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Original article

Effectiveness and time-course adaptation of resistance training *vs.* plyometric training in prepubertal soccer players

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Abstract

Purpose: This study assessed the effectiveness and time course for improvements in explosive actions through resistance training (RT) *vs.* plyometric training (PT) in prepubertal soccer players.
Methods: Thirty-four male subjects were assigned to a control group ($n = 11$); 5 regular soccer training sessions per week, an resistance training group (RTG) ($n = 12$); 3 soccer training sessions and 2 RT sessions per week, and a plyometric training group (PTG) ($n = 11$); 3 soccer training sessions and 2 PT sessions per week. The outcome measures included tests for the assessment of muscle strength (e.g., 1-RM half-squat test), jump ability (e.g., countermovement jump, squat jump, standing long jump, and multiple 5 bounds test), linear speed (e.g., 20-m sprint test), and change of direction (e.g., Illinois change of direction test).
Results: The RTG showed an improvement in the half-squat (Δ13%; $d = 1.3$, $p < 0.01$) and countermovement jump (Δ9%; $d = 2.4$, $p < 0.001$) at Week 4, whereas improvements in the 20-m sprint (20 m) Δ4.3%, $d = 1.1$, $p < 0.05$; change of direction (CoD) Δ3.8%, $d = 2.1$, $p < 0.05$; multiple 5 bounds Δ5%, $d = 1.5$, $p < 0.05$; standing long jump Δ7%, $d = 1.2$, $p < 0.01$; squat jump Δ19.6%, $d = 1.5$, $p < 0.01$; were evident at Week 8. The PTG showed improvements in CoD Δ2.1%, $d = 1.3$, $p < 0.05$; standing long jump Δ9.3%, $d = 1.1$, $p < 0.05$; countermovement jump Δ16%, $d = 1.2$, $p < 0.05$; and squat jump Δ16.6%, $d = 1.5$, $p < 0.01$; at Week 8 whereas improvements in the 20 m Δ4%, $d = 1.2$, $p < 0.05$; and multiple 5 bounds Δ7.4%, $d = 0.7$, $p < 0.001$; were evident only after Week. The RT and PT groups showed improvements in all sprint, CoD, and jump tests ($p < 0.05$) and in half-squat performance, for which improvement was only shown within the RTG ($p < 0.001$).
Conclusion: RT and PT conducted in combination with regular soccer training are safe and feasible interventions for prepubertal soccer players. In addition, these interventions were shown to be effective training tools to improve explosive actions with different time courses of improvements, which manifested earlier in the RTG than in the PTG. These outcomes may help coaches and fitness trainers set out clear and concise goals of training according to the specific time course of improvement difference between RT and PT on proxies of athletic performance of prepubertal soccer players.

Keywords: Change of direction; Jump performances; Plyometric training; Resistance training; Soccer; Time course

1. Introduction

The capacity of soccer players to produce varied forceful and explosive actions (i.e., sprinting, jumping, and changing direction) highly influences soccer match outcomes.[1-3] In fact, despite the aerobic context in which the match is developed, the most crucial events are represented by high-intensity work because the majority of the goals are preceded by a linear sprint, a vertical jump, or a change of direction (CoD) of the scoring or assisting player.[1,3] Determinant moments of the game such as winning ball possession, scoring, and conceding goals depend on high-speed sprinting,[4] which represents approximately 3% of the total distance covered in a youth soccer player's total game.[4] In addition to maximal running speed, future success

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in youth soccer players was shown to be based on CoD performance,[4] and, therefore, the testing of CoD should be used for early selection.[2,4-6] These actions are considered the most influential moments of the game and those which can make the difference in determining the outcome of the match.[1,3,7] In addition, although the time spent performing these explosive actions represents only a small percentage of a match's total time, these actions discriminate between a successful and less successful performance.[1,3] As a consequence, training programs to promote higher explosive action in youth should be considered a priority.[8]

