Effects of Plyometric Training on Physical Performance: An Umbrella Review

Short Title: Plyometric Training and Performance

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Abstract

Background: Plyometric training can be performed through many types of exercises involving the stretch-shortening cycle in lower limbs. In the last decades, a high number of studies have investigated the effects of plyometric training on several outcomes in different populations.

Objectives: To systematically review, summarize the findings, and access the quality of published meta-analyses investigating the effects of plyometric training on physical performance.

Design: Systematic umbrella review of meta-analyses.

Data Sources: Meta-analyses were identified using a systematic literature search in the databases PubMed/MEDLINE, Scopus, SPORTDiscus, Web of Science, Cochrane Library and Scielo.

Eligibility Criteria for Selecting Meta-analyses: Meta-analyses that examined the effects of plyometric training on physical fitness in different populations, age groups, and sex.

Results: Twenty-nine meta-analyses with moderate-to-high methodological quality were included in this umbrella review. We identified a relevant weakness in the current literature, in which only one meta-analysis included control group comparisons, while 24 included pre-to-post effect sizes. Trivial to large effects were found considering the effects of plyometric training on physical performance for healthy individuals, medium-trivial effects for the sports athletes' groups and medium effects for different sports athletes' groups, age groups, and physical performance.

Conclusion: It is evidenced that plyometric training improves vertical jump height, but there is also a transfer to other physical fitness parameters and sports performance. However, it is important to outline that most meta-analyses included papers lacking a control condition. As such the results should be interpreted with caution.

Key-Words: vertical jump, motor actions, sports-performance, muscle power

Key Points

1. This umbrella review identified 29 systematic meta-analyses investigating the effects of plyometric training on physical performance characteristics in the healthy and athletes' population with different age ranges, male and female groups.
2. This umbrella review identified some important gaps in the literature. Most meta-analysis used a within-subjects design (pre vs post intervention effect sizes) with no control group comparison. This was consequence of a lack of original controlled trials in the literature. Control groups are fundamental to ensure that the observed adaptations can be attributed to the proposed intervention rather than other confounding factors. Also, most of the included studies were considered with low-to-moderate quality. Therefore, the outcomes provided by the available meta-analyses must not be considered level 1 evidence and should be taken with caution.
3. The available meta-analyses suggest that plyometric training induces trivial to large effects on physical performance for healthy people, and enhanced performance for the athletes from different sports (e.g., vertical jump height, sprint performance and muscle strength). However, this should be interpreted cautiously as, for example, the lack of control group for studies with athletes from different sports does not allow to discriminate if other training characteristics influenced their enhanced performance.
4. Future original studies should include control groups in their experimental design to support the effects of plyometric training on physical and sports performance.

1. Introduction

Plyometric training is broadly used to improve physical performance in many sports activities involving sprinting, jumping, change of direction ability and so forth [1-6]. The definition for plyometric training has been debated in the literature over the years and it is normally associated with stretch-shortening cycle (SSC) process. A general concept proposes that plyometric training can include many types of exercises involving the SSC [7,8]. It can be divided into different classifications, such as impact and non-impact plyometrics, or even according to the velocity of the SSC (e.g. short or long use of SSC) [9-11]. The effective use of the SSC is related to the different contributions of mechanisms associated with SSC, such as the accumulation of elastic energy [7], pre-load [12], increase the time to muscle activation [13], muscle history dependence (force enhancement) [14], stretch-reflexes [15] and muscle-tendon interactions [16] that facilitates greater mechanical work production in subsequent concentric muscle actions [17,18], which justifies the great use of plyometric exercises in physical training programs.

Over the last decades numerous experimental studies suggest positive effects of plyometric training on neuromuscular performance (e.g., power output of lower limbs) [19-22], muscle mechanical properties (e.g., change in the musculotendinous stiffness and architecture) [23,24], and physiological parameters (e.g., running economy and endurance performance) [21, 25]. The significant number of publications investigating the effects of plyometric training on physical capacities has grown widely, as are systematic reviews with meta-analyses studies. Especially in the last 14 years papers included a wide range of sports activities, ages, and physical performance outcomes. To summarize the current knowledge on the topic and to identify possible methodological limitations in published meta-analyses, an umbrella review might be conducted [26], as this kind of review is considered on the highest level of the evidence pyramid [27]. Umbrella reviews highlight findings from already published meta-analyses, providing the state of the art about a given overarching topic with a high number of publications. Thus, it can help the reader to understand the current strengths and limitations of the entire body of literature on a specific topic from different perspectives and applications.

This study aimed (*i*) to systematically review the available meta-analytical evidence that has examined the effects of plyometric training on physical fitness performance (e.g., muscle strength, muscle power, change of direction, sprint ability) considering different populations (*ii*) to address the quality, strengths and limitations of the meta-analytical evidence considering plyometric training; and (*iii*) to identify current limitations in the literature and provide suggestions for future research. Our findings may be useful for coaches, scientists, athletes and physical training practitioners in understanding the meaningful and clinical effects of the plyometric training for different populations (athletes and non-athletes, male and female) and different age ranges (young and older adults).

2. Methods

Our umbrella review was conducted in accordance with recommendations of Aromataris and colleagues [26] and addressed all items recommended in the PRISMA statement [27]. It was registered in the PROSPERO data base with the number: CRD42020217918.

2.1 Literature Search

We conducted a systematic literature search in the databases PubMed/MEDLINE, Scopus, SPORTDiscus, Web of Science, Cochrane Library and Scielo during February and May 2022. A Boolean search syntax was used (appendix 1). The reference list of each included meta-analysis was screened for titles to identify additional meta-analyses to be included in the umbrella review.

2.2 Selection Criteria

Based on a priori defined inclusion/exclusion criteria (PICOS = population, intervention, comparison, outcome, study design; Table 1), four independent reviewers (Author name, Author name, Author name, Author name) screened potentially relevant articles by analyzing titles, abstracts, and full texts of the respective articles to elucidate their eligibility. When the four reviewers did not reach an agreement concerning inclusion of an article, LBRO adjudicated.

Table 1. Selection criteria used in this Umbrella review.

Category	**Inclusion criteria**	**Exclusion criteria**
Population	Healthy people, with no restrictions on sex, age or sports modalities.	People with health problems (e.g., injuries and recent surgery).
Intervention	A plyometric jump training program, defined as lower and upper body unilateral or bilateral bounds, jumps, and hops that commonly utilize a pre-stretch or countermovement stressing the stretch-shortening cycle.	Exercise interventions not involving plyometric jump training or exercise interventions involving plyometric jump delivered in conjunction with other training interventions (e.g., resistance training).
Comparator	Control group or control situation.	No active control group or control situation.
Outcome	Direct measure of physical fitness (e.g., jump height), maximal velocity speed, change of direction, or muscle strength) before and after the training intervention.	Lack of baseline or follow-up data.
Study design	A Systematic Reviews and meta-analysis or only meta-analysis.	No meta-analysis.

2.3 Data Extraction

The following data were extracted from the included meta-analyses: (1) first author and year of publication; (2) the number and type of primary studies included in the meta-analysis; (3) the study characteristics and the number of included participants; (4) the respective physical fitness outcome; (5) effect sizes and the equations used to compute effect sizes with their respective confidence intervals

(CI). Data were extracted and crosschecked for accuracy by Author name, Author name, Author name, Author name and Author name.

