

Review

The effects of plyometric jump training on physical fitness attributes in basketball players: A meta-analysis

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Abstract

Background: There is a growing body of experimental evidence examining the effects of plyometric jump training (PJT) on physical fitness attributes in basketball players; however, this evidence has not yet been comprehensively and systematically aggregated. Therefore, our objective was to meta-analyze the effects of PJT on physical fitness attributes in basketball players, in comparison to a control condition.

Methods: A systematic literature search was conducted in the databases PubMed, Web of Science, and Scopus, up to July 2020. Peer-reviewed controlled trials with baseline and follow-up measurements investigating the effects of PJT on physical fitness attributes (muscle power, i.e., jumping performance, linear sprint speed, change-of-direction speed, balance, and muscle strength) in basketball players, with no restrictions on their playing level, sex, or age. Hedge's *g* effect sizes (ES) were calculated for physical fitness variables. Using a random-effects model, potential sources of heterogeneity were selected, including subgroup analyses (age, sex, body mass, and height) and single training factor analysis (program duration, training frequency, and total number of training sessions). Computation of meta-regression was also performed.

Results: Thirty-two studies were included, involving 818 total basketball players. Significant ($p < 0.05$) small-to-large effects of PJT were evident on vertical jump power (ES = 0.45), countermovement jump height with (ES = 1.24) and without arm swing (ES = 0.88), squat jump height (ES = 0.80), drop jump height (ES = 0.53), horizontal jump distance (ES = 0.65), linear sprint time across distances ≤ 10 m (ES = 1.67) and > 10 m (ES = 0.92), change-of-direction performance time across distances ≤ 40 m (ES = 1.15) and > 40 m (ES = 1.02), dynamic (ES = 1.16) and static balance (ES = 1.48), and maximal strength (ES = 0.57). The meta-regression revealed that training duration, training frequency, and total number of sessions completed did not predict the effects of PJT on physical fitness attributes. Subgroup analysis indicated greater improvements in older compared to younger players in horizontal jump distance (> 17.15 years, ES = 2.11; ≤ 17.15 years, ES = 0.10; $p < 0.001$), linear sprint time > 10 m (> 16.3 years, ES = 1.83; ≤ 16.3 years, ES = 0.36; $p = 0.010$), and change-of-direction performance time ≤ 40 m (> 16.3 years, ES = 1.65; ≤ 16.3 years, ES = 0.75; $p = 0.005$). Greater increases in horizontal jump distance were apparent with > 2 compared with ≤ 2 weekly PJT sessions (ES = 2.12 and ES = 0.39, respectively; $p < 0.001$).

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Conclusion: Data from 32 studies (28 of which demonstrate moderate-to-high methodological quality) indicate PJT improves muscle power, linear sprint speed, change-of-direction speed, balance, and muscle strength in basketball players independent of sex, age, or PJT program variables. However, the beneficial effects of PJT as measured by horizontal jump distance, linear sprint time >10 m, and change-of-direction performance time ≤ 40 m, appear to be more evident among older basketball players.

Keywords: Exercise therapy; Human physical conditioning; Resistance training; Stretch reflex; Team sports

1. Introduction

Basketball strength and conditioning programs typically contain a strong emphasis on developing power and speed attributes.¹ This focus is predicated on specific game activities such as jumps, linear sprints, accelerations, decelerations, and changes-of-direction, which are performed repeatedly by players in defensive and offensive situations.^{2–4} Adequate balance^{5–7} and strength^{8–10} also seem to be crucial for basketball players to be able to perform various multi-directional, high-intensity actions during games. Therefore, designing effective training programs to improve basketball players' power, speed, balance and strength attributes is fundamental to optimize their performance during games.¹¹

Several training approaches are used by basketball players to improve power, speed, balance, and strength attributes.¹ However, plyometric jump training (PJT) seems to be particularly common¹ and equally¹² or even more effective¹³ than other training methods (e.g., traditional resistance training). The common incorporation of PJT among training practices in basketball¹ may be due to its high translatability to game scenarios. For instance, there is a strong reliance on vertical expressions of power when players are defending, shooting, and rebounding.^{2–4} According to the principle of training specificity, then, basketball players should regularly engage in PJT programs.^{1,14,15}

PJT capitalizes on the stretch-shortening cycle (SSC) wherein musculotendinous units are eccentrically stretched during the loading or impact phase before being concentrically shortened in the push-off or take-off phase.^{16,17} Indeed, jump exercises that utilize the SSC seem to be more effective at improving physical fitness attributes (e.g., sprinting, jumping, change of direction) than those that do not involve the SSC.¹⁸ Previous reviews have addressed both the potential mechanisms (e.g., stretch reflex, elastic energy) involved in the SSC and its potential for human performance enhancement extensively.^{16,19,20} They have found that PJT results in a wide range of distinct physiological and biomechanical adaptations (e.g. increased motor unit recruitment and rate of force development).^{21–24} Several meta-analyses have been published demonstrating the effectiveness of PJT at improving distinct power-related attributes in athletes from different disciplines, including soccer,²⁵ handball,²⁶ and volleyball.²⁷ Likewise, there is a growing body of experimental evidence examining the effects of PJT on physical fitness attributes in basketball players, specifically;^{28–30} however, this evidence has not yet been comprehensively aggregated.

To the best of our knowledge, only one meta-analysis is available in the literature, and it solely examines the effects of

PJT on vertical jump performance in basketball players.¹² Although the analysis showed significant improvement for vertical jump performance,¹² several relevant physical fitness attributes required of basketball players—such as linear and change-of-direction speed, balance, and muscle strength³¹—were neglected, as were factors that inform PJT prescription such as training duration, frequency, and volume.¹² Moreover, the existing meta-analysis included a small number of studies (5 studies, $n = 94$ participants),¹² meaning its outcomes are rather preliminary. Indeed, since the publication of the aforementioned analysis,¹² a recent scoping review revealed a total of 48 PJT studies have been conducted among basketball players.³² Owing to the lack of comprehensive analysis regarding the effects of PJT on player fitness in basketball, and to the high practical relevance of PJT in basketball settings, this meta-analysis aimed to examine the effects of PJT on various physical fitness attributes in basketball players (muscle power, i.e., jumping performance, linear and change-of-direction speed, balance and muscle strength), in comparison to a control condition.

2. Methods

2.1. Procedures

A meta-analysis was conducted following the guidelines of the Cochrane Collaboration.³³ Findings were reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).³⁴ This study was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (No. 202040088).

