THE EFFECTS OF MATURATION ON PHYSICAL FITNESS ADAPTATIONS TO PLYOMETRIC DROP JUMP TRAINING IN MALE YOUTH SOCCER PLAYERS

ABSTRACT

The objective of the present study was to compare the effects of maturation on physical fitness adaptations to a twice weekly, 7-week plyometric drop jump training program. Seventy-six young male soccer players (aged 10-16 years) participated in this randomized controlled trial. Before and after the intervention a physical fitness test battery was applied (countermovement jump; drop jump from 20-cm and 40-cm; 5 multiple bounds test; 20-m sprint-time; change of direction speed; 2.4-km running time trial; five-repetition maximum squat; and maximal kicking distance). Participants were randomly divided into an active soccer-control group with Tanner stage maturation of 1-3 (CG-early; n=16) or Tanner stage 4-5 (CG-late; n=22), and to plyometric drop jump training groups with Tanner stage 1-3 (PJT-early; n=16) or 4-5 (PJT-late; n=22). The analysis of variance and effect size measures revealed that when compared to their age-matched controls, the PJT-early (ES= 0.39 to 1.58) and PJT-late (ES= 0.21 to 0.65) groups showed greater improvements ($p<0.05$) in sprint-time, 2.4-km running time trial, change of direction speed, five repetition maximum squat, jumping, and kicking distance. The PJT-early exceeded the PJT-late group with greater ($p<0.05$) improvements in drop jump from 20-cm (ES= 1.58 vs. 0.51) and 40-cm (ES= 0.71 vs. 0.4) and kicking distance (ES= 0.95 vs. 0.65). Therefore, a 7-week plyometric drop jump training program was effective in improving physical fitness traits in both younger and older male youth soccer players, with greater jumping and kicking adaptations in the less mature athletes.

Key words: stretch-shortening cycle; force-velocity curve; ballistic training; biological age; long-term athletic development.

INTRODUCTION

Plyometric jump training (PJT) is an effective means of physical conditioning to leverage the stretch-shortening cycle (SSC), promoting improvements in skill-related measures of athletic performance, as well as in health and resistance to injury (23). To implement safe and effective PJT programs, several key methodological characteristics should be considered (35), such as variability of drills (15), overload principle (46), intensity of jumps (37), order of drill execution in the training session (38), amongst other factors. In addition to PJT programming configuration, the characteristics of the training participants should also be considered to optimise adaptive responses, especially the biological maturity status among young populations (32). Biological maturation seems to play an influential role in the magnitude of physical fitness adaptations to exercise, lending credence to the theory of the existence of periods of accelerated adaptation to training in youth (32). For example, Lloyd et al. (21) suggested the possibility of 'synergistic adaptation' which could occur when training is strategically programmed to coincide with the development of a physical quality that is being concurrently enhanced by the processes of growth and maturation. Supporting this, previous meta-analyses (1), and some interventions, in male youth (3, 31) have indicated greater adaptive responses to physical training in more mature youth and the potential for "synergistic adaptation" (21) to the imposed demands of training remains a compelling concept. However, conflicting results have arisen, indicating greater adaptive responses to physical training in less mature youth (6, 7, 27, 32).

The above cited studies underline, to varying degrees, the efficacy of PJT as a training method in youth, and the potential role of maturity on adaptations to PJT. It has previously been shown that PJT has the potential to improve several physical fitness components in young soccer players (5), and may even reduce the risk of sustaining injuries (47). However, it is currently not fully known how the maturation status of male soccer players affects adaptations to PJT across a wide range of physical fitness traits relevant to the sport. To our knowledge, only one randomized controlled study has been conducted in relation to the effects of maturation on physical fitness adaptations to PJT in male youth soccer players, with conflicting results arising (3). In the aforementioned study, older more-mature players obtained greater ($p<0.05$) improvements in vertical jump height (ES=0.73) and linear sprinting (ES= 0.66) than less-mature players (ES= 0.48 and 0.12, respectively). However, both maturation groups achieved similar gains ($p>0.05$) in vertical jumping power (ES= 0.6-0.76; derived from vertical jump height), standing long jump distance (ES= 0.62-0.7), and linear sprinting speed with ball dribbling (ES= 0.44-0.55) after 6 weeks of PJT. Thus, similar high-quality research is needed to elucidate the role of maturation status on adaptations in physical fitness after PJT in male soccer players. The results arising from such research may help practitioners to adequately design strength and conditioning programs, to stimulate motor potential and athletic development, and to help prevent acute and overuse injuries.