2.4 Evaluation of the Methodological Quality

Meta-analyses of randomized controlled trials and controlled studies are subject to different sources of bias. Therefore, it is important that readers have the option to distinguish between low- and high-quality meta-analyses. The methodological quality of the included meta-analyses was independently assessed by three reviewers (Author name, Author name, and Author name) using the validated AMSTAR2 (A Measurement Tool to Assess Systematic Reviews) checklist [28]. This checklist contains 16 items that include the literature search procedure, data extraction, quality assessment, and statistical analyses of the meta-analyses (for more details see Shea et al. [28]. Each item on this checklist was answered with a ‘yes’ (1 point), ‘partial yes’ (0.5 points) or ‘no’ (0 points). Based on the summary point scores (i.e., maximum 16 points), the meta-analyses were categorized as high quality if ≥ 80% of the possible score was achieved, moderate quality if 40–79% of the possible score was reached, or low quality if < 40% of the possible score was achieved [29].

2.5 Data Interpretation

The main objective of this umbrella review is summarize the findings, and access the quality of published meta-analyses investigating the effects of plyometric training on physical performance. The use of one effect size measure makes this comparison straightforward. However, it is important to acknowledge that even if most of the included meta-analyses used the standardized mean difference (SMDs) as an effect size measure, differences were found in the respective equations that were used to compute SMDs. For instance, some meta-analyses weighted single studies and/or conducted sample size adjustment (e.g., Hedges’ g). Therefore, we extracted the equations used to compute effect sizes for each included meta-analysis (Table 2). According to Cohen [30,31], the SMD values were classified as: < 0.20 as trivial, 0.20 ≤ SMD < 0.50 as small, 0.50 ≤ SMD < 0.80 as moderate, and SMD ≥ 0.80 as large effects.

Table 2. Included meta-analyses that examined the effects of plyometric training on physical fitness in different populations groups

Study	**Population/Sport**	**N participants**	**N study design**	**Statistical model**	**Physical fitness outcome**	**Effect size (95% CI, p value); I^2 (p value)**
Alfaro-Jimenez et al. [39]	Team sports – young and adults (e.g., basketball, handball, volleyball, football and netball)	N = 50	N = 31	Within subject SMD	Explosive Strength	0.98 (0.77–1.19, p < 0.05); 72% (p = n.a)
Asadi et al. [37]	Youth athletes – practitioners and non-practitioners of sports	N = 46	N = 24	Within subject SMD	Change of direction	0.59 (-0.08 - 1.24, n.a); n.a
Asadi et al. [36]	Youth athletes – practitioners and non-practitioners of sports	N = 667	N= 16	Within subject SMD	Change of direction	0.96 (n.a, n.a); n.a
Behm et al. [38]	Healthy trained or untrained boys and girls	N = 1351	N = 107	Within subject SMD	Vertical jump height, sprint performance and Lower body strength	**Jump Measures** Total 0.69 (0.53–0.84, p < 0.001); 51% (p < 0.001) Trained Boys 0.67 (0.52–0.82, p < 0.001); 39% (p < 0.05) Untrained 0.80 (0.24–1.35, p < 0.001); 80% (p = 0.005) Children 0.74 (0.53–0.94, p < 0.001); 62% (p < 0.001) Adolescents 0.57 (0.37–0.77, p < 0.01); 14% (p > 0.05) **Sprint Performance** Total 0.38 (0.23–0.53, p (p < 0.001); 12% (p > 0.05) Trained Boys 0.32 (0.18 – 0.46, p < 0.001); 0% (p > 0.05) Untrained

						1.19 (− 0.32 - 2.69, p < 0.001); 87% (p <0.001) Children 0.47 (0.28–0.67, p < 0.001); 31% (p > 0.05) Adolescents 0.13 (− 0.17 - 0.44, p > 0.05); 0% (p > 0.05) **Lower body strength** Adolescents 0.16 (-0.26–0.58, p= 0.59); 0% (p > 0.05)
Berton et al. [45]	Healthy individuals trained or untrained men	N = 158	N = 7	Within subject SMD	Vertical Jump Height	0.15 (-0.30–0.60, p = 0.51); 21% (p = 0.97)
de Villarreal et al. [41]	Healthy individuals - with elite, good, normal and bad levels	N= 122	N = 56	Within subject SMD	Vertical Jump Height	Squat jump 0.79 (n.a, n.a); n.a CMJ 0.74 (n.a, n.a); n.a Drop jump 0.71 (n.a, n.a); n.a Sargent jump 0.57 (n.a, n.a); n.a
de Villarreal et al. [42]	Healthy individuals - with elite, good, normal and bad levels	N = 24	N = 15	Within subject SMD	Strength performance	0.97 (n.a, n.a); n.a
de Villarreal et al. [43]	Healthy individuals - with elite, good, normal and bad levels	N = 41	N = 26	Within subject SMD	Sprint	0.37 (n.a, n.a); n.a
Kayantas et al. [48]	Athletes in general sports (e.g., basketball and football)	N = 1201	N = 6	Within subject SMD	Speed parameters	0.67 (0.38–0.96, p < 0.001); 68% (p < 0.007)
Kayantas et al. [40]	Athletes in general sports (e.g., judo, basketball, volleyball, handball, football and wrestling)	N = 362	N = 11	Within subject SMD	Muscle Strength	0.40 (0.19–0.61, p < 0.001); 7% (p = 0.36)
Makaruk et al. [46]	Healthy individuals - age > 18 years	N = 602	N = 11	Within subject SMD	Vertical Jump Height	Traditional Plyometric 0.68 (0.37–0.99, p < 0.001); 31% (p = 0.16) Assisted Plyometric 0.70 (0.20–1.20, p = 0.006); 0% (p = 0.94) Resisted Plyometric 0.48 (0.17–1.19, p = 0.002); 33% (p = 0.14)

Markovic et al. [31]	Healthy individuals – athletes and non-athletes	N = 1024	N = 43	Experimental vs. Control SMD	Vertical jump height	Squat jump 0.44 (0.15–0.72, n.a); 33% (n.a) CMJ 0.88 (0.64–1.11, n.a); 11% (n.a) CMJ with the arm swing 0.71 (0.49–0.93, n.a); 26% (n.a) Drop jump 0.62 (0.18–1.05, n.a); 20% (n.a)
Moran et al. [32]	Older healthy individuals' adults (>50)	N = 444	N = 9	Experimental vs. Control SMD	Lower limbs power	0.66 (0.33–0.98, p = 0.02); 51% (p < 0.001)
Moran et al. [33]	Healthy trained or untrained girls	(8-18 years); N = 452	N = 14	Experimental vs. Control SMD	Vertical jump height	0.57 (0.21–0.93; p < 0.01); 68% (p < 0.001)
Moran et al. [47]	Healthy individuals – Untrained and trained	N = n.r	N = 9	Within subject SMD	Vertical and Horizontal jump performance	Horizontal plyometric training Horizontal Jump 1.05 (0.38 - 1.72, n.a); 73% (p = 0.002) Vertical Jump 0.74 (0.08 – 1.40, n.a); 75% (p = 0.03) Vertical plyometric training Horizontal Jump 0.84 (0.37 – 1.31, n.a); 52% (p = 0.0005) Vertical Jump 0.72 (0.02 – 1.43, n.a); 78% (p = 0.04)
Ozdemir et al. [50]	Athletes in general sports (e.g., badminton, basketball, football, wrestling, handball and volleyball	N = 40	N = 43	Within subject SMD	Vertical jump performance	0.68 (0.57–0.80, p < 0.001); 49% (p < 0.001)
Ramirez-Campillo [56]	Handball players	N = 129	N = 5	Within subject SMD	Vertical jump height	2.15 (0.95–3.36, p < 0.001); 51% (p < 0.001))
Ramirez-Campillo [53]	Volleyball players	N = 346	N = 14	Within subject SMD	Vertical jump height	2.07 (1.22–2.93, p < 0.001); 34.4% (p = 0.087))
Ramirez-Campillo [52]	Team Sports (e.g. soccer, volleyball, basketball and futsal)	N = 278	N = 14	Within subject SMD	Vertical jump height	0.73 (0.45–1.02, p < 0.001); 18% (p = 0.22))

