EFFECT OF PROGRESSIVE VOLUME-BASED OVERLOAD DURING PLYOMETRIC TRAINING ON EXPLOSIVE AND ENDURANCE PERFORMANCE IN YOUNG SOCCER PLAYERS

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ABSTRACT

Ramírez-Campillo, R, Henríquez-Olguín, C, Burgos, C, Andrade, DC, Zapata, D, Martínez, C, Álvarez, C, Baez, EI, Castro-Sepúlveda, M, Peñailillo, L, and Izquierdo, M. Effect of progressive volume-based overload during plyometric training on explosive and endurance performance in young soccer players. *J Strength Cond Res* 29(7): 1884–1893, 2015—The purpose of the study was to compare the effects of progressive volume-based overload with constant volume-based overload on muscle explosive and endurance performance adaptations during a biweekly short-term (i.e., 6 weeks) plyometric training intervention in young soccer players. Three groups of young soccer players (age 13.0 ± 2.3 years) were divided into: control (CG; $n = 8$) and plyometric training with (PPT; $n = 8$) and without (NPPT; $n = 8$) a progressive increase in volume (i.e., 16 jumps per leg per week, with an initial volume of 80 jumps per leg each session). Bilateral and unilateral horizontal and vertical countermovement jump with arms (CMJA), 20-cm drop jump reactive strength index (RSI20), maximal kicking velocity (MKV), 10-m sprint, change of direction speed (CODS), and Yo-Yo intermittent recovery level 1 test (Yo-Yo IR1) were measured. Although both experimental groups significantly increased CMJA, RSI20, CODS, and endurance performance, only PPT showed a significant improvement in MKV and 10-m sprint time. In addition, only PPT showed a significantly higher performance improvement in jumping, MKV, and Yo-Yo IR1 compared with CG. Also, PPT showed higher meaningful improvement compared with NPPT in all (except 1) jump performance measures. Furthermore, although PPT involved a higher total volume compared with NPPT, training efficiency (i.e., percentage change in performance/total jump volume) was similar between groups. Our results show that PPT and NPPT ensured significant improvement in muscle explosive and endurance performance measures. However, a progressive increase in plyometric training volume seems more advantageous to induce soccer-specific performance improvements.

KEY WORDS explosive strength, stretch-shortening cycle, team sports, strength training, football

INTRODUCTION

It has been shown that explosive muscle actions such as sprinting, jumping, and change of direction speed (CODS), along with aerobic power, influence game performance in young soccer players (3). For instance, although sprinting contributes only up to 3% of the total game distance covered by young soccer players (3), most crucial moments (e.g., scoring) depend on it (39). In addition, along with the relevance of neuromuscular pathway training from an explosive-development stand point at young ages (i.e., *trainability window*) (25), soccer-related explosive activities may be important qualities not only at young level (12,45) but also at a later stage of a player's career (18). Therefore, it has been proposed that such explosive actions could affect game performance of soccer players and that they have to be trained independently from aerobic performance from a young age (13).

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Plyometric training (i.e., an explosive-type strength training method) has been established as a sport-specific, effective, time-saving, economical, and easy-to-implement training strategy in soccer facilities with young soccer players, which has shown to induce improvements in several explosive (e.g., jump, sprint, CODS) (8,26,29) and soccer-specific endurance performance measures (46). Thus, plyometric training has been advocated as an appropriate approach to achieve soccer-related performance improvements, which can be attributed mainly to neuromuscular adaptations (23). However, although coaches and researchers have attempted to identify the primary governing factors underlying plyometric training effects, the optimal handling of program variables to maximize performance adaptations is not yet clear (41), particularly in young soccer players.

The progressive overload training principle aims to stimulate continuing adaptations and consists of progressively increasing the training loads in time, by modifying mainly the training volume and intensity (36,42). This training principle may have a positive effect on young soccer player's jump, sprint, and CODS performance during resistance training (5). More so, plyometric training with a progressive overload has been used in young soccer players (8,9,22,26,29,46), although these studies did not compare the effect of progressive overload with constant overload (i.e., they did not use a control group). Only 1 study (42) conducted in young rugby players have analyzed the independent effect of progressive intensity-based overload during plyometric training. However, to the best of our knowledge, no study has shown the effect of a progressive volume-based compared with constant volume-based overload during plyometric training in young soccer players. Therefore, the purpose of this study was to compare the effect of progressive volume-based overload with constant volume-based overload during a short-term (i.e., 6 weeks) plyometric training intervention in young soccer players during their in-season period, by replacing some of their soccer-specific technical and tactical drills. We hypothesized that a progressive increase in volume during a short-term plyometric training program would induce higher performance improvements compared with a constant volume of plyometric drills.

