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A META-ANALYSIS OF PLYOMETRIC TRAINING IN
FEMALE YOUTH: ITS EFFICACY AND SHORTCOMINGS IN
THE LITERATURE

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ABSTRACT

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 XX(X): 000–000, 2018—This meta analysis characterized female youths' adaptability to plyometric training (PT). A second objective was to highlight the limitations of the body of literature with a view to informing future research. Fourteen studies were included in the final analysis. The effect size (ES = Hedges' g) for the main effect of vertical jump performance was "small" (ES = 0.57, 95% confidence interval: 0.21–0.93). Effect sizes were larger in younger (,15 years; ES = 0.78 [0.25–1.30] vs. 0.31 [20.18 to 0.80]), shorter (,163 cm; ES = 1.03 [0.38–1.68] vs. 0.25 [20.20 to 0.70]), and lighter (,54 kg; ES = 1.14 [0.39–1.89] vs. 0.26 [20.15 to 0.67]) participants. Programming variables seemed to influence adaptive responses with larger effects in interventions which were longer (8 weeks; ES = 1.04 [0.35–1.72] vs. 0.24 [20.11 to 0.59]), had greater weekly training frequency (.2; ES = 1.22 [0.18–2.25] vs. 0.37 [0.02–0.71]), and whose sessions were of longer duration ($30 minutes ES = 1.16 [0.14–2.17] vs. 0.33 [0.03–0.63]). More than 16 sessions per program (0.85 [0.18–1.51]) was more effective than exactly 16 sessions (0.46 [0.08–0.84]) which, in turn, was more effective than less than 16 (0.37 [20.44 to 1.17]). These findings can inform the prescription of PT in female youth.

KEY WORDS girls, exercise, sport, athlete, jump, maturation

INTRODUCTION

The stretch forces that occur during dynamic movement incite eccentric muscle actions, with the resultant elastic energy potentiating force production in subsequent concentric actions (33,59). An individual's ability to use this mechanism is an important factor in physical performance with rapid actions such as sprinting and jumping underpinned by efficient usage of the stretch-shortening cycle (54). Plyometric training (PT) is defined as any exercise that can help a working muscle to exert maximal force in as short a time as possible (7). This training method is used to improve impulsive capacities and typically includes various unilateral and bilateral jumps, hops, and bounds (7). A recent meta-analysis reinforced the variable effectiveness of PT in male youth (54); yet, no such investigation has ever been conducted in female youth.

A limitation of the current body of literature relating to PT in female youth is that a large amount of studies address only the role of exercise as a mechanism of injury prevention (87), particularly relating to the anterior cruciate ligament. That is a necessary and worthwhile line of inquiry but far less research focuses on the extent to which female youth adapt to different types of training as they mature. Indeed, it could be argued that the higher levels of physical robustness associated with trained individuals (15), characterized by relatively higher performance levels, could play a role in offsetting injury itself. In this way, the goals of injury prevention and performance enhancement may be intertwined and should be concurrently pursued by coaches with a view to optimizing health and athleticism (42).

Plyometric training has been found to have varying degrees of effectiveness at different stages of development in youth, owing to the rapid and concurrent underlying processes of maturation (54,78). This has implications for the training practitioner because if an individual is relatively less likely to adapt to a given training type based on maturational characteristics, a reduction in the chronic load of that training type could be justified with a view offsetting potential overreaching or burnout (9). In this way, the magnitude of adaptive responses can dictate the composition of the training program (42). Recent research (48,69,78) in males has facilitated the formation of conclusions such as this, which can inform the approach adopted by the training practitioner. Yet, the same attention has not been directed toward female youth, a curious observation, given the common occurrence of injuries in that population (81) and the suggestion that increased fitness reduces susceptibility (18).

A recent meta-analysis (88) in female athletes did include some studies in youth females but this population constituted just a very small minority of the included studies (n = 4), likely due to differing inclusion criteria. This justifies a more focused investigation in that population: our review includes 3 of the 4 studies in female youth that were included in that meta-analysis and 11 further additions.

The purpose of this systematic review and meta-analysis is 2-fold. First, it was our intention to finally quantify the effects of PT in a female youth population with a view to clarifying the impact of this type of exercise on explosive performance (jumping). We hypothesized that PT would be effective in female youth but would be influenced by age, anthropometric factors, and program variables. The second objective of this review was to describe the state of the current body of literature as it relates to this topic, highlighting shortcomings in current research and describing the path that investigators must take to address these shortcomings. These factors have recently been addressed in relation to resistance training (51), but never for PT.

METHODS

Experimental Approach to the Problem

This meta-analytical review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (40).