Youth resistance training (RT) and plyometric training (PT) are recognized as safe methods to improve explosive actions and should be important components of fitness programs among soccer players.[9-13] Several studies have reported that RT[14-17] and PT[5,8] conducted within high-level prepubertal soccer players are better able to enhance varied forceful and explosive actions beyond the improvement level that can be attributed to normal growth in youth[14,15,17,18] However, despite the increasing popularity of RT[10,14,18-20] and PT[8,12] with adolescent athletes, research in regard to the time course of adaptations to RT and PT in prepubertal athletes is limited. The knowledge about the time needed to improve explosive actions following an RT *vs.* a PT program is of importance,[5,8,10,12] particularly for strength professionals who work with prepubertal athletes. In addition, the question in regard to effective RT and/or PT protocols is still open for debate in prepubertal soccer players, indicating a gap in the literature.[8] To the authors' best knowledge, there is no previous study examining the benefits in conjunction with the adequate time period required to stimulate significant improvement on proxies of athletic performance of prepubertal soccer players between RT and PT. Therefore, the aims of the current study were to (1) explore whether a 12-week RT and PT program would enhance the explosive actions (i.e., sprinting, CoD, strength, and jumping) of prepubertal soccer players and (2) determine the adequate time needed to stimulate improvement in regard to varied forceful and explosive actions based on either an RT or a PT program. We hypothesized that biweekly RT or PT, replacing the regular soccer training, induces greater strength and power gains in prepubertal soccer players compared with soccer training alone. In addition, we hypothesized that the time course of improvement of the various fitness parameters differs between the 2 experimental groups (i.e., RT group (RTG) and PT group (PTG)).

2. Methods

2.1. Participants

Thirty-four prepubertal soccer players from a single regional soccer team (age = 12.8 ± 0.2 years, body mass = 44.9 ± 7.4 kg, height = 156.4 ± 8.9 cm) were included in the study. They were randomly assigned into the RTG (n = 12), PTG (n = 11), and control group (CG) (n = 11). The physical characteristics of all 3 groups are presented in Table 1. They all had been playing soccer on a regular basis (3-5 times per week) for more than 4 years. Their mean soccer experience was 4.0 ± 1.3 years. Soccer training sessions included technical training, coordination exercise, and sport-specific exercises. The same team physician examined all the players, with a particular focus on conditions that might preclude RT and PT, and all were found to be in good health and free of injuries. The evaluation was conducted during the second half of the competitive season (i.e., January to March 2015). Players were instructed to maintain their normal intake of food and fluids and to avoid any kind of physical exercise for 1 day before testing. The maturation status of the participants was determined according to the development of pubic hair, based on the Tanner 5-point scale,[21] and the predicted age at peak height velocity[22] at the beginning of the study and after 12 weeks by the same physician. Prior to the start of the study, all participants and their legal representatives were contacted and informed about testing and training procedures as well as possible benefits and risks related to the study and signed informed consent document prior to the investigation. The study received approval from the Institutional Review Board of the University of Ksar Said, Tunisia, and was conducted in accordance with the Declaration of Helsinki.

2.2. Procedures

A 3-group repeated measures experimental design was applied to examine the effects of RT and PT on proxies of athletic performance in prepubertal soccer players. In 2 sessions per week, the regular soccer training was replaced for the RTG and the PTG. The CG continued its regular soccer training. Baseline and postintervention testing included tests of speed, CoD performance, strength, and jumping abilities. The sprint evaluation was accomplished through a speed test that was carried out in a straight 20-m line. The CoD was evaluated through the Illinois Change of Direction Speed Test. This test evaluates the capacity of subjects to quickly change direction.

Table 1
Physical characteristics of the subjects (mean ± SD).

	CG (n = 11)		PTG (n = 11)		RTG (n = 12)	
	Baseline	Post-test	Baseline	Post-test	Baseline	Post-test
Age (year)	12.8 ± 0.3	13.0 ± 0.3	12.7 ± 0.3	12.9 ± 0.3	12.8 ± 0.3	13.0 ± 0.3
Height (cm)	153.2 ± 8.6	153.7 ± 9.0	156.4 ± 9.5	156.7 ± 9.4	159.3 ± 8.4	160.1 ± 8.0
Weight (kg)	42.5 ± 5.5	43.2 ± 5.5	45.9 ± 8.4	46.6 ± 8.3	47.8 ± 6.8	48.9 ± 7.2
Body mass index (kg/m^2)	18.1 ± 1.4	18.3 ± 1.5	18.6 ± 1.3	18.9 ± 1,6	18.9 ± 2.4	19.1 ± 2.9
Tanner score	1.6 ± 0.6	1.6 ± 0.6	1.8 ± 0.8	2.0 ± 0.8	1.6 ± 0.6	1.7 ± 0.6
Maturity offset (year)	−1.51 ± 0.73	−1.36 ± 0.75	−1.52 ± 0.83	−1.33 ± 0.90	−1.32 ± 0.44	−1.13 ± 0.51
APHV (year)	14.28 ± 0.79	14.35 ± 0.83	14.22 ± 0.85	14.25 ± 0.29	14.11 ± 0.48	14.14 ± 0.55

