Effects of Maturation on Physical Fitness Adaptations to Plyometric Jump Training in Youth Females

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Abstract

Romero, C, Ramirez-Campillo, R, Alvarez, C, Moran, J, Slimani, M, Gonzalez, J, and Banzer, WE. Effects of maturation on physical fitness adaptations to plyometric jump training in youth females. *J Strength Cond Res* XX(X): 000–000, 2019—The aim of this study was to compare the effects of maturation on physical fitness adaptations to plyometric jump training (PJT) in youth females. Jumping, sprinting, change of direction speed, endurance, and maximal strength were measured pre-post 6 weeks of PJT in 7th- and 10th-grade subjects. In the seventh grade, subjects formed a PJT group (Plyo-7, $n = 10$; age, 12.7 ± 0.6 years; breast maturation stages IV [$n = 2$], III [$n = 7$], and II [$n = 1$]) and an active control group (Con-7, $n = 9$; age, 12.8 ± 0.6 years; breast maturation stages IV [$n = 2$], III [$n = 6$], and II [$n = 1$]). In the 10th grade, subjects conformed a PJT group (Plyo-10, $n = 9$; age, 16.3 ± 0.5 years; breast maturation stages V [$n = 5$] and IV [$n = 4$]) and an active control group (Con-10, $n = 9$; age, 16.2 ± 0.5 years; breast maturation stages V [$n = 5$] and IV [$n = 4$]). Magnitude-based inferences were used for data analysis, with effect sizes (ESs) interpreted as <0.2 = trivial; 0.2–0.6 = small; 0.6–1.2 = moderate; 1.2–2.0 = large; and 2.0–4.0 = very large. The Plyo-7 and Plyo-10 showed meaningful improvements in all physical fitness measures (ES = 0.21–2.22), while Con-7 and Con-10 showed only trivial changes. The Plyo-7 and Plyo-10 showed meaningful (ES = 0.16–2.22) greater improvements in all physical fitness measures when compared with their control counterparts. The Plyo-10 showed meaningful greater improvements in 20-m sprint, 2-km running time trial, maximal strength, squat jump, and drop jump from 20 cm (ES = 0.21–0.42) when compared with Plyo-7. In conclusion, PJT is effective in improving physical fitness in younger and older female youths. However, greater adaptations were observed in more mature subjects.

Key Words: explosive training, stretch-shortening cycle, women, force-velocity curve, strength, ballistic training, biological age, long-term athletic development

Introduction

Competent levels of strength, power, speed, agility, and endurance are required by youths to perform a range of movements with precision and confidence in a variety of athletic scenarios (13). Habitual development of these qualities may improve health and fitness, enhance physical performance, reduce the relative risk of injury, and develop confidence and competence in youths (13–16).

Plyometric jump training (PJT) is an effective means of physical conditioning, promoting improvements in skill-related measures of athletic performance, as well as in health (i.e., bone health) and resistance to injury (3,21,35). To implement safe and effective PJT programs, several key methodological characteristics should be considered. These include the overload principle (47), the volume and intensity of prescribed jumps (2,38,41), the order of within-session drill execution (39), the type of landing surface, and the direction of the jump drill (e.g., vertical vs. horizontal) (36).

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In addition to PJT configuration, the characteristics of program subjects should also be considered to optimize adaptive responses. Among the factors that can affect PJT outcomes are sex (46) and maturity status (3,27,30). A recent scoping review on PJT (36) postulated that more research should be conducted in female youths, with due consideration given to the effects of biological maturity on training adaptations. Specifically, from 242 reviewed articles, only ~10% were conducted in females younger than 18 years. In addition, only 3 studies incorporated a description of female subjects' maturation status (20,52,54). Unfortunately, none of these studies compared the response between maturity groups, and to the best of our knowledge, no controlled randomized study has examined the effects of maturation on physical fitness adaptations to PJT in female youth.

Maturation seems to play an influential role in the magnitude of fitness adaptations to exercise, lending credence to the theory of the existence of periods of accelerated adaptation to training (26,27,30). In a cross-sectional study, Lloyd et al. (17) demonstrated that there may exist periods of accelerated adaptation for stretch-shortening cycle (SSC) development before (between the ages of 10 and 11) and near (between the ages of 14 and 16) the time of peak height velocity (PHV). However, it is not yet entirely clear whether undertaking PJT during these periods can elicit greater performance increases than those that could be realized through maturation alone. Nevertheless, previous meta-analyses (3,26,30) and some interventions in male youth (4,28,29) have indicated greater adaptive responses to physical training in more mature individuals, also supporting the concept of "synergistic adaptation" (19) to the imposed demands of training.

The above cited studies underline, to varying degrees, the efficacy of PJT as a training method in youth. However, while detailed, evidence-based recommendations for young males have recently emerged, research in female youth remains scarce. This is an important issue in the prescription of exercise given the maturational differences that exist between males and females in and around the pubertal period. Despite maturing later than girls, boys gain around 7.2 kg of muscle mass annually during PHV, while girls achieve much less (3.5 kg per year) while also gaining a higher amount of fat mass (53). These concurrent processes can disproportionately reduce a female's relative strength and, by extension, her ability to jump higher and optimize adaptations to PJT through greater drop heights and, as a result, increased effectiveness of PJT due to resultant higher impact forces (18). Indeed, in females, few studies offer guidance as to when and how PJT should be implemented. Information relating to these factors may help practitioners to design strength and conditioning programs to stimulate motor/athletic development and to help prevent acute and overuse injuries. On that basis, the aim of this study was to compare the effects of maturation on physical fitness adaptations to PJT in youth females. According to relevant literature (3,27,30), it was hypothesized that greater adaptations would be apparent in older, more mature females compared with younger, less mature females.