Literature Search

With no date restrictions, a systematic search of the Google Scholar database was initially undertaken. This was supported by further searches of the PubMed and Web of Science databases from which only English language articles were considered. Boolean logic was used to refine the results with the following terms used: youth AND training AND female AND plyometric OR stretch-shortening cycle OR jump OR strength OR power OR weightlifting OR resistance OR speed OR velocity OR agility OR sprint OR sprinting OR alactic OR acceleration OR running OR exercise OR change of direction OR paediatric OR pediatric OR young OR children OR adolescence OR athletes OR sport OR volume OR intensity OR fitness OR high OR load OR rest OR sets OR repetitions. In selecting studies for inclusion, a review of all relevant article titles within was conducted before an examination of article abstracts and, then, full published articles. Only peer-reviewed articles were included in the meta-analysis. The reference lists of those that remained were hand-searched for further articles that could have met the inclusion criteria, in addition to the hand searching of relevant reviews. The search process is outlined in Figure 1. This brief review was approved by Hartpury College, University of the West of England.

Procedures

The extraction of data from gathered articles was undertaken by 3 reviewers (J.M., C.C.C.T., and M.J.D.) with a standardized form created in Microsoft Excel. The first reviewer collected the data before the second and third reviewers investigated its accuracy and the eligibility of studies for inclusion. Where required data were not clearly or completely reported, article authors were contacted for clarification. Five authors (16,22,35,79,89) responded to requests to provide original data. The following criteria determined the eligibility of studies for inclusion in the review: healthy females, between the mean age of 8 and 18 years. Plyometric interventions must have been between 4 and 16 weeks in duration and must have included a control group. We defined plyometrics as "lower-body unilateral and bilateral bounds, jumps, and hops that use a pre-stretch or countermovement that incites usage of the stretch-shortening cycle" (6,7). The training protocols of included interventions must have had an element of unloaded PT with an appropriate performance test that was based on a logically defensible rationale (91), most often some form of countermovement jump (CMJ). The CMJ is reminiscent of athletic movements because it is performed with a fast transition between the downward and upward stages of the action, which requires utilization of the stretchshortening cycle (23). The CMJ also seems particularly sensitive to the applied stimuli of PT (93), possibly owing to the similarity of the motor pattern in training and outcome variables. The measure also has very high test-retest reliability (85) and so was chosen on the basis of establishing a degree of consistency between analyzed studies. Mean values and SDs for a measure of post-intervention performance were used to calculate an effect size (ES). The characteristics of the study participants are displayed in Table 1.

Analysis and Interpretation of Results. Meta-analytical comparisons were performed in RevMan version 5.3 (75). Included were 14 studies that comprised 17 individual experimental groups. The inverse-variance random-effects model for meta-analyses was used because it allocates a proportionate weight to trials based on the size of their individual standard errors (8) and facilitates analysis while accounting for heterogeneity across studies (34). Effect sizes are represented by the standardized mean difference (Hedges' g) to account for small sample sizes and are presented alongside 95% confidence intervals. The calculated ESs were interpreted using the conventions outlined for standardized mean difference by Hopkins et al. (28) (,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).

In cases in which there was more than one intervention group in a given study, the control group was proportionately divided to facilitate comparison across all participants (26).

To gauge the degree of heterogeneity among the included studies, the I2 statistic was referred to. This represents the proportion of effects that are due to heterogeneity as opposed to chance (40). Low, moderate, and high levels of heterogeneity correspond to I2 values of 25, 50, and 75%; however, these thresholds are considered tentative (27). The x2 statistic determines whether the differences in the results of the analysis are due to chance and in such a case, a low p value, or high x2 statistic, relative to degrees of freedom would be apparent (8).

A risk of bias quality scale was not used for a number of reasons: The Cochrane Collaboration has previously discouraged the use of these scales, stating that the practice is not underpinned by empirical evidence and assessment criteria may apply inaccurate study weights (25). Also, the subjectivity of personal opinion undermines the accuracy of such scales (25). Blinding of study participants and trainers is undermined owing to the constraints that make such a practice difficult to implement in training intervention studies (5). Indeed, a recent review (39) that applied the PEDro scale (63) found that only 4 of 43 resistance training studies were able to meet the associated criteria, potentially preventing a meta-analysis occurring in the first instance. Given the dearth of relevant data pertaining to PT in female youth, this was a potential danger to this study. Previous systematic reviews (4,30) of PTamong children and adolescents suggest that studies tend to be of low to medium quality.

