Plyometric training in young male soccer players: potential effect of jump height

Running head: Transference effect of plyometrics in youth soccer

ABSTRACT

Purpose: To compare the effects of plyometric drop jump training against those induced by regular soccer training, and to assess the transference effect coefficient (TEC) of drop-jumps ("trained exercises") performed from 20- [DJ20] and 40-cm [DJ40] height boxes with respect to different physical qualities (jumping; linear and change of direction speed; kicking; endurance; maximal strength) in youth male soccer players. **Methods:** Participants were randomly divided into a control group (n=20; age: 13.5±1.9 years) and a drop jump (DJ) training group (n=19; age: 13.2±1.8 years); and trained for 7 weeks. To calculate the TEC between DJ20-DJ40 and the physical tests, the ratio between the "result gain" (effect-size [ES]) in the analyzed physical qualities and the result gain in the trained exercises were calculated. The TECs were only calculated for variables presenting an ES ≥0.2. **Results:** Significant improvements (ES=0.21-0.46; $P < 0.05$) were observed in the DJ training group, except in linear sprint performance. The control group improved only maximal strength (ES=0.28). Significant differences were observed in all variables (ES=0.20-0.55; $P < 0.05$) in favor of the DJ training group, except for maximal strength. Greater TECs were observed for DJ40 (0.58-1.28) than DJ20 (0.55-1.21). **Conclusion:** Our data suggest that youth players can improve their physical performance through the use of drop jumps. This is the first study that used the TEC to demonstrate the carry-over effect of plyometric training using drop jumps on physical performance of young soccer players.

Keywords: resistance training; neuromuscular training; force-velocity; maturity; football.

INTRODUCTION

Although aerobic capacity is important during a soccer game (50), high-intensity single-bout efforts also play an important role for physical performance (5, 14). This includes sprinting, jumping, changing direction, and kicking actions (50, 58). Youth elite and sub-elite players were found to be faster, more agile and powerful than non-elite players (17, 54), whereas future international players usually present superior levels of speed and power at youth level than future amateur players (19). Therefore, improvements of such abilities through adequate training strategies may be considered and prioritized from a young age (20, 28, 34), potentially leading toward optimal adulthood motor capacity (32).

Plyometric jump training (PJT) seems to be an effective way to promote progressive improvements in the neuromuscular abilities, as well as helping in the injury prevention (3, 37). These positive effects of PJT includes soccer players of different maturity status and age ranges (3, 4, 33). Interventions with PJT has the advantage of promoting meaningful increases in athletic performance even in congested fixture periods (i.e., in-season) (9, 44). Moreover, PJT may induce a carry-over (i.e., gains in a untrained exercise in relation to a trained PJT exercise) of its specific neuromechanical gains to explosive motor-tasks, such as maximum acceleration actions and maximum short sprints (22, 28).

To implement safe and effective PJT programs, several methodological aspects must be considered (38), such as the volume (11, 41) and intensity of the jumps (1, 39), the landing surfaces, order of drills execution, recovery time (41, 47), and the type of training exercises (7, 43), including those that stress the musculotendinous unit (52) (e.g., drop jump [DJ]) (7). DJ is probably the most frequently used and investigated type of PJT drill (38). When properly implemented, either isolated or combined with other drills, DJ has already proved to be practical, safe and very effective to improve physical performance of youth soccer players with different maturity status (30, 31, 38, 40). However, the carry-over effects of the

DJ gains to physical performance of young soccer players has not been described yet (21-23, 57).

The study of the transference effect of DJ training to relevant physical qualities of soccer players may help coaches and researchers to select the most efficient drills, optimize the training load and reduce injury risk (10, 27). To calculate this transference effect, previous recommendations have been provided (60). Zatsiorsky's transference coefficient (60) is a valuable tool for assessing meaningful changes in actual performance (e.g., CMJ, MB5, COD, 5RM, 2400-m TT, MKD) due to a "non-specific training stimulus" (e.g., DJ). To our knowledge, only four studies have analyzed the transference effect coefficient (TEC) of distinct strength and power training strategies on physical performance of athletes and non-athletes (21-23, 57). However, none of the aforementioned studies: i) determined the TEC of a drop jump training scheme; ii) determined the TEC in youth athletes (i.e., athletes with ages ranging from 10 to 16 years); iii) determined the TEC in a test battery that considered jumps, sprint, agility, endurance, strength, and kicking ability.

Considering that different PJT drills may induce different effects on the physical fitness of youth male soccer players (42, 43), clarification is needed regarding the TEC induced by drop jumps. In addition, considering that the effects of PJT may vary according to the maturity and age of the participants (13, 31), and the relevance of jumping (2), sprinting (14), change of direction speed (50), endurance (55), kicking and maximal strength (58) in soccer, it was considered relevant to clarify these issues. Thus, the aim of this study was to compare the effects of plyometric drop jump training against those induced by regular soccer training, and to assess the TEC of drop-jumps ("trained exercises") performed from 20- [DJ20] and 40-cm [DJ40] height boxes with respect to different physical capacities (jumping, linear and change of direction speed, kicking, endurance, and maximal strength) of youth male soccer players.