Methods

Experimental Approach to the Problem

A single-blind randomized controlled trial was conducted to compare the effects of a 6-week PJT program, conducted in recreationally active youth females of different maturation status, on components of physical fitness (i.e., squat jump [SJ]; countermovement jump [CMJ]; drop jump from 20 cm [DJ20]; 20-m sprint time; change of direction speed [CODS-Illinois test]; 2-km running time trial; and 5 repetition maximum [5RM] half-squat).

Subjects

All subjects, as well as their respective parents or legal guardians, were informed about the experimental procedures and their possible risks and benefits before the start of the study. Written informed consent of legal representatives and subjects was also obtained. The study protocol was approved by the ethical review board for use of human subjects from the responsible institutional department and was in accordance with the latest version of the Declaration of Helsinki.

From a total population of 57 female students from the 7th and 10th grades of a local school, 38 females (aged 12–17 years) completed this study. In the seventh grade, subjects formed a PJT group (Plyo-7, n = 10; age, 12.7 ± 0.6 years; breast Tanner stages IV [*n* = 2], III [*n* = 7], and II [*n* = 1]) and an active control group (Con-7, *n* = 9; age, 12.8 ± 0.6 years; breast Tanner stages IV [*n* = 2], III [*n* = 6], and II [*n* = 1]). Similarly, in the 10th grade, subjects conformed a PJT group (Plyo-10, *n* = 9; age, 16.3 ± 0.5 years; breast Tanner stages V [*n* = 5] and IV [*n* = 4]) and an active control group (Con-10, *n* = 9; age, 16.2 ± 0.5 years; breast Tanner stages V [*n* = 5] and IV [*n* = 4]). All subjects met the following inclusion criteria: (a) a background of ≥2 years of systematic recreationally sports (i.e., basketball; indoor soccer; volleyball; and handball), (b) continuous participation in physical education classes for the previous 2 months without having sustained any musculoskeletal injuries, (c) no systematic PJT experience during the 4 months before the start of the study, (d) absence of potential medical problems that could compromise participation or performance in the study, and (e) absence of any lower-extremity surgery in the 2 years before the study.

The randomization procedure was conducted electronically (https://www.randomizer.org) and was concealed until the interventions were assigned. Subjects assigned to the PJT condition performed jump drills, replacing part of their physical education classes, twice per week. Subjects in the Con groups followed their regular physical education classes, twice per week. Before and after 6 weeks of training, subjects performed fitness tests in this following sequence: day 1: SJ, CMJ, DJ20, 20-m sprint time, CODS, and 2-km time trial; day 2: 5RM test. The training intervention was performed during the midterm of the school year. Four familiarization sessions were conducted with all subjects before the start of the study to explain testing and training procedures and to minimize any potential learning effects.

On recruitment to the study, subjects completed two 90-minute physical education sessions per week. In addition, subjects completed 2 weekly 60-minute sessions of recreational sports. Subjects had similar physical education and recreational sport schedules, as they belonged to the same public school and attended the same classes (7th and 10th, respectively). In addition, the same physical education teachers were in charge of their activities, and these teachers agreed to implement similar activities for the subjects for the duration of the study.

Procedures

Before and after training, physical fitness tests were scheduled ≥72 hours after a hard physical education class or recreational sport training session to minimize the effects of fatigue. Tests were completed, between 15:00 and 18:00 hours, on the same indoor wooden gym floor where subjects usually performed their physical education class and recreational sport training. Subjects used the same sport clothes that they usually wore during physical education class or recreational sport training. The same investigator, who was blinded to subjects' group allocation, conducted all measurements. Subjects were asked to perform the tests with maximal effort and were evaluated over 2 days. On the first day, data on age, stature, body mass, and maturity status according to self-assessment of secondary sex characteristics were collected, as previously outlined (40,44). Briefly, subjects were asked to self-determine maturation stage using standard diagrams of breasts 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 1 week later for test-retest reliability. An intraclass correlation coefficient of 0.91 was observed between measurements. On the first day, subjects also performed the following tests in this sequence: SJ, CMJ, DJ20, 20-m sprint time, CODS, and the 2-km time trial test. On day 2, the 5RM test was performed. For statistical analyses, the highest score from 3 attempts was retained for all tests except for the maximal 2-km time trial and 5RM tests. A rest interval of at least

2 minutes was allowed between each physical fitness trial. While waiting, subjects performed low-intensity activities (e.g., walking, low-intensity ball games) to maintain their readiness for the next test. Ten minutes of general (i.e., submaximal running with changes of direction) and specific (i.e., vertical and horizontal submaximal jumps) (1) exercises was performed before each testing session as a warm-up. In addition, subjects performed a test-specific warm-up that comprised 2 practice jumps, runs, or lifts.

Anthropometry. Stature was measured using a stadiometer (Bodymeter 206; SECA, Hamburg, Germany, to 0.1 cm) and body mass on an electrical scale (InBody120, model BPM040S12FXX; Biospace, Inc., Seoul, Korea, to 0.1 kg). The body mass index was determined by dividing body mass by the square height of the subject ($kg·m^{-2}$).