Analysis of Moderator Variables. To assess the potential effects of moderator variables, subgroup analyses were performed in addition to the main analysis. The moderator variables were analyzed with a random-effects model and were selected based on differences in participants' characteristics and training program variables that could be deemed to exert an influence on the training effect of applied interventions. An age-based division was made between study groups whose participants were younger or older than 15 years. This division was made on the basis that this is the age at which full adult height is typically achieved in females (20), thus allowing for a comparison of those study participants who were undergoing maturational change and those who had largely completed it. As there were no groups aged below 11 years (44), which coincides with the initiation of the female growth spurt, this represented a valid subgroup for analysis. Such a factor could be an important determinant of trainability in female youth. A similar division was made between groups whose participants were greater or less than 163 cm in stature. This represents an approximation of average female stature in the fully mature state (64). Plyometric training has previously been found to be less effective in pubertal males (54) and this was hypothesized to be the case in females also. With the high variability of body mass across various populations, body mass was divided into subgroups with a median split (greater or less than 54 kg) for the entire sample of participants. Age, height, and body mass were all chosen as moderator variables because of the effect of age and biological maturation on explosive performance in female youth (13). The moderator variables of program duration (weeks), training frequency (sessions per week), total number of training sessions, and session duration (minutes) were chosen based on the accepted influence of the FITT principle on adaptations to exercise (66). Each variable was divided using a median split, except for mean total sessions in which studies were allocated as 16 sessions, more than 16 sessions, and less than 16 sessions groups.

RESULTS

Main Effect

Across all included studies, there was a small, significant improvement in jump performance (ES = 0.57 [0.21–0.93], Z = 3.09 [p = 0.002]). The overall estimate was of small magnitude but showed a significant level of between-study heterogeneity (I2 = 68% [p , 0.0001]). These results are displayed in Figure 2.

Effect of Moderator Variables

A summary of the effect of moderator variables can be viewed in Table 2. Subgroup analysis suggested moderate to moderately high levels of between-group heterogeneity with stature, body mass, and number of weeks achieving statistical significance (p , 0.05). Older, taller, and heavier study participants adapted to PT to a substantially lesser degree than their younger, shorter, and lighter counterparts, respectively, with “moderate” effects being achieved in the groups with larger adaptations. Interventions with a training frequency of more than 2 sessions per week produced the largest effect (ES = 1.22 [0.18–2.25], Z = 2.31 [p = 0.02]); however, this may be conflated, given that the longest programs (in weeks) generally had the most frequent training sessions. In relation to this, those PT programs that lasted longer than 8 weeks demonstrated substantially larger effects (ES = 1.04 [0.35–1.72], Z = 2.97 [p = 0.003]) than those that lasted less than 8 weeks (ES = 0.24 [20.11 to 0.59], Z = 1.37 [p = 0.17]).

Similarly, sessions that lasted longer than 30 minutes were substantially more effective (ES = 1.16 [0.14–2.17], Z = 2.24 [p = 0.25]) than those that lasted less than 30 minutes (ES = 0.33 [0.03–0.63], Z = 2.14 [p = 0.03]). Mean estimates remained mostly heterogeneous across subgroups and the level of heterogeneity was higher in subgroups with larger ESs, longer programs, greater training frequency, more training sessions, and longer training session durations.

DISCUSSION

The main finding of this meta-analysis was that PT was effective in female youth, but only to a small magnitude. However, because PT is often combined with other forms of training, these results should be interpreted with caution.

Several studies have previously underlined the effectiveness of PT in female youth (57,58,61), with potential mechanisms being attributed to enhanced neural drive to agonist muscles, alterations to musculotendinous stiffness, increases in muscle size and architecture, improved intermuscular coordination, greater excitability of the stretch reflex, and changes in muscle fiber mechanics (84). It is plausible that these factors play a role in adaptations to PT across different populations to varying degrees, but manipulation of training variables, in addition to age and anthropometric factors, might also play a moderating role.

