., Arslanoglu, E., Demirci, N., Karakas, F., Dogan, E., Cakaloglu, E., Sahin, F. N.,& Kucuk, H. (2024). An effective method of aerobic capacity development: Combined training with maximal aerobic speed and small-sided games for amateur football players. *Applied Sciences, 14*(19), Article 9134. https://doi.org/10.3390/app14199134

Åstrand, I., Åstrand, P. O., Christensen, E. H., & Hedman, R. (1960). Intermittent muscular work. *Acta Physiologica Scandinavica, 48*(3–4), 448–453. https://doi.org/10.1111/j.1748-1716.1960.tb01879.x

Atan Siti Azilah, Andrew Foskett, Ajmol Ali. (2014). Special populations: Issues and considerations in youth soccer match analysis. *International Journal of Sports Science, 4*(3), 103–114. https://doi.org/10.5923/j.sports.20140403.05

Balsom, P. D., & Ekblom, B. (1994). Enhanced oxygen availability during high intensity intermittent exercise decreases anaerobic metabolite concentrations in blood. *Acta Physiologica Scandinavica, 150*(4), 455–456. https://doi.org/10.1111/j.1748-1716.1994.tb09711.x

Bangsbo, J., Mohr, M., & Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences, 24*(7), 665–674. https://doi.org/10.1080/02640410500482529

Barker, A. R., Day, J., Smith, A., Bond, B., & Williams, C. A. (2014). The influence of 2 weeks of low-volume high-intensity interval training on health outcomes in adolescent boys. *Journal of Sports Sciences, 32*(8), 757–765. https://doi.org/10.1080/02640414.2013.853132

Berthoin, S., Mantéca, F., Gerbeaux, M., & Lensel-Corbeil, G. (1995). Effect of a 12-week training programme on maximal aerobic speed (MAS) and running time to exhaustion at 100% of MAS for students aged 14 to 17 years. *Journal of Sports Medicine and Physical Fitness, 35*(4), 251–256.

Billat, V. (1998). *Physiology and methodology of training: From theory to practice*. De Boeck University.

Billat, V. L., Hamard, L., & Koralsztein, J. P. (2002). The influence of exercise duration at VO2max on the off-transient pulmonary oxygen uptake phase during high intensity running activity. *Archives of Physiology and Biochemistry, 110*(5), 383–392. https://doi.org/10.1076/apab.110.5.383.8794

Boisseau, N., & Delamarche, P. (2000). Metabolic and hormonal responses to exercise in children and adolescents. *Sports Medicine, 30*(6), 405–422. https://doi.org/10.2165/00007256-200030060-00003

Buchan, D. S., Ollis, S., Young, J. D., Thomas, N. E., Cooper, S. M., Tong, T. K., Nie, J., Malina, R. M., & Baker, J. S. (2011). The effects of time and intensity of exercise on novel and established markers of CVD in adolescent youth. *American Journal of Human Biology, 23*(4), 517–526. https://doi.org/10.1002/ajhb.21166

Buchan, D. S., Young, J. D., & Simpson, A. D. (2012). The effects of a novel high intensity exercise intervention on established markers of cardiovascular disease and health in Scottish adolescent youth. *Journal of Public Health Research, 1*(2), Article e24. https://doi.org/10.4081/jphr.2012.e24

Buchheit, M., & Laursen, P. B. (2014). High-intensity interval training: Solutions to the programming puzzle—Part II. *Sports Medicine, 44*(7), 927–954. https://doi.org/10.1007/s40279-013-0066-5

Buchheit, M., Haydar, B., Hader, K., Ufland, P., & Ahmaidi, S. (2011). Assessing running economy during field running with changes of direction: Application to 20 m shuttle runs. *International Journal of Sports Physiology and Performance, 6*(3), 380–395. https://doi.org/10.1123/ijspp.6.3.380

Buchheit, M., Mendez-Villanueva, A., & Simpson, B. (2010). *Match running performance and physical capacity in youth football (soccer)* [Conference presentation]. ASPIRE, Academy for Sports Excellence, Doha, Qatar. https://pdfs.semanticscholar.org/presentation/c0fe/b0fb90a68983eb77033e4234fc6ace25447f.pdf

Burns, S. F., Oo, H. H., & Tran, A. T. T. (2012). Effect of sprint interval exercise on postexercise metabolism and blood pressure in adolescents. *International Journal of Sport Nutrition and Exercise Metabolism, 22*(1), 47–54. https://doi.org/10.1123/ijsnem.22.1.47