METHODS

Study Design

To compare the effects of plyometric drop jump training against those induced by regular soccer training, and to assess the TEC of DJ20 and DJ40 on jumping, linear and change of direction speed, kicking, endurance and maximal strength in youth male soccer players, athletes were randomly allocated into two groups as follows: DJ training group and control group (CG, soccer players performing a regular soccer training program). The TEC was considered as the gains in an untrained exercise in relation to a trained drop jump exercise. In another words, the TEC was the difference between the improvement in the DJ20 and DJ40 and the improvement in the other physical performance tasks in the youth soccer players who trained in drop jumps (see *Statistical Analyses* for a complete description of its calculation).

Before and after a 7-week training period, players from both groups executed a series of physical assessments, recorded by the same investigators who were blind to the intervention. Before performing these respective tests, the players executed a 90-minute familiarization session in order to reduce possible learning effects. Measurements were performed over two non-consecutive days, after a 48-h resting period, under similar weather, time, and field conditions. On day 1, players executed: countermovement jump (CMJ), DJ20 and DJ40; the 5 alternated leg bounds test (MB5); 20-m sprint test; and Illinois COD test. On day 2, they performed: the maximum kicking distance (MKD) test, and a 2400-m time trial (TT). Players were instructed to arrive at the sports laboratory in a fasted state for at least 2-

h. A standardized warm-up was performed before the tests. The warm-up comprised light to moderate self-selected running for 5-min with a 180° change of direction every ~20-m, 10 submaximal countermovement jumps, 10 submaximal DJ20, without the incorporation of dynamic stretching exercises. Moreover, sub-maximal attempts at each test were also executed prior to the maximal tests.

Participants

Thirty-nine male young soccer players of four different soccer teams with similar competitive and training schedules (1 official game per week and regular soccer training twice a week) took part in this study. The inclusion criteria to participate in this study comprised: 1) more than 2-year background of systematic soccer training and competition experience, 2) continuous soccer training in the previous 6 months, 3) no DJ training experience in the previous 6 months, 4) no background in regular strength training or competitive sports activity that involved any kind of DJ training during the experimental period.

Soccer players were randomly divided into two groups: CG [(n = 20; age: 13.5 ± 1.9 years; height: 1.55 ± 0.11 m; weight: 49.1 ± 12.0 kg; genital maturation stage 2 (n = 3), stage 3 (n = 4), stage 4 (n = 6) and stage 5 (n = 7)] and DJ training group [(n = 19; age: 13.2 ± 1.8 years; height: 1.54 ± 0.11 m; weight: 48.6 ± 9.9 kg; genital maturation stage 2 (n = 3), stage 3 (n = 3), stage 4 (n = 7) and stage 5 (n = 6)]. The genital maturation was determined by self-assessment of Tanner stage (51) as a measure of the athlete´s maturation status.

An institutional review board approved the study, and all subjects, their parents or guardians, were informed about the experimental procedures and possible risks and benefits associated with participation in the study. An appropriate parental signed informed consent document and participant assent were obtained pursuant to law before any tests were performed.

Training Program

The study was performed during the mid-portion of the competitive (in-season) period. A detailed description of the usual soccer training applied during this period is shown in Table 1. Before the competitive period, participants completed two months of summer preseason training, including body-weight strength and power drills, were drop jumps where introduced with a technical competency approach. Before starting the DJ training period, a session was used, where the participants were re-instructed and reminded in relation to the appropriate execution of the DJ, were screening for technical competency was assessed. During the interventional period, the DJ training group replaced part of the technical training content with drop jumps, within the usual 90-minute practice, twice a week separated by at least 48-h, for 7 weeks. All DJ training sessions lasted ~20 minutes and were performed after the warm-up, on a grass soccer field. From week 1 to week 7, all drop jump training sessions included 3 sets of 10 repetitions of drop jumps from 20- and 40-cm box heights (i.e., 60 contacts), with 15 and 90 seconds of rest between repetitions (48) and sets, respectively. Participants were instructed to jump for maximal height and minimum contact time, every jump, to maximize reactive strength (i.e., bounce drop jumps). Despite their maximal effort, athletes were always required to perform the movements with technical efficiency. Therefore, progression was not allowed until adequate competency was acquired. In addition, to limit stress on the muscle-tendon unit, a very conservative number of jumps were used per training session (38, 41). To assure adequate progression and monitoring, a “coach:athlete ratio” of 1:4 was used during all drop jump training sessions, that follow previous guidelines (35, 53).

For the different soccer teams, the drop jump training was administered by the same coaches. Although the training volume was not increased during the 7-week period, as high-intensity drills (i.e., drop jumps) were performed, this was considered as an adequate training stimulus during each plyometric session (24, 36, 45).