Ramirez-Campillo [57]	Female soccer players	N = 99	N = 8	Within subject SMD	Vertical jump height	1.01 (0.36–1.66, p = 0.002); 13% (p = 0.33)
Ramirez-Campillo [55]	Basketball players	N = 818	N = 32	Within subject SMD	Vertical jump power, Countermovement jump with arm swing height, Countermovement jump height, Squat jump height, drop jump height, Horizontal jump distance, <10-m linear sprint time, >10-m linear sprint time, <40-m change-of-direction performance time, >40-m change-of-direction performance time, Dynamic balance, Static balance, Maximal strength, Hamstring/quadriceps strength ratio at 60°/s, Hamstring/quadriceps strength ratio at ≥120°/s	**Jumping** Vertical jump power, 0.45 (0.07 - 0.84, p = 0.021); 0% (p = 0.32) Countermovement jump with arm swing height 1.24 (0.72 - 1.75, <0.001); 71% (p<0.001) Countermovement jump height 0.88 (0.55 - 1.22, p<0.001) 67% (p = 0.071) Squat jump height 0.80 (0.47 - 1.14, p<0.001); 52% (p=0.008) Drop jump height 0.53 (0.25 - 0.80, p<0.001); 0.0% (p=0.567) Horizontal jump distance 0.65 (-0.02 - 1.31, p< 0.001); 80% (p= 0.008) **Sprint** <10-m linear sprint time 1.67 (0.32 - 3.03, p=0.016); 85% (p=0.307) >10-m linear sprint time 0.92 (0.40 - 1.44, p<0.001); 74% (p=0.061) <40-m change-of-direction performance time 1.15 (0.75 - 1.55, p<0.001); 59% (p=0.189) >40-m change-of-direction performance time 1.02 (0.29 - 1.76, p=0.006); 64% (p=0.272) **Balance** Dynamic balance

						1.16 (0.43 - 1.89, p=0.002); 76% (p=0.586) Static balance 1.48 (-0.19 - 3.15, p=0.002); 93% (p=0.252) **Strength variables** Maximal strength 0.57 (0.07 - 1.07, p=0.025); 38% (p=0.117) Hamstring/quadriceps strength ratio at 60°/s -0.10 (-0.56 -0.36, p=0.661); 23% (p=0.060) Hamstring/quadriceps strength ratio at ≥120°/s -0.04 (-0.56 to 0.48, p=0.885); 39% (p=0.785)
Ramirez-Campillo [54]	Volleyball players	N = 746	N = 18	Within subject SMD	Linear sprint speed, squat jump height, countermovement jump height, CMJ with arm swing, drop jump and spike jump height	Linear sprint speed 0.70 (0.31 - 1.09, p < 0.001); 46% p=0.609 Squat jump 0.56 (0.24–0.88, p = 0.001); 0% p=0.409 Countermovement jump 0.80 (0.37–1.22, p < 0.001); 66% p = 0.270 Countermovement jump with arm swing, 0.63 (0.21–1.04, p = 0.003); 0% p = 0.002 Drop jump 0.81 (0.15 – 1.47, p = 0.016); 37% p=0.496 Spike jump height 0.84 (0.36–1.32, p = 0.001); 0% (p < 0.05)
Sánchez et al. [58]	Female soccer players	N = 250	N = 10	Within subject SMD	countermovement jump, drop jump, kicking performance, linear sprint, change of direction speed, and endurance	Countermovement jump 0.71 (0.20–1.23, p = 0.007); 62% (p= 0.224) Countermovement jump with Arm Swing

						0.41 (-0.34–1.15, p = 0.28); 65% (p= 0.452) Drop jump 0.79 (0.12–1.47, p = 0.021); 73% (p = 0.063) Kicking performance 2.24 (0.13–4.36, p < 0.037); 89% (p=0.040) Linear sprint 0.79 (0.39–1.18, p < 0.001); 38% (p = 0.257) Change of direction speed 0.73 (0.39–1.06, p < 0.001); 0% (p = 0.813) Endurance 0.60 (0.09–1.10, p = 0.020); 53% (p =0.328)
Singla et al. [48]	Healthy individuals - practitioners and non-practitioners of sports	N = 287	N = 11	Within subject SMD	Ball throwing velocity and distance. Upper body power and strength.	Velocity 0.68 (0.01–1.36, p < n.a); 7% (p = 0.07) Distance 0.42 (-0.07–0.92, p < n.a); 3% (p = 0.17) Power -0.08 (-0.45–0.29, p < n.a); 1% (p =0.45) Strength 0.15 (-0.52–0.82, p < n.a); 4% (p = 0.14)
Slimani et al. [34]	Soccer players	N = 355	N = 10	Experimental vs. Control SMD	Vertical jump height	0.85 (0.47–1.23, p < 0.001); 68% (p < 0.001)
Sole et al. [51]	Individual sport athletes (e.g., runners, gymnastics, golfers, tennis, swimmers, throwers, fencers, cyclists and recreational resistance training)	N = 667	N = 26	Within subject SMD	Vertical jump, linear sprint, maximal strength, endurance performance	Vertical jump 0.49 (0.32–0.65, p < 0.001); 0% (p < 0.117) Linear sprint 0.23 (0.02–0.44, p = 0.032); 10% (p = 0.518) Maximal strength 0.50 (0.23–0.77, p < 0.001); 0% (p = 0.004) Sprint with change of direction

						0.34 (-0.19–0.87, p = 0.205); 70% (p = 0.657) Endurance performance 0.30 (0.03–0.57, p = 0.028); 11% (p = 0.119)
Stojanovic et al. [59]	Female general athletes (e.g., basketball, amateur soccer, elite runners, collegiate soccer players, hockey and volleyball players	N = 437	N = 16	Within subject SMD	Countermovement Jump Without Arm Swing, Countermovement Jump with Arm Swing, Squat Jump, Drop Jump	Countermovement Jump Without Arm Swing 1.87 (0.73–3.01, n.a); 75% (n.a) Countermovement Jump with Arm Swing 1.31 (-0.04–2.65, n.a); 92% (n.a) Squat Jump 0.44 (-0.09–0.97, n.a); 0% (n.a) Drop Jump 3.62 (3.03–4.21, n.a); 96% (n.a)
Taylor et al. [44]	Healthy individuals trained sports practitioners	N = 188	N = 31	Within subject SMD	Vertical jump, Sprint (10, 20, 30m) ability and high-intensity intermittent running performance	Vertical jump 0.33 (0.03 - 0.63), n.a); 33% (n.a) Sprint 10m 0.42 (0.18 - 0.66, n.a); 0% (n.a) Sprint 20m 0.49 (0.03 – 0.95 0.46, n.a); 61% (n.a) Sprint 30m 1.01 (0.08 – 1.94± 0.93, n.a); 47% (n.a) Repeated sprint ability 0.62 (0.37 - 0.87, n.a); 0% (n.a) High intermittent running performance 0.61 (0.07 – 1.15; 0.54, n.a); 56% (n.a)
van de Hoef et al. [35]	Male Soccer Players	N = 564	N = 17	Experimental vs. Control SMD.	Vertical jump, Sprint (5, 10, 15, 20, 30m) CMJ vertical jump height performance, strength, agility and Yo-Yo Intermittent Recovery Test 1 & 2	Vertical jump (cm) 1.07 (0.13–2.00, n.a); 0% (p = 0.46) Sprint 5m (s) 0.00 (-0.02– 0.02, n.a); 0% (p = 0.98) Sprint 10m (s) 0.01 (-0.01–0.04, n.a); 27% (p = 0.23) Sprint 15m (s)

