

Effect of a high-intensity interval training program on aerobic and anaerobic performance indices in adolescent soccer players

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Abstract

Introduction. High-intensity interval training (HIIT) is widely used in team sports, particularly in soccer. Aim of study. This study aimed to examine the effects of a short-term, progressive overload HIIT program on the performance of under-15 soccer players. **Material and Methods.** The sample consisted of 30 adolescent soccer players, aged 14, who were randomly assigned to either the control group (CG, $n = 15$) or the intervention group (EG, $n = 15$), the latter completing additional HIIT sessions. The intervention program lasted six weeks, with progressive overload implemented every two weeks. Performance indicators, including speed over 10 and 30 meters, change of direction (COD) to the right and left (505 right and left), maximal oxygen uptake ($30\text{-}15\text{I}_{PT}$), and repeated-sprint ability (RSA) ($\text{RSA}_{\text{total}}$, RSA_{mean} , RSA_{decr}), were measured before and after the training program. Two-way (group \times time) ANOVA with repeated measures was used for statistical analysis. **Results.** Significant interactions were observed in the intervention group in 10-m sprint, $\text{RSA}_{\text{total}}$ and RSA_{mean} . Improvements were also recorded in the experimental group in the COD performance (505 right and left) and in the $30\text{-}15\text{I}_{PT}$. **Conclusions.** The findings of the present study suggest that a short-term, progressively overloaded HIIT program can enhance speed, COD ability, aerobic capacity, and repeated-sprint performance.

KEYWORDS: repeated-sprint ability, agility, youth soccer, speed, maximal oxygen uptake.

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Introduction

Soccer is an intermittent sport that requires a high level of technical, tactical and psychological preparation, as well as equally high levels of physical abilities such as endurance, speed, strength, and flexibility [1, 2]. During a match, players typically cover more than 10 km and perform actions at very high speed (>19.8 km/h) every 70-90 seconds [3]. For example, during the FIFA World Cup in Qatar, teams covered an average of 108.1 km in total per match, of which 9.001 m and 2.345 m were covered at high intensities (>20 km/h and >25 km/h), respectively [4].

Youth soccer is also characterized by constant intensity changes in various actions (running, sprinting, directional changes, jumping, tackling), making it necessary to produce energy from both aerobic and anaerobic energy mechanisms [5]. The same researchers note that although aerobic capacity is an important factor for success during developmental ages, other elements—technical and tactical skills—also play a crucial role in youth development. For this reason, it is important that coaches working with athletes in the developmental ages employ training methods that provide stimuli addressing the broad demands of youth player – technically, tactically, and physically.

A widely used and time-efficient training method that develops both aerobic and anaerobic capacity, while still leaving room to train other key elements such as neuromuscular skills, technique, tactics, and general fitness, is High Intensity Interval Training (HIIT) [6]. This method has been extensively applied to improve aerobic and anaerobic fitness across various populations (adults, healthy or diseased individuals, team or individual athletes), yet its application in children and adolescents is not as extensive as in adults [6]. Several studies have been conducted on adolescent soccer players, but their findings have been inconsistent [2, 7-9]. Michailidis et al. [8] implemented an 8-week HIIT program for 16-year-old adolescent soccer players that consisted of running 2-3 sets of 4-minute intervals performed as 15 seconds of work followed by 15 seconds of rest at 120% of the athletes' maximum speed determined in the Yo-Yo Intermittent Recovery 1 Test (YYIR1). Results showed a significant decrease in 10-meter sprint time (9%), Illinois Agility Test time (3%) and a significant improvement in RSA_{mean} (1.7%). Sperlich et al. [2] recorded a decrease (improvement) in the sprint time among 13.5-year-old soccer players, with speed times over 20, 30 and 40 meters decreasing by 4.3%, 4.4% and 2.8% respectively and in VO_{2max} by 6.8% after a 5-week interventional HIIT program. In contrast, another study did not observe a significant improvement in speed performance in the 30-m sprint and recorded a decline in jumping performance both in countermovement jump (CMJ) and drop jump (DJ) in 16-year-old elite soccer players [7]. The conflicting results are likely due to differences in protocols, the variables measured, the tests (trials) employed, or the age and competitive level of the participants. According to Engel et al. [6], in their review and meta-analysis, the intervention periods of the analyzed studies ranged from 5 days to 26 weeks, with an average of 2.5 HIIT sessions per week. Several studies involving adolescents team-sport athletes used intervention programs lasting 4-6 weeks [1, 2, 7, 8, 10, 11] and two training sessions per week. The majority of studies in football have used fixed intervention protocols without any form of periodization [7, 10-12]. Los Arcos et al. [10] applied a protocol consisting of three 4-minute running intervals at 90-95% of HR_{max} with 3-minute recovery periods at 50-60% of HR_{max} over a 6-week period, while Impellizzeri et al. [12] and Impellizzeri et al. [13] applied a 4 × 4-minute protocol in soccer players aged 17 and 18 years, respectively. However, based on the principle of progressive overload, it is possible that a gradual increase in load would give