*****INSERT TABLE 1 HERE*****

Vertical Jump Tests

Vertical jump tests comprised CMJ, DJ20, and DJ40. All jumps were performed on a contact mat (Ergojump; Globus, Codogne, Italy) with arms on the hips. Take-off and landing were 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 drop jumps. Five attempts were performed for each test. The highest jump for the CMJ and the best reactive strength index (RSI) for the DJs, calculated as jump height (mm) divided by contact time (ms), as previously reported (59), were retained for analysis.

Multiple 5 Bounds Test.

The MB5 test was started from a standing position. Players performed a set of 5 forward jumps with alternative left- and right-leg contacts, covering the longest distance possible. The distance of the MB5 was measured to the nearest 0.5-cm using a tape measure (29).

Five Repetition Maximum Test (5RM)

The test was applied as previously described (41). Briefly, a parallel squat test was performed, where participants had to complete 5 consecutive repetitions with the highest possible load (kilograms).

Twenty-Meter Sprint Test

The sprint time was measured to the nearest 0.01 seconds 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. The photoelectric signal was positioned at 20-m and set ~0.7-m above the floor (i.e., hip level) to capture the trunk movement rather than a false trigger from a limb. The soccer players sprinted twice, and the fastest time was retained for the analyses.

Illinois Change of Direction Speed Test

The Illinois COD test was performed as previously described (16). Briefly, the test is set up with 4 cones forming the agility area. To perform the test, athletes run 9.2-m, turn, and return to the starting line. After returning to the starting line, they swerve in and out of 4 markers, completing two 9.2-m sprints to finish the agility course. The timing system and procedures were the same as the 20-m sprint, except that subjects started lying on their stomach on the floor with their face down. The soccer players performed two attempts, and the fastest time was retained for the analyses.

Maximal Kicking Distance Test

Following previous guidelines (46), participants kicked a soccer ball for maximal distance on a soccer field. Participants performed 3 valid attempts for 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. The distance was measured to the nearest centimeter. All measurements were completed with a wind velocity <20-km.h^{-1} (local Meteorological Service). A new size 5 soccer ball (Nike Seitiro, FIFA certified) was used for all measurements.

The 2400-m Time Trial Test.

As previously recommended (46), the 2400-m TT test was used because of its multifaceted demands (maximal oxygen consumption, lactate threshold, running economy, muscle power) (12), which are likely to affect soccer performance. After a warm-up run of 800-m and four minutes of rest, players individually performed six laps of a 400-m outdoor dirt track, timed to the nearest second, with a stopwatch. The wind velocity and its direction at baseline and post-training was similar (i.e., 7.8-9.9 km.h^{-1}), with a relative humidity between 50 and 70%, and a temperature between 15 and 20° C (local Meteorological Service), respectively. Motivation was considered maximal as the test was conducted as part of the team selection process for the next scheduled match of the in-season.

Statistical Analyses

All values are reported as mean ± standard deviation. Normality was checked using the Shapiro-Wilk test. Analyses of variance were used to test for interactions in between-group comparisons and training-effects over time. Bonferroni post-hoc test was performed to indicate statistically significant differences. The level of significance used was set at $P < 0.05$. All calculations were performed using IBM-SPSS Statistics for Windows, Version 20.0 (IBM Corp., Armonk, NY, USA). To determine the magnitude of the differences between the groups pre and post-training and its delta changes, the effect size (ES: Cohen's *d*) was calculated (18). The ES magnitudes were interpreted using the following thresholds: <0.2, 0.2-0.6, 0.6-1.2, 1.2-2.0, 2.0-4.0, and >4.0 for trivial, small, moderate, large, very large, and near perfect, respectively (18).

The TEC was calculated as previously described, using a within-group analysis, considering its ability to differentiate the transference effects of different exercises performed by a given group of participants (60). Although a within-group analysis was used for the calculation of the TEC, such analysis was employed after the verification of the assumption that the training drills (i.e., DJ20 and DJ40) were effective (induced a meaningful effect), as compared to a control group.

The TEC is a theoretical method (60), validated in previous studies (21-23, 57) which demonstrated its ability to differentiate the transference effects of different types of training in different types of athletes; including some forms of plyometric drills (e.g., vertical and horizontal jumps) in soccer players (22). Similar to the ES norms previously described, to evaluate the TEC, a magnitude-based inference approach is applied, using the ratio between the result gain (ES) in the analyzed physical qualities (e.g., CMJ, MB5, COD, 5RM, 2400-m TT, and MKD; also considered as the "non-trained exercises" (60) and the result gain in the trained exercises (e.g., $DJ20_{RSI}$, $DJ40_{RSI}$). The TECs were only calculated for variables presenting an ES of at least 0.2, considered a small ES based on Cohen's principle (18).

RESULTS

High within-session intraclass correlation coefficients were obtained for CMJ, DJ20, DJ40, MB5, 20-m sprint, COD, and MKD performance tests, varying between 0.81 and 0.98. No significant differences between groups were observed before or after training in the anthropometric measures, age, or maturity status, and no within-group changes were observed ($P > 0.05$). Although 39 soccer players completed the study, 8 players did not, due to lack of comply with inclusion criteria (i.e., completion of all familiarization sessions [n=1], training sessions [n=5], and tests [n=2]). Of note, although some players manifested mild delayed onset of muscle soreness during the first week of drop jump training, no injury associated with the program was observed during the intervention.