2.2. Literature search

To conduct the literature search, we considered recommendations from the 2 largest scoping reviews that have previously examined PJT.^{32,35} Computerized literature searches were conducted in the electronic databases PubMed (comprising MEDLINE), Web of Science Core Collection, and Scopus. The search strategy was conducted using the Boolean operators AND as well as OR with the following keywords: “ballistic”, “training”, “complex”, “explosive”, “force”, “velocity”, “plyometric”, “stretch”, “jump”, “shortening”, “basketball”, “team sport”, and “cycle”. For example, the following search was adopted using PubMed: (“randomized controlled trial” (Publication Type) OR “controlled clinical trial” (Publication Type) OR “randomized” (Title/Abstract) OR “trial” (Title) OR “clinical trials as topic” (MeSH Major Topic)) AND (“basketball” (Title/Abstract) OR “basketball players” (Title/Abstract) OR “basketball teams” (Title/Abstract)) AND

("training"(Title/Abstract) OR "plyometric"(Title/Abstract)). After an initial search in April 2017, accounts were created for the lead author (RRC) in each of the respective databases, through which they received automatically generated email updates regarding the search terms used. The search was refined in May 2019, and updates were received daily (if available); studies were eligible for inclusion up to July 1, 2020. The lead author (RRC) conducted the initial search and removed duplicates. Thereafter, the search results were analyzed according to the eligibility criteria (Table 1).

In selecting studies for inclusion, a review of all relevant titles was conducted before examination of the abstracts and full-text versions. Following the formal systematic searches, additional hand searches were conducted using the authors' personal libraries and known published reviews, systematic reviews, and meta-analyses. Two authors (RRC and AGH) independently screened the titles, abstracts, and full-text versions of retrieved studies. During the search and review process, potential discrepancies between the same 2 authors regarding inclusion and exclusion criteria (e.g., type of control group, intervention adequacy) were resolved through consensus with a third author (YN).

2.3. Inclusion and exclusion criteria

A PICOS (participants, intervention, comparators, outcomes, and study design) approach was used to rate studies for eligibility.³⁴ The respective inclusion/exclusion criteria adopted in our meta-analysis are reported in Table 1.

Additionally, only full-text, peer-reviewed, original studies were considered for the present meta-analysis. Excluded were books, book chapters, and congress abstracts, as well as cross-sectional review papers, and training-related studies that did not focus on the effects of PJT exercises (e.g., studies examining the effects of upper-body plyometric exercises). Also excluded were retrospective studies, prospective studies, studies in which the use of jump exercises was not clearly described, studies for which only the abstract was available, case reports, special communications, letters to the editor, invited commentaries, errata, overtraining studies, and detraining studies. In the case of detraining

studies, if they involved a training period prior to a detraining period then the study was considered for inclusion. Not considered for inclusion were studies that drew participants from sports other than basketball, unless the data for basketball players were reported independently. Finally, in view of the potential difficulties of translating articles written in different languages—and the fact that 99.6% of the PJT literature is published in English³⁵—only articles written in English were considered for this meta-analysis.

2.4. Data extraction

Physical fitness attributes measured during jumping (e.g., countermovement jump), linear sprinting (e.g., 10 m, 20 m), change-of-direction (e.g., Illinois test), balance (e.g., dynamic, static), and strength (e.g., maximal, dynamic, isometric) tests were extracted as dependent variables from included studies. We sought to analyze the effects of PJT on different jumping actions (i.e., countermovement jump, countermovement jump with arm swing (Abalakov jump), drop jump, squat jump, horizontal jump), on distances during linear sprints (≤ 10 m and > 10 m), and on change-of-direction tests (≤ 40 m and > 40 m), as these effects may reflect different physiological and biomechanical indicators relevant to basketball performance.^{36,37} Moreover, we sought to analyze the effects of PJT on hamstring/quadriceps strength ratios at different velocities (60 °/s and 120 °/s–300 °/s), since they present distinct lower limb strength imbalances and injury risks.^{8,38} In addition, tests examining the chosen fitness variables (jump, linear and change-of-direction sprint, balance, and strength) usually present very high test-retest reliability (with an intraclass correlation coefficient of > 0.9),^{39–41} which is essential to ensure strong consistency between analyzed studies within a meta-analysis.³⁴

The means and standard deviations (SDs) of dependent variables were extracted at pre- and post-PJT time points from included studies using Microsoft Excel (Microsoft Corp., Redmond, WA, USA). In cases where the required data were not clearly or completely reported, the authors of the study were contacted for clarification.^{28,42–45} If no response was obtained from the authors (after 2 attempts), or if the authors could not

Table 1
Selection criteria used in the meta-analysis.

Category	Inclusion criteria	Exclusion criteria
Population	Apparently healthy basketball players, with no restrictions on their playing level, sex, or age	Basketball players with health problems (e.g., injuries, recent surgery)
Intervention	A plyometric jump training program, defined as lower 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 training programs representing less than 50% of the total training load when delivered in conjunction with other training interventions (e.g., high-load resistance training)
Comparator	Active control group	Absence of active control group
Outcome	At least 1 measure of physical fitness (e.g., muscle power (i.e., jumping), linear and change of direction speed, balance, or muscle strength) before and after the training intervention.	Lack of baseline and/or follow-up data
Study design	Controlled trials	Non-controlled trials

provide the requested data, the study outcome was excluded from the analysis. However, even when no numerical data were provided by the authors upon contact, in cases where data were displayed in a figure, the meta-analysis used validated ($r = 0.99$, $p < 0.001$)⁴⁶ software (WebPlotDigitizer; <https://apps.automeris.io/wpd/>) to derive the relevant numerical data. Two authors (RRC and YN) performed data extraction independently, and any discrepancies between them (e.g., mean value for a given outcome, total number of participants in a group) were resolved through consensus with a third author (AGH).

2.5. Methodological quality of the included studies

The Physiotherapy Evidence Database (PEDro) scale was used to assess the methodological quality of the included studies, which were rated from 0 (*lowest quality*) to 10 (*highest quality*). As outlined previously, the methodological quality was interpreted using the following convention:⁴⁷ ≤ 3 points was considered as poor quality, 4–5 points was considered as moderate quality, and 6–10 points was considered as high quality. If trials had already been assessed and listed on the PEDro database, these scores were adopted. The methodological quality for each included study was assessed independently by 2 authors (YN and RRC), and any discrepancies between them were resolved via consensus with a third author (ATS).

2.6. Summary measures, synthesis of results, and publication bias

Although meta-analyses can be done with as few as 2 studies,⁴⁸ considering the fact that reduced sample sizes are common in the sports science literature⁴⁹ (including PJT studies^{32,35,50}), meta-analysis was only conducted in the present case when ≥ 3 studies were available.^{51–53} Effect sizes (ESs; Hedge's g) for each physical fitness attribute in the PJT and control groups were calculated using pre-training and post-training mean and SD for each dependent variable. Data were standardized using post-intervention SD values. The random-effects model was used to account for differences between studies that might impact the PJT effect.^{54,55} The ES values are presented with 95% confidence intervals (95% CIs). Calculated ES were interpreted using the following scale: trivial: <0.2 ; small: $0.2–0.6$; moderate: $>0.6–1.2$; large: $>1.2–2.0$; very large: $>2.0–4.0$; extremely large: >4.0 .⁵⁶ In studies including more than 1 intervention group, the sample size in the active control group was proportionately divided to facilitate comparisons across multiple groups.⁵⁷ Heterogeneity was assessed using the I^2 statistic, with values of $<25\%$, $25\%–75\%$, and $>75\%$ representing low, moderate, and high levels of heterogeneity, respectively.⁵⁸ The risk of bias was explored using the extended Egger's test.⁵⁹ In cases of bias, the trim and fill method was applied.⁶⁰ All analyses were carried out using the Comprehensive Meta-Analysis software (Version 2.0; Biostat, Englewood, NJ, USA). Statistical significance was set at $p \leq 0.05$.