METHODS

Experimental Approach to the Problem

This study was designed to compare the effects of a 6-week plyometric training program, with and without an increase in volume across time on several explosive and endurance performance measures in young soccer players. Sample size was computed based on the changes observed in the reactive strength index ($\Delta = 0.33$ mm·ms^{-1}; SD = 0.3) after a short-term plyometric training study performed in young soccer players (37). Thus, a total of 6 participants per group would yield a power of 80% and an alpha level of 0.05. After baseline measurements, participants were randomly assigned to a control group (CG, $n = 8$), which received only soccer training and to 2 groups that completed a plyometric training program with (PPT, $n = 8$) and without (NPPT, $n = 8$) progressive increase in training volume in 6 weeks. The randomization sequence was generated electronically and concealed until interventions were assigned. Although initially a fourth research group was considered with a total jump volume equal to that achieved by the PPT but without a progressive increase in volume (i.e., to control for the effect of volume compared with the effect of progressive volume-based overload), unfortunately this group was not incorporated because this training approach would have involved a high volume of plyometric training over hard training surface from the beginning of intervention, which may have increased the injury risk in participants. Therefore, ethical issues preclude us from including a fourth group.

Subjects

Twenty-four young (Age range 11–15 years of age) male soccer players from the same soccer club and without previous or current regular strength or plyometric training volunteered for this study. All groups participated in the same soccer club and training program (i.e., 20 minutes of technical drills; 40 minutes of tactical drills; 20 minutes of small-sided games; 40 minutes of simulated competitive games), receiving a similar soccer-related load (i.e., session rating of perceived exertion, Table 1), in addition to a similar competitive training load (i.e., 4-5 competitive games during the experimental period). Subjects were reminded to maintain their usual physical activity habits during the experiment. Weekly nonsoccer sport practice was similar between CG (1.5 ± 1.2 h·wk^{-1}), NPPT (1.6 ± 1.4 h·wk^{-1}), and PPT (1.6 ± 1.9 h·wk^{-1}). In addition, all groups received a similar volume of weekly physical education-related activity (CG = 113 ± 31 min·wk^{-1}), NPPT (113 ± 31 min·wk^{-1}), and PPT (105 ± 32 min·wk^{-1}).

Exclusion criteria were (a) potential medical problems or a history of ankle, knee, or back injury that could compromise participation or performance in the study, (b) any lower extremity reconstructive surgery in the past 2 years or unresolved musculoskeletal disorders. Individuals taking medically prescribed vitamins or minerals supplements were not excluded. Despite not pair-matching individuals based on an independent variable, there were no significant differences between group characteristics at baseline (Table 1). Participants (and their parents or guardians) were informed about the experimental procedures and about possible risks and benefits associated with participation in the study, and they signed an informed consent before the start of the study. The study was conducted in accordance with the Declaration of Helsinki and was approved by the ethics committee of the responsible department.

Testing Procedures

The participants were carefully familiarized with the measurements during several submaximal and maximal actions in 2 nonconsecutive learning sessions in 2 weeks before basal measurements. Each participant also completed several

TABLE 1. Descriptive data of the control group (CG; $n = 8$), plyometric training group with (PPT; $n = 8$) and without (NPPT; $n = 8$) a progressive increase in volume across time.

	CG	PPT	NPPT
Age (y)	13.0 ± 1.9	12.8 ± 2.8	13.0 ± 2.1
Height (cm)	159 ± 8.5	160 ± 13.4	161 ± 10.1
Body mass (kg)	53.2 ± 11.1	53.9 ± 14.1	53.8 ± 7.6
Body mass index ($kg \cdot m^{-2}$)	20.8 ± 2.3	20.6 ± 1.0	20.7 ± 2.4
Body fat (%)	14.2 ± 4.8	14.6 ± 5.8	13.7 ± 3.2
Upper-body fat (%)	15.5 ± 3.8	15.5 ± 6.5	14.8 ± 3.2
Lower-body fat (%)	13.3 ± 5.6	13.8 ± 5.3	12.6 ± 3.3
Muscle mass (%)	46.2 ± 6.8	45.1 ± 4.9	45.5 ± 2.6
Predicted years from age of peak height velocity (y)	0.4 ± 1.6	0.3 ± 2.0	0.4 ± 1.5
Session rating of perceived exertion	371 ± 243	428 ± 180	428 ± 249
Soccer experience (y)	4.1 ± 1.5	4.0 ± 1.4	4.1 ± 1.5

explosive-type actions to become familiar with the exercises used during training. Measurements were taken 1 week before and 1 week after the intervention. All tests were always administered in the same order, same time of day, and by the same investigator, who was blinded to the training group of the participants. Testing sessions were scheduled >48 hours after a match or hard physical training to minimize the influence of fatigue. All participants (and their parents or guardians) were instructed to (a) have a good night sleep (≥8 hours) before each testing day and (b) have a meal rich in carbohydrates and to be well hydrated before measurements. Participants were motivated to give their maximum effort during the performance measurements. All tests were completed in 2 days. On day 1, standing and sitting height, body mass, vertical countermovement jump with arms (CMJA), horizontal bilateral and unilateral CMJA, and 20-cm drop jump reactive strength index (RSI20) were measured (in this order). On day 2, measurements taken included a 10-m sprint test (i.e., acceleration), maximal kicking velocity test (MKV), CODS test (i.e., *t*-test), and the Yo-Yo intermittent recovery level 1 test (Yo-Yo IR1) (in this order). Ten minutes of standard warm-up (6 minutes of submaximal running with several displacements and 2 submaximal jump exercises of 20 vertical jumps and 10 longitudinal