better results across various indicators of aerobic or anaerobic performance. A few studies implemented protocols with progressive overload [1, 2, 8, 9, 11] in participants of different ages and sports. Chtara et al. [1] observed improvements on 30-m sprint performance and RSA_{mean} , manipulating the training load each week in 14-year-old soccer players. Michailidis et al. [8], who also increased the training load each week in U17 soccer players, found improvements in 10-m speed, agility, and RSA_{mean} . Harrison et al. [11] implemented a 6-week intervention (12 training sessions) consisting of Small-Sided Games (SSGs) only or a mixed program combining SSGs and HIIT sessions performed in different training sessions per week in U15 field hockey and rugby players. The training load was increased each week leading to an improvement in peak oxygen uptake after mixed program, but no improvements in speed or jumping ability were observed.

Aim of Study

The purpose of this study was to examine the effect of a 6-week HIIT program with an increase in training volume every two weeks on the physical abilities of adolescent soccer players under 15 years of age (U15). Based on the results of previous studies, we hypothesize that the intervention program will positively influence the performance of young soccer players across all the indicators we are evaluating.

Material and Methods

Subjects

Based on the power analysis conducted prior to the study [14], it was determined that the minimum acceptable sample size for analyzing the interaction between groups and measurement time points was 24 subjects. For the above analysis, Gpower software (G*Power, version 3.1.9.2, Universität Kiel, Düsseldorf, Germany) was used with an effect size > 0.6, an error probability of 0.05 and a power of 0.9 for the two groups and two time points (before and after). The study inclusion criteria were defined as follows: i) no musculoskeletal injury for at least four months prior to the study, ii) participation in more than 95% of the training sessions, and iii) not taking any medication. Thirty teenage soccer players under 15 years old (U15) from an academy in Thessaloniki, who competed in the developmental championships of the Local Football Union of Macedonia in the corresponding age category (U15), participated in the study. Participants were randomly divided into two subgroups: the control group (CG, $n = 15$) and the experimental group (EG,

$n = 15$). All players and their parents were informed about the benefits and potential risks of the study and they provided written informed consent for participation. The research followed the guidelines of the Research Code of Ethics of the Aristotle University of Thessaloniki and was conducted in accordance with the principles of the Declaration of Helsinki (Approval number 199/2024). The characteristics of the participants are presented in Table 1.

Table 1. Physiological characteristics of the participants

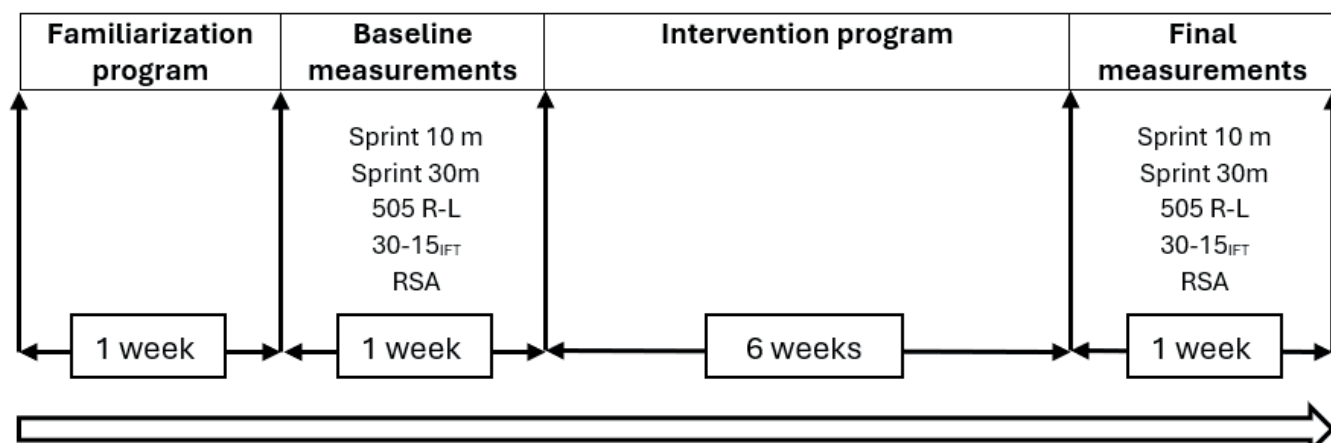
	CG ($n = 15$)		EG ($n = 15$)	
	Pre	Post	Pre	Post
Age (years)	14.63 \pm 0.42	14.81 \pm 0.41	14.54 \pm 0.46	14.71 \pm 0.47
Height (cm)	173 \pm 0.6	174 \pm 0.6	169 \pm 0.8	170 \pm 0.8
Weight (kg)	66.2 \pm 13.1	66.3 \pm 13.1	63.6 \pm 12.3	61.9 \pm 12.4

