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SYSTEMATIC REVIEW

Effects of Plyometric Jump Training on Jump and Sprint Performance in Young Male Soccer Players: A Systematic Review and Meta-analysis

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Abstract

Background Even from a young age, modern soccer requires high levels of physical fitness development, particularly jumping and sprinting. Plyometric jump training (PJT), combined with young athletes' regular soccer sessions, has the potential to improve jumping and sprinting. However, studies exploring the effects of PJT are generally limited by small sample sizes. This problem of underpowered studies may, thus, be resolved by pooling study results in a meta-analysis.

Objective The objective of this systematic review with meta-analysis (SRMA) was to assess the effects of plyometric jump training (PJT) on jumping and sprinting among young male soccer players.

Methods The SRMA included peer-reviewed articles that incorporated PJT in healthy players (i.e., < 23 years of age), a control group, and a measure of jumping or sprinting. Means and standard deviations of outcomes were converted to Hedges' *g* effect sizes (ES), using the inverse variance random-effects model. Moderator analyses were conducted for PJT duration, frequency, total number of sessions, participants' chronological age, and FIFA age categories (i.e., U-17 vs. U-20 vs. U-23). A multivariate random-effects meta-regression was also conducted.

Results Thirty-three studies were included, comprising 1499 participants. PJT improved vertical jump tests (ES = 0.60–0.98; all $p < 0.01$) and linear sprint performance (ES = 0.60–0.98; $p < 0.03$). Interventions of > 7 weeks and > 14 PJT sessions induced greater effects compared to PJT with ≤ 7 weeks and ≤ 14 total sessions on 10-m sprint performance (between group $p = 0.038$).

Conclusion PJT is effective in improving jumping and sprinting performance among young male soccer players. Greater 10-m linear sprinting improvements were noted after interventions > 7-week duration and > 14 sessions, suggesting a greater return from exposure to longer PJT interventions, partially in support for the adoption of a long-term approach to athletic development in young athletes. However, with reference to the findings of the meta-regression, and those from the remaining subgroup and single factors analysis, a robust confirmation regarding the moderator role of participant's age or PJT configuration effects on young soccer player's fitness qualities needed.

Key Points

Jumping and sprinting are key physical fitness proxies of soccer performance for young players.

Plyometric jump training may improve both jumping and sprinting performance.

Plyometric jump training may be particularly effective after interventions > 7 weeks.

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1 Introduction

Even from a young age, modern soccer requires high levels of physical fitness development [1–3]. Although aerobic physical fitness is important during a soccer game [2], maximal- or near-maximal-intensity single-bout efforts are key factors for optimal physical performance [1, 4, 5]. Therefore, aside from endurance activity, soccer players must also perform numerous explosive actions [6], including jumping, kicking, accelerating, decelerating and changing of movement direction, with most of these preceding goal-scoring opportunities in competitive leagues [4, 7]. Specifically, the straight sprint (45%) and the vertical jump (16%) have been shown to be the two most frequent actions preceding goal situations in soccer [4]. Moreover, a significant relationship between team average for vertical jump height and the final league standing of teams has been observed [1]. Furthermore, youth elite and sub-elite players were shown to jump higher and run faster than non-elite [8, 9]; whereas, future international and professional players had superior jump and speed ability at youth level than future amateur players [10]. Therefore, jump and sprint-related actions may not only be important qualities at youth-soccer level [8, 9], but also at a later stage of a player's career [10]. Because of this, jumping and straight sprint qualities should be developed at an early age to help players to cope with the increased competitive demands of modern play [11, 12]. On this basis, the investigation of methods to improve jumping and straight sprint actions in young soccer players is essential to optimise on-field performance.

It has previously been shown that the inclusion of plyometric jump training (PJT), combined with young athletes' regular soccer sessions, has the potential to improve many components of physical fitness [13], and may even reduce the risk of sustaining injuries [14]. A PJT program is characterized by exercises that utilize the stretch–shortening cycle of the musculotendinous unit [15, 16]. Typically, PJT exercises can be conducted with short (< 250 ms; fast stretch–shortening cycle) or long duration (> 250 ms; long stretch–shortening cycle) ground contact times [17–19]. Regarding PJT's effects on sprinting and jumping in young soccer players, previous research in U-17 male soccer players showed that PJT can substantially improve these physical fitness traits after eight weeks of exercise [20]. Similar benefits have also been shown in U-20 [21] and U-23 [22] male soccer players after 6 weeks of PJT. However, not all PJT studies corroborate these findings. For example, among U-17 [23] male soccer players, 6 weeks of PJT did not facilitate a significant improvement in sprinting or jumping performance; while, among U-20 [24] male soccer players, 8 weeks of PJT did not induce a significant improvement in sprinting. Moreover, among U-23 [25] male soccer players, 6 weeks of PJT did not induce a significant improvement in sprinting or jumping performance. Indeed, in the last two studies [24, 25], it was noted that a significant reduction in sprinting and jumping performance occurred after PJT. Such contrasting findings may be related to several factors, such as the methodological characteristics of PJT interventions (e.g., duration, intensity), participants' characteristics (e.g., initial fitness level) [26, 27] or the sprint or jump testing protocols [28, 29]. Moreover, a common limitation of PJT interventions, which could limit conclusive recommendations on prescription for sprinting and jumping performance, is the commonly low number of participants included in PJT interventions [26, 27]. Indeed, from 420 articles analyzed in a previous PJT scoping review, an average of 10 participants per group was noted [27]. In this way, studies exploring the effects of PJT are generally limited by small sample sizes, affecting the generalizability of the results. This problem of underpowered studies may, thus, be resolved by pooling study results in a meta-analysis.

Specifically, by pooling the results of several primary studies, the overall statistical power facilitates the drawing of more robust conclusions on the effectiveness of PJT on sprinting and jumping among young soccer players. However, to our knowledge, only one systematic review with meta-analysis (SRMA) has been conducted regarding the effects of PJT on sprinting and jumping among soccer players [30]. This SRMA [30] included only adult soccer players and no moderator analyses were incorporated (e.g., effects of PJT according to duration, frequency or total number of PJT sessions), thus limiting knowledge of factors that could influence the main effect. Further, in some of the analyzed outcomes (i.e., 15-m sprint) very few studies were included ($n = 2$) [30], precluding a robust conclusion regarding the effects of PJT on sprint performance among soccer players. Furthermore, although a previous systematic review [13] analyzed the effects of PJT on the physical fitness of young soccer players, no meta-analysis was conducted. Additionally, both male and female soccer players aged between 10 and 17 years were included in the aforementioned systematic review [13]. As males and females experience different effects from PJT according to sex-specific maturational development [31–37], the pooling of the sexes in this way can be misleading.

Given the increased scientific awareness of the relevance of PJT, evidenced by a 25-fold increase in PJT-related scientific publications between the years of 2000 and 2020, the contrasting findings among PJT interventions, and the typically small sample sizes used in intervention studies, a contemporary SRMA on the topic is warranted. Therefore, the aim of this SRMA was to assess the effects of PJT on jumping and sprinting among young male soccer players. Considering the beneficial effects of PJT on physical fitness in adult female [38] and male soccer players [30], and in athletes from other team sports similar to soccer in terms of intermittent profile and requirements of power expression, such as handball [39] and volleyball [40], we hypothesized PJT would exert beneficial effects on jumping and sprinting among young male soccer players.

