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Effects of vertical versus horizontal plyometric training on adolescent soccer players' physical performance

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Abstract
Introduction. **Plyometric training has become a popular training method of youth soccer players. Researchers have sought to use different forms of training to maximize performance responses.** Aim of Study. **This study examined effects of a vertical versus horizontal plyometric jump training program on physical performance of adolescent male soccer players. Material and** Methods. **Thirty participants, aged 14.2 ± 0.7 years, were divided into a vertical group (VG; n = 10), a horizontal group (HG; n = 10) and a control group (CG; n = 10). Before and after 12 weeks of training, as well as after 4 weeks, anthropometric characteristics, sprint/repeated sprint ability within straight speed tests, speed tests with 180° turns ($RSA_{best/mean/total}$), vertical jumping ability, and the 5-repetition maximum (5-RM) load in leg curls and split squats (single right/left leg) were measured.** Results. **The VG and the HG improved significantly ($p < 0.05$) compared to the CG in speed tests with 180° turns, $RSA_{best/mean/total}$ sprints, squats/countermovement jumps, drop jumps' contact time, leg curls, and split squats (single right/left leg).** Conclusions. **Adding vertical or horizontal training exercises twice a week to regular soccer training improves speed, jumping ability and maximum lower limbs strength in youth soccer players.**

KEYWORDS: strength, power, youth, lower limbs, speed.

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Introduction

Soccer is an intermittent, high-intensity sport which requires a high level of physical fitness and in which players perform accelerations, decelerations, repeated sprints, changes of direction (CODs), and vertical and horizontal jumps [21, 27]. An ability to perform these actions, which require great strength, power, and speed, is an important success factor in a soccer match and has also been shown to distinguish between more and less successful players at a youth level [19]. Therefore, design and application of well-structured training interventions, which target key elements of physical performance in youth soccer players, is of utmost importance to achieve success in competition [29].

Plyometric training has been widely used in explosive training. It uses the principle of the "stretch-shortening cycle" to transform elastic potential energy in an eccentric contraction stage into kinetic energy in a concentric contraction stage and has a significant effect on improving explosive power [30]. Plyometric training typically includes various unilateral/bilateral jumps, hops and bounds in a multidirectional, vertically and horizontally oriented manner [17] and is safe and effective for improving measures of physical fitness (e.g., linear sprint speed, muscle strength/power, COD speed, and repeated sprint ability [RSA]) in youth soccer players [29].

Relevant studies have applied different plyometric training interventions (vertical, horizontal, or combined vertical/horizontal plyometric exercises) to enhance athletic performance of youth soccer players [2]. However, only a limited number of studies have examined effectiveness of horizontal versus vertical plyometric training on performance of young soccer players. Significant improvements in various measures of soccer performance have been observed in similar studies, e.g., 10- to 30-m sprint times [15, 16, 24], vertical/horizontal jump performance [16, 24], agility [16], and lower body strength [24]. Nevertheless, no improvement in most of the above measures of soccer performance has been reported [14].

Plyometric exercises are effective not only in promoting skill-related athletic performance, but also in preventing injuries [22]. In this context, plyometric training may be particularly suitable for inclusion in a well-designed training program for young soccer players.

Aim of Study

To the best of our knowledge, this is the first study conducted in the among adolescent soccer players in this particular age group (14.2 ± 0.7 years). The purpose was to compare the effects of a vertical plyometric training program to a horizontal plyometric training program on their overall physical performance. It was hypothesized that during a 12-week in-season training period, both (vertical and horizontal) plyometric training programs would improve speed, RSA performance, jumping ability and maximal strength of youth soccer players.

Material and Methods

Participants

Thirty male adolescents aged 14.2 ± 0.7 years, all regional soccer players, voluntarily participated in the current study. The players and their parents were informed about the nature and the aim of the study, as well as its benefits and risks. Afterwards, the parents signed an informed consent form, which was approved by the institutional review board and the ethics committee of the Department of Physical Education and Sport Sciences at the Democritus University of Thrace in Komotini, Greece, on February 4, 2019. All the procedures were in accordance with the Declaration of Helsinki. The participants were divided into a vertical group (VG; n = 10), a horizontal group (HG; n = 10), and a control group (CG; n = 10) (Table 1).

Training program

The soccer players from the three groups (VG, HG, CG) trained together four days/week (Mondays, Tuesdays, Wednesdays and Thursdays) on a soccer field with natural grass (the same as in competitions). Each training session lasted 90 minutes. The 12-week intervention program was integrated two days/week on Tuesdays and Thursdays (24 sessions in total), immediately after a warm-up program before a regular soccer practice, and consisted of vertical plyometric exercises for the VG and horizontal ones for the HG. Prior to the start of the program, all participants were instructed to perform all exercises correctly. They were performed with maximal effort and supervised by a main investigator. Both groups performed the identical volume of total jumps, which gradually increased from 80 to 130 jumps (1st week – 12th week). Simultaneously, the CG performed low-intensity technical exercises. Furthermore, all participants played an official regional match on Saturdays, lasting 2 × 40 minutes/half time. The training contents applied throughout the 12-week intervention program are presented respectively in Figure 1 for the VG and Figure 2 for the HG. Tables 2 and 3 for the VG and the HG show the quantified data accordingly.