Note: CG – control group, EG – experimental group, Pre – baseline values, Post – after the experimental values

Procedure

The study was conducted during the competitive season (March-May) and lasted a total of nine weeks. All participants followed the same training program that consisted of four training sessions per week and participation in one game. The measurements included assessments of anthropometric characteristics (height, weight) and performance indicators: 10- and 30-meter sprint speed, COD performance using the 505 agility test with both right- and left-foot turn, maximal oxygen uptake (VO_{2max}) assessed with the 30-15 Incremental Fitness Test (30-15_{IFT}) and repeated-sprint ability (RSA)

evaluated with six 30-meter sprints. Two weeks prior to the start of the intervention program, the soccer players were familiarized with the measurement procedures to minimize potential learning-effect error. One week before the start of the intervention, baseline measurements were taken on two different days (due to the number of trials), with 48 hours between sessions. During the first measurement session, anthropometric characteristics were assessed, along with 10- and 30-meter sprint speed, COD performance using the 505 agility test with both right- and left-foot turn, VO_{2max} assessed with the 30-15_{IFT} and RSA evaluated with six 30-meter sprints. Two weeks prior to the start of the intervention program, the soccer players were familiarized with the measurement procedures to minimize potential learning-effect error. One week before the start of the intervention, baseline measurements were taken on two different days (due to the number of trials), with 48 hours between sessions. During the first measurement session, anthropometric characteristics were assessed, along with 10- and 30-meter sprint speed and VO_{2max} (30-15_{IFT}). During the second measurement session, the remaining tests – the 505 agility test and the RSA test were performed. All the above-mentioned procedures were repeated one week after the completion of the intervention training program for both groups, following the same order (Figure 1). On the day of the measurements before the start of the evaluation, a 25-minute warm-up was performed. It included running exercises, neuromuscular coordination exercises, four repetitions of 15-meter sprint and four repetitions with COD, followed by a 6 vs. 2 SSG. The warm-up was followed by a 5-minute rest period. The entire procedure was done on synthetic turf.



505R – The value of 505 test with rightwards turn, 505L – The value of 505 test with leftwards turn, 30-15_{IFT} – The 30-15 Intermittent Fitness Test, RSA – Repeated Sprint Ability

Figure 1. Study design

Intervention program

The intervention program was implemented over a six-week period, consisting of two training sessions per week, scheduled 48 hours apart (12 training sessions in total). The total duration of the training sessions was 90 minutes. Both groups began with the warm-up protocol. After the warm-up, the EG completed the intervention program, while the CG performed technical and tactical exercises. Once the EG completed the intervention program, they continued with the same technical-tactical training as the CG until the end of the session. The total duration of the intervention program in each training session ranged from 15 to 21 minutes, progressing from 15 minutes during the first two weeks, to 18 minutes in weeks three and four, and to 21 minutes in the last two weeks. The total training time was identical for both the intervention and control groups. The intervention program was carried out immediately after the warm-up to ensure full neuromuscular activation. The detailed structure of the intervention program is presented in Table 2.

Anthropometric measurements

Height and body mass were measured using an electronic scale with an integrated SECA 767 stadiometer (BodyScale 500, Seca GmbH & Co. KG, Hamburg, Germany). During the assessments, participants were barefoot and wore only underwear.