The aim of this study was to compare the effects of maturation on physical fitness adaptations to plyometric drop jump training in separate groups of youth male soccer players, divided by maturity status. According to the relevant literature (1-3, 6, 7, 21, 27-32), it was hypothesized that adaptations would be modulated by maturity.

METHODS

Experimental Approach to the Problem

A randomized controlled trial was conducted to compare the effects of a 7 week plyometric drop jump training program, conducted in male youth soccer players of different maturation status, on components of physical fitness (countermovement jump [CMJ]; drop jump from 20-cm [DJ20] and 40-cm [DJ40]; 5 multiple bounds ; 20-m sprint-time; change of direction speed [Illinois test]; 2.4-km running time trial; five-repetition maximum squat; and maximal kicking distance). Participants aged 10 to 16 years were recruited and groups were formed, one followed modified soccer practice including plyometric drop jump training and the other followed regular soccer practice (control group [CG]) without plyometric drop jump training. In both groups, players were divided into two maturation groups according to their self-reported maturation status (Tanner stage system).

Subjects

With institutional ethics approval, 76 participants were recruited from four different soccer teams with similar competitive match (one official competitive game per week) and practice schedules (twice-weekly training sessions). A typical soccer training session involved 90 minutes of mainly technical-tactical drills, in addition to simulation of competitive matches and small-side games, and injury preventative drills.

Soccer players fulfilled the following inclusion criteria: (a) >2 years of systematic soccer training and competition experience, (b) continuous soccer training in the previous six months, (c) no systematic plyometric drop jump training experience in the previous six months, (d) no background in regular strength training or competitive sports activity that involved systematic jump training during the treatment. Participants were randomly divided into a CG (n=38) and plyometric drop jump training group (n=38). Furthermore, participants in the CG were divided according to their pubic hair growth maturation status (as described in the *Subject Characteristics* section) into a CG-early (n=16; Tanner stage II [n=8] and III [n=8]) and CG-late (n=22; Tanner stage IV [n=14] and V [n=8]). Similarly, participants in the plyometric jump training (PJT) group were divided into a PJT-early (n=16; Tanner stage I [n=2], II [n=4] and III [n=10]) and PJT-late (n=22; Tanner stage IV [n=15] and V [n=7]). Subject characteristics are provided in Table 1.

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

Parental consent and participant assent and written informed consent was obtained after ethical approval from the Institutional Review Board from the responsible Department.

Procedures

Standardized tests were scheduled ≥48 hours after a competition or hard physical training to minimize the influence of fatigue. They were performed under similar standardized conditions, over two days. On day one, athletes' characteristics (height, body mass, and self-assessed Tanner-stage of pubic hair and genital maturation), and performance tests were conducted in the following order: CMJ, DJ20, DJ40, 5 multiple bounds, 20-m sprint-time, and change of direction speed. On the second day, the maximal kicking distance, the five-repetition maximum squat, followed by the 2.4-km time-trial tests were performed. Evaluators were blinded to participants' group allocation. At least two minutes of rest was allowed between each trial to reduce fatigue effects. The best score of three trials was recorded for all performance tests in order to assess reliability, apart from the single five-repetition maximum squat and 2.4-km time trial tests, which was performed only once.

Subject Characteristics. Height was measured using a wall-mounted stadiometer (Butterfly, Shanghai, China) and was 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 ($kg.m^{-2}$). Maturity was determined by self-assessment of Tanner stage as previously described (51, 54) and validated in males between 11 and 18 years-old (12). Briefly, subjects were asked to self-determine their maturation stage using standard diagrams of pubic hair growth and genital development. Privacy was maintained from other subjects and investigators by providing booths for completing forms and placing them in sealed and coded envelopes for later analysis. This procedure was repeated one week later for test-retest reliability. Of note, as values of pubic hair growth and genital development were almost identical (i.e., mean differences of ~0.2 across all groups and maturation stages), in the current study, pubic hair growth maturation stage values were used for analysis and group allocation, as it showed greater reliability compared to genital development maturation stage measurement (intra-class correlation coefficient of 0.9 vs. 0.84, respectively). In addition, the use of pubic hair growth maturation stage values may aid in the comparison between sexes in further research efforts.