Abbreviations: APHV = age at peak height velocity; CG = control group; PTG = plyometric training group; RTG = resistance training group.

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In addition, muscle strength was evaluated through the 1 repetition maximum (1RM) half-squat test, and jumping abilities were assessed through the countermovement jump (CMJ), squat jump (SJ), standing long jump (SLJ), and multiple 5 bounds test (MB5). Two weeks prior to baseline testing, 2 familiarization sessions with fitness testing were held to avoid problems due to the learning effect. All tests were conducted 48 h after the last training session, at the same time (7:30 a.m. to 9:30 a.m.), and under the same environmental conditions (29°C-33°C, no wind). All groups were tested after 4, 8, and 12 weeks. Players who missed more than 20% of the total training sessions and/or more than 2 consecutive sessions were excluded from the study. Testing was preceded by a 20-min standardized warm-up session. All players performed 2 trials for each test, and the best performance was recorded. Tests were performed in a fixed order over 3 days. On the first test day, anthropometric measurements were made, followed by CoD and sprinting tests over a 20-m distance. The second day was devoted to jumping tests. During the third day, players undertook the 1RM half-squat test.

2.3. *Sprint testing*

The 20-m sprint performance data were collected using an electronic timing system (Microgate SRL, Bolzano, Italy). Participants started by standing 0.3 m behind the first infrared photoelectric gate, which was placed 0.75 m above the ground. The intraclass correlation coefficient (ICC) for test–retest trials was 0.96.

2.4. *The Illinois Change of Direction Test*

On the command "Go", subjects sprinted 10 m, turned, and returned to the starting line. After returning to the starting line, they swerved in and out of 4 markers, completing two 10-m sprints to finish the course.[23]

The performance outcome was collected using an electronic timing system (Microgate SRL). The ICC for test–retest trials was 0.94.

2.5. *SJ and CMJ*

For the SJ, the participant started from a stationary semi-squatted position and jumped upward as high as possible. For the CMJ, the participant started from an upright standing position, completed a fast downward movement by flexing the knees and hips, and then immediately jumped vertically. Performance was recorded via an Optojump photoelectric cell (Microgate SRL). The ICCs for test–retest trials were 0.97 and 0.98 for the CMJ and SJ, respectively.

2.6. *Multiple MB5*

The participant started from a standing position with both feet on the ground. Participants tried to cover as much distance as possible with 5 forward jumps by alternating left- and right-leg contact.[24] The covered distance was measured to the nearest 1 cm using a tape measure. The ICC for test–retest trials was 0.96.

2.7. *SLJ*

From a starting position behind a line marked on the ground, with their feet at shoulder-width distance and their hands in a neutral position, participants executed a countermovement with their legs and arms and attempted to jump as far as possible. The horizontal distance between the starting line and the heel of the participant's rear foot was recorded using a tape measure to the nearest 1 cm. The ICC for test–retest trials was 0.93.

2.8. *Half-squat*

Each participant maintained an upright position, looking forward and firmly grasping the bar, which was supported on the shoulders. Next, the participant bent his knees until he reached a 90° angle. Finally, the participant raised himself to an upright position with his lower limbs completely extended.

2.9. *Maximal strength assessment*

1RM assessment was conducted according to the protocol proposed by Faigenbaum et al.[18] Before attempting 1RM, participants performed 5 or 6 repetitions with a relatively light load (~40% of their estimated 1RM), then 3 or 4 repetitions with a heavier load (~70% of their estimated 1RM), and finally a single repetition with 95% of their estimated 1RM. Participants then attempted a single repetition with the perceived 1RM load. If this weight was lifted with proper form, the weight was increased by 1 kg to 2.5 kg, and the participant attempted another repetition. Failure was defined as a lift falling short of the full range of motion on at least 2 attempts spaced at least 2 min apart. The 1RM was typically determined within 4 or 5 trials.