10- and 30-m sprint speed

The 30-m sprint test was used to assess sprint speed, with an additional split time recorded at 10 m. All sprints were

performed on synthetic turf while wearing football boots. The footballers performed two attempts, and the best time was used for statistical analysis. Photocell timing gates (Witty Microgate, Microgate, Bolzano, Italy) were positioned at the starting line and at the 10- and 30-m marks. Players started from an upright position, standing 30 cm behind the first timing gate. The photocells were placed 0.7 m above the ground (at approximately hip height) to detect torso movement and minimize false triggers caused by lower-limb motion [15]. A finish cone was placed 5 m beyond the 30-m timing gates to prevent participants from decelerating prematurely. Full recovery was provided between the two trials.

Change of direction (COD) (505 agility test)

Participants started from a standing position, 30 cm behind the starting line. From position A (starting position), they sprinted to position C, where they planted one foot, changed direction, and then accelerated toward the finish line, crossing through gate B. The test was performed twice for each leg (right and left), and the best timed trial for each side was used for statistical analysis. Position C was located 15 m from position A, while position B was positioned 5 m from C and 10 m from A. Photocell timing gates were placed at positions B and C to record performance time.

Repeated-sprint ability (RSA test)

The RSA test consisted of six 30-meter sprints with a 20-second recovery interval between repetitions. Photocell timing gates were positioned at the start line

Table 2. The intervention program

Week	Training unit	HIIT protocol
1	1	3 × 3-min 15''-15'' at 100% of maximal aerobic speed – 2-min break between sets
	2	3 × 3-min 15''-15'' at 100% of maximal aerobic speed – 2-min break between sets
2	3	3 × 3-min 15''-15'' at 100% of maximal aerobic speed – 2-min break between sets
	4	3 × 3-min 15''-15'' at 100% of maximal aerobic speed – 2-min break between sets
3	5	3 × 4-min 15''-15'' at 100% of maximal aerobic speed – 2-min break between sets
	6	3 × 4-min 15''-15'' at 100% of maximal aerobic speed – 2-min break-between sets
4	7	3 × 4-min 15''-15'' at 100% of maximal aerobic speed – 2-min break between sets
	8	3 × 4-min 15''-15'' at 100% of maximal aerobic speed – 2-min break-between sets
5	9	3 × 5-min 15''-15'' at 100% of maximal aerobic speed – 2-min break between sets
	10	3 × 5-min 15''-15'' at 100% of maximal aerobic speed – 2-min break between sets
6	11	3 × 5-min 15''-15'' at 100% of maximal aerobic speed – 2-min break between sets
	12	3 × 5-min 15''-15'' at 100% of maximal aerobic speed – 2-min break between sets

Note: HIIT – high intensity interval training

and at the 30-m finish line at hip height (0.7 m above the ground). Each player started 30 cm behind the start line and initiated the first sprint when ready. Subsequent repetitions were performed following the examiner's signal, which was given precisely at 20 seconds, with a readiness alert provided at 15 seconds. For statistical analysis, total time (RSA_{total}), mean time (RSA_{mean}) and percentage performance decrement (RSA_{decr}) were calculated.

30-15 intermittent fitness test (30-15_{IFT})

The 30-15_{IFT} [16] is a progressively intensifying intermittent running test consisting of 30-second bouts of running interspersed with 15-second periods of passive recovery. The test was conducted using the standard 40-m format proposed for soccer [16]. The 40-m distance is defined by two boundary lines, A and C, with a midpoint line (B) positioned between them. In front of lines A and C, two 3-m zones are also marked. Footballers ran back and forth between lines A and C at a pace dictated by recorded audio signals (beeps). These signals indicated when athletes should reach the 3-m entry zones and the midpoint line B, helping them adjust their running speed accordingly. Players began the test at a speed of 8 km/h, with running speed increasing by 0.5 km/h every 45 seconds. The 30-15_{IFT} mobile application was used to administer the test; it was downloaded from Apple App Store and contains the original audio signals required for pacing. During the 15-second recovery period, footballers walked to the nearest line (A, B or C), depending on where they completed their preceding 30-second run, and began the next stage from that point. The test was terminated for each player when they were unable to maintain the required speed or failed to reach the 3-m entry zones at the sound signal on three consecutive occasions. The speed at which the player was running at the moment of termination was considered their maximal running speed [16] and was used to prescribe the intervention program.

Statistical analysis

Data are presented as mean \pm standard deviation (SD) and confidence intervals (CI) (95%) were calculated. The one-sample Kolmogorov-Smirnov test was used to assess the normality of data distribution. The results indicated that non-parametric statistical methods were not required. A two-way ANOVA (group and time) with repeated measures was then applied for statistical analysis. Partial eta square was used as the measure of effect size and was classified as small (0.01-0.059),

medium (0.06-0.137) and large (>0.138) [17]. The significance level was set at $p < 0.05$. All analyses were performed using SPSS version 25.0 (SPSS Inc., Chicago, IL, USA).