TABLE 2. Six-week plyometric training program.*

	Set × repetitions (mode of execution)					
Exercises	Week 1†	Week 2	Week 3	Week 4	Week 5	Week 6
Horizontal left leg	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)	2 × 8 (C)	2 × 9 (C)	2 × 10 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)	2 × 8 (A)	2 × 9 (A)	2 × 10 (A)
Horizontal right leg	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)	2 × 8 (C)	2 × 9 (C)	2 × 10 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)	2 × 8 (A)	2 × 9 (A)	2 × 10 (A)
Vertical left leg	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)	2 × 8 (C)	2 × 9 (C)	2 × 10 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)	2 × 8 (A)	2 × 9 (A)	2 × 10 (A)
Vertical right leg	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)	2 × 8 (C)	2 × 9 (C)	2 × 10 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)	2 × 8 (A)	2 × 9 (A)	2 × 10 (A)
Bilateral vertical	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)	2 × 8 (C)	2 × 9 (C)	2 × 10 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)	2 × 8 (A)	2 × 9 (A)	2 × 10 (A)
Bilateral horizontal	2 × 5 (C)	2 × 6 (C)	2 × 7 (C)	2 × 8 (C)	2 × 9 (C)	2 × 10 (C)
	2 × 5 (A)	2 × 6 (A)	2 × 7 (A)	2 × 8 (A)	2 × 9 (A)	2 × 10 (A)

*The group that did not progressively increase training volume across time used the volume depicted in week 1 during the 6 weeks of training.

†The volume of contacts described is per session and that remains the same for the 2 plyometric training session completed each week.

C = cyclic; A = acyclic.

Table 3. Training effects (with 90% confidence limits) for the jump performance variables for the control group (CG; $n = 8$) and plyometric training group with (PPT; $n = 8$) and without (NPPT; $n = 8$) a progressive increase in volume across time.

	Baseline mean ± SD	Performance change (%)	Magnitude of training effect
Vertical countermovement jump with arms (cm)			
CG	29.2 ± 9.4	2.6 (−4.0 to 9.6)	0.07 (−0.11 to 0.24)
NPPT	28.5 ± 10.4	10.9 (−2.0 to 25.4)^{a}	0.23 (−0.04 to 0.50)*
PPT	27.9 ± 8.7	16.6 (1.6 to 36.8)^{a}	0.54 (0.06 to 1.02)*
Horizontal countermovement jump with arms (cm)			
CG	154 ± 35.3	−1.8 (−5.7 to 2.3)	−0.07 (−0.22 to 0.08)
NPPT	163 ± 42.6	4.6 (−2.9 to 12.7)	0.13 (−0.09 to 0.35)
PPT	160 ± 27.9	7.9 (0.3 to 16.0)^{a,d}	0.40 (0.02 to 0.79)*
Right leg horizontal countermovement jump with arms (cm)			
CG	135 ± 33.4	4.0 (−2.9 to 11.4)	0.14 (−0.10 to 0.39)
NPPT	138 ± 35.3	2.8 (−3.7 to 9.6)	0.08 (−0.11 to 0.28)
PPT	138 ± 27.7	13.5 (3.4 to 24.7)^{b,d}	0.59 (0.15 to 1.02)*
Left leg horizontal countermovement jump with arms (cm)			
CG	135 ± 30.1	1.0 (−4.4 to 6.7)	0.04 (−0.17 to 0.25)
NPPT	136 ± 42.9	14.1 (6.5 to 22.3)^{b}	0.36 (0.17 to 0.55)*
PPT	134 ± 27.0	21.2 (10.8 to 32.7)^{c,e}	0.95 (0.50 to 1.40)†
20-cm drop jump reactive strength index ($mm \cdot ms^{-1}$)			
CG	0.080 ± 0.029	−1.9 (−20.4 to 21.1)	−0.04 (−0.44 to 0.37)
NPPT	0.062 ± 0.022	14.0 (−15.2 to 53.3)^{a}	0.23 (−0.29 to 0.75)*
PPT	0.072 ± 0.034	36.1 (1.7 to 82.3)^{a,d}	0.73 (0.0.4 to 1.43)†

*Small standardized effect.

