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Research article

The Effects of Interset Rest on Adaptation to 7 Weeks of Explosive Training in Young Soccer Players

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Abstract

The aim of the study was to compare the effects of plyometric training using 30, 60, or 120 s of rest between sets on explosive adaptations in young soccer players. Four groups of athletes (age 10.4 ± 2.3 y; soccer experience 3.3 ± 1.5 y) were randomly formed: control (CG; n = 15), plyometric training with 30 s (G30; n = 13), 60 s (G60; n = 14), and 120 s (G120; n = 12) of rest between training sets. Before and after intervention players were measured in jump ability, 20-m sprint time, change of direction speed (CODS), and kicking performance. The training program was applied during 7 weeks, 2 sessions per week, for a total of 840 jumps. After intervention the G30, G60 and G120 groups showed a significant (p = 0.0001 – 0.04) and small to moderate effect size (ES) improvement in the countermovement jump (ES = 0.49; 0.58; 0.55), 20 cm drop jump reactive strength index (ES = 0.81; 0.89; 0.86), CODS (ES = -1.03; -0.87; -1.04), and kicking performance (ES = 0.39; 0.49; 0.43), with no differences between treatments. The study shows that 30, 60, and 120 s of rest between sets ensure similar significant and small to moderate ES improvement in jump, CODS, and kicking performance during high-intensity short-term explosive training in young male soccer players.

Key words: Biological age, explosive strength, team sports, childhood, strength training.

Introduction

A high aerobic capacity is important for success during a 90-minute soccer game (Stolen et al., 2005). However, the ability to produce explosive single-bout effort (i.e. sprinting, jumping, changing direction) is as important as aerobic capacity for success in soccer (Faude et al., 2012; Stolen et al., 2005). Although some evidence show no difference in explosive strength (i.e. jump) between elite and recreational youth soccer players (Chrisman et al., 2012), most studies show that players selected in National teams vs. their non-selected counterparts (Buchheit et al., 2013), and future international and professional players vs. future amateur players (le Gall et al., 2010) had superior explosive characteristics (i.e. speed, power) at youth level. In an attempt to improve these characteristics, and hence the performance and future competitive level of athletes, plyometric training (PT) have been commonly used in young soccer players (Diallo et al., 2001; Meylan and Malatesta, 2009; Michailidis et al., 2013; Thomas et al., 2009), with the advantage of being easy to integrate in soccer practice (space, time, equipment), and replicating the neuromuscular stimulus encountered in explosive soccer activities such as jumping and sprinting (Gehri et al., 1998). Therefore, PT may be advocated as an appropriate approach for enhancing soccer-related performance abilities. However, although the primary governing factors regulating the performance of repeated power-oriented drills are their intensity, duration and recovery duration (ACSM, 2009), the characteristics of between sets recovery of a PT that generates optimal gains are not clear (Saez de Villarreal et al., 2012), especially in young soccer players.

To the best of the authors' knowledge a limited number of studies have established the optimum PT design (i.e. interset rest intervals) for explosive strength enhancement (de Salles et al., 2009). Rest interval can have a significant acute effect on metabolic, hormonal, cardiovascular, and performance responses to strength exercise (Garcia-Lopez et al., 2007; Kraemer et al., 1987; Kraemer and Ratamess, 2005). Power performance is highly dependent on the phosphagen energy system, which requires 4 min for replenishment after an intense exercise set (Harris et al., 1976). An inadequate rest interval may lead to accumulation of inorganic phosphate (Westerblad et al., 2002) or alterations in the concentration gradients of several ions (i.e. H^+, Na^+, K^+, Ca^{2+} Mg^{2+}, Cl^-) (de Salles et al., 2009). In boys, incomplete recovery between sets can increase blood lactate and acidosis (Ratel et al., 2002b), These alterations may reduce the force or shortening velocity capabilities of skeletal muscle (de Salles et al., 2009; Westerblad et al., 2002). Therefore adequate rest may be vital to ensure the quality of each repetition being performed in exercise sets designed to develop muscle power (ACSM, 2009). For non-athletes, two to five min of rest had been recommended between sets when training for muscle power (ACSM, 2009). However, research to sustain this affirmation is scarce (de

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Salles et al., 2009). In fact, although 40 or 160 s of rest between sets had the same chronic impact on muscular power (Pincivero and Campy, 2004), the short rest induce greater neuromuscular adaptations (Pincivero et al., 2004). Also, compared to 60 s of rest between sets, a 10 s recovery period was more effective to induce chronic improvements in endurance sprint performance after 8 weeks of training (Saraslanidis et al., 2011).