It is interesting to note that older, taller, and heavier study participants demonstrated substantially smaller effects than their younger, smaller, and lighter counterparts, respectively.
There are a number of different explanations that could underpin these findings. The age range of the younger subgroup (,15 years) encompasses the interval of maximal growth, which occurs between the ages of 11 and 13 in female youth (44). During the interval of maximal growth, there is a concurrent increase in performance (45) that could be additive if combined with training that elicits similar adaptations. This is a phenomenon recently termed as “synergistic adaptation” (43) and although it has been tested (69) in male youth, there are no relevant investigations in youth females to the best of the authors’ knowledge. Moreover, although boys gain around 7.2 kg of muscle mass annually during peak height velocity, girls achieve much less (3.5 kg per year) while also gaining a higher amount of fat mass (90).
These concurrent processes can reduce a female’s relative strength and, by extension, her ability to jump higher and optimize adaptations to PT. This could potentially favor younger, less mature females in facilitating adaptive responses to this type of training. As the interval of maximal growth in females occurs in close proximity to peak weight velocity, it is entirely possible that the negative effects of increased body mass are coincident with progressing stature.
To address this, practitioners could add resistance training to a PT program with a view to offsetting decreases in relative strength, an addition that may be especially effective during adolescence (78).
In reference to maturational factors, a comparatively smaller body of literature in female youth prevented us from adopting the same approach as a previous meta-analysis (54) in male youth that quantified effects in its main analysis into pre-, mid-, and post-peak height velocity groups. Indeed, relatively little attention has been paid to the concept of performance enhancement in female youth in general (88).
Reviews (2,52,53,78) and interventions (43,48,69,77) of resistance, plyometric, and sprint training in males are abundant.
With a more recent focus on maturation (48,69,77), this has added another dimension to the depth of knowledge relating to male youths. However, training interventions that focus on the mediating effect of maturation on performance in females are scarce. Previous evidence has demonstrated that variables related to force production and impulse are affected by maturation status in female youth (13). Indeed, despite the gradual progression of peak force production capability across the maturation spectrum, the ultimate difference between more and less mature female youth is significant (13). Maturation status has previously been shown to be a differentiator of performance levels in young males and

these differences must be considered when prescribing training programs (54). It stands to reason that the same considerations should apply within a female population; however, to date, there has been no clear consensus on the degree to which girls of different maturity status adapt to training. This is a direct result of the lack of studies that focus on PT in female youth, from a performance perspective at least, and this is reflected in the age profile of the participants of the studies in this analysis.

As researchers have generally failed to control for maturation status, the clarity of inferences that can be made from current literature is further undermined. Noninvasive methods of maturation assessment such as those developed by Khamis and Roche (32) and Mirwald (49) are commonly used in both research and practice to gauge the biological maturation status of youth. Although these methods are undermined by certain limitations, the data that they can generate are nonetheless helpful in categorizing youth into maturation groups. In none of the included studies, or those excluded due to lacking a control group, did researchers report maturation status with these methods. This is particularly puzzling, given that altered motor coordination during puberty has been suggested to be a key factor in the higher incidence of anterior cruciate ligament injury in female youth, a risk that is compounded by emergent strength deficits, which could further predispose the knee joint to acute and chronic injury (67). It stands to reason that even an approximate identification of the timing of the growth spurt could afford researchers the facility to test training interventions that are specific to participants' stage of biological maturation, thus targeting the aforementioned weaknesses.

Given that in the majority of studies, researchers collect both stature and body mass data, the addition of seated stature to a typical testing battery is neither work-intensive or time consuming; yet, this option is availed far less than in male youth (43,48,50,69,77). The addition of this information can facilitate calculation of maturation status with the method of Mirwald (49). In future studies, researchers are encouraged to report biological maturity status in female youth participants.

Compounding the above matter is the common trend of researchers grouping both males and females together within study groups for the purposes of statistical analysis (11,21,37). In certain cases, this may be warranted, for instance when attempting to test the effectiveness of a given training method independent of sex (74) or maturation status.

Furthermore, the small sample sizes that are typical in training studies somewhat justify such an approach to enhance statistical power. However, this does not mean that researchers cannot also report the results of males and females separately within the same study. The grouping of the sexes at the expense of individual analyses is suboptimal in isolation and should be policed by reviewers. Indeed, this should be considered an essential element of any study in youth: males and females experience different maturational changes, which occur at different times and rates (46) as they grow. This results in discrepancies in physical performance (17), which can undermine the validity of study conclusions if such factors are not controlled for. Researchers are encouraged to report anthropometric and performance data of males and females separately with a view to increasing the amount of studies that can be included in future meta-analyses. For an exemplary demonstration of how to present quantitative and graphical data for boys and girls within a single intervention study, the reader is referred to the works of Lindblom et al. (41) and Muehlbauer et al. (55).

Related to this, a further limitation of the current body of literature relating to this issue is the relatively high number of studies that did not include a control group. Five studies (38,58,60–62) were excluded only on the basis that they did not provide any, or sufficient, control group data. This is a particularly important study design feature in interventions in youth, given that rapid changes in maturation status can result in both increases or decreases in physical performance (24,94). The recruitment of individuals to studies, particularly those studies that are of high quality (63,92) and large sample size (60), is difficult and the addition of a control group is not always possible. Nevertheless, with a view to progressing this area of pediatric exercise science, researchers are encouraged to prioritize this during the conceptualization and design stages of studies.