Vertical Jump Tests. All jump tests were based on previous recommendations (41,43,45). Briefly, for the vertical jumps (i.e., SJ, CMJ, and DJ20), subjects executed maximal jumps on a contact mat (Ergojump; Globus, Codogne, Italy) with hands positioned on the hips. The obtained flight time (t) was used to estimate the height of the rise of the body's center of gravity (h) during the vertical jumps (i.e., $h = gt^2/8$, where $g = 9.81\ m·s^{-2}$). Take-off and landing were standardized to the same spot on the ground, and subjects were required to maintain full knee and ankle extension during the flight phase. Subjects were instructed to maximize their jump height. During the SJ, the subject was instructed to adopt a flexed knee position (~90°) during 3 seconds, followed by a maximal effort vertical jump. During the CMJ, the subject performed a downward movement with no restriction imposed over the knee angle achieved, followed by a maximal effort vertical jump. In addition, for the DJ20 test, the subjects were instructed to minimize ground contact time (<250 ms; controlled during testing sessions) after dropping down from a 20-cm box. To this aim, the subjects were instructed to step off the platform with the leading leg straight to avoid any initial upward propulsion ensuring a drop height of 20 cm. The reactive strength index was calculated as jump height (millimeter) divided by ground contact time (milliseconds) (37).

Linear and Change of Direction Speed Sprint. Sprint time was assessed to the nearest 0.01 seconds using single-beam timing [gates (Brower Timing System, Salt Lake City, UT, USA). Subjects started in a standing position with the toe of the preferred foot placed forward and behind a starting line. Time began automatically when the subject voluntarily initiated the test. The timing gates were positioned at the start line (0.3 m in front of the subject) and at the 20-m point, being set ~0.7 m above the floor (i.e., hip level). This system enabled the capturing of trunk movement rather than a false trigger from a limb. For the CODS test, the timing system and procedures were the same as for the 20-m sprint except that the subjects had to run as quickly as possible while performing several changes of direction (i.e., the Illinois CODS test) (41). The test was used to determine the ability to accelerate, decelerate, turn in different directions, and run at different angles.

2.4-km Time Trial. Considering the recreational sport involvement of subjects, the 2.4-km time trial was used because of its multidimensional demands (maximal oxygen consumption, lactate threshold, running economy, and muscle power) on the aerobic energy system. After a warm-up run of 800 m and 4 minutes of rest, subjects individually performed 6 laps of a 400-m outdoor tartan track, timed to the nearest second, with a stopwatch. The wind velocity was approximately ≤7.9 $km·h^{-1}$, and relative humidity was between 60 and 70%. The temperature was between 16 and 19° C (local meteorological service). This was the only test that took place outdoors. Subjects were instructed to run for maximal performance, with motivation provided continuously.

Maximal Dynamic Strength (5 Repetition Maximum Test). A parallel squat was selected to test maximal dynamic strength of the lower extremity muscles, using a concentric-eccentric 5RM parallel squat action. A complete anatomical and biomechanical description of the parallel squat test has been provided elsewhere (33). Briefly, the test was completed using free weights, with the subject assuming an initial bipedal position with the bar at shoulder level. From the initial position, subjects performed a downward movement until the upper portion of the thighs was parallel with the ground (determined visually by the investigators). After this, the subjects performed a concentric leg extension (as fast as possible) in an effort to stand erect with the weight. The action was repeated 5 times, with the maximum weight possible. The warm-up involved a set of 10 repetitions at 40–60% of the perceived 5RM. After 1 minute of rest and mild stretching, subjects performed another warm-up set of 3–5 repetitions at 60–80% of the perceived 5RM. Thereafter, the subjects had a maximum of 5 maximal attempts, with 3–5 minutes of rest between each. The attempt with the highest possible load (kilograms) was deemed as the 5RM.

Training Program. The PJT program was completed during the third trimester of the school year (October–November, springtime, southern hemisphere). The drills, sets, repetitions, and progressions per week are detailed in Table 1. The design of the [T1] PJT intervention was based on subjects' previous training records and research results (36,42). Thus, the PJT included bilateral, unilateral, cyclic, acyclic, vertical, horizontal, and turn jumps, in addition to fast ground contact times <250 ms) and slow (ground contact times >250 ms) SSC muscle actions, with a strong emphasis on landing technique and force absorption. The PJT replaced some drills in physical education class, twice per week, and was immediately performed after a warm-up (39) for the 6-week intervention period. The PJT replacement activity accounted for ~9% of the total physical education and recreational sport activities of the subjects (friendly matches were not accounted for). Each PJT session included 3 sets of 5 different jump drills with 7–11 repetitions per set. The jump drills included DJ, standing long jump, unilateral CMJ, 180° jump, and repeated CMJ. A detailed technical description of each jump drill has been provided elsewhere (37). Briefly, the DJ and the repeated CMJ were performed with hands on the hips, and the other jump drills were performed using an arm swing. During vertical and horizontal jumps, subjects were encouraged to achieve maximal vertical height and horizontal distance, respectively. During DJs, subjects were instructed to minimize ground contact time (<250 ms) after dropping down from an optimal height drop box to maximize the ratio between vertical height and ground contact time. During DJs, all subjects used individualized box heights (i.e., 5- to 35-cm) as previously recommended (38).