It has stated that for short duration (i.e. < 6 s) all-out efforts, a rest interval of ten-fold the exercise time allow adequate recovery between efforts (Balsom et al., 1992a; 1992b). This was partially corroborated in adult soccer players, where a sprint-to-rest ratio of 1:10 allow adequate recovery of acute performance during 10 sets of 15-m sprints (i.e. < 3 s per sprint), but not during long duration 50-m sprints (i.e. > 6 s per sprint) (Abt et al., 2011). In young subjects the recovery capacity from high-intensity plyometric exercises has been reported to be better than in adults (Marginson et al., 2005). For example, 15 s of rest between 10 sets of maximal cycling allow for maintenance of 86% of their peak power (Ratel et al., 2004) and with 30 s the peak power show no decline (Ratel et al., 2002a; 2002b). A high level of flexibility, slower muscle fiber-type composition, and a high level of habitual physical activity in young subjects may help explain their higher recovery ability after high-intensity PT (Marginson et al., 2005). Therefore, as the recovery capacity of young athletes is better than in adults, especially from high-intensity exercise, one may hypothesize that brief (i.e. 30 s) interset rest between PT drills could be viewed as an adequate recovery period to induce training adaptations in this population, especially considering that a typical bounce drop jump takes less than 1 s of maximal effort, with a relatively low metabolic demand, which reduce the time needed to recover from the exercise (Balsom et al., 1992a; Chaouachi et al., 2011). Also, although long and short rest intervals may be equally efective, short inter-set rest may best accommodate the logistical constraints of the training sessions. Thus, the aim of the study was to compare the effects of plyometric training using 30, 60, or 120 s of rest between sets on explosive adaptations in young soccer players.

Methods

Subjects and experimental design

Participants with more than 2 years of soccer experience were recruited from an amateur soccer team. Subjects trained 2 sessions per week, in addition to one or two competitive games per week. Athletes also participate in their regular weekly physical education classes. Initially 90 male participants between 8 and 14 years of age fulfilled the inclusion criteria to participate in the study. Participants were randomly assigned to four groups: control group (CG; n = 23), 30s rest interval group (G30; n = 23), 60s rest interval group (G60; n = 22) and 120s rest interval group (G120; n = 22). To be included in the final analyses participants were required to complete >90% of all the training sessions and attend to all measurements sessions. As a result of these requirements 36 participants were removed from the study. Therefore 54 young male soccer players were included for the final analyses. The number of subjects that were included in each group for the final analyses, and their characteristics, are provided in Table 1. None of the participants had any background in regular weight training or competitive sports that involved any of the training methods used in the investigation. To know the soccer-specific weekly training load during the intervention, the session rating of perceived exertion (RPE) was determined by multiply the soccer training duration (minutes) by session RPE as described previously in young soccer players (Impellizzeri et al., 2004). This product represents in a single number the magnitude of training load in arbitrary units (AU). We used the Chilean translation of the 10 points category ratio scale (CR10-scale) modified by Foster et al. (Foster et al., 2001). All groups in the study design had similar soccer-specific weekly training load (Table 1).

Exclusion criteria included participants with 1) potential medical problems or a history of ankle, knee, or back pathology in the 3 months prior to the study, and 2) medical or orthopedic problems that compromised their participation or performance in the study. All participants (and their parents or guardians) were fully informed about the experimental procedures and possible risks and benefits associated with the study. They were then invited to sign an informed consent document before any of the tests were performed. The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Department of Physical Activity Sciences from University of Los Lagos, Osorno, Chile.

Testing procedures

All tests were carried out between 18:00-20:00 h. All participants (and their parents or guardians) were instructed to a) have a good night's sleep (≥9 h) before each testing day, b) have a meal rich in carbohydrates and to be well hydrated before measurements, c) use the same sport shoes during the pre and post intervention testing. All participants were motivated to give their maximum effort during performance measurements. In previous studies

Table 1. Subject characteristics at the start of the 7-week period. Data are means (±SD).