Results

The two groups did not differ in age, body measurements or baseline fitness test results. Furthermore, neither regular soccer training nor the intervention program produced significant changes in the participants' anthropometric characteristics.

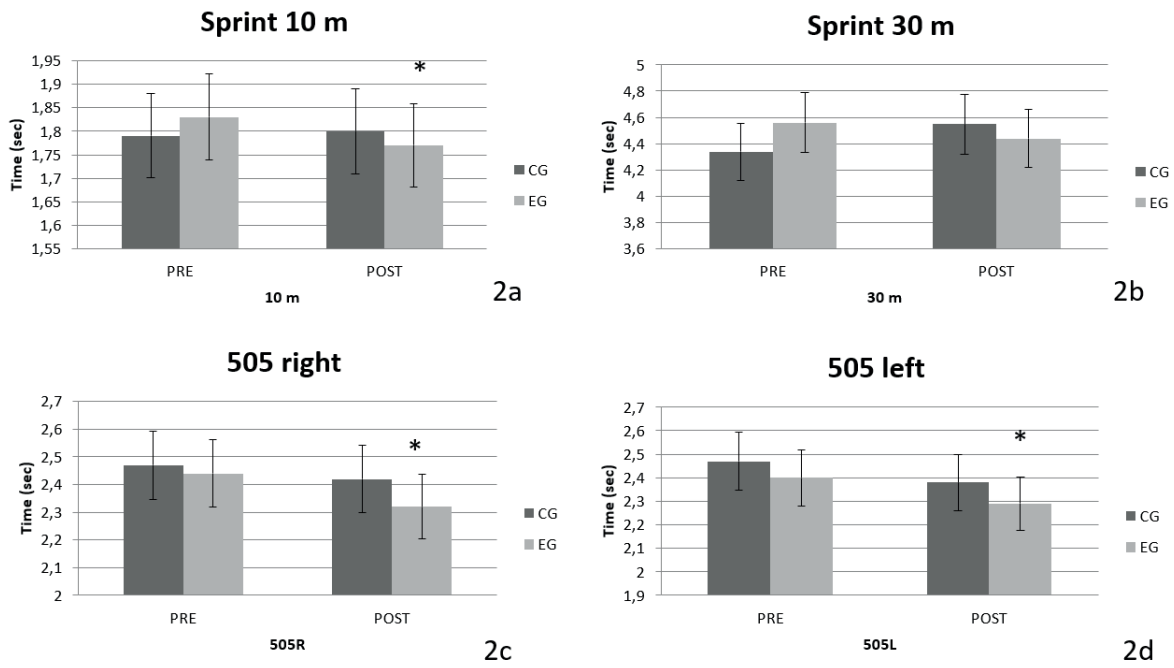
Analysis of the 10-m sprint performance revealed a significant group \times time interaction ($F = 6.053$, $p = 0.027$, $\eta^2 = 0.302$). In contrast, neither the main effect of group ($F = 0.030$, $p = 0.864$, $\eta^2 = 0.002$) nor the main effect of time ($F = 3.973$, $p = 0.066$, $\eta^2 = 0.221$) was statistically significant. No significant differences were observed in players' 30-m sprint performance ($p > 0.05$). The changes in parameter values are presented in Figure 2a and 2b.

For the 505 test, no significant group \times time interaction was observed for either the right-leg ($F = 1.591$, $p = 0.228$, $\eta^2 = 0.102$) or left-leg performance ($F = 0.106$, $p = 0.74$, $\eta^2 = 0.008$). The changes in parameter values are presented in Figure 2c and 2d.

In the 30-15_{IFT} test and VO_{2max} performance, no significant group \times time interaction was detected ($F = 0.3949$, $p = 0.067$, $\eta^2 = 0.22$). The changes in parameter values are shown in Figure 3a.