Table 2 demonstrates the comparison between the DJ training group and CG in the variables tested pre- and post-training period. No significant differences were observed in the physical tests performed, comparing both groups in the pre-measures ($P > 0.05$). When comparing the changes from pre to post training, the DJ training group showed significant small improvements in all variables tested (ES varying from 0.21 to 0.46; $P < 0.05$), with the exception of the 20-m sprint time. In the CG, a significant impairment in the 20-m sprint and COD speed performances were observed (ES = 0.22 and 0.26, respectively; $P < 0.05$), while a significant increase in the 5RM test was observed (ES = 0.28; $P < 0.05$), when comparing pre- and post-assessments. When comparing the groups for changes from pre to post training, significant differences were observed in all variables tested (ES varying from 0.20 to 0.55; $P < 0.05$), with the exception of the 5RM test for which no significant difference was found ($P > 0.05$). Figure 1 depicts the TEC between the analyzed physical qualities (CMJ, MB5, COD, 5RM, 2400-m TT, and MKD) and the trained exercises ($DJ20_{RSI}$, $DJ40_{RSI}$). Sprinting time in 20-m did not achieve a significant improvement during the intervention; therefore, the TEC was not calculated. Although the TECs between DJ20 and the physical qualities ranged from 0.55 to 1.21 (i.e., CMJ = 0.55; MB5 = 0.71; COD = 0.71; 5RM = 0.87; 2400-m TT = 0.58; MKD = 1.21) on average, greater TECs were observed for DJ40 in relation to the same measure, from 0.58 to 1.28 (i.e., CMJ = 0.58; MB5 = 0.75; COD = 0.75; 5RM = 0.92; 2400-m TT = 0.61; MKD = 1.28).

*****INSERT TABLE 2 HERE*****

*****INSERT FIGURE 1 HERE*****

DISCUSSION

Our main findings suggest significant improvements (ES = 0.21-0.46; $P < 0.05$) in the DJ training group, except in linear sprint performance. The control group improved only maximal strength (ES = 0.28; $P < 0.05$). Significant differences were observed in all variables (ES=0.20-0.55; $P < 0.05$), in favor of the DJ group, except for maximal strength. In the DJ group, greater TECs were observed for DJ40 (0.58-1.28) than DJ20 (0.55-1.21) (Figure 1).

Since there was no change in the physical fitness of the CG, and considering the aforementioned characteristics of both training programs, it can be inferred that the improvements observed in the DJ training group were a direct result of the respective DJ drills. Although several researchers have demonstrated that various models of PJT programs were able to increase youth soccer players' performance (6, 38), to our knowledge, this is the first study to assess the TECs of DJ training with respect to different physical traits of youth athletes. Despite its practical relevance, the absence of this calculation in some investigations can be explained by the applied experimental procedures and the impossibility to control and isolate the specific training stimulus (i.e., "trained exercise"). Therefore, comparison of our results with previous studies is difficult due to differences in trained exercises, physical fitness measurements, and characteristics of the participants (i.e., adults). However, a few studies have already applied this calculation. In one study (57) young (mean age, 23.7 years) males and females completed 9 weeks of squat training with different ranges of motion (i.e., depth vs. shallow). The TEC for deep squats was 2.32 for standing vertical jump and 1.68 for depth vertical jump, substantially greater than for shallow squats (0.31 and 0.11, respectively). In a more recent study (23), physically active adult males (mean age, ~20 years) obtained greater TECs in different measures of physical fitness after a 9-week training period of traditional strength-power training (TEC = 1.24-3.32) than complex training (TEC = 0.9-2.19). Accordingly, a study conducted with under-20 (mean age, ~18 years) soccer players (22) compared the TECs of a group that trained 3 weeks with either vertical jumps (i.e., CMJ) or horizontal jumps. In the vertically-trained group, the TEC between the vertical jump (i.e., CMJ) and 20-m sprinting speed was 1.31, and for acceleration in 10-20-m was 2.75. In the horizontally-trained group, the TEC between the horizontal jump and 10-m sprinting speed was 0.44, for 20-m sprinting speed was 0.17, and for acceleration in 0-10-m was 0.44. Moreover, when under-20 (mean age, ~18 years) male soccer players trained for 6 weeks with either jump squat or push-press exercises at the optimum power load (21), a meaningful TEC was detected only for those players that trained with jump squats, obtaining TECs between 0.77-1.29 for 5-, 10-, 20-, and 30-m sprints. Nonetheless, to date, no study has examined the transference effects of drop jumps with respect to a more comprehensive variety of fitness attributes. Researchers may consider to assess the TEC of the trained exercises, by including a test battery with such trained exercises among the dependent variables.