2.7. Moderator analyses

Using a random-effects model and independent computed single factor analysis, potential sources of heterogeneity likely to influence the effects of training were selected *a priori*.

2.7.1. Subgroup analyses

As the adaptive responses to PJT programs may be affected by participant age^{61–63} and sex,⁶⁴ these factors were considered as potential moderator variables. *A posteriori*, subgroup analyses according to participant's body mass and height were included.

2.7.2. Single training factor analysis

Single training factor analyses were computed for the program duration (number of weeks and total number of training sessions)⁶⁴ and training frequency (number of sessions per week)⁶⁵ based on the reported influence of these variables on physical fitness adaptations to PJT.

When appropriate, subgroup analyses and single training factor analyses were divided using the median split technique.^{66–68} The median was calculated if at least 3 studies provided data for a given moderator. Of note, when 2 experimental groups with the same information for a given moderator were included in a study, only one of the groups was considered in order to avoid an undue influence on the median calculation. In addition, to minimize heterogeneity, instead of using a global median value for a given moderator (e.g., median age derived from all included studies), median values were calculated using only those studies that provided data for the outcome being analyzed.

2.7.3. Meta-regression

A multivariate random-effects meta-regression was conducted to verify whether any of the training variables (frequency, duration, and total number of sessions) predicted the effects of PJT on physical fitness variables. Computation of meta-regression was performed with at least 10 studies per covariate.⁶⁹

3. Results

3.1. Study selection

The search process identified 7533 studies (2370 from PubMed; 2387 from Scopus; and 2776 from WoS). Fig. 1 provides a graphical schematization of the study selection process. Duplicated studies were removed ($n = 4863$). After study titles and abstracts were screened, a further 2172 studies were removed. Accordingly, full-text versions of 498 studies were screened, with 32 studies^{28–30,42–45,70–94} considered eligible for meta-analysis. The included studies involved 442 participants in 37 experimental groups and 376 participants in 32 control groups. The characteristics of the participants and the PJT interventions used in the included studies are displayed in Table 2 and Supplementary Table 1, respectively. Supplementary Table 2 presents the mean \pm SD for the physical fitness variables in experimental and control groups as reported in the included studies.

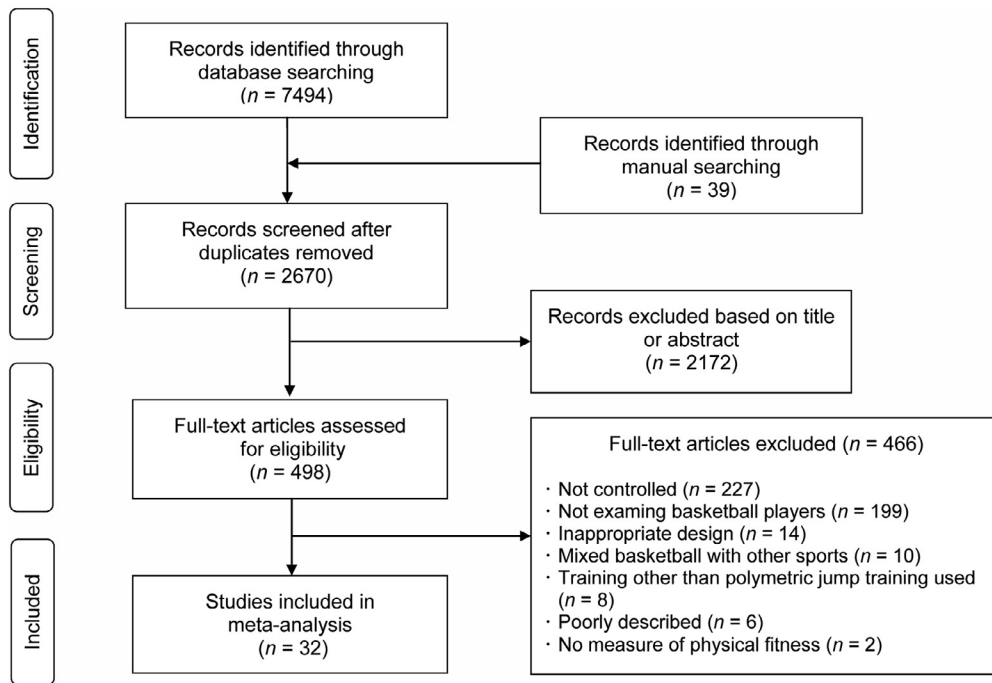


Fig. 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

3.2. Methodological appraisal of the included studies

Using the PEDro checklist, 4 studies were classified as low quality (3 points), 22 studies were classified as moderate quality (4–5 points), while 6 studies were considered to be high quality (6–8 points) (Supplementary Table 3). A sensitivity analysis revealed that the main meta-analysis results remained consistent after removal of studies classified as low quality. Therefore, no studies were excluded based on methodological quality.

3.3. Meta-analysis results

The overall effects of PJT on physical fitness attributes are displayed in Table 3. Forest plots are shown in Supplementary Figures. There were significant ($p \leq 0.001$) small-to-large effects of PJT on vertical jump power, countermovement jump height with and without arm swing, squat jump height, drop jump height, and horizontal jump distance ($ES = 0.45$ – 1.24 ; Supplementary Figs. 1–6). For linear sprints across distances categorized as ≤ 10 m and > 10 m, significant ($p \leq 0.001$) moderate-to-large effects of PJT were observed ($ES = 0.92$ – 1.67 ; Supplementary Figs. 7 and 8). Similarly, significant ($p \leq 0.001$) moderate effects of PJT were noted during change-of-direction speed tests across distances categorized as ≤ 40 m and > 40 m ($ES = 1.02$ – 1.15 ; Supplementary Figs. 9 and 10). Regarding dynamic and static balance, significant ($p = 0.002$) and near-significant ($p = 0.087$) moderate-to-large effects of PJT were found ($ES = 1.16$ – 1.48 ; Supplementary Figs. 11 and 12). In terms of muscle strength, significant ($p = 0.025$) moderate effects of PJT on maximal strength were noted ($ES = 0.57$; Supplementary Fig. 13). However, non-significant ($p = 0.661$ – 0.885) trivial effects of PJT were observed for hamstring/quadriceps strength ratios categorized at speeds of

$60^\circ/s$ and $120^\circ/s$ – $300^\circ/s$ ($ES = -0.04$ to -0.10 ; Supplementary Figs. 14 and 15). The risk of bias was explored using the extended Egger's test, and 13 out of 15 meta-analyses showed no risk of bias. For the remaining 2 meta-analyses (i.e., squat jump height, horizontal jump distance), the trim and fill method was applied to adjust observed values (Table 3).