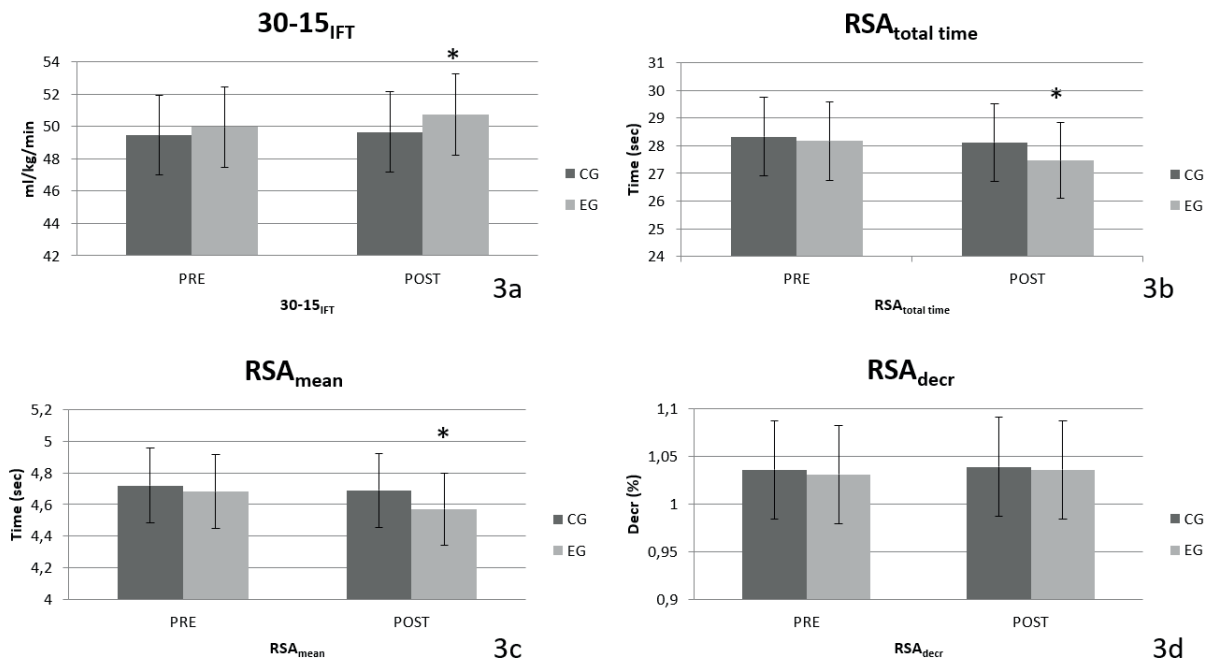
In the RSA test, and specifically for the total time variable, a significant group \times time interaction was observed ($F = 5.781$, $p = 0.031$, $\eta^2 = 0.292$). No significant main effect of group was found ($F = 0.382$, $p = 0.546$, $\eta^2 = 0.027$), whereas the main effect of time was significant ($F = 18.491$, $p = 0.001$, $\eta^2 = 0.569$). The changes in parameter values are presented in Figure 3b. Similar results were observed for RSA performance in the RSA_{mean} variable. A significant group \times time interaction was detected ($F = 5.963$, $p = 0.028$, $\eta^2 = 0.299$). No significant main effect of group was found ($F = 0.387$, $p = 0.544$, $\eta^2 = 0.027$), whereas the main effect of time was significant ($F = 17.817$, $p = 0.001$, $\eta^2 = 0.560$). For RSA_{decr} performance, no significant group \times time interaction ($F = 0.099$, $p = 0.758$; $\eta^2 = 0.007$) Likewise, neither the main effect of group ($F = 0.227$, $p = 0.641$, $\eta^2 = 0.016$) nor the main effect of time ($F = 1.240$, $p = 0.284$, $\eta^2 = 0.081$) reached statistical significance. The changes parameter values are presented in Figure 3c and 3d.

The results of the statistical analyses for all tests are presented in Table 3.



505Right – The value of 505 test with rightwards turn;, 505Left – The value of 505 test with leftwards turn, CG – Control Group, EG – Experimental Group, *p < 0.05

Figure 2. Changes in performance on 10m (2a), 30 m (2b) sprint, 505 agility test on the right (2c) and on the left (2d)



30-15_{IFT} – The 30-15 Intermittent Fitness Test, RSA_{total} – Repeated Sprint Ability-total time, RSA_{mean} – Repeated Sprint Ability-mean time, RSA_{decr} – Repeated Sprint Ability-% of decrement, CG – Control Group, EG – Experimental Group,*p < 0.05.