Vertical Jump Tests and Multiple 5 Bounds Test. Testing included the execution of maximal CMJ, DJ20, and DJ40. All jumps were performed on a mobile contact mat (Ergojump; Globus, Codogne, Italy) with arms akimbo. The participants were instructed to maximize jump height and minimize ground contact time during the DJ20 and DJ40 after dropping down from a 20- and 40-cm drop box, respectively. The multiple 5 bounds test (MB5) was started from a standing position and was performed with a set of five forward jumps with alternative left- and right-leg contacts to cover the longest distance possible. The distance of the MB5 was measured to the nearest 0.5 cm using a tape measure (24).

Twenty-Meter Sprint and Change of Direction Speed. 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. Sprint start was given by a random sound which triggered timing. Photoelectric cells were positioned at 20 m and were 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 change of direction speed was measured using the Illinois agility test, previously described and its reliability addressed elsewhere (14). The timing system and procedures were the same as the 20-m sprint-time, except that subjects started by lying on their stomach in a face-down position. Before their three maximal trials, participants practiced the test four times at submaximal intensity in order to become familiarized with test.

Maximal Kicking Distance Test. After a standard warm-up, each player kicked a new size 5 soccer ball (Nike Seitiro, FIFA certified) for maximal distance on a soccer field. 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 landed after the kick. By visual inspection, the assessor marked the point of contact where the rear part of the ball landed, using a small metal stake. Then, the assessor measured the distance kicked from the kick line to the nearest centimeter where the ball landed, using the 75-m metric tape placed between the kicking line and across the soccer field to guide the measurement. All measurements were completed with a wind velocity less than 20 km.h^{-1} (local Meteorological Service, Santiago, Chile).

2.4-km Time Trial. As previously recommended (44), the time-trial 2.4 km test was used because of its multifaceted demands (maximal oxygen consumption, lactate threshold, running economy, muscle power) (10), likely to affect aerobic-related performance in soccer. After a warm-up run of 800-m and four minutes of rest, players performed six laps of a 400-m outdoor dirt track, timed to the nearest second, with a stopwatch. The wind velocity at all times was ≤9.9 km.h^{-1}, the relative humidity was between 50 and 70%, and the temperature was between 15 and 20° C (local Meteorological Service). Motivation was considered maximal as the test was conducted as part of the team selection process.

Maximal Dynamic Strength. A parallel squat test was selected to provide data on maximal dynamic strength (kg) of the lower extremity muscles. Maximal strength assessment, using concentric-eccentric five-repetition maximum parallel squat action, has been previously demonstrated to be safe for youth soccer players (37) and sensitive to the effects of plyometric drop jump training (37, 41). A complete anatomical and biomechanical description of the parallel squat test have been provided elsewhere (33). Briefly, the assessments were completed using free weights (after athletes had participated in two practice sessions), with the participant assuming an initial erect position with the bar behind the shoulders. Then, the participants lowered the bar until the upper portion of the thighs was parallel with the floor (determined visually by an experienced investigator). Finally, the participant performed a concentric leg extension (as fast as possible) to reach the full knee extension of 180° against the resistance determined by the weight. This action was repeated five times, with the maximum weight possible. Warm-up consisted of a set of 10 repetitions at loads of 40–60% of the perceived maximum (according to practice sessions). After 1 minute of rest and mild static stretching, participants performed a second set of 3–5 repetitions at loads of 60–80% of the perceived maximum. Thereafter, the athletes had a maximum of four separate attempts to find their 5RM. Of note, all athletes achieved ther maximum between the first or fourth attempt. The last acceptable five consecutive repetitions with highest possible load (kilograms) were determined as 5RM. The rest period between the actions was approximately five minutes. The reliability of lower-body 5RM testing has been previously established (45).