Variable	Control (n=15)	G30 (n=13)	G60 (n=14)	G120 (n=12)
Pubic hair Tanner stage	2.4 (1.0)	2.2 (1.0)	2.3 (1.1)	2.3 (1.2)
Genital Tanner stage	2.2 (0.6)	2.4 (0.8)	2.2 (0.6)	2.3 (0.9)
Age (y)	10.1 (2.0)	10.4 (2.0)	10.4 (2.3)	10.3 (2.3)
Height (m)	1.43 (.10)	1.41 (.10)	1.41 (.10)	1.42 (.10)
Body mass (kg)	39.0 (9.3)	37.0 (7.0)	37.2 (6.1)	38.0 (10.0)
Soccer experience (y)	3.4 (1.6)	3.1 (1.9)	3.6 (1.5)	3.0 (1.3)
Session rating of perceived exertion (AU)	369 (180)	328 (201)	343 (166)	378 (159)

G30, G60, and G120: 30 s, 60 s, and 120 s rest interval groups, respectively.

from our laboratory (Ramírez-Campillo et al., 2013; Ramírez-Campillo et al., 2014a; Ramírez-Campillo et al., 2014b) we obtained high intraclass correlation coefficients for the different performance measurements, varying betweens 0.81 to 0.98.

For performance measurements, participants were carefully familiarized with the test procedures during two practice sessions per week during two weeks, performing 20 min of technique training for the testing exercises to be used during measurement. The participants also completed several explosive type actions during these four sessions to become familiar with the exercises used during training. Participants did not report subjective feelings of muscle damage after the familiarization sessions. Considering that the ability to produce explosive single-bout effort such as sprinting, jumping, kicking, or changing direction is as important as aerobic power for success in soccer (Faude et al., 2012; Stolen et al., 2005), the following performance tests were applied in this respective order: countermovement jump (CMJ) for maximal vertical distance (cm); 20 (RSI20) and 40 (RSI40) cm drop jump reactive strength index (mm/ms); maximal kicking distance (m); 20-m sprint time (s); L-run CODS (s). Ten minutes of standard warm-up were executed before each testing day.

Anthropometrics

Height was measured using a wall-mounted stadiometer (Butterfly, Shanghai, China) recorded to the nearest 0.5 cm, body mass was measured to the nearest 0.1 kg using a digital scale (BC-554 Ironman Body Composition Monitor, Tanita, Illinois, USA) and body mass index (BMI) was calculated ($kg \cdot m^{-2}$). Maturity was determined by self-assessment of Tanner stage (Weeks and Beck, 2010). The validity of this method for research had previously been reported (Duke et al., 1980). Briefly, subjects were asked to self-determine Tanner stage using standard diagrams of pubic hair growth and penis/scrotum development (Tanner, 1962). Privacy was maintained from other subjects and investigators by providing booths for completing forms and placing them in sealed, coded envelopes for later analysis.

Jumps

Testing included the execution of maximal CMJ, RSI20, and RSI40, in that respective order. All jumps were performed on a mobile contact mat (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 during the RSI20 and RSI40 after dropping down from a 20 and 40 cm drop box. The RSI20 and RSI40 were calculated as previously reported (Young et al., 2002). Three trials were completed for each type of jump, with at least 1 min of rest between them, and the best performance trial was used for the subsequent statistical analysis.

Kicking distance

After a standard warm-up, each player kicked a new size five soccer ball (Nike Seitiro, FIFA certified) (FIFA, 2012) for maximal distance on a soccer field, according to previous indications (Ball, 2009). Basically, two markers were placed on the ground side by side to define the kick line. Participants performed a maximal instep kick with their dominant leg after a run up of two strides. A 75 m metric tape was placed between the kicking line and across the soccer field. An assessor was placed near the region where the ball land after the kick to mark the point of contact and to measure the distance kicked. The distance was measured to the nearest 0.2 m. All measurements were completed with a wind velocity <20 km/h (Chilean Meteorological Service, Santiago, Chile). Five trials were completed, with at least 1 min of rest between them, and the best performance trial was used for the subsequent statistical analysis.

Sprint

The sprint time was measured to the nearest 0.01 s using single beam infrared reds photoelectric cells (Globus Italia, Codogne, Italy). 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 photoelectectric signal was positioned at 20 m and set approximately 0.7 m above the floor (i.e. hip level) to capture the trunk movement rather than a false trigger from a limb. Three trials were completed, with at least 1 min of rest between them, and the best performance trial was used for the subsequent statistical analysis.