†Moderate standardized effect; a, b, and c denote significant difference pretraining to posttraining ($p \le 0.05$, $p < 0.01$, and $p < 0.001$, respectively). d and e: denote significant difference with the CG after training ($p \le 0.05$ and $p < 0.01$, respectively).

jumps) were executed before each testing day. Participants were instructed to use the same athletic shoes and clothes during the preintervention and postintervention testing. All tests were conducted indoor on a wooden surface. At least 2 minutes of rest was allowed between each trial to reduce the effects of fatigue. While waiting, participants performed low-intensity activity to maintain physiological readiness for the next test. The best score of 3 trials was recorded for all performance tests, apart from the single Yo-Yo IR1.

Anthropometric Measurements. Height and sitting height were measured using a stadiometer (Bodymeter 206; SECA, Hamburg, Germany), and body mass was measured with an electrical bioimpedance scale (BF 100_Body Complete; Beurer, Ulm, Germany). Furthermore, the athletes' maturity status was determined using predicted years from age of peak height velocity (PHV) (i.e., PHV offset) (31). To predict PHV offset, the following variables were considered: gender, date of birth, date of measurement, height, sitting height, and body mass. A growth utility program (http://taurus.usask.ca/growthutility/phv_ui.cfm?type=1) based on the study by Mirwald et al. (31) was used to analyze values for these variables and calculate PHV offset. Based on PHV offset, participants ranged from −2.2 to +1.6 years, −2.4 to +1.9 years, and −2.4 to +1.9 years in the CG, NPPT, and PPT group, respectively. Therefore, in the 3 groups of soccer players, an equal distribution of subjects (i.e., 4:4) before and after pubertal spurt of body height (i.e., maturity status) was achieved. More so, based on PHV offset, the participants from the CG (PHV offset = 0.4 ± 1.6), NPPT (PHV offset = 0.4 ± 1.5), and PPT (PHV offset = 0.3 ± 2.0) did not show significant differences at baseline.

Countermovement Jump With Arms Measurements. Vertical jumps were measured using an electronic contact mat system (Ergojump; Globus, Codogne, Italy), and maximal horizontal jump distance was measured using a 5-m long fiber glass metric tape endorsed to a wooden floor. Participants were instructed to use their arms to aid in the jump, positioning their foot shoulders wide apart for the bilateral jumps and with 1 foot stand (right and leg) for the unilateral jumps. In addition, subjects were instructed to perform a fast

Table 4. Training effects (with 90% confidence limits) for the soccer-specific explosive and endurance performance variables for the control group (CG; $n = 8$) and plyometric training group with (PPT; $n = 8$) and without (NPPT; $n = 8$) a progressive increase in volume across time.

	Baseline mean ± SD	Performance change (%)	Magnitude of training effect
Maximal kicking velocity ($km \cdot h^{-1}$)			
CG	64.4 ± 13.9	−0.9 (−4.9 to 3.2)	−0.04 (−0.22 to 0.14)
NPPT	68.3 ± 15.4	5.7 (4.4 to 7.0)	0.17 (0.14 to 0.21)
PPT	67.1 ± 16.3	10.1 (8.4 to 11.8)[b,d]	0.34 (0.28 to 0.39)*
10-m sprint time (s)			
CG	2.60 ± 0.21	−1.1 (−4.1 to 2.0)	−0.13 (−0.48 to 0.23)
NPPT	2.64 ± 0.36	−0.9 (−4.1 to 2.3)	−0.06 (−0.26 to 0.14)
PPT	2.71 ± 0.29	−1.6 (−4.2 to −1.1)[a]	−0.14 (−0.37 to −0.09)
Change of direction speed test time (s)			
CG	13.0 ± 1.4	−6.0 (−10.9 to 0.9)[a]	−0.58 (−1.08 to −0.09)*
NPPT	13.0 ± 2.1	−7.6 (−10.8 to −4.3)[b]	−0.43 (−0.62 to −0.24)*
PPT	13.1 ± 1.5	−9.0 (−13.0 to −4.8)[b]	−0.82 (−1.21 to −0.43)†
Yo-Yo intermittent recovery level 1 test (m)			
CG	987 ± 394	2.7 (−2.7 to 8.3)	0.07 (−0.08 to 0.22)
NPPT	990 ± 440	11.6 (8.5 to 14.7)[b]	0.27 (0.20 to 0.34)*
PPT	993 ± 457	15.3 (10.3 to 20.4)[c,d]	0.31 (0.21 to 0.40)*

*Small standardized effect.

†Moderate standardized effect; a, b, and c denote significant difference pretraining to posttraining ($p \leq 0.05$, $p < 0.01$, and $p < 0.001$, respectively). d denotes significant difference with the CG after training ($p \leq 0.05$).

downward movement (approximately to 120° of knee angle) followed by a maximal jump effort, landing in an upright position during vertical jumps.