Based on the data presented in Table 2, certain programming characteristics such as longer session times (.30 minutes), greater session frequency (more than 2 sessions per week), longer PT programs (.8 weeks), and a greater number of sessions in total (.16) could enhance the effectiveness of a training cycle, although there is no suggestion that these factors are necessarily synergistic when combined. Slimani et al. (84) state that to maximize the chances of adaptation, programs must contain 20 sessions or last for 10 weeks. This is consistent with the results of this meta-analysis, although it is unclear whether the 8-week program duration recommended here is due to youths' ability to adapt faster, given relatively lower exposure to a PT stimulus and, thus, a higher ceiling for adaptation. In any case it seems that in female youth, 3 sessions per week is substantially more effective than 2 or less per week, underlining the general trend of a positive dose response in the population. This is reinforced by the finding that programs with a total of more than 16 sessions seem more effective than those with exactly 16 sessions which, in turn, are more effective than those with less than 16 sessions. A dose response is also apparent in male youth (54) and it could therefore be recommended that female youths who are appropriately prepared to train (14) can benefit from PT 3 times per week over an 8-week period. It seems that sessions that last 30 minutes or longer are the most effective, but it is unclear as to why this is the case. One potential explanation is that the longer a given training session, the higher the volume of training that is undertaken within that session.

Another potential reason is that sessions may be longer in duration due to the prescription of longer rest periods between sets of PT. Readiness to perform subsequent sets of PT within a training session is dependent on adequate replenishment of ATP and creatine phosphate (36). Indeed, Ramirez-Campillo et al. (71) reported larger effects on CMJ in youth soccer players who rested for 60 or 120 seconds between sets as compared to a group that rested for only 30 seconds. In that study, it seemed that 60 seconds was the optimal rest time between sets, although it was conducted in male participants. A further limitation of the research relating to female training programs is that although some robust training interventions have been implemented, researchers have very often not measured their effects on performance tests that demonstrate participants' ability to develop propulsive forces. For example, DiStefano et al. (10) implemented a plyometric program but measured effects on biomechanical variables only, reporting only limited changes. If measures of physical performance, such as CMJ, are not used, some important adaptations that occur due to PT may not be captured. This is not an insignificant issue owing to the specificity of adaptive responses to different types of training (93), including PT (72,73), as well as practitioners' need to respect the principle of training specificity (19) when constructing programs of physical preparation.

The aforementioned issues are part of a wider trend of inadequate data reporting and presentation within the literature on physical training in female youths. One such study (47) provides highly detailed, group-specific baseline data for male and female cohorts, each consisting of 2 training groups and 1 control group. It is unfortunate that the follow-up data are only graphically presented, making it difficult to calculate an accurate ES and this is compounded by the pooling of each of the training cohorts, making it impossible to distinguish intervention-specific effects. A similar problem arises in other studies (29,86,89) and although these represent just a few examples of such reporting flaws, perusal of the reasons for the exclusion of other studies from this review (Figure 1) reveals the greater extent of the issue. This is particularly disappointing in studies of relatively large sample sizes (60), which can provide much-needed statistical power to pooled analyses. This issue is serious enough to conclude that knowledge on the effectiveness of PT in female youth is resultantly scarce, given that meta-analysis of much of the existing body of knowledge is not possible.

Myer et al. (58) demonstrate the benefit of presenting data both graphically and in text.

Such issues of data presentation are impediments to the meta-analyst, given that the body of literature is not necessarily small; yet, because physical training studies tend to be inherently of low quality (63,92), the statistical power of single studies is limited. The contacting of study authors to clarify certain issues relating to data presentation can be successful; however, due to language barriers, changing contact details, and some researcher's unwillingness or inability to share original data sets, this is by no means a reliable form of data collection. The reporting of ESs by researchers in their studies is also a welcome trend; however, this does not necessarily solve the problem of substandard data reporting because the original raw data are still required if a metaanalyst wants to analyze data under fixed- or randomeffects models with suitable software (75).

One notable feature of the gathered studies in this metaanalysis was the preponderance of investigations that have not been peer-reviewed and remain unpublished. This is unfortunate as there are likely to be many unknown investigations that can add value to the body of literature, thereby compounding the already problematic trend of publication bias. Researchers are encouraged to publish their study results even if intervention effects are trivial, small, or nonsignificant and journal editors are, in turn, encouraged to consider the value of such results. From the practitioner's perspective, knowing which methods not to apply is as important a factor in training prescription as is the adoption of a best practice approach.

We believe this research to have some limitations. The lack of uniformity in how training programs are constructed within studies could contribute to high levels of heterogeneity.