2 Methods

A SRMA was conducted following the guidelines of the Cochrane Collaboration [41]. Findings were reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [42].

2.1 Eligibility Criteria

The a priori inclusion criteria for this SRMA were the following: (i) studies that incorporated a PJT program of at least 2 weeks in duration, defined as "lower body unilateral or bilateral bounds, jumps and hops that commonly utilize a pre-stretch or countermovement that incites usage of the stretch–shortening cycle" [26, 43, 44], (ii) cohorts of healthy young male soccer players, aged 23 years or less (as per FIFA competitions and tournaments regulations according to player's age) [45], (iii) a control group (including active controls) of young male soccer players, (iv) a measure of physical fitness (i.e., jumping, sprinting) that was selected based on a logically defensible rationale [4, 44, 46], usually with a high measurement reliability (ICC > 0.75; CV < 8%) [47, 48]. Trials that included combined training (e.g., PJT and strength training) were included when the control group included the same training, except for the PJT component. Only peer-reviewed articles were included in this SRMA. Articles were excluded if they were cross-sectional, a review, or a training-related study not focused on the effect of PJT exercises. Description of the study selection process is detailed in Sect. 3 of the manuscript. Briefly, we also excluded 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, studies with ambiguous study protocols, non-human investigations, special communications, repeated-bout effect interventions, letters to the editor, invited commentaries, errata, overtraining studies, and detraining studies. In the case of detraining studies, if there was a training period prior to a detraining period, the study was considered for inclusion. Non-English language studies were not explored [26].

2.2 Search Strategy

The PubMed, MEDLINE, Web of Science, and SCOPUS electronic databases were searched from inception until 9 December 2019. Keywords were collected through experts' opinion, a systematic literature review, and controlled vocabulary (e.g., Medical Subject Headings: MeSH). Boolean search syntax using the operators "AND", "OR" was applied. The words "ballistic", "complex", "explosive", "force–velocity", "plyometric", "stretch–shortening cycle", "jump", "training", "male", "men", "football", and "soccer" were used. An example of a PubMed search is: ("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 "soccer"[Title/Abstract]) AND "training"[Title/Abstract]) OR "plyometric"[Title/Abstract]. After an initial search, accounts were created in the respective databases. Through these accounts, the lead investigator received automatically generated emails for updates regarding the search terms used. These updates were received on a daily basis (if available), and studies were eligible for inclusion until June 2020. In addition to the main electronic systematic searches, hand-searches were also conducted.

2.3 Study Selection and Data Collection Process

In selecting studies for inclusion, a review of all relevant article titles was conducted before an examination of article abstracts and then full-published articles. Two authors conducted the process independently. Potential discrepancies between the two reviewers about study conditions were resolved by consensus with a third author. Full-text articles excluded, with reasons, were recorded. Data were extracted from gathered articles by two authors independently (JRG, RRC), using a form created in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

2.4 Data Items

For the current SRMA, vertical jumping (i.e., vertical height) and linear sprint (i.e., time to complete different distances) performance were chosen as the main outcomes based on establishing a degree of consistency between analyzed studies. We sought to analyze different jumping actions and sprint distances as they are considered as separate indicators of fitness relevant to soccer performance, particularly at youth level when maturational changes are taking place [12, 49, 50]. Extracted data also included the following information: quality of PJT treatment description (e.g., well described versus insufficiently described), type of control, type of randomization, number of participants per group. In addition, sample demographics, including age (years), body mass (kg), height (m), fitness level, and previous experience with PJT were extracted. Regarding PJT characteristics, extracted data also included the frequency of training (days/week), duration of training (weeks), and number of total jumps completed during the intervention. A complete description of the aforementioned PJT characteristics has been previously published [26, 27].

2.5 Methodological Quality in Primary Studies

The Physiotherapy Evidence Database (PEDro) scale was used to assess the methodological quality of eligible studies included in the SRMA. This scale evaluates internal study validity on a scale from 0 (high risk of bias) to 10 (low risk of bias). As in previous PJT meta-analyses [51, 52], the study quality assessment was interpreted using the following 10-point scale: ≤ 3 points was considered poor quality, 4–5 points as moderate quality, and 6–10 points as high quality. Two independent reviewers (JRG, DC), performed this process. Disagreements in the rating of the studies between the reviewers were resolved through discussion and consensus with a third author. Agreement between reviewers was assessed using a Kappa correlation for risk of bias. The a priori agreement rate between reviewers was set at $k \geq 0.8$. If trials had already been assessed and listed on the PEDro database (or similar sources), these scores were adopted. However, methodological quality was not an inclusion criterion. Moreover, the Cochrane Collaboration has previously discouraged the use of these scales, stating that the practice is not underpinned by empirical evidence and assessment criteria may apply inaccurate study weights [53]. In this sense, the subjectivity of personal opinion may undermine the accuracy of such scales.

2.6 Summary Measures

For analysis and interpretation of results, meta-analyses were conducted if at least three studies provided baseline and follow-up data for the same parameter [44, 54, 55]. Means and standard deviations for a measure (jumping; sprinting) of pre-post-intervention were converted to Hedges' *g* effect size (ES) for between-group comparisons. An example (including equations) for Hedges' *g* ES calculation for between-group comparisons is provided in Electronic Supplementary Material Table S1. The inverse variance random-effects model for meta-analyses was used because it allocates a proportionate weight to trials based on the size of their individual standard errors [56] and facilitates analysis while accounting for heterogeneity across studies [57]. In this sense, the likelihood approach with random effects was used to better account for the inaccuracy in the estimate of between-study variance [58]. The ESs were presented alongside 95% confidence intervals (CIs). The calculated ES were interpreted using the thresholds outlined for standardized mean difference: < 0.2, trivial; 0.2–0.6, small; > 0.6–1.2, moderate; > 1.2–2.0, large; > 2.0–4.0, very large; > 4.0, extremely large [59]. In some studies in which there was more than one intervention group, the control group was proportionately divided to facilitate comparison across all participants [60]. All meta-analyses were carried out using the Comprehensive Meta-Analysis program (version 2; Biostat, Englewood, NJ, USA). Comparisons between the control and the experimental groups for the mean, median, and inter-quartile range (IQR) relative change in a given outcome were calculated from the studies' raw data using a form created in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

2.7 Synthesis of Results

To gauge the degree of heterogeneity amongst the included studies, the percentage of total variation across the studies due to heterogeneity (Cochran's *Q*-statistic) [61] was used to calculate the I^2 statistic. This represents the proportion of effects that are due to heterogeneity as opposed to chance [42]. Low, moderate and high levels of heterogeneity correspond to I^2 values of < 25%, 25–75%, and > 75%, respectively [61, 62]. However, these thresholds are considered tentative [61]. The Chi square test assesses if any observed differences in results are compatible with chance alone. A low *p* value, or a large Chi square statistic relative to its degree of freedom, provides evidence of heterogeneity of intervention effects beyond those attributed to chance [56].