20-cm Drop Jump Reactive Strength Index. The RSI20 was determined on a contact mat (Ergojump; Globus, Codogne, Italy) with arms akimbo. Take-off and landing was standardized to full knee and ankle extension on the same spot. The participants were instructed to maximize jump height and minimize ground contact time after dropping down from a 20-cm drop box.

Sprint and Change of Direction Speed Performance. The 10-m sprint time were measured to the nearest 0.01 seconds using single beam infrared photoelectric cells (Ergotester; Globus). The starting position was standardized to a still split standing position with the toe of the preferred foot forward and behind the starting line. Sprint start was given by a random sound, which triggers timing. The photoelectric signal was positioned at 10-m and set ~0.7 m above the floor (i.e., hip level) to capture trunk movement rather than a false trigger from a limb. The CODS test has been described previously (35). The timing system and procedures were same as the 10-m sprint.

Maximal Kicking Velocity. Participants kicked a size 5 soccer ball (Nike Seitiro, Fédération Internationale de Football Association-certified) for maximal velocity measured by a radar gun (Sports Radar Speed Gun SR3600, Homosassa, FL, USA), according to a previously described protocol (1). Basically, participants performed a maximal instep kick with their dominant leg after a run-up of 2 strides, directed toward a goal net with a cue to aim (i.e., a vertical square target placed in its center) to increase the reliability of the test. The distance between the ball and the target was 4 m.

Yo-Yo IR1. The test was executed as previously described (17). Basically, 2 markers were positioned at a distance of 20 m, and the players performed repeated 20-m shuttle runs interspersed with 10 seconds of active recovery. The time allowed for a shuttle was progressively decreased. Before testing, participants performed a warm-up consisting of the first 4 running bouts in the test. Throughout testing, an investigator to participant ratio of 1:1 was maintained. Participants achieved ≥96% of theoretical maximal heart rate (measured with hearth rate monitor Forerunner 910XT, Garmin, Taipei, Taiwan) at the end of the test, suggesting maximal effort.

Internal Training Load Determination. To assure that all soccer players receive the same total soccer training load during intervention, the session rating of perceived exertion (RPE) was determined as previously described (15). In this study, the Spanish version of the 10-point category ratio scale (CR10-scale) modified by Foster et al. (10) was used.

Table 5. Differences between control group (CG; $n = 8$), plyometric training group with (PPT; $n = 8$) and without (NPPT; $n = 8$) a progressive increase in volume across time in the training effects* (with 90% confidence limits) on performance variables.

	NPPT − CG	PPT − CG	PPT − NPPT
Vertical countermovement jump with arms	8.9 (−6.6 to 26.9) Small	15.2 (−2.5 to 36.0) Small	6.5 (−11.8 to 28.6) Trivial
Horizontal countermovement jump with arms	6.5 (−3.0 to 16.9) Small	11.8 (2.9 to 21.4) Small	4.9 (−5.0 to 15.9) Small
Right leg horizontal countermovement jump with arms	−2.6 (−11.0 to 6.6) Trivial	9.8 (−2.8 to 24.0) Small	11.2 (−1.5 to 25.5) Small
Left leg horizontal countermovement jump with arms	14.4 (4.8 to 24.9) Small	20.7 (7.8 to 35.2) Moderate	6.9 (−5.1 to 20.4) Small
20-cm drop jump reactive strength index	15.3 (−21.5 to 69.2) Small	51.8 (9.4 to 110.5) Moderate	30.7 (−10.6 to 91.0) Small
Maximal kicking velocity	6.5 (2.1 to 11.1) Small	11.2 (6.5 to 16.1) Small	4.2 (2.1 to 6.4) Trivial
10-m sprint time	1.1 (−3.1 to 5.4) Trivial	−1.1 (−4.9 to 2.8) Trivial	−1.3 (−5.2 to 2.8) Trivial
Change of direction speed test time	−1.6 (−7.6 to 4.7) Trivial	−3.8 (−10.2 to 3.0) Small	−2.2 (−7.6 to 3.6) Trivial
Yo-Yo intermittent recovery level 1 test	8.0 (1.9 to 14.5) Small	12.3 (4.8 to 20.3) Small	3.4 (−2.2 to 9.3) Trivial

*Effects are shown in percentage units and probabilistic inferences about the true standardized magnitude.

Training Efficiency. Training efficiency was calculated as the relative (i.e., percentage) change of a performance variable divided by the total volume of jumps per leg completed during the 6 weeks of plyometric training, as suggested previously (7).