This is an extremely difficult variable to quantify and control for across plyometric studies, but a recent review by Ramirez-Campillo et al. (70) offers some clarity as to how researchers can achieve this in the future, across a variety of populations. This can give rise to inconsistencies among the results, which can undermine the confidence of study recommendations (27). Related to this, many studies in this analysis include not only PT, but also other forms of exercise such as resistance training. This could lead to confounded results, although the specificity of the outcome measure to the applied training stimuli counteracts this to a certain extent (54,92). Nonetheless, the presented results should be interpreted with caution. In future, researchers could consider performing PT without the potential interfering effects of other forms of training (70). Also, in relation to subgroup analysis, the division of continuous data through median split can result in residual confounding and reduced statistical power (1). Furthermore, the effects of these programming variables were calculated independently, and not interdependently. Univariate analysis must be interpreted with caution because the programming parameters were calculated as single factors, irrespective of betweenparameter interactions. The conclusions are, nonetheless, in line with conventional recommendations for the programming of PT (12).

PRACTICAL APPLICATIONS

Plyometric training seems to enhance jumping ability in female youth. However, the current body of literature prevents more detailed conclusions relating to the potential variability of adaptive responses across the maturational continuum, as in males. As a general recommendation, practitioners could expose trainees to 3 sessions of more than 30-minute duration over a period of 8 weeks. However, older, taller, or heavier individuals may be less responsive to training owing to maturation-related increases in body fat that can potentially reduce relative strength. The addition of resistance training to a PT program could serve as a solution to this problem (52); however, workloads should be sensibly balanced, particularly during the interval of maximal growth when reduced motor control can result in injury. Researchers are urged to continue to investigate the effects of training in youth and to concentrate more effort into measuring performance and maturation status and to strive to include control groups in intervention studies. If researchers include both males and females in the same study, the resultant data should be presented in a way that discerns one group from the other so that sex-specific inferences can be made. Data should be presented in its raw form, with graphical representations being used to add context to the reported results.
In addition, researchers are encouraged to publish both positive and negative study results. It is important for the training practitioner to know which PT strategies could be detrimental to performance, or even injurious, and this can underpin improved practice as the body of knowledge grows in the coming years.

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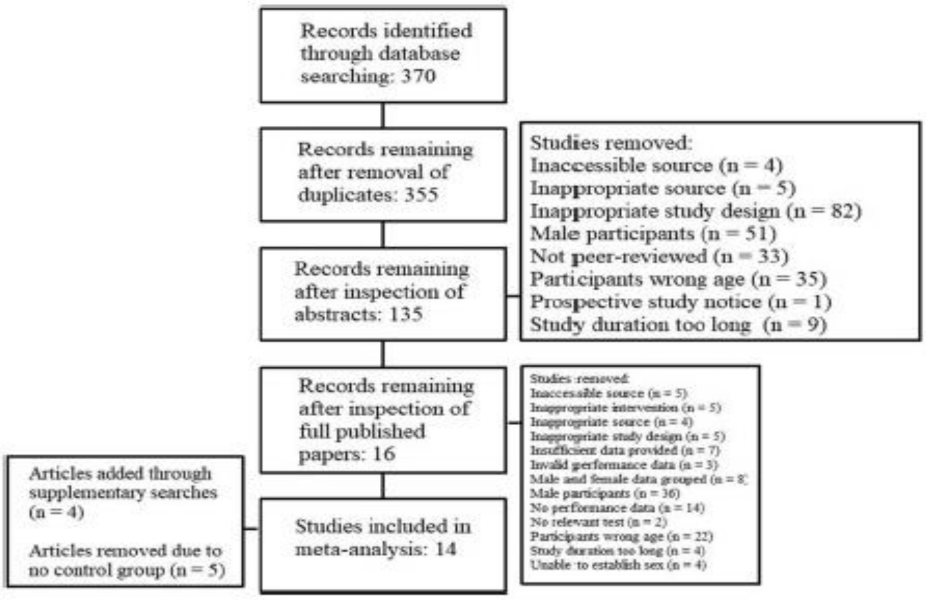

Figure 1

Table 1.

Table 1. Characteristics of study participants.