Change of direction speed (CODS)

CODS times were recorded from the L-run test, were athletes completed a distance of 20-m, following previously described instructions (Gabbett et al., 2008). The timing system and procedures were the same as the 20-m sprint. Three trials were completed, with at least 1 min of rest between them, and the best performance trial was used for the subsequent statistical analysis.

Plyometric training program

The intervention took place during the competitive period. During the intervention participants kept their usual soccer training (i.e. two weekly training sessions of 90 min, consisting in 30 min of technical-tactical exercises, 30 min of small-sided games, and 30 min of simulated competitive games) and competition schedule. The PT was completed two days per week for the PT groups, with at least 48 hours of rest between sessions as previously recommended (Wathen, 1993, Faigenbaum, 2006), and just after the warm-up to ensure that the players were in a rested state and gain optimal benefits from the specific program, according to the priority training principle. The same warm up was completed by the CG and plyometrically trained groups, consisting of 5 min of submaximal running and several displacements, 20 submaximal vertical jumps, and 10 submaximal longitudinal jumps). While the CG keeps their regular soccer drills, the G30, G60, and G120 groups replaced the technical-tactical drills by plyometric exercises. After the plyometric drills, participants from the G30, G60, G120, and CG completed the same soccer training sessions.

Athletes complete a total of 60 bounce drop jumps per session (2 sets of 10 jumps from 20, 40, and 60 cm boxes). During jumps, athletes were instructed to place their hands on their hips and step off the box with the leading leg straight to avoid any initial upward propulsion ensuring a drop height of 20, 40, and 60 cm. They were instructed to jump for maximal height and minimal contact time, to maximize jump reactive strength. The subjects were again instructed to leave the floor (i.e. soccer field) with knees and ankles fully extended and to land in a similarly extended position. Basic jumping techniques were stressed during training: (a) correct posture (i.e., spine erect and shoulders back) and body alignment (e.g., chest over knees) throughout the jump; (b) jumping straight up with no excessive side-to-side or forward-backward movement; (c) instant recoil for the concentric part of the jump. Phrases such as “on your toes,” “straight as a stick,” “light as a feather,” and “recoil like a spring” were used as verbal and visualization cues during the jumps. The instruction given to the subjects were “jump as high as you can, with minimum ground contact time”.

As players did not have any history of formal plyometrics, all exercises were supervised and particular attention was paid to demonstration and execution, giving maximal motivation to athletes during each jump. Although we did not increase the training volume during the 7-weeks period, as we used high-intensity plyometric exercises performed with maximal effort, an effective and safe training stimulus was applied during each plyometric session, as previously demonstrated in similar plyometric training interventions in young boys (Ramírez-Campillo et al., 2013) and soccer players (Ramírez-Campillo et al., 2014b; Thomas et al., 2009). The exercise were completed 2 times per week, for a total of 7 weeks. This time frame and/or number of sessions are higher (Tonnessen et al., 2011, Maio Alves et al., 2010, Thomas et al., 2009) or very similar (Buchheit et al., 2010, Meylan and Malatesta, 2009, Chelly et al., 2009) to those previously reported to induce significant explosive adaptations in young soccer players and young physical active subjects (Ramírez-Campillo et al., 2013; Ramírez-Campillo et al., 2014a; Ramírez-Campillo et al., 2014b). A detailed description of the 7-week training program is depicted in Table 2.

The different rest periods between sets of plyometric drills for the three experimental groups were choose based on previous recommendations (ACSM, 2009; Abt et al., 2011; Read and Cisar, 2001), corresponding to 30 s, 60 s, and 120 s of rest between sets for the G30, G60 and G120 groups, respectively. The rest between repetitions was of 15 s (Read and Cisar, 2001). A low intensity active interset and interrepetition rest was used to favor recovery (Bogdanis et al., 1996). Each plyometric training session last approximately 25, 20, and 15 min for the G120, G60, and G30 groups, respectively.

To assure the safety of plyometric sessions, subjects were asked to classify their actual pain level though a visual analog scale (VAS). A continuous line of 10 cm was presented to athletes with the Spanish words for “no pain” in the cm 0 and with the Spanish word for “maximal pain” in the cm 10. Subjects were asked to classify their pain while they were sitting. Similar protocols had been applied previously (Grant et al., 1999; Itoh et al., 2008; Marginson et al., 2005). We measure the intensity of muscle pain from the lower extremities before the first session of plyometric training, immediately after, 24h, 48h, 72h, and 96h after the first session. Also, during the last week of training we repeated the protocol.