Table 1. Mean and standard deviation of the participants' characteristics before the intervention

	Vertical group (n = 10)	Horizontal group (n = 10)	Control group (n = 10)
Age (years)	14.0 ± 0.8	14.3 ± 0.8	14.2 ± 0.6
Training age (years)	6.2 ± 1.8	7.5 ± 3.2	5.1 ± 2.6
Height (m)	1.72 ± 0.06	1.75 ± 0.08	1.70 ± 0.07
Weight (kg)	63.76 ± 8.50	66.48 ± 12.68	59.96 ± 11.04
BMI (kg/m^2)	21.44 ± 2.29	21.35 ± 2.41	20.46 ± 2.99
Waist circumference (cm)	72.50 ± 6.46	72.10 ± 6.13	69.80 ± 7.06
Dominant leg (right/left)	9/1	9/1	9/1

Note: BMI – body mass index

No group differences were significant ($p > 0.05$).

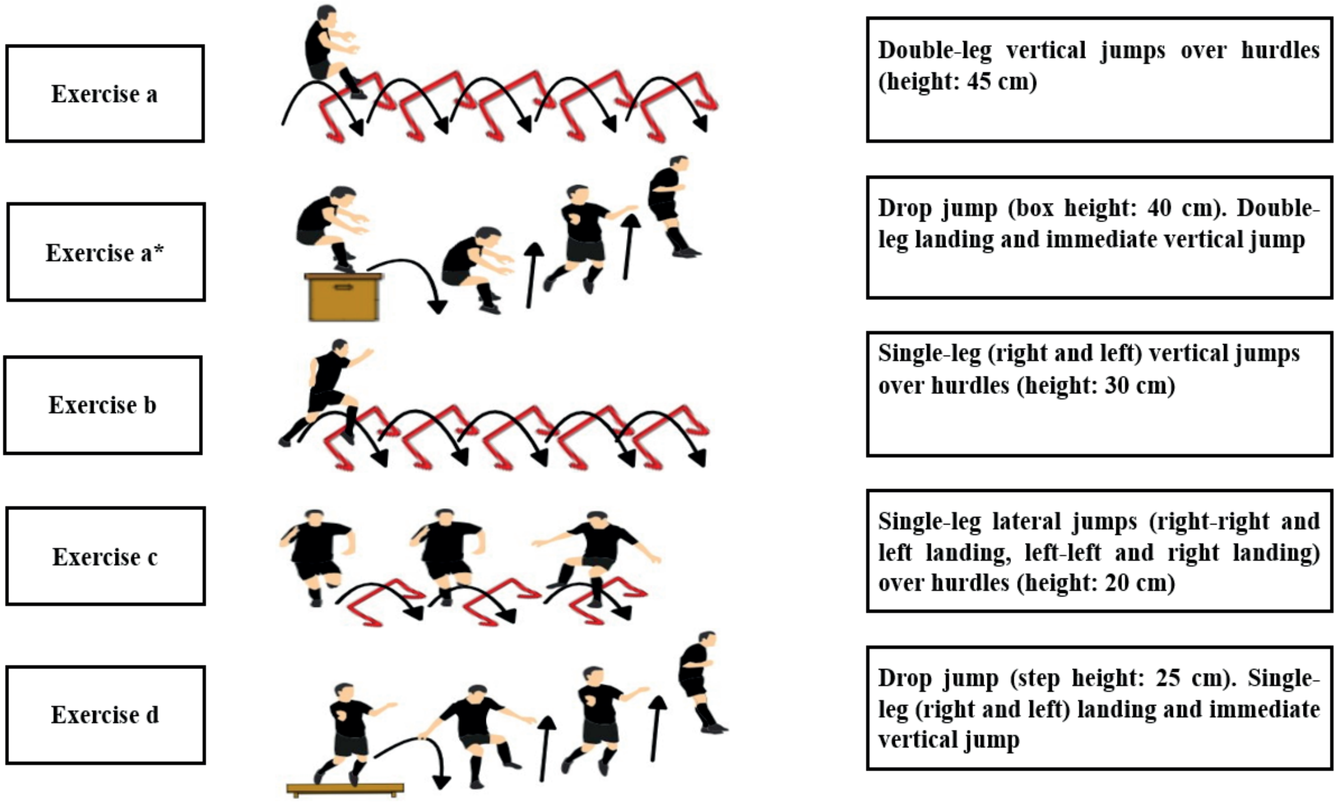

Figure 1. Training contents of the vertical group applied throughout the 12-week intervention program