0.04 (-0.03–0.12, n.a); 46% (p = 0.17) Sprint 20m (s) 0.05 (-0.01–0.10, n.a); 0% (p = 0.48) Sprint 30m (s) 0.05 (-0.02–0.11, n.a); 0% (p = 0.53) Strength (kg) 8.49 (-10.64–27.61, n.a); 97% (p < 0.001) Agility (s) 0.01 (-0.07–0.10, n.a); 34% (p = 0.18) Yo-Yo Intermittent Recovery Test 1 and 2 (cm) 120.74 (3.00–238.49, n.a); 42% (p = 0.16)

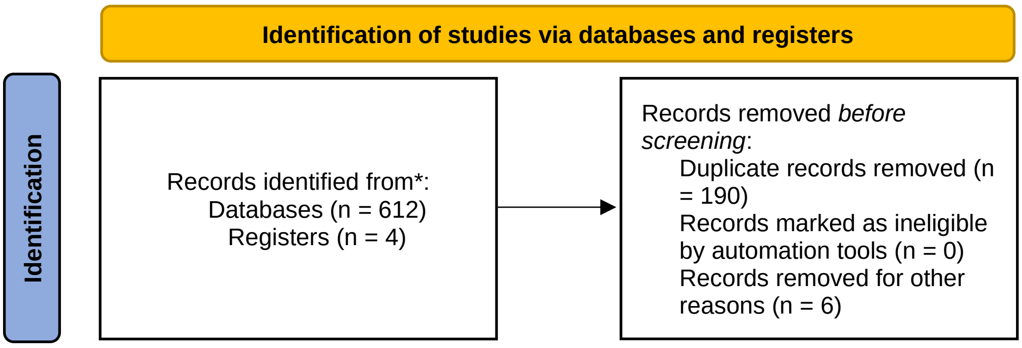
n.a = not assessed; n.r = not reported; SMD= Standardized Mean Difference

****Table 2 here****

3. Results

3.1 Search Results

A total of 612 potentially relevant studies were identified in the electronic databases (Figure 1). Finally, 29 meta-analyses were eligible for inclusion in this umbrella review based on a priori defined selection criteria. We further separated the included meta-analyses into those that reported between subject effect sizes (i.e., post-test comparison of the intervention versus control group, n = 5) and those that reported within-subject effect sizes (i.e., pre- versus post-test comparison of the intervention group, n = 24) (Table 2).



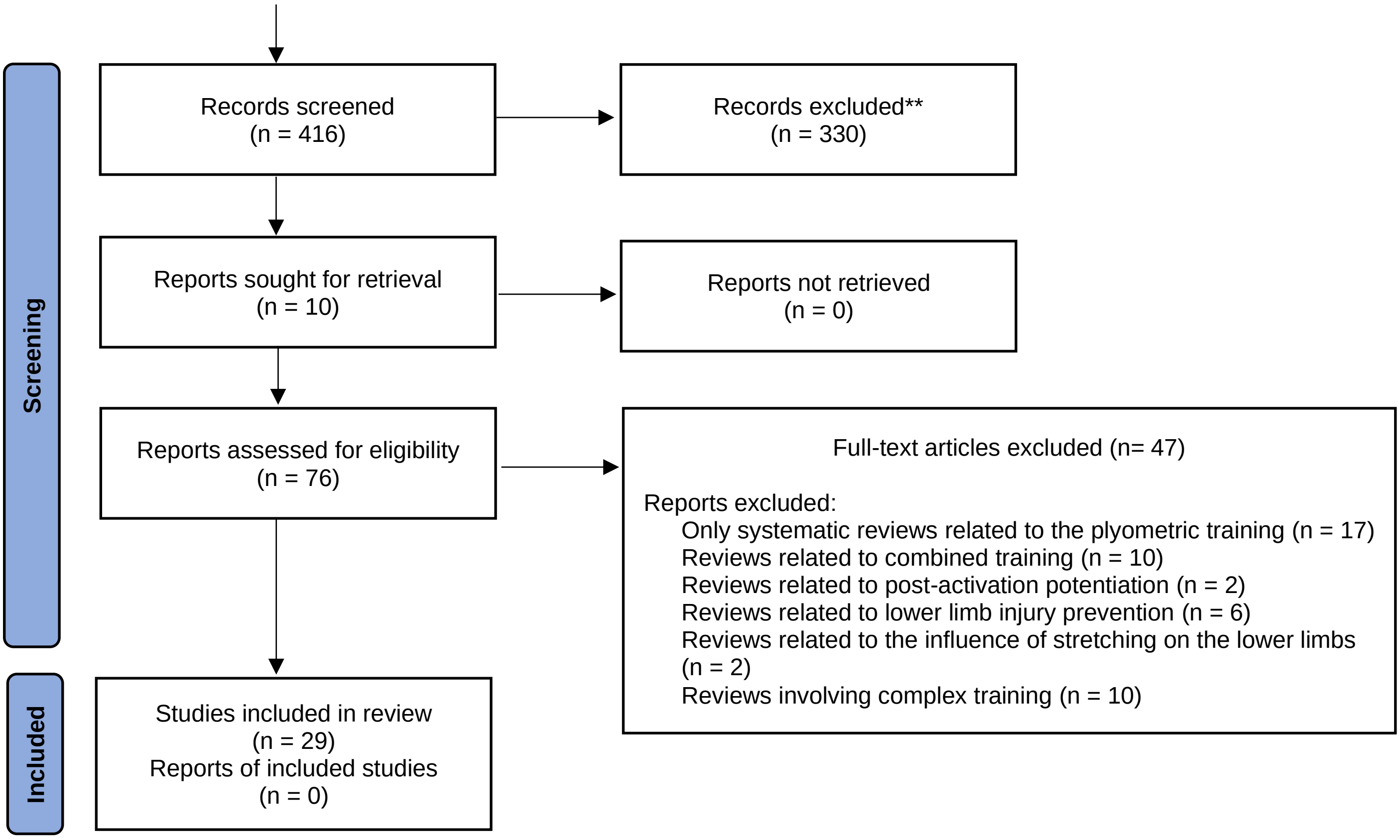


Figure 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only

3.2 Characteristics of the Meta -Analyses

The 29 included meta-analyses were published from 2007 to 2022 (Table 2). Five meta-analyses compared the effects of intervention to control group [31-35], while the other compared within-intervention-group effects (i.e., pre vs post effect sizes). The number of included original studies ranged from six to 107 with an average of 22 original studies. Sample sizes included 24 to 2471 athletes of specific sports (e.g., volleyball, soccer, handball and basketball), groups of sports (e.g., team sports and individual sports), healthy people, and individuals from different age groups (i.e., young, young adults and older adults) (on average 459 participants). The chronological age of the included participants ranged from 15 to 71 years. Five meta-analyses included adolescents [36-40], ten meta-analyses involved healthy people [31, 32, 41-48,], three meta-analyses focused on athletes participating in general sports [40,49,50], one meta-analysis involved older adults (> 50 years) [32], one meta-analyses included female athletes participating in general sports [40] and one meta-analyses focused on individual sports athletes (e.g., runners, gymnasts, golfers, swimmers, tennis players, javelin, fencers and cyclists) [51]. When considering the sports modality, two meta-analyses included general team sports [39,52] and one meta-analysis individual sports [51]. Within the team sports, two meta-analyses analyzed female soccer players [34,59], two meta-analyses volleyball players [53,54], two meta-analyses male soccer players, [34,35] one meta-analysis basketball players [55], and one meta-analysis handball players [56] considering both sexes.