Training Program

The study was completed during the mid-portion of the participants' competition period. Prior to the competitive period, subjects completed two months of summer pre-season training, mainly devoted to strength and conditioning drills, including speed, change of direction, injury-prevention drills, body-mass resistance training drills (e.g., Nordic hamstring exercise), plyometric drills that included jump drills aimed at mastering technique (e.g., landing technique and shock absorption), small-sided games, and sporadic friendly matches. To measure the training load during the intervention, the session rating of perceived exertion (RPE) was determined once per week, as previously outlined (44). The plyometric drop jump training groups replaced some technical drills (i.e., ball control, ball pass, ball conduction and dribbling, ball kicking, ball heading exercises) with plyometric drop jump drills within the usual 90-minute practice twice per week (Tuesday and Thursday) for 7 weeks. All plyometric drop jump training sessions lasted ~21 minutes and were performed just after the warm-up to ensure that the players were in a rested state and gained optimal benefits (38). Plyometric drop jump drills included two sets of 10 repetitions of bounce drop jumps from 20, 40, and 60 cm (i.e., 60 contacts) performed on a grass soccer field, as in previous studies (37, 40, 44), where very similar (37) or identical (40, 44) interventions were demonstrated to be highly effective and safe in youth male soccer players. Previous studies have demonstrated the positive effects of different types of plyometric jump drills in youth soccer players (35, 42, 43), However, to avoid the role of different types of plyometric jump drills as a confounder in relation to the potential moderating role of maturity on the effects of plyometric jump training on physical fitness adaptations, only bounce drop jumps were included.

Although the athletes did not have any history of formal plyometric drop jump training, they were habituated to injury-prevention drills, including body-mass resistance training drills (e.g., Nordic hamstring exercise) and plyometric drills that included sprinting and jump drills aimed at mastering technique (e.g., landing technique and shock absorption). Independent from this, all participants were familiarized with proper jumping and landing techniques prior to the start of the training period by means of a 90 minute practice session.

The volume of training was not increased during the 7-weeks period, as maximal-effort plyometric drop jump exercises were employed. The intensity of the training sessions were self-regulated according to the progression rate of each individual, a technique that has been previously demonstrated to be safe and effective in similar plyometric training interventions in young boys (41), and youth soccer players (40, 44, 52). In this sense, athletes progressed from drop jumps of 20, 40, and 60 cm as long as they could manage a correct and safe execution, as described in the next paragraph.

The rest period between repetitions and sets was ~15 and 90 seconds, respectively. Participants were instructed to jump for maximal height and minimum contact time (37). Exercises were supervised using a coach-trainee ratio 1:4, and particular attention was paid to demonstration and execution. The strength and conditioning coaches were oriented to control training attendance and administration, provided technical instruction, feedback, and motivation to ensure adequate training intensity; provided social and mental support and exhibited a supportive attitude and avoided over-expectation. Basic techniques were stressed, such as correct posture (i.e., spine erect and shoulders back) and body alignment (e.g., chest over knees) throughout the jumps, jumping straight up with no excessive side-to-side or forward-backward movement, landing-shock absorption using toe-to-heel rocking and bent knees, and 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 training sessions. Aside from the formal training intervention, all participants attended their regular physical education classes, twice per week.

Statistical Analyses

The sample size for this study was determined a priori, computed according to the changes observed in plyometric (i.e., reactive strength index) performance (d = 0.3 $mm.ms^{-1}$; standard deviation = 0.04 $mm.ms^{-1}$) in a group of young adolescents submitted to the same training program applied in this study (41). Eight participants per group would yield a power of 80% and α=0.05. All values were reported as mean ± standard deviation (SD). Relative changes (%) in performance and effect size (ES) are expressed with a 90% Confidence Limits (CL). After data logaritmization, the normality and homoscedasticity assumptions for all data before and after intervention were checked respectively with Shapiro-Wilks and Levene tests. Dependent variables were analyzed in separate 2 (Groups: PJT – Control) × 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. To compare between PJT-early and PJT-late groups, a one-way analysis of variance was applied for the pre-post changes, taking the pre values as co-factor, with Bonferroni post-hoc procedures. The α level was set at $p<0.05$. Statistical analyses were performed by STATISTICA software (version 8.0; StatSoft, Inc., Tulsa, OK, USA). In addition to this null hypothesis testing, considering the need to gauge practical relevance, our collected data was also analyzed using Cohen´s *d* ES, as previously outlined (<0.2 = trivial; 0.2–0.6 = small; >0.6–1.2 = moderate; >1.2–2.0 = large; >2.0–4.0 = very large; >4.0 = extremely large) (17). A detectable effect size [*d*] of 0.2, as previously suggested after the application of comparable PJT programs (30), was considered as meaningful (i.e., smallest worthwhile change). To assess reliability, thresholds of ≥0.80 for the intra-class correlation coefficient were set (16).