To ensure that subjects used sufficient intensity during PJT sessions, jump heights, distances, and contact times for selected drills were verified in a randomly assigned subsample of subjects (2 from each group) during 2 randomly selected PJT sessions. During these sessions, ground contact times, jump heights, and

Table 1
Training program.*

	Weeks 1–2	Week 3	Week 4	Week 5	Week 6
Drop jumps (repetitions)	3 × 8	3 × 9	3 × 10	3 × 11	3 × 7
Standing long jumps (repetitions)	3 × 8	3 × 9	3 × 10	3 × 11	3 × 7
Unilateral countermovement jumps (repetitions)	3 × 8	3 × 9	3 × 10	3 × 11	3 × 7
180° jumps (repetitions)	3 × 8	3 × 9	3 × 10	3 × 11	3 × 7
Repeated countermovement jumps (repetitions)	3 × 8	3 × 9	3 × 10	3 × 11	3 × 7

*The order of execution for the jump drills was randomized each week to add variation into the training program.

distances were tested using the same procedures and equipment as described above. Briefly, the maximal or near-maximal intensity for CMJ, standing long jump, and DJ20 was verified by measuring height, distance, or contact time of the respective jump training drill.

The order of drills was randomized in each week to add variation during training (8). In this way, players started with 120 jumps per leg during each session in the first week of training, graduating to 165 jumps per leg during each session in the fifth week. During the sixth week, the number of jumps per leg was reduced to 105 jumps in each session. An investigator to subject ratio of 1:4 was realized in all training sessions, and particular attention was paid to the technical execution of jumps. The PJT sessions lasted between 16 and 56 minutes, with a mean of ~21 minutes. The 2 PJT groups achieved the same number of jump repetitions during the intervention with the same progressive overload and taper strategies. Also, both PJT groups trained at the same time of day (11:30–13:00 hours), with the same rest intervals between sessions (i.e., 72–96 hours), drills and sets (i.e., 30–60 seconds) (40), and jumps (i.e., 5–15 seconds for acyclic jumps) (36,44). In addition, the PJT volume was equally distributed (i.e., 530 foot contacts) over 3 different surfaces (i.e., wood, gym mat, and tartan track) per session. All surface types occurred at the same indoor (i.e., wood and gym mat) and outdoor (i.e., tartan track) locations, and the order of surface usage was randomized weekly.

Statistical Analyses

Statistical analyses were performed by STATISTICA software (version 8.0; StatSoft, Inc., Tulsa, OK, USA). Descriptive statistics (mean ± *SD*) for the different variables were calculated. Normality for all data before and after the intervention was checked with the Shapiro-Wilk test. Magnitude-based inferences were preferred to traditional null hypothesis testing which can be biased by small sample sizes and can be ineffective in gauging practical importance (12). Cohen's d effect sizes [ESs] were interpreted using previously outlined ranges (<0.2 = trivial; 0.2–0.6 = small; 0.6–1.2 = moderate; 1.2–2.0 = large; 2.0–4.0 = very large; and >4.0 = extremely large) (12), with an ES of 0.2 considered to be the *smallest worthwhile change* (9,12,24,34). The estimates were considered unclear when the chance of a beneficial effect was high enough to justify the use of the intervention, but the risk of impairment was unacceptable. An odds ratio of benefit to impairment of <66 was representative of such unclear effects (28). This odds ratio corresponds to an effect that is borderline possibly beneficial (25% chance of benefit) and borderline most unlikely detrimental (0.5% risk of harm). This was calculated using an available spreadsheet (10). Otherwise, the effect was considered as clear and was reported as the magnitude of the observed value, with the qualitative probability that the true value was at least of this magnitude (28). The scale for interpreting the probabilities was as follows: possible = 25–75%; likely = 75–95%; very likely = 95–99.5%; and most likely >99.5% (12). Uncertainty in the ESs was represented by 90% confidence limits. Effects were considered unclear if the confidence interval overlapped thresholds for substantial positive and negative values. Otherwise, the effect was clear and reported as the magnitude of the observed value with a qualitative probability (12,28,29), using the expression beneficial, harmful, or trivial. The used confidence limits of 90% are important in intervention studies in which one is presented with an inexpensive intervention that is most unlikely to be harmful but likely to demonstrate at least a trivial increase in performance (i.e., ES of 0.2) (10,28). Analyses were conducted (a) within all groups, to examine the pre-post changes in performance for the intervention period, (b) between control and PJT groups to examine the effect of the PJT intervention, and (c) between the PJT groups to examine the effect of maturation on PJT-induced adaptations. To assess reliability, thresholds of ≥0.80 for the intraclass correlation coefficient were set (11). As in a previous PJT study (38), the reliability of the applied tests, both before and after the intervention, was above the established threshold and ranged from 0.89 to 0.98.

Results

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

Age, Maturation, and Somatic Traits

The Plyo-7 and the Con-7 groups had similar chronological ages (ES = 0.17, trivial) and maturation breast stage (ES = 0.01, trivial). Both the Plyo-7 and the Con-7 groups showed small increments in body mass (ES = 0.23 and 0.39, respectively) and height (ES = 0.32–0.28, respectively), with trivial changes in body mass index (ES = 0.06 and 0.07, respectively) (Table 2). [T2] Trivial (ES = 0.00–0.03) differences were observed between the Plyo-7 and the Con-7 groups regarding changes in somatic variables (Table 3).