3.3 Assessment of the Methodological Quality

The assessment of the methodological quality (AMSTAR2) of the included meta-analyses is summarized in Electronic Supplementary Material (supplementary material 1). The included articles received scores ranging from 12 to 84% of the maximum score (16 points). Twenty-two meta-analyses (75.9% of total articles included) [31-34,37,38,41-44,46-48,51-59] were considered of moderate quality, six were low quality (20.7% of total articles included) [36,39,40,45,49,50] and one scored high (3.4% of total articles included) [35]. The following criteria were not sufficiently addressed in the included meta-analyses: (n=2) establish methods prior to the conduct the meta-analysis (written protocol); (n=3) explain the choice of study design for inclusion; (n=7) provide a list of excluded studies to justify the exclusion; and (n=10) report sources of funding for included studies.

3.4 Effect of Plyometric training on sprint or speed performance

Nine meta-analyses identified positive effects and one meta-analysis reported no effect of plyometric training on sprint or speed performance. Figure 2 summarizes the effects in terms of standardized mean difference between baseline and post training values. In a general population of healthy individuals, there was small effect for 10-m and 20-m sprint performance, and large effect for 30-m sprint performance [44], and a small effect for general sprint performance [43] (Figure 2). For young (<18 years old) participants, there was a small effect when analyzing the total effect from trained and untrained participants [38]. When analyzing meta-analyses that including only athletes, there was a small effect observed for individual sport [51], but a moderate effect for athletes in general sports [49]. A moderate effect was observed for female soccer players [58], handball players [56], and volleyball players [53], while a large effect size was observed for basketball players (for sprints > or < than 10 m) [55]. There was an unclear effect in 5, 10, 15, 20, and 30-m sprint performance in male soccer players [35].

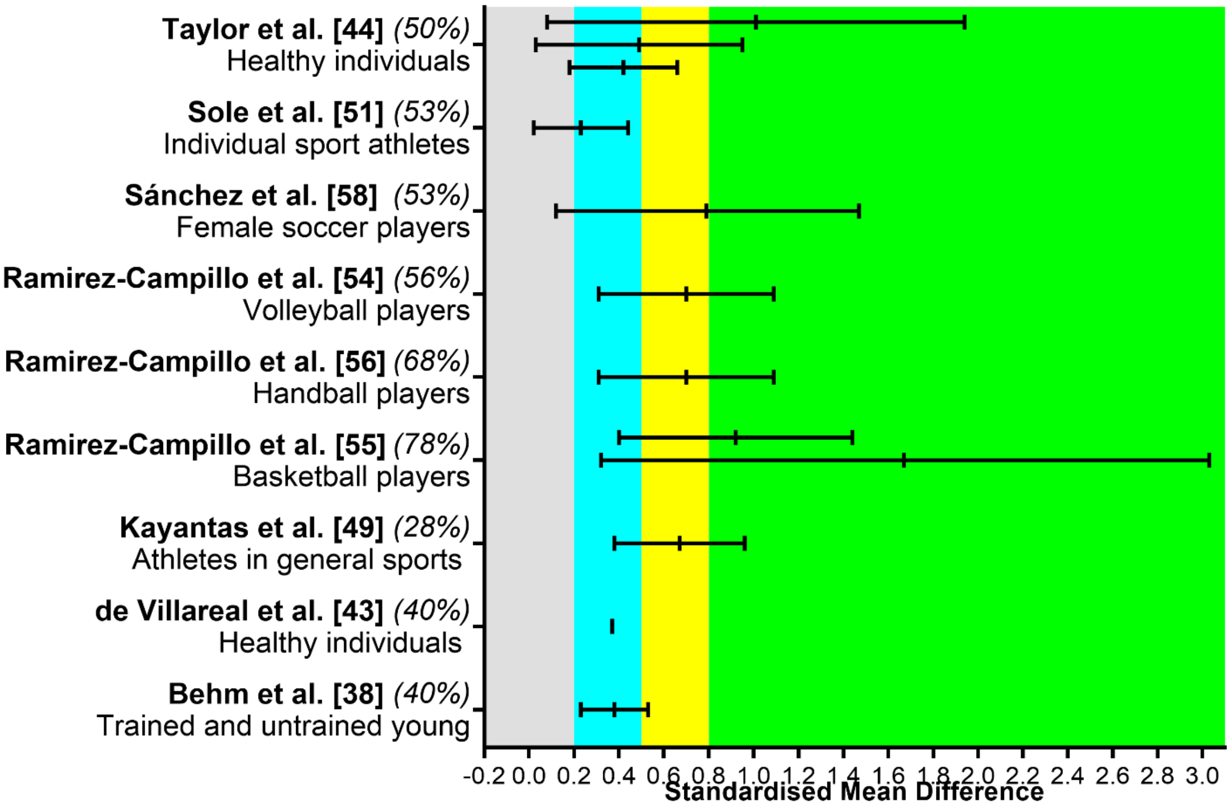


Figure 2. Summary of standardized mean difference and 95% confidence intervals reported in meta-analyses comparing the baseline to post plyometric training changes on sprint or speed performance. Author name and year are followed by the quality of the studies score ranked with the AMSTAR 2. Positive values represent improved performance effects. Each colored area represents a different magnitude of effect: gray = trivial, blue = small, yellow = moderate, and green = large effects. De Villareal et al. [43] 95% confidence interval is not clearly described in their manuscript, therefore we reported standardized mean difference only. Taylor et al. [44] reported results from 30-, 20-, and

10-m sprints, presented in the respective order. Ramirez-Campillo et al. [55] reported results from >10- and <10-m sprints, presented in the respective order.

3.5 Effect of Plyometric training on change of direction

Figure 3 summarizes the effects observed in change of direction in the four studies reporting standardized mean difference comparing baseline and post training values. Two meta-analyses reported improvements and two found unclear differences on change of direction performance after plyometric training. A large effect was observed in basketball players (for running distances shorter or longer than 40 m) [55] and moderate effect for female soccer players [58]. Unclear effect was observed for individual sport athletes [51] and young athletes [37]. For instance, a study reported no effect of plyometric training on agility in male soccer players after comparing groups' mean differences [35].