2.10. *RT and PT interventions*

Both RT and PT sessions lasted 35–40 min. The second RT and PT session was completed 72 h after the first. In total, 24 sessions were devoted for each training program. For the RT program, low-to-moderate training load (40%-60% of 1RM) was adjusted and increased over the course of the training. The RT program comprised 4 sets of 10 to 12 repetitions of half-squats, with 2 min of rest between sets. The load was increased following the first, second, and third weeks (40%, 50%, and 60% of 1RM, respectively) and was decreased in the fourth week to 40% 1RM. The 1RM was also recalculated every 4 weeks. This 3:1 cycle was applied 3 times over the 12-week training period. Furthermore, abdominal curl and back extension exercises were performed in every session, and athletes completed up to 6 sets of 15 repetitions to provide a general conditioning effect. A qualified instructor certified by the Tunisian soccer association supervised the RT program. The PT program was based on recommendations of intensity and volume from Söhnlein et al.[8] In brief, every first PT session in each week was focused on improving the vertical-horizontal leap, whereas every second session was focused on improving the lateral jumping ability. To ensure an appropriate training intensity for players and to limit stress on musculotendinous units, the training volume and intensity were progressively increased. The total number of ground contacts per week started at 112 during the first week and increased to 280 after 12 weeks.

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Plyometric exercises were executed at maximal intensity. Furthermore, all PT sessions were completed on an artificial turf pitch to minimize first landing impact and to be as soccer-specific as possible. During every vertical-horizontal PT session, the following jumps were performed: 2-footed ankle hop forward, hurdle jumps, and squat jump. During every lateral PT session, the following jumps were performed: lateral bound stabilization, lateral hurdle jumps, and double-leg zigzag. No drill lasted more than 10 s to ensure that muscular energy was mainly produced by intramuscular phosphagen degradation, and a 90 s rest period was provided between each set of exercises to allow for the resynthesis of phosphagens.[5]

2.11. Statistical analysis

Data are presented as the means ± SD. Data were checked for normal distribution with the Shapiro-Wilks test. Two-way analysis of variance (ANOVA) with repeated measures was applied to test for main effects between baseline and post-intervention testing and among the 3 groups (RTG *vs.* PTG *vs.* CG). In cases of significant main effects of time and/or time multipled by group interaction effects, within-subject effects for all groups were analyzed using paired sample *t* tests. Analysis of covariance (ANCOVA) was performed to examine the differences among the groups in the post-training test values; for ANCOVA, the baseline mean value was used as the covariate (Table 2). Bonferroni pairwise comparisons were used to identify the significantly different means. The decision to use ANCOVA (rather than ANOVA, which also showed significant group differences) was made *post hoc* to better adjust for baseline differences. The time course of changes in the RTG and PTG was assessed by repeated-measures ANOVA. In addition, the values obtained were further evaluated by calculating the effect size (ES) and statistical power. The classification of ES was determined by converting partial η^2 to Cohen's *d*. According to Cohen,[25] ES can be classified as small ($0.00 \le d \le 0.49$), medium ($0.50 \le d \le 0.79$), or large ($d \ge 0.80$). Reliability for test–retest trials was assessed using ICC, with a value of 0.7–0.8 being questionable and >0.9 being high.[26] Significance was set at an α level of 0.05. All data analyses were performed using SPSS Version 19.0 (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Effects of 12 weeks of RT vs. PT on measures of muscle strength and explosive actions

No significant differences were found between PTG and RTG in regard to chronological age, height, weight, body mass, stages of puberty development according to Tanner, age at peak height velocity, and soccer experience, suggesting that (1) boys were all in prepubertal period and (2) both groups had similar age and anthropometric characteristics (Table 1). All participants completed the aforementioned training programs. The baseline and post-intervention values for all variables are presented in Table 2. After training, the RTG showed significant improvements in all tests ($p < 0.05$); the PTG showed significant improvements in all tests ($p < 0.05$) except for the 1RM half-squat test ($p > 0.05$), and the CG showed no changes. No differences were found in the improvements between experimental groups except in the 1RM half-squat test ($p < 0.001$), for which greater changes were demonstrated in the RTG than in the PTG.