The Plyo-10 and the Con-10 groups showed trivial to small differences in chronological ages (ES = 0.20, small) and maturation breast stage (ES = 0.01, trivial). Both the Plyo-10 and the Con-10 groups showed trivial changes in body mass (ES = 0.15 and 0.08, respectively), height (ES = 0.09–0.06, respectively), and body mass index (ES = 0.07 and 0.03, respectively) (Table 2). Trivial (ES = 0.02–0.08) differences were observed between the Plyo-10 and the Con-10 groups regarding changes in somatic variables (Table 3).

When the Plyo-7 and the Plyo-10 groups were compared, the later showed greater chronological age (ES = 6.50, extremely large) and maturation breast stage (ES = 2.70, very large).

Table 2

Training effects (with 90% confidence limits) for the somatic and physical fitness variables of the female 7th-grade control group (Con-7, *n* = 9), 10th-grade control group (Con-10, *n* = 9), 7th-grade plyometric training group (Plyo-7, *n* = 10), and 10th-grade plyometric training group (Plyo-10, *n* = 9).

	Before	After	Δ%	Effect size	Clinical inference
Body mass (kg)					
Plyo-7	40.9 ± 3.0	41.7 ± 3.2	2.0 (1.6 to 2.4)	0.23 (0.19 to 0.28)	Likely beneficial
Con-7	43.8 ± 2.0	44.6 ± 1.8	1.8 (1.4 to 2.3)	0.39 (0.29 to 0.49)	Most likely beneficial
Plyo-10	54.0 ± 3.0	54.5 ± 3.1	0.9 (0.7 to 1.1)	0.15 (0.11 to 0.19)	Very likely trivial
Con-10	56.1 ± 2.8	56.4 ± 2.9	0.4 (0.1 to 0.7)	0.08 (0.02 to 0.13)	Most likely trivial
Height (m)					
Plyo-7	145.8 ± 3.2	146.9 ± 3.1	0.7 (0.6 to 0.9)	0.32 (0.27 to 0.37)	Most likely beneficial
Con-7	150.5 ± 3.1	151.5 ± 3.2	0.7 (0.4 to 0.9)	0.28 (0.19 to 0.38)	Likely beneficial
Plyo-10	153.9 ± 3.6	154.3 ± 3.5	0.2 (0.1 to 0.4)	0.09 (0.04 to 0.14)	Most likely trivial
Con-10	155.9 ± 3.8	156.2 ± 3.7	0.2 (0.0 to 0.3)	0.06 (0.01 to 0.11)	Most likely trivial
Body mass index (kg·m^{-2})					
Plyo-7	19.3 ± 1.5	19.4 ± 1.4	0.5 (0.1 to 0.9)	0.06 (0.01 to 0.11)	Most likely trivial
Con-7	19.4 ± 1.2	19.5 ± 1.2	0.5 (0.1 to 0.9)	0.07 (0.01 to 0.13)	Most likely trivial
Plyo-10	22.8 ± 1.2	22.9 ± 1.3	0.4 (0.1 to 0.7)	0.07 (0.02 to 0.12)	Most likely trivial
Con-10	23.1 ± 0.8	23.1 ± 0.8	0.1 (−0.4 to 0.6)	0.03 (−0.12 to 0.17)	Very likely trivial
20-m sprint (s)					
Plyo-7	4.8 ± 0.3	4.5 ± 0.3	5.8 (−6.7 to −4.9)	0.89 (−1.03 to −0.75)	Most likely beneficial
Con-7	4.8 ± 0.2	4.7 ± 0.2	0.9 (−1.8 to 0.0)	0.19 (−0.38 to 0.0)	Possible beneficial
Plyo-10	4.4 ± 0.3	4.0 ± 0.2	9.0 (−9.7 to −8.2)	1.53 (−1.67 to −1.39)	Most likely beneficial
Con-10	4.6 ± 0.2	4.6 ± 0.3	0.8 (−2.0 to 0.3)	0.14 (−0.32 to 0.05)	Possible beneficial
2-km time trial (s)					
Plyo-7	562 ± 35.5	540 ± 40.2	4.0 (−5.1 to −2.8)	0.54 (−0.7 to −0.38)	Most likely beneficial
Con-7	541 ± 65.1	548 ± 67.9	1.1 (−1.1 to 3.4)	0.09 (−0.08 to 0.26)	Likely trivial
Plyo-10	612 ± 65.9	576 ± 68.1	5.9 (−7.2 to −4.7)	0.51 (−0.62 to −0.4)	Most likely beneficial
Con-10	625 ± 57.4	636 ± 48.6	2.0 (−0.2 to 4.2)	0.21 (−0.02 to 0.44)	Unclear
Change of direction speed test (s)					
Plyo-7	22.7 ± 2.0	20.8 ± 2.2	8.6 (−9.8 to −7.3)	0.85 (−0.98 to −0.72)	Most likely beneficial
Con-7	22.1 ± 1.3	22.1 ± 1.3	0.2 (−1.6 to 1.2)	0.04 (−0.26 to 0.18)	Likely trivial
Plyo-10	21.1 ± 0.9	18.8 ± 1.0	11.1 (−12.1 to −10.1)	2.22 (−2.43 to −2.0)	Most likely beneficial
Con-10	21.0 ± 0.9	20.9 ± 1.3	0.8 (−2.1 to 0.5)	0.13 (−0.36 to 0.09)	Possible beneficial
5 repetition maximum squat (kg)					
Plyo-7	29.6 ± 5.58	33.7 ± 6.9	13.7 (10.1 to 17.3)	0.6 (0.45 to 0.75)	Most likely beneficial
Con-7	32.1 ± 7.0	32.8 ± 6.6	2.4 (0.4 to 4.4)	0.11 (0.02 to 0.2)	Likely trivial
Plyo-10	37.7 ± 9.8	45.1 ± 8.9	21.2 (15.4 to 27.3)	0.8 (0.6 to 1.01)	Most likely beneficial
Con-10	38.4 ± 7.4	39.0 ± 7.4	1.5 (0.0 to 3.0)	0.07 (0.0 to 0.14)	Most likely trivial
Squat jump (cm)					
Plyo-7	19.8 ± 2.8	20.9 ± 2.7	5.6 (3.7 to 7.5)	0.37 (0.25 to 0.5)	Very likely beneficial
Con-7	19.4 ± 3.0	19.3 ± 2.2	0.1 (−3.5 to 3.4)	0.01 (−0.23 to 0.22)	Likely trivial
Plyo-10	22.3 ± 2.5	24.4 ± 2.9	9.2 (7.3 to 11.2)	0.68 (0.54 to 0.81)	Most likely beneficial
Con-10	22.9 ± 1.8	22.9 ± 1.6	0.2 (−1.9 to 2.3)	0.03 (−0.23 to 0.28)	Likely trivial
Countermovement jump (cm)					
Plyo-7	21.3 ± 2.7	22.7 ± 2.8	6.4 (3.8 to 9.0)	0.44 (0.27 to 0.62)	Very likely beneficial
Con-7	20.8 ± 3.5	21.0 ± 3.7	0.9 (−2.0 to 3.9)	0.04 (−0.11 to 0.19)	Likely trivial
Plyo-10	24.1 ± 2.3	26.5 ± 3.0	9.8 (7.3 to 12.4)	0.81 (0.61 to 1.01)	Most likely beneficial
Con-10	23.8 ± 2.1	24.4 ± 2.2	2.4 (−0.2 to 5.1)	0.24 (−0.02 to 0.51)	Unclear
20-cm drop jump (mm·ms^{-1})					
Plyo-7	0.8 ± 0.3	0.9 ± 0.3	8.7 (5.9 to 11.6)	0.21 (0.14 to 0.28)	Possible beneficial
Con-7	0.9 ± 0.2	1.0 ± 0.3	0.9 (−4.5 to 6.6)	0.03 (−0.17 to 0.24)	Likely trivial
Plyo-10	1.0 ± 0.3	1.2 ± 0.3	21.6 (13.5 to 30.3)	0.81 (0.52 to 1.09)	Most likely beneficial
Con-10	1.0 ± 0.1	1.1 ± 0.2	2.7 (−4.7 to 10.6)	0.18 (−0.33 to 0.68)	Unclear