2.8 Risk of Bias Across Studies

Risk of bias across studies was assessed using the extended Egger's test [63]. Sensitivity analyses were conducted to assess the robustness of the summary estimates in order to determine whether a particular study accounted for the heterogeneity. Thus, to examine the effects of each result from each study on the overall findings, results were analyzed with each study deleted from the model once. It is acknowledged that other factors, such as differences in trial quality or true study heterogeneity, could produce asymmetry.

2.9 Additional Analyses

To assess the potential effects of moderator variables, subgroup analyses were performed. Using a random-effects model, potential sources of heterogeneity likely to influence the effects of training were selected a priori. Using the median split technique [64–66], the moderator variables of program duration (i.e., ≤ 7 vs. > 7 weeks), training frequency (i.e., ≤ 2 vs. > 2 sessions per week), and total number of training sessions (i.e., ≤ 14 vs. > 14 sessions), were chosen based on the accepted influence of these variables on adaptations to exercise [64, 65, 67], in addition to participants' chronological age (i.e., ≤ 13.2 years vs. > 13.2 years). Additionally, FIFA age categories (i.e., U-17 vs. U-20 vs. U-23) were also considered as potential moderator variables. Meta-analyses stratification by each of these factors was performed, with a p value of < 0.05 considered as the threshold for statistical significance.

2.10 Meta-Regression

A multivariate random-effects meta-regression was conducted to verify if any of the training variables (i.e., frequency, duration, and total number of sessions) or participant's age predicted the effects of PJT on measures of physical fitness. According to the Cochrane handbook for systematic reviews, computation of meta-regression was performed with at least ten studies per covariate [41].

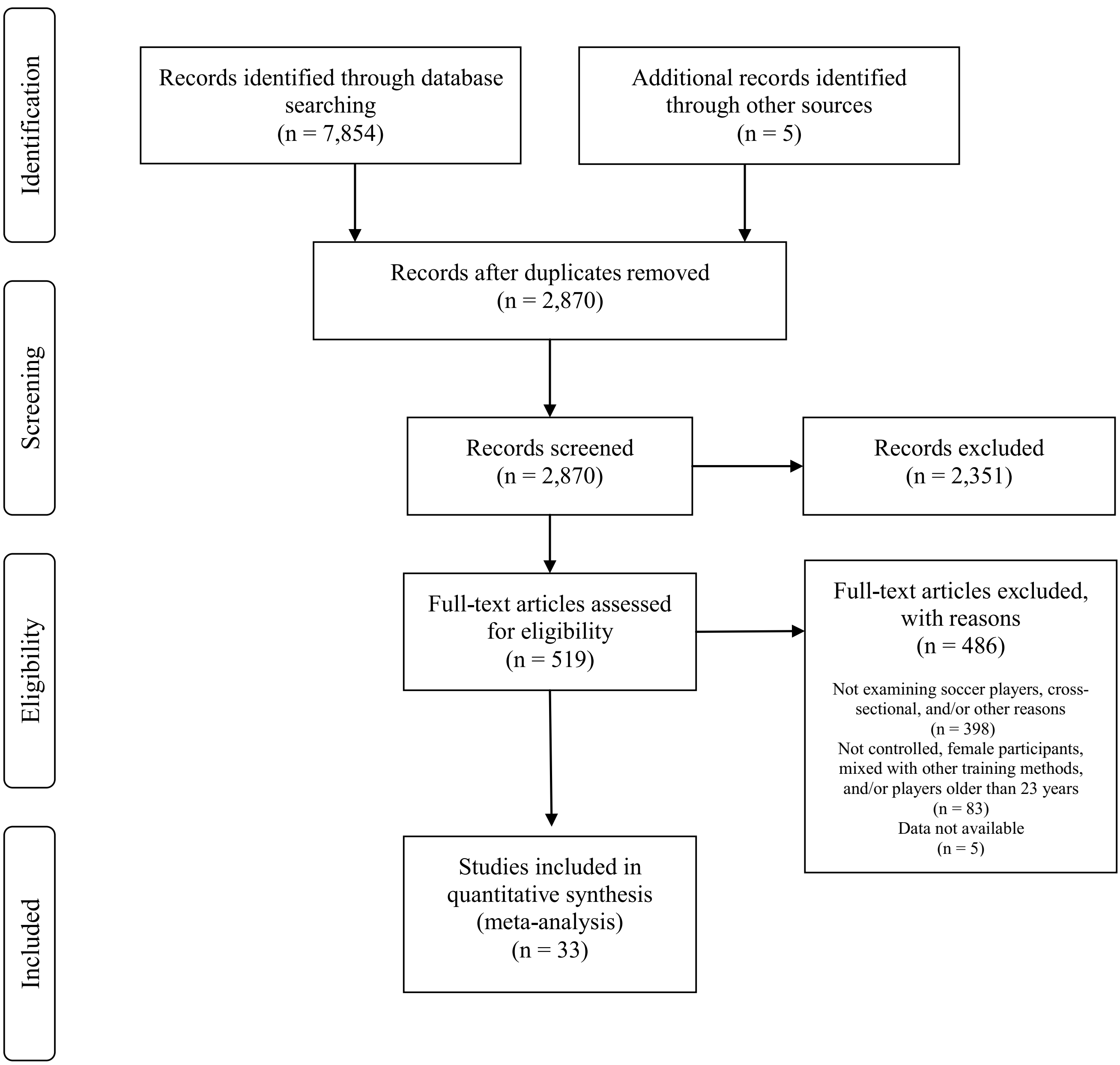

Fig. 1 PRISMA flow diagram

3 Results

Figure 1 provides a graphical schematization of the study selection process. Through database searching, 7859 records were initially identified, and 33 [20, 22, 68–98] were considered in the meta-analysis. The included studies provided mean and standard deviation pre-post-intervention data for at least one main outcome. The included studies comprised 48 individual experimental groups and 752 participants (747 in the control groups).

3.1 Study Characteristics

The basic characteristics of the participants and the programming parameters of the PJT interventions from the included studies are displayed in Table 1.

3.2 Methodological Quality of Included Studies

The 33 included studies achieved 6–7 points (i.e., high quality) (Table 2).

3.3 Meta-Analysis Results for Vertical Jump Performance

3.3.1 Countermovement Jump

From the included studies, 21 provided data for countermovement jump height performance, involving 30 experimental groups. The relative weight of each study in the analysis varied between 1.8% and 4.6%. Of note, in the sensitivity analysis, the results remained consistent ($p < 0.05$) across all deletions. There was a significant favoring of PJT for increase in countermovement jump height performance (ES = 0.79 [95%CI = 0.56–1.02], p <0.001) (Electronic Supplementary Material Fig. S1). A moderate heterogeneity ($I^2 = 68.7\%$) was observed, and the Egger's test indicated p =0.002. After the trim and fill method, the adjusted values indicated a point estimate of ES = 0.88 (95%CI = 0.65–1.12). Compared to the control groups, the mean relative improvement in the PJT groups was 8.6% (median = 7.9; IQR = 4.2–12.1).

3.3.2 Countermovement Jump with Arms

From the included studies, 6 provided data for countermovement jump with arms height performance, involving 12 experimental groups. The relative weight of each study in the analysis varied between 5.7% and 12.8%. Of note, in the sensitivity analysis, the results remained consistent ($p < 0.05$) across all deletions. There was a significant favoring of PJT for increase in countermovement jump with arms height performance (ES = 0.48 [95%CI = 0.25–0.71], p <0.001) (Electronic Supplementary Material Fig. S2). A low heterogeneity ($I^2 = 9.2\%$) was observed, and the Egger's test indicated p = 0.869. Compared to the control groups, the mean relative improvement in the PJT groups was 7.9% (median = 7.0; IQR = 5.9–9.1).