RESULTS

The reliability of all applied physical fitness tests exceeded generally accepted thresholds, with intra-class correelation coefficients of 0.94, 0.91, 0.89, 0.88, 0.98, 0.89 and 0.81 for the CMJ, DJ20, DJ40, 5 multiple bounds, 20-m sprint-time, change of direction speed, and maximal kicking distance tests, respectively.

The PJT-early and PJT-late had large-very large differences in chronological ages (ES= 3.47, very large), pubic hair maturation stage (ES= 3.04, very large), body mass (ES=2.97, very large), height (ES=3.1, very large), BMI (ES=1.45, large), and soccer experience (ES=1.34, large). In contrast, the PJT-early compared to the Control-early, and the PJT-late compared to the Control-late had only trivial-small differences in chronological ages, pubic hair maturation stage, body mass, height, BMI, and soccer experience. Regarding session rating of perceived exertion, trivial-small (ES=0.11-0.2) differences were observed between the groups.

Within-group comparisons

Table 2 shows the within-group changes in the physical fitness tests after the intervention. The PJT-early group showed small to large improvements in all physical fitness measures (p<0.05; ES= 0.39 to 1.58), except in 20-m sprint-time (ES= 0.08). In contrast, the Control-early group showed only trivial-small changes in 20-m sprint-time, 2.4-km running time-trial, five multiple bounds , five repetition maximum squat, CMJ, DJ20, DJ40, and maximal kicking distance tests (p>0.05; ES= 0.0-0.37). Moreover, the Control-early demonstrated a detrimental effect on change of direction speed (p<0.05; ES=0.46).

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

The PJT-late group showed small to moderate improvements in all physical fitness measures (p<0.05; ES= 0.21 to 0.65), except in 20-m sprint-time (ES= 0.03). In contrast, the Control-late group showed only trivial-small changes in the 2.4-km running time trial, five repetition maximum squat, CMJ, DJ20, DJ40, and maximal kicking distance tests ($p>0.05$; ES= 0.02-0.29). Moreover, the Control-late showed a detrimental effect on 20-m sprint-time ($p<0.05$; ES=0.53) and change of direction speed ($p<0.05$; ES=0.36).

Between-group comparison

When compared to the Control-early group, the PJT-early group showed greater improvements in the 20-m sprint-time ($p<0.05$; ES=0.45), 2.4-km running time trial ($p<0.001$; ES=0.36), change of direction speed ($p<0.001$; ES=1.24), five repetition maximum squat ($p<0.05$; ES=0.13), five multiple bounds ($p<0.05$; ES=0.37), DJ20 ($p<0.001$; ES=1.45), DJ40 ($p<0.001$; ES=0.7) and maximal kicking distance tests ($p<0.001$; ES=1.25) (Table 2). No difference between groups were noted for the pre-post changes in CMJ ($p>0.05$; ES=0.13) (Table 2).

When compared to the Control-late group, the PJT-late group showed greater improvements in the 20-m sprint-time ($p<0.001$; ES=0.44), 2.4-km running time trial ($p<0.05$; ES=0.25), change of direction speed ($p<0.001$; ES=0.62), five repetition maximum squat ($p<0.05$; ES=0.27), CMJ ($p<0.05$; ES=0.16), five multiple bounds ($p<0.01$; ES=0.55), DJ20 ($p<0.001$; ES=0.62), DJ40 ($p<0.001$; ES=0.71) and maximal kicking distance tests ($p<0.05$; ES=0.75) (Table 2).