Cavar, M., Marsic, T., Corluka, M., Culjak, Z., Cerkez Zovko, I., Müller, A., Tschakert, G., & Hofmann, P. (2018). Effects of 6 weeks of different high-intensity interval and moderate continuous training on aerobic and anaerobic performance. *Journal of Strength and Conditioning Research*. Advance online publication. https://doi.org/10.1519/JSC.0000000000002798

Clemente, F. M., Ramirez-Campillo, R., Nakamura, F. Y., & Sarmento, H. (2021). Effects of high-intensity interval training in men soccer players' physical fitness: A systematic review with meta-analysis of randomized-controlled and non-controlled trials. *Journal of Sports Sciences, 39*(8), 901–916. https://doi.org/10.1080/02640414.2020.1863644

Clemente, F. M., & Sarmento, H. (2021). Combining small-sided soccer games and running-based methods: A systematic review. *Biology of Sport, 38*(4), 617–627. https://doi.org/10.5114/biolsport.2021.102932

Daussin, F. N., Ponsot, E., Dufour, S. P., Lonsdorfer-Wolf, E., Doutreleau, S., Geny, B., Piquard, F., & Richard, R. (2007). Improvement of VO2max by cardiac output and oxygen extraction adaptation during intermittent versus continuous endurance training. *European Journal of Applied Physiology, 101*(3), 377–383. https://doi.org/10.1007/s00421-007-0499-3

Daussin, F. N., Zoll, J., Dufour, S. P., Ponsot, E., Lonsdorfer-Wolf, E., Doutreleau, S., Mettauer, B., Piquard, F., Geny, B., & Richard, R. (2008). Effect of interval versus continuous training on cardiorespiratory and mitochondrial functions: Relationship to aerobic performance improvements in sedentary subjects. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology, 295*(1), R264–R272. https://doi.org/10.1152/ajpregu.00875.2007

Dupont, G., Akakpo, K., & Berthoin, S. (2004). The effect of in-season, high-intensity interval training in soccer players. *Journal of Strength and Conditioning Research, 18*(3), 584–589. https://doi.org/10.1519/1533-4287(2004)18<584:TEOIHI>2.0.CO;2

Dupont, G., Blondel, N., & Berthoin, S. (2003). Performance for short intermittent runs: Active versus passive recovery. *European Journal of Applied Physiology, 89*(6), 548–554. https://doi.org/10.1007/s00421-003-0834-2

Dupont, G., Blondel, N., Lensel, G., & Berthoin, S. (2002). Critical velocity and time spent at a high level of VO2 for short intermittent runs at supramaximal velocities. *Canadian Journal of Applied Physiology, 27*(2), 103–115. https://doi.org/10.1139/h02-008

Engel, F. A., Ackermann, A., Chtourou, H., & Sperlich, B. (2018). High-intensity interval training performed by young athletes: A systematic review and meta-analysis. *Frontiers in Physiology, 9*, Article 1012. https://doi.org/10.3389/fphys.2018.01012

Ferrari Bravo, D., Impellizzeri, F. M., Rampinini, E., Castagna, C., Bishop, D., & Wisløff, U. (2016). Sprint vs. interval training in football. *International Journal of Sports Medicine, 37*(5), 397–404. https://doi.org/10.1055/s-2007-989371

De Frutos, J. M., Orquín-Castrillón, F. J., Marcos-Pardo, P. J., Rubio-Arias, J. Á., & Martínez-Rodríguez, A. (2021). Acute effects of work rest interval duration of 3 HIIT protocols on cycling power in trained young adults. *International Journal of Environmental Research and Public Health, 18*(8), Article 4225. https://doi.org/10.3390/ijerph18084225

Gist, N. H., Fedewa, M. V., Dishman, R. K., & Cureton, K. J. (2014). Sprint interval training effects on aerobic capacity: A systematic review and meta-analysis. *Sports Medicine, 44*(2), 269–279. https://doi.org/10.1007/s40279-013-0115-0

Hall, A. J., Aspe, R. R., Craig, T. P., Kavaliauskas, M., Babraj, J., & Swinton, P. A. (2023). The effects of sprint interval training on physical performance: A systematic review and meta-analysis. *Journal of Strength and Conditioning Research, 37*(2), 457–481. https://doi.org/10.1519/JSC.0000000000004257

Helgerud, J., Engen, L. C., Wisløff, U., & Hoff, J. (2001). Aerobic endurance training improves soccer performance. *Medicine & Science in Sports & Exercise, 33*(11), 1925–1931. https://doi.org/10.1097/00005768-200111000-00019