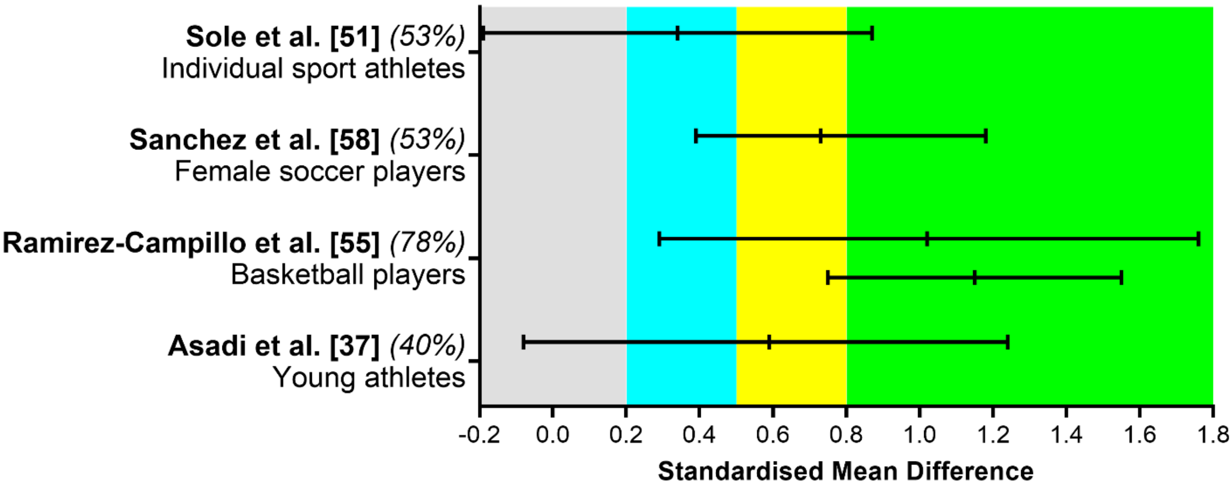


Figure 3. Summary of standardized mean difference and 95% confidence intervals reported in meta-analyses comparing the baseline to post plyometric training changes on change of direction performance. Author name and year are followed by the quality of the studies score ranked with the AMSTAR 2. Positive values represent improved performance effects and negative values detrimental effects. Each colored area represents a different magnitude of effect: gray, trivial; blue, small; yellow, moderate; and green, large effects. Ramirez-Campillo et al. [55] reported results from >40- and <40-m testing distances, presented in the respective order.

3.6 Effect of Plyometric training on maximal strength

Figure 4 summarizes the effects of plyometric training on maximal strength performance. Seven studies reported standardized mean difference comparing baseline and post training values. Four meta-analyses reported positive effects and three reported unclear differences on strength performance after plyometric training. A large effect was observed for healthy individuals [42], a moderate effect for basketball players [55] and individual sport athletes [51], and a small effect for athletes from general sports [40]. An unclear effect was observed for healthy individuals [48] and adolescents [38]. Also, one study reported unclear effect in soccer players [35]. Only one study showed that an unclear effect was also observed for hamstring/quadriceps strength ratios at 60 and ≥120°/s in basketball players [55].

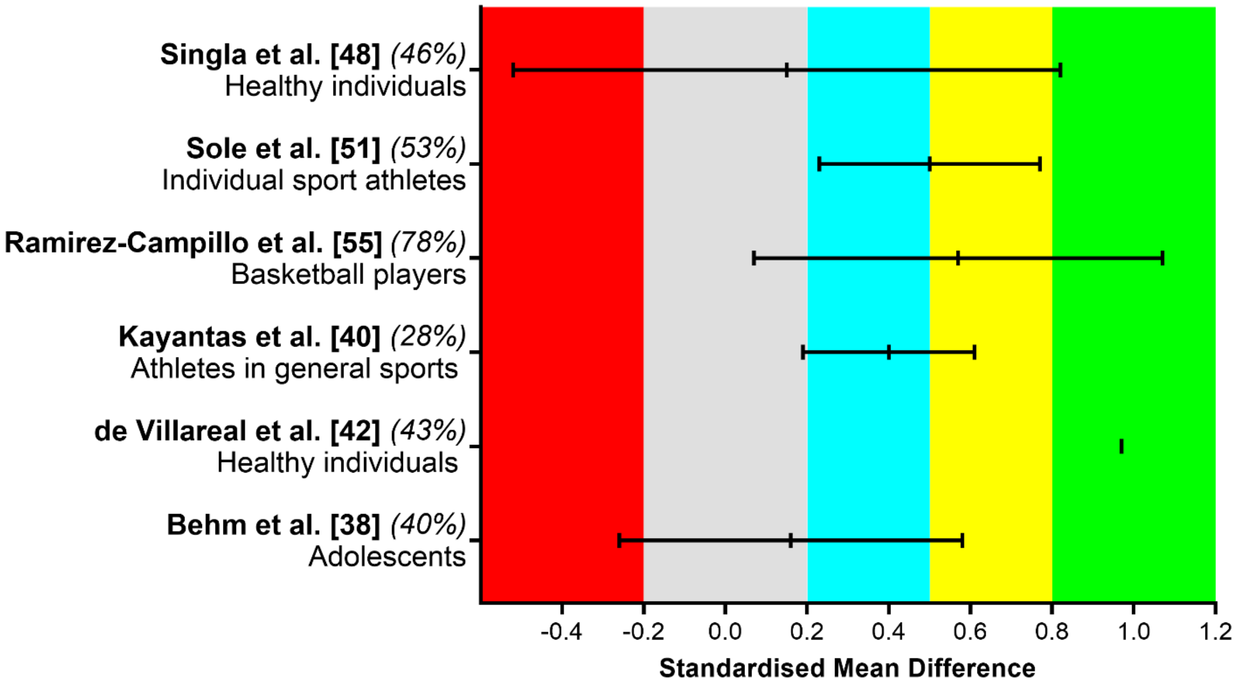


Figure 4. Summary of standardized mean difference and 95% confidence intervals reported in meta-analyses comparing the baseline to post plyometric training changes on maximal strength performance. Author name and year are followed by the quality of the studies score ranked with the AMSTAR 2. Positive values represent improved performance effects and negative values detrimental effects. Each colored area represents a different magnitude of effect: gray = trivial, blue = small, yellow = moderate, and green = large effects; while red area represents detrimental effects. De Villareal et al. [43] did not clearly describe the 95% confidence interval, thus we only reported standardized mean difference.

3.7 Effect of Plyometric training on muscle power and explosive strength

There was a large effect observed for explosive strength in team sport athletes [39]. For muscular power, there was a moderate effect for older adults [32], a small effect for basketball players [55], and an unclear effect for healthy individuals [48]. Figure 5 summarizes the effects observed on power and explosive strength performance in the four studies reporting standardized mean difference comparing baseline and post training values.

