# SEQUENCING EFFECTS OF PLYOMETRIC TRAINING APPLIED BEFORE OR AFTER REGULAR SOCCER TRAINING ON MEASURES OF PHYSICAL FITNESS IN YOUNG PLAYERS

**This is an Accepted Manuscript of an article published in the Journal of Strength and Conditioning Research and can be accessed at http://dx.doi.org/ 10.1519/JSC.0000000000002525**

**Ramirez-Campillo, Rodrigo; Alvarez, Cristian; Gentil, Paulo; Loturco, Irineu; Sanchez-Sanchez, Javier; Izquierdo, Mikel; Moran, Jason; Nakamura, Fabio Y.; Chaabene, Helmi; Granacher, Urs. Sequencing Effects of Plyometric Training Applied Before or After Regular Soccer Training on Measures of Physical Fitness in Young Players, Journal of Strength and Conditioning Research: July 2020 - Volume 34 - Issue 7 - p 1959-1966 doi: 10.1519/JSC.0000000000002525**

**ABSTRACT**

To compare the effects of short-term (i.e., 7 week) plyometric training applied before (PJT-B) or after (PJT-A) soccer practice on components of physical fitness in young soccer players, a single-blind randomized controlled trial was conducted. Post-pubertal boys aged 17.0±0.5 years were allocated to three groups: PJT-B (n=12), PJT-A (n=14), and control (CON; n=12). The outcome measures included tests to evaluate 20-m speed, standing long jump [SLJ], squat jump [SJ], countermovement jump [CMJ], and drop jump [DJ], 20-m multistage shuttle running speed [MSSRT], and Illinois change of direction speed [ICODT]. While the CON performed soccer-specific training, the PJT-A and PJT-B groups conducted the same soccer-specific sessions but replaced ~11% of their time with plyometric training. The PJT-B group performed plyometric exercises after a warm-up program, and the PJT-A group conducted plyometric exercises ~10 minutes after the completion of soccer training. Analyses of variance (ANOVAs) were used to detect differences between groups in all variables for pre- and post-training tests. Main effects of time (all $p<.01$; $d=0.19$-$0.79$) and group x time interactions (all $p<.05$; $d=0.17$-$0.76$) were observed for all examined variables. Post hoc analyses revealed significant increases in the PJT-B group (SLJ: 9.4%, d=1.7; CMJ: 11.2%, d=0.75; 20-m MSSRT: 9.0%, d=0.77) and the PJT-A group (SLJ: 3.1%, d=0.7; CMJ: 4.9%, d=0.27; 20-m MSSRT: 9.0%, d=0.76). Post hoc analyses also revealed significant increases in the PJT-B group (20-m speed: -7.4%, d=0.75; 20-cm DJ reactive strength index: 19.1%, d=1.4; SJ: 6.3%, d=0.44; ICODT results: -4.2%, d=1.1). In general, our study revealed that plyometric training is effective in improving measures of physical fitness in young male soccer players when combined with regular soccer training. More specifically, larger training induced effects on physical fitness were registered if plyometric training was conducted prior to soccer specific training.

**KEY WORDS**: football; physical maturity; training optimization; stretch-shortening cycle.

## INTRODUCTION

Lower-limb muscle power is related to team positioning in competitive soccer leagues (3). In addition, sprinting is a common action related to the creation of goal scoring opportunities, (13) while high endurance capabilities (15) are essential to maintain repetitive high-intensity actions during a match (8). Therefore, these physical qualities should be developed to help players cope with the increased competitive demands of modern soccer (40). In this regard, it has been well established that plyometric jump training (PJT) is an effective stimulus to develop young athletes' stretch-shortening cycle (SSC) function (24, 29). The inclusion of PJT into regular soccer training of young players has been shown to optimize physical fitness, including actions and qualities such as jumping, sprinting, kicking, change-of-direction speed (COD), endurance, and repeated sprint ability (RSA) (30, 41). PJT takes advantage of the muscle SSC (21), which results in more efficient movements and optimizes the rate of force development, the relative force per-motor unit recruited and, thus, muscle power. It allows athletes to outperform their opponents for instance by jumping higher (29). In this context, PJT might be particularly well-suited for the inclusion in a well-designed training program for young soccer players.