Table 2
Time course of improvements and effects of 12 weeks of resistance training *vs.* plyometric training on explosive actions (mean ± SD).

Variables	Group	Baseline	4 weeks	8 weeks	12 weeks	*p* value	Cohen's *d*	Power
20-m sprint (s)	RTG	3.57 ± 0.24	3.55 ± 0.14	3.42 ± 0.20**	3.40 ± 0.17***[c]	<0.01 [a]	1.00	0.95
	PTG	3.66 ± 0.25	3.64 ± 0.23	3.55 ± 0.24	3.51 ± 0.22**[c]	<0.05 [b]	0.50	0.50
	CG	3.74 ± 0.18	3.73 ± 0.10	3.68 ± 0.13	3.75 ± 0.21			
ICODT (s)	RTG	17.54 ± 0.83	17.54 ± 0.58	16.87 ± 0.66**	16.78 ± 0.53**[c]	<0.05 [a]	0.66	0.63
	PTG	17.75 ± 0.85	17.67 ± 1.22	17.38 ± 0.99*	17.16 ± 0.95 **[c]	<0.05 [b]	0.54	0.64
	CG	17.73 ± 0.36	17.89 ± 0.31	17.89 ± 0.65	17.81 ± 0.47			
MB5 (m)	RTG	9.09 ± 0.84	8.98 ± 0.90	9.55 ± 0.74*	9.66 ± 0.74***[c]	<0.05 [a]	0.66	0.65
	PTG	8.82 ± 0.87	8.87 ± 1.05	9.11 ± 0.83	9.47 ± 1.02***[c]	<0.05 [b]	0.54	0.57
	CG	8.73 ± 0.62	8.70 ± 0.73	8.71 ± 0.48	8.77 ± 0.65			
SLJ (m)	RTG	1.66 ± 0.19	1.65 ± 0.18	1.78 ± 0.19**	1.91 ± 0.18***[c]	<0.01 [a]	0.84	0.81
	PTG	1.61 ± 0.23	1.63 ± 0.22	1.76 ± 0.21**	1.86 ± 0.27 ***[c]	<0.000 [b]	1.03	0.96
	CG	1.58 ± 0.13	1.56 ± 0.10	1.57 ± 0.08	1.63 ± 0.15			
CMJ (cm)	RTG	23.52 ± 4.22	25.74 ± 3.66***	28.64 ± 3.34***	29.6 ± 3.47***[c]	<0.001 [a]	1.03	0.96
	PTG	22.89 ± 6.06	24.35 ± 5.02	26.57 ± 5.56**	28.17 ± 5.93***[c]	<0.000 [b]	0.96	0.97
	CG	21.13 ± 2.96	22.01 ± 3.59	23.75 ± 3.34	21.99 ± 1.88			
SJ (cm)	RTG	22.22 ± 3.76	24.19 ± 4.10	26.58 ± 3.69**	27.13 ± 4.07***[c]	<0.000 [a]	1.15	0.98
	PTG	22.20 ± 5.27	23.42 ± 4.58	25.9 ± 6.03 **	26.82 ± 5.84***[c]	<0.001 [b]	0.84	0.91
	CG	19.06 ± 2.29	20.05 ± 3.13	20.10 ± 3.02	20.16 ± 3.13			
Half-squat (kg)	RTG	97.83 ± 21.09	110.75 ± 16.94***	121.42 ± 15.45***	125.08 ± 12.25***[c,d]	<0.001 [a]	1.21	0.99
	PTG	86.18 ± 3.67	86.18 ± 23.67	90.55 ± 24.98	89.82 ± 24.14	<0.01 [b]	0.70	0.76
	CG	83.82 ± 18.34	85.64 ± 16.9	90.00 ± 14.28	91.45 ± 15.39			

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, compared with baseline values.
The adjusted post-training means (analysis of covariance): [a] a main effect of group; [b] a main effect of time; [c] a significant difference with CG; [d] a significant difference with PTG.
Abbreviations: CG = control group; CMJ = countermovement jump; ICODT = Illinois Change of Direction Test; MB5 = multiple 5 bounds test; PTG = plyometric training group; RTG = resistance training group; SJ = squat jump test; SLJ = standing long jump test.