Statistical analysis

All values were reported as mean ± SD. Relative changes (%) in performance and effect size (ES) are expressed with a 90% Confidence Limits (CL). Normality and homoscedasticity assumptions for all data before and after intervention were checked respectively with Kolmogorov-Smirnov and Levene tests. To determine the effect of intervention on performance adaptations, a 2-way variance analysis with repeated measurements (4 groups × 2 times) was applied. When a significant F value was achieved across time or between groups, Tukey post hoc procedures were performed to locate the pairwise differences between the means. The α level was set at $p < 0.05$ for statistical significance. Statistical analyses were performed by STATISTICA software (version 8.0; StatSoft, Inc., Tulsa, OK, USA). In addition to this null hypothesis testing, data was also assessed for clinical significance using an approach based on the magnitudes of change. Threshold values for assessing magnitudes of ES (changes as a fraction or multiple of baseline standard deviation) were 0.20, 0.60, 1.2 and 2.0 for small, moderate, large and very large respectively (Hopkins et al., 2009).

Results

Despite not pair-matching individuals based on an independent variable, there were no significant differences (p = 0.1 - 0.9) between groups’ descriptive data (Table 1).

Before training no significant differences were observed between groups in CMJ (P = 0.6 – 0.9), RSI20 (P = 0.1 – 0.9), RSI40 (P = 0.1 – 0.9), 20-m sprint time (P = 0.1 – 0.9), CODS time (P = 0.2 – 0.9), or kicking test (P = 0.1 – 0.8) (Table 3).

No significant changes in the CG were observed, except for a significant (p = 0.03) moderate increase in 20-m sprint test time (i.e. reduced performance) (Table 3). The 2-way variance analysis with repeated measurements (4 groups × 2 times) showed a similar significant

Table 2. Seven weeks plyometric training program

Exercises*	Set × Repetitions						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Bounce drop jump from 20 cm boxes	2 × 10	2 × 10	2 × 10	2 × 10	2 × 10	2 × 10	2 × 10
Bounce drop jump from 40 cm boxes	2 × 10	2 × 10	2 × 10	2 × 10	2 × 10	2 × 10	2 × 10
Bounce drop jump from 60 cm boxes	2 × 10	2 × 10	2 × 10	2 × 10	2 × 10	2 × 10	2 × 10

*: denotes that the order of exercises execution was randomized each training session.

Table 3. Anthropometrics and performance variables before and after 7 weeks of plyometric training in young soccer players.

Variable	Control (n=14)	G30 (n=13)	G60 (n=13)	G120 (n=11)
Countermovement jump (cm)				
Before	22.1 (4.9)	22.2 (4.1)	21.9 (2.1)	21.7 (4.4)
After	21.9 (4.7)	24.0 (5.6)	23.9 (3.1)	23.5 (5.4)
Training effect (%)	-.9 (-1.9, +1.9)	+8.1 (+1.3, +16.8)	+9.1 (+1.9, +21.9)	+8.5 (+1.8, +18.6)
Effect size	-.1 (-.34, +.24)	+.49 (+.24, +.79)*	+.58 (+.29, +.88)*	+.55 (+.27, +.82)*
P value Pre-Post	.4	.04	.02	.03
20 cm drop jump reactive strength index (mm/ms)				
Before	.78 (.2)	.77 (.21)	.75 (0.2)	.75 (.3)
After	.85 (.2)	1.03 (.2)	1.01 (0.2)	1.02 (.3)
Training effect (%)	+8.1 (-14.4, +24.7)	+33.2 (+14.4, +76.1)	+35.3 (+15.9, +74.3)	+36.6 (+14.3, +81.1)
Effect size	+.27 (-.31, +.59)*	+.81 (+.38, +1.27)**	+.89 (+.48, +1.22)**	+.86 (+.39, +1.33)**
P value Pre-Post	.09	.0004	.0004	.0002
40 cm drop jump reactive strength index (mm/ms)				
Before	.75 (.3)	.74 (.3)	.74 (.2)	.73 (.3)
After	.84 (.2)	1.03 (.3)	1.02 (.3)	1.06 (.3)
Training effect (%)	+12.9 (-9.0, +28.7)	+39.0 (+8.9, +66.4)	+38.9 (+9.0, +65.3)	+46.4 (+15.4, +79.7)
Effect size	+.48 (-.36, +.72)*	+.86 (+.39, +1.6)**	+.88 (+.29, +1.41)**	+.98 (+.44, +1.51)**
P value Pre-Post	.1	.0001	.0003	.0001
20m (s)				
Before	4.3 (.3)	4.4 (.5)	4.3 (.2)	4.3 (.4)
After	4.5 (.4)	4.4 (.3)	4.3 (.3)	4.4 (.4)
Training effect (%)	+6.6 (+2.9, +9.6)	-1.8 (-3.9, +0.7)	+.3 (-1.2, +1.9)	+.4 (-3.0, +3.3)
Effect size	+.65 (+.44, +1.32)**	-.3 (-.68, +0.28)*	+.09 (-.19, +0.33)	+.13 (-.33, +.60)
P value Pre-Post	.03	.09	.8	.2
Change of direction speed (s)				
Before	7.4 (.5)	7.4 (.6)	7.4 (.5)	7.4 (.7)
After	7.3 (.4)	7.0 (.4)	7.1 (.5)	7.0 (.6)
Training effect (%)	-2.6 (-5.0, +2.5)	-6.5 (-10.9, -2.3)	-5.2 (-9.9, -1.1)	-6.9 (-12.1, -2.4)
Effect size	-.4 (-.77, +0.45)*	-1.03 (-1.42, -.4)**	-.87 (-1.5, -.29)**	-1.04 (-1.6, -.49)**
P value Pre-Post	.1	.03	.03	.02
Maximal kicking distance (m)				
Before	20.0 (5.3)	19.7 (7.4)	18.9 (5.0)	19.3 (7.0)
After	20.1 (5.8)	22.0 (8.9)	21.8 (4.1)	21.6 (7.0)
Training effect (%)	+1.1 (-2.4, +6.6)	+11.3 (+2.3, +23.4)	+15.0 (+2.7, +29.9)	+12.6 (+4.0, +24.1)
Effect size	+.01 (-.09, +.21)	+.39 (-.03, +.68)*	+.49 (-.01, +.88)*	+.43 (+.08, +.77)*
P value Pre-Post	.8	.03	.02	.03

Before and after values are means (± SD). Training effect and effect size values are mean (90% confidence limits). G30, G60, and G120: 30 s, 60 s, and 120 s rest interval groups, respectively; * small standardized effect; ** moderate standardized effect. P value Pre-Post: P value of pre to post training change.

small-moderate increase for G30, G60 and G120 groups in CMJ (p = 0.04; 0.02; 0.03, respectively), RSI20 (p < 0.001), RSI40 (p < 0.001), CODS (p = 0.03; 0.03; 0.02, respectively), and kicking performance (p = 0.03; 0.02; 0.03, respectively) after training (Table 3). None of the plyometrically trained groups achieve a statistically significant change in 20-m sprint performance (Table 3).

Subjects report relatively low pain level (between 0-3) during plyometric intervention, with no significant differences among groups. As a whole, plyometrically trained athletes show a mean pain level of 0, 1.3, 0.8, 0.3, 0.1 and 0 at times points before, immediately after, 24h, 48h, 72h, and 96h after the first plyometric training session, respectively. Muscle pain was elevated above baseline immediately after (p = 0.01), and at 24 h post exercise (p = 0.03). Compared with the first week, during the last week of plyometric training the pain level did not show a significant change at the different time points, except at 24h after exercise, were a significant reduction was observed (0.8 ± 0.7 pre; 0.3 ± 0.3 post; p = 0.04).

Discussion

The current study suggests that 7 weeks of PT, with either 30, 60 or 120 s of rest between sets of low-volume and high-intensity plyometric drills, induced significant and small to moderate similar improvements in CMJ, RSI20, RSI40, CODS time, and kicking test performances in young male soccer players. Also, these results show that the combination of soccer drills and specific explosive strength training with no additional training time in-season is a meaningful stimulus to enhance explosive strength adaptations in young male soccer payers.

Although 2 to 5 min of rest has been recommended to ensure the quality of each repetition being performed in exercise sets designed to develop muscle power (ACSM, 2009), and although several power-oriented studies indicate superior acute effects with long vs. short rest between training sets (Abdessemed et al., 1999; de Salles et al., 2009;, Pincivero et al., 1998; 1999), our results show that 30, 60, and 120 s of rest between sets of high-intensity plyometric jumps ensure significant small-moderate similar adaptations during 7 weeks of training in young male soccer players. Compared to our intervention, previous studies that applied plyometric (i.e. jumps) training to young soccer players had used a volume per session 200% higher (Michailidis et al., 2013), 320% higher (Meylan and Malatesta, 2009), or even 500% higher (Diallo et al., 2001). Therefore, it may be argued that during our intervention a relatively low training load was applied; therefore a relatively short period of recovery between training sets to achieve performance adaptations was sufficient. However, during training players completed 60 jumps each session, including bounce drop jumps from 20, 40, and 60 cm, which can be considered high-intensity exercises (aside from the maximal voluntary intensity required to complete all jumps). This load is similar to that reported in previously effective training intervention with young soccer players (Ramírez-Campillo et al., 2014b; Thomas et al., 2009) and adolescents (Ramírez-Campillo et al., 2013). Also, 50 jumps per session (or more) seem to maximize the probability of obtaining significantly greater improvements in explosive performance (de Villarreal et al., 2009). Accordingly, it is unlikely that our results can be explained by a “low” training load. Therefore, several possible mechanisms can be postulated to understand how a relatively short rest period betweens PT sets allow significant explosive performance adaptations in young male soccer players. For example, compared to adults, young subjects posses a smaller muscle mass (Ratel et al., 2006), reduced proportion of fast twitch fibers (Lexell et al., 1992), and higher muscle oxidative activity (Ratel et al., 2006), which reduce their possibilities to generate power during high-intensity exercise and to accumulate muscle by-products (Ratel et al., 2006), hence helping to reduce the rest time needed between sets of high-intensity exercise. In addition, a faster phosphocreatine resynthesis, faster clearance of by products (e.g. lactate, H+ ions), faster regulation of acid-base balance, faster reconstitution of maximal power output, among others factors (Ratel et al., 2006) may also help explain a better ability of young athletes to recover from high-intensity exercise. Interestingly, it has been suggested that muscle function (i.e. jump ability, sprint performance) is probably the best indicator of muscle recovery after intense exercise, especially in athletes (Eston et al., 2003); hence, future studies in young soccer players may consider the evaluation of muscle function performance after plyometric drills with different rest times between sets to better understand the recuperation process in this population segment.

The G30, G60, and G120 groups significantly increased jumping performance (CMJ, RSI20, and RSI40), with no difference between groups. The magnitude of change in performance was similar to that previously reported in young soccer players submitted to power-oriented interventions (Buchheit et al., 2010; Meylan and Malatesta, 2009; Rubley et al., 2011), of similar duration and/or number of sessions as in the present study (Buchheit et al., 2010; Meylan and Malatesta, 2009; Rubley et al., 2011). Various neuromuscular adaptations could help explain the increased performance, such as increased neural drive to the agonist muscles, improved intermuscular coordination, and/or changes in the muscle-tendon mechanical-stiffness characteristics (Markovic and Mikulic, 2010); but because no physiological measurements were made, only speculations are possible.

The lack of improvement in 20-m sprint time after PT demonstrated that other training stimulus may be necessary to enhance sprinting performance. A lack of change in sprint time after drop jump-based PT has been previously reported in 17 years old soccer players (Ramírez-Campillo et al., 2014b; Thomas et al., 2009). As the training stimulus was only vertical in nature, this may had reduced the chances to gain adaptations considering the importance of horizontal force production and application in sprint performance (Morin et al., 2012) and the principle of training specificity (Randell et al., 2010; Saez de Villarreal et al., 2012). Despite the lack of 20-m sprint improvement, all plyometrically trained groups exhibit a significant and similar reduction to complete the CODS test. The current results are similar to those previously reported (Ramírez-Campillo et al., 2014b; Thomas et al., 2009), where high-intensity bounce drop jumps had a small positive effect on agility performance in young soccer players but only a trivial effect on 15-m sprint time. An increase in power development (Negrete and Brophy, 2000) reactive strength (Young et al., 2002) and eccentric strength (Sheppard and Young, 2006), may have contributed to the improvement in CODS performance, while acceleration may be more dependent in a slower stretch-shorten cycle and rate of power production similar to the CMJ (Cronin and Hansen, 2005), which was not targeted in the current training program. Contrary to the positive explosive adaptations observed in the plyometrically trained groups, the CG exhibited a significant increase in their 20-m sprint test time. These observations reinforce the value of an independent power training program to enhance explosive actions of young soccer players during their in season training.

As a novelty, our results show that kicking performance can be similarly enhanced during the competitive period with a PT program implemented as a substitute for some soccer drills, either using 30, 60 or 120 s of rest between sets. An improvement in kicking performance after PT has been previously reported in pre-adolescent (Michailidis et al., 2013) and adolescent soccer players (Rubley et al., 2011). As players had more than a 2-year background of systematic soccer training and competition experience, and given the lack of improvement in the CG, the increased performance is unlikely to be related to the technical training over the short-term period of 7-week. It had been suggested that an increased strength and power of legs’ extensor muscles due to PT may increase kicking performance, and these changes could be attributed solely to neuromuscular adaptations (Michailidis et al., 2013); and these adaptations may had an effect on biomechanical factors related to kicking performance, such as maximum linear velocity of the toe, ankle, knee and hip at ball contact (Lees et al., 2010), resultant in higher ball kicking velocity and hence kicking performance.

From a practical point of view, it must be considered that the PT applied induced general (i.e. jumping, CODS) and soccer-specific (i.e. kicking) explosive adaptations, which may have high transference into game-play performance. Thus, a twice weekly short-term high-intensity PT program, implemented as a substitute for some soccer drills within regular in-season soccer practice, can enhance explosive performance in young soccer players compared with soccer training alone, and these improvements can be achieved using 30, 60 or 120 s of rest between plyometric sets. Considering that a shorter rest period will reduce the total training time dedicated to plyometric drills, this will give the chance to redistribute a greater amount of time to exercises needed to maximize performance in young soccer players. Also, it must be considered that although the results of the study demonstrated an increase in explosive ability after PT, it is recommend that this training method should be adequately incorporated in a comprehensive training program that develops the sport-specific abilities that are critical to achieve adequate performance, especially at young ages (early engagement hypothesis) (Ford et al., 2012), and with an adequate aerobic conditioning program to optimize training adaptations.

Although concern has been expressed by some researchers with regard to the injury risk during plyometric training, to the best of the author's knowledge, when adequate controlled plyometric training intervention had been applied, no important injuries had been reported. In fact, plyometric training had been advocated as a preventive injury strategy (Ford et al., 2005; Lephart et al., 2005) and even as a rehabilitation tool (Heiderscheit et al., 1996). It is important to notice that in the present investigation no injuries were reported. More so, our results show that athletes report relatively little subjective muscle pain (between 0 and 3 in a 10 point VAS) from their lower extremities muscles immediately after, 24h, 48h, 72h, and 96h after the first session of the first and last week of training. In fact, the muscle pain was significant different from basal only immediately, and 24h after the first session of plyometric training. Also, we observe a significant reduction in pain 24h after plyometric drills in the last week of training. In this way, after 7 weeks of plyometric training, athletes did not show muscle pain in the days after their training sessions. Interestingly, the interset rest period used during training did not affect these outcomes. This result seems to be common in young subjects (Eston et al., 2003; Marginson and Eston, 2001; Marginson et al., 2005), suggesting a muscle adaptive mechanism that protects young athletes from the possible muscle damage induced by repetitive high-intensity plyometric drills. As we measure muscle pain only during the first and last week of training, we do not know if our results can be present earlier during training, however, previous reports suggest that 2 weeks are enough to induce a protective mechanism (Marginson et al., 2005).

Conclusion

In conclusion, G30, G60 and G120 groups achieved similar improvements in explosive performance after training. Therefore, when PT sets are prescribed, 30, 60 or 120 s of rest between these is adequate to induce significant explosive adaptations in young male soccer players.

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Key points

- Replacing some soccer drills by low volume high-intensity plyometric training would be beneficial in jumping, change of direction speed, and kicking ability in young soccer players.
- A rest period of 30, 60 or 120 seconds between low-volume high-intensity plyometric sets would induce significant and similar explosive adaptations during a short-term training period in young soccer players.
- Data from this research can be helpful for soccer trainers in choosing efficient drills and characteristics of between sets recovery programs to enhance performances in young male soccer players.

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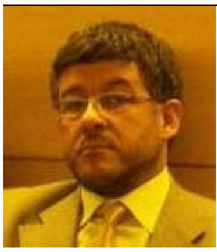

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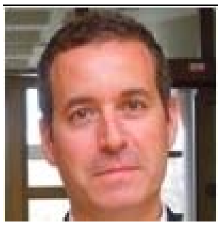

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