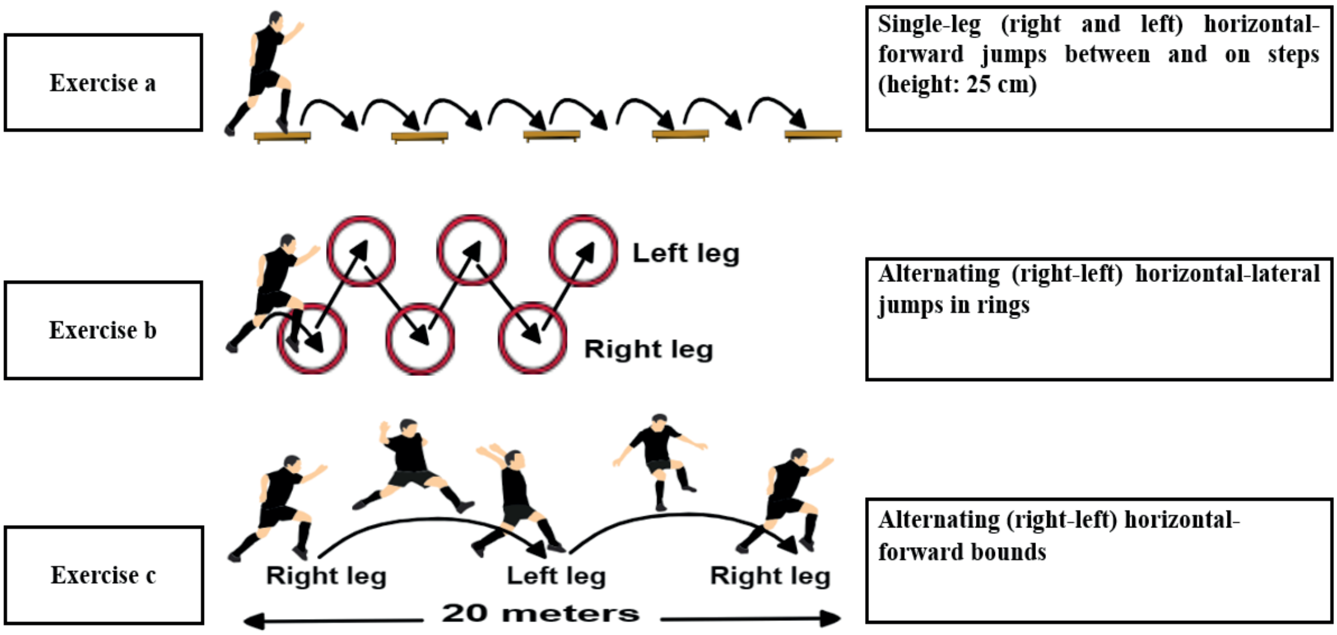

Figure 2. Training contents of the horizontal group applied throughout the 12-week intervention program

Table 2. Training program of the vertical group during the 12-week training period

Exercises	Week 1		Week 2		Week 3		Week 4	
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8
a)	4 × 5	–	3 × 5	–	4 × 5	–	4 × 5	–
a*)	–	4 × 5	–	3 × 5	–	–	–	–
b)	2 + 2 × 5	2 + 2 × 5	3 + 3 × 5	–	–	2 + 2 × 5	–	3 + 3 × 5
c)	–	–	–	3 + 3 × 5	4 + 4 × 5	–	4 + 4 × 5	–
d)	–	–	–	–	–	2 + 2 × 5	–	2 + 2 × 5
	Total: 80		Total: 90		Total: 100		Total: 110	

Exercises	Week 5		Week 6		Week 7		Week 8	
	Session 9	Session 10	Session 11	Session 12	Session 13	Session 14	Session 15	Session 16
a)	6 × 5	–	6 × 5	–	6 × 5	–	6 × 5	–
a*)	–	–	–	–	–	–	–	–
b)	–	3 + 3 × 5	–	3 + 3 × 5	–	3 + 3 × 5	–	3 + 3 × 5
c)	4 + 4 × 5	–	4 + 4 × 5	–	4 + 4 × 5	–	4 + 4 × 5	–
d)	–	2 + 2 × 5	–	3 + 3 × 5	–	3 + 3 × 5	–	3 + 3 × 5
	Total: 120		Total: 130		Total: 130		Total: 130	

Exercises	Week 9		Week 10		Week 11		Week 12	
	Session 17	Session 18	Session 19	Session 20	Session 21	Session 22	Session 23	Session 24
a)	6 × 5	–	6 × 5	–	6 × 5	–	6 × 5	–
a*)	–	–	–	–	–	–	–	–
b)	–	3 + 3 × 5	–	3 + 3 × 5	–	3 + 3 × 5	–	3 + 3 × 5
c)	4 + 4 × 5	–	4 + 4 × 5	–	4 + 4 × 5	–	4 + 4 × 5	–
d)	–	3 + 3 × 5	–	3 + 3 × 5	–	3 + 3 × 5	–	3 + 3 × 5
	Total: 130		Total: 130		Total: 130		Total: 130	

All exercises were defined as sets × repetitions. Exercise intensity: 100%. Interset rest was 60 sec. for the weeks 1-4 and 90 sec. for the weeks 5-12. Rest between the exercises was 2 min. for the weeks 1-4 and 3 min. for the weeks 5-12.