3.3.3 Squat Jump

From the included studies, 9 provided data for squat jump height performance, involving 10 experimental groups. The relative weight of each study in the analysis varied between 8.7% and 12.5%. Of note, in the sensitivity analysis, the results remained consistent ($p < 0.05$) across all deletions. There was a significant favoring of PJT for increase in squat jump height performance (ES = 0.73 [95%CI = 0.29 to 1.16], p =0.001) (Electronic Supplementary Material Fig. S3). A high heterogeneity ($I^2 = 77.4\%$) was observed, and the Egger's test indicated p =0.241. After we removed either the Sedano et al. study [94] or the Vaczi et al. study [97] from the analysis, although the significant effect of PJT remained ($p < 0.001$ to 0.003), the heterogeneity was reduced (70.3–71.8%). Compared to the control groups, the mean relative improvement in the PJT groups was 8.2% (median = 7.6; IQR = 4.9–12.9).

3.4 Meta-Analysis Results for Linear Sprint Performance

3.4.1 5-m Linear Sprint

From the included studies, 6 provided data for 5-m linear sprint performance, involving 6 experimental groups. The relative weight of each study in the analysis varied between 15.4% and 17.3%. Of note, in the sensitivity analysis, the results remained consistent ($p < 0.05$) across all deletions. There was a significant favoring of PJT for increase in 5-m linear sprint performance (ES = 0.98 [95%CI = 1.83–0.13], p =0.024) (Electronic Supplementary Material Fig. S4). A high heterogeneity ($I^2 = 82.1\%$) was observed, and the Egger's test indicated $p = 0.296$. After we removed one study from the analysis [81], although the significant effect of PJT remained ($p < 0.001$), the heterogeneity was reduced to 31.3%. Compared to the control groups, the mean relative improvement in the PJT groups was 7.5% (median = 11.7; IQR = 6.6–12.7).

3.4.2 10-m Linear Sprint

From the included studies, 10 provided data for 10-m linear sprint performance, involving 12 experimental groups. The relative weight of each study in the analysis varied between

Table 1 Basic characteristics of included study participants and plyometric jump training programs

	Treat	Ran	Age (years)*	Body mass (kg)*	Height (m)*	SPT	Fit	Frequency (days/week)	Duration (weeks)	NTJ
Asadi et al. (2018) pre-PHV [68]	WD	Yes	11.5	31.0	1.38	No	Moderate	2	6	720
Asadi et al. (2018) mid-PHV [68]			14.0	43.5	1.55					
Asadi et al. (2018) post-PHV [68]			16.6	60.6	1.72					
Beato et al. (2018) [69]	ID	Yes	17.0	69.2	1.75	NR	Moderate	1	6	360
Brito et al. (2014) [70]	WD	Yes	19.9	72.2	1.80	No	Normal	2	9	360 + 90 m
Chelly et al. (2010) [71]	WD	Yes	19.1	70.3	1.76	NR	Moderate–High	2	8	860
Chtara et al. (2017) [72]	ID	Yes	13.6	54.1	1.65	No	Moderate–High	2	6	632
Coratella et al. (2018) body mass [73]	WD	Yes	21.0	73.0	1.78	NR	Moderate	2	8	800
Coratella et al. (2018) loaded [73]			21.1							
Hammami et al. (2016) [74]	WD	Yes	15.7	59.0	1.76	No	High	2	8	722
Hammami et al. (2019) [75]	WD	Yes	15.7	58.9	1.75	NR	Moderate	2	8	722
Jlid et al. 2019 [76]	WD	Yes	11.8	36.5	1.43	NR	Moderate	2	8	1596
Jlid et al. 2020 [77]	WD	Yes	19.0	67.6	1.76	NR	High	2	6	2112
McKinlay et al. (2018) [78]	WD	No	12.6	47.2	1.58	No	Moderate	3	8	3438
Meylan and Malatesta (2009) [79]	ID	No	13.2	48.6	1.59	No	Normal–Moderate	2	8	≥768
Michailidis et al. (2013) [80]	ID	Yes	10.7	42.5	1.47	No	Moderate	2	12	≥1560
Nakamura et al. (2012) [81]	ID	NR	22.7	68.8	1.75	NR	High	2	3	360 + 198 m
Negra et al. 2016 [82]	ID	Yes	12.7	45.9	1.56	NR	Moderate	2	12	≥1344
Negra et al. (in press) [20]	WD	Yes	12.7	43.7	1.59	NR	Moderate–High	5	8	1284
Ramirez-Campillo et al. (2014) [83]	WD	Yes	13.2	47.9	1.54	No	Moderate	2	7	840
Ramirez-Campillo et al. (2014) 30 s [84]	WD	Yes	10.4	37.0	1.41	No	Moderate	2	7	840
Ramirez-Campillo et al. (2014) 60 s [84]			10.4	37.2	1.41					
Ramirez-Campillo et al. (2014) 120 s [84]			10.3	38.0	1.42					
Ramirez-Campillo et al. (2015) 24 h [85]	WD	Yes	14.2	50.3	1.58	No	Normal–Moderate	2	6	2400
Ramirez-Campillo et al. (2015) 48 h [85]			14.1	51.8	1.59					
Ramirez-Campillo et al. (2015) no increase [86]	WD	Yes	12.8	53.9	1.60	No	Moderate	2	6	1440
Ramirez-Campillo et al. (2015) increase [86]			13.0	53.8	1.61					2160
Ramirez-Campillo et al. (2015) bilateral [87]	WD	Yes	11.0	43.5	1.46	No	Moderate	2	6	2160
Ramirez-Campillo et al. (2015) unilateral [87]			11.6	45.0	1.47					
Ramirez-Campillo et al. (2015) combined [87]			11.6	42.2	1.44					
Ramirez-Campillo et al. (2015) vertical [88]	WD	Yes	11.6	40.0	1.44	No	Moderate	2	6	1610
Ramirez-Campillo et al. (2015) horizontal [88]			11.4	44.6	1.50					1610
Ramirez-Campillo et al. (2015) combined [88]			11.2	44.1	1.41					1440
Ramirez-Campillo et al. (2016) [22]	WD	Yes	20.4	68.4	1.71	No	Moderate	2	6	1440

Table 1 (continued)