The larger TEC observed for DJ40 compared to DJ20 (Figure 1) may be due to the proposed neuromuscular adaptations induced by PJT (24). Nevertheless, the underlying mechanisms leading to potentially greater neuromuscular adaptations after DJ40 compared to DJ20 are not clear, since no physiological measurements were conducted in the current study. The greater TEC with DJ40 (0.58 to 1.28) compared to DJ20 (0.55 to 1.21) may be related to the potentially greater intensity achieved with higher heights (8). Indeed, several PJT studies have reported that to increase the intensity-based load during training, the height of the jump boxes was progressively increased, including studies in youth soccer players (15, 38). In this sense, among male volleyball players (mean age, 24.4 years) a 40-cm drop height was demonstrated to induce 22% greater intensity (i.e., reactive strength index) compared to a 20-cm drop height (1). If among highly jump-trained individuals a 40-cm drop height demonstrated greater intensity compared to a 20-cm drop height, this may also be the case for youth soccer players. Therefore, greater height during drop jump drills may have stimulated greater neuromuscular adaptations and, thus, greater TECs. In fact, in the aforementioned study, which compared 20-cm and 40-cm drop jumps, a 31% greater jump height was observed after jumping from a 40-cm height. From a mechanical perspective, the greater jumping height achieved may reflect greater participation of the stretch-shortening cycle governing mechanisms (i.e., stretch reflex; H-reflex) (52), which are especially relevant in youths under growth and maturation (37). In this sense, a larger stretch-shortening cycle may be accompanied by greater muscle activation, including key muscle groups for players such as the medial gastrocnemius, biceps, and rectus femoris (1), thus contributing to the larger TEC observed for DJ40. Moreover, a greater PJT intensity may also be associated to morphological adaptations (24), especially under the influence of growth and maturation (37). However, recently was found that plyometric jump training may induce physical fitness improvements in youth (mean age, ~12 years) male soccer players without changes in muscle activation (26). To clarify this issue, further research should be conducted regarding the identification of potential underlying mechanisms of different types of plyometric jump training drills and it's TEC on different measures of physical fitness among youth male soccer players.

Although in our study the DJ40 induced greater TEC than the DJ20, logistical constraints and methodological issues (i.e., young players, 13.2 ± 1.8 years of age) impeded us from incorporating training sessions or even measurements using 60-cm drop jumps. Therefore, we were unable to determine if additional increases in drop heights during DJ training would further improve the TEC. However, in a previous study with youth (15-16 years-old) male basketball athletes (25), six weeks of DJ training using either 50- or 100-cm drop jump height boxes resulted in similar improvements between groups in jump height (i.e., 4.8- and 5.6-cm, respectively), muscle strength, and rate of force development. Moreover, whether drop heights equal to or greater than 50-cm are beneficial or even appropriate for youth athletes is still controversial. In fact, drop heights of 50-cm or greater in male youth (mean age, ~13 years) soccer players may exceed optimal training stimulus (39). Although an increase from 20- to 40-cm drop jump height could increase reactive strength index, jump height, and muscle activity, it has been reported that additional increases do not ensure greater training intensities, and may even reduce potential improvements in athletic performance, even among highly jump-trained adult athletes (1). Nevertheless, such assumptions should be confirmed in future studies.

A potential limitation of this study is the absence of other treatment conditions (i.e., another group performing alternative exercises), thereby avoiding comparisons between different neuromuscular training schemes. On the other hand, the possibility of isolating the "trained exercises" (i.e., drop jumps) and determining their transference effects with respect to some important soccer-specific capacities has crucial importance for training interventions. Based on our results, coaches involved in youth soccer should consider implementing plyometric training programs using drop jumps, in substitution for extended technical training practices. This strategy could be very effective in optimizing the physical fitness and kicking performance of youth soccer players, requiring a light volume of jumps (~60 jumps per session), two times per week, and 15-20 minutes per session.

CONCLUSION

Compared to a CG, in-season replacement of some low-intensity technical soccer drills with maximal-effort DJ drills induced significant improvements in the athletic performance of male youth soccer players, during a short-term period of 7 weeks. In the DJ group, compared to DJ20 drills, on average, greater TECs (i.e., 0.58-1.28) were observed for DJ40 drills with respect to a wide variety of physical attributes of male youth soccer players. Hence, male youth players were able to improve CMJ, MB5, COD, 5RM, 2400-m TT, and MKD through the use of DJ20 and DJ40, but with a greater TEC being observed for the DJ40. Further studies should be conducted to compare the transference effects of different plyometric drills (e.g., vertical versus horizontal jumps) and other strength-power exercises (e.g., loaded jumps) on physical and technical qualities of youth athletes of different sport disciplines. Considering the lack of studies dealing with the effects of different types of jump drills on youth male soccer player's physical and technical abilities (38) and the TEC between these, current results offer novel findings. Therefore, the present results expand the limited knowledge available regarding the plastic heterogeneity of different physical-technical qualities of youth male soccer players when a short-term in-season program is applied using DJ20 and DJ40 drills.