Table 3. Training program of the horizontal group during the 12-week training period

Exercises	Week 1		Week 2		Week 3		Week 4	
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8
a)	4 + 4 × 5	–	5 + 5 × 5	–	5 + 5 × 5	–	6 + 6 × 5	–
b)	–	4 × 5	–	4 × 5	–	5 × 5	–	5 × 5
c)	–	4 × 5	–	4 × 5	–	5 × 5	–	5 × 5
	Total: 80		Total: 90		Total: 100		Total: 110	

Exercises	Week 5		Week 6		Week 7		Week 8	
	Session 9	Session 10	Session 11	Session 12	Session 13	Session 14	Session 15	Session 16
a)	2 × (4 + 4 × 5)	–	2 × (4 + 4 × 5)	–	2 × (4 + 4 × 5)	–	2 × (4 + 4 × 5)	–
b)	–	4 × 5	–	5 × 5	–	5 × 5	–	5 × 5
c)	–	4 × 5	–	5 × 5	–	5 × 5	–	5 × 5
	Total: 120		Total: 130		Total: 130		Total: 130	

Exercises	Week 9		Week 10		Week 11		Week 12	
	Session 17	Session 18	Session 19	Session 20	Session 21	Session 22	Session 23	Session 24
a)	2 × (4 + 4 × 5)	–	2 × (4 + 4 × 5)	–	2 × (4 + 4 × 5)	–	2 × (4 + 4 × 5)	–
b)	–	5 × 5	–	5 × 5	–	5 × 5	–	5 × 5
c)	–	5 × 5	–	5 × 5	–	5 × 5	–	5 × 5
	Total: 130		Total: 130		Total: 130		Total: 130	

All exercises were defined as sets × repetitions. Exercise intensity: 100%. Interset rest was 60 sec. for the weeks 1-4 and 90 sec. for the weeks 5-12. Rest between the exercises was 2 min. for the weeks 1-4 and 3 min. for the weeks 5-12.

Testing procedures

Physical abilities were evaluated a week before (pre) and two days after the 12-week intervention training period (post), and a follow-up evaluation was performed four weeks after the postmeasurements.

The tests were executed on an outdoor soccer field with natural grass, where the participants wore soccer shoes, and at a gym with fitness equipment, where they wore indoor shoes. During the week before testing, research assistants familiarized the participants through practice with types of physical ability tests, their proper forms and techniques. The soccer players abstained from physical activity for one day before testing. Verbal encouragement was used throughout all tests to achieve maximum effort. The same researcher measured all the participants and was blinded to the participants' group allocation.

Sprint and RSA testing: Six 40-m (20 + 20 m) shuttle sprints' times were measured with three paired photocells using the Witty Microgate (Bolzano, Italy), beginning with a standardized 20-minute warm-up. A photocell was placed at the start, at 5th and 10th meter, at a height of 90 cm from the ground. The participants started from a standing position, 50 cm from the first photocell to avoid early activation of a timing mechanism, sprinted 20 m, touched a marked line with a foot, turned 180° and returned to the starting photocell as fast as possible. After 20 seconds of passive rest, the participants started again. Five seconds before the start of each sprint, the participants assumed the ready position and were given a 5-second countdown to an acoustic starting signal [26]. Immediately after the warm-up, the participants completed a single shuttle practice sprint and rested for five minutes before starting the definitive test. The best time in a single trial (RSA_{best}) in straight sprint at 5 m and 10 m, with 180° turns in 30- (20 + 10 m), 35- (20 + 15 m) and 40-m (20 + 20 m) sprints, the mean and total times all of them (RSA_{mean}, RSA_{total}) were recorded and the 6 × 40 m (20 + 20 m) fatigue index ($RSA_{fatigue\ index}$) was calculated according to the following formula: Fatigue = ([slower of two sprint times ÷ 2] – [faster of two sprint times ÷ 2]) ÷ ([faster of two sprint times ÷ 2]) × 100 [11], and used for further analysis.

Vertical jump performance: Vertical jumping ability was assessed using the squat jump (SJ), the countermovement jump (CMJ), and the drop jump (DJ). Vertical jump height (SJ, CMJ, DJ), contact time, and power (DJ) were assessed using an optical measurement system consisting of a transmitting and receiving bar (Optojump Microgate, Bolzano, Italy). To perform the SJ, the participants placed their feet in an area between the bars with their arms akimbo, adopted a semi-squat position (knees at 90°) and, without any pre-stretching, performed a maximal vertical jump and landed with their toes approximately in the same area between the bars. For the CMJ, the participants placed their feet in the area between the bars with their bodies in an upright position and their arms akimbo, then from the upright position they moved down to the semi-squat position and performed the maximal vertical jump (stretch-shortening cycle), making sure to land approximately in the same area between the bars with their legs outstretched during the jump. For the DJ, 40-cm drop height was used. The participants stood on a box with their arms akimbo, took one step forward with a straightened leading leg to ensure the 40-cm drop height and landed in the area between the bars with both legs on the ground with short, powerful contact, extending their ankles. Next, they performed the vertical jump, without bending their knees, and landed also in an extended position, in the same area between the bars. The average of the three trials of each test was used for further analysis, with one minute of rest between the three trials of each test.

Maximum strength: Lower limbs maximum strength was measured with single-leg exercises: leg curls and split squats. As an index of maximum strength, a maximum load that could be lifted for five repetitions (5-RM load) was considered for each exercise. As a warm-up, one set of eight repetitions with a 50% load of the estimated 5-RM load, and one set of five repetitions with a 75% load of the estimated 5-RM load were performed. After the five repetitions with the load estimated to be the 5-RM load, trials were conducted. If a trial was successful, the load was increased by 10%, until the participants were unable to successfully perform five repetitions, which occurred within two to four trials. Rest periods between the sets were three minutes.