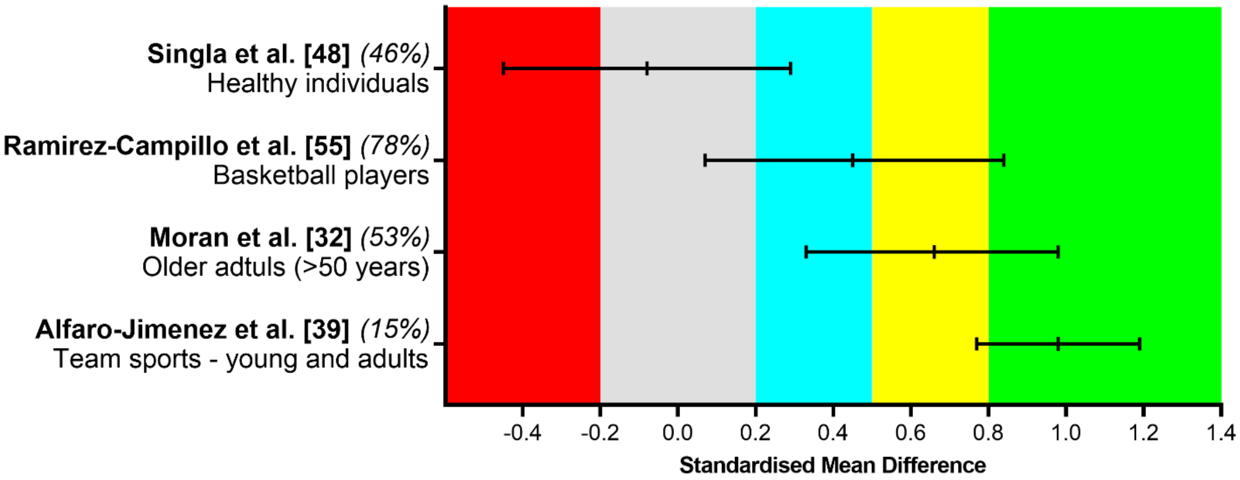


Figure 5. Summary of standardized mean difference and 95% confidence intervals reported in meta-analyses comparing the baseline to post plyometric training changes on power or explosive strength performance. Author name and year are followed by the quality of the studies score ranked with the AMSTAR 2. Positive values represent improved performance effects and negative values detrimental effects. Each colored area represents a different magnitude of effect: gray = trivial, blue = small, yellow = moderate, and green = large effects; while red area represents detrimental effects. Alfaro-Jimenez et al. [39] investigated the effects on explosive strength and the other authors on muscular power.

3.8 Effect of plyometric training on vertical and horizontal jump performance

Several studies investigated the effects of plyometric training on squat jump, countermovement jump (with arm swing or hands on the hip), drop jump, Sargent jump, and/or spike jump performance (i.e., jump height). In summary, for healthy people an unclear to large effect was observed [31,41,44,45]. Athletes from team sports, such as soccer [34,35,57,58], volleyball [53,54], basketball [55], handball

[56], or when grouped as team sports [52], presented mostly moderate to large effects. Trained and untrained young individuals presented moderate effect sizes [35,38].

Two studies investigated the effects on horizontal jump performance. One study reported a large effect on horizontal jump performance after either horizontal (SMD = 1.05) or vertical plyometric training (SMD = 0.84) [47]. Another study reported unclear effects of plyometric training on horizontal jump distance in basketball players [55]. Detailed SMDs for each study are reported in Table 2 and Figure 6 summarizes the 18 studies reporting standardized mean difference comparing baseline and post training values.

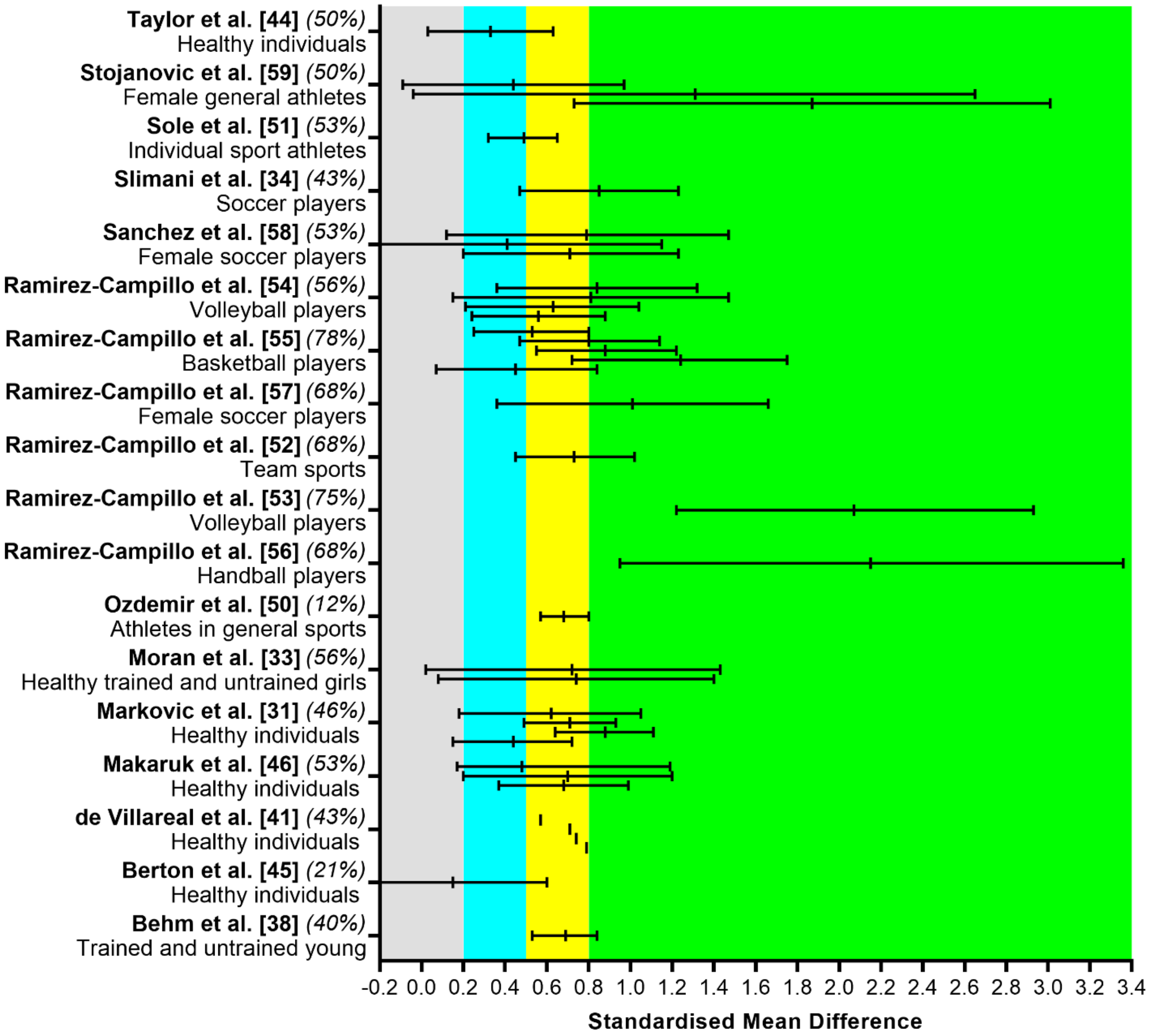


Figure 6. Summary of standardized mean difference and 95% confidence intervals reported in meta-analyses comparing the baseline to post plyometric training changes on jump performance.

Author name and year are followed by the quality of the studies score ranked with the AMSTAR 2. Positive values represent improved performance effects and negative values detrimental effects. Each colored area represents a different magnitude of effect: gray = trivial, blue = small, yellow = moderate, and green = large effects; while red area represents detrimental effects.

3.9 Effect of Plyometric training on additional outcomes

Plyometric training resulted in a small effect on endurance performance for individual sport athletes [51]), and moderate effect for endurance in female soccer players [58] and for high intermittent running performance in healthy peoples [44]. A large effect was observed on kicking performance in female soccer players [58]. There was also a large effect on dynamic balance, but an unclear effect on static balance in basketball players [55]. Plyometric training is effective to improve the yo-yo intermittent recovery test when comparing baseline and post training mean differences [35]. Table 2 presents detailed SMD for each of these studies and variables.