	Treat	Ran	Age (years)*	Body mass (kg)*	Height (m)*	SPT	Fit	Frequency (days/week)	Duration (weeks)	NTJ
Ramirez-Campillo et al. (2018) fixed [89]	WD	Yes	13.9	46.7	1.53	No	Moderate	2	7	906
Ramirez-Campillo et al. (2018) optimal [89]			13.1	47.2	1.53					
Ramirez-Campillo et al. (2019) [90]	WD	Yes	13.2	48.6	1.54	No	Normal–Moderate	2	7	840
Ramirez-Campillo et al. (in press) before [91]	WD	Yes	16.9	64.9	1.72	No	Moderate	2	7	1944
Ramirez-Campillo et al. (in press) after [91]			17.1	65.4	1.73					
Ramirez-Campillo et al. (in press) s-surface [92]	WD	Yes	12.9	44.4	1.54	No	Moderate	2	8	810
Ramirez-Campillo et al. (in press) com-surface [92]			12.1	45.6	1.59					
Rosas et al. (2016) jump [93]	WD	Yes	12.3	47.3	1.50	No	Moderate	2	6	1152
Rosas et al. (2016) jump + haltere [93]			12.1	45.0	1.50					
Sedano et al. (2011) [94]	WD	Yes	18.4	70.7	1.74	Yes	Moderate–High	3	10	2880
Sohnlein et al. (2014) [95]	ID	No	13.0	51.0	1.62	NR	Moderate	2	16	~3467
Spineti et al. (2016) [96]	ID	Yes	18.4	70.2	1.80	NR	High	2	8	1440
Vaczi et al. (2013) [97]	WD	Yes	21.9	75.9	1.80	Yes	Moderate–High	2	6	925
Vlachopoulos et al. (2018) [98]	ID	Yes	13.8	49.3	1.61	NR	Normal–High	3 to 5	36	8800

*Mean values reported for the experimental groups; **Fit**: physical fitness/playing level. The physical fitness/playing level was categorized following an adaptation of previous recommendations for plyometric jump training reviews and meta-analysis, and after consensus among authors from current review. In this sense, the physical fitness/playing level of experimental groups was classified as: (i) **high**, for professional/elite athletes with regular enrollment in national and/or international competitions, highly trained participants with ≥ 10 training hours per week or ≥ 6 training sessions per week and a regularly scheduled official and friendly competitions, (ii) **moderate**, for non-elite/professional athletes, with a regular attendance in regional and/or national competitions, between 5 and 9.9 training hours per week or 3–5 training sessions per week and a regularly scheduled official and friendly competitions, (iii) **normal**, for recreational athletes with < 5 training hours per week with sporadic or no competitions' participation, and school-age youths regularly involved in after-school soccer classes. The jump-training load was not considered as part of the regular training load of participants, hence, it was not considered to classify participants' physical fitness/playing level; **Freq**: frequency (sessions per week); **ID**: insufficiently described; **NR**: not clearly reported information; **NTJ**: number of total jumps; **Ran:** randomization; **SPT**: systematic plyometric jump training experience before intervention. If authors stated that participants had previous experience, a dichotomy characterization identifier was used as yes or no, without consideration the extent of the experience; **Treat:** treatment description quality. The plyometric jump training treatments were further categorized as (i) **well described**, when treatment description allowed for adequate study replication, including the reporting of duration, frequency, intensity, type of exercises, sets, and repetitions, or (ii) **insufficiently described**, when the treatment description omitted any of the six aforementioned descriptors; **WD**: well described

Table 2 Physiotherapy evidence database (PEDro) scale ratings

Asadi et al. (2018) [68]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Beato et al. (2018) [69]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Brito et al. (2014) [70]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Chelly et al. (2010) [71]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Chtara et al. (2017) [72]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Coratella et al. (2018) [73]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Hammami et al. (2016) [74]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Hammami et al. (2019) [75]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Jlid et al. (2019) [76]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Jlid et al. (2020) [77]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
McKinlay et al. (2018) [78]	Yes	No	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**6**
Meylan and Malatesta (2009) [79]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Michailidis et al.(2013) [80]	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	**6**
Nakamura et al. (2012) [81]	Yes	No	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**6**
Negra et al. (2016) [82]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Negra et al. (in press) [20]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Ramirez-Campillo et al. (2014) [83]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Ramirez-Campillo et al. (2014) (30 vs. 60 vs. 120 s) [84]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Ramirez-Campillo et al. (2015) (24 vs 48 h) [85]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Ramirez-Campillo et al. (2015) (progressive vs- non-progressive) [86]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Ramirez-Campillo et al. (2015) (unilateral vs. bilateral vs. comb) [87]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Ramirez-Campillo et al. (2015) (vertical vs. horizontal vs. comb) [88]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Ramírez-Campillo et al. (2016) [22]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Ramirez-Campillo et al. (2018) (fixed vs. optimal RSI) [89]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Ramirez-Campillo et all. (2019) [90]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Ramirez-Campillo et al. 2020 (before vs. after) [91]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Ramirez-Campillo et al. (in press) (surface vs. comb surfaces) [92]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Rosas et al. (2016) [93]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Sedano et al. (2011) [94]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Sohnlein et al. (2014) [95]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Spineti et al. (2016) [96]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Vaczi et al. (2013) [97]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**
Vlachopoulos et al. (2018) [98]	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	**7**

*PEDro scale items number. A detailed explanation for each PEDro scale item can be accessed at https://www.pedro.org.au/english/downloads/pedro-scale (Access for this review: March 1, 2020)

**The total number of points from a possible maximal of 10

7.1% and 9.8%. Of note, in the sensitivity analysis, the results remained consistent ($p < 0.05$) across all deletions. There was a significant favoring of PJT for increase in 10-m linear sprint performance (ES = 0.60 [95%CI = 1.04–0.17], p = 0.007) (Electronic Supplementary Material Fig. S5). A moderate heterogeneity ($I^2 = 70.1\%$) was observed, and the Egger's test indicated $p = 0.280$. Compared to the control groups, the mean relative improvement in the PJT groups was 2.8% (median = 1.7; IQR = 0.1–3.7).

3.4.3 20-m Linear Sprint

From the included studies, 14 provided data for 20-m linear sprint performance, involving 21 experimental groups. The relative weight of each study in the analysis varied between 2.9% and 6.2%. Of note, in the sensitivity analysis, the results remained consistent ($p < 0.05$) across all deletions. There was a significant favoring of PJT for increase in 20-m linear sprint performance (ES = 0.62 [95%CI = 0.90 to 0.33], p < 0.001) (Electronic Supplementary Material Fig. S6). A moderate heterogeneity ($I^2 = 73.3\%$) was observed, and the Egger's test indicated $p = 0.425$. Compared to the control groups, the mean relative improvement in the PJT groups was 4.8% (median = 4.5; IQR = 2.3 – 6.0).

3.4.4 30-m Linear Sprint

From the included studies, 10 provided data for 30-m linear sprint performance, involving 16 experimental groups. The relative weight of each study in the analysis varied between 4.5% and 8.8%. Of note, in the sensitivity analysis, the results remained consistent ($p < 0.05$) across all deletions. There was a significant favoring of PJT for increase in 30-m linear sprint performance (ES = 0.64 [95%CI = 0.89–0.39], p <0.001) (Electronic Supplementary Material Fig. S7). A moderate heterogeneity ($I^2 = 37.1\%$) was observed, and the Egger's test indicated p =0.679. Compared to the control groups, the mean relative improvement in the PJT groups was 3.6% (median = 4.1; IQR = 1.6–5.2).