Training

PPT and NPPT performed a plyometric intervention with and without a progressive increase in training volume, respectively. The plyometric interventions were created based on previous research experience from our research team (38). Both groups used arm-swing during jumps, combining cyclic and acyclic, in addition to unilateral and bilateral, jumps. For acyclic drills, participants were motivated during each jump to achieve maximal intensity vertical height and horizontal distance; while during cyclic jumps, participants were motivated to maximize the ratio between vertical height or horizontal distance and ground contact time. Maximal intensity was verified in a randomly assigned subsample of participants (2 from each group) during 2 randomly assigned training sessions, by measuring contact times, height, and distance of jumps drills, using same procedures as in CMJA and RSI20 measurement procedures (described above). A detailed description of the training program is depicted in Table 2. The order of exercises execution was randomized in each training session to add variation during training.

Plyometric training was completed during the in-season period. Participants performed plyometric drills as a substitute for some low-intensity technical-tactical soccer drills at the beginning of their usual 120-minute practice twice per week for 6 weeks. The PPT group replaces the technical drills and the first portion (i.e., first 20 minutes) of the tactical drills by plyometric drills. Before the intervention, participants were instructed to properly execute the exercises to be done during the training period. Plyometric sessions were performed after the warm-up, which was the same for the plyometric training groups and for the control group. Both groups used the same surface and time of day for training, with the same rest intervals between sessions (i.e., 48 hours), sets (i.e., 60 seconds), and jumps (i.e., 15 seconds for acyclic jumps).

Statistical Analyses

All values are reported as mean ± SD. Relative changes (%) in performance and standardized effects (SE − changes as a fraction or multiple of baseline SD) are expressed with 90% confidence limits. Normality and homoscedasticity assumptions for all data before and after intervention were checked with Shapiro-Wilk and Levene tests, respectively. To determine the effect of the intervention on dependent variables, a 2-way analysis of variance with repeated measurements (3 groups × 2 times) was used. When a significant F value was achieved across time or between groups, Sheffe post hoc procedures were performed to locate the pairwise differences between the means. In addition, a 1-way analysis of variance was used to compare relative changes between groups. The α level was set at $p \leq 0.05$ for statistical significance. All statistical calculations were performed using

TABLE 6. Training efficiency* (% per jump) for plyometric training group with (PPT; $n = 8$) and without (NPPT; $n = 8$) a progressive increase in volume across time.

Vertical countermovement jump with arms	
NPPT	0.0014 ± 0.006
PPT	0.0055 ± 0.009
Horizontal countermovement jump with arms	
NPPT	0.0027 ± 0.0059
PPT	0.0029 ± 0.0041
Right leg horizontal countermovement jump with arms	
NPPT	0.0017 ± 0.0051
PPT	0.0051 ± 0.0058
Left leg horizontal countermovement jump with arms	
NPPT	0.0077 ± 0.0065
PPT	0.0077 ± 0.0056
20-cm drop jump reactive strength index	
NPPT	0.012 ± 0.028
PPT	0.016 ± 0.020
Maximal kicking velocity	
NPPT	0.0030 ± 0.001
PPT	0.0035 ± 0.001
10-m sprint time	
NPPT	−0.00042 ± 0.0025
PPT	−0.00053 ± 0.0014
Change of direction speed test time	
NPPT	−0.0039 ± 0.0025
PPT	−0.0031 ± 0.0021
Yo-Yo intermittent recovery level 1 test	
NPPT	0.0061 ± 0.0024
PPT	0.0054 ± 0.0027

*Efficiency was calculated as percentage change of performance variable divided by the total volume of jumps per leg completed during the 6 weeks of plyometric training.

STATISTICA statistical package (version 8.0; StatSoft, Inc., Tulsa, OK, USA). In addition to this null hypothesis testing, data were also assessed for meaningful significance using an approach based on the magnitudes of change. Threshold values for assessing magnitudes of SE (changes as a fraction or multiple of baseline SD) were 0.20, 0.60, 1.2, and 2.0 for small, moderate, large, and very large, respectively (14). Magnitudes of differences in training effects between groups were evaluated as follow (14): if the confidence interval overlapped thresholds for substantial positive and negative values, the effect was deemed unclear. The effect was otherwise clear and reported as the magnitude of the observed value with a qualitative probability, as above. Performance measurement reliabilities were determined using the intraclass correlation coefficient (ICC). A coefficient below 0.40 was considered poor, 0.40 to 0.59 fair, 0.60 to 0.74 good, and 0.75 to 1.00 excellent (21). We obtained excellent ICC for the different performance measurements, ranging between 0.85 and 0.99.

RESULTS

Before training, no significant differences were observed between groups in descriptive or anthropometric variables (Table 1), and no significant changes were observed after intervention in any group. Before training, no significant differences were observed between groups in CMJA (i.e., vertical, horizontal, bilateral, and unilateral), RSI20 (Table 3), MKV, 10-m sprint, CODS, or Yo-Yo IR1 (Table 4) test performance.