To implement PJT programs optimally, several factors should be taken into account, such as the type of jump drills (32, 33), their combined effects (32, 33), the training surface (31), the type of overload (41) and volume (31), and the intensity of the jumps (2). Previous recommendations have also suggested that PJT should be conducted prior to regular (technical-tactical) training sessions (7, 14) so that PJT drills are not performed in a fatigued state (26), to maximize neuromuscular responses. Based on this premise, PJT has usually been applied at the beginning of training sessions (34, 37, 42). However, PJT has also been implemented after regular workouts. In one such study (6), female endurance runners improved their running economy and cross-country performance after executing 10 weeks of in-season combined resistance and plyometric training, when the PJT was conducted 30 min after the endurance training sessions. However, according to the same study (6), males responded differently to the intervention, showing potentially harmful effects on their competitive performance. Remarkably, previous studies suggested that children and adolescents recover faster than adults from neuromuscular activity (i.e., 80 maximal-intensity plyometric jumps) (20, 39). Therefore, the sequencing effects in which PJT is performed might not be the same in youth as compared to adults. In this sense, female young volleyball players (22) performed water-based plyometric sessions 30 min after preseason volleyball training sessions, and they showed improved vertical jump performance after 6 weeks of training. In young male basketball players (23), six weeks of PJT was performed after regular basketball sessions. Athletes significantly improved their jump performance and rate of force development of the knee extensors after training.

Considering i) that there is controversy regarding the results of studies that examined the effects of PJT applied either before or after regular sport-specific training sessions, ii) that the effectiveness of PJT applied at the beginning (PJT-B) compared to after (PJT-A) regular training sessions is currently unknown among young soccer athletes, and iii) that from a practical and rational point of view, some youth soccer teams schedule strength and conditioning training sessions at the end of their regular soccer practice, the aim of this study was to compare the effects of PJT-B and PJT-A on measures of physical fitness (i.e., sprint time, CoD and jump performance, aerobic endurance) in young soccer players. We hypothesized that both, PJT-B and PJT-A training interventions would enhance young soccer players' physical fitness, and that PJT-B would produce larger performance improvements compared with PJT-A.

## METHODS

### Experimental Approach to the Problem

This single-blind randomized controlled trial was conducted to compare the effects of a 7-week plyometric training program applied before or after soccer practice on components of physical fitness in young soccer players (age range: 15.5 to 17.9 years). To this aim, thirty-eight young soccer players were randomly assigned to PJT-B group (n=12), PJT-A group (n=14) or control group (n=12). The athletes assigned to PJT-B completed plyometric training before regular soccer practices, the players in the PJT-A performed plyometric training after regular soccer practices, whereas players assigned to the control group only completed their habitual soccer training. Athletes were assessed before and after 7 weeks of plyometric training with a fitness test battery composed of the following testing order: standing long jump (SLJ), countermovement jump (CMJ), 20-cm drop jump reactive strength index (DJ), and the squat jump test (SJ) on day one. On the second day, the 20-m sprints, change-of-direction speed tests (Illinois change-of-direction test [ICODT]), and the 20-m multistage shuttle run endurance tests (MSSRTs) were carried out. The intervention was carried out during the in-season period. Participants were accustomed to the testing and training procedures with the help of four familiarization sessions over two weeks to reduce potential learning effects. In addition, the performance tests were regularly used for monitoring training practices.

**Subjects**

Thirty-eight male participants were recruited from a high-level soccer team (i.e., professional Club) competing at national level. In the last national championship, the team finished in fifth place. Upon recruitment, players completed three training sessions, plus a competitive match per week and won 62.5% of their matches during the time in which the study was scheduled. Players had similar competitive schedules and similar involvement in soccer drills, resulting in similar soccer-specific weekly training loads for all the players involved (Table 1). In a single-blinded randomized controlled design, participants were allocated to one of three experimental groups: two training groups and a control group. The training groups conducted a plyometric training program as a substitution for some technical-tactical soccer drills, whereas the control group undertook their regular soccer training program (control condition). Before and after a 7-week training period, all players performed a battery of eight tests related to maximal-intensity exercise and aerobic endurance performance. The randomization sequence was generated electronically (https://www.randomizer.org) and was concealed until interventions were assigned. All included soccer players met the following inclusion criteria: (1) a background of ≥4 years of systematic soccer training and competitive experience, (2) continuous soccer training for the previous 3 months and no musculoskeletal injury, (3) no systematic plyometric training experience in the previous 5 months, (4) the absence of potential medical problems that could compromise participation or performance in the study, and (5) the absence of any lower-extremity surgery in the past 2 years. Initially, 49 participants who fulfilled the inclusion criteria were selected to participate in this study. To be included in the final analyses, participants needed to complete all training sessions and attend all assessment sessions. Because of these strict requirements, 11 participants were excluded from the study. Therefore, 38 soccer players were included in the final analyses and were allocated as follows: PJT-B group (n=12), PJT- A group (n=14), and control (n=12) group. Details of the participants' characteristics according to each group are provided in Table 1. A similar number of goalkeepers (1; 1; 1), defenders (4; 4; 3), midfielders (4; 4; 4) and forwards (3; 5; 4) were present in the PJT-B, PJT-A, and control groups, respectively.