3.4. Moderator analyses

Moderator analyses were considered, given that ≥ 3 studies per moderator were available. In total, 37 subgroup and single training factor analyses were conducted for: countermovement jump height with arm swing (duration, frequency, total sessions, age, body mass, and height) and without (duration, frequency, total sessions, age, sex, body mass, and height), squat jump height (duration, frequency, age, body mass, and height), drop jump height (duration, total sessions, age, body mass, and height), horizontal jump distance (duration, frequency, total sessions, age, body mass, and height), linear sprint time > 10 m (total sessions, age, body mass, and height), and change-of-direction performance time ≤ 40 m (duration, frequency, total sessions, age, body mass, and height). The analyses are summarized below, with full descriptions presented in Supplementary Appendix 1.

3.4.1. Subgroup analyses

Significantly greater improvements were apparent following PJT in older basketball players, as compared to their younger counterparts, for horizontal jump distance (> 17.15 years of age, $ES = 2.11$; ≤ 17.15 years of age, $ES = 0.10$; $p < 0.001$), linear sprint time > 10 m (> 16.3 years of age, $ES = 1.83$; ≤ 16.3 years of age, $ES = 0.36$; $p = 0.010$), and change-of-

Table 2
Characteristics of participants examined in the included studies.

Study	Randomized	<i>n</i>	Sex	Age ^a (year)	Body mass ^a (kg)	Height ^a (m)	SPT	Fitness ^b
Adigüzel and Günay (2016) ⁷¹	NR	30	M	15.0/18.0	NR	NR	NR	NR
Amato et al. (2018) ⁷²	Yes	23	M	11.0/12.0	47.1/50.3	1.53/1.57	NR	NR
Andrejic (2012) ⁷³	Yes	21	M	12.5/12.6	58.0/62.0	1.71/1.73	No	Normal
Arazi and Asadi (2011) ^{45,c}	Yes	18	M	18.0/20.4	60.2/75.6	1.75/1.82	No	Moderate-high
Arazi et al. (2012) ^{43,c}	Yes	18	M	18.0/20.4	60.2/75.6	1.75/1.82	No	Moderate-high
Arede et al. (2019) ⁷⁴	No	16	M	14.2/14.8	56.2/62.6	1.65/1.75	Yes	Moderate
Asadi et al. (2017) ⁷⁵	Yes	16	M	18.5 ± 0.8	78.4 ± 7.6	1.86 ± 0.06	Yes	Moderate
Asadi (2013) ⁷⁶	Yes	20	M	20.1/20.2	78.5/79.5	1.80/1.82	NR	Moderate-normal
Asadi (2013) ⁷⁷	Yes	20	M	20.1/20.2	78.5/79.5	1.80/1.82	NR	Moderate-normal
Attene et al. (2015) ⁷⁸	Yes	36	F	14.8/15.2	51.8/57.5	1.63/1.65	NR	Moderate
Benis et al. (2016) ²⁹	Yes	28	F	20.0 ± 2.0	62.0/63.0	1.70/1.72	NR	Moderate-high
Bouteraa et al. (2020) ⁷⁹	Yes	26	F	16.4/16.5	55.6/56.6	1.68/1.68	NR	Normal
Brown et al. (1986) ⁸⁰	Yes	26	M	15.0 ± 0.7	67.9 ± 8.1	1.81 ± 0.08	NR	Normal-moderate
Canavan and Vescovi (2004) ⁴²	Yes	20	F	20.1 ± 1.6	65.9 ± 8.9	NR	NR	Normal
Cherni et al. (2019) ⁸¹	No	25	F	20.9/21.0	65.1/67.3	1.72/1.73	NR	Moderate
Fachina et al. (2017) ⁸³	Yes	39	M	15.2/16.4	72.6/72.8	1.76/1.80	No	Moderate
Floría et al. (2019) ⁸⁴	Yes	34	F	23.1/23.2	60.4/64.9	1.68/1.69	Yes	NR
Fontenay et al. (2013) ⁸²	No	14	F	15.5 ± 0.7	NR	NR	No	Normal
Gottlieb et al. (2014) ⁸⁵	Yes	19	M	16.3 ± 0.5	78.2 ± 5.9	1.85 ± 0.04	No	Normal-moderate
Hernández et al. (2018) ^{86,c}	Yes	19	M	9.7/11.0	36.3/39.4	1.42/1.44	No	Normal-moderate
Khlifa et al. (2010) ^{30,c}	Yes	27	M	23.1/24.1	81.7/83.1	1.91/1.93	NR	High
Latorre Román et al. (2018) ⁸⁷	Yes	58	M/F	8.7 ± 1.0	30.5/35.1	1.33/1.40	No	Moderate
Matavulj et al. (2001) ^{28,c}	Yes	33	M	15.0/16.0	NR	NR	NR	Moderate-high
McLeod et al. (2009) ⁸⁸	No	50	F	15.6/16.0	58.9/62.3	1.70/1.71	NR	Normal-moderate
Meszler and Vácz (2019) ⁸⁹	Yes	18	F	15.7/15.8	63.5/66.1	1.76/1.77	Yes	Moderate
Poomsalood and Pakulanon (2015) ⁹⁰	Yes	10	M	19.2/19.6	65.2/66.3	1.73/1.74	No	NR
Santos and Janeira (2008) ⁹¹	Yes	24	M	14.5/15.0	61.1/62.6	1.72/1.73	No	NR
Santos and Janeira (2009) ⁹²	Yes	15	M	14.0/15.0	69.3/75.6	1.74/1.77	Yes	NR
Santos and Janeira (2011) ⁹³	Yes	25	M	14.2/14.7	61.1/72.7	1.73/1.75	No	NR
Vescovi et al. (2008) ⁹⁴	Yes	20	F	19.9/20.3	64.8/66.9	1.68/1.71	No	Normal
Wilkerson et al. (2004) ⁴⁴	No	19	F	19.0 ± 1.4	69.1/74.9	1.70/1.73	NR	Moderate
Zribi et al. (2014) ⁷⁰	Yes	51	M	12.1/12.2	41.1/41.2	1.54/1.55	No	Normal-moderate

^a Mean values for experimental/control groups (mean ± SD are reported for those studies where authors reported combined data for experimental and control groups).

^b Fitness was classified here as it was in the recent review by Ramirez-Campillo et al.:³² (1) NR; (2) high encompasses professional/elite athletes with regular enrollment in national and/or international competitions, or highly trained participants with ≥10 training hours/week or ≥6 training sessions/week and a regularly scheduled official or friendly competition; (3) moderate encompasses non-elite/professional athletes with a regular attendance in regional and/or national competitions, between 5.0–9.9 training hours/week or 3–5 training sessions/week and a regularly scheduled official or friendly competition; and (4) normal encompasses recreational athletes with <5 training hours/week with sporadic or no participation in competition.

^c Denotes studies that included more than 1 experimental group.