When the PJT-late group and the PJT-early groups were compared, no significant differences ($p>0.05$) were observed in physical fitness changes for the 20-m sprint-time, 2.4-km running time trial, change of direction speed, five repetition maximum squat, CMJ, and five multiple bounds tests (Table 2). However, greater improvements ($p<0.05$) were noted in favour of the PJT-early group compared to the PJT-late for the DJ20 (ES=0.5), DJ40 (ES=0.21), and maximal kicking distance (ES=0.23) tests (Table 2).

DISCUSSION

The aim of this study was to compare the effects of maturation on physical fitness adaptations to plyometric drop jump training in youth male soccer players. Main findings indicate that a 7-week plyometric drop jump training program was effective in improving physical fitness traits in both younger and older youth male soccer players. Moreover, although of small magnitude, plyometric drop jump training induced greater kicking, and jumping adaptations in less mature athletes compared to their older counterpart. Considering that previous studies have called for more research to elucidate the influence of biological age on the adaptive potential of PJT in youth (35), current results expand the limited knowledge available with regard to the trainability of different fitness qualities in this population.

The beneficial effects of PJT on sprint performance (ES=0.37) have been previously reported in a meta-analysis (50), especially after interventions in youth that incorporated horizontally oriented PJT drills (43). As our intervention incorporated only vertical-oriented drills, this may help to explain the lack of within-group improvements in both plyometric drop jump training groups (Table 2). Furthermore, a meta-analysis (6) reported that jump power training, while effective for improving jump measures was less effective than strength training for improving sprint performance. Of note, although within-groups improvements were not observed in the plyometric drop jump training groups, these groups maintained their sprinting performance, contrary to both control groups, which showed detrimental changes in 20-m sprint-time performance (Table 2). Previous PJT research in youth has demonstrated similar trends (30, 48), which in the current study may be related to the fact that soccer players completed a summer pre-season training devoted to strength and conditioning drills (i.e., speed training), while during the intervention a typical soccer training session involved mainly low-intensity technical-tactical drills. Of note, the PJT-late group achieved a similar change in 20-m sprint-time compared to the PJT-early group. Although hormonally- and physiologically-driven maturational thresholds (22), which regulate training adaptations may exist, current findings do not necessarily support such a contention. However, considering that, speed-related athleticism is a key trait for the long-term athletic development, and that its improvement may contribute to youth health and fitness, physical performance, injury prevention, confidence and competence (19), current results confirm the relevance of plyometric drop jump training to help youth male soccer players to maintain their sprinting speed performance, regardless of maturation status.

In the 2.4-km running time-trial test, both plyometric drop jump training groups improved to a greater extent than their respective control groups (ES=0.33-0.47; Table 2). Improvements in time-trial endurance physical fitness tests have been previously reported in youth after plyometric drop jump training (44). Of note, both plyometric drop jump training groups achieved similar improvements in the 2.4-km running time-trial test. Difficulties in identifying the role of maturation on endurance adaptations have been identified (4), with only a few studies reporting the maturation of participants in intervention studies. This is also a common problem among PJT literature (36). Therefore, it is difficult to compare current results with previous literature. PJT improves the neuromuscular SSC functioning (23) through improvements in motor unit activation, muscle action velocity, pre-activation and reliance on the short-latency stretch reflex, resulting in a more efficient SSC function (34). This could result in a greater magnitude of transference toward neuromuscular-related physical fitness in older youth (30), likely influencing running economy (9), and thus 2.4-km running time trial performance. However, future studies are needed to clarify this hypothesis, perhaps with the use of different doses (i.e., type of jump drill; volume), as current results indicate similar improvements in 2.4-km running time trial performance in both older and younger youths.