Helgerud, J., Høydal, K., Wang, E., Karlsen, T., Berg, P., Bjerkaas, M., Simonsen, T., Helgesen, C., Hjorth, N., Bach, R., & Hoff, J. (2007). Aerobic high-intensity intervals improve VO2max more than moderate training. *Medicine & Science in Sports & Exercise, 39*(4), 665–671. https://doi.org/10.1249/mss.0b013e3180304570

Hostrup, M., Lemminger, A. K., Stocks, B., Gonzalez-Franquesa, A., Larsen, J. K., Quesada, J. P., Thomassen, M., Weinert, B. T., Bangsbo, J., & Deshmukh, A. S. (2022). High-intensity interval training remodels the proteome and acetylome of human skeletal muscle. *eLife, 11*, e69802. https://doi.org/10.7554/eLife.69802

Hostrup, M., Gunnarsson, T. P., Fiorenza, M., Mørch, K., Onslev, J., Pedersen, K. M., & Bangsbo, J. (2019). In-season adaptations to intense intermittent training and sprint interval training in sub-elite football players. *Scandinavian Journal of Medicine & Science in Sports, 29*(5), 669–677. https://doi.org/10.1111/sms.13395

Iaia, F. M., Fiorenza, M., Perri, E., Alberti, G., Millet, G. P., & Bangsbo, J. (2015). The effect of two speed endurance training regimes on performance of soccer players. *PLoS ONE, 10*(9), Article e0138096. https://doi.org/10.1371/journal.pone.0138096

Iaia, F. M., Rampinini, E., & Bangsbo, J. (2022). High-intensity training in football: New perspectives. *International Journal of Sports Physiology and Performance, 17*(3), 317–325. https://doi.org/10.1123/ijspp.4.3.291

Islam, H., Townsend, L. K., & Hazell, T. J. (2017). Modified sprint interval training protocols. Part I: Physiological responses. *Applied Physiology, Nutrition, and Metabolism, 42*(4), 339–346. https://doi.org/10.1139/apnm-2016-0478

Koral, J., Oranchuk, D. J., Herrera, R., & Millet, G. Y. (2018). Six sessions of sprint interval training improves running performance in trained athletes. *Journal of Strength and Conditioning Research, 32*(3), 617–623. https://doi.org/10.1519/JSC.0000000000002286

Krustrup, P., Ørtenblad, N., Nielsen, J., Nybo, L., Gunnarsson, T. P., Iaia, F. M., Madsen, K., Stephens, F., Greenhaff, P., & Bangsbo, J. (2011). Maximal voluntary contraction force, SR function and glycogen resynthesis during the first 72 h after a high-level competitive soccer game. *European Journal of Applied Physiology, 111*(12), 2987–2995. https://doi.org/10.1007/s00421-011-1919-y

Kunz, P., Engel, F. A., Holmberg, H.-C., & Sperlich, B. (2019). A meta-comparison of the effects of high-intensity interval training to those of small-sided games and other training protocols on parameters related to the physiology and performance of youth soccer players. *Sports Medicine - Open, 5*(1), 7. https://doi.org/10.1186/s40798-019-0180-5

Laursen, P., & Buchheit, M. (2019). *Science and application of high-intensity interval training*. Human Kinetics.

Léger, L. A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences, 6*(2), 93–101. https://doi.org/10.1080/02640418808729800

Lloyd, R. S., Oliver, J. L., Faigenbaum, A. D., Howard, R., De Ste Croix, M. B., Williams, C. A., Best, T. M., Alvar, B. A., Micheli, L. J., Thomas, D. P., Hatfield, D. L., Cronin, J. B., & Myer, G. D. (2021). Long-term athletic development: Part 2—Barriers to success and potential solutions. *Journal of Strength and Conditioning Research, 35*(5), 1441–1455. https://doi.org/10.1519/01.JSC.0000465424.75389.56

Macpherson, T. W., & Weston, M. (2015). The effect of low-volume sprint interval training on the development and subsequent maintenance of aerobic fitness in soccer players. *International Journal of Sports Physiology and Performance, 10*(3), 332–338. https://doi.org/10.1123/ijspp.2014-0075

McKie, G. L., Islam, H., Townsend, L. K., Robertson-Wilson, J., Eys, M., & Hazell, T. J. (2017). Aerobic and anaerobic effects of manipulating sprint interval training work and rest period durations [Abstract]. *Medicine & Science in Sports & Exercise, 49*(5S), 615. https://doi.org/10.1249/01.mss.0000518688.96723.0b