Effects of Plyometric Jump Training on Physical Fitness

The Plyo-7 group showed small to moderate improvements in all physical fitness measures (ES = 0.21–0.89), while the Con-7 group showed only trivial changes (Table 2). The Plyo-7 group showed trivial to moderate (ES = 0.16–1.10) greater improvements in all physical fitness measures when compared with the Con-7 group (Table 3).

Similarly, the Plyo-10 group showed moderate to very large improvements in all physical fitness measures (ES = 0.51–2.22), while the Con-10 group showed only trivial changes (Table 2). The Plyo-10 group showed moderate to very large (ES = 0.69–2.22) greater improvements in all physical fitness measures when compared with the Con-10 group (Table 3).

Effects of Plyometric Jump Training on Physical Fitness According to Maturation Status

The Plyo-10 group showed meaningful (ES = 0.21 to 0.42) greater improvements in 20-m sprint (ES = 0.42), 2-km time trial (ES = 0.21), 5RM (ES = 0.26), SJ (ES = 0.23), and 20DJ

Table 3

Between-group comparison of the training effects (with 90% confidence limits) for the somatic and physical fitness variables of the female 7th-grade control group (Con-7, *n* = 9), 10th-grade control group, (Con-10, *n* = 9), 7th-grade plyometric training group (Plyo-7, *n* = 10), and 10th-grade plyometric training group (Plyo-10, *n* = 9).