*****Table 1 near here*****

Participants (and their respective parents or guardians) were informed about the experimental procedures, possible risks and benefits associated with participation in this study. They then signed informed assent and consent forms, respectively, before performing any of the fitness tests and training sessions. This study protocol was approved by the ethical review board for use of human participants from the responsible institutional department.

The sample size was determined according to changes in plyometric (i.e., vertical jump) performance in a group of trained, young, male soccer players who underwent a control (Δ=0.5 cm; standard deviation [SD]=1.1) or a short-term plyometric (Δ=2.6 cm; SD=1.6) training program comparable with that applied in this study (32). A total of 8 participants per group was predicted to yield a power of 80% at α=0.05, with a detectable effect size [ES] of 0.2.

**Procedures**

Before and immediately after the intervention period, standardized tests were scheduled ≥72 h after a soccer match or hard physical training session. Tests were completed in the same order, between 15:00 and 20:00 hours at an indoor venue, with the same sports clothes and by the same investigator, who was blinded to the group allocation of the participants. All players (their guardians were also informed) were instructed to (1) get a good night's sleep (≥8 h) before each testing day and (2) to have a rich meal in carbohydrates (examples were provided to parents) and be well hydrated before each assessment. The participants were asked to give their maximum effort during testing, in addition to receiving regular, individual performance feedback. Players were evaluated over two days. On the first day, data on age, stature, body mass, physical maturity, weekly time spent in physical education classes, weekly hours spent on other sports or on soccer with other clubs, and years of soccer experience were collected. In addition, SLJ, CMJ, DJ, and SJ test performances were recorded. On the second day, the 20-m sprints, ICODT, and the MSSRTs were carried out. The highest score from three attempts (37) was recorded for all performance tests, except for the single MSSRT. A rest interval of at least two minutes was allowed between each physical fitness trial. While waiting, participants performed low-intensity activities (e.g., walking, ball passing) to maintain their readiness for the next test. Ten minutes of general (i.e., submaximal running with changes of direction) and specific (1) (20 vertical and 10 horizontal submaximal jumps) exercises were performed before each testing session as a warm-up. In addition, participants performed a test-specific warm-up that comprised two practice jumps or runs, except for before the MSSRT, where players completed the first minute of the test as a warm-up.

*Anthropometry*. Comprised measures of stature, on a stadiometer (Bodymeter 206, SECA, Germany to 0.1 cm), and body mass, on an electrical scale (InBody120, model BPM040S12FXX, Biospace, Inc., Seoul, Korea, to 0.1 kg). Physical maturity was determined by self-assessment, as previously described (30).

*Jumping performance.* Test protocols were based on previous recommendations (31, 33, 36). Briefly, for the vertical jumps (i.e., SJ, CMJ, DJ), players executed maximal-effort jumps on a mobile contact mat (Ergojump; Globus, Codogne, Italy) with arms akimbo. Take-off and landing were standardized to the same spot, and players were required to perform full knee and ankle extension during the flight phase. The participants were instructed to maximize jump height. In addition, for the DJ tests, players were instructed to minimize ground contact time after dropping down from a 20-cm drop box. The reactive strength index was calculated from jump height (expressed as flight time - ms) divided by contact time (ms) (28). The SLJ test was performed using a 5-m fiberglass metric tape laid on a wooden floor. Subjects were instructed to jump after positioning (behind the starting line) their feet shoulder width apart and performing a fast, downward movement (approximately 120° knee angle) followed by a maximal effort horizontal jump. The distance was measured from the starting line to the point where the heels of the subjects made contact with the ground after landing.