Author	Study group	Mean age (yrs)	Mean stature (cm)	Mean body mass (kg)	Sport	Participants	Wks	Frequency (per wk)	Total sessions	Mean session duration (mins)	Exercise type	Test
Attene et al. (3)	Basketball plyometric training	14.8	163.0	51.9	Basketball	18	6	2	12	20	Hurdle jumps, box jumps, drop jumps, lunge jumps	Countermovement jump (hands on hips) (cm)
Attene et al. (3)	Basketball technique training	15.2	165.0	57.5	Basketball	18						Countermovement jump (hands on hips) (cm)
de Fontenay et al. (16)	Specific physical training group	15.5			Basketball	9	8	2	16	20	Vertical jumps, side jumps, rotational jumps, long jumps, scissors jumps, drop jumps	31-cm drop jump (flight time–ms)
de Fontenay et al. (16)	Combined physical and mental training group	15.5			Basketball	7	8	2	16	20	Vertical jumps, side jumps, rotational jumps, long jumps, scissors jumps, drop jumps	31-cm drop jump (flight time - ms)
de Fontenay et al. (16)	Control group	15.5			Basketball	8						31 cm drop jump (flight time–ms)
Hall et al. (22)	Plyometrics training group	12.5			Gymnastics	10	6	2	12	45	Tuck jumps, split jumps, squat jumps, barrier jumps (15 cm, 30 cm), alternate-leg push-offs, single-leg bounding, box jumps (to and from), standing long jumps	Countermovement jump (cm)
Hall et al. (22)	Control group	12.5			Gymnastics	10						Countermovement jump (cm)
Karadenizli (31)	Experimental group	15.6	161.3	56.4	Handball	14	10	2	20	22.5	Hurdle jumps	Countermovement jump with arms (cm)
Karadenizli (31)	Control group	15.4	160.1	55.9	Handball	12						Countermovement jump with arms (cm)
Krističević et al. (35)	Plyometric group	15.4	170.8	60.8	Volleyball	27	5	2	10		Hurdle jumps, depth jumps, lateral hurdle jumps, lunge jumps, vertical jumps	Countermovement jump (cm)
Krističević et al. (35)	Control group	15.5	169.1	61.3	Volleyball	27						Countermovement jump (cm)

Lindblom et al. (41)	Intervention group	14.2	165.0	53.9	Soccer	23	11	2	22	15	Forward/backward single-leg jumps, lateral jumps w/ single-leg landing, forward jump w/ single-leg landing	Countermovement jump (hands on hips) (cm)
Lindblom et al. (41)	Control group	14.2	164.2	51.6	Soccer	18						Countermovement jump (hands on hips) (cm)
Mulcahy and Crowther (56)	Intervention group	16.4	165.0	57.0	Netball	8	8	2	16	30	Depth jumps, countermovement jumps, single-leg bounds	Vertical jump (cm)
Mulcahy and Crowther (56)	Control group	15.6	171.9	70.0	Netball	8						Vertical jump (cm)
Pereira et al. (65)	Experimental group	14.0	160.0	52.0	Volleyball	10	8	2	16	20	Bilateral jumps (with and without knee bends), unilateral jumps (for speed and for distance)	Countermovement jump (hands on hips) (cm)
Pereira et al. (65)	Control group	13.8	160.0	53.5	Volleyball	10				20		Countermovement jump (hands on hips) (cm)
Racil et al. (68)	Combined plyometric exercise and high-intensity interval training	16.5	163.0	82.5	General population	26	12	3	36		Double-leg jumps, hurdle hops, zig-zag jumps, single-leg cone hops	Countermovement jump (hands on hips) (cm)
Racil et al. (68)	Control group	16.9	164.0	81.8	General population	19						Countermovement jump (hands on hips) (cm)
Rubley et al. (76)	Plyometric	13.4	162.5	50.8	Soccer	10	12	1	12		Single-leg cone hops, 10-inch hurdle hops (forward and lateral), 12-inch box shuffles, 10-inch box jumps, 10-inch depth jumps	Vertical jump with one step (cm)
Rubley et al. (76)	Control	13.4	162.5	50.8	Soccer	6						Vertical jump with one step (cm)
Sannicandro et al. (79)	Experimental group	12.8	162.5	47.5	Tennis	4	6	2	12	30	Single-leg bounds, forward bounds, successive jumps from inflatable disk w/3 s landing hold	Unilateral hop distance (mean of both legs, cm)
Sannicandro et al. (79)	Control group	13.0	157.3	44.5	Tennis	4						Unilateral hop distance (mean of both legs, cm)
Santos et al. (80)	Strength training	13.5	159.4	58.9	Various	21	8	2	16		Box jumps, hurdle jumps	Countermovement jump (hands on hips) (m)
Santos et al. (80)	Combined strength and endurance training	13.5	157.9	54.8	Various	25	8	2	16		Box jumps, hurdle jumps	Countermovement jump (hands on hips) (m)
Santos et al. (80)	Control group	13.5	156.8	51.5	Various	21						Countermovement jump (hands on hips) (m)
Siegler et al. (82)	Experimental group	16.5	167.4	61.5	Soccer	17	10	3	30	12.5	Box jumps, timed jumps, skipping, lateral hops, single and double leg vertical jumps, clock jumps, depth jumps, speed skater jumps	Countermovement jump with arms (cm)
Siegler et al. (83)	Control group	16.3	166.7	58.0	Soccer	17						Countermovement jump with arms (cm)
Theos et al. (89)	Sand	11.2	151.6	40.8	Volleyball	15	10	3	30	90	Single jumps, repeated jumps, drop jumps	Countermovement jump (cm)
Theos et al. (89)	Hard	11.3	151.3	39.9	Volleyball	15	10	3	30	90	Single jumps, repeated jumps, drop jumps	Countermovement jump (cm)
Theos et al. (89)	Control	10.8	147.0	35.4	Physical education	15						Countermovement jump (cm)