Of practical relevance and as lines of future research, current results would allow the selection of more efficient DJ training drills, potentially reducing the load needed to achieve a given effect, thus reducing the risk of injury associated to greater PJT loads observed in young (mean age, ~19 years) male and female athletes (10), which may also be the case for youth male soccer players. Alternatively, the selection or more efficient drills would allow the addition of complementary key PJT drills or similar conditioning exercises, potentially leading toward greater adaptations, as previously observed in youth male soccer players (42, 43).

REFERENCES

1. 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. *Journal of Strength and Conditioning Research*, IN PRESS.
2. 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.
3. Asadi A, Arazi H, Ramirez-Campillo R, Moran J, and Izquierdo M. Influence of maturation stage on agility performance gains after plyometric training: A systematic review and meta-analysis. *J Strength Cond Res* 31: 2609-2617, 2017.
4. Asadi A, Ramirez-Campillo R, Arazi H, and Saez de Villarreal E. The effects of maturation on jumping ability and sprint adaptations to plyometric training in youth soccer players. *J Sports Sci*, IN PRESS.

5. Barnes C, Archer DT, Hogg B, Bush M, and Bradley PS. The evolution of physical and technical performance parameters in the English Premier League. *Int J Sports Med* 35: 1095-1100, 2014.

6. 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.

7. Bobbert MF. Drop jumping as a training method for jumping ability. *Sports Med* 9: 7-22, 1990.

8. Bompa TO. Power training for sport: plyometrics for maximum power development. *Oakville, Ont : Mosaic Press*, 1996.

9. Bouguezzi R, Chaabene H, Negra Y, Ramirez-Campillo R, Jlalia Z, Mkaouer B, and Hachana Y. Effects of Different Plyometric Training Frequency on Measures of Athletic Performance in Prepuberal Male Soccer Players. *J Strength Cond Res*, 2018.

10. Brumitt J, Wilson V, Ellis N, Petersen J, Zita CJ, and Reyes J. Preseason lower extremity functional test scores are not associated with lower quadrant injury - A validation study with normative data on 395 division III athletes. *Int J Sports Phys Ther* 13: 410-421, 2018.

11. Chaabene H and Negra Y. The Effect of Plyometric Training Volume in Prepubertal Male Soccer Players' Athletic Performance. *Int J Sports Physiol Perform*: 1-22, 2017.

12. Coyle EF. Integration of the physiological factors determining endurance performance ability. *Exerc Sport Sci Rev* 23: 25-63, 1995.

13. de Villarreal ES, Kellis E, Kraemer WJ, and Izquierdo M. Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. *J Strength Cond Res* 23: 495-506, 2009.

14. 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.

15. Granacher U, Prieske O, Majewski M, Busch D, and Muehlbauer T. The role of instability with plyometric training in sub-elite adolescent soccer players. *Int J Sports Med* 36: 386-394, 2015.

16. Hachana Y, Chaabene H, Nabli MA, Attia A, Moualhi J, Farhat N, and Elloumi M. Test-retest reliability, criterion-related validity, and minimal detectable change of the Illinois agility test in male team sport athletes. *J Strength Cond Res* 27: 2752-2759, 2013.

17. Hansen L, Bangsbo J, Twisk J, and Klausen K. Development of muscle strength in relation to training level and testosterone in young male soccer players. *J Appl Physiol* 87: 1141-1147, 1999.

18. Hopkins WG, Marshall SW, Batterham AM, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Medicine and science in sports and exercise* 41: 3-13, 2009.

19. le Gall F, Carling C, Williams M, and Reilly T. Anthropometric and fitness characteristics of international, professional and amateur male graduate soccer players from an elite youth academy. *J Sci Med Sport* 13: 90-95, 2010.

20. Loturco I, Jeffreys I, Kobal R, Cal Abad C, RamirezCampillo R, Zanetti V, Pereira LA, and Nakamura FY. Acceleration and speed performance of Brazilian elite soccer players of different age-categories. *J Human Kinetics*, IN PRESS.

21. Loturco I, Pereira LA, Kobal R, Maldonado T, Piazzi AF, Bottino A, Kitamura K, Cal Abad CC, de Arruda M, and Nakamura FY. Improving sprint performance in

soccer: effectiveness of jump squat and olympic push press exercises. *PLoS One* 11: e0153958, 2016.

22. 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. *Journal of sports sciences* 33: 2182-2191, 2015.

23. Loturco I, Tricoli V, Roschel H, Nakamura FY, Cal Abad CC, Kobal R, Gil S, and Gonzalez-Badillo JJ. Transference of traditional versus complex strength and power training to sprint performance. *J Hum Kinet* 41: 265-273, 2014.

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

25. 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.

26. McKinlay BJ, Wallace P, Dotan R, Long D, Tokuno C, Gabriel D, and Falk B. Effects of Plyometric and Resistance Training on Muscle Strength, Explosiveness and Neuromuscular Function in Young Adolescent Soccer Players. *J Strength Cond Res*, 2018.

27. Mersmann F, Bohm S, Schroll A, Boeth H, Duda GN, and Arampatzis A. Muscle and tendon adaptation in adolescent athletes: A longitudinal study. *Scand J Med Sci Sports* 27: 75-82, 2017.