*Linear and CoD sprinting performance.* Sprint time was assessed to the nearest 0.01 s using timing gates (Brower Timing System, Salt Lake City, UT). Participants used a standing start, with the toe of the preferred foot forward and just behind the starting line. Sprints started when the athlete voluntarily initiated the test, which triggered timing. The timing gates were positioned at the beginning (0.3 m in front of the athlete) and at 20 m and were set ~0.7 m above the floor (i.e., hip level). To increase the accuracy and reliability of measurement two single-beam timing gates were mounted one over the other. This system enables capturing trunk movement rather than a false trigger from a limb. For the ICODT, the timing system and procedures were the same as for the 20-m sprint except that players had to run in a straight line with maximal effort, as well as perform several changes of directions (35).

*Endurance performance*. For the MSSRT and as previously described (36), players ran back and forth between two lines, spaced 20 m apart, in time with the "beep" sounds from an electronic audio recording. Each successful run of the 20-m distance was a completion of a shuttle. The beep sounded at a progressively increasing pace at each minute of the test, and the player had to increase his speed accordingly. The player was warned if he did not reach the end line in time once. The test was terminated when the examinee: (1) could not follow the set pace of the beeps for two successive shuttles or (2) stopped voluntarily. The scores were expressed as the last minute that the player completed.

Soccer training load was assessed to ensure that all players received the same soccer-training stimulus during the intervention. Session rating of perceived exertion was determined as previously described (30). Briefly, each player's session rating of perceived exertion was collected approximately 30 min after each soccer training session and match to ensure that the perceived effort reflected the entire session rather than the most recent exercise intensity. Total training load was calculated as the rating of perceived exertion × training session duration (i.e., minutes). Athletes regularly used the scale during training, so that they were familiarized with it.

**Training Program**

The plyometric training was completed during the mid-portion of the competitive season. The control group did not perform the plyometric training but performed their usual soccer training (i.e., mainly technical- tactical drills and small-sided and simulated games). The design of the plyometric intervention was based on the players' previous training records and research results (16, 32, 36). Plyometric training was not added to the regular soccer training of players, instead, some low-intensity technical-tactical soccer drills were replaced with plyometric drills that were performed within their usual 120 min training period, twice per week, during the 7-week intervention period. Plyometric jump training replacement activity accounted for ~11% of the total soccer-training load (irrespective of competitive and friendly matches).

Each plyometric session included 13 jump exercises (i.e., cyclic and acyclic horizontal and vertical jumps, with left, right, and both legs) performed with the involvement of stretch-shortening cycle muscle activity, with arm swinging freely. For the acyclic drills, participants were instructed during each jump to achieve maximal vertical height or horizontal distance (according to the type of exercise), while during cyclic jumps, participants were motivated to maximize the ratio between vertical height/horizontal distance and ground contact time. The reliability of jump heights for selected drills was verified in a randomly assigned subsample of participants (two from each group) during two randomly assigned training sessions, by assessing jumps contact times, height, and distance, using the same procedures as described above. Before starting the training period, players were instructed on how to perform all the exercises, and an emphasis was put on the technique of jumps execution before increasing overload during the intervention. The order of tasks was randomized in each week to add variation during training. The drills, sets, repetitions, and progressions per week are detailed in table 2. In this way, players progressed from 104 jumps per leg during each session in the 1st week to 204 jumps per leg during each session in the 6th week of plyometric training, with a taper during the 7th week (i.e., 48 jumps per leg/session). An investigator to participant ratio of 1:2 was achieved in all training sessions and particular attention was paid to technical competency. All plyometric sessions lasted approximately ~20 minutes and were performed just after the warm-up for the PJT-B, or ~10 minutes after completion of the soccer training session for the PJT-A. The two PJT groups completed the same number of total jump repetitions during intervention, using the same surface (i.e., grass soccer-field) and time of day (afternoon) for plyometric training, with the same rest intervals between sessions (i.e., 72-96 h), drills sets (i.e., 30-60 s) (30) and jumps (i.e., 5-15 s for acyclic jumps) (35).