3.4.5 40-m Linear Sprint

From the included studies, 4 provided data for 40-m linear sprint performance, involving 4 experimental groups. The relative weight of each study in the analysis varied between 22.0% and 26.7%. Of note, in the sensitivity analysis, the results remained consistent ($p > 0.05$) across all deletions. There was a non-significant favoring of PJT for increase in 40-m linear sprint performance (ES = 0.94 [95%CI = 1.95 to -0.08], $p = 0.070$) (Electronic Supplementary Material Fig. S8). A high heterogeneity ($I^2 = 81.8\%$) was observed, and the Egger's test indicated p =0.162. After we removed one study from the analysis [71], although the non-significant effect of PJT remained ($p = 0.072$), the heterogeneity was reduced to 0.0%. Compared to the control groups, the mean relative improvement in the PJT groups was 1.6% (median = 1.8; IQR = 1.3–1.9).

3.5 Additional Meta-Analyses for Vertical Jump and Linear Sprint Performance

Regarding interventions with ≤ 14 total PJT sessions, also comprising a duration of ≤ 7 weeks (5 study groups; ES = 0.11 [95%CI = 0.65 to − 0.42], $p = 0.677$; within-group $I^2 = 39.7\%$) and those with > 14 sessions, also comprising a duration of > 7 weeks (7 study groups; ES = 0.93 [95%CI = 1.47–0.38], $p = 0.001$; within-group $I^2 = 71.9\%$), only the latter induced a significant improvement on 10-m linear sprint performance, with a significant between-group difference (p = 0.038) (Fig. 2).

No other significant between-group difference was noted for the remaining of the additional analyses; including PJT frequency, PJT duration, and total number of PJT sessions, participant's age, and FIFA age categories. A detailed description of all additional analyses is provided as supplementary material (Electronic Supplementary Material Appendix S1).

3.6 Results of Meta-Regression

The meta-regression analysis was computed for the outcomes countermovement jump and 10-m linear sprint performance, and included three different training variables (i.e., training frequency, training duration, and total number of training sessions) and participants' chronological age (Table 3). Irrespective of the training type, none of the training variables predicted the effects of PJT on countermovement jump height or 10-m linear sprint performance ($p = 0.095$–0.713). The coefficient of determination was $R^2 = 0.07$ and 0.0 for countermovement jump height and 10-m linear sprint performance The regression was not computed for 20-m and 30-m linear sprint due to a problem with collinearity. For the remaining outcomes, less than 10 studies were available, precluding a robust meta-regression.

3.7 Adverse Effects

Among the included studies, three [83–85] reported low level of pain experienced by participants. Although prevalence was not reported in the aforementioned studies, authors reported relatively low pain level among participants (all < 3, in a 10-point scale). Moreover, mean pain levels of 0, 1.3, 0.8, 0.3, 0.1 and 0 were observed at time points before, immediately after, 24 h, 48 h, 72 h, and 96 h after the first plyometric training session, respectively. Furthermore, compared to the first week of PJT, muscle pain after plyometric training sessions was reduced toward the last week

Group by Total sessions (n)	Statistics for each study						
	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
14 or less	-0.114	0.273	0.074	-0.648	0.421	-0.417	0.677
More than 14	-0.926	0.280	0.078	-1.474	-0.378	-3.311	0.001

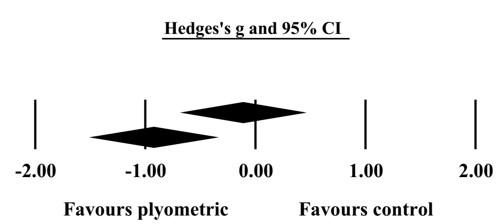

Fig. 2 Forest plot of increases in 10-m linear sprint performance in young male soccer players participating in plyometric jump training compared to controls, after ≤ 14 total PJT sessions (also comprising a duration of ≤ 7 weeks) or > 14 total PJT sessions (also comprising a duration of > 7 weeks) of intervention. Values shown are effect sizes with 95% confidence intervals (CI)

Table 3 Results of the multivariate random-effect meta-regression for training variables to predict PJT effects on vertical jump and linear sprint performance in young male soccer players

Covariate	Coefficient	95% CI, lower	95% CI, upper	*Z* value	*P* value
CMJ (N = 27)					
Intercept	− 0.7915	− 4.7029	3.1199	− 0.40	0.6917
Frequency	0.4507	− 0.9436	1.8450	0.63	0.5264
Training duration	0.2979	− 0.0519	0.6477	1.67	0.0951
Total sessions	− 0.0786	− 0.1710	0.0138	− 1.67	0.0954
Participant's chronological age	− 0.0211	− 0.1332	0.0911	− 0.37	0.7128
10-m linear sprint (N = 12)					
Intercept	4.2645	− 6.8485	15.3775	0.75	0.4520
Frequency	− 1.1923	− 6.4320	4.0475	− 0.45	0.6556
Training duration	− 0.5130	− 1.8177	0.7917	− 0.77	0.4409
Total sessions	0.1909	− 0.4495	0.8313	0.58	0.5591
Participant's chronological age	− 0.0924	− 0.2346	0.0498	− 1.27	0.2029

CI Confidence interval, *CMJ* countermovement jump height, *N* number of study groups, *PJT* plyometric jump training

of PJT [83–85]. Another study [98] reported soreness in the lower leg muscle groups (13% of participants), pain in the knees mainly during the last stage of the intervention (8% of participants), and fatigue (13% of participants). However, no intervention-related injuries were reported. The remaining studies reported no soreness, pain, fatigue, injury, damage or adverse effects related to the PJT intervention.

4 Discussion

The aim of this SRMA was to assess the effects of PJT on jumping and sprinting among young male soccer players. The data showed that PJT induced significant improvements in vertical jump and linear sprint performance, with an small to moderate magnitude when compared to controls. Regarding training prescription effects, PJT interventions of longer duration (> 7 weeks and > 14 PJT sessions) induced significantly greater moderate improvements in linear sprint performance. Findings are explored in more detail throughout the rest of this section.

Improvements in jumping and sprinting after PJT can likely be attributed to enhanced neural drive to agonist muscles, alterations to musculotendinous stiffness, improved intermuscular coordination (e.g., enhanced antagonist muscle inhibition), greater excitability of the stretch reflex, changes in muscle fiber mechanics, and changes in muscle size and architecture [99, 100]. In fact, a 6-week intervention, comprised of three sessions per week [101], in young adult female and male team sport players (including soccer), resulted in a significant improvement of 8.5–13.2% in unloaded jumping height performance. This improvement was in line with increases in maximal voluntary force and electromyographic activity of the leg extensor muscles, as well as greater thickness, fascicle length and pennation angle of knee flexor and extensor muscles [101]. However, when compared to the aforementioned study [101], others have found greater (~ 28%) [80], similar (~ 9%) [102] or lower (~ 3%) [103] improvement in vertical jump height. Differences in the participants' characteristics, including age, may help to explain differences in physical fitness changes, including jumping and sprinting, after PJT among young male soccer players [33, 35, 104]. However, differences between PJT programs (e.g., frequency, duration, total number of PJT sessions) may also help to explain the different magnitudes of physical fitness changes among studies. To analyze these possibilities, the effects of potential moderator variables were explored.