Abbreviations: F = female; M = male; NR = not reported; SPT = systematic experience with plyometric jump training.

direction performance time ≤40 m (>16.3 years of age, ES = 1.65; ≤16.3 years of age, ES = 0.75; $p = 0.005$).

3.4.2. Single training factor analysis

Significantly greater improvements ($p < 0.001$) in horizontal jump distance were evident when players performed >2 sessions/week (ES = 2.12), as opposed to when they performed ≤2 sessions/week (ES = 0.39).

3.4.3. Results of meta-regression

Computation of meta-regression was performed with at least 10 studies per covariate. Initially, countermovement jump height with and without arm swing, squat jump height, linear sprint time >10 m, and change-of-direction performance time <40 m were all considered for meta-regression analyses. However, the regression was not computed for

linear sprint time >10 m and change-of-direction performance time <40 m due to collinearity. Therefore, meta-regression analyses were computed for countermovement jump height with and without arm swing, as well as squat jump height, and it included 3 training variables (frequency, duration, and total number of sessions) (Table 4). Irrespective of training type, none of the training variables were found to predict the effects of PJT on countermovement and squat jump performance ($p > 0.05$), except for the total number of training sessions with respect to squat jump height ($p = 0.040$), although $R^2 = 0$.

3.5. Adverse effects

Among the included studies, none reported soreness, pain, fatigue, injury, damage, or adverse effects related to the PJT

Table 3

Synthesis of results across included studies regarding the effects of plyometric jump training on fitness attributes in basketball players.

Fitness attribute	<i>n</i> ^a	ES (95%CI)	<i>p</i>	<i>I</i> ² (%)	Egger's test (<i>p</i>)	RW (%)
Jumping variables						
Vertical jump power	4, 4, 4, 102	0.45 (0.07 to 0.84)	0.021	0	0.323	20.8–34.1
Countermovement jump with arm swing height	11, 12, 11, 256	1.24 (0.72 to 1.75)	< 0.001	71.2	0.120	4.8–10.4
Countermovement jump height	18, 21, 18, 500	0.88 (0.55 to 1.22)	< 0.001	67.0	0.071	2.6–6.4
Squat jump height	11, 12, 11, 331	0.80 (0.47 to 1.14)	< 0.001	51.8	0.008 ^b	3.5–12.3
Drop jump height	8, 9, 8, 204	0.53 (0.25 to 0.80)	< 0.001	0.0	0.567	4.8–29.1
Horizontal jump distance	8, 10, 8, 230	0.65 (−0.02 to 1.31) ^c	0.001	80.9	0.008	7.4–12.5
Sprint variables						
≤10-m linear sprint time	3, 3, 3, 93	1.67 (0.32 to 3.03)	0.016	85.1	0.307	24.8–38.7
>10-m linear sprint time	11, 13, 11, 281	0.92 (0.40 to 1.44)	< 0.001	74.3	0.061	5.5–10.2
≤40-m change-of-direction performance time	13, 15, 13, 307	1.15 (0.75 to 1.55)	< 0.001	59.7	0.189	4.0–9.9
>40-m change-of-direction performance time	5, 6, 5, 93	1.02 (0.29 to 1.76)	0.006	64.9	0.272	13.9–19.4
Balance variables						
Dynamic balance	5, 5, 5, 149	1.16 (0.43 to 1.89)	0.002	76.1	0.586	17.6–22.5
Static balance	4, 4, 4, 119	1.48 (−0.19 to 3.15)	0.002	93.3	0.252	25.0–25.4
Strength variables						
Maximal strength	5, 7, 5, 104	0.57 (0.07 to 1.07)	0.025	38.0	0.117	10.1–17.5
Hamstring/quadriceps strength ratio at 60 °/s	4, 4, 4, 92	−0.10 (−0.56 to 0.36)	0.661	23.6	0.060	20.4–30.7
Hamstring/quadriceps strength ratio at ≥120 °/s	4, 4, 4, 92	−0.04 (−0.56 to 0.48)	0.885	39.8	0.785	21.8–29.4

Note: Bolded *p* values mean significant (*p* < 0.05) improvement in the experimental group after plyometric jump training as compared with the control group.

^a Data denote the number of studies that provided data for the analysis, the number of experimental groups, the number of control groups, and the total number of basketball players included in the analysis, respectively.

^b Adjusted values remained the same (as the observed values) after the trim and fill method.

^c Adjusted values are displayed using the trim and fill method.

Abbreviations: 95%CI = 95% confidence interval; ES = effect sizes (Hedge's *g*); RW = relative weight of each study in the analysis.

intervention. However, 1 study⁸⁹ hypothesized that the lack of positive adaptations observed after the PJT program may be partially explained by a high load of regular basketball training, games, and PJT, which was likely to induce fatigue due to incomplete recovery between sessions. The authors did not provide evidence to support this supposition.

Table 4

Results of the multivariate random-effect meta-regression for training variables to predict plyometric jump training effects on vertical jump performance^a in basketball players.

Covariate	Coefficient	95%CI	Z	<i>p</i>
Countermovement jump height (<i>n</i> = 21)				
Intercept	0.448	−3.557 to 4.455	0.22	0.826
Training duration	−0.008	−0.407 to 0.389	−0.04	0.966
Frequency	0.097	−1.801 to 1.999	0.10	0.920
Total sessions	0.015	−0.192 to 0.224	0.15	0.881
Countermovement jump with arm swing height (<i>n</i> = 12)				
Intercept	−0.397	−8.252 to 7.457	−0.10	0.921
Training duration	0.005	−0.663 to 0.674	0.02	0.987
Frequency	0.961	−2.989 to 4.913	0.48	0.633
Total sessions	−0.028	−0.404 to 0.348	−0.15	0.883
Squat jump height (<i>n</i> = 12)				
Intercept	4.223	−0.039 to 8.487	1.94	0.052
Training duration	−0.393	−0.815 to 0.029	−1.82	0.068
Frequency	−2.439	−4.910 to 0.030	−1.94	0.052
Total sessions	0.287	−0.011 to 0.562	2.04	0.040

Notes: *n* means number of study groups. Bolded *p* values mean significant (*p* < 0.05) prediction effect of plyometric jump training on jumping performance.

^a Computation of meta-regression was performed with at least 10 studies per covariate, available only for countermovement and squat jump performance from the investigated fitness variables.

Abbreviation: 95%CI = 95% confidence interval.

Participants' previous experience with PJT was not reported in 14 of the studies (Table 2). Moreover, while most of the included studies (24 of 32) applied progressive PJT overload in the form of either volume, intensity, and/or type drill (Supplementary Table 1), none of the studies reported a clear relationship between a minimum set of movement quality requirements during plyometric jump drills and progressive overload, or even plyometric jump drill prescription.