Regarding the change of direction speed test, both plyometric drop jump training groups improved to a greater extent (ES=0.28-0.9) than their respective control groups (Table 2). Improvements in change of direction speed have been previously reported in youth after plyometric drop jump training (44). Of note, although the within-group analysis indicated that the participants classified as early pubertal showed a moderate (ES=0.9) improvement and the youth classified as late pubertal showed only a small (ES=0.28) improvement, the between-group analysis indicated that both plyometric drop jump training groups achieved similar change of direction speed improvements (Table 2). Although the effects of plyometric drop jump training on change of direction speed have not been reported according to the maturation stage of male youth soccer players, a previous meta-analysis in male youth (1) indicated that PJT was effective in improving change of direction speed, however, greater gains were observed in older more mature youth (ES=0.95-0.99) compared to younger less mature youth (ES=0.68). Moreover, in the aforementioned meta-analysis it was indicated that change of direction speed could be improved with a volume of ~1,400 jumps, a greater dose of PJT than that applied in the current intervention study. Future studies may elucidate if a greater dose of plyometric drop jump training is needed to induce adaptations in change of direction speed in young male soccer players of different maturation status. Of note, both control groups reduced their change of direction speed after the seven weeks of intervention, as in previous studies (30, 48), possible reflecting the need of an increased focus on strength and conditioning drills during the in-season.

Both PJT-early (ES=0.49) and PJT-late (ES=0.49) groups improved five repetition maximum squat performance (Table 2). Improvements in maximum squat performance have been demonstrated after plyometric training in a meta-analysis (49). In the aforementioned meta-analysis, most included studies used drop jumps as the main type of plyometric jump drill. In addition, 40 jumps per session maximized the probability to improve strength performance, in less than 10 weeks (49). Such findings coincide closely with current results, as both PJT-early and PJT-late groups used 60 drop jumps per session during the seven weeks intervention period. Moreover, in addition to the aforementioned meta-analysis (49), current findings are in line with previous studies including interventions with youth (41) and youth soccer players (37) that completed similar volumes (60 jumps per session) of drop jump training. However, when PJT-early and PJT-late groups were compared, no differences ($p>0.05$) were noted for changes in squat performance after the seven weeks of intervention. Such results seems to contrast with those observed after traditional resistance training programs in youths. For example, a recent meta-analysis (28) observed greater gains in maximal strength in older more mature females (ES=0.72) compared to their younger less mature counterparts (ES=0.38) when resistance training interventions were analyzed. Similarly, in a study conducted in male youth (31), greater gains in maximal strength were observed in older more mature youth (ES=1.3, large) compared to their younger less mature counterparts (ES=0.8, moderate) after 8 weeks of resistance training. Therefore, maturation seems to exert a moderating role in the adaptive response of maximal strength of youth after resistance training, a phenomenon that may differ after short-term plyometric drop jump training interventions. In fact, although not focused on maturation-related adaptations, in a previous meta-analysis, age was not related to maximal strength adaptations after PJT (49), which in youth may be related to their rapid development of the nervous system and the marked role of neural-adaptations to PJT (23). However, to optimize strength enhancement, it seems that the combination of different types of plyometrics with weight-training is a relevant issue (49). Considering that maturation may exert a moderating role in the adaptive response of maximal strength of youth after resistance training (28, 31), further research is warranted in regard to the potential role of maturation on the adaptive response of maximal strength of youth after combined resistance training and different doses of plyometric jump drills.

Both plyometric drop jump training groups improved CMJ, five multiple bounds, DJ20, and DJ40 (Table 2). Moreover, both plyometric drop jump training groups achieved greater ($p<0.05$) improvements in five multiple bounds, DJ20, and DJ40 when compared to their respective control groups (Table 2). The beneficial effects of PJT on jumping ability have been previously reported (32). Of note, the PJT-early achieved significantly greater improvements in DJ20 (ES=0.5) and DJ40 (ES=0.21) when compared to the PJT-late group. This finding was corroborated in a recent meta-analysis, observing greater jumping improvements in younger (<15 yrs; ES = 0.78) compared to older females (ES=0.31) (27). Similarly, a meta-analysis observed greater jump improvements in younger less mature males (age, 10-12.9 years; ES=0.90) compared to older more mature counterparts (age, 13-15.9 years; ES=0.47) (32). It may be argued that during peak height velocity stage, the accelerated growth affects co-ordination and balance, which in this case might have adversely affected jump performance in the older boys, because of differential timing in the development of the trunk and legs (20) and rapid growth (8). Of note, in the present study the apparent effect of maturity on jumping adaptations to plyometric drop jump training (i.e., greater DJ20 and DJ40 improvements in PJT-early compared to PJT-late) occurred only in the jumping tests (i.e., DJ20 and DJ40) more similar to the jumping training drills used during the intervention (i.e., drop jumps from 20-cm and 40-cm). Therefore, if the effect of maturity depends of the specificity of the training program, further study must be undertaken to confirm this finding.