	Effect size	Clinical inference
Body mass (kg)		
Plyo-7 vs. Con-7	0.02 (−0.11 to 0.06)	Most likely trivial
Plyo-10 vs. Con-10	0.08 (−015 to −0.01)	Most likely trivial
Plyo-10 vs. Plyo-7	0.06 (0.03 to 0.09)	Most likely trivial
Height (m)		
Plyo-7 vs. Con-7	0.03 (−0.12 to 0.07)	Most likely trivial
Plyo-10 vs. Con-10	0.02 (−0.09 to 0.05)	Most likely trivial
Plyo-10 vs. Plyo-7	0.13 (0.09 to 0.18)	Very likely trivial
Body mass index ($kg \cdot m^{-2}$)		
Plyo-7 vs. Con-7	0.0 (−0.08 to 0.08)	Most likely trivial
Plyo-10 vs. Con-10	0.08 (−0.22 to 0.06)	Likely trivial
Plyo-10 vs. Plyo-7	0.0 (−0.04 to 0.04)	Most likely trivial
20-m sprint (s)		
Plyo-7 vs. Con-7	0.87 (0.67 to 1.7)	Most likely beneficial
Plyo-10 vs. Con-10	1.37 (1.13 to 1.6)	Most likely beneficial
Plyo-10 vs. Plyo-7	0.42 (0.26 to 0.59)	Very likely beneficial
2-km time trial (s)		
Plyo-7 vs. Con-7	0.52 (0.25 to 0.8)	Very likely beneficial
Plyo-10 vs. Con-10	0.76 (0.51 to 1.02)	Most likely beneficial
Plyo-10 vs. Plyo-7	0.21 (0.03 to 0.38)	Possible beneficial
Change of direction speed test (s)		
Plyo-7 vs. Con-7	1.1 (0.86 to 1.35)	Most likely beneficial
Plyo-10 vs. Con-10	2.2 (1.88 to 2.53)	Most likely beneficial
Plyo-10 vs. Plyo-7	0.04 (0.03 to 0.05)	Most likely trivial
5 repetition maximum squat (kg)		
Plyo-7 vs. Con-7	0.52 (−0.69 to −0.36)	Most likely beneficial
Plyo-10 vs. Con-10	0.75 (−0.96 to −0.53)	Most likely beneficial
Plyo-10 vs. Plyo-7	0.26 (−0.48 to −0.05)	Possible beneficial
Squat jump (cm)		
Plyo-7 vs. Con-7	0.38 (−0.64 to −0.12)	Likely beneficial
Plyo-10 vs. Con-10	0.84 (−1.1 to −0.58)	Most likely beneficial
Plyo-10 vs. Plyo-7	0.23 (−0.4 to −0.06)	Possible beneficial
Countermovement jump (cm)		
Plyo-7 vs. Con-7	0.27 (−0.49 to −0.06)	Possible beneficial
Plyo-10 vs. Con-10	0.69 (−1.05 to −0.33)	Very likely beneficial
Plyo-10 vs. Plyo-7	0.19 (−0.43 to 0.04)	Unclear
20-cm drop jump ($mm \cdot ms^{-1}$)		
Plyo-7 vs. Con-7	0.16 (−0.32 to −0.01)	Possible beneficial
Plyo-10 vs. Con-10	0.84 (−1.38 to −0.31)	Very likely beneficial
Plyo-10 vs. Plyo-7	0.32 (−0.53 to −0.11)	Likely beneficial

(ES = 0.32) when compared with the Plyo-7 group (Table 3). Regarding the CODS (ES = 0.04) and the CMJ (ES = 0.19) tests, trivial differences were observed between the groups (Table 3).

Discussion

The aim of this study was to compare the effects of maturation on physical fitness adaptations to PJT in youth females. Main results indicate that the Plyo-10 group showed improvements in 20-m sprint, 2-km time trial, CODS, 5RM, SJ, CMJ, and 20DJ test between ES 0.51–2.22, whereas the Plyo-7 group showed improvements between ES 0.21–0.89. To the best of our knowledge, this is the first study that investigated maturation-related responses to PJT in female youth. We speculate that, compared with less mature females, older females may achieve greater physical fitness improvements after PJT due to progressive improvements in neuromuscular-related functioning of the SSC (22,23,35), neural drive to the agonist muscles (21), optimization of relative force generated per motor unit recruited (35), leg muscle qualities (50), direction of force production and application (31), and running economy (6).

The beneficial effects of PJT on sprint performance have been previously reported, especially after interventions in youths who incorporated horizontally oriented PJT drills (43), as in the current study. Improvements may be related to increased horizontal force production and application (31), in addition to other factors (49) such as increased muscular power, muscle composition, and neuromuscular adaptations. Of note, the Plyo-10 group achieved a large improvement (ES = 1–53), whereas the Plyo-7 group achieved only a moderate improvement (ES = 0.89) in the 20-m sprint time test (Table 2). Similarly, previous results obtained in male youth hockey players indicated greater improvements in 10-m sprint performance after 6 weeks of PJT in older (ES = 0.4) compared with younger (ES = 0.1) youths (28). In addition, greater improvements in 20-m sprint performance were observed in older (ES = 0.66) than in younger (ES = 0.12) male soccer players after 6 weeks of PJT (4). Furthermore, in a recent meta-analysis in male youth (26), sprint training seemed to be more effective in older (ES = 1.39) than it was in younger study subjects (ES = −0.18), considering interventions that lasted between 4 and 16 weeks. In this sense, maturational thresholds may exist (27,29,30), and they could moderate responses to physical training. Considering that speed-related athleticism is a key trait in long-term athletic development, its improvement may contribute to youths' health and fitness, physical performance, injury resistance, confidence, and competence (13).

In the 2-km time trial, both PJT groups improved, with ES values of 0.54 and 0.51 for the Plyo-7 and Plyo-10 groups, respectively (Table 2). Increases in time trial endurance have been previously reported in youths after PJT (5,44), and the results of the current study may be partially related to improved running economy owing to improvements in neuromuscular variables such as reactive strength index (6). In a recent scoping review of 242 articles on PJT (36), only 3 studies incorporated a description of female subjects' maturation status, with none comparing the response between maturity groups. Accordingly, it is difficult to AU7 ascertain the mechanisms responsible for the adaptations in older and younger females. However, PJT improves the SSC muscle function (21) through improvements to motor unit activation, muscle action velocity, preactivation, and reliance on the short-latency stretch reflex, resulting in a more efficient SSC function (35). This could result in a meaningful transference toward neuromuscular-related physical fitness (3,26,30), likely influencing running economy and thus 2-km time trial performance.