*****Table 2 near here*****

**Statistical Analysis**

Data are presented as group mean values ± standard deviations. After data normality assumption was verified with the Shapiro-Wilk test, an analyses of variance (ANOVA) were used to detect differences between study groups in all variables at pre- and post-tests. Measures of dependent variables were analyzed in separate 3

(Groups) × 2 (Time: pre, post) ANOVA with repeated measures on time. Post-hoc tests with Bonferroni-adjusted α were conducted to identify comparisons that were statistically significant. Effect sizes were determined by calculating Cohen's *d* values (9). Cohen's d describes the effectiveness of a treatment and determines whether a statistically significant difference is a difference of practical concern. Cohen's *d* values are classified as small ($0.00 \le d \le 0.49$), medium ($0.50 \le d \le 0.79$), and large effects ($d \ge 0.8$) (9). Statistical analyses were carried out using STATISTICA statistical package (Version 8.0; StatSoft, Inc, Tulsa). Significance levels were set at α = 5%. The reliability of assessments was determined using the intraclass correlation coefficient and ranged from 0.87 to 0.98.

## RESULTS

All participants received treatment as allocated. No test or PJT-related injuries occurred over the course of the study.

### Before the intervention

No significant between-group baseline differences were observed for all examined variables (Table 1 and Table 3). The main effects of group, time and the group × time interaction are presented in Table 3.

*****Table 3 near here*****

### Training-induced effects on physical fitness

The analyses revealed significant main effects of time (all $p<.01$; d=0.19-0.79) and the group x time interaction (all $p<.05$; d=0.17-0.76) for all examined variables. Post hoc analyses revealed significant increases for the PJT-B group (SLJ: 9.4%, d=1.7; CMJ: 11.2%, d=0.75; MSSRT: 9.0%, d=0.77) and the PJT-A group (SLJ: 3.1%, d=0.7; CMJ: 4.9%, d=0.27; MSSRT: 9.0%, d=0.76). Post hoc analyses also revealed significant increases for the PJT-B group (20-m sprint-time: -7.4%, d=0.75; DJ: 19.1%, d=1.4; SJ: 6.3%, d=0.44; ICODT: -4.2%, d=1.1).

## DISCUSSION

The aim of this single-blind randomized controlled trial was to compare the effects of PJT-B with PJT-A on measures of physical fitness (i.e., sprint time, CoD speed and jump performance, and endurance) of young male soccer players. As hypothesized, both PJT-B and PJT-A improved young soccer players' performance, although the improvement was greater with PJT-B, particularly for the linear 20-m sprint test, the DJ, SJ, and ICODT which is indicative of PJT sequencing effects when conducted in combination with regular soccer training.

The performance of neuromuscular training before or after the principal part of the session devoted to technical and tactical development is dependent on several factors, such as coaches' planning, players' schedules and the availability of training facilities. In our study, undertaking soccer-specific training before PJT might have promoted increases in metabolites able to impair the capacity of producing high-intensity fast contractions (38). Accordingly, previous studies have shown that running and sprinting activities may impair neuromuscular performance (10), and a recent study has indicated that muscle fatigue might be harmful to improvements in muscle power and velocity (27). To some extent, these previous findings could explain why PJT performed after soccer training did not maximize training adaptations in comparison to PJT performed before soccer training.

With regard to sprinting, improvements have been commonly reported after plyometric jump training interventions that incorporated horizontally orientated drills (19, 33). However, in the current study, it is notable that only the PJT-B group showed enhanced sprint speeds in comparison to the control group. This result suggests that performing plyometric training in a fatigued state could blunt any improvements to sprinting speed. Since maximal sprinting necessitates high levels of neural activation (43), the disruption of processes such as the temporal sequencing of muscle activation and rapid firing rates to recruit fast motor units can lead to suboptimal speed development. Indeed, soccer-specific activities can induce central fatigue and impair the capacity for muscle force generation, which can, in turn, reduce sprinting speeds (38, 44). Therefore, plyometric training performed in a fatigued state can lead to an impaired transference of the benefits of jumping to sprinting abilities. Plyometric training performed before technical and tactical training is therefore recommended to optimize speed gains.

As with sprinting speed, the ability to CoD has previously been observed to improve after plyometric jump training (4, 17). However, in our study, only the PJT-B group improved its performance in comparison to the control group. In addition to a higher contribution of eccentric strength, the ability to change of direction is as dependent on neural factors as sprinting speed. Hence, it would be reasonable to assume that plyometric training undertaken in the absence of fatigue would further enhance the ability to change of direction relative to the benefits of training in a fatigued state.