Figure 3. Changes in performance on 30-15_{IFT} test (3a) and on RSA_{total} (3b), RSA_{mean} (3c) and on RSA_{decr} (3d)

Table 3. ANOVA results

Variables	Group	Pre (Mean ± SD)	95% CI (Pre)	Post (Mean ± SD)	95% CI (Post)	Change scores %	Effect	F	p	η ²
10-m sprint	CG	1.79 ± 0.12	1.72-1.86	1.80 ± 0.10	1.74-1.86	0.6	Main effect of group	0.030	0.86	0.002
	EG	1.83 ± 0.09	1.78-1.90	1.77 ± 0.07	1.74-1.81	-3.3	Main effect of time Interaction	3.973 6.053	0.06 0.02*	0.221 0.302
30-m sprint	CG	4.35 ± 0.72	3.95-4.75	4.55 ± 0.26	4.41-4.70	4.6	Main effect of group	0.220	0.65	0.015
	EG	4.57 ± 0.21	4.45-4.68	4.45 ± 0.20	4.33-4.56	-2.6	Main effect of time Interaction	0.167 2.566	0.69 0.13	0.012 0.155
505R	CG	2.47 ± 0.16	2.38-2.56	2.44 ± 0.14	2.33-2.52	-1.23	Main effect of group	1.702	0.21	0.108
	EG	2.43 ± 0.17	2.36-2.52	2.32 ± 0.19	2.21-2.42	-4.53	Main effect of time Interaction	10.882 1.591	0.005* 0.23	0.437 0.102
505L	CG	2.48 ± 0.18	2.38-2.6	2.40 ± 0.12	2.26-2.51	-3.23	Main effect of group	2.405	0.14	0.147
	EG	2.39 ± 0.23	2.33-2.47	2.29 ± 0.12	2.29-2.36	-4.18	Main effect of time Interaction	29.766 0.106	0.001* 0.75	0.680 0.008
30-15 _{FT}	CG	49.46 ± 3.51	47.51-51.40	49.67 ± 3.26	47.86-51.47	0.42	Main effect of group	0.443	0.52	0.031
	EG	49.96 ± 2.34	48.66-51.26	50.73 ± 2.12	49.56-51.91	1.54	Main effect of time Interaction	7.619 3.949	0.02* 0.067	0.352 0.22
RSA _{total}	CG	28.32 ± 1.83	27.31-29.33	28.16 ± 1.68	27.23-29.13	-0.56	Main effect of group	0.382	0.54	0.027
	EG	28.11 ± 1.7	27.17-29.05	27.46 ± 1.75	26.5-28.4	-2.31	Main effect of time Interaction	18.491 5.781	0.001* 0.03*	0.569 0.292
RSA _{mean}	CG	4.72 ± 0.3	4.55-4.89	4.68 ± 0.28	4.54-4.85	-0.85	Main effect of group	0.387	0.54	0.027
	EG	4.70 ± 0.28	4.53-4.84	4.58 ± 0.29	4.42-4.74	-2.55	Main effect of time Interaction	17.817 5.963	0.001* 0.03*	0.560 0.299
RSA _{decr}	CG	1.036 ± 0.03	1.022-1.05	1.039 ± 0.02	1.027-1.051	2.9	Main effect of group	0.227	0.64	0.016
	EG	1.031 ± 0.02	1.021-1.041	1.036 ± 0.02	1.022-1.050	0.5	Main effect of time Interaction	1.240 0.099	0.28 0.75	0.081 0.007

Note: CG – control group, EG – experimental group, Pre – baseline values, Post – after the experimental values, 505R – the value of 505 test with rightwards turn, 505L – the value of 505 test with leftwards turn, 30-15_{FT} – the 30-15 intermittent fitness test, RSA_{total} – repeated-sprint ability-total time, RSA_{mean} – repeated-sprint ability-mean time, RSA_{decr} – repeated-sprint ability-% of decrement, 95% CI – confidence interval (95%), *p < 0.05

Discussion

The results of the study partially confirmed our initial hypothesis. More specifically, the results of the present study revealed significant interaction between group and time only in the 10-m sprint, as well as in the total time and mean repeated-sprint variables (RSA_{total} and RSA_{mean} , respectively). It is also evident that the intervention group improved their performance following the program in both COD ability and aerobic capacity (VO_{2max}). In contrast, no significant difference was observed in 30-m sprint performance.

The 10-m sprint speed (acceleration) improved following the HIIT protocol. Similar improvements were reported by Arslan et al. [18], who observed a 5% decrease (improvement) in acceleration speed in 14-year-old adolescent soccer players and by Michailidis et al. [8], who reported a 9% improvement in 10-m sprint performance in adolescent football players from an older age category (U17). On the other hand, the lack of improvement in 30-m sprint speed seems to be in line with the findings of Michailidis et al. [8], but not with those of Arslan et al. [18], who reported performance gains in adolescent football players. Engel et al. [6], in their review and meta-analysis, reported a large positive effect of HIIT training on sprint ability over distances ranging from 5 to 40 meters. However, the participants included in the various studies of the meta-analysis were not all football players, and both the age groups and training protocols differed. These discrepancies between studies are likely due to the differences in the training protocols and the specific HIIT variables manipulated.