Regarding PJT frequency, moderator analyses and meta-regression analyses were available only for countermovement jump height and 10-m linear sprint performance. No between-group differences were noted for the improvements in countermovement jump and 10-m linear sprinting after interventions with ≤ 2 sessions per week or > 2 sessions per week. Indeed, previous PJT meta-analyses also observed no significant subgroup differences or correlation for training frequency and vertical jump height [28, 64] or linear sprinting [105] changes. Furthermore, studies in adult futsal and soccer players [106, 107] compared the relative effects of one and two PJT sessions per week, equated for total volume, intensity and jump type, and found similar effects in vertical jump height and linear sprinting. Of note, results of the multivariate random-effect meta-regression revealed that training frequency did not predict PJT effects on countermovement jump and linear sprint performance in young male soccer players. Although two sessions per week seemed more effective than one for the improvement of linear sprinting among young male athletes [105], three sessions per week may have a lower effect than two sessions per week [105]. Indeed, greater training frequencies are associated with higher training volumes and because of this, could increase the risk of injury [108]. However, the lack of a significant difference between ≤ 2 sessions/week compared to > 2 sessions/week in our meta-analysis may be related to an imbalance of studies in the respective subgroups. For countermovement jump height, 24 study groups were available for ≤ 2 sessions/week, whereas only three studies were available for > 2 sessions/week. Indeed, compared to the moderate heterogeneity for ≤ 2 sessions/week, the presence of high heterogeneity after subgroup analysis for > 2 sessions/week suggests that moderators of the main effect may not have been found, meaning other factors (aside from training frequency) could account for training adaptations. This would seem to imply a potential synergy between programming variables and other factors, such as biological maturity, in determining the magnitude of response to PJT in young athletes [105]. To this end, a moderator analysis accounting for player age would clarify this issue.

Although the maturity status of the players would be ideal to perform moderator analyses for the effects of PJT, maturity is often not reported. In fact, a recent scoping review [27] of 420 PJT studies, observed that 37% of the included studies involved youth groups, with only a third of these reporting physiological maturity status. This important research gap seems common among resistance training research literature [109]. This limitation is compounded by the utilization of different measures of physiological maturity across studies, making it difficult to compare results [26, 27]. This could be viewed as a critical limitation among PJT interventions performed with youth, especially since physiological maturity seems to affect adaptations to PJT interventions with young males. In the current SRMA, with regard to player age, moderator analyses were available for countermovement jump height and squat jump height performance, and 10-m, 20-m and 30-m linear sprint. From these studies, data indicate that players > 13.2 years old experienced a similar moderate (ES = 0.64-0.77) beneficial training effect on jumping performance compared those ≤ 13.2 years old (ES = 0.81–0.94). For the 10-m, 20-m and 30-m linear sprint, players > 13.2 years old experienced a moderate beneficial training effect (ES = 0.83–0.89), compared to a small beneficial effect on those ≤ 13.2 years old (ES = 0.40-0.53). Results of the multivariate random-effect meta-regression revealed that player's age did not predict PJT effects on jump and linear sprint performance in young male soccer players. Although for the analyzed outcomes in the current SRMA no significant between-group differences were noted regarding player age, the moderate beneficial effect of PJT on linear sprint performance among the older young players, compared to only a small beneficial effect among their younger counterpart, is in line with previous meta-analyses. In one meta-analysis [105], greater improvements in sprinting were noted among participants with mean ages of 14.1 years (ES = 1.15) and 16.8 years (ES = 1.39), compared with those with a mean age of 11.2 years (ES = − 0.18) after sprinting programs (also involving high-intensity, stretch–shortening cycle muscle actions). In another meta-analysis [110], improvements in non-linear sprinting (i.e., change of direction speed) were noted among participants with a mean age of 14.5 years (ES = 0.95) and 17 years (ES = 0.99), compared with those with a mean age of 11.5 y (ES = 0.68) after PJT interventions. Moreover, when participants between the mean ages of 10 and 12.9 years, 13 and 15.9 years, as well as 16 and 18 years were exposed to PJT, the greatest magnitude of improvement in countermovement jump height performance was noted among the older group (ES = 1.02) [33]. However, in the aforementioned meta-analysis [33], the magnitude of adaptation to PJT between the mean ages of 13 and 15.9 years was lower (ES = 0.47) compared to the younger group (ES = 0.91). In relation to this finding, complex changes occur in physical performance during growth and maturation and these can affect both jumping [31] and sprinting [111, 112]. During growth and maturation, the natural development of the stretch–shortening cycle is of key relevance for both jump and sprint performance and this occurs due to greater muscular size, increased limb length, changes to musculotendinous tissue, enhanced neural and motor development and better movement quality and coordination [31, 111, 112]. As the timing and tempo of these factors seem highly variable across individuals [32, 33, 113], this can make it difficult for coaches to determine how best to structure training during this highly sensitive period of development. Therefore, soccer coaches involved with youth populations should consider not only the characteristics of the applied training program, but also the dynamic physiological change that takes place across the adolescent years. Such a training principle related to the interaction between training and maturation has been termed "synergistic adaptation" [34, 114, 115] and should be considered of utmost importance when working with young soccer players.

Regarding intervention duration and total PJT sessions, results of the multivariate random-effect meta-regression revealed that none of these training factors predict PJT effects on countermovement jump and 10-m linear sprint performance in young male soccer players. However, analyses for intervention duration and total PJT sessions as single-factor moderators were available for countermovement and squat jump height, and for 10-m, 20-m and 30-m linear sprint performance. From these, interventions with a duration of > 7 weeks and > 14 total PJT sessions induced a greater beneficial training effect compared to those interventions with ≤ 7 weeks and ≤ 14 total PJT sessions on 10-m linear sprint performance. Unsurprisingly, the moderator analysis supported the use of longer programs (> 7 weeks) and more training sessions per program (> 14) for the enhancement of horizontally orientated outcomes and skills such as short sprints. It was surprising, however, that longer programs (> 7 weeks, > 14 session) were no more effective than shorter programs in eliciting increases in vertically orientated outcome measures such as countermovement and squat jump height performance. The reasons for these contrasting findings are unclear but could suggest that increases in vertically orientated performance are achievable in the short term, whilst the attainment of the more sport-specific horizontally orientated performance [4] could take longer to achieve. This could indicate a differential in the time-course of adaptation of vertically and horizontally orientated performance or could also represent a bias towards the selection of vertically orientated exercises in modern strength and conditioning programs for young soccer players [12]. Alternatively, current findings may indicate that the longer-term programs were not sufficiently periodized and the players were not exposed to sufficient PJT load, particularly PJT intensity. In general, coaches have traditionally been cautious of higher training intensities; however, this prescription variable is crucial for long-term PJT programs [35, 116, 117].