4. Discussion

This meta-analysis aimed to examine the effects of PJT on physical fitness attributes in basketball players, in comparison with a control condition. Our findings showed small-to-large effects of PJT on muscle power, linear and change-of-direction sprint speed, balance, and muscle strength, regardless of sex and age. However, subgroup analyses showed that, as compared with younger (≤16.3 years) basketball players, older players (>16.3 years) experienced greater improvements in horizontal jump distance, linear sprint time across distances >10 m, and change-of-direction performance time across distances ≤40 m following PJT. Except for the significant positive effect of total PJT sessions on squat jump height, meta-regression analyses revealed that none of the training variables (duration, frequency, and total number of sessions) predicted the effects of PJT on physical fitness attributes in basketball players. Single training factors analysis for those variables (PJT program duration, session frequency, and total number of sessions) revealed that none of them moderate the effects of PJT on measures of physical fitness in basketball players.

4.1. Muscle power

Compared to a control, there were significant small-to-large benefits following PJT with respect to countermovement jump height with ($ES = 1.24$) and without arm swing ($ES = 0.88$), squat jump height ($ES = 0.80$), drop jump height ($ES = 0.53$), and horizontal jump distance ($ES = 0.65$). Improvements in jumping performance with PJT may be attributed to various adaptive mechanisms, such as enhanced motor unit recruitment, greater inter-muscular coordination, heightened neural drive to agonist muscles, and enhanced utilization of the SSC.^{16,21} Significantly larger improvements ($p \leq 0.005$) were apparent for horizontal jump distance in older basketball players (>17.15 years, $ES = 2.11$), as compared to their younger counterparts (≤ 17.15 years, $ES = 0.10$), a finding that is in line with a previous PJT meta-analysis of older youth basketball players.⁶³ Indeed, when participants between the mean ages of 10–12.99 years, 13–15.99 years, and 16–18 years, respectively, were exposed to PJT, the greatest magnitude of improvement in countermovement jump height was noted among the older group ($ES = 1.02$).⁶³ The greater improvement in older youth players may be attributable to their wider array of (neural and morphological) mechanisms for adaptation as compared to younger athletes, whose mechanisms are neurological only because they have yet to experience the increased anabolic hormonal concentrations concomitant with puberty.^{19,63,67} However, another explanation for the larger gains in horizontal jump distance among basketball players >17.15 years of age may be related to the fact that, in our meta-analysis, a mean age of 14.2 years was observed among the younger players and, notably, most of the studies involved males. That is, most of the study groups with players ≤ 17.15 years of age examined players in their “adolescent awkwardness” phase.^{63,95,96} This phase is characterized by a diminished return in terms of the beneficial effects of PJT on jumping performance.⁶³ With this in mind, future studies may be able to elucidate the ways in which maturity and training age interact with PJT and physical fitness changes in basketball players.

In addition to age, greater improvements in horizontal jump distance were evident when >2 sessions/week were performed in PJT programs, as opposed to ≤ 2 sessions/week ($ES = 2.12$ and $ES = 0.39$, respectively; $p < 0.001$). In this regard, the analyses supported the use of greater training frequency for the enhancement of horizontal expression of power. A greater training frequency allows for a greater volume of jumps to be performed across days. When combined with adequate recovery between sessions to reduce fatigue, high training intensities can be implemented along with the more frequent training sessions, which is a key element to achieving optimal benefits with PJT.^{97–99} For example, if a given volume of total jumps (e.g., 1680) is prescribed during a given time period (e.g., 7 weeks), such a volume would probably induce greater absolute physical fitness improvements compared to a lower volume (e.g., 420 jumps).¹⁰⁰ With reference to the previous study,¹⁰⁰ 4 sessions per week requires only 60 jumps/session (whereas 240 jumps should be completed per session if only one weekly

session is scheduled). A reduced volume of jumps per session is likely to allow for improved recovery between jumps (e.g., 15 s),¹⁰¹ which in turn permits players to achieve greater training intensity, hence, better training results.^{98,99,102} In addition, a session of 60 jumps would take approximately 15 min, and so could easily be imbedded in the regular training sessions of basketball players. It was surprising, however, that programs with greater training frequencies were no more effective than programs with lower training frequencies at increasing vertical jumping performance. The reasons for these contrasting findings are unclear, but could suggest that increases in vertical jump performance are achievable with less training stimuli than are increases in horizontal jump performance. This finding could indicate a differential time-course of adaptation between vertical and horizontal jump performance, or it could represent a bias toward prescription of vertically orientated exercises in modern strength and conditioning programs for basketball players.^{13,103} From a practical standpoint, PJT seems to be particularly effective for enhancing horizontal expression of power when applied with a greater weekly frequency in young players of advanced age (post-pubertal), which is in line with long-term athletic development approaches,^{104–106} particularly those advocating for PJT.¹⁰⁷

4.2. Linear sprinting

Sprinting bouts are regularly performed during decisive defensive and offensive game situations in basketball.^{2–4} Our findings showed significant improvements in shorter (≤ 10 m) and longer (> 10 m) sprint times in basketball players after PJT, in comparison to a control. These results are in line with those reported in a previous meta-analysis examining athletes from different team sports.¹⁰⁸ Increases in sprint performance after PJT may be due to increased neuromuscular activation of the trained muscles.¹⁰⁹ More specifically, increases in the number and/or firing frequencies of activated motor units, as well as changes in the recruitment pattern of the motor units (primarily in fast-twitch muscle fibers), might account for the observed improvements in linear sprint performance following PJT.¹⁰⁹ In turn, these adaptations will likely increase maximal muscle force and power capabilities, permitting players to explode more rapidly at the start of sprints and to execute longer stride lengths as sprints progress.^{110,111} Moreover, neuro-mechanical adaptations induced by lower body PJT, such as enhanced neural drive to agonist muscles and optimization of muscle-tendon stiffness,²¹ may improve SSC efficacy. As a result of improvements in SSC efficacy in lower body musculature, greater force production likely occurs in the concentric movement phase after a rapid eccentric muscle action,^{17,19,21} which is a key requirement for enhanced sprint performance.¹¹¹ Of note, 27 of the 32 studies included in our meta-analysis employed a mixture of horizontal and vertical jumps in the PJT program. While horizontal force-related capabilities are of particular relevance in the acceleration phase of linear sprints (i.e., ≤ 10 m), vertical force application to the ground becomes more prominent as sprints progress and speed increases (i.e., > 10 m).^{110,112,113} In this sense, the combination of horizontal and vertical jumps

included in PJT may be an adequate strategy for basketball players aiming to improve sprinting performance.

Concerning subgroup analyses, significantly larger improvements in linear sprint time >10 m were observed after PJT among basketball players aged ≥ 16.3 years, as compared with those aged <16.3 years ($ES = 1.83$ vs. $ES = 0.36$). The greater benefits with PJT on linear sprint speed among players aged ≥ 16.3 years concurs with findings in a previous meta-analysis,¹¹⁴ where greater improvements in sprinting performance were reported among athletes from different sport backgrounds aged 14.1 ± 0.7 years ($ES = 1.15$) and 16.8 ± 0.7 years ($ES = 1.39$), as compared to athletes aged 11.2 ± 0.3 years ($ES = -0.18$), following sprint training programs involving high-intensity SSC muscle actions similar to PJT. Complex changes in physical performance take place during an athlete's growth and maturation, which can affect their sprinting capabilities.^{115,116} Namely, the natural development of the SSC integral to sprint performance occurs during growth and maturation due to greater muscular size, increased limb length, changes to musculotendinous tissue (e.g., increased stiffness), enhanced neural and motor development, and better movement quality and coordination.^{19,115} As the timing and tempo of the aforementioned factors^{19,115} are highly variable between individuals, basketball coaches working with youth populations should consider not only the characteristics of the applied PJT program, but also the dynamic physiological changes that transpire throughout adolescence.