Regarding the CODS test, the within-group analysis indicated that the Plyo-10 group achieved a very large improvement (ES = 2.2), whereas the Plyo-7 group achieved only a moderate improvement (ES = 0.85) (Table 2). Improvements in CODS have previously been reported in youths after PJT (32,44). Several factors may explain CODS performance changes including movement technique, straight sprinting speed, anthropometry, reactive strength, concentric strength, and power or left-right muscle asymmetry (50). Although the effects of PJT on CODS have not previously been reported according to maturation status of youth females, a previous meta-analysis in youth males (3) indicated that PJT was effective in improving CODS. However, greater gains were observed in older more mature youths (ES = 0.95–0.99) compared with younger less mature youths (ES = 0.68). In the aforementioned meta-analysis, it was indicated that

CODS could be improved with 2 weekly sessions of PJT, with a volume of ~1,400 jumps, a similar dose of PJT as that applied in the current intervention study.

Regarding the 5RM test, both PJT groups improved, with ES values of 0.6 and 0.8 for the Plyo-7 and Plyo-10 groups, respectively (Table 2). The beneficial effects of PJT on maximal strength have previously been reported (ES = 0.97) (48). Improvements in strength after short-term PJT may be related to neural adaptations, including improved motor-unit firing frequency, synchronization, excitability, and efferent motor drive, among other factors (21). This can result in the optimization of the relative force generated per each motor unit recruited (35). The lack of studies addressing the effects of PJT in youth females according to maturation status makes current results difficult to compare. However, adding some important context, a recent meta-analysis on resistance training (25) observed greater gains in maximal strength in older more mature females (ES = 0.72), compared with their younger less mature counterparts (ES = 0.38). Similarly, in a study conducted in male youth (29), greater gains in maximal strength were observed in older more mature youths (ES = 1.3, large) compared with 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 to PJT in youth females, a phenomenon that seems to be reflective of male populations. Considering the role of maximal strength on the health status of youths (7), current results have key implications.

Both PJT groups improved jumping physical fitness traits (SJ, CMJ, and DJ20), with small ES values of 0.21–0.44 for the Plyo-7, whereas the Plyo-10 group achieved moderate ES values of 0.68–0.81 (Table 2). The beneficial effects of PJT on jumping ability have previously been reported (30). Improvements in jumping height may be related to several neuromuscular adaptations, such as improvements in SSC function, neural drive to the agonist muscles, muscle activation strategies such as inter-
AU8 muscular and intramuscular coordination, muscle size and/or architecture, and single-fiber mechanics (21).In a previous study in male youth, greater vertical jump improvements were observed in older more mature males (ES = 0.4, small) compared with their younger less mature counterparts (ES = 0.02, trivial) (29). Similarly, a meta-analysis observed greater jump improvements in older more mature males (ES = 1.02) compared with younger less mature subjects (ES = 0.47) (30). A lack of clarity in how the aforementioned neuromuscular improvements induced by PJT (21) are manifested in females of different maturation, in addition to the confounding effects of maturation-related changes on the SSC function (35), means that explanations of the effects are speculative and more research is needed to elucidate underlying mechanisms.

The current novel findings are not without limitations that should be acknowledged. We did not control for the menstrual cycle, which may potentially affect the behavior of the SSC (51) and, thus, long-term adaptive responses. In addition, considering the potential of PJT to induce a broad range of neuromusculoskeletal and performance adaptations (21) related to health and fitness (13–16), future studies may also consider the analysis of such adaptations. In this sense, future studies should strive to incorporate physiological and biomechanical analyses to better understand the potential underlying mechanisms of the changes observed in the physical fitness variables analyzed in female youths with different maturation status after a short-term lower-body PJT program. Finally, future studies may aim toward replication of current findings using a greater sample size.

In conclusion, a 6-week PJT program was effective in improving meaningful physical fitness traits in both younger and older youth females, including 20-m sprint, 2-km time trial, CODS, 5RM, SJ, CMJ, and 20DJ. However, greater improvements for 20-m sprint, 2-km time trial, 5RM, SJ, and 20DJ were observed in older, more mature female youths. Considering that previous studies have called for more research to elucidate the influence of biological age on the adaptive potential after PJT (30,36) in youth females, current results expand the limited knowledge available with regard to the trainability of different fitness qualities in this population.

Practical Applications

The plyometric training program applied induced physical fitness improvements which may have transference to sport performance and health status. Thus, a twice-weekly, short-term high-intensity PJT program, implemented as a substitute for some physical education drills, can enhance jumping, sprinting, CODS, endurance, and maximal dynamic strength in youth females compared with physical education classes alone. These improvements are greater in older youths. However, PJT is also effective in younger youths. Considering that some young sport teams and physical education classes schedule training sessions without considering youths' maturation status, the current findings may be relevant to programming PJT in this context. Although PJT could be effectively conducted in both younger and older female youth, whenever possible, and assuming technical competency is present, they can be programed according to maturity.

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