McKie, G. L., Islam, H., Townsend, L. K., Robertson-Wilson, J., Eys, M., & Hazell, T. J. (2018). Modified sprint interval training protocols: Physiological and psychological responses to four weeks of training. *Applied Physiology, Nutrition, and Metabolism, 43*(6), 595–601. https://doi.org/10.1139/apnm-2017-0590

Medbø, J. I., Mohn, A. C., Tabata, I., Bahr, R., Vaage, O., & Sejersted, O. M. (1988). Anaerobic capacity determined by maximal accumulated O2 deficit. *Journal of Applied Physiology, 64*(1), 50–60. https://doi.org/10.1152/jappl.1988.64.1.50

Mendez-Villanueva, A., Buchheit, M., Kuitunen, S., Douglas, A., Peltola, E., & Bourdon, P. (2018). Age-related differences in acceleration, maximum running speed, and repeated-sprint performance in young soccer players. *Journal of Sports Sciences, 36*(13), 1493–1499. https://doi.org/10.1080/02640414.2010.536248

Mendez-Villanueva, A., Buchheit, M., Simpson, B., & Bourdon, P. C. (2013). Match play intensity distribution in youth soccer. *International Journal of Sports Medicine, 34*(2), 101–110. https://doi.org/10.1055/s-0032-1306323

Mohr, M., & Krustrup, P. (2016). Comparison between two types of anaerobic speed endurance training in competitive soccer players. *Journal of Human Kinetics, 51*(1), 183–192. https://doi.org/10.1515/hukin-2015-0181

Naughton, G., Farpour-Lambert, N. J., Carlson, J., Bradney, M., & Van Praagh, E. (2000). Physiological issues surrounding the performance of adolescent athletes. *Sports Medicine, 30*(5), 309–325. https://doi.org/10.2165/00007256-200030050-00001

Nikolaidis, P. T. (2011). Anaerobic power across adolescence in soccer players. *Human Movement, 12*(4), 342–347. https://doi.org/10.2478/v10038-011-0039-1

Rabbani, A., Clemente, F. M., Kargarfard, M., & Jahangiri, S. (2019). Combined small-sided game and high-intensity interval training in soccer players: The effect of exercise order. *Journal of Human Kinetics, 69*(1), 249–257. https://doi.org/10.2478/hukin-2018-0092

Rampinini, E., Sassi, A., Morelli, A., Mazzoni, S., Fanchini, M., & Coutts, A. J. (2019). Repeated-sprint ability in professional and amateur soccer players: A follow-up study. *Applied Physiology, Nutrition, and Metabolism, 44*(6), 669–675. https://doi.org/10.1139/H09-111

Riddell, M. C. (2008). The endocrine response and substrate utilization during exercise in children and adolescents. *Journal of Applied Physiology, 105*(2), 725–733. https://doi.org/10.1152/japplphysiol.00031.2008

Son'kin, V., & Tambovtseva, R. (2012). Energy metabolism in children and adolescents. In K. Clark (Ed.), *Bioenergetics* (pp. 81–104). IntechOpen. https://www.intechopen.com/books/bioenergetics/energy-metabolism-in-children-and-adolescents

Salazar-Martínez, J. L., Valencia-Sánchez, W. G., & Clemente, F. M. (2023). Comparative impact of small-sided games and high-intensity interval training on physical performance in youth soccer players. *Journal of Physical Education and Sport, 23*(10), 317–324. https://doi.org/10.7752/jpes.2023.10317

Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). Physiology of soccer. *Sports Medicine, 35*(6), 501–536. https://doi.org/10.2165/00007256-200535060-00004

Vollaard, N. B., Metcalfe, R. S., & Williams, S. (2017). Effect of number of sprints in an SIT session on change in VO2max: A meta-analysis. *Medicine & Science in Sports & Exercise, 49*(6), 1147–1156. https://doi.org/10.1249/MSS.0000000000001204

Willoughby, T. N., Thomas, M. P., Schmale, M. S., Copeland, J. L., & Hazell, T. J. (2016). Four weeks of running sprint interval training improves cardiorespiratory fitness in young and middle-aged adults. *Journal of Sports Sciences, 34*(13), 1207–1214. https://doi.org/10.1080/02640414.2015.1102316

Yüksel, Y., Akyüz, Ö., Çetinkaya, T., Sezer, S., Dinç, M., & Öztürk, Ö. (2023). The effect of maximal aerobic speed training combined with small-sided games on performance parameters in soccer. *Kinesiology, 55*(2), 349–358. https://doi.org/10.26582/k.55.2.14

Zuhl, M., & Kravitz, L. (2012). HIIT vs. continuous endurance training: Battle of the aerobic titans. *IDEA Fitness Journal, 9*(2), 34–40.