Compared to their respective control groups, both plyometric drop jump training groups achieved greater improvements in the maximal kicking distance test compared to trivial changes in both control groups (Table 2). The beneficial effects of PJT on kicking ability have been previously reported (13). Improvements in kicking performance might be attributed to neuromuscular adaptations such as increased strength and explosiveness of the leg extensor muscles (25), which can affect the instep kick in soccer (18). Additionally, improvements in coordination-related measures have been observed after PJT (53), potentially leading to improved coordination during kicking a soccer ball. Of note, the PJT-early achieved a significantly greater (ES=0.23) improvement in kicking performance when compared to the PJT-late group (Table 2). To our knowledge, this novel finding warrants further investigation in order to understand the underlying mechanisms.

Of note, current results were observed after the application of a specific type of plyometric jump drill, referred as drop jumps, in line with a conservative volume given its high-intensity nature. Drop jumps are probably the most common type of plyometric jump drill reported in the literature (35), and ~60 maximal-effort jumps per session have demonstrated to be a safe and effective volume to enhance the physical fitness variables analyzed in this study for youth male soccer players (11, 39-41, 49, 50). However, current results offer novel findings. In this sense, the effects of plyometric drop jump training varied according to the maturity status of youth male soccer players. This was especially marked in physical fitness traits (i.e., DJ20 and DJ40) directly related with the type of jump training drills used during the intervention. Further research is warranted in regard to the potential of other types of plyometric jump drills (and volumes) to improve relevant physical fitness traits in youth athletes in relation to their maturity status, including females.

A potential limitation of the study was the lack of physiological measures, including measures of biological maturation (e.g., skeletal maturation) due to logistical constraints. In addition, the utilised method of measurement related only to sexual maturation. Although participants self-reported values of sexual maturation with high reliability (i.e., intra-class correlation coefficient 0.9), such measure may not necessarily be equivalent to other measures, such as skeletal maturation or those that incorporate anthropometric variables to assess maturation status (26). Standardization of maturity assessment across studies is required to clarify the effects of maturation on adaptations to plyometric drop jump training (21, 34, 35).

In conclusion, a 7-week plyometric drop jump training program was effective in improving physical fitness traits in both younger and older male youth soccer players, but possibly, to a greater extent in less mature athletes, after a short-term program, that included a moderate-volume of vertical-oriented and maximal-effort plyometric drop jump training drills, during the in-season period.

PRACTICAL APPLICATION

The plyometric drop jump training program applied induced physical fitness improvements. Thus, a twice-weekly short-term high-intensity plyometric drop jump training program, implemented as a substitute for some soccer drills, can enhance jumping, sprinting, change of direction speed, endurance, maximal dynamic strength, and kicking ability in youth male soccer players compared with their peers than only training soccer, and these improvements are greater in younger youths. However, plyometric drop jump training is still effective in older youths. Considering that some young sport teams schedule training sessions without considering youth's maturation, the current findings may be relevant to programming plyometric drop jump training in this context. Although plyometric drop jump training could be effectively conducted in both younger and older youth male soccer players, whenever possible, plyometric drop jump training drills should be programed according to maturity.

Training history (i.e., soccer experience, strength and conditioning experience) may have a moderating role on the effects of plyometric jump training on physical fitness measures such as sprint (6) and jump (6, 11). Given the difficulty to portion out maturity and training history, the current study did not control for training history. Thus, the possibility exists that older youth may not have responded as strongly to the current plyometric drop jump training intervention due to a longer training history. It is tempting to hypothesize that older youth, thus, would require more demanding plyometric training programmes to make similar gains in physical fitness measures compared to less mature players with a lower training history. However, the moderating role of training history on the effects of plyometric jump training on other measures of physical fitness such as maximal strength (6, 49) and sprint (50) seems less clear. Further research would be needed in order to elucidate the potential role of maturation and both the volume and the quality of the training history on the adaptive response of different physical fitness measures of youth after different doses of plyometric jump training drills.

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