The leg curl test was performed on a leg curl machine (Super Sport, Athens, Greece). The participants lay face down, with their hands grasping handles and performed a single right/left full knee flexion.

The split squat test was executed using a Smith machine (Sfitness, Shanghai, China). The participants started the test standing upright on one leg. The top of the leg not involved in the movement was placed on a standard gym bench, positioned behind a participant, to ensure that the working leg was isolated for the trail. The participants were performing a single right/left leg squat until a 90° angle was formed between a thigh and a shank.

Reliability and validity of the physical ability tests have been reported in previous studies, specifically for speed [1], RSA [11, 26], vertical jumps (SJ, CMJ, and DJ)

[6, 20], split squats (single right/left leg) [13], and leg curls (single right/left leg) [8].

Statistical analysis

The IBM SPSS Statistics for Windows, version 19 (IBM Corp., Armonk, N.Y., USA) was used for statistical analysis. The normal distribution criterion was satisfied after contacting the Shapiro–Wilk test. The two-way repeated measures ANOVAs were used statistically process the data (three repeated measures × three groups). The "group" was used as a between-subjects factor and the "time of measurement" as a within-subjects factor, along with the Bonferroni post hoc test. The level of statistical significance was set at $p < 0.05$. All results are reported as mean ± SD.

Results

Thirty participants successfully completed the study, without any injury during the training program, and the three groups (VG, HG, CG) did not differ significantly (all, $p > 0.05$) regarding chronological age, training age/background and their anthropometric characteristics before the intervention ($p > 0.05$, Table 1). No statistically significant differences in the performance changes were observed between the VG and HG in all measurements, but the VG was slightly more effective in the RSA_{best} sprints with 180° turns in 30-, 35- and 40-m sprints than the HG, and the HG was more effective than the VG in the SJs and the strength performance tests. After the 12-week training, statistically significant interactions were revealed between the two factors "group" and "time of measurement". The VG and the HG showed statistically significant improvement compared to the CG in the $RSA_{best/mean/total}$ sprints with 180° turns in 30- (20 + 10 m), 35- (20 + 15 m), 40-m (20 + 20 m) sprints, in the SJ/CMJ height, the DJ' contact time, the leg curls and split squats (single right leg and single left leg) ($p < 0.05$, Table 4).
A statistically significant effect of the factor "time of measurement" was observed in the VG and the HG in the $RSA_{best/mean/total}$ sprints with 180º turns in 30- (20 + 10 m), 35- (20 + 15 m), 40-m (20 + 20 m) sprints, in the CMJ height, the DJ' contact time, the single left leg curls and the single right and left leg split squats ($p < 0.05$) (Table 4).
A statistically significant effect of the factor "time of measurement" was observed in all groups in the SJ height and in the single right leg curls ($p < 0.05$) (Table 4).
A statistically significant main effect of the factor "time of measurement" was observed regardless of the "group" in the 5- and 10-m straight sprint in the $RSA_{best/mean/total}$ sprints and the $RSA_{fatigue\ index}$ ($p < 0.05$).

Discussion

The aim of the current study was to compare the vertical to horizontal plyometric training programs and their effects on physical performance of adolescent soccer players aged 14.2 ± 0.7 years. After 12 weeks (2 days/week, 24 sessions in total), the main findings were that the $RSA_{best/mean/total}$ sprint speed in 30, 35 and 40 m, the vertical jump ability, the drop jumps' contact time and the lower limbs strength of the young soccer players were significantly improved in both the VG and the HG, compared to the CG in the postmeasurements and the follow-up measurements, with no significant differences between the VG and the HG, while the $RSA_{best/mean/total}$ sprint speed in 5 and 10 m, the drop jump height and power were not affected. However, it was revealed that the vertical plyometric training was slightly more effective in improving the RSA_{best} sprints with 180° turns in 30-, 35- and 40-m sprints compared to the horizontal plyometric training, which was slightly more effective in improving the jumping ability (SJs) and the lower limbs maximal strength (leg curls and split squats, both single right and single left leg).
Studies which compared vertical to horizontal and/or combined vertical/horizontal plyometric trainings in young soccer players are limited. Improving speed is often a primary goal of plyometric training. Several contradictory findings regarding various speed distances were observed [17]. The current study's results are consistent with those that reported an improvement in sprint performance, but only over longer distances. Buchheit et al. [5] observed an improvement in RSA_{best} sprints with 180° turns in 30 m (15 + 15 m) sprints in male soccer players aged 14.5 ± 0.5 years after a 10-week, in-season program performed once a week. However, the researchers used a combined plyometric training (unilateral CMJs, calf/squat plyometric jumps, and short sprints). Manouras et al. [16] compared VG/HG plyometric trainings in male soccer players aged 19.1 ± 5.8 years in an eight-week, program applied once a week, and observed no improvement in 10-m speed in either group (VG, HG). Similarly to the above studies, the current study observed significant improvements in the RSA_{best} sprints with 180° turns in 30- (20 + 10 m), 35- (20 + 15 m) and 40-m (20 + 20 m) sprints in both groups (VG, HG) compared to the CG, but not in the straight RSA_{best} sprints in 5 and 10 m. In contrast to all of the above, Kurt et al. [14] compared VG/HG plyometric trainings for six weeks, twice a week in male soccer players aged 12.09 ± 0.89 years and observed no improvement in 10- and 20-m speed in either group (VG, HG). The differences in the results can be explained by