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Results in time of course improvements in all the outcome measures were shown in Table 3.

3.2. Time course of improvements

The test values for the RTG and PTG at baseline, 4, 8, and 12 weeks are presented in Table 2.

Table 3
Performance changes (△) after training (%).

Test	RTG	PTG	CG
20 m sprint			
8 weeks			
△	4.2[b]	NS	NS
d	1.1		
12 weeks			
△	4.8[a]	4.1[b]	0.3[d]
d	1.1	1.3	
ICODT			
8 weeks			
△	3.8[b]	2.1[c]	
d	2.1	1.3	
12 weeks			
△	4.3[b]	3.3[b]	0.5[d]
d	1.9	1.8	
MB5			
8 weeks			
△	5.1[c]	NS	NS
d	1.5		
12 weeks			
△	6.3[a]	7.4[a]	0.5[d]
d	1.7	2.4	
SLJ			
8 weeks			
△	7.2[b]	9.3[b]	NS
d	1.2	1.1	
12 weeks			
△	15.1[a]	15.5[a]	3.2[d]
d	3.1	1.7	
CMJ			
4 weeks			
△	9.4[a]		NS
d	2.4		
8 weeks			
△	21.8[a]	16.1[b]	
d	2.4	1.2	
12 weeks			
△	25.9[a]	23.1[a]	4.1[d]
d	3.2	2.2	
SJ			
8 weeks			
△	19.6[b]	16.7[b]	NS
d	1.5	1.4	
12 weeks			
△	22.1[a]	20.8[a]	5.8[d]
d	1.4	1.8	
Half-squat			
4 weeks			
△	13.2[a]	NS	NS
d	1.3		
8 weeks			
△	24.1[a]	NS	NS
d	2.3		
12 weeks			
△	27.9[a]	NS	NS
d	3.1		

[a] $p < 0.001$; [b] $p < 0.01$; [c] $p < 0.05$; [d] $p > 0.05$. NS = non significant.

Results in time of course improvements in all the outcome measures were shown in Table 3.

4. Discussion

For coaches and strength and conditioning professionals, it is useful to know the effectiveness and specific program duration necessary to improve certain explosive actions in prepubertal soccer players. It is worth noting that most of the previous studies and meta-analyses mixed prepubertal, adolescent, and adult athletes.[8,9,27] In addition, with the exception of the study conducted by Söhnlein et al.,[8] who mixed early puberty and midpuberty soccer players, no recommendations are available for the time needed to improve explosive action performance in general and especially with prepubertal soccer players. Therefore, the current study aimed to compare the effectiveness and feasibility of RT and PT programs in addition to the time course needed to stimulate improvement in CoD, strength, sprinting, and jumping performances in prepubertal elite soccer players. To the best of our knowledge, the present study is the first to investigate the effects of 12 weeks of RT and PT on the explosive action of youth soccer players and the time course of the improvements of RT and PT after 4, 8, and 12 weeks. Results showed that an RT or a PT program in addition to soccer training induced greater increases of explosive actions than did standard soccer training alone. With the exception of the 1RM half-squat, for which improvements were only seen in the RTG, both the RTG and the PTG showed similar improvements in all tests.

It has been well established that explosive actions such as jumping, sprinting, and changing direction are key in soccer.[8,12] Therefore, these tests were selected because they provided clear information about soccer's physical demands.[8,12,24] In the current study, the RTG showed improvement in the CMJ after 4 weeks, whereas the PTG showed improvement after only 8 weeks. In addition, the RT and the PT programs led to an improvement in CMJ and SJ performance ranging from 16.7% to 25.9% after 12 weeks. These results are in line with the finding of Christou et al.,[10] who found an improvement of approximately 13% to 14% (ES = 0.76-0.86) for the SJ and CMJ after an 8-week RT program and 25% to 31% (ES = 1.65-1.49) after 16 weeks among adolescent soccer players. Similar results were shown by Michailidis et al.,[12] who found improvements of 23.3% and 27.6% in SJ and CMJ performance, respectively, after a 12-week PT program. For both the RTG and the PTG, significant improvements in SLJ performance were observed starting after 8 weeks (7.2% and 9.3%, respectively), and the greatest increase was found after 12 weeks (15.1% and 15.5%, respectively). Additionally, significant improvement in the MB5 in the RTG was observed after 8 weeks (5.1%), with the greatest improvement observed after 12 weeks (6.3%), whereas improvements in the PTG were observed only after 12 weeks (7.4%). Our results were in accordance with those of Söhnlein et al.,[8] who showed that 16 weeks of PT were sufficient to increase SLJ and MB5 performance by 7.3% and 11.8%, respectively, as well as with those of Michailidis et al.,[12] who demonstrated 2.6% and 4.2% improvements after 6 and 12 weeks, respectively, in the SLJ and a 22.9% improvement in the MB5 after 12 weeks of PT.