28. Meylan C, Cronin J, Oliver J, Hughes M, and Manson S. An evidence-based model of power development in youth soccer. *Int J Sports Sci Coach* 9: 1241-1264, 2014.

29. Meylan C and Malatesta D. Effects of in-season plyometric training within soccer practice on explosive actions of young players. *Journal of strength and conditioning research / National Strength & Conditioning Association* 23: 2605-2613, 2009.

30. Moran J, Clark CCT, Ramirez-Campillo R, Davies MJ, and Drury B. A meta-analysis of plyometric training in female youth: its efficacy and shortcomings in the literature. *J Strength Cond Res*, IN PRESS.

31. 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.

32. Myer GD, Lloyd RS, Brent JL, and Faigenbaum AD. How Young is "Too Young" to Start Training? *ACSM's health & fitness journal* 17: 14-23, 2013.

33. Negra Y, Chaabene H, Fernandez-Fernandez J, Sammoud S, Bouguezzi R, Prieske O, and Granacher U. Short-Term Plyometric Jump Training Improves Repeated-Sprint Ability in Prepuberal Male Soccer Players. *J Strength Cond Res*, 2018.

34. Negra Y, Chaabene H, Sammoud S, Bouguezzi R, Abbes MA, Hachana Y, and Granacher U. Effects of plyometric training on physical fitness in prepuberal soccer athletes. *Int J Sports Med* 38: 370-377, 2017.

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

36. Palma-Muñoz I, Ramírez-Campillo R, Azocar-Gallardo J, Álvarez C, Asadi A, Moran J, and Chaabene H. Effects of progressed and non-progressed volume-based overload plyometric training on components of physical fitness and body composition variables in youth male basketball players. *J Strenth Cond Res*, IN PRESS.

37. 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 Medicine*, 2017.

38. Ramirez-Campillo R, Alvarez C, Garcia-Hermoso A, Ramirez-Velez R, Gentil P, Asadi A, Chaabene H, Moran J, Meylan C, Garcia-de-Alcaraz A, Sanchez-Sanchez J, Nakamura FY, Granacher U, Kraemer W, and Izquierdo M. Methodological characteristics and future directions for plyometric jump training research: A scoping review. *Sports Med* 48: 1059-1081, 2018.

39. Ramirez-Campillo R, Alvarez C, García-Pinillos F, Sanchez-Sanchez J, Yanci J, Castillo D, Loturco I, Chaabene H, Moran J, and Izquierdo M. Optimal reactive strength index: is it an accurate variable to optimize plyometric training effects on measures of physical fitness in young soccer players? *J Strength Cond Res* 32: 885-893, 2018.

40. 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. *Journal of sports science & medicine* 13: 287-296, 2014.

41. Ramirez-Campillo R, Andrade DC, and Izquierdo M. Effects of plyometric training volume and training surface on explosive strength. *Journal of strength and conditioning research / National Strength & Conditioning Association* 27: 2714-2722, 2013.

42. 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.

43. 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. *Journal of strength and conditioning research / National Strength & Conditioning Association* 29: 1784-1795, 2015.

44. Ramirez-Campillo R, Garcia-Pinillos F, Garcia-Ramos A, Yanci J, Gentil P, Chaabene H, and Granacher U. Effects of different plyometric training frequencies on components of physical fitness in amateur female soccer players. *Frontiers in physiology* 9: 934, 2018.

45. Ramirez-Campillo R, Henriquez-Olguin C, Burgos C, Andrade DC, Zapata D, Martinez C, Alvarez C, Baez EI, Castro-Sepulveda M, Penailillo 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: 1884-1893, 2015.

46. 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.

47. 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.

48. Read MM and Cisar C. The influence of varied rest interval lengths on depth jump performance. *J Strength Cond Res* 15: 279-283, 2001.

49. Rossler R, Donath L, Bizzini M, and Faude O. A new injury prevention programme for children's football--FIFA 11+ Kids--can improve motor performance: a cluster-randomised controlled trial. *J Sports Sci* 34: 549-556, 2016.

50. Stolen T, Chamari K, Castagna C, and Wisloff U. Physiology of soccer: an update. *Sports Med* 35: 501-536, 2005.

51. Tanner J. *Growth of Adolescents.* Oxford, UK: Blackwell Scientific Publications, 1962.

52. Taube W, Leukel C, and Gollhofer A. How neurons make us jump: the neural control of stretch-shortening cycle movements. *Exerc Sport Sci Rev* 40: 106-115, 2012.

53. Triplett T, Williams C, McHenry P, and Doscher M. *Strength and conditioning professional standards and guidelines.* Colorado Springs, CO: NSCA, 2009.

54. Vaeyens R, Malina RM, Janssens M, Van Renterghem B, Bourgois J, Vrijens J, and Philippaerts RM. A multidisciplinary selection model for youth soccer: the Ghent Youth Soccer Project. *Br J Sports Med* 40: 928-934; discussion 934, 2006.

55. Watson A, Brindle J, Brickson S, Allee T, and Sanfilippo J. Preseason Aerobic Capacity Is an Independent Predictor of In-Season Injury in Collegiate Soccer Players. *Clin J Sport Med* 27: 302-307, 2017.