4. Discussion

This umbrella review aimed to systematically review the meta-analytical evidence about the effects of plyometric training on physical performance considering different groups, to address the quality, strengths and limitations of the evidence, and to identify current gaps in the literature, which helps in providing suggestions for future research. The most concerning finding from our study is the lack of control group comparisons and the low-to-moderate quality for most of the meta-analyses available in literature. Therefore, we highlight that the outcomes from these meta-analyses should not be interpreted as level 1 evidence. After summarizing the findings from the available meta-analyses, we observed that plyometric training induces trivial to large effects on different physical performance (e.g., jump height, sprint performance and muscle strength) for healthy people; enhances performance of athletes from different sports in several motor tasks (e.g., vertical jump height, change of direction, kicking performance and linear sprint); and induces moderate effects on physical fitness (e.g., power output in lower limbs, change of direction and vertical jump height) of older adults (>60 years) and young individuals (<18 years).

4.1 Quality of the Included Meta‑analyses

The methodological quality of the included meta-analyses varied from low to high. However, the majority of the studies (~75%) presented moderate quality. For the assessment of the methodological quality, Shea et al. [28] recommend that individual AMSTAR2 item ratings should not be combined to create an overall score. Users should consider the potential impact of an inadequate rating for each item independently. Unfortunately, although it is important to record the meta-analysis protocols in a specific platform, only the study of van de Hoef et al.[35], registered their protocol on the specific platform (PROSPERO). Overall, evidence shows a low-quality bias of umbrella reviews [60,61]. The reasons are probably related to the type of review, which is recently adopted in movement science literature, as well as word/table/figure restrictions and/or the absence of databases for supplementary materials.

A very important limitation observed in most of the meta-analyses included in our umbrella review (24 out of 29) was the absence of control groups, and thus, these meta-analyses only included within-group pre to post effect sizes. A control group allows the interpretation of the research outcomes removing the influence of possible factors (e.g. direct effect in the specific group). This is crucial when investigating sports performance enhancement because (recreational) athletes follow a training plan during a season, which also influences sports performance. Therefore, the majority of findings presented in this umbrella review should be interpreted with caution. Only five systematic reviews with meta-analysis [31-35] considered the analysis between control versus experimental group. We strongly recommend that future studies investigating the effects of plyometric training on physical performance adopt randomized controlled trial designs.

4.2 Effect of Plyometric training on physical performance in healthy people

Most studies indicate an improvement of vertical jump height, muscle strength and to a lesser extent speed performance in healthy people after plyometric training. Considering this population, experimental protocols using plyometric exercises may be a good strategy to optimize health related aspects [62,63]. Muscle strength and lower limb muscle power are important capacities for healthy people during daily activities (e.g. walking and climbing stairs), especially when using mechanisms related to the SSC [64].

The vertical jump height was the variable most positively affected by plyometric training according to the included meta-analyses. This variable may be considered as an indicator of muscle power of lower limbs [31,65,66] and it is commonly used to verify the effects of plyometric training on physical performance [21,31,41-43,45]. These results are not surprising due to the great specificity, since the same skill (i.e., vertical jump) is used in the testing method and applied in the plyometric training. For the sprint performance, a small effect was found for 10-m and 20-m sprint, a large effect for 30-m sprint and a small effect for sprint performance. For muscle strength, a large effect was observed for healthy individuals, a moderate effect for basketball players and individual sport athletes, a small effect for athletes involved in common sports activities, and an unclear effect for healthy individuals. These results demonstrate a transfer from plyometric training to other physical tasks involving lower limbs [41-43], probably due to neural and muscular adaptations [67].

Upper limb muscle power also demonstrated trivial to medium effects of plyometric training. A previous experimental study indicates that plyometric push-ups results in better outcomes compared to non-plyometric push-ups (i.e., dynamic push-ups) [68]. Therefore, neuromuscular adaptations in the upper limbs from plyometric training can be verified especially in movements involving plyometric push-ups (e.g. medicine ball throw).

4.3 Effect of Plyometric training on physical performance of athletes in different sports

When focusing on different sports, plyometric training induces a large effect on vertical jump height, power output and explosive strength (i.e. rate of force development), while a small effect was observed for agility. Most meta-analyses including athletes analyzed the effects of plyometric training on physical performance, since maximizing aspects related to sports performance beneficially impacts the training process and competitions [69].

The effects of plyometric training for individual sports demonstrated a medium effect for different variables (e.g., vertical jump height, strength, sprint and change of direction performances) [51]. When considering team sports, the effects of plyometric training were moderate to large, showing the greater relevance in enhancing performance in this target population. Particularly, for female soccer athletes a high effect was found on vertical jump task [57]. Plyometric training is a practice of physical training widely spread in the sports context, performed by athletes of different modalities. In this review larger effect sizes were observed for team sports compared to the other sports groups. Probably athletes from sports such as volleyball, basketball, handball, among others, allow greater adaptation to plyometric training due to the greater specificity of the jumping motor task that is present in training and during the matches.

4.4 Effect of Plyometric training on physical performance in different age groups

This umbrella review indicates that plyometric interventions can enhance physical fitness in children and adolescents beyond a level which is not exclusively achievable from growth and maturation. In addition, improvements also occurred in middle-aged adults who did not practice sports. Positive effects of plyometric training were found in untrained children and adolescents, especially in vertical jump height, sprint performance and muscle strength [38]. Recently, Lesinski et al. [60] observed small-to-medium effects of plyometric training on muscle power of lower limbs in children and adolescent athletes. Other studies also support that plyometric training is an effective training method to improve exercise performance in non-athlete young people [70]. However, moderating factors, such as maturity, sex and age in the youth group appear to modulate the effects following plyometric training [60,61]. Thus, future studies should consider these aspects.

In older people, plyometric training improved indicators of muscle power of lower limbs, however, it is supported by only one systematic review with meta-analysis [33]. The aging process is associated with a progressive decline of neuromuscular function, increased risk of falls and injuries related to the impaired functional performance [71,72]. From this perspective, Vetrovsky et al. [74] verified that plyometric training positively affected muscular strength, vertical jump performance, and functional performance (e.g., 30-s sit-to-stand test, figure-of-8 running test, timed up-and-go test, 6-m walk, stair climb) in older adults. Therefore, plyometric training can be considered as a feasible and safe alternative to improve physical fitness in older adults. Future investigations should further explore moderating variables (e.g., age, level of conditioning and body composition).

4.6 Strengths and Methodological Limitations

This umbrella review presented findings on the highest level of the evidence regarding the effects of plyometric training on several physical performance variables in different populations (athletes and non-athletes, male and female) and different age ranges (young and older adult). The majority of the included studies (75%) presented moderate methodological quality when AMASTAR2 was considered. Finally, this study identified some gaps in the literature to provide guidelines for future research. As limitation, despite the inclusion of a reasonable number of studies (n=29), few represented females and older individuals. Ultimately, the most important limitation observed in our study was the high prevalence of meta-analysis with the absence of control group comparisons. This is likely a consequence of low-quality original studies and this should be addressed in future investigations.

5. Conclusion

There is empirical support that plyometric training benefits, however, bear in mind that most meta-analyses do not include a control condition. This systematic umbrella review unveiled an important weakness of the present research topic. Although several meta-analyses investigated the effects of plyometric training on physical performance outcomes, most of them lack comparisons with control groups and are classified as low-to-moderate quality. It is advised that the outcomes from this umbrella review must not be considered as level 1 evidence. Future research should opt for randomized controlled trials, which will eventually lead to higher-quality meta-analyses. The current evidence, presented by this umbrella review, suggesting that plyometric training may improve a large number of physical fitness-related variables for healthy people and performance for athletes from different sports, and its effects are verified in different age groups and sex, should be taken with caution.

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