No statistically significant changes over time were observed in the CG, except for a significant ($p \le 0.05$) improvement in CODS performance (Table 4). PPT showed a statistically significant ($p \le 0.05$) increase in all jump performance test, with a small-to-moderate meaningful effect (Table 3). NPPT also showed a statistically significant ($p \le 0.05$) increase in vertical CMJA, left leg horizontal CMJA, and RSI20, with a small meaningful effect (Table 3). In comparison with CG, only PPT showed a significantly ($p \le 0.05$) higher performance improvement in all (except vertical CMJA) jump test (Table 3).

PPT showed a statistically significant ($p \le 0.05$) increase in MKV, 10-m sprint, CODS, and Yo-Yo IR1 test performance, with a small-to-moderate meaningful effect (Table 4). NPPT also showed a statistically significant ($p \le 0.05$) increase in CODS and Yo-Yo IR1 test performance, with a small meaningful effect (Table 4). Compared with CG, only PPT showed a significantly ($p \le 0.05$) higher performance improvement in MKV and Yo-Yo IR1 test (Table 4).

Although no statistically significant differences in performance changes were observed between plyometric training groups, PPT showed higher meaningful improvement compared with NPPT in all jump performance measures (except vertical CMJA) (Table 5).

No significant differences were observed for training efficiency between PPT and NPPT in any of the dependent variables (Table 6).

DISCUSSION

This study showed that PPT and NPPT ensured significant improvement in several explosive (i.e., vertical jump, horizontal jump, RSI20, CODS) and endurance (i.e., Yo-Yo IR1) performance measures. However, only PPT induced a significant increase in MKV and sprint performance. In addition, only PPT achieved significantly higher improvements in vertical jump, horizontal jump, MKV, and Yo-Yo IR1 compared with CG. More so, based on meaningful significance analysis, PPT achieved a greater increase in several explosive performance measures compared with NPPT and CG. Therefore, the study hypothesis is accepted. Although concern may exist regarding increased load and risk of fatigue, an increase in plyometric training volume-based load requires only 12 to 18 repetitions per week (16). In addition, young subjects possess high fatigue resistance and recovery capacity after high-intensity strength exercise (33). Therefore, an adequate progressive increase in plyometric training volume-based load would not negatively affect fatigue in young soccer players, and as our results show, should result in greater performance adaptations in explosive movements and aerobic endurance.

Both plyometric training groups showed a significant increase in vertical CMJA, horizontal CMJA, and RSI20 performance, with a small-to-moderate SE (Table 3). In this study, the magnitude of improvement was similar to that previously reported for analogous slow stretch-shortening cycle (SSC) (i.e., CMJA; SE = 0.43–0.59) (26) and fast SSC (i.e., RSI20; SE = 0.81–0.89) muscle actions (37) after plyometric training with young soccer players using interventions of similar duration or number of sessions and partially agreed with a previous study that applied an intensity-based progressive increase in plyometric load in young rugby players (42). Interestingly, only PPT showed a significantly ($p \leq 0.05$) greater performance improvement in CMJA and RSI20 performance compared with CG (Table 3). More so, PPT showed greater meaningful improvements than NPPT in all horizontal jump performance measures and RSI20 (Table 5). Because participants in this study were instructed to produce maximal intensity vertical height and horizontal distance for acyclic jumps, with minimum ground contact time for cyclic jumps (instructions intended to maximize reactive strength), it is plausible that these instructions have permitted an adequate stimulation of slow and fast SSC muscle performance. Considering the necessity to produce a high rate of force development in explosive jump actions during soccer games (25), the improvement observed in explosive jump performance could also induce some enhancements in physical parameters of game performance. The improvement observed could have been induced by various neuromuscular adaptations (23); however, because no physiological measurements were made, only speculations are possible. These results support the need for a progressive increase in plyometric training volume-based load during short-term interventions with young soccer players to induce greater performance adaptations in explosive movements requiring slow and fast SSC muscle actions.

To the best of our knowledge, this is the first study to compare the effect of progressive volume-based overload to constant volume-based overload during short-term plyometric training in MKV in young soccer players. Our results showed that only PPT achieved a statistically significant ($p \leq 0.05$) increase in MKV performance, with a small SE, and this performance improvement was significantly greater compared with CG (Table 4). These results suggest that plyometric training incorporating a progressive volume-based overload in the short-term may induce greater MKV performance improvements in young soccer players. Although differences in the type of training program applied make comparisons between different studies difficult, other studies have also reported significant increases in kicking performance after plyometric training in young soccer players (29,37). Increases in MKV performance may be attributed to increased strength and explosiveness of legs' extensor muscles (29), factors that are important during the instep kick in soccer (20); these adaptations have been attributed to neuromuscular adaptations (29). It may be that these neuromuscular and strength-explosive adaptations had an effect on the biomechanical factors related to kicking performance, such as maximum linear velocity of the toe, ankle, knee, and hip at ball contact (19), which may have cumulatively or individually contributed to a higher ball kicking velocity.