Table 4. Mean and SD values of the pre-intervention, after 12 weeks of the training intervention, and after the 4-week follow-up period in the vertical group, the horizontal group, and the control group

	Vertical group (n = 10)			Horizontal group (n = 10)			Control group (n = 10)		
	Pre	Post	Follow-up	Pre	Post	Follow-up	Pre	Post	Follow-up
Sprint/RSA_{best} performance									
30 m (20 + 10 m) sprint (s)	6.22 ± 0.27	6.08 ± 0.23 ŧ	6.02 ± 0.20 ŧ	6.11 ± 0.45	6.00 ± 0.28	5.97 ± 0.29 ŧ	6.05 ± 0.32	6.10 ± 0.35	6.08 ± 0.25
35 m (20 + 15 m) sprint (s)	7.02 ± 0.30	6.86 ± 0.27 ŧ	6.78 ± 0.23 ŧ	6.89 ± 0.53	6.78 ± 0.34	6.73 ± 0.35 ŧ	6.84 ± 0.36	6.90 ± 0.39	6.86 ± 0.28
40 m (20 + 20 m) sprint (s)	7.84 ± 0.36	7.63 ± 0.29 ŧ	7.54 ± 0.27 ŧ	7.68 ± 0.63	7.50 ± 0.41 ŧ	7.47 ± 0.41 ŧ	7.61 ± 0.40	7.67 ± 0.43	7.66 ± 0.33
Sprint/RSA_{mean} performance									
30 m (20 + 10 m) sprint (s)	6.51 ± 0.29	6.29 ± 0.24 ŧ	6.31 ± 0.23 ŧ	6.40 ± 0.40	6.20 ± 0.27 ŧ	6.20 ± 0.26 ŧ	6.46 ± 0.35	6.45 ± 0.40	6.46 ± 0.35
35 m (20 + 15 m) sprint (s)	7.35 ± 0.34	7.13 ± 0.27 ŧ	7.14 ± 0.27 ŧ	7.22 ± 0.47	7.00 ± 0.32 ŧ	7.00 ± 0.31 ŧ	7.31 ± 0.41	7.29 ± 0.47	7.30 ± 0.42
40 m (20 + 20 m) sprint (s)	8.23 ± 0.41	7.94 ± 0.32 ŧ	7.95 ± 0.30 ŧ	8.06 ± 0.56	7.78 ± 0.37 ŧ	7.79 ± 0.35 ŧ	8.18 ± 0.46	8.13 ± 0.52	8.16 ± 0.47
Sprint/RSA_{total} performance									
30 m (20 + 10 m) sprint (s)	39.09 ± 1.79	37.79 ± 1.49 ŧ	37.87 ± 1.39 ŧ	38.42 ± 2.42	37.23 ± 1.64 ŧ	37.21 ± 1.59 ŧ	38.80 ± 2.13	38.72 ± 2.42	38.78 ± 2.15
35 m (20 + 15 m) sprint (s)	44.11 ± 2.05	42.79 ± 1.67 ŧ	42.85 ± 1.62 ŧ	43.32 ± 2.84	42.03 ± 1.92 ŧ	42.02 ± 1.90 ŧ	43.89 ± 2.50	43.76 ± 2.82	43.80 ± 2.53
40 m (20 + 20 m) sprint (s)	49.39 ± 2.49	47.67 ± 1.94 ŧ	47.75 ± 1.82 ŧ	48.38 ± 3.37	46.68 ± 2.26 ŧ	46.78 ± 2.15 ŧ	49.12 ± 2.92	48.82 ± 3.16	48.99 ± 2.85
Jump performance									
Squat jump height (cm)	23.08 ± 4.18	24.65 ± 3.58 ŧ	25.07 ± 3.56 ŧ	25.72 ± 4.93	27.53 ± 5.08 ŧ	29.16 ± 5.06 ŧ§*	24.87 ± 4.27	23.61 ± 4.09	22.07 ± 4.36 ¡ɸ
Countermovement jump height (cm)	25.87 ± 4.86	27.64 ± 5.23	28.94 ± 4.89 ŧ§	29.63 ± 6.62	30.92 ± 5.86	32.46 ± 5.90 ŧ§	28.52 ± 5.40	27.35 ± 4.75	26.96 ± 5.08
Drop jump contact time (s)	0.204 ± 0.02	0.208 ± 0.02	0.196 ± 0.02 §*	0.203 ± 0.01	0.200 ± 0.02	0.191 ± 0.01 ŧ§*	0.213 ± 0.01	0.220 ± 0.01	0.221 ± 0.01
Strength performance									
5-RM right leg leg curl (kg)	20.70 ± 3.94	24.00 ± 3.85 ŧ	26.30 ± 3.74 ŧ§	25.10 ± 12.27	28.80 ± 12.04 ŧ	31.10 ± 11.31 ŧ§*	18.40 ± 6.20	20.20 ± 6.95 ŧ	21.40 ± 7.72 ŧ
5-RM left leg leg curl (kg)	19.70 ± 3.80	23.00 ± 3.77 ŧ	25.00 ± 2.98 ŧ§	22.80 ± 10.26	27.70 ± 10.04 ŧ*	29.60 ± 9.40 ŧ§*	17.60 ± 6.31 ŧ	18.20 ± 5.59	19.80 ± 6.61
5-RM right leg split squat (kg)	59.80 ± 14.62	74.00 ± 10.27 ŧ	84.80 ± 9.93 ŧ§*	68.30 ± 15.69	83.40 ± 15.64 ŧ*	93.90 ± 18.10 ŧ§*	65.80 ± 12.59	65.30 ± 12.46	66.10 ± 13.93
5-RM left leg split squat (kg)	56.80 ± 14.57	73.90 ± 9.82 ŧ	83.70 ± 9.71 ŧ§*	65.80 ± 13.71	81.70 ± 12.59 ŧ*	91.50 ± 11.91 ŧ§*	65.70 ± 12.78	64.90 ± 12.67	65.40 ± 14.15