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The marked improvement in both jumping tests might indicate that essential components of the stretch-shortening cycle, such as the speed of contraction and ground contact time and the increase in maximal muscle force as a result of RT despite the absence of specific exercises for the improvement of jump performance,[8,10] were effectively enhanced by the applied PT and RT programs, with more rapid changes in MB5 and CMJ performance in the RTG compared with the PTG.

In the current study, sprint performance was enhanced to a similar magnitude within the 2 experimental groups compared with the CG. Clear improvements in 20 m sprint test after 8 weeks were demonstrated for the RTG (+4.2%) and after 12 weeks for the PTG (+4.1%). A previous investigation by Söhnlein et al.[8] revealed an improvement in all sprint phases after 16 weeks of PT, with a 3.2% increase for the 20 m sprint test. In addition, Michailidis et al.[12] reported a marked improvement in the initial acceleration time and the maximal velocity phase after a 12-week PT program, with changes of −5% in 10 m, −3.5% in 20 m, and −3% in 30 m sprint tests. In addition, Christou et al.[10] revealed a significant improvement in the 30 m sprint test (2.5%, ES = −0.3) after 16 weeks of RT among adolescent soccer players. This discrepancy might be based on differences in the frequency, intensity, and volume of the applied RT and PT programs within these studies and differences in the participants' conditioning levels.

Improvements in the 20 m sprint test after RT and PT may result primarily from increases in maximal muscle strength and power, allowing the athletes to explode from the start faster or have longer stride lengths.[10,28] In addition, because the training in our PT program incorporates horizontal stimulus, this may increase the chances of gaining adaptations, considering the importance of horizontal force production and application in sprint performance.[28] This agrees with previous studies in which vertical PT fail to improve sprint performance.[29]

The CoD performance improved in both the RTG and the PTG after 8 weeks and showed its greatest improvement after 12 weeks compared with baseline. This is consistent with the findings of Christou el al.,[10] which showed an improvement in the 10 × 5 m shuttle run CoD test of approximately 3.4% (ES = −0.83) after 8 weeks and 5.4% (ES = −1.74) after 16 weeks of an RT program among adolescent soccer players. In addition, Söhnlein et al.[8] found an improvement in CoD test performance after 8 weeks of a PT program among early puberty to midpuberty soccer players and showed a 6.1% enhancement after 16 weeks. In the study by Michailidis et al.,[12] similar results were reported with preadolescent soccer players, including a 22.8% improvement after 12 weeks. Plisk[30] established that CoD requires rapid force development and high power output, as well as the ability to proficiently utilize the stretch shortening cycle in ballistic movements. PT and RT have been shown to improve these requirements, and several studies have recommended the inclusion of plyometrics in soccer training to familiarize players with unanticipated changes in direction.[6,8,10] In view of the high correlation found between lower body strength and CoD performance,[31] previous research findings revealed that improving the eccentric strength directly improves the ability to tolerate the braking loads and/or the braking capacity required to produce efficient CoDs, particularly when multiple directional changes or a greater degree of directional change is involved.[31] Based on the results mentioned, we concluded that RT and PT programs might have improved the eccentric strength of the lower limbs,[19] a prevalent component in the deceleration phase of CoD.[8] In addition, it must be acknowledged that the PTG completed a training program with several plyometric exercises designed to induce short contact times that may increase reactive strength index and subsequently the ability to change directions.[32] In addition, exercises such as the half-squat or plyometrics emphasizing the eccentric phase will enable greater opportunity to translate that strength into effective CoD performance.