Regarding 10-m sprint performance, only PPT showed a statistically significant improvement (Table 4). Although previous plyometric interventions with young soccer players showed a positive impact on 10-m sprint performance during the in-season period (26,29,46), to the best of our knowledge, this is the first study to compare the effect of progressive volume-based overload with constant volume-based overload during plyometric training on 10-m sprint times in young soccer players. It has been shown that although vertical strength and explosiveness may be related with sprint performance in young male athletes (28), incorporation of horizontal drills during plyometric training probably played a more important role in sprint performance improvement (41), considering the importance of horizontal force production and application in sprint performance (32) and the principle of training specificity (41). This agrees with previous studies in which vertical-only plyometric training failed to improve sprint performance in young soccer players (37). Although NPPT also incorporates horizontal plyometric drills, the lower volume of training may have reduced the probability of achieving significant sprint performance adaptations (41). Also, the higher acceleration performance improvement (i.e., 10-m sprint) in participants from PPT may be related to their greater improvement in slow SSC muscle performance (i.e., CMJA) and transference to unilateral horizontal performance compared with NPPT (Table 5), because acceleration may be more dependent on a slower SSC muscle action and explosive production similar to the CMJ (4) and because unilateral horizontal jump performance may better predict sprint performance (27). Interestingly, although CG achieves a similar relative performance improvement compared with PPT (Table 4), the nonsignificant improvement in the former may be related to the fact that only 4 of 8 soccer players in the CG achieve a reduced 10-m sprint time, whereas all soccer players from the PPT achieve a reduction in the 10-m sprint time. These observations reinforce the value of a progressive volume-based overload explosive training program to enhance acceleration sprint ability of young soccer players during the in-season.

In relation with CODS, the control group and the plyometric training groups achieved a statistically significant and meaningful increase in performance. There are important differences between CODS tests used among studies, which make a comparative analysis difficult with our results; however, other studies have found a significant improvement in CODS performance after plyometric training (26) and soccer training (37). The improvement in CODS performance may be related to an improved RSI20 (30,47), explosive-development improvements (34), or an increase in eccentric strength of the lower limbs, which can impact changes of direction performance during the deceleration phase (43). The increase in CODS performance observed in the CG may be related to the fact that soccer coaches use technical and tactical drills that focus on the player's agility (6); also, this increased performance suggests that participants were not submitted to a poor soccer stimulus, highlighting the positive impact of plyometric training on other variables of young soccer players performance. Interestingly, although all groups achieved a significant increase in CODS performance, only PPT showed a higher meaningful increase compared with CG (Table 5), suggesting that progressive volume-based overload during plyometric training induces a greater CODS performance.

Our results showed that both plyometric training groups achieve a statistically significant ($p \leq 0.05$) increase in Yo-Yo IR1 test, with a small SE (Table 4). Plyometric training in young soccer players has shown not to induce a significant increase in the aerobic outcomes such as $\dot{V}O_2max$ (29) or lactate threshold (11), but still has a meaningful effect on a intermittent recovery endurance performance test with repeated changes of direction (i.e., Yo-Yo IR1) (46). An increase in running economy (24) associated with increased musculotendinous stiffness (44) and neuromuscular explosive improvements after plyometric training may be the underlying mechanisms behind this improvement in young soccer players (2), and these adaptations can occur independent of changes in $\dot{V}O_2max$ (29) or lactate threshold (11). A novel finding of this study was that PPT showed a significantly higher performance improvement in Yo-Yo IR1 test compared with CG (Table 4), suggesting that a progressive increase in volume during short-term plyometric training improves the recovery to intermittent efforts of soccer player's that are required during competitive games.

In conclusion, replacement of some low-intensity technical-tactical soccer drills during the in-season period with a short-term (i.e., 6 weeks) plyometric training intervention with a progressive increase in volume of jumps during this period in young soccer players would induce higher nonspecific and soccer-specific explosive and endurance performance improvements compared with a similar training program but without a progressive increase in volume.

PRACTICAL APPLICATIONS

Replacement of some soccer drills with high-intensity plyometric exercises positively affected jump, sprint, kicking, CODS, and endurance performance in young soccer players during the in-season period. These adaptations can be achieved in the short-term and may potentially increase competitive performance and reduce the risk of injury of young soccer players (40). In addition, based on the present results, a progressive volume-based overload across time would be more advantageous to young soccer players. This volume-based progressive overload may induce meaningful improvements in explosive performance and intermittent aerobic capacity when compared with a nonprogressive plyometric training; and although a progressive increase in volume would involve a greater total training volume, the same training efficiency can be achieved. Finally, although plyometric training can induce improvements in explosive and endurance performance in young soccer players, this training strategy should incorporate other explosive exercises (e.g., sprints), intermittent endurance exercises, and technical and tactical-oriented training methods to optimize game performance.

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