(continued on next page)

Figure 2

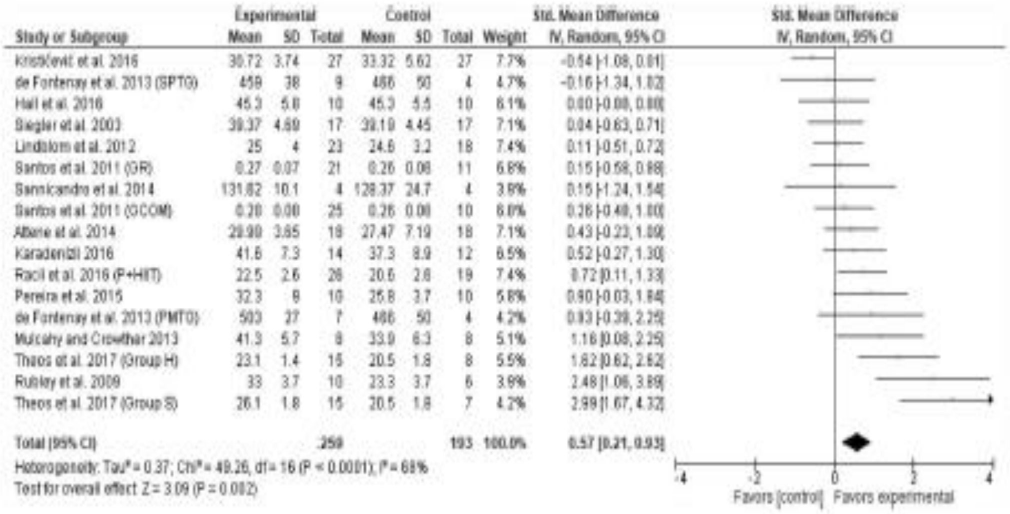

Table 2

Subgroup	Effect size and confidence interval	Effect descriptor	*p*	Groups	*N*	Between-group I² (%)	Between-group *p*	Within-group I² (%)	Within-group *p*
<15 yrs	0.78 (0.25 to 1.30)	Moderate	0.004	10	253	39.0	0.2	71	0.00
>15 yrs	0.31 (−0.18 to 0.80)	Small	0.21	7	199			61	0.02
<163 cm	1.03 (0.38 to 1.68)	Moderate	0.002	8	182	73.1	0.05	72	0.0007
≥163 cm	0.25 (−0.20 to 0.70)	Small	0.28	6	226			63	0.02
<54 kg	1.14 (0.39 to 1.89)	Moderate	0.003	7	166	75.5	0.04	76	0.0003
≥54 kg	0.26 (−0.15 to 0.67)	Small	0.21	7	242			56	0.03
≤8 wks	0.24 (−0.11 to 0.59)	Small	0.17	10	245	75.6	0.04	38	0.11
>8 wks	1.04 (0.35 to 1.72)	Moderate	0.00	7	207			79	0.00
≤2 session per wk	0.37 (0.02 to 0.71)	Small	0.04	13	328	57.2	0.13	52	0.01
>2 session per wk	1.22 (0.18 to 2.25)	Large	0.02	4	124			83	0.00
<16 sessions	0.37 (−0.44 to 1.17)	Small	0.38	5	134	0	0.55	77	0.002
16 sessions	0.46 (0.08 to 0.84)	Small	0.02	6	127			1	0.41
>16 sessions	0.85 (0.18 to 1.51)	Moderate	0.01	6	191			77	0.0006
<30 min per session	0.33 (0.03 to 0.63)	Small	0.03	7	181	57.8	0.12	0	0.62
≥30 min per session	1.16 (0.14 to 2.17)	Moderate	0.03	5	89			76	0.002