Our meta-analyses demonstrated that young soccer players may improve vertical jump (ES = 0.48–0.79) and linear sprint performance (ES = 0.60–0.98) to a similar extent after PJT. Although this may be considered not in line with the principle of training specificity, most of the included studies in our meta-analyses involved mixed PJT programs that combined horizontal and vertical drills. Indeed, while vertically oriented PJT may induce greater improvements in vertical jump performance, horizontal-oriented PJT may induce greater improvements in linear sprint performance [87]. However, a combination of both may be of particular relevance to improve both vertical jump (12.3%; ES = 0.51) and linear sprint performance (5.8–6.0%; ES = 0.63–0.99) among young male soccer players [87]. In addition to the PJT characteristics, similar improvements in vertical jump and linear sprint performance among young soccer players in our meta-analysis are in line with the findings from previous PJT meta-analyses, which have shown an improvement in vertical jump (ES = 0.84) [28] and linear sprint performance (ES = 0.37) [29]. However, such effects were noted for participants with a wide range of sport backgrounds. In the aforementioned meta-analyses soccer players demonstrated vertical jump improvements of ES = 0.51 [28] and linear sprint ES = 0.69 [29]. The reasons for these findings are unclear but could suggest that the underlying mechanisms responsible for vertical jump and linear sprint performance may be similarly improved after PJT. Indeed, PJT can increase neural drive to agonist muscles, lower-limb stiffness, intermuscular coordination, excitability of the stretch reflex, among others [99, 100]. Such factors are important for both jumping and sprinting [15, 118–123]. The underlying mechanisms (e.g., physiological; biomechanical) responsible for improvements in vertical jump and linear sprint after PJT should be considered in future studies. From a practical point of view, combination of both vertical-oriented and horizontal-oriented PJT drills in the young soccer player's program seems a sound approach.

Our meta-analyses revealed linear sprint improvements after PJT in a range from ES = 0.60–0.98 for distances between 5-m and 40-m. Although linear sprint performance may correlate across different distances [118], the underlying mechanisms (e.g., physiological; biomechanical) responsible for the athlete performance across different linear sprint distances may be differentially affected. Such effects may be related to the distinct characteristics of the PJT interventions across analyzed studies (e.g., total program duration; as previously discussed) and the nature of the plyometric exercises. Indeed, depending on the training approach, one may expect greater improvements in one particular distance over another. For example, at shorter-distances (e.g., 5 m), horizontal force application on the ground is of paramount importance, thus a greater load of horizontal PJT may lead to larger improvements during the early acceleration phase (horizontal GRF; push-off phase) [87, 119, 124]. In addition, exercises with horizontal orientation and longer ground contact times will allow for more time to generate force, thus greater impulse and, therefore, acceleration. In contrast, PJT with a greater emphasis in the vertical direction may induce larger improvements when nearing top speed (vertical GRF) [87, 119, 124], particularly after vertical exercises with faster ground contact times and higher rate of force development. In this meta-analysis, most of the included studies involved mixed PJT programs that combined horizontal and vertical drills. This may help to explain the improvements noted across different linear sprint distances.

Among the included studies, no intervention-related injuries were reported. The relative safety of PJT programs has been previously reported [26, 27, 99]. Moreover, when adequately programmed and well coached, PJT interventions may reduce the risk of injury among young soccer players [14, 125]. Although PJT seems safe for young male soccer players, caution is recommended when applying this type of training in poor-conditioned athletes with lower strength levels and an inability to decelerate their body mass during landing tasks. Of note, in a study by Vlachalopolous et al. [98], participants reduced the volume of jumps in the last 12 weeks due to soreness and some muscle problems (not injuries). It is possible that a volume-based taper in the last stage of a PJT can increase control over inflammation caused by the overload induced by large eccentric loads [126, 127] and, in this way, a taper strategy may facilitate the processes of adaptation of the musculoskeletal system and physical fitness [128, 129]. In addition to taper strategies, low volumes of high-intensity work may be more advantageous at the long-term compared to greater volumes [28, 106, 108, 130–132]. In other words, intervention-related injuries may be reduced, and physical fitness improved to a greater extent using sufficiently periodized longer-term programs, taking into account PJT intensity as a key prescription variable for young athletes in long-term athletic development programs [35, 116, 117].

To our knowledge, this is the first SRMA to examine the effects of PJT on jumping and sprinting performance in young soccer players. In the current SRMA 752 participants (in addition to 747 controls) partook in PJT among the single studies reported in the literature. This large pooled sample size is a strength of the current SRMA, addressing the ongoing problem of underpowered studies due to reduced sample size [133]. However, aside from the aforementioned strengths, some potential limitations should be acknowledged. For some outcomes (i.e., 5-m linear sprint), additional analyses regarding PJT frequency, duration, total PJT sessions or participants' age were not possible as < 3 studies were available for at least one of the moderators. Moreover, for some outcomes (i.e., 40-m linear sprint) and/or moderator analysis, only three studies were available in total, suggesting that results should be interpreted with caution, and confirmed in the future. Additionally, the dichotomisation of continuous data (e.g., ≤ 7 weeks compared to > 7 weeks) with the median split technique could result in residual confounding and reduced statistical power [134]. Furthermore, the effects of these programming variables were calculated independently, and not interdependently. Univariate analysis must be interpreted with caution because the programming parameters were calculated as single factors, irrespective of between-parameter interactions. However, our meta-analysis also incorporated a meta-regression, revealing that none of the analyzed training factors predicted PJT effects on either jump or linear sprint performance in young male soccer players. Finally, the current SRMA was focused on young male participants. As young males and females clearly experience different effects from PJT according to sex-specific maturational development [31–35, 37], future SRMAs should take a similar approach for female participants. Additionally, although our analyses did not reveal a significant difference between participants aged < 13.2 compared to > 13.2 (or between FIFA age categories U-17, U-21, and U-23), these were limited only to chronological age. A moderator analysis for biological maturity was limited somewhat with the evidence that is available. Indeed, not many PJT studies report well-controlled measures of maturity status [27]. Considering that biological maturity may affect adaptations to strength and conditioning practices in general, and resistance training and PJT in particular [31, 33, 35, 112, 115], future PJT meta-analyses should strive to include youth athletes' biological maturity as a moderator in the analyses. Despite these limitations, the current SRMA makes an original and significant contribution to the literature and clearly shows the merits of including PJT as part of a well-rounded athletic development program to enhance jumping and sprinting performance in young soccer players.

5 Conclusion

In conclusion, PJT seems safe and was proved to be effective in improving vertical jumping and linear sprinting performance among young male soccer players. Greater 10-m linear sprinting improvements were noted after interventions > 7-week duration and > 14 sessions, suggesting a greater return from exposure to longer PJT interventions, partially in support for the adoption of a long-term approach to athletic development in young athletes. However, with reference to the findings of the meta-regression, and those from the remaining subgroup and single factors analysis, a robust confirmation regarding the moderator role of participant's age, or PJT configuration, including duration, on its effects on young soccer player's fitness qualities needs future confirmation. Practitioners working in youth soccer should take into account the dose–response trends identified in this SRMA to prescribe the appropriate level of training for the young male soccer player. Importantly, rather than an independent entity, PJT should be a component of an integrated approach to youth physical development, which targets multiple physical fitness qualities and aligns with the goals of long-term physical development strategies. Practitioners should seek to periodize PJT for young athletes by manipulating both volume and intensity to ensure ongoing adaptations.

Data Availability Statement The datasets generated during and/or analyzed during the current review are available from the corresponding author on reasonable request.

Compliance with Ethical Standards

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Conflicts of interest Rodrigo Ramirez-Campillo, Daniel Castillo, Javier Raya-González, Jason Moran, Eduardo Sáez de Villarreal and Rhodri Lloyd declare that they have no conflicts of interest relevant to the content of this review.

Authorship Contributions RRC, DC and JRG wrote the first draft of the manuscript. RRC, DC and JRG collected data. RRC and JM analyzed and interpreted the data. ESV and RD revised the original manuscript. All authors read and approved the final manuscript.

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