Jump performance is a physical fitness indicator that is commonly improved after plyometric jump training interventions (7, 19). Previous studies have observed improvements in jumping performance after interventions applied either after (6, 22, 23) or before (30, 32, 35) athletes' regular sports practices. These findings were corroborated in the current study, with both PJT-B and PJT-A groups improving jumping performance in assessments involving an important elastic-energy component, such as the SLJ and the CMJ. However, the improvement in jump tests requiring meaningful concentric-only explosive (i.e., SJ) and reactive strength (i.e., DJ) improved to a greater extent only in the PJT-B group. Further research is required to expand our knowledge regarding the underlying physiological mechanism potentially explaining current findings.

Similar to previous studies with soccer players (36), time to exhaustion in the 20-m multistage shuttle run test was equally improved in both the PJT-B and PJT-A groups after plyometric training (Table 3). The observed improvements in endurance due to plyometric training might have occurred due to neuromuscular-mediated changes in athletes' running efficiency (5, 45), neuromechanical improvements (21) and increased tendon stiffness. This can allow a faster transfer of force from contracting muscles to moving bones via tendons (18), reducing reaction times (25) and positively affecting athletes' ability to change direction This is the first study to demonstrate that both PJT-B and PJT-A induced a greater ($p<0.05$) increase in 20-m multistage shuttle run test times compared to a control group (Table 3).

Young athletes (adolescents) recover faster than their older peers after high-intensity efforts (12). This may have contributed to the adaptations observed in athletes from the PJT-A group. Future studies should be conducted to examine the effects of PJT before and after training in children, since they are usually more resistant to fatigue and recover faster than adolescents (11).

In conclusion, to increase the effectiveness of PJT, it should be conducted immediately after the warm-up program and before regular soccer practice in young male players. Our study additionally revealed that PJT is even effective when conducted after soccer training although to a significantly lower extent.

## PRACTICAL APPLICATIONS

The plyometric training program applied induced explosive and endurance adaptations, which may have transference into game-play performance. Thus, a twice weekly short-term high-intensity plyometric training program, implemented as a substitute for some soccer drills within regular in-season soccer practice, can enhance explosive and endurance performance in young soccer players compared with soccer training alone, and these improvements can be maximized if PJT is conducted immediately after the warm-up program and before regular soccer practice in young male players. However, PJT is even effective when conducted after soccer training. Considering that some young soccer teams schedule training sessions after regular soccer practice, the current findings may be relevant to programming PJT in this context. Although we strongly advice that PJT be conducted whenever possible immediately after the warm-up program and before regular soccer practice.

**REFERENCES**


1. Andrade DC, Henriquez-Olguin C, Beltran AR, Ramirez MA, Labarca C, Cornejo M, Alvarez C, and Ramirez-Campillo R. Effects of general, specific and combined warm-up on explosive muscular performance. *Biol Sport* 32: 123-128, 2015.
2. Andrade DC, Manzo O, Beltrán AR, Alvares C, Del Río R, Toledo C, Moran J, and Ramirez-Campillo R. Kinematic and neuromuscular measures of intensity during plyometric jumps. *J Strength Cond Res*, IN PRESS.
3. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, and Bahr R. Physical fitness, injuries, and team performance in soccer. *Med Sci Sports Exerc* 36: 278-285, 2004.
4. Asadi A, Arazi H, Young WB, and Saez de Villarreal E. The effects of plyometric training on change-of-direction ability: A meta-analysis. *Int J Sports Physiol Perform* 11: 563-573, 2016.
5. Balsalobre-Fernandez C, Santos-Concejero J, and Grivas GV. Effects of strength training on running economy in highly trained runners: A systematic review with meta-analysis of controlled trials. *J Strength Cond Res* 30: 2361-2368, 2016.
6. Barnes KR, Hopkins WG, McGuigan MR, Northuis ME, and Kilding AE. Effects of resistance training on running economy and cross-country performance. *Med Sci Sports Exerc* 45: 2322-2331, 2013.
7. Bedoya AA, Miltenberger MR, and Lopez RM. Plyometric training effects on athletic performance in youth soccer athletes: A systematic review. *J Strength Cond Res* 29: 2351-2360, 2015.
8. Carling C, Le Gall F, and Dupont G. Analysis of repeated high-intensity running performance in professional soccer. *J Sports Sci* 30: 325-336, 2012.

9. Cohen J. *Statistical Power Analysis for the Behavioral Sciences.* Hillsdale, N.J. : Lawrence Erlbaum, 1988.

10. de Souza EO, Tricoli V, Franchini E, Paulo AC, Regazzini M, and Ugrinowitsch C. Acute effect of two aerobic exercise modes on maximum strength and strength endurance. *J Strength Cond Res* 21: 1286-1290, 2007.