4.3. Change-of-direction speed

Accelerations and decelerations involving changes of direction are common, and are performed repeatedly during any basketball game.²⁻⁴ Our results showed that PJT improves change-of-direction performance time in basketball players, as compared to a control. These findings are in accordance with those of previous meta-analyses.^{61,117} Improvements in change-of-direction speed following PJT were expected, considering the extensive empirical evidence supporting the effectiveness of PJT on this fitness attribute.^{81,86,118} As eccentric strength is an important determinant of deceleration ability during change-of-direction actions,¹¹⁹ the higher inertia accumulated in the braking phase during PJT may have contributed to increases in eccentric workload and, therefore, larger strength improvements.¹²⁰ Indeed, improvements in change-of-direction speed may be due to the fact that athletes undergo extensive eccentric loading during PJT^{98,99,121} to increase the eccentric strength of the quadriceps muscles,¹²² which may translate to a more effective braking ability when changing direction.¹²²⁻¹²⁴ Likewise, improvements in change-of-direction performance with PJT could be due to the interaction of several neuromuscular adaptations including improved neural drive to agonist muscles, neuromuscular patterns that enable rapid switching between deceleration and acceleration motions (i.e., higher efficiency of the SSC), and muscle activation strategies that promote improved inter- and intra-muscular coordination.^{21,125} Moreover, PJT can decrease ground reaction times by increasing muscular force output and movement

efficiency, thereby positively affecting change-of-direction speed.¹²⁶

According to our subgroup analysis, a greater improvement in change-of-direction performance time across distances ≤ 40 m was evident among basketball players aged >16.3 years, as compared with those aged ≤ 16.3 years ($ES = 1.65$ vs. $ES = 0.75$, respectively; $p = 0.005$). In another meta-analysis,⁶¹ greater improvements in change-of-direction speed were also noted among participants aged 13.9 ± 1.0 years ($ES = 0.95$) and 17.4 ± 0.6 years ($ES = 0.99$), as compared with participants aged 11.3 ± 0.8 years ($ES = 0.68$), following PJT. The findings mimic our results for linear sprint performance. As linear and change-of-direction speed are significantly correlated in basketball players,^{127,128} this trend for change-of-direction speed may be explained by the same underlying mechanisms that account for greater linear sprint improvements among older players, as discussed elsewhere in this article.

4.4. Dynamic and static balance

Regarding dynamic and static balance, significant ($p = 0.002$) and near-significant ($p = 0.087$) moderate-to-large benefits were apparent with PJT ($ES: 1.16-1.48$). Improvements in balance have been observed in previous PJT studies, particularly after interventions that incorporated a combination of unilateral, bilateral, horizontal, and vertical jumping exercises.^{112,129,130} Of note, all studies included in our meta-analysis incorporated a combination of different jumping drills. This training approach may partially explain the rather large improvements ($ES: 1.16-1.48$) noted in balance performance after PJT, in comparison to a control condition. All of the studies included in our meta-analysis that assess balance performance administered training programs between 6-8 weeks in duration. This program length seems to be an adequate period of time to induce significant improvements in balance performance,¹³¹ especially with respect to PJT interventions.^{129,132} Because balance improvements may not only enhance various aspects of physical performance, but also reduce lower body injury risk,¹³¹ our results reinforce the value of PJT as an effective strategy to promote positive adaptive responses and counteract negative maladaptive responses.^{133,134} Such a protective effect against injury may be particularly prominent after training programs involving a combination of different PJT drills (e.g., unilateral, bilateral),¹³⁵ which was the case in the studies included in our meta-analysis. The improvement in balance performance may be related to improved co-contraction of lower body muscles¹³⁶ and/or to changes in proprioception and neuromuscular control.¹³⁷ However, the physiological and biomechanical mechanisms underlying balance improvements in basketball players after PJT remain unclear, and future research is needed to gather further insight into the adaptation mechanisms involved.

4.5. Muscle strength

In terms of muscle strength, significant moderate improvements in maximal strength were noted with PJT ($ES = 0.57$).

This finding supports data from a previous meta-analysis examining the benefits of PJT on maximal strength in participants with different sport and non-sport backgrounds.⁶⁵ Improvements in strength with PJT may be related to neural adaptations, including improved motor-unit firing frequency, synchronization, excitability, and efferent motor drive.²¹ The adaptive mechanisms can optimize the relative force generated per each motor unit recruited.¹⁹ However, improvements in muscle strength after PJT may also be related to muscle hypertrophy.¹³⁸ Aside from maximal strength, we analyzed measures of hamstring/quadriceps strength ratio to indicate lower body strength imbalances. Our analyses considered different velocities (i.e., 60 %/s and 120 %/s–300 %/s), which may represent different functional imbalances and levels of injury risk.^{8,38} However, for hamstring/quadriceps strength ratios at 60 %/s and 120 %/s–300 %/s, non-significant trivial effects of PJT were observed in comparison to a control condition (ES: –0.10 to –0.04). These findings cannot be attributed to the results of any particular study, given that the removal of any one of them^{44,71,81,89} from the meta-analysis (sensitivity analysis) did not significantly affect the results ($p > 0.05$). Although our results do not show a beneficial effect from PJT on hamstring/quadriceps strength ratios, meta-analyses suggest that PJT can be complemented with other training exercises to improve their impact on hamstrings/quadriceps strength ratios. More specifically, neuromuscular training,^{134,139,140} Nordic hamstring exercises,¹⁴¹ and/or balance training^{131,142} may complement PJT to optimize the hamstring/quadriceps strength ratio in basketball players. Interestingly, although PJT elicited only trivial changes in hamstring/quadriceps strength ratios, players did exhibit a robust balance between these muscle groups, when compared to normal values reported in previous studies.^{8,38} To confirm the effects of PJT on basketball players with imbalanced hamstring/quadriceps strength ratios, further studies simultaneously evaluating the influence of multi-modal training approaches are needed.