Note: RSA – repeated sprint ability, 5-RM – 5-repetition maximum
* significantly different from the control group; ŧ significantly improved in comparison with the pre-intervention measurement; § significantly improved in comparison with the post-intervention measurement; ¡ significantly got worse in comparison with the pre-intervention measurement; ɸ significantly got worse in comparison with the post-intervention measurement

the duration of the programs (12 weeks vs 6 weeks) and by the number of foot-ground contacts (80-130 first-last week vs 60-90 first-last week). This is further supported by the study of Ramírez-Campillo et al. [24], which lasted six weeks, but used more foot-ground contacts (80-160 first-last week). After plyometric training applied twice a week, comparing VG/HG/VHG in male soccer players aged 10 to 14 years, the researchers found a significant improvement in 15- and 30-m speed in the HG and the combined VHG, but not in the VG. However, Loturco et al. [15] suggested, after a three-week (11 sessions) plyometric intervention in a preseason, comparing VG/HG in high-level U-20 male soccer players, that horizontal plyometrics is able to increase acceleration/velocity over short distances (10 m), whereas vertical plyometrics produces greater improvements in longer sprints (20 m). Although the present study lasted 12 weeks, which is longer than most of studies that last 6-10 weeks, the horizontal plyometric training was performed, but the 5- and 10-m sprints were not affected. It seems that the stimuli resulting from the vertical/horizontal training have been insufficient to improve at shorter distances, and perhaps more specific protocols related to these skills are required. Regarding the RSA_{mean}, the RSA_{total} sprints and the $RSA_{fatigue\ index}$, the present study's results demonstrated the significant improvements in RSA_{mean} and RSA_{total} sprints with 180° turns in 30- (20 + 10 m), 35- (20 + 15 m) and 40-m (20 + 20 m) sprints in both groups (VG, HG) compared to the CG, but not in the straight RSA_{mean} and the RSA_{total} sprints in 5- and 10-m sprints and the $RSA_{fatigue\ index}$. The current study's findings are consistent with a study that applied an eight-week, twice-weekly in-season combined vertical/horizontal plyometric training program in male soccer players aged 12.7 ± 0.2 years, and observed an improvement in a RSA_{total} 40-m (20 + 20 m) sprint, but not in a $RSA_{fatigue\ index}$, using the same RSA test as in the present study [18]. Regarding RSA_{mean} sprint time, similarly to the current study's results, Buchheit et al. [5] observed an improvement in 30 m (15 + 15 m) in male soccer players aged 14.5 ± 0.5 years after a 10-week, once-weekly in-season program (unilateral CMJs, calf/squat plyometric jumps, and short sprints). In this context, Ramirez-Campillo et al. [25] reported in their review that plyometric training improves RSA_{best} and RSA_{mean} performance, while $RSA_{fatigue\ resistance}$ is not affected. This is likely due to neuromechanical factors (e.g., strength, muscle activation and coordination) that affect actual sprint performance rather than an ability to recover between sprints. The results of the present study confirm the above and are further explained because the study's main goal was not to improve anaerobic endurance. It is important to note that the present study conducted the RSA test which consisted of six 40-m shuttle sprints (20 m straight, 180° turn, and 20 m straight again) that included acceleration/deceleration, i.e., all major components of COD. Ramírez-Campillo et al. [24] reported that improved COD performance may be related to changes in power development or increased eccentric strength level, which can impact COD performance during a deceleration phase. Similarly, Oliver et al. [19] reported in their systematic review of U-18 youth soccer players that mechanical and neuromuscular demands imposed by plyometric training may have great training transfer to COD. It seems that the plyometric training in the current study met these demands.