56. Waugh CM, Korff T, Fath F, and Blazevich AJ. Effects of resistance training on tendon mechanical properties and rapid force production in prepubertal children. *J Appl Physiol (1985)* 117: 257-266, 2014.

57. WEISS LW, FRX AC, WOOD LE, RELYEA GE, and MELTON C. Comparative Effects of Deep Versus Shallow Squat and Leg-Press Training on Vertical Jumping

Ability and Related Factors. *The Journal of Strength & Conditioning Research* 14: 241-247, 2000.

58. Wisloff U, Castagna C, Helgerud J, Jones R, and Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British journal of sports medicine* 38: 285-288, 2004.

59. Young WB, James R, and Montgomery I. Is muscle power related to running speed with changes of direction? *J Sports Med Phys Fitness* 42: 282-288, 2002.

60. Zatsiorsky V and Kraemer WJ. *Science and Practice of Strength Training.* Champaign, IL: Human Kinetics, 2006.

FIGURE CAPTION

Figure 1. Transference effect coefficients for the drop jump trained group between the analyzed physical qualities (i.e., countermovement jump [CMJ]; 5 alternated leg bounds test [MB5]; Illinois change-of-direction test [COD]; 5 repetition maximum test [5RM] in the squat exercise; maximal kicking distance test [MKD]; 2400-m time trial [TT]) and the "trained exercises" (i.e., drop jumps from boxes heights of 20- and 40-cm [DJ20 and DJ40]), after a 7-week training period.

Table 1. Schematic presentation of a typical training session.

Type of training	**Duration (min)**
Technical (goal shooting, ball control, passing drills)	20
Tactical (defensive and offensive situations, counter-attack, corner kick situations)	20
Small-sided games (different formats with distinct pitch sizes, number of players, and rules modification)	20
Simulated matches	30

Table 2. Comparisons of the physical tests pre- and post- a 7-week training period for both groups of young soccer players.

	Control Group			Drop Jump Training			Group x time interaction
	Pre[#]	**Post**	**ES (± 90% CI)** ***Rating***	**Pre[#]**	**Post**	**ES (± 90% CI)** ***Rating***	**ES (± 90% CI)** ***Rating***
CMJ (cm)	27.1 ± 4.8	27.3 ± 4.4	0.05 (±0.09) *Trivial*	27.2 ± 5.6	28.4 ± 5.7*	0.21 (±0.08) *Small*	0.20 (±0.12)* *Small*
$DJ20_{RSI}$ ($mm \cdot ms^{-1}$)	1.09 ± 0.41	1.03 ± 0.38	0.13 (±0.15) *Trivial*	1.07 ± 0.43	1.24 ± 0.38*	0.38 (±0.12) *Small*	0.55 (±0.20)* *Small*
$DJ40_{RSI}$ ($mm \cdot ms^{-1}$)	1.09 ± 0.35	1.05 ± 0.32	0.11 (±0.18) *Trivial*	1.05 ± 0.44	1.22 ± 0.49*	0.36 (±0.10) *Small*	0.50 (±0.19)* *Small*
MB5 (m)	8.85 ± 1.17	8.87 ± 1.14	0.02 (±0.03) *Trivial*	9.12 ± 1.16	9.44 ± 1.23*	0.27 (±0.12) *Small*	0.25 (±0.12)* *Small*
Time 20-m (s)	4.33 ± 0.52	4.45 ± 0.38*	0.22 (±0.19) *Small*	4.25 ± 0.53	4.21 ± 0.54	0.07 (±0.07) *Trivial*	0.31 (±0.21)* *Small*
COD speed (s)	19.6 ± 0.28	20.3 ± 2.9*	0.26 (±0.07) *Small*	20.1 ± 2.8	19.4 ± 2.4*	0.27 (±0.09) *Small*	0.55 (±0.12)* *Small*
2400-m TT (min)	10.6 ± 0.9	10.6 ± 0.9	0.03 (±0.10) *Trivial*	10.5 ± 0.8	10.3 ± 0.7*	0.22 (±0.11) *Small*	0.20 (±0.15)* *Small*
MKD (m)	32.1 ± 7.6	31.5 ± 8.5	0.08 (±0.08) *Trivial*	33.6 ± 8.7	37.8 ± 9.7*	0.46 (±0.14) *Small*	0.54 (±0.16)* *Small*
5RM (kg)	31.7 ± 9.3	33.4 ± 9.7*	0.19 (±0.16) *Small*	32.7 ± 11.1	36.6 ± 12.1*	0.33 (±0.10) *Small*	0.11 (±0.18) *Trivial*

Note: ES: effect sizes; CI: confidence intervals; CMJ: countermovement jump; DJ: drop jump; RSI: reactive strength index; MB5: multiple 5 bounds test; COD: change of direction; TT: time-trial; MKD: maximal kicking distance; RM: repetition maximum. [#]no significant differences were observed at Pre, between groups. *$P < 0.05$.