4.6. Different responses across physical fitness attributes and potential advantages derived from PJT

There is evidence that aspects of maximal strength, sprinting and jumping ability, and change-of-direction speed are associated with one another.^{9,143} In other words, it may be reasonably hypothesized that these different physical fitness attributes share a relatively similar set of underlying adaptation mechanisms (e.g., physiological, biomechanical) with respect to PJT programs. Our meta-analyses revealed that physical fitness improvements after PJT (ES: 0.45–1.67 for vertical jump power and linear sprinting across distances ≤ 10 m). Such variety of responses among studies could reflect a number of factors including differences in participant characteristics (e.g., training status) and methodological differences between analyzed studies (e.g., measurement protocol and instrumentation), as well as the distinct characteristics of the PJT interventions analyzed across the studies (e.g., total number of sessions, training frequency). Depending on the training approach, one may expect greater improvements in certain

physical fitness attributes over others. For example, when sprinting across shorter distances (e.g., ≤ 10 m), horizontal force application to the ground is of paramount importance, thus a greater load of horizontal PJT may lead to larger improvements during the early acceleration phase of a sprint (horizontal ground reaction force; push-off phase).^{110,112,113} In contrast, PJT with a greater emphasis in the vertical direction may induce larger improvements when nearing top speed (vertical ground reaction force).^{110,112,113} In this meta-analysis, most of the included studies involved mixed PJT programs that combined horizontal and vertical drills, as well as unilateral and bilateral drills, which may explain why improvements were noted across different physical fitness attributes.^{13,144,145}

In comparison with other training methods, PJT exhibits inherent advantages that deserve further discussion. Indeed, although there are several training approaches used among basketball players to improve physical fitness attributes,¹ PJT seems to be particularly common and equally¹² or even more effective¹³ than other training methods (e.g., traditional resistance training). Among its potential advantages, PJT programs tend to be inexpensive to implement compared to other resistance training methods. They require little or no equipment, usually involving drills that use the body's weight as resistance.¹⁴⁶ Plyometric jump drills, for example, can be conducted in a relatively small physical space, which may be an important advantage during certain scenarios (e.g., encountering pandemic restrictions) where athletes are forced to train at home.¹⁴⁷ Among younger athletes especially, plyometric jump drills may even be considered more fun than other training methods (e.g., flexibility, endurance).¹⁴⁸ Last but not least, PJT may reduce the risk of injury.¹⁴⁰ That said, PJT is most effective when it is one component in an integrated approach to training that targets basketball players' multiple physical fitness attributes and aligns with their goals of long-term physical development strategies.^{7,104,107}

The most appealing advantage derived from PJT seems to be the potential connection between improvements in players' physical fitness attributes and improvements in their competitive performance. According to our findings, many of the defensive and offensive game activities performed by players—including jumps, linear sprints, accelerations, decelerations, and changes-of-direction^{2–4}—have been shown to improve with PJT. Likewise, to better perform various high-intensity actions during games, players must possess adequate balance^{5–7} and strength levels,^{8–10} which are also shown to improve with PJT. Based on this evidence, it may be plausible to hypothesize that PJT will help basketball players gain some competitive advantages.^{2,13,149} However, this hypothesis would need to be explored in future studies.

4.7. Adverse effects

Among the studies included in our meta-analysis, no intervention-related injuries were reported, and the relative safety of PJT programs has been previously demonstrated.^{21,32,35} When adequately programmed and supervised, PJT interventions may actually reduce the risk of injury.^{133,134} Although PJT seems to

be safe for basketball players, caution is recommended when applying this type of training to any poorly conditioned player with low strength levels and an inability to decelerate their body mass during landing tasks. Higher volumes of PJT have been associated with increased injury risk, particularly in females.^{150,151} For this reason, the periodic application of taper strategies may also be of value, given that a reduction in the PJT volume of a program appears to correlate with a reduction in overload-induced inflammation from large eccentric loads.^{152,153} Tapering strategies may help an athlete avoid injury and facilitate adaptative processes in their musculoskeletal system, thereby optimizing physical fitness in the process.¹⁵⁴

While none of the included studies reported adverse effects, 14 of them also declined to report on participants' previous experience with PJT. Moreover, none of the studies reported on participants' movement quality during plyometric jump drills and progressive overload. Although the potential relationship between movement competency and PJT progression has been reported,^{104,107,155} along with some factors potentially associated with the safety of PJT drills,^{121,156,157} conclusive evidence is still lacking. There is also a lack of clear cut-off values for the prescription and progression of PJT¹⁵⁸ and for the use of adequate markers of PJT intensity.^{98,102,159} To improve physical fitness attributes in basketball players, and to reduce any adverse effects that could result from PJT programs, the aforementioned issues should be investigated further.

4.8. Limitations

Some potential limitations of this meta-analysis should be acknowledged. First, additional analyses regarding PJT frequency, duration, and total sessions were not always possible because in some cases there were fewer than 3 studies available for at least one of the moderators. This limitation was also apparent with respect to PJT intensity, which was not clearly reported in 12 of the studies. Second, even though the included studies did not specify any adverse events associated with the PJT interventions, it remains unclear whether there was an attempt by the researchers to comprehensively record all possible negative responses. Therefore, to expand our knowledge on the safety of this form of training, future studies are encouraged to be fully transparent regarding any injuries, pain, or other adverse effects that occur as a result of PJT. Thirdly, although 28 of the 32 included studies were classified as moderate to high quality, 22 of the studies failed to score more than 5 points on the PEDro scale, and only 6 were ultimately deemed high quality. Previous systematic reviews that focus on PJT and use the PEDro scale have also suggested that published studies in this area are generally of medium quality.^{47,132,160} This is likely due to the difficulty of conducting studies in which participants and/or therapists are blinded. Nonetheless, future studies on this topic should strive for greater methodological quality in their designs. Fourthly, physiological maturity status was reported in only 25% of the PJT studies that included youth participants. (This research gap is a common one in resistance training studies,¹⁶¹ and particularly so in the PJT literature.³²) Moreover, when it is reported, different maturation assessment techniques

are used, which introduces heterogeneity across studies; the gold standard assessment technique (i.e., skeletal age)^{162–164} is rare. Considering that physiological maturation may affect adaptations to PJT in both male and female youths,^{19,63,66} future studies should attempt to overcome this methodological issue that arises when examining younger players. Finally, since fewer than 3 studies examined measures of aerobic fitness (e.g., 20 m shuttle-run test, Yo-Yo intermittent recovery test), a meta-analysis could not be conducted for the variable. However, literature from other sports demonstrates the potential benefits of PJT on endurance.^{165–167} To expand the evidence base on the connection between aerobic fitness and basketball,^{36,168} future PJT studies should include endurance performance measures as part of basketball players' physical fitness examinations.

5. Conclusion

PJT improves various physical fitness attributes (muscle power, linear and change-of-direction sprint speed, balance, and muscle strength) in basketball players, independent of sex, age, or PJT program variables. However, it seems that older players are more responsive than younger players are to the beneficial effects of PJT on certain physical fitness variables, including horizontal jump distance, linear sprint time across distances > 10 m, and change-of-direction performance time across distances of ≤ 40 m.

Authors' contributions

All authors made significant contributions in the preparation of the first draft of the manuscript, by participating in the process of interpreting data, and by providing meaningful revision and feedback. RCC participated in the processing of collecting and analyzing data; AGH participated in the processing of collecting data. All authors have read and approved the final manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

Supplementary materials

Supplementary materials associated with this article can be found in the online version at doi:[10.1016/j.jshs.2020.12.005](https://doi.org/10.1016/j.jshs.2020.12.005).

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