11. Faigenbaum AD, Ratamess NA, McFarland J, Kaczmarek J, Coraggio MJ, Kang J, and Hoffman JR. Effect of rest interval length on bench press performance in boys, teens, and men. *Pediatr Exerc Sci* 20: 457-469, 2008.

12. Falk B and Dotan R. Child-adult differences in the recovery from high-intensity exercise. *Exerc Sport Sci Rev* 34: 107-112, 2006.

13. Faude O, Koch T, and Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. *J Sports Sci* 30: 625-631, 2012.

14. Fernandez-Fernandez J, Granacher U, Sanz-Rivas D, Sarabia Marin JM, Hernandez-Davo JL, and Moya M. Sequencing effects of neuromuscular training on physical fitness in youth elite tennis players. *J Strength Cond Res*, IN PRESS.

15. Helgerud J, Engen LC, Wisloff U, and Hoff J. Aerobic endurance training improves soccer performance. *Med Sci Sports Exerc* 33: 1925-1931, 2001.

16. Hewett TE, Lindenfeld TN, Riccobene JV, and Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med* 27: 699-706, 1999.

17. Ingle L, Sleap M, and Tolfrey K. The effect of a complex training and detraining programme on selected strength and power variables in early pubertal boys. *J Sports Sci* 24: 987-997, 2006.

18. Legerlotz K, Marzilger R, Bohm S, and Arampatzis A. Physiological adaptations following resistance training in youth athletes-A narrative review. *Pediatr Exerc Sci* 28: 501-520, 2016.

19. Loturco I, Pereira LA, Kobal R, Zanetti V, Kitamura K, Abad CC, and Nakamura FY. Transference effect of vertical and horizontal plyometrics on sprint performance of high-level U-20 soccer players. *J Sports Sci* 33: 2182-2191, 2015.

20. Marginson V, Rowlands AV, Gleeson NP, and Eston RG. Comparison of the symptoms of exercise-induced muscle damage after an initial and repeated bout of plyometric exercise in men and boys. *J Appl Physiol* 99: 1174-1181, 2005.

21. Markovic G and Mikulic P. Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Med* 40: 859-895, 2010.

22. Martel GF, Harmer ML, Logan JM, and Parker CB. Aquatic plyometric training increases vertical jump in female volleyball players. *Med Sci Sports Exerc* 37: 1814-1819, 2005.

23. Matavulj D, Kukolj M, Ugarkovic D, Tihanyi J, and Jaric S. Effects of plyometric training on jumping performance in junior basketball players. *J Sports Med Phys Fitness* 41: 159-164, 2001.

24. Moran JJ, Sandercock GR, Ramirez-Campillo R, Meylan CM, Collison JA, and Parry DA. Age-related variation in male youth athletes' countermovement jump after plyometric training: A meta-analysis of controlled trials. *J Strength Cond Res* 31: 552-565, 2017.

25. Myers AM, Beam NW, and Fakhoury JD. Resistance training for children and adolescents. *Translational pediatrics* 6: 137-143, 2017.

26. NSCA A. Position statement: Explosive/plyometric exercises. *NSCA Journal* 15: 16, 1993.

27. Pareja-Blanco F, Rodriguez-Rosell D, Sanchez-Medina L, Sanchis-Moysi J, Dorado C, Mora-Custodio R, Yanez-Garcia JM, Morales-Alamo D, Perez-Suarez I, Calbet JAL, and Gonzalez-Badillo JJ. Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. *Scand J Med Sci Sports* 27: 724-735, 2017.

28. Pedley JS, Lloyd RS, Read P, Moore IS, and Oliver JL. Drop jump: A technical model for scientific application. *Strength Cond J* 39: 36-44, 2017.

29. Radnor JM, Oliver JL, Waugh CM, Myer GD, Moore IS, and Lloyd RS. The influence of growth and maturation on stretch-shortening cycle function in youth. *Sports Med* 48: 57-71, 2018.

30. Ramirez-Campillo R, Andrade DC, Alvarez C, Henriquez-Olguin C, Martinez C, Baez-Sanmartin E, Silva-Urra J, Burgos C, and Izquierdo M. The effects of interset rest on adaptation to 7 weeks of explosive training in young soccer players. *J Sports Sci Med* 13: 287-296, 2014.