Performance in COD ability, as assessed by the 505 agility test in the present study, improved by 3% in the intervention group. However, the literature reports conflicting findings regarding the effect of HIIT on COD performance [8, 19-21]. The results of Fernandez-Fernandez et al. [20] in tennis athletes and Fang and Jiang [19] in male and female basketball players are consistent with the results of the present study. Similarly, Michailidis et al. [8] recorded improvements in COD ability among 16-year-old soccer players. In contrast, Wen et al. [21] did not observe significant improvements in adult female soccer players following an 8-week HIIT intervention. The differences in results are likely attributable to variations in participant age, the specific tests used, and the distinct characteristics of the HIIT protocols (e.g., duration, intensity, density, work-to-rest intervals). Kyranoudis et al. [22] reported that COD ability improves with increasing age. Change-of-direction actions require repeated accelerations

and decelerations; therefore, effective use of the stretch-shortening cycle (SSC) is critical for optimal performance [23]. The improvement in COD performance ability may be attributed to increased ability of muscle metabolites, such as phosphocreatine, resulting from HIIT, which can enhance energy supply during high-intensity activities [8]. Several mechanisms, such as increased muscle-fiber recruitment, higher firing frequency and improved timing of motor-unit activation, are thought to contribute to enhanced performance in burst-type activities [24]. These adaptations enhance the ability of the muscular system to generate force and respond more rapidly to motor stimuli, which is critical for sports that require explosiveness, speed and power, such as soccer [8].

A significant improvement in RSA performance, particularly in the RSA_{total} and RSA_{mean} variables, was observed in the intervention group compared with the control group. In contrast, there does not seem to be a significant improvement in RSA_{decr} . Similar results in RSA_{mean} were recorded by Chtara et al. [1] in soccer athletes of similar age to the participants in the present study. The ability to perform repetitive sprints (RSA) depends on metabolic, neural and mechanical factors [25]. Improving one or more factors by implementing training programs leads to improvements in the above-mentioned ability [8]. Although there are no measurements available in the present study, we hypothesize that possible improvements in glycolysis and the phosphagen system, the percentage of oxidative muscle fibers and the ability of muscle homeostasis and lactic acid management may have contributed to improvements in RSA [26].

HIIT is a form of training that improves aerobic capacity [16]. The results of the present study support this, as participants in the intervention group demonstrated a significant increase in VO_{2max} compared with the control group. Improvements in VO_{2max} following HIIT interventions were also reported by Milanovic et al. [27] in a meta-analysis involving 723 adult athletes from various sports. Similarly, Arslan et al. [18] and Sperlich et al. [2] observed increases of 4.3% and 7%, respectively, in VO_{2max} among under-15 soccer players after 5-week HIIT protocols. The improvements observed following the HIIT intervention are likely attributable to the fact that high-intensity training at or near VO_{2max} induces both peripheral adaptations (e.g., increased mitochondrial and capillary density) and central adaptations (e.g., enhanced stroke volume and cardiac output) [28].

This study also has certain limitations. First of all, no assessment of the children's biological maturation was

performed, despite its potential influence on physical performance. Moreover, the duration of the study was relatively short, which may have limited the extent of the adaptations observed. The sample size was adequate according to the power analysis; however, the larger the sample, the stronger the conclusions of the study. Finally, this study used a specific exercise protocol. HIIT can take many forms; therefore, the present study examined only a small portion of the potential effects associated with such protocols.

Conclusions

The use of HIIT training is widespread across team sports, particularly in soccer, as it improves the performance of athletes in a short period of time, ensuring time for other elements (technical- tactical) of training. The findings of the present study indicate that a short-duration HIIT program, performed twice per week, led to improvements in agility (505 agility test), aerobic capacity (30-15_{IFT} test), and RSA. The lack of adaptations in certain parameters may be due to the characteristics of the intervention program used in this study. Because few studies have examined these topics in developmental age groups, further research on similar training programs in adolescent soccer players could provide coaching staff with valuable insights into the effectiveness of such training programs.

Funding

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Conflict of Interest

The authors declare no conflict of interest.

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