Interestingly, both distinctly different training interventions led to similar improvements. Thus, RT and PT appear to constitute equally good strength training alternatives in early pubertal soccer players for the development of CoD skills. The change in CoD time performance demonstrated that a PT and an RT program can have a positive influence on a field test valid to game play[1,8] and therefore may have an impact on true soccer performance.

These findings suggested that youth soccer players could increase their explosive strength by doing PT or low-to-moderate intensity RT exercises 2 times per week (i.e., exercises at 40% to 60% 1RM) in addition to their standard soccer training program, with improvements beginning after 4 to 8 weeks in the majority of the measured parameters. Furthermore, a trend toward faster improvements in the RTG than in the PTG was observed.

Numerous studies have demonstrated improvements in strength performance via RT[10,19,33,34] and PT.[35] In contrast, Markovic et al.[36] failed to report significant effects of PT on strength performance.

In our study, the results of the maximum strength outcomes showed significant improvement only in the RTG compared with the PTG and the CG. Recent research has argued that a typical strength gain of approximately 30% is expected after an RT program lasting between 8 and 20 weeks in children and adolescents.[33] Payne et al.[34] found significant strength gains following RT that were approximately 13% to 30% greater than those that should be expected from growth and maturation. Our findings are in accordance with the aforementioned study, demonstrating lower body strength gains of 24.1% after 8 weeks and 27.9% after 12 weeks of RT.

In contrast to the results of all other tests within the RTG, 4 weeks were sufficient to show improvements in lower body strength (+13.2%), with the greatest increase again observed after 12 weeks (+27.9%). Furthermore, this gain in lower body strength was larger than the gains in sprinting and CoD performance. These findings are in accordance with Christou et al.,[10] who revealed greater increases in leg strength (58.8%, ES = 2.77) than in 30 m sprint speed (2.5%, ES = −0.3) after 16 weeks of an RT program.

Conversely, the PTG and the CG did not show any significant improvement in maximal strength. These findings are likely related to the nature of muscular strength, with greater strength gains made during the low-velocity movement of the eccentric contraction phase, such as in weight RT, than those made during the high-velocity movement of this phase within the PT[9,19,33] or those due to alterations in neural factors caused by the training intensity;[37] therefore, a weight RT program may stimulate greater strength adaptations. Thus, our findings lead to speculation that the muscle force stimulus experienced by PT cannot be effective enough for maximal strength development.

Future studies should examine age- and sex-specific effects of RT and PT on measures of physical fitness and additionally scrutinize the underlying neuromuscular adaptations following short- and long-term RT and PT in youth soccer players.

5. Conclusion

Explosive power is important in most sports, including soccer, and should be one of the main focuses for strength and conditioning coaches. Our study shows that in addition to soccer technical training, 12 weeks of well-planned RT or PT, 2 days per week, influences multidimensional development of muscular performance. Despite the well-acknowledged and numerous benefits associated with RT and PT, there is a lack of information concerning the adequate period required to show increases in explosive actions in prepubertal soccer players. Results obtained from the present study revealed that both RT and PT conducted in conjunction with regular soccer training are safe (i.e., no injuries occurred) and feasible (2 training sessions per week) interventions that create positive effects on proxies of athletic performance in prepubertal soccer players. Regarding the time course of improvement, lower body strength performance increased only after the RT program, and improvement was shown for the first time after 4 weeks, whereas sprinting, CoD, and jump performances increased largely after 8 weeks, with the greatest improvements observed after 12 weeks in both the RT and the PT programs. These outcomes may help coaches and sport scientists develop better guidelines and recommendations for athletes' assessment and selection, training prescription and monitoring, and competition preparation. In light of the difference observed in regard to the time course of improvement between the 2 training interventions, coaches and sport scientists have to be very concise with respect to their training goals. Finally, the current findings suggest that both RT and PT combined with soccer training lead to greater improvements in speed, power, and CoD than soccer training alone, with faster improvements shown with RTG.

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Authors' contributions

YN and HC carried out the study concepts/design, acquisition of data, data analysis/interpretation, manuscript preparation, and approval of the article; TS carried out the study data analysis/interpretation manuscript preparation, approval of the article and critical revision of the manuscript and funds collection; MH carried out the study concepts/design and acquisition of data; MSC and YH participated in coordination, helped to edit the manuscript and approval of the article. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

None of the authors declare competing financial interests.

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