Taking power into account, the vertical jump performance measured by the squat and CMJ tests conducted in the current study improved significantly in the VG and the HG compared to the CG, as expected. The findings are in agreement with a recent meta-analysis which showed that plyometric training is an effective method of improving jumping performance in adolescent athletes [7]. Furthermore, the results confirmed that horizontal plyometric training is at least as effective as vertical plyometric training in enhancing vertical performance [17]. On the contrary, Loturco et al. [15] reported a significant improvement in CMJs only in a VG compared to a CG. However, it has been stated that plyometric training can increase neural drive to agonist muscles, lower limb stiffness, intermuscular coordination, stretch reflex excitability, and changes in muscle fiber mechanics/size [23]. There is a possibility that the 12-week overall vertical/horizontal training program in this specific age sample improved the above elements, either fully or partially. Regarding the DJ test in this study, the VG and the HG improved significantly compared to the CG only in the ground contact time, but not in height and power. Contrary to the present study's results in the same test, Negra et al. [18] observed a significant improvement in jump height in a plyometric group compared to a CG in a 40-cm DJ, but they reported that plyometric training can decrease ground reaction time by increasing muscle power output and movement efficiency, which is consistent with the findings of the current study.

Studies using only plyometric training and measuring a maximal lower body strength improvement in youth soccer players are limited. In this study, the VG and the HG achieved significantly higher strength performance compared to the CG, using the leg curls and split squats (single right leg and single left leg) as the training exercises with 5-RM. The current study's results are in agreement with studies that have shown improvements in strength performance in young soccer players, following plyometric training [10, 24]. However, studies that found no effects were reported [12, 24]. In their systematic review, Behm et al. [3] reported that plyometric training exhibited small and moderate training improvements in lower body strength. On the other hand, Sáez-Sáez de Villarreal et al. [28] reported in their meta-analysis that plyometric training involves a rapid development of maximal force during an eccentric phase and that a body experiences high impact forces during foot-ground contact in vigorous movements, thus, it can be speculated that a muscle force stimulus during any plyometric training can be effective for strength development. Furthermore, training volume of <10 weeks to >15 sessions of high intensity (>40 jumps per session) will maximize a probability of obtaining significant improvements in strength performance. The current study's overall intervention program was even more intense, and the results seem to be explained and/or related to the above.

The present study revealed several improvements in the follow-up measurements, after four weeks at the end of the training period. According to this, Diallo et al. [9] applied a 10-week plyometric training program three times a week, which increased soccer performance in male soccer players aged 12-13. Furthermore, the researchers demonstrated that the improvements were maintained after a reduced training period of eight weeks. In the current study, the performance on some of the measures was not only maintained, but also increased, possibly enhancing positive physical adaptations that resulted from the plyometric training combined with the regular soccer training in this period. It has also been found that a reduced 16-week training period leads to a decrease only in the SJs performance in the CG. Conversely, the improvement in the single right leg curls in the CG can only happen due to participation in soccer training leading to an improvement in lower body performance, and is reinforced by the fact that a right leg is a dominant leg for 9 out of 10 soccer players. Similarly, Bogiatzidis et al. [4] observed significant increases in lower body strength (single right leg split squat) in male soccer players aged 15 ± 0.5 years, not only in an experimental group (EG) after 12 weeks of strength/soccer training (additional weighted shorts), but also in a CG, which participated only in regular soccer training. The results remained the same even after 16 weeks of follow-up, which is consistent with the findings of the present study.

To the best of our knowledge, the current study is the first to compare vertical to horizontal plyometric training and their effects on physical performance in the specific age group (14.2 ± 0.7 years) of adolescent soccer players. In this overall in-season training program (e.g., volume, intensity) using the double-leg and single-leg exercises, the principle of progressive overload has been followed, starting at a lower point and progressing to higher intensities. No training-related injuries have been reported, so it appears to be a safe training method. Based on the results, it can be suggested that introducing this type of specially designed training into soccer practice can increase power-related aspects of young soccer players' performance which often influence an outcome of a match and cannot be achieved through soccer training alone.

However, the limitations of the study are evident. It should be noted that the sample size was small, which is the main limitation of this study, and in order to obtain more comprehensive findings, a larger sample size should be included in future studies. Also, the participants consisted only of the male soccer players in the specific adolescent age (U-16), and therefore the results cannot be generalized, especially to other developmental ages and genders. Additionally, the results were presented in accordance with their chronological age, as their biological maturation was not assessed before the study, and differences between them might have occurred. Furthermore, the aforementioned improvements relate only to the selected soccer performance tests, and different results and correlations in other tests may have been achieved. Therefore, it is also advisable for future studies to include soccer players of different ages and levels of training experience and assessment of biological maturation, as well as female players in their intervention programs. In any case, soccer scientists/experts can interpret the results and immediately use this effective and inexpensive training method.

Conclusions

The current study showed, as expected, that both vertical and horizontal plyometric training lead to improvements in most of the speed, power and strength-related parameters of soccer performance in the U-16 soccer players. The vertical plyometric training was slightly more effective in improving the RSA_{best} sprints with 180° turns, and the horizontal plyometric training was slightly more effective in improving the jumping ability and the lower limbs maximal strength. However, the results should be interpreted with caution, mainly due to the small sample size. A larger sample may provide a better and more comprehensive picture of vertical and horizontal plyometric training effects. In any case, the findings are encouraging, because vertical and horizontal plyometric training can be incorporated directly into regular soccer training, without losing valuable training time. Considering the above, soccer coaches/experts are able to maximize overall performance of their young soccer players by introducing both modalities of plyometric training.

Conflict of Interest

The author has no conflict of interest.

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