31. Ramirez-Campillo R, Andrade DC, and Izquierdo M. Effects of plyometric training volume and training surface on explosive strength. *J Strength Cond Res* 27: 2714-2722, 2013.

32. Ramirez-Campillo R, Burgos CH, Henriquez-Olguin C, Andrade DC, Martinez C, Alvarez C, Castro-Sepulveda M, Marques MC, and Izquierdo M. Effect of unilateral, bilateral, and combined plyometric training on explosive and endurance performance of young soccer players. *J Strength Cond Res* 29: 1317-1328, 2015.

33. Ramirez-Campillo R, Gallardo F, Henriquez-Olguin C, Meylan CM, Martinez C, Alvarez C, Caniuqueo A, Cadore EL, and Izquierdo M. Effect of vertical, horizontal, and combined plyometric training on explosive, balance, and endurance performance of young soccer players. *J Strength Cond Res* 29: 1784-1795, 2015.

34. Ramirez-Campillo R, Gonzalez-Jurado JA, Martinez C, Nakamura FY, Penailillo L, Meylan CM, Caniuqueo A, Canas-Jamet R, Moran J, Alonso-Martinez AM, and Izquierdo M. Effects of plyometric training and creatine supplementation on maximal-intensity exercise and endurance in female soccer players. *J Sci Med Sport* 19: 682-687, 2016.

35. Ramirez-Campillo R, Meylan C, Alvarez C, Henriquez-Olguin C, Martinez C, Canas-Jamett R, Andrade DC, and Izquierdo M. Effects of in-season low-volume high-intensity plyometric training on explosive actions and endurance of young soccer players. *J Strength Cond Res* 28: 1335-1342, 2014.

36. Ramirez-Campillo R, Meylan CM, Alvarez-Lepin C, Henriquez-Olguin C, Martinez C, Andrade DC, Castro-Sepulveda M, Burgos C, Baez EI, and Izquierdo M. The effects of interday rest on adaptation to 6 weeks of plyometric training in young soccer players. *J Strength Cond Res* 29: 972-979, 2015.

37. Ramirez-Campillo R, Vergara-Pedreros M, Henriquez-Olguin C, Martinez-Salazar C, Alvarez C, Nakamura FY, De La Fuente CI, Caniuqueo A, Alonso-Martinez AM, and Izquierdo M. Effects of plyometric training on maximal-intensity exercise and endurance in male and female soccer players. *J Sports Sci* 34: 687-693, 2016.

38. Rampinini E, Bosio A, Ferraresi I, Petruolo A, Morelli A, and Sassi A. Match-related fatigue in soccer players. *Med Sci Sports Exerc* 43: 2161-2170, 2011.

39. Ratel S, Duche P, and Williams CA. Muscle fatigue during high-intensity exercise in children. *Sports Med* 36: 1031-1065, 2006.

40. Reilly T and Gilbourne D. Science and football: a review of applied research in the football codes. *J Sports Sci* 21: 693-705, 2003.

41. Rosas F, Ramirez-Campillo R, Diaz D, Abad-Colil F, Martinez-Salazar C, Caniuqueo A, Canas-Jamet R, Loturco I, Nakamura FY, McKenzie C, Gonzalez-Rivera J, Sanchez-Sanchez J, and Izquierdo M. Jump training in youth soccer players: effects of haltere type handheld loading. *Int J Sports Med* 37: 1060-1065, 2016.

42. Rosas F, Ramirez-Campillo R, Martinez C, Caniuqueo A, Canas-Jamet R, McCrudden E, Meylan C, Moran J, Nakamura FY, Pereira LA, Loturco I, Diaz D, and Izquierdo M. Effects of plyometric training and beta-alanine supplementation on maximal-intensity exercise and endurance in female soccer players. *J Hum Kinet* 58: 99-109, 2017.

43. Ross A, Leveritt M, and Riek S. Neural influences on sprint running: training adaptations and acute responses. *Sports Med* 31: 409-425, 2001.

44. Sanchez-Sanchez J, Sanchez M, Hernandez D, Ramirez-Campillo R, Martinez C, and Nakamura FY. Fatigue in U12 soccer-7 players during repeated one-day tournament games - A pilot study. *J Strength Cond Res*, IN PRESS.

45. Yamamoto LM, Lopez RM, Klau JF, Casa DJ, Kraemer WJ, and Maresh CM. The effects of resistance training on endurance distance running performance among highly trained runners: a systematic review. *J Strength Cond Res* 